OpenDDS

Release 3.24.0

OpenDDS Foundation

Apr 11, 2023

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Welcome to the documentation for OpenDDS 3.24.0!

It is available for download on GitHub.

CHAPTER

ONE

DEVELOPER'S GUIDE

1.1 Introduction

1.1.1 What is OpenDDS?

OpenDDS is an open source implementation of a group of related Object Management Group (OMG) specifications.

1. **Data Distribution Service (DDS) for Real-Time Systems v1.4** (OMG document `formal/2015-04-10`). DDS defines a service for efficiently distributing application data between participants in a distributed application. This specification details the core functionality implemented by OpenDDS for real-time publish and subscribe applications and is described throughout this document. Users are encouraged to read the DDS Specification as it contains in-depth coverage of all the service's features.
2. **The Real-time Publish-Subscribe Wire Protocol DDS Interoperability Wire Protocol Specification (DDSI-RTPS) v2.3** (OMG document `formal/2019-04-03`). Although the document number is v2.3, it specifies protocol version 2.4. This specification describes the requirements for interoperability between DDS implementations.
3. **DDS Security v1.1** (OMG document `formal/2018-04-01`) extends DDS with capabilities for authentication and encryption. OpenDDS's support for the DDS Security specification is described in *DDS Security*.
4. **Extensible and Dynamic Topic Types for DDS (XTypes) v1.3** (OMG document `formal/2020-02-04`) defines details of the type system used for the data exchanged on DDS Topics, including how schema and data are encoded for network transmission. OpenDDS's support for DDS-XTypes is described in *XTypes*.

OpenDDS is implemented in C++ and contains support for Java. Users in the OpenDDS community have contributed and maintain bindings for other languages include C#, nodejs, and Python.

OpenDDS is sponsored by the OpenDDS Foundation and is available via https://opendds.org and https://github.com/OpenDDS/OpenDDS.

1.1.2 Licensing Terms

OpenDDS is *open source software*. The source code may be freely downloaded and is open for inspection, review, comment, and improvement. Copies may be freely installed across all your systems and those of your customers. There is no charge for development or run-time licenses. The source code is designed to be compiled, and used, across a wide variety of hardware and operating systems architectures. You may modify it for your own needs, within the terms of the license agreements. You must not copyright OpenDDS software. For details of the licensing terms, see the file named LICENSE that is included in the OpenDDS source code distribution or visit https://opendds.org/about/license.html.

OpenDDS also utilizes other open source software products including MPC (Make Project Creator), ACE (the ADAPTIVE Communication Environment), and TAO (The ACE ORB).

OpenDDS is open source and the development team welcomes contributions of code, tests, documentation, and ideas. Active participation by users ensures a robust implementation. Contact the OpenDDS Foundation if you are interested

in contributing to the development of OpenDDS. Please note that any code or documentation that is contributed to and becomes part of the OpenDDS open source code base is subject to the same licensing terms as the rest of the OpenDDS code base.

1.1.3 About This Guide

This Developer's Guide corresponds to OpenDDS version 3.23. This guide is primarily focused on the specifics of using and configuring OpenDDS to build distributed publish-subscribe applications. While it does give a general overview of the OMG Data Distribution Service, this guide is not intended to provide comprehensive coverage of the specification. The intent of this guide is to help you become proficient with OpenDDS as quickly as possible. Readers are encouraged to submit corrections to this guide using a GitHub pull request. The source for this guide can be found at docs/devguide and *Documentation Guidelines* contains guidance for editing and building it.

1.1.4 Highlights of the 3.23 Release

NOTE: Numbers in parenthesis are GitHub pull requests

Additions:

- DataRepresentationQosPolicy and TypeConsistencyEnforcementQosPolicy can be set through XML (#3763)
- RTPS send queue performance improvements (#3794)
- Cross-compiling improvements (#3853)
- New support for DynamicDataWriter and enhanced support for DynamicDataReader (#3827, #3727, #3871, #3718, #3830, #3893, #3904, #3885, #3933, #3935)
- New config option for RtpsDiscovery `SpdpRequestRandomPort` (#3903)
- New `opendds_mwc.pl` Wrapper Script (#3821, #3913)
- Improve support for loading signed documents (#3864)

Fixes:

- Unauthenticated participant leads to invalid iterator (#3748)
- Shmem Association race (#3549)
- Shmem and tcp null pointer (#3779)
- Submodule checkout on Windows (#3812)

Notes:

- Docker images are built for release tags https://github.com/OpenDDS/OpenDDS/pkgs/container/opendds (#3776)

ACE/TAO Version Compatibility

OpenDDS 3.23 is compatible with the current DOC Group micro release in the ACE 6.x / TAO 2.x series. See the README.md file for details.

Conventions

This guide uses the following conventions:

`Fixed pitch text`	Indicates example code or information a user would enter using a keyboard.
Italic text	Indicates a point of emphasis.
...	An ellipsis indicates a section of omitted text.

1.1.5 Examples

The examples in this guide are intended for the learning of the reader and should not be considered to be "production-ready" code. In particular, error handling is sometimes kept to a minimum to help the reader focus on the particular feature or technique that is being presented in the example. The source code for all these examples is available as part of the OpenDDS source code distribution in the DevGuideExamples directory. MPC files are provided with the examples for generating build-tool specific files, such as GNU Makefiles or Visual C++ project and solution files. To run an example, execute the `run_test.pl` Perl script.

1.1.6 Related Documents

This guide refers to various specifications published by the Object Management Group (OMG) and from other sources.

OMG references take the form *group/number* where *group* represents the OMG working group responsible for developing the specification, or the keyword `formal` if the specification has been formally adopted, and *number* represents the year, month, and serial number within the month the specification was released. For example, the OMG DDS version 1.4 specification is referenced as `formal/2015-04-10`.

OMG specifications can be downloaded directly from the OMG web site by prepending `http://www.omg.org/cgi-bin/doc?` to the specification's reference. Thus, the specification `formal/07-01-01` can be downloaded from http://www.omg.org/cgi-bin/doc?formal/07-01-01. Providing this destination to a web browser should take you to a site from which you can download the referenced specification document.

Additional documentation for OpenDDS is produced and maintained by the OpenDDS Foundation and is available from the OpenDDS Website at https://opendds.org.

Here are some documents of interest and their locations:

Document	Location
Data Distribution Service (DDS) for Real-Time Systems v1.4 (OMG Document formal/2015-04-10)	http://www.omg.org/spec/DDS/1.4/PDF
The Real-time Publish-Subscribe Wire Protocol DDS Interoperability Wire Protocol Specification (DDSI-RTPS) v2.3 (OMG Document formal/2019-04-03)	https://www.omg.org/spec/DDSI-RTPS/2.3/PDF
OMG Data Distribution Portal	http://portals.omg.org/dds/
OpenDDS Build Instructions, Architecture, and Doxygen Documentation	https://opendds.org/documentation.html
OpenDDS Frequently Asked Questions	https://opendds.org/faq.html

1.1.7 Supported Platforms

The OpenDDS Foundation regularly builds and tests OpenDDS on a wide variety of platforms, operating systems, and compilers. The OpenDDS Foundation continually updates OpenDDS to support additional platforms. See the README.md file in the distribution for the most recent platform support information.

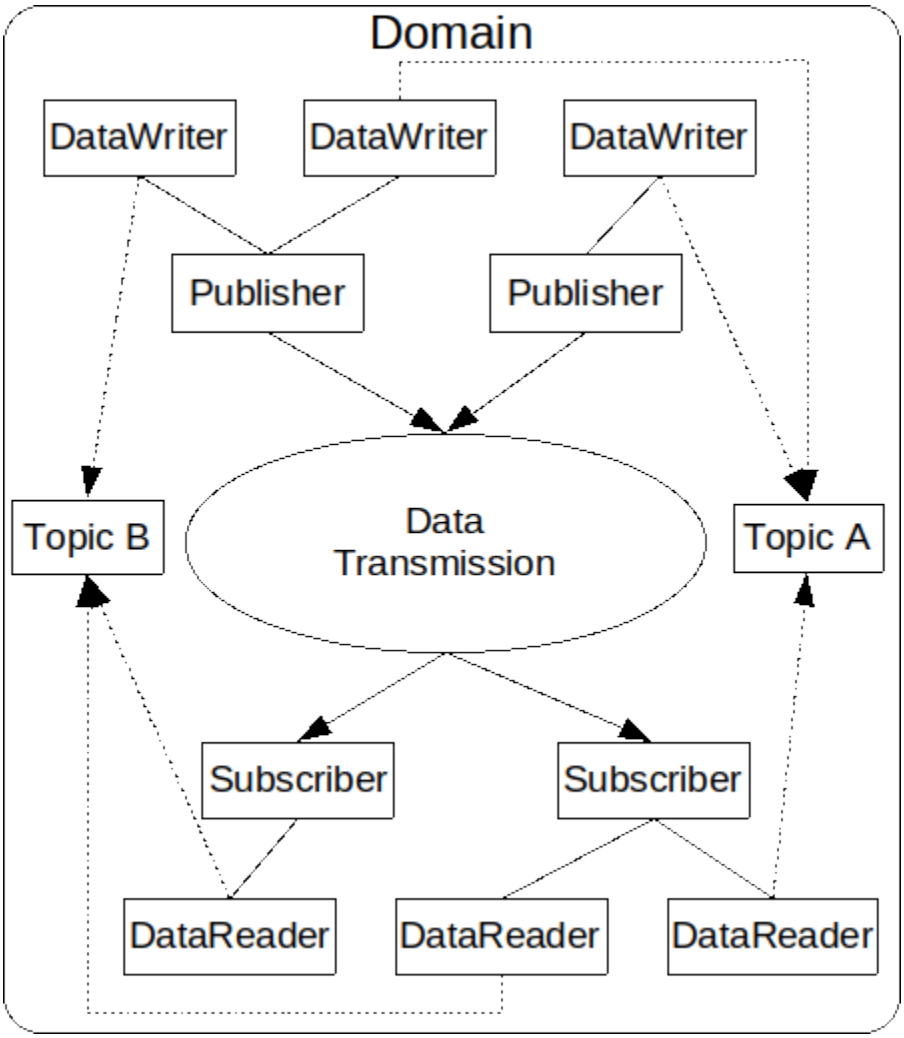
1.1.8 Data-Centric Publish-Subscribe (DCPS) Overview

Data-Centric Publish-Subscribe (DCPS) is the application model defined by the DDS specification. This section describes the main concepts and entities of the DCPS API and discuss how they interact and work together.

Basic Concepts

Figure 1-1 shows an overview of the DDS DCPS layer. The following subsections define the concepts shown in this diagram.

Figure DCPS Conceptual Overview



Domain

The *domain* is the fundamental partitioning unit within DCPS. Each of the other entities belongs to a domain and can only interact with other entities in that same domain. Application code is free to interact with multiple domains but must do so via separate entities that belong to the different domains.

DomainParticipant

A *domain participant* is the entry-point for an application to interact within a particular domain. The domain participant is a factory for many of the objects involved in writing or reading data.

Topic

The *topic* is the fundamental means of interaction between publishing and subscribing applications. Each topic has a unique name within the domain and a specific data type that it publishes. Each topic data type can specify zero or more fields that make up its *key*. When publishing data, the publishing process always specifies the topic. Subscribers request data via the topic. In DCPS terminology you publish individual data *samples* for different *instances* on a topic. Each instance is associated with a unique value for the key. A publishing process publishes multiple data samples on the same instance by using the same key value for each sample.

DataWriter

The *data writer* is used by the publishing application code to pass values to the DDS. Each data writer is bound to a particular topic. The application uses the data writer's type-specific interface to publish samples on that topic. The data writer is responsible for marshaling the data and passing it to the publisher for transmission.

Dynamic data writers (*Creating and Using a DynamicDataWriter or DynamicDataReader*) can be used when code generated from IDL is not available or desired. Dynamic data writers are also type-safe, but type checking happens at runtime.

Publisher

The *publisher* is responsible for taking the published data and disseminating it to all relevant subscribers in the domain. The exact mechanism employed is left to the service implementation.

Subscriber

The *subscriber* receives the data from the publisher and passes it to any relevant data readers that are connected to it.

DataReader

The *data reader* takes data from the subscriber, demarshals it into the appropriate type for that topic, and delivers the sample to the application. Each data reader is bound to a particular topic. The application uses the data reader's type-specific interfaces to receive the samples.

Dynamic data readers (*Creating and Using a DynamicDataWriter or DynamicDataReader*) can be used when code generated from IDL is not available or desired. Dynamic data readers are also type-safe, but type checking happens at runtime.

Built-In Topics

The DDS specification defines a number of topics that are built-in to the DDS implementation. Subscribing to these *built-in topics* gives application developers access to the state of the domain being used including which topics are registered, which data readers and data writers are connected and disconnected, and the QoS settings of the various entities. While subscribed, the application receives samples indicating changes in the entities within the domain.

The following table shows the built-in topics defined within the DDS specification:

Table Built-in Topics

Topic Name	Description
`DCPSParticipant`	Each instance represents a domain participant.
`DCPSTopic`	Each instance represents a normal (not built-in) topic.
`DCPSPublication`	Each instance represents a data writer.
`DCPSSubscription`	Each instance represents a data reader.

Quality of Service Policies

The DDS specification defines a number of Quality of Service (QoS) policies that are used by applications to specify their QoS requirements to the service. Participants specify what behavior they require from the service and the service decides how to achieve these behaviors. These policies can be applied to the various DCPS entities (topic, data writer, data reader, publisher, subscriber, domain participant) although not all policies are valid for all types of entities.

Subscribers and publishers are matched using a request-versus-offered (RxO) model. Subscribers *request* a set of policies that are minimally required. Publishers *offer* a set of QoS policies to potential subscribers. The DDS implementation then attempts to match the requested policies with the offered policies; if these policies are compatible then the association is formed.

The QoS policies currently implemented by OpenDDS are discussed in detail in *Quality of Service*.

Listeners

The DCPS layer defines a callback interface for each entity that allows an application processes to listen for certain state changes or events pertaining to that entity. For example, a Data Reader Listener is notified when there are data values available for reading.

Conditions

Conditions and *Wait Sets* allow an alternative to listeners in detecting events of interest in DDS. The general pattern is

The application creates a specific kind of `Condition` object, such as a `StatusCondition`, and attaches it to a `WaitSet`.

- The application waits on the `WaitSet` until one or more conditions become true.
- The application calls operations on the corresponding entity objects to extract the necessary information.
- The `DataReader` interface also has operations that take a `ReadCondition` argument.
- `QueryCondition` objects are provided as part of the implementation of the Content-Subscription Profile. The `QueryCondition` interface extends the `ReadCondition` interface.

1.1.9 OpenDDS Implementation

Compliance

OpenDDS complies with the OMG DDS and the OMG DDSI-RTPS specifications. Details of that compliance follows here. OpenDDS also implements the OMG DDS Security specification. Details of compliance to that specification are in *DDS Security Implementation Status*. Details of XTypes compliance are in *Unimplemented Features* and *Differences from the specification*.

DDS Compliance

Section 2 of the DDS specification defines five compliance points for a DDS implementation:

- Minimum Profile
- Content-Subscription Profile
- Persistence Profile
- Ownership Profile
- Object Model Profile

OpenDDS complies with the entire DDS specification (including all optional profiles). This includes the implementation of all Quality of Service policies with the following notes:

- RELIABILITY.kind = RELIABLE is supported by the RTPS_UDP transport, the TCP transport, or the IP Multicast transport (when configured as reliable).
- TRANSPORT_PRIORITY is not implemented as changeable.

Although version 1.5 of the DDS specification is not yet published, OpenDDS incorporates some changes planned for that version that are required for a robust implementation:

- DDS15-257: The IDL type BuiltinTopicKey_t is a struct containing an array of 16 octets

DDSI-RTPS Compliance

The OpenDDS implementation complies with the requirements of the OMG DDSI-RTPS specification.

OpenDDS RTPS Implementation Notes

The OMG DDSI-RTPS specification (formal/2019-04-03) supplies statements for implementation, but not required for compliance. The following items should be taken into consideration when utilizing the OpenDDS RTPS functionality for transport and/or discovery. Section numbers of the DDSI-RTPS specification are supplied with each item for further reference.

Items not implemented in OpenDDS:

1. Writer-side content filtering (8.7.3)

   OpenDDS may still drop samples that aren't needed (due to content filtering) by any associated readers — this is done above the transport layer

2. Coherent sets for `PRESENTATION` QoS (8.7.5)
3. Directed writes (8.7.6)
   - OpenDDS will use the Directed Write parameter if it's present on incoming messages (for example, messages generated by a different DDS implementation)
4. Property lists (8.7.7)
5. Original writer info for `DURABLE` data (8.7.8) – this would only be used for transient and persistent durability, which are not supported by the RTPS specification (8.7.2.2.1)
6. Key Hashes (8.7.9) are not generated, but they are optional
7. `nackSuppressionDuration` (Table 8.47) and `heartbeatSuppressionDuration` (Table 8.62).

Note: Items 3 and 4 above are described in the DDSI-RTPS specification. However, they do not have a corresponding concept in the DDS specification.

IDL Compliance

OMG IDL is used in a few different ways in the OpenDDS code base and downstream applications that use it:

- Files that come with OpenDDS such as dds/DdsDcpsTopic.idl define parts of the API between the middleware libraries and the application. This is known as the OMG IDL Platform Specific Model (PSM).
- Users of OpenDDS author IDL files in addition to source code files in C++ or Java.

This section only describes the latter use.

The IDL specification (version 4.2) uses the term "building block" to define subsets of the overall IDL grammar that may be supported by certain tools. OpenDDS supports the following building blocks, with notes/caveats listed below each:

- Core Data Types
  - Support for the "fixed" data type (fixed point decimal) is incomplete.
- Anonymous Types

  - There is limited support for anonymous types when they appear as sequence/array instantiations directly as struct field types. Using an explicitly-named type is recommended.

- Annotations
  - See *Defining Data Types with IDL* and *IDL Annotations* for details on which built-in annotations are supported.
  - User-defined annotation types are also supported.
- Extended Data Types
  - The integer types `int8`, `uint8`, `int16`, `uin16`, `int32` `uint32`, `int64`, and `uint64` are supported.
  - The rest of the building block is not supported.

Extensions to the DDS Specification

Data types, interfaces, and constants in the **DDS** IDL module (C++ namespace, Java package) correspond directly to the DDS specification with very few exceptions:

- `DDS::SampleInfo` contains an extra field starting with `opendds_reserved`.
- Type-specific DataReaders (including those for Built-in Topics) have additional operations `read_instance_w_condition()` and `take_instance_w_condition()`.

Additional extended behavior is provided by various classes and interfaces in the OpenDDS module/namespace/package. Those include features like Recorder and Replayer (*Alternate Interfaces to Data*) and also:

- `OpenDDS::DCPS::TypeSupport` adds the `unregister_type()` operation not found in the DDS spec.
- `OpenDDS::DCPS::ALL_STATUS_MASK`, `NO_STATUS_MASK`, and `DEFAULT_STATUS_MASK` are useful constants for the `DDS::StatusMask` type used by `DDS::Entity`, `DDS::StatusCondition`, and the various `create_*()` operations.

OpenDDS Architecture

This section gives a brief overview of the OpenDDS implementation, its features, and some of its components. The `$DDS_ROOT` environment variable should point to the base directory of the OpenDDS distribution. Source code for OpenDDS can be found under the dds/ directory. Tests can be found under tests/.

Design Philosophy

The OpenDDS implementation and API is based on a fairly strict interpretation of the OMG IDL PSM. In almost all cases the OMG's IDL-to-C++ Language Mapping is used to define how the IDL in the DDS specification is mapped into the C++ APIs that OpenDDS exposes to the client.

The main deviation from the OMG IDL PSM is that local interfaces are used for the entities and various other interfaces. These are defined as unconstrained (non-local) interfaces in the DDS specification. Defining them as local interfaces improves performance, reduces memory usage, simplifies the client's interaction with these interfaces, and makes it easier for clients to build their own implementations.

Extensible Transport Framework (ETF)

OpenDDS uses the IDL interfaces defined by the DDS specification to initialize and control service usage. Data transmission is accomplished via an OpenDDS-specific transport framework that allows the service to be used with a variety of transport protocols. This is referred to as *pluggable transports* and makes the extensibility of OpenDDS an important part of its architecture. OpenDDS currently supports TCP/IP, UDP/IP, IP multicast, shared-memory, and RTPS_UDP transport protocols as shown in *Figure 1-2*. Transports are typically specified via configuration files and are attached to various entities in the publisher and subscriber processes. See *Transport Configuration Options* for details on configuring ETF components.

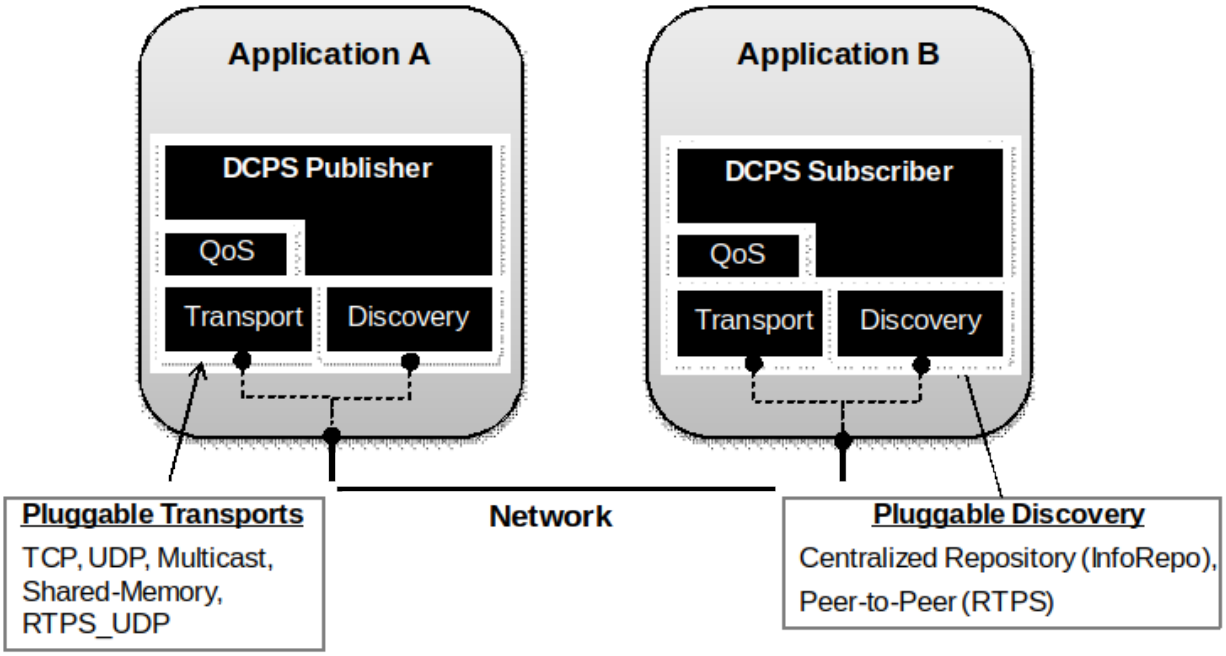


Figure OpenDDS Extensible Transport Framework

The ETF enables application developers to implement their own customized transports. Implementing a custom transport involves specializing a number of classes defined in the transport framework. The `udp` transport provides a good foundation developers may use when creating their own implementation. See the dds/DCPS/transport/udp/ directory for details.

DDS Discovery

DDS applications must discover one another via some central agent or through some distributed scheme. An important feature of OpenDDS is that DDS applications can be configured to perform discovery using the DCPSInfoRepo or RTPS discovery, but utilize a different transport type for data transfer between data writers and data readers. The OMG DDS specification (`formal/2015-04-10`) leaves the details of discovery to the implementation. In the case of interoperability between DDS implementations, the OMG DDSI-RTPS (`formal/2014-09-01`) specification provides requirements for a peer-to-peer style of discovery.

OpenDDS provides two options for discovery.

1. Information Repository: a centralized repository style that runs as a separate process allowing publishers and subscribers to discover one another centrally or
2. RTPS Discovery: a peer-to-peer style of discovery that utilizes the RTPS protocol to advertise availability and location information.

Interoperability with other DDS implementations must utilize the peer-to-peer method, but can be useful in OpenDDS-only deployments.

Centralized Discovery with DCPSInfoRepo

OpenDDS implements a standalone service called the DCPS Information Repository (DCPSInfoRepo) to achieve the centralized discovery method. It is implemented as a CORBA server. When a client requests a subscription for a topic, the DCPS Information Repository locates the topic and notifies any existing publishers of the location of the new subscriber. The DCPSInfoRepo process needs to be running whenever OpenDDS is being used in a non-RTPS configuration. An RTPS configuration does not use the DCPSInfoRepo. The DCPSInfoRepo is not involved in data propagation, its role is limited in scope to OpenDDS applications discovering one another.

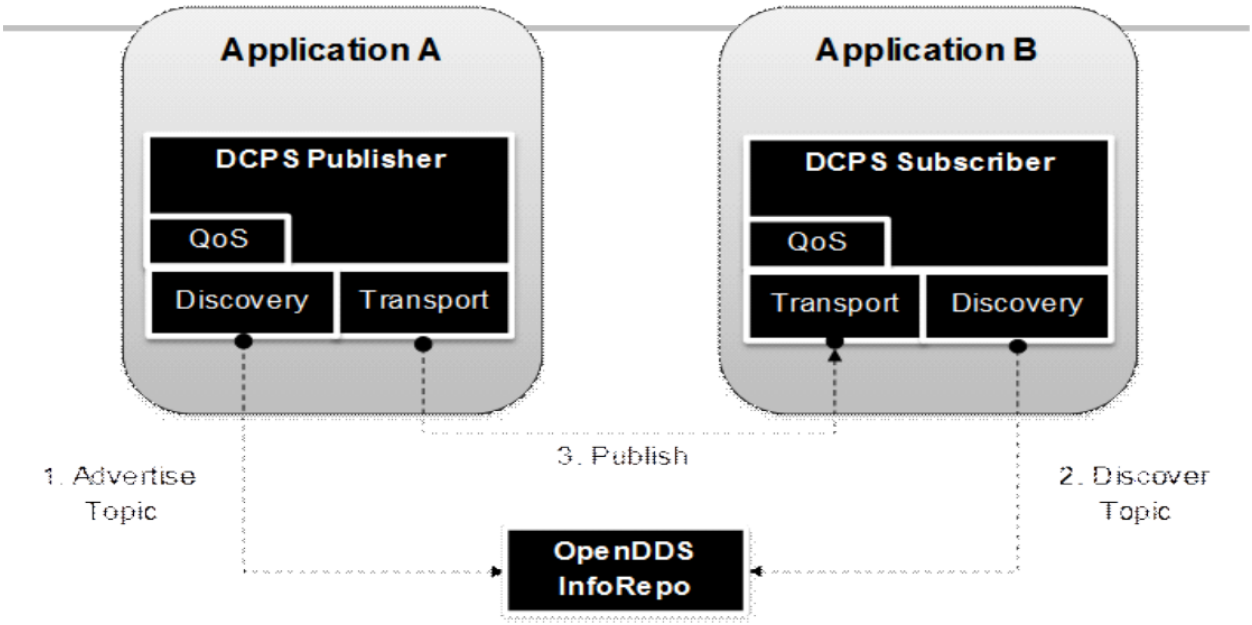


Figure : Centralized Discovery with OpenDDS InfoRepo

Application developers are free to run multiple information repositories with each managing their own non-overlapping sets of DCPS domains.

It is also possible to operate domains with more than a single repository, thus forming a distributed virtual repository. This is known as *Repository Federation*. In order for individual repositories to participate in a federation, each one must specify its own federation identifier value (a 32-bit numeric value) upon start-up. See *Repository Federation* for further information about repository federations.

Peer-to-Peer Discovery with RTPS

DDS applications requiring a Peer-to-Peer discovery pattern can be accommodated by OpenDDS capabilities. This style of discovery is accomplished only through the use of the RTPS protocol as of the current release. This simple form of discovery is accomplished through simple configuration of DDS application data readers and data writers running in application processes as shown in *Figure 1-4*. As each participating process activates the DDSI-RTPS discovery mechanisms in OpenDDS for their data readers and writers, network endpoints are created with either default or configured network ports such that DDS participants can begin advertising the availability of their data readers and data writers. After a period of time, those seeking one another based on criteria will find each other and establish a connection based on the configured pluggable transport as discussed in Extensible Transport Framework (ETF). A

more detailed description of this flexible configuration approach is discussed in *Transport Concepts* and *RTPS_UDP Transport Configuration Options*.

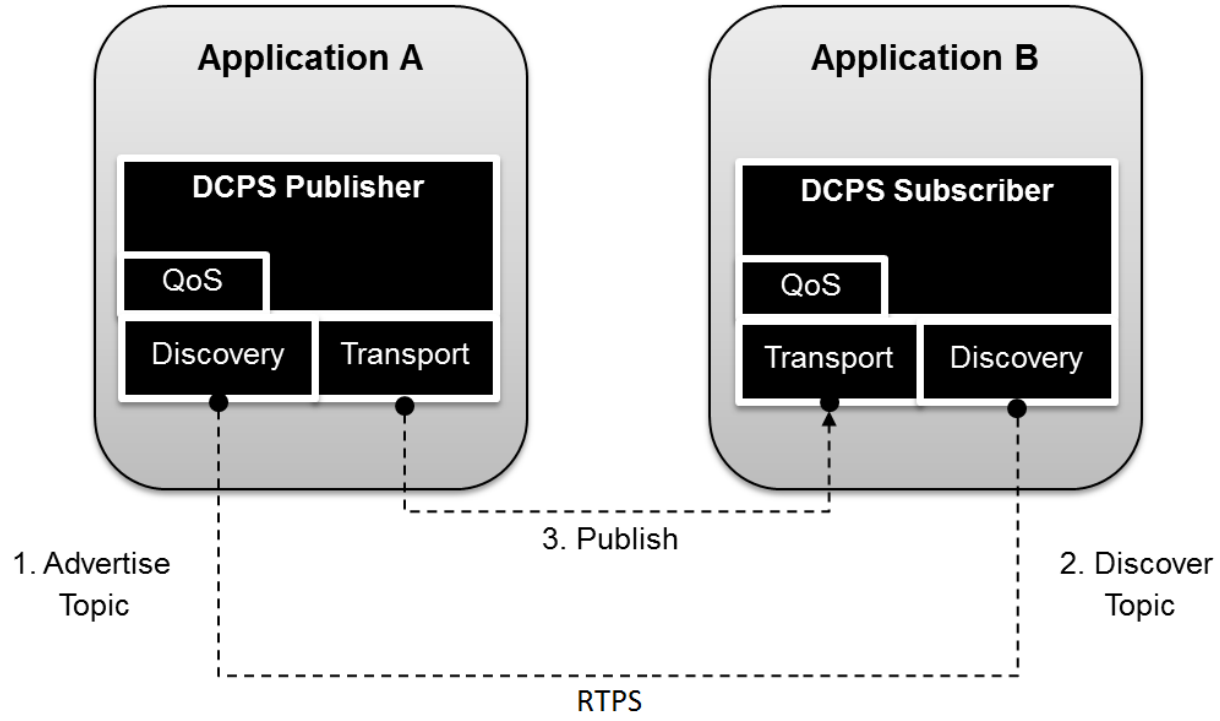


Figure : Peer-to-peer Discovery with RTPS

The following are additional implementation limits that developers need to take into consideration when developing and deploying applications that use RTPS discovery:

1. Domain IDs should be between 0 and 231 (inclusive) due to the way UDP ports are assigned to domain IDs. In each OpenDDS process, up to 120 domain participants are supported in each domain.
2. Topic names and type identifiers are limited to 256 characters.
3. OpenDDS's native multicast transport does not work with RTPS Discovery due to the way GUIDs are assigned (a warning will be issued if this is attempted).

For more details in how RTPS discovery occurs, a very good reference to read can be found in Section 8.5 of the Real-time Publish-Subscribe Wire Protocol DDS Interoperability Wire Protocol Specification (DDSI-RTPS) v2.2 (OMG Document `formal/2014-09-01`).

Threading

OpenDDS creates its own ORB (when one is required) as well as a separate thread upon which to run that ORB. It also uses its own threads to process incoming and outgoing transport I/O. A separate thread is created to cleanup resources upon unexpected connection closure. Your application may get called back from these threads via the Listener mechanism of DCPS.

When publishing a sample via DDS, OpenDDS normally attempts to send the sample to any connected subscribers using the calling thread. If the send call blocks, then the sample may be queued for sending on a separate service thread. This behavior depends on the QoS policies described in *Quality of Service*.

All incoming data in the subscriber is read by a service thread and queued for reading by the application. DataReader listeners are called from the service thread.

Configuration

OpenDDS includes a file-based configuration framework for configuring both global items such as debug level, memory allocation, and discovery, as well as transport implementation details for publishers and subscribers. Configuration can also be achieved directly in code, however, it is recommended that configuration be externalized for ease of maintenance and reduction in runtime errors. The complete set of configuration options are described in *Run-time Configuration*.

1.1.10 Installation

The steps on how to build OpenDDS can be found in INSTALL.md.

To build OpenDDS with DDS Security, see *Building OpenDDS with Security Enabled*.

To avoid compiling OpenDDS code that you will not be using, there are certain features than can be excluded from being built. The features are discussed below.

Users requiring a small-footprint configuration or compatibility with safety-oriented platforms should consider using the OpenDDS Safety Profile, which is described in *Safety Profile* of this guide.

Building With a Feature Enabled or Disabled

Most features are supported by the `configure` script. The `configure` script creates config files with the correct content and then runs MPC. If you are using the `configure` script, run it with the `--help` command line option and look for the feature you wish to enable/disable. If you are not using the `configure` script, continue reading below for instructions on running MPC directly.

For the features described below, MPC is used for enabling (the default) a feature or disabling the feature. For a feature named *feature*, the following steps are used to disable the feature from the build:

1. Use the command line `features` argument to MPC:

   ```
   mwc.pl -type type -features feature=0 DDS.mwc
   ```

   Or alternatively, add the line `feature=0` to the file `$ACE_ROOT/bin/MakeProjectCreator/config/default.features` and regenerate the project files using MPC.

2. If you are using the `gnuace` MPC project type (which is the case if you will be using GNU make as your build system), add line `feature=0` to the file `$ACE_ROOT/include/makeinclude/platform_macros.GNU`.

To explicitly enable the feature, use `feature=1` above.

Note: You can also use the configure script to enable or disable features. To disable the feature, pass `--no-feature` to the script, to enable pass `--feature`. In this case `-` is used instead of `_` in the feature name. For example, to disable feature `content_subscription` discussed below, pass `--no-content-subscription` to the configure script.

Disabling the Building of Built-In Topic Support

Feature Name: `built_in_topics`

You can reduce the footprint of the core DDS library by up to 30% by disabling Built-in Topic Support. See *Built-In Topics* for a description of Built-In Topics.

Disabling the Building of Compliance Profile Features

The DDS specification defines *compliance profiles* to provide a common terminology for indicating certain feature sets that a DDS implementation may or may not support. These profiles are given below, along with the name of the MPC feature to use to disable support for that profile or components of that profile.

Many of the profile options involve QoS settings. If you attempt to use a QoS value that is incompatible with a disabled profile, a runtime error will occur. If a profile involves a class, a compile time error will occur if you try to use the class and the profile is disabled.

Content-Subscription Profile

Feature Name: `content_subscription`

This profile adds the classes `ContentFilteredTopic`, `QueryCondition`, and `MultiTopic` discussed in *Content-Subscription Profile*.

In addition, individual classes can be excluded by using the features given in the table below.

Table : Content-Subscription Class Features

Class	Feature
ContentFilteredTopic	`content_filtered_topic`
QueryCondition	`query_condition`
MultiTopic	`multi_topic`

Persistence Profile

Feature Name: `persistence_profile`

This profile adds the QoS policy `DURABILITY_SERVICE` and the settings `TRANSIENT` and `PERSISTENT` of the `DURABILITY` QoS policy `kind`.

Ownership Profile

Feature Name: `ownership_profile`

This profile adds:

- the setting `EXCLUSIVE` of the `OWNERSHIP` `kind`
- support for the `OWNERSHIP_STRENGTH` policy
- setting a `depth > 1` for the `HISTORY` QoS policy.

Some users may wish to exclude support for the Exclusive OWNERSHIP policy and its associated OWNERSHIP_STRENGTH without impacting use of HISTORY. In order to support this configuration, OpenDDS also has the MPC feature ownership_kind_exclusive (configure script option –no-ownership-kind-exclusive).

Object Model Profile

Feature Name: `object_model_profile`

This profile includes support for the `PRESENTATION` access_scope setting of `GROUP`.

Note: Currently, the `PRESENTATION` access_scope of `TOPIC` is also excluded when `object_model_profile` is disabled.

1.1.11 Building Applications that use OpenDDS

This section applies to any C++ code that directly or indirectly includes OpenDDS headers. For Java applications, see *Java Bindings*.

C++ source code that includes OpenDDS headers can be built using either build system: MPC or CMake.

MPC: The Makefile, Project, and Workspace Creator

OpenDDS is itself built with MPC, so development systems that are set up to use OpenDDS already have MPC available. The OpenDDS configure script creates a "setenv" script with environment settings (`setenv.cmd` on Windows; `setenv.sh` on Linux/macOS). This environment contains the `PATH` and `MPC_ROOT` settings necessary to use MPC.

MPC's source tree (in `MPC_ROOT`) contains a "docs" directory with both HTML and plain text documentation (`USAGE` and `README` files).

The example walk-through in *Using DCPS* uses MPC as its build system. The OpenDDS source tree contains many tests and examples that are built with MPC. These can be used as starting points for application MPC files.

CMake

Applications can also be built with CMake. See the included documentation in the OpenDDS source tree: docs/cmake.md

The OpenDDS source tree also includes examples of using CMake. They are listed in the `cmake.md` file.

Custom Build systems

Users of OpenDDS are strongly encouraged to select one of the two options listed above (MPC or CMake) to generate consistent build files on any supported platform. If this is not possible, users of OpenDDS must make sure that all code generator, compiler, and linker settings in the custom build setup result in API- and ABI-compatible code. To do this, start with an MPC or CMake-generated project file (makefile or Visual Studio project file) and make sure all relevant settings are represented in the custom build system. This is often done through a combination of inspecting the project file and running the build with verbose output to see how the toolchain (code generators, compiler, linker) is invoked.

1.2 Getting Started

1.2.1 Using DCPS

This section focuses on an example application using DCPS to distribute data from a single publisher process to a single subscriber process. It is based on a simple messenger application where a single publisher publishes messages and a single subscriber subscribes to them. We use the default QoS properties and the default TCP/IP transport. Full source code for this example may be found under the DevGuideExamples/DCPS/Messenger/ directory. Additional DDS and DCPS features are discussed in later sections.

Defining Data Types with IDL

In this example, data types for topics will be defined using the OMG Interface Definition Language (IDL). For details on how to build OpenDDS applications that don't use IDL for topic data types, see *DynamicDataWriters and DynamicDataReaders*.

Identifying Topic Types

Each data type used by DDS is defined using OMG Interface Definition Language (IDL). OpenDDS uses IDL annotations[1] to identify the data types that it transmits and processes. These data types are processed by the TAO IDL compiler and the OpenDDS IDL compiler to generate the necessary code to transmit data of these types with OpenDDS. Here is the IDL file that defines our Message data type:

```
module Messenger {

  @topic
  struct Message {
    string from;
    string subject;
    @key long subject_id;
    string text;
    long count;
  };
};
```

The `@topic` annotation marks a data type that can be used as a topic's type. This must be a structure or a union. The structure or union may contain basic types (short, long, float, etc.), enumerations, strings, sequences, arrays, structures, and unions. See *IDL Compliance* for more details on the use of IDL for OpenDDS topic types. The IDL above defines the structure Message in the Messenger module for use in this example.

[1] For backwards compatibility, OpenDDS also parses `#pragma` directives which were used before release 3.14. This guide will describe IDL annotations only.

Keys

The `@key` annotation identifies a field that is used as a key for this topic type. A topic type may have zero or more key fields. These keys are used to identify different DDS Instances within a topic. Keys can be of scalar type, structures or unions containing key fields, or arrays of any of these constructs.

Multiple keys are specified with separate `@key` annotations. In the above example, we identify the `subject_id` member of `Messenger::Message` as a key. Each sample published with a unique `subject_id` value will be defined as belonging to a different DDS Instance within the same topic. Since we are using the default QoS policies, subsequent samples with the same subject_id value are treated as replacement values for that DDS Instance.

`@key` can be applied to a structure field of the following types:

- Any primitive, such as booleans, integers, characters, and strings.
- Other structures that have a defined key or set of keys. For example:

```
struct StructA {
  @key long key;
};

struct StructB {
  @key StructA main_info;
  long other_info;
};

@topic
struct StructC {
  @key StructA keya; // keya.key is one key
  @key StructB keyb; // keyb.main_info.key is another
  DDS::OctetSeq data;
};
```

In this example, every type from the key marked on the topic type down to what primitive data types to use as the key is annotated with `@key`. That isn't strictly necessary though, as the next section shows.

- Other structures that don't have any defined keys. In the following example, it's implied that all the fields in InnerStruct are keys.

```
struct InnerStruct {
  long a;
  short b;
  char c;
};

@topic
struct OuterStruct {
  @key InnerStruct value;
  // value.a, value.b, and value.c are all keys
};
```

If none of the fields in a struct are marked with `@key` or `@key(TRUE)`, then when the struct is used in another struct and marked as a key, all the fields in the struct are assumed to keys. Fields marked with `@key(FALSE)` are always excluded from being a key, such as in this example:

```
struct InnerStruct {
  long a;
  short b;
  @key(FALSE) char c;
};

@topic
struct OuterStruct {
  @key InnerStruct value;
  // Now just value.a and value.b are the keys
};
```

- Unions can also be used as keys if their discriminator is marked as a key. There is an example of a keyed union topic type in the next section, but keep in mind a union being used as a key doesn't have to be a topic type.
- Arrays of any of the previous data types. `@key` can't be applied to sequences, even if the base type would be valid in an array. Also `@key`, when applied to arrays, it makes every element in the array part of the key. They can't be applied to individual array elements.

Union Topic Types

Unions can be used as topic types. Here is an example:

```
enum TypeKind {
  STRING_TYPE,
  LONG_TYPE,
  FLOAT_TYPE
};

@topic
union MyUnionType switch (@key TypeKind) {
case STRING_TYPE:
  string string_value;
case LONG_TYPE:
  long long_value;
case FLOAT_TYPE:
  float float_value;
};
```

Unions can be keyed like structures, but only the union discriminator can be a key, so the set of possible DDS Instances of topics using keyed unions are values of the discriminator. Designating a key for a union topic type is done by putting `@key` before the discriminator type like in the example above. Like structures, it is also possible to have no key fields, in which case `@key` would be omitted and there would be only one DDS Instance.

Topic Types vs. Nested Types

In addition to `@topic`, the set of IDL types OpenDDS can use can also be controlled using `@nested` and `@default_nested`. Types that are "nested" are the opposite of topic types; they can't be used for the top-level type of a topic, but they can be nested inside the top-level type (at any level of nesting). All types are nested by default in OpenDDS to reduce the code generated for type support, but there a number of ways to change this:

- The type can be annotated with `@topic` (see *Identifying Topic Types*), or with `@nested(FALSE)`, which is equivalent to `@topic`.
- The enclosing module can be annotated with `@default_nested(FALSE)`.
- The global default for `opendds_idl` can be changed by adding `--no-default-nested`, in which case it would be as if all valid types were marked with `@topic`. If desired for IDL compatibility with other DDS implementations or based on preference, this can be done through the build system:
  - When using MPC, add `dcps_ts_flags += --no-default-nested` to the project.
  - When using CMake, this can be done by setting either the `OPENDDS_DEFAULT_NESTED` global variable to `FALSE` or adding `--no-default-nested` to the `OPENDDS_IDL_OPTIONS` parameter for `OPENDDS_TARGET_SOURCES`. See `$DDS_ROOT/docs/cmake.md` in the source for more information about using OpenDDS with CMake.

In cases where the module default is not nested, you can reverse this by using `@nested` or `@nested(TRUE)` for structures/unions and `@default_nested` or `@default_nested(TRUE)` for modules. NOTE: the `@topic` annotation doesn't take a boolean argument, so `@topic(FALSE)` would cause an error in the OpenDDS IDL Compiler.

Processing the IDL

This section uses the OMG IDL-to-C++ mapping ("C++ classic") as part of the walk-through. OpenDDS also supports the OMG IDL-to-C++11 mapping, see *Using the IDL-to-C++11 Mapping* for details.

The OpenDDS IDL is first processed by the TAO IDL compiler.

```
tao_idl Messenger.idl
```

In addition, we need to process the IDL file with the OpenDDS IDL compiler to generate the serialization and key support code that OpenDDS requires to marshal and demarshal the Message, as well as the type support code for the data readers and writers. This IDL compiler is located in bin and generates three files for each IDL file processed. The three files all begin with the original IDL file name and would appear as follows:

- `<filename>TypeSupport.idl`
- `<filename>TypeSupportImpl.h`
- `<filename>TypeSupportImpl.cpp`

For example, running `opendds_idl` as follows

```
opendds_idl Messenger.idl
```

generates `MessengerTypeSupport.idl`, `MessengerTypeSupportImpl.h`, and `MessengerTypeSupportImpl.cpp`. The IDL file contains the `MessageTypeSupport`, `MessageDataWriter`, and `MessageDataReader` interface definitions. These are type-specific DDS interfaces that we use later to register our data type with the domain, publish samples of that data type, and receive published samples. The implementation files contain implementations for these interfaces. The generated IDL file should itself be compiled with the TAO IDL compiler to generate stubs and skeletons. These and the implementation file should be linked with your OpenDDS applications that use the Message type. The OpenDDS IDL compiler has a number of options that specialize the generated code. These options are described in *opendds_idl*.

Typically, you do not directly invoke the TAO or OpenDDS IDL compilers as above, but let your build system do it for you. Two different build systems are supported for projects that use OpenDDS:

- MPC, the "Make Project Creator" which is used to build OpenDDS itself and the majority of its included tests and examples
- CMake, a build system that's commonly used across the industry (cmake.org)

Even if you will eventually use some custom build system that's not one of the two listed above, start by building an example OpenDDS application using one of the supported build systems and then migrate the code generator command lines, compiler options, etc., to the custom build system.

The remainder of this section will assume MPC. For more details on using CMake, see the included documentation in the OpenDDS repository: `docs/cmake.md`

The code generation process is simplified when using MPC, by inheriting from the dcps base project. Here is the MPC file section common to both the publisher and subscriber

```
project(*idl): dcps {
  // This project ensures the common components get built first.

  TypeSupport_Files {
    Messenger.idl
  }
  custom_only = 1
}
```

The dcps parent project adds the Type Support custom build rules. The TypeSupport_Files section above tells MPC to generate the Message type support files from `Messenger.idl` using the OpenDDS IDL complier. Here is the publisher section:

```
project(*Publisher): dcpsexe_with_tcp {
  exename = publisher
  after  += *idl

  TypeSupport_Files {
    Messenger.idl
  }

  Source_Files {
    Publisher.cpp
  }
}
```

The `dcpsexe_with_tcp` project links in the DCPS library.

For completeness, here is the subscriber section of the MPC file:

```
project(*Subscriber): dcpsexe_with_tcp {

  exename = subscriber
  after  += *idl

  TypeSupport_Files {
    Messenger.idl
  }
```

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```
  Source_Files {
    Subscriber.cpp
    DataReaderListenerImpl.cpp
  }
}
```

A Simple Message Publisher

In this section we describe the steps involved in setting up a simple OpenDDS publication process. The code is broken into logical sections and explained as we present each section. We omit some uninteresting sections of the code (such as `#include` directives, error handling, and cross-process synchronization). The full source code for this sample publisher is found in the `Publisher.cpp` and `Writer.cpp` files in DevGuideExamples/DCPS/Messenger/.

Initializing the Participant

The first section of `main()` initializes the current process as an OpenDDS participant.

```
int main (int argc, char *argv[]) {
  try {
    DDS::DomainParticipantFactory_var dpf =
      TheParticipantFactoryWithArgs(argc, argv);
    DDS::DomainParticipant_var participant =
      dpf->create_participant(42, // domain ID
                              PARTICIPANT_QOS_DEFAULT,
                              0,  // No listener required
                              OpenDDS::DCPS::DEFAULT_STATUS_MASK);
    if (!participant) {
      std::cerr << "create_participant failed." << std::endl;
      return 1;
    }
    // ...
  }
}
```

The `TheParticipantFactoryWithArgs` macro is defined in `Service_Participant.h` and initializes the Domain Participant Factory with the command line arguments. These command line arguments are used to initialize the ORB that the OpenDDS service uses as well as the service itself. This allows us to pass `ORB_init()` options on the command line as well as OpenDDS configuration options of the form `-DCPS*`. Available OpenDDS options are fully described in *Run-time Configuration*.

The `create_participant()` operation uses the domain participant factory to register this process as a participant in the domain specified by the ID of 42. The participant uses the default QoS policies and no listeners. Use of the OpenDDS default status mask ensures all relevant communication status changes (e.g., data available, liveliness lost) in the middleware are communicated to the application (e.g., via callbacks on listeners).

Users may define any number of domains using IDs in the range (0x0 ~ 0x7FFFFFFF). All other values are reserved for internal use by the implementation.

The Domain Participant object reference returned is then used to register our Message data type.

Registering the Data Type and Creating a Topic

First, we create a `MessageTypeSupportImpl` object, then register the type with a type name using the `register_type()` operation. In this example, we register the type with a nil string type name, which causes the `MessageTypeSupport` interface repository identifier to be used as the type name. A specific type name such as "*Message*" can be used as well.

```
Messenger::MessageTypeSupport_var mts =
  new Messenger::MessageTypeSupportImpl();
if (DDS::RETCODE_OK != mts->register_type(participant, "")) {
  std::cerr << "register_type failed." << std::endl;
  return 1;
}
```

Next, we obtain the registered type name from the type support object and create the topic by passing the type name to the participant in the `create_topic()` operation.

```
CORBA::String_var type_name = mts->get_type_name ();

DDS::Topic_var topic =
  participant->create_topic ("Movie Discussion List",
                             type_name,
                             TOPIC_QOS_DEFAULT,
                             0,  // No listener required
                             OpenDDS::DCPS::DEFAULT_STATUS_MASK);
if (!topic) {
  std::cerr << "create_topic failed." << std::endl;
  return 1;
}
```

We have created a topic named "*Movie Discussion List*" with the registered type and the default QoS policies.

Creating a Publisher

Now, we are ready to create the publisher with the default publisher QoS.

```
DDS::Publisher_var pub =
  participant->create_publisher(PUBLISHER_QOS_DEFAULT,
                                0,  // No listener required
                                OpenDDS::DCPS::DEFAULT_STATUS_MASK);
if (!pub) {
  std::cerr << "create_publisher failed." << std::endl;
  return 1;
}
```

Creating a DataWriter and Waiting for the Subscriber

With the publisher in place, we create the data writer.

```
// Create the datawriter
  DDS::DataWriter_var writer =
    pub->create_datawriter(topic,
                           DATAWRITER_QOS_DEFAULT,
                           0,  // No listener required
                           OpenDDS::DCPS::DEFAULT_STATUS_MASK);
  if (!writer) {
    std::cerr << "create_datawriter failed." << std::endl;
    return 1;
  }
```

When we create the data writer we pass the topic object reference, the default QoS policies, and a null listener reference. We now narrow the data writer reference to a `MessageDataWriter` object reference so we can use the type-specific publication operations.

```
Messenger::MessageDataWriter_var message_writer =
     Messenger::MessageDataWriter::_narrow(writer);
```

The example code uses *conditions* and *wait* sets so the publisher waits for the subscriber to become connected and fully initialized. In a simple example like this, failure to wait for the subscriber may cause the publisher to publish its samples before the subscriber is connected.

The basic steps involved in waiting for the subscriber are:

- Get the status condition from the data writer we created
- Enable the Publication Matched status in the condition
- Create a wait set
- Attach the status condition to the wait set
- Get the publication matched status
- If the current count of matches is one or more, detach the condition from the wait set and proceed to publication
- Wait on the wait set (can be bounded by a specified period of time)
- Loop back around to step *5)*

Here is the corresponding code:

```
// Block until Subscriber is available
DDS::StatusCondition_var condition = writer->get_statuscondition();
condition->set_enabled_statuses(DDS::PUBLICATION_MATCHED_STATUS);

DDS::WaitSet_var ws = new DDS::WaitSet;
ws->attach_condition(condition);

while (true) {
  DDS::PublicationMatchedStatus matches;
  if (writer->get_publication_matched_status(matches) != DDS::RETCODE_OK) {
    std::cerr << "get_publication_matched_status failed!"
              << std::endl;
```

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```
    return 1;
  }

  if (matches.current_count >= 1) {
    break;
  }

  DDS::ConditionSeq conditions;
  DDS::Duration_t timeout = { 60, 0 };
  if (ws->wait(conditions, timeout) != DDS::RETCODE_OK) {
    std::cerr << "wait failed!" << std::endl;
    return 1;
  }

}

ws->detach_condition(condition);
```

For more details about status, conditions, and wait sets, see *Conditions and Listeners*.

Sample Publication

The message publication is quite straightforward:

```
// Write samples
Messenger::Message message;
message.subject_id = 99;
message.from = "Comic Book Guy";
message.subject = "Review";
message.text = "Worst. Movie. Ever.";
message.count = 0;
for (int i = 0; i < 10; ++i) {
  DDS::ReturnCode_t error = message_writer->write(message, DDS::HANDLE_NIL);
  ++message.count;
  ++message.subject_id;
  if (error != DDS::RETCODE_OK) {
    // Log or otherwise handle the error condition
    return 1;
  }
}
```

For each loop iteration, calling `write()` causes a message to be distributed to all connected subscribers that are registered for our topic. Since the subject_id is the key for Message, each time subject_id is incremented and `write()` is called, a new instance is created (see *Topic*). The second argument to `write()` specifies the instance on which we are publishing the sample. It should be passed either a handle returned by `register_instance()` or `DDS::HANDLE_NIL`. Passing a `DDS::HANDLE_NIL` value indicates that the data writer should determine the instance by inspecting the key of the sample. See *Registering and Using Instances in the Publisher* for details on using instance handles during publication.

Setting up the Subscriber

Much of the subscriber's code is identical or analogous to the publisher that we just finished exploring. We will progress quickly through the similar parts and refer you to the discussion above for details. The full source code for this sample subscriber is found in the `Subscriber.cpp` and `DataReaderListener.cpp` files in DevGuideExamples/DCPS/Messenger/.

Initializing the Participant

The beginning of the subscriber is identical to the publisher as we initialize the service and join our domain:

```
int main (int argc, char *argv[])
{
 try {
    DDS::DomainParticipantFactory_var dpf =
      TheParticipantFactoryWithArgs(argc, argv);
    DDS::DomainParticipant_var participant =
      dpf->create_participant(42, // Domain ID
                              PARTICIPANT_QOS_DEFAULT,
                              0,  // No listener required
                              OpenDDS::DCPS::DEFAULT_STATUS_MASK);
    if (!participant) {
      std::cerr << "create_participant failed." << std::endl;
      return 1;
    }
```

Registering the Data Type and Creating a Topic

Next, we initialize the message type and topic. Note that if the topic has already been initialized in this domain with the same data type and compatible QoS, the `create_topic()` invocation returns a reference corresponding to the existing topic. If the type or QoS specified in our `create_topic()` invocation do not match that of the existing topic then the invocation fails. There is also a `find_topic()` operation our subscriber could use to simply retrieve an existing topic.

```
Messenger::MessageTypeSupport_var mts =
  new Messenger::MessageTypeSupportImpl();
if (DDS::RETCODE_OK != mts->register_type(participant, "")) {
  std::cerr << "Failed to register the MessageTypeSupport." << std::endl;
  return 1;
}

CORBA::String_var type_name = mts->get_type_name();

DDS::Topic_var topic =
  participant->create_topic("Movie Discussion List",
                            type_name,
                            TOPIC_QOS_DEFAULT,
                            0,  // No listener required
                            OpenDDS::DCPS::DEFAULT_STATUS_MASK);
if (!topic) {
  std::cerr << "Failed to create_topic." << std::endl;
```

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```
  return 1;
}
```

Creating the subscriber

Next, we create the subscriber with the default QoS.

```
// Create the subscriber
DDS::Subscriber_var sub =
  participant->create_subscriber(SUBSCRIBER_QOS_DEFAULT,
                                 0,  // No listener required
                                 OpenDDS::DCPS::DEFAULT_STATUS_MASK);
if (!sub) {
  std::cerr << "Failed to create_subscriber." << std::endl;
  return 1;
}
```

Creating a DataReader and Listener

We need to associate a listener object with the data reader we create, so we can use it to detect when data is available. The code below constructs the listener object. The `DataReaderListenerImpl` class is shown in the next subsection.

```
DDS::DataReaderListener_var listener(new DataReaderListenerImpl);
```

The listener is allocated on the heap and assigned to a `DataReaderListener_var` object. This type provides reference counting behavior so the listener is automatically cleaned up when the last reference to it is removed. This usage is typical for heap allocations in OpenDDS application code and frees the application developer from having to actively manage the lifespan of the allocated objects.

Now we can create the data reader and associate it with our topic, the default QoS properties, and the listener object we just created.

```
// Create the Datareader
DDS::DataReader_var dr =
  sub->create_datareader(topic,
                         DATAREADER_QOS_DEFAULT,
                         listener,
                         OpenDDS::DCPS::DEFAULT_STATUS_MASK);
if (!dr) {
  std::cerr << "create_datareader failed." << std::endl;
  return 1;
}
```

This thread is now free to perform other application work. Our listener object will be called on an OpenDDS thread when a sample is available.

The Data Reader Listener Implementation

Our listener class implements the `DDS::DataReaderListener` interface defined by the DDS specification. The `DataReaderListener` is wrapped within a `DCPS::LocalObject` which resolves ambiguously-inherited members such as `_narrow` and `_ptr_type`. The interface defines a number of operations we must implement, each of which is invoked to inform us of different events. The `OpenDDS::DCPS::DataReaderListener` defines operations for OpenDDS's special needs such as disconnecting and reconnected event updates. Here is the interface definition:

```
module DDS {
  local interface DataReaderListener : Listener {
    void on_requested_deadline_missed(in DataReader reader,
                                      in RequestedDeadlineMissedStatus status);
    void on_requested_incompatible_qos(in DataReader reader,
                                       in RequestedIncompatibleQosStatus status);
    void on_sample_rejected(in DataReader reader,
                            in SampleRejectedStatus status);
    void on_liveliness_changed(in DataReader reader,
                               in LivelinessChangedStatus status);
    void on_data_available(in DataReader reader);
    void on_subscription_matched(in DataReader reader,
                                 in SubscriptionMatchedStatus status);
    void on_sample_lost(in DataReader reader, in SampleLostStatus status);
  };
};
```

Our example listener class stubs out most of these listener operations with simple print statements. The only operation that is really needed for this example is `on_data_available()` and it is the only member function of this class we need to explore.

```
void DataReaderListenerImpl::on_data_available(DDS::DataReader_ptr reader)
{
  ++num_reads_;

  try {
    Messenger::MessageDataReader_var reader_i =
      Messenger::MessageDataReader::_narrow(reader);
    if (!reader_i) {
      std::cerr << "read: _narrow failed." << std::endl;
      return;
    }
```

The code above narrows the generic data reader passed into the listener to the type-specific `MessageDataReader` interface. The following code takes the next sample from the message reader. If the take is successful and returns valid data, we print out each of the message's fields.

```
Messenger::Message message;
DDS::SampleInfo si;
DDS::ReturnCode_t status = reader_i->take_next_sample(message, si);

if (status == DDS::RETCODE_OK) {

  if (si.valid_data == 1) {
      std::cout << "Message: subject = " << message.subject.in() << std::endl
        << "  subject_id = " << message.subject_id  << std::endl
```

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```
        << "  from = " << message.from.in()  << std::endl
        << "  count = " << message.count  << std::endl
        << "  text = " << message.text.in()  << std::endl;
  }
  else if (si.instance_state == DDS::NOT_ALIVE_DISPOSED_INSTANCE_STATE)
  {
    std::cout << "instance is disposed" << std::endl;
  }
  else if (si.instance_state == DDS::NOT_ALIVE_NO_WRITERS_INSTANCE_STATE)
  {
    std::cout << "instance is unregistered" << std::endl;
  }
  else
  {
    std::cerr << "ERROR: received unknown instance state "
              << si.instance_state << std::endl;
  }
} else if (status == DDS::RETCODE_NO_DATA) {
    cerr << "ERROR: reader received DDS::RETCODE_NO_DATA!" << std::endl;
} else {
    cerr << "ERROR: read Message: Error: " <<  status << std::endl;
}
```

Note the sample read may contain invalid data. The valid_data flag indicates if the sample has valid data. There are two samples with invalid data delivered to the listener callback for notification purposes. One is the *dispose* notification, which is received when the `DataWriter` calls `dispose()` explicitly. The other is the *unregistered* notification, which is received when the `DataWriter` calls `unregister()` explicitly. The dispose notification is delivered with the instance state set to `NOT_ALIVE_DISPOSED_INSTANCE_STATE` and the unregister notification is delivered with the instance state set to `NOT_ALIVE_NO_WRITERS_INSTANCE_STATE`.

If additional samples are available, the service calls this function again. However, reading values a single sample at a time is not the most efficient way to process incoming data. The Data Reader interface provides a number of different options for processing data in a more efficient manner. We discuss some of these operations in *Data Handling Optimizations*.

Cleaning up in OpenDDS Clients

After we are finished in the publisher and subscriber, we can use the following code to clean up the OpenDDS-related objects:

```
participant->delete_contained_entities();
dpf->delete_participant(participant);
TheServiceParticipant->shutdown();
```

The domain participant's `delete_contained_entities()` operation deletes all the topics, subscribers, and publishers created with that participant. Once this is done, we can use the domain participant factory to delete our domain participant.

Since the publication and subscription of data within DDS is decoupled, data is not guaranteed to be delivered if a publication is disassociated (shutdown) prior to all data that has been sent having been received by the subscriptions. If the application requires that all published data be received, the `wait_for_acknowledgments()` operation is available to allow the publication to wait until all written data has been received. Data readers must have a `RELIABLE` setting for the `RELIABILITY` QoS (which is the default) in order for `wait_for_acknowledgments()` to work. This operation is

called on individual DataWriters and includes a timeout value to bound the time to wait. The following code illustrates the use of wait_for_acknowledgments() to block for up to 15 seconds to wait for subscriptions to acknowledge receipt of all written data:

```
DDS::Duration_t shutdown_delay = {15, 0};
DDS::ReturnCode_t result;
result = writer->wait_for_acknowledgments(shutdown_delay);
if( result != DDS::RETCODE_OK) {
  std::cerr << "Failed while waiting for acknowledgment of "
            << "data being received by subscriptions, some data "
            << "may not have been delivered." << std::endl;
}
```

Running the Example

We are now ready to run our simple example. Running each of these commands in its own window should enable you to most easily understand the output.

First we will start a DCPSInfoRepo service so our publishers and subscribers can find one another.

Note: This step is not necessary if you are using peer-to-peer discovery by configuring your environment to use RTPS discovery.

The DCPSInfoRepo executable is found in bin/DCPSInfoRepo. When we start the DCPSInfoRepo we need to ensure that publisher and subscriber application processes can also find the started DCPSInfoRepo. This information can be provided in one of three ways: a.) parameters on the command line , b.) generated and placed in a shared file for applications to use, or c.) parameters placed in a configuration file for other processes to use. For our simple example here we will use option 'b' by generating the location properties of the DCPSInfoRepo into a file so that our simple publisher and subscriber can read it in and connect to it.

From your current directory type:

Windows:

```
%DDS_ROOT%\bin\DCPSInfoRepo -o simple.ior
```

Unix:

```
$DDS_ROOT/bin/DCPSInfoRepo -o simple.ior
```

The -o parameter instructs the DCPSInfoRepo to generate its connection information to the file simple.ior for use by the publisher and subscriber. In a separate window navigate to the same directory that contains the simple.ior file and start the subscriber application in our example by typing:

Windows:

```
subscriber -DCPSInfoRepo file://simple.ior
```

Unix:

```
./subscriber -DCPSInfoRepo file://simple.ior
```

The command line parameters direct the application to use the specified file to locate the DCPSInfoRepo. Our subscriber is now waiting for messages to be sent, so we will now start the publisher in a separate window with the same parameters:

Windows:

```
publisher -DCPSInfoRepo file://simple.ior
```

Unix

```
./publisher -DCPSInfoRepo file://simple.ior
```

The publisher connects to the `DCPSInfoRepo` to find the location of any subscribers and begins to publish messages as well as write them to the console. In the subscriber window, you should also now be seeing console output from the subscriber that is reading messages from the topic demonstrating a simple publish and subscribe application.

You can read more about configuring your application for RTPS and other more advanced configuration options in *Configuring for DDSI-RTPS Discovery* and *RTPS_UDP Transport Configuration Options* . See *Discovery Configuration* and *The DCPS Information Repository* for configuring and using the `DCPSInfoRepo` . See *Quality of Service* for setting and using QoS features that modify the behavior of your application.

Running Our Example with RTPS

The prior OpenDDS example has demonstrated how to build and execute an OpenDDS application using basic OpenDDS configurations and centralized discovery using the `DCPSInfoRepo` service. The following details what is needed to run the same example using RTPS for discovery and with an interoperable transport. This is important in scenarios when your OpenDDS application needs to interoperate with a non-OpenDDS implementation of the DDS specification or if you do not want to use centralized discovery in your deployment of OpenDDS.

The coding and building of the Messenger example above is not changed for using RTPS, so you will not need to modify or rebuild your publisher and subscriber services. This is a strength of the OpenDDS architecture in that to enable the RTPS capabilities, it is an exercise in configuration. For this exercise, we will enable RTPS for the Messenger example using a configuration file that the publisher and subscriber will share. More details concerning the configuration of all the available transports including RTPS are described in *Run-time Configuration*.

Navigate to the directory where your publisher and subscriber have been built. Create a new text file named `rtps.ini` and populate it with the following content:

```
[common]
DCPSGlobalTransportConfig=$file
DCPSDefaultDiscovery=DEFAULT_RTPS

[transport/the_rtps_transport]
transport_type=rtps_udp
```

The two lines of interest are the one that sets the discovery method and the one that sets the data transport protocol to RTPS.

Now lets re-run our example with RTPS enabled by starting the subscriber process first and then the publisher to begin sending data. It is best to start them in separate windows to see the two working separately.

Start the subscriber with the `-DCPSConfigFile` command line parameter to point to the newly created configuration file…

Windows:

```
subscriber -DCPSConfigFile rtps.ini
```

Unix:

```
./subscriber -DCPSConfigFile rtps.ini
```

Now start the publisher with the same parameter...

Windows:

```
publisher -DCPSConfigFile rtps.ini
```

Unix:

```
./publisher -DCPSConfigFile rtps.ini
```

Since there is no centralized discovery in the RTPS specification, there are provisions to allow for wait times to allow discovery to occur. The specification sets the default to 30 seconds. When the two above processes are started there may be up to a 30 second delay depending on how far apart they are started from each other. This time can be adjusted in OpenDDS configuration files and is discussed in *Configuring for DDSI-RTPS Discovery*.

Because the architecture of OpenDDS allows for pluggable discovery and pluggable transports the two configuration entries called out in the `rtps.ini` file above can be changed independently with one using RTPS and the other not using RTPS (e.g. centralized discovery using `DCPSInfoRepo`). Setting them both to RTPS in our example makes this application fully interoperable with other non-OpenDDS implementations.

1.2.2 Data Handling Optimizations

Registering and Using Instances in the Publisher

The previous example implicitly specifies the instance it is publishing via the sample's data fields. When `write()` is called, the data writer queries the sample's key fields to determine the instance. The publisher also has the option to explicitly register the instance by calling `register_instance()` on the data writer:

```
Messenger::Message message;
message.subject_id = 99;
DDS::InstanceHandle_t handle = message_writer->register_instance(message);
```

After we populate the Message structure we called the register_instance() function to register the instance. The instance is identified by the subject_id value of 99 (because we earlier specified that field as the key).

We can later use the returned instance handle when we publish a sample:

```
DDS::ReturnCode_t ret = data_writer->write(message, handle);
```

Publishing samples using the instance handle may be slightly more efficient than forcing the writer to query for the instance and is much more efficient when publishing the first sample on an instance. Without explicit registration, the first write causes resource allocation by OpenDDS for that instance.

Because resource limitations can cause instance registration to fail, many applications consider registration as part of setting up the publisher and always do it when initializing the data writer.

Reading Multiple Samples

The DDS specification provides a number of operations for reading and writing data samples. In the examples above we used the `take_next_sample()` operation, to read the next sample and "take" ownership of it from the reader. The Message Data Reader also has the following take operations.

- `take()`—Take a sequence of up to max_samples values from the reader
- `take_instance()`—Take a sequence of values for a specified instance
- `take_next_instance()`—Take a sequence of samples belonging to the same instance, without specifying the instance.

There are also "read" operations corresponding to each of these "take" operations that obtain the same values, but leave the samples in the reader and simply mark them as read in the `SampleInfo`.

Since these other operations read a sequence of values, they are more efficient when samples are arriving quickly. Here is a sample call to `take()` that reads up to 5 samples at a time.

```
MessageSeq messages(5);
DDS::SampleInfoSeq sampleInfos(5);
DDS::ReturnCode_t status = message_dr->take(messages,
                                            sampleInfos,
                                            5,
                                            DDS::ANY_SAMPLE_STATE,
                                            DDS::ANY_VIEW_STATE,
                                            DDS::ANY_INSTANCE_STATE);
```

The three state parameters potentially specialize which samples are returned from the reader. See the DDS specification for details on their usage.

Zero-Copy Read

The read and take operations that return a sequence of samples provide the user with the option of obtaining a copy of the samples (single-copy read) or a reference to the samples (zero-copy read). The zero-copy read can have significant performance improvements over the single-copy read for large sample types. Testing has shown that samples of 8KB or less do not gain much by using zero-copy reads but there is little performance penalty for using zero-copy on small samples.

The application developer can specify the use of the zero-copy read optimization by calling `take()` or `read()` with a sample sequence constructed with a max_len of zero. The message sequence and sample info sequence constructors both take max_len as their first parameter and specify a default value of zero. The following example code is taken from `DevGuideExamples/DCPS/Messenger_ZeroCopy/DataReaderListenerImpl.cpp`:

```
Messenger::MessageSeq messages;
DDS::SampleInfoSeq info;

// get references to the samples (zero-copy read of the samples)
DDS::ReturnCode_t status = dr->take(messages,
                                    info,
                                    DDS::LENGTH_UNLIMITED,
                                    DDS::ANY_SAMPLE_STATE,
                                    DDS::ANY_VIEW_STATE,
                                    DDS::ANY_INSTANCE_STATE);
```

After both zero-copy takes/reads and single-copy takes/reads, the sample and info sequences' length are set to the number of samples read. For the zero-copy reads, the `max_len` is set to a `value >= length`.

Since the application code has asked for a zero-copy loan of the data, it must return that loan when it is finished with the data:

```
dr->return_loan(messages, info);
```

Calling `return_loan()` results in the sequences' `max_len` being set to 0 and its owns member set to false, allowing the same sequences to be used for another zero-copy read.

If the first parameter of the data sample sequence constructor and info sequence constructor were changed to a value greater than zero, then the sample values returned would be copies. When values are copied, the application developer has the option of calling `return_loan()`, but is not required to do so.

If the `max_len` (the first) parameter of the sequence constructor is not specified, it defaults to 0; hence using zero-copy reads. Because of this default, a sequence will automatically call `return_loan()` on itself when it is destroyed. To conform with the DDS specification and be portable to other implementations of DDS, applications should not rely on this automatic `return_loan()` feature.

The second parameter to the sample and info sequences is the maximum slots available in the sequence. If the `read()` or `take()` operation's `max_samples` parameter is larger than this value, then the maximum samples returned by `read()` or `take()` will be limited by this parameter of the sequence constructor.

Although the application can change the length of a zero-copy sequence, by calling the `length(len)` operation, you are advised against doing so because this call results in copying the data and creating a single-copy sequence of samples.

1.3 Quality of Service

1.3.1 Introduction

The previous examples use default QoS policies for the various entities. This section discusses the QoS policies which are implemented in OpenDDS and the details of their usage. See the DDS specification for further information about the policies discussed in this section.

1.3.2 QoS Policies

Each policy defines a structure to specify its data. Each entity supports a subset of the policies and defines a QoS structure that is composed of the supported policy structures. The set of allowable policies for a given entity is constrained by the policy structures nested in its QoS structure. For example, the Publisher's QoS structure is defined in the specification's IDL as follows:

```
module DDS {
  struct PublisherQos {
   PresentationQosPolicy presentation;
   PartitionQosPolicy partition;
   GroupDataQosPolicy group_data;
   EntityFactoryQosPolicy entity_factory;
 };
};
```

Setting policies is as simple as obtaining a structure with the default values already set, modifying the individual policy structures as necessary, and then applying the QoS structure to an entity (usually when it is created). See *Default QoS Policy Values* for examples of how to obtain the default QoS policies for various entity types.

Applications can change the QoS of any entity by calling the set_qos() operation on the entity. If the QoS is changeable, existing associations are removed if they are no longer compatible and new associations are added if they become compatible. The `DCPSInfoRepo` re-evaluates the QoS compatibility and associations according to the QoS specification. If the compatibility checking fails, the call to set_qos() will return an error. The association re-evaluation may result in removal of existing associations or addition of new associations.

If the user attempts to change a QoS policy that is immutable (not changeable), then `set_qos()` returns `DDS::RETCODE_IMMUTABLE_POLICY`.

A subset of the QoS policies are changeable. Some changeable QoS policies, such as `USER_DATA`, `TOPIC_DATA`, `GROUP_DATA`, `LIFESPAN`, `OWNERSHIP_STRENGTH`, `TIME_BASED_FILTER`, `ENTITY_FACTORY`, `WRITER_DATA_LIFECYCLE`, and `READER_DATA_LIFECYCLE`, do not require compatibility and association re-evaluation. The `DEADLINE` and `LATENCY_BUDGET` QoS policies require compatibility re-evaluation, but not for association. The `PARTITION` QoS policy does not require compatibility re-evaluation, but does require association re-evaluation. The DDS specification lists `TRANSPORT_PRIORITY` as changeable, but the OpenDDS implementation does not support dynamically modifying this policy.

Default QoS Policy Values

Applications obtain the default QoS policies for an entity by instantiating a QoS structure of the appropriate type for the entity and passing it by reference to the appropriate `get_default_entity_qos()` operation on the appropriate factory entity. (For example, you would use a domain participant to obtain the default QoS for a publisher or subscriber.) The following examples illustrate how to obtain the default policies for publisher, subscriber, topic, domain participant, data writer, and data reader.

```
// Get default Publisher QoS from a DomainParticipant:
DDS::PublisherQos pub_qos;
DDS::ReturnCode_t ret;
ret = domain_participant->get_default_publisher_qos(pub_qos);
if (DDS::RETCODE_OK != ret) {
  std::cerr << "Could not get default publisher QoS" << std::endl;
}

// Get default Subscriber QoS from a DomainParticipant:
DDS::SubscriberQos sub_qos;
ret = domain_participant->get_default_subscriber_qos(sub_qos);
if (DDS::RETCODE_OK != ret) {
  std::cerr << "Could not get default subscriber QoS" << std::endl;
}

// Get default Topic QoS from a DomainParticipant:
DDS::TopicQos topic_qos;
ret = domain_participant->get_default_topic_qos(topic_qos);
if (DDS::RETCODE_OK != ret) {
  std::cerr << "Could not get default topic QoS" << std::endl;
}

// Get default DomainParticipant QoS from a DomainParticipantFactory:
DDS::DomainParticipantQos dp_qos;
ret = domain_participant_factory->get_default_participant_qos(dp_qos);
if (DDS::RETCODE_OK != ret) {
  std::cerr << "Could not get default participant QoS" << std::endl;
}
```

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```
// Get default DataWriter QoS from a Publisher:
DDS::DataWriterQos dw_qos;
ret = pub->get_default_datawriter_qos(dw_qos);
if (DDS::RETCODE_OK != ret) {
  std::cerr << "Could not get default data writer QoS" << std::endl;
}

// Get default DataReader QoS from a Subscriber:
DDS::DataReaderQos dr_qos;
ret = sub->get_default_datareader_qos(dr_qos);
if (DDS::RETCODE_OK != ret) {
  std::cerr << "Could not get default data reader QoS" << std::endl;
}
```

The following tables summarize the default QoS policies for each entity type in OpenDDS to which policies can be applied.

Table Default DomainParticipant QoS Policies

Policy	Member	Default Value
USER_DATA	value	(empty sequence)
ENTITY_FACTORY	autoenable_created_entities	true

Table Default Topic QoS Policies

Policy	Member	Default Value
TOPIC_DATA	value	(empty sequence)
DURABILITY	kind	VOLATILE_DURABILITY_QOS
	service_cleanup_delay.sec	DURATION_ZERO_SEC
	service_cleanup_delay.nanosec	DURATION_ZERO_NSEC
DURABILITY_SERVICE	service_cleanup_delay.sec	DURATION_ZERO_SEC
	service_cleanup_delay.nanosec	DURATION_ZERO_NSEC
	history_kind	KEEP_LAST_HISTORY_QOS
	history_depth	1
	max_samples	LENGTH_UNLIMITED
	max_instances	LENGTH_UNLIMITED
	max_samples_per_instance	LENGTH_UNLIMITED
DEADLINE	period.sec	DURATION_INFINITE_SEC
	period.nanosec	DURATION_INFINITE_NSEC
LATENCY_BUDGET	duration.sec	DURATION_ZERO_SEC
	duration.nanosec	DURATION_ZERO_NSEC
LIVELINESS	kind	AUTOMATIC_LIVELINESS_QOS
	lease_duration.sec	DURATION_INFINITE_SEC
	lease_duration.nanosec	DURATION_INFINITE_NSEC
RELIABILITY	kind	BEST_EFFORT_RELIABILITY_QOS
	max_blocking_time.sec	DURATION_INFINITE_SEC
	max_blocking_time.nanosec	DURATION_INFINITE_NSEC
DESTINATION_ORDER	kind	BY_RECEPTION_TIMESTAMP_DESTINATIONORDER_QOS
HISTORY	kind	KEEP_LAST_HISTORY_QOS
	depth	1
RESOURCE_LIMITS	max_samples	LENGTH_UNLIMITED
	max_instances	LENGTH_UNLIMITED
	max_samples_per_instance	LENGTH_UNLIMITED
TRANSPORT_PRIORITY	value	0
LIFESPAN	duration.sec	DURATION_INFINITE_SEC
	duration.nanosec	DURATION_INFINITE_NSEC
OWNERSHIP	kind	SHARED_OWNERSHIP_QOS

Table Default Publisher QoS Policies

Policy	Member	Default Value
PRESENTATION	access_scope	INSTANCE_PRESENTATION_QOS
	coherent_access	0
	ordered_access	0
PARTITION	name	(empty sequence)
GROUP_DATA	value	(empty sequence)
ENTITY_FACTORY	autoenable_created_entities	true

Table Default Subscriber QoS Policies

Policy	Member	Default Value
PRESENTATION	access_scope	INSTANCE_PRESENTATION_QOS
	coherent_access	0
	ordered_access	0
PARTITION	name	(empty sequence)
GROUP_DATA	value	(empty sequence)
ENTITY_FACTORY	autoenable_created_entities	true

Table Default DataWriter QoS Policies

Policy	Member	Default Value
DURABILITY	kind	VOLATILE_DURABILITY_QOS
DURABILITY_SERVICE	service_cleanup_delay.sec	DURATION_ZERO_SEC
	service_cleanup_delay.nanosec	DURATION_ZERO_NSEC
	history_kind	KEEP_LAST_HISTORY_QOS
	history_depth	1
	max_samples	LENGTH_UNLIMITED
	max_instances	LENGTH_UNLIMITED
	max_samples_per_instance	LENGTH_UNLIMITED
DEADLINE	period.sec	DURATION_INFINITE_SEC
	period.nanosec	DURATION_INFINITE_NSEC
LATENCY_BUDGET	duration.sec	DURATION_ZERO_SEC
	duration.nanosec	DURATION_ZERO_NSEC
LIVELINESS	kind	AUTOMATIC_LIVELINESS_QOS
	lease_duration.sec	DURATION_INFINITE_SEC
	lease_duration.nanosec	DURATION_INFINITE_NSEC
RELIABILITY	kind	RELIABLE_RELIABILITY_QOS[1]
	max_blocking_time.sec	0
	max_blocking_time.nanosec	100000000 (100 ms)
DESTINATION_ORDER	kind	BY_RECEPTION_TIMESTAMP_DESTINATIONORDER_QOS
HISTORY	kind	KEEP_LAST_HISTORY_QOS
	depth	1
RESOURCE_LIMITS	max_samples	LENGTH_UNLIMITED
	max_instances	LENGTH_UNLIMITED
	max_samples_per_instance	LENGTH_UNLIMITED
TRANSPORT_PRIORITY	value	0
LIFESPAN	duration.sec	DURATION_INFINITE_SEC
	duration.nanosec	DURATION_INFINITE_NSEC
USER_DATA	value	(empty sequence)
OWNERSHIP	kind	SHARED_OWNERSHIP_QOS
OWNERSHIP_STRENGTH	value	0
WRITER_DATA_LIFECYCLE	autodispose_unregistered_instances	1

Table Default DataReader QoS Policies

[1] For OpenDDS versions, up to 2.0, the default reliability kind for data writers is best effort. For versions 2.0.1 and later, this is changed to reliable (to conform to the DDS specification).

Policy	Member	Default Value
DURABILITY	kind	VOLATILE_DURABILITY_QOS
	service_cleanup_delay.sec	DURATION_ZERO_SEC
	service_cleanup_delay.nanosec	DURATION_ZERO_NSEC
DEADLINE	period.sec	DURATION_INFINITE_SEC
	period.nanosec	DURATION_INFINITE_NSEC
LATENCY_BUDGET	duration.sec	DURATION_ZERO_SEC
	duration.nanosec	DURATION_ZERO_NSEC
LIVELINESS	kind	AUTOMATIC_LIVELINESS_QOS
	lease_duration.sec	DURATION_INFINITE_SEC
	lease_duration.nanosec	DURATION_INFINITE_NSEC
RELIABILITY	kind	BEST_EFFORT_RELIABILITY_QOS
	max_blocking_time.sec	DURATION_INFINITE_SEC
	max_blocking_time.nanosec	DURATION_INFINITE_NSEC
DESTINATION_ORDER	kind	BY_RECEPTION_TIMESTAMP_DESTINATIONORDER_QOS
HISTORY	kind	KEEP_LAST_HISTORY_QOS
	depth	1
RESOURCE_LIMITS	max_samples	LENGTH_UNLIMITED
	max_instances	LENGTH_UNLIMITED
	max_samples_per_instance	LENGTH_UNLIMITED
USER_DATA	value	(empty sequence)
OWNERSHIP	kind	SHARED_OWNERSHIP_QOS
TIME_BASED_FILTER	minimum_separation.sec	DURATION_ZERO_SEC
	minimum_separation.nanosec	DURATION_ZERO_NSEC
READER_DATA_LIFECYCLE	autopurge_nowriter_samples_delay.sec	DURATION_INFINITE_SEC
	autopurge_nowriter_samples_delay.nanosec	DURATION_INFINITE_NSEC
	autopurge_disposed_samples_delay.sec	DURATION_INFINITE_SEC
	autopurge_disposed_samples_delay.nanosec	DURATION_INFINITE_NSEC

LIVELINESS

The LIVELINESS policy applies to the topic, data reader, and data writer entities via the liveliness member of their respective QoS structures. Setting this policy on a topic means it is in effect for all data readers and data writers on that topic. Below is the IDL related to the liveliness QoS policy:

```
enum LivelinessQosPolicyKind {
  AUTOMATIC_LIVELINESS_QOS,
  MANUAL_BY_PARTICIPANT_LIVELINESS_QOS,
  MANUAL_BY_TOPIC_LIVELINESS_QOS
};

struct LivelinessQosPolicy {
  LivelinessQosPolicyKind kind;
  Duration_t lease_duration;
};
```

The LIVELINESS policy controls when and how the service determines whether participants are alive, meaning they are still reachable and active. The kind member setting indicates whether liveliness is asserted automatically by the service or manually by the specified entity. A setting of AUTOMATIC_LIVELINESS_QOS means that the service will send a liveliness indication if the participant has not sent any network traffic for the lease_duration. The MANUAL_BY_PARTICIPANT_LIVELINESS_QOS or MANUAL_BY_TOPIC_LIVELINESS_QOS setting means the specified

entity (data writer for the "by topic" setting or domain participant for the "by participant" setting) must either write a sample or manually assert its liveliness within a specified heartbeat interval. The desired heartbeat interval is specified by the lease_duration member. The default lease duration is a pre-defined infinite value, which disables any liveliness testing.

To manually assert liveliness without publishing a sample, the application must call the `assert_liveliness()` operation on the data writer (for the "by topic" setting) or on the domain participant (for the "by participant" setting) within the specified heartbeat interval.

Data writers specify (*offer*) their own liveliness criteria and data readers specify (*request*) the desired liveliness of their writers. Writers that are not heard from within the lease duration (either by writing a sample or by asserting liveliness) cause a change in the `LIVELINESS_CHANGED_STATUS` communication status and notification to the application (e.g., by calling the data reader listener's `on_liveliness_changed()` callback operation or by signaling any related wait sets).

This policy is considered during the establishment of associations between data writers and data readers. The value of both sides of the association must be compatible in order for an association to be established. Compatibility is determined by comparing the data reader's requested liveliness with the data writer's offered liveliness. Both the kind of liveliness (automatic, manual by topic, manual by participant) and the value of the lease duration are considered in determining compatibility. The writer's offered kind of liveliness must be greater than or equal to the reader's requested kind of liveliness. The liveliness kind values are ordered as follows:

```
MANUAL_BY_TOPIC_LIVELINESS_QOS >
MANUAL_BY_PARTICIPANT_LIVELINESS_QOS >
AUTOMATIC_LIVELINESS_QOS
```

In addition, the writer's offered lease duration must be less than or equal to the reader's requested lease duration. Both of these conditions must be met for the offered and requested liveliness policy settings to be considered compatible and the association established.

RELIABILITY

The `RELIABILITY` policy applies to the topic, data reader, and data writer entities via the reliability member of their respective QoS structures. Below is the IDL related to the reliability QoS policy:

```
enum ReliabilityQosPolicyKind {
  BEST_EFFORT_RELIABILITY_QOS,
  RELIABLE_RELIABILITY_QOS
};

struct ReliabilityQosPolicy {
  ReliabilityQosPolicyKind kind;
  Duration_t max_blocking_time;
};
```

This policy controls how data readers and writers treat the data samples they process. The "best effort" value (`BEST_EFFORT_RELIABILITY_QOS`) makes no promises as to the reliability of the samples and could be expected to drop samples under some circumstances. The "reliable" value (`RELIABLE_RELIABILITY_QOS`) indicates that the service should eventually deliver all values to eligible data readers.

The `max_blocking_time` member of this policy is used when the history QoS policy is set to "keep all" and the writer is unable to proceed because of resource limits. When this situation occurs and the writer blocks for more than the specified time, then the write fails with a timeout return code. The default for this policy for data readers and topics is "best effort," while the default value for data writers is "reliable."

This policy is considered during the creation of associations between data writers and data readers. The value of both sides of the association must be compatible in order for an association to be created. The reliability kind of data writer must be greater than or equal to the value of data reader.

HISTORY

The HISTORY policy determines how samples are held in the data writer and data reader for a particular instance. For data writers these values are held until the publisher retrieves them and successfully sends them to all connected subscribers. For data readers these values are held until "taken" by the application. This policy applies to the topic, data reader, and data writer entities via the history member of their respective QoS structures. Below is the IDL related to the history QoS policy:

```
enum HistoryQosPolicyKind {
  KEEP_LAST_HISTORY_QOS,
  KEEP_ALL_HISTORY_QOS
};

struct HistoryQosPolicy {
  HistoryQosPolicyKind kind;
  long depth;
};
```

The "keep all" value (KEEP_ALL_HISTORY_QOS) specifies that all possible samples for that instance should be kept. When "keep all" is specified and the number of unread samples is equal to the "resource limits" field of max_samples_per_instance then any incoming samples are rejected.

The "keep last" value (KEEP_LAST_HISTORY_QOS) specifies that only the last depth values should be kept. When a data writer contains depth samples of a given instance, a write of new samples for that instance are queued for delivery and the oldest unsent samples are discarded. When a data reader contains depth samples of a given instance, any incoming samples for that instance are kept and the oldest samples are discarded.

This policy defaults to a "keep last" with a depth of one.

DURABILITY

The DURABILITY policy controls whether data writers should maintain samples after they have been sent to known subscribers. This policy applies to the topic, data reader, and data writer entities via the durability member of their respective QoS structures. Below is the IDL related to the durability QoS policy:

```
enum DurabilityQosPolicyKind {
  VOLATILE_DURABILITY_QOS,          // Least Durability
  TRANSIENT_LOCAL_DURABILITY_QOS,
  TRANSIENT_DURABILITY_QOS,
  PERSISTENT_DURABILITY_QOS         // Greatest Durability
};

struct DurabilityQosPolicy {
  DurabilityQosPolicyKind kind;
};
```

By default the kind is VOLATILE_DURABILITY_QOS.

A durability kind of VOLATILE_DURABILITY_QOS means samples are discarded after being sent to all known subscribers. As a side effect, subscribers cannot recover samples sent before they connect.

A durability kind of TRANSIENT_LOCAL_DURABILITY_QOS means that data readers that are associated/connected with a data writer will be sent all of the samples in the data writer's history.

A durability kind of TRANSIENT_DURABILITY_QOS means that samples outlive a data writer and last as long as the process is alive. The samples are kept in memory, but are not persisted to permanent storage. A data reader subscribed to the same topic and partition within the same domain will be sent all of the cached samples that belong to the same topic/partition.

A durability kind of PERSISTENT_DURABILITY_QOS provides basically the same functionality as transient durability except the cached samples are persisted and will survive process destruction.

When transient or persistent durability is specified, the DURABILITY_SERVICE QoS policy specifies additional tuning parameters for the durability cache.

The durability policy is considered during the creation of associations between data writers and data readers. The value of both sides of the association must be compatible in order for an association to be created. The durability kind value of the data writer must be greater than or equal to the corresponding value of the data reader. The durability kind values are ordered as follows:

```
PERSISTENT_DURABILITY_QOS >
TRANSIENT_DURABILITY_QOS >
TRANSIENT_LOCAL_DURABILITY_QOS >
VOLATILE_DURABILITY_QOS
```

DURABILITY_SERVICE

The DURABILITY_SERVICE policy controls deletion of samples in TRANSIENT or PERSISTENT durability cache. This policy applies to the topic and data writer entities via the durability_service member of their respective QoS structures and provides a way to specify HISTORY and RESOURCE_LIMITS for the sample cache. Below is the IDL related to the durability service QoS policy:

```
struct DurabilityServiceQosPolicy {
  Duration_t              service_cleanup_delay;
  HistoryQosPolicyKind    history_kind;
  long                    history_depth;
  long                    max_samples;
  long                    max_instances;
  long                    max_samples_per_instance;
};
```

The history and resource limits members are analogous to, although independent of, those found in the HISTORY and RESOURCE_LIMITS policies. The service_cleanup_delay can be set to a desired value. By default, it is set to zero, which means never clean up cached samples.

RESOURCE_LIMITS

The RESOURCE_LIMITS policy determines the amount of resources the service can consume in order to meet the requested QoS. This policy applies to the topic, data reader, and data writer entities via the resource_limits member of their respective QoS structures. Below is the IDL related to the resource limits QoS policy.

```
struct ResourceLimitsQosPolicy {
  long max_samples;
  long max_instances;
```

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```
  long max_samples_per_instance;
};
```

The `max_samples` member specifies the maximum number of samples a single data writer or data reader can manage across all of its instances. The `max_instances` member specifies the maximum number of instances that a data writer or data reader can manage. The `max_samples_per_instance` member specifies the maximum number of samples that can be managed for an individual instance in a single data writer or data reader. The values of all these members default to unlimited (`DDS::LENGTH_UNLIMITED`).

Resources are used by the data writer to queue samples written to the data writer but not yet sent to all data readers because of backpressure from the transport. Resources are used by the data reader to queue samples that have been received, but not yet read/taken from the data reader.

PARTITION

The `PARTITION` QoS policy allows the creation of logical partitions within a domain. It only allows data readers and data writers to be associated if they have matched partition strings. This policy applies to the publisher and subscriber entities via the partition member of their respective QoS structures. Below is the IDL related to the partition QoS policy.

```
struct PartitionQosPolicy {
  StringSeq name;
};
```

The name member defaults to an empty sequence of strings. The default partition name is an empty string and causes the entity to participate in the default partition. The partition names may contain wildcard characters as defined by the POSIX `fnmatch` function (POSIX 1003.2-1992 section B.6).

The establishment of data reader and data writer associations depends on matching partition strings on the publication and subscription ends. Failure to match partitions is not considered a failure and does not trigger any callbacks or set any status values.

The value of this policy may be changed at any time. Changes to this policy may cause associations to be removed or added.

DEADLINE

The `DEADLINE` QoS policy allows the application to detect when data is not written or read within a specified amount of time. This policy applies to the topic, data writer, and data reader entities via the deadline member of their respective QoS structures. Below is the IDL related to the deadline QoS policy.

```
struct DeadlineQosPolicy {
  Duration_t period;
};
```

The default value of the `period` member is infinite, which requires no behavior. When this policy is set to a finite value, then the data writer monitors the changes to data made by the application and indicates failure to honor the policy by setting the corresponding status condition and triggering the `on_offered_deadline_missed()` listener callback. A data reader that detects that the data has not changed before the period has expired sets the corresponding status condition and triggers the `on_requested_deadline_missed()` listener callback.

This policy is considered during the creation of associations between data writers and data readers. The value of both sides of the association must be compatible in order for an association to be created. The deadline period of the data reader must be greater than or equal to the corresponding value of data writer.

The value of this policy may change after the associated entity is enabled. In the case where the policy of a data reader or data writer is made, the change is successfully applied only if the change remains consistent with the remote end of all associations in which the reader or writer is participating. If the policy of a topic is changed, it will affect only data readers and writers that are created after the change has been made. Any existing readers or writers, and any existing associations between them, will not be affected by the topic policy value change.

LIFESPAN

The `LIFESPAN` QoS policy allows the application to specify when a sample expires. Expired samples will not be delivered to subscribers. This policy applies to the topic and data writer entities via the lifespan member of their respective QoS structures. Below is the IDL related to the lifespan QoS policy.

```
struct LifespanQosPolicy {
  Duration_t duration;
}
```

The default value of the `duration` member is infinite, which means samples never expire. OpenDDS currently supports expired sample detection on the publisher side when using a `DURABILITY kind` other than `VOLATILE`. The current OpenDDS implementation may not remove samples from the data writer and data reader caches when they expire after being placed in the cache.

The value of this policy may be changed at any time. Changes to this policy affect only data written after the change.

USER_DATA

The `USER_DATA` policy applies to the domain participant, data reader, and data writer entities via the user_data member of their respective QoS structures. Below is the IDL related to the user data QoS policy:

```
struct UserDataQosPolicy {
  sequence<octet> value;
};
```

By default, the `value` member is not set. It can be set to any sequence of octets which can be used to attach information to the created entity. The value of the `USER_DATA` policy is available in respective built-in topic data. The remote application can obtain the information via the built-in topic and use it for its own purposes. For example, the application could attach security credentials via the `USER_DATA` policy that can be used by the remote application to authenticate the source.

TOPIC_DATA

The `TOPIC_DATA` policy applies to topic entities via the topic_data member of TopicQoS structures. Below is the IDL related to the topic data QoS policy:

```
struct TopicDataQosPolicy {
  sequence<octet> value;
};
```

By default, the `value` is not set. It can be set to attach additional information to the created topic. The value of the `TOPIC_DATA` policy is available in data writer, data reader, and topic built-in topic data. The remote application can obtain the information via the built-in topic and use it in an application-defined way.

GROUP_DATA

The GROUP_DATA policy applies to the publisher and subscriber entities via the group_data member of their respective QoS structures. Below is the IDL related to the group data QoS policy:

```
struct GroupDataQosPolicy {
  sequence<octet> value;
};
```

By default, the value member is not set. It can be set to attach additional information to the created entities. The value of the GROUP_DATA policy is propagated via built-in topics. The data writer built-in topic data contains the GROUP_DATA from the publisher and the data reader built-in topic data contains the GROUP_DATA from the subscriber. The GROUP_DATA policy could be used to implement matching mechanisms similar to those of the PARTITION policy described in 1.1.6 except the decision could be made based on an application-defined policy.

TRANSPORT_PRIORITY

The TRANSPORT_PRIORITY policy applies to topic and data writer entities via the transport_priority member of their respective QoS policy structures. Below is the IDL related to the TransportPriority QoS policy:

```
struct TransportPriorityQosPolicy {
  long value;
};
```

The default value member of transport_priority is zero. This policy is considered a hint to the transport layer to indicate at what priority to send messages. Higher values indicate higher priority. OpenDDS maps the priority value directly onto thread and DiffServ codepoint values. A default priority of zero will not modify either threads or codepoints in messages.

OpenDDS will attempt to set the thread priority of the sending transport as well as any associated receiving transport. Transport priority values are mapped from zero (default) through the maximum thread priority linearly without scaling. If the lowest thread priority is different from zero, then it is mapped to the transport priority value of zero. Where priority values on a system are inverted (higher numeric values are lower priority), OpenDDS maps these to an increasing priority value starting at zero. Priority values lower than the minimum (lowest) thread priority on a system are mapped to that lowest priority. Priority values greater than the maximum (highest) thread priority on a system are mapped to that highest priority. On most systems, thread priorities can only be set when the process scheduler has been set to allow these operations. Setting the process scheduler is generally a privileged operation and will require system privileges to perform. On POSIX based systems, the system calls of sched_get_priority_min() and sched_get_priority_max() are used to determine the system range of thread priorities.

OpenDDS will attempt to set the DiffServ codepoint on the socket used to send data for the data writer if it is supported by the transport implementation. If the network hardware honors the codepoint values, higher codepoint values will result in better (faster) transport for higher priority samples. The default value of zero will be mapped to the (default) codepoint of zero. Priority values from 1 through 63 are then mapped to the corresponding codepoint values, and higher priority values are mapped to the highest codepoint value (63).

OpenDDS does not currently support modifications of the transport_priority policy values after creation of the data writer. This can be worked around by creating new data writers as different priority values are required.

LATENCY_BUDGET

The LATENCY_BUDGET policy applies to topic, data reader, and data writer entities via the latency_budget member of their respective QoS policy structures. Below is the IDL related to the LatencyBudget QoS policy:

```
struct LatencyBudgetQosPolicy {
  Duration_t duration;
};
```

The default value of duration is zero indicating that the delay should be minimized. This policy is considered a hint to the transport layer to indicate the urgency of samples being sent. OpenDDS uses the value to bound a delay interval for reporting unacceptable delay in transporting samples from publication to subscription. This policy is used for monitoring purposes only at this time. Use the TRANSPORT_PRIORITY policy to modify the sending of samples. The data writer policy value is used only for compatibility comparisons and if left at the default value of zero will result in all requested duration values from data readers being matched.

An additional listener extension has been added to allow reporting delays in excess of the policy duration setting. The OpenDDS::DCPS::DataReaderListener interface has an additional operation for notification that samples were received with a measured transport delay greater than the latency_budget policy duration. The IDL for this method is:

```
struct BudgetExceededStatus {
  long total_count;
  long total_count_change;
  DDS::InstanceHandle_t last_instance_handle;
};

void on_budget_exceeded(
       in DDS::DataReader reader,
       in BudgetExceededStatus status);
```

To use the extended listener callback you will need to derive the listener implementation from the extended interface, as shown in the following code fragment:

```
class DataReaderListenerImpl
      : public virtual
        OpenDDS::DCPS::LocalObject<OpenDDS::DCPS::DataReaderListener>
```

Then you must provide a non-null implementation for the on_budget_exceeded() operation. Note that you will need to provide empty implementations for the following extended operations as well:

```
on_subscription_disconnected()
on_subscription_reconnected()
on_subscription_lost()
on_connection_deleted()
```

OpenDDS also makes the summary latency statistics available via an extended interface of the data reader. This extended interface is located in the OpenDDS::DCPS module and the IDL is defined as:

```
struct LatencyStatistics {
  GUID_t        publication;
  unsigned long n;
  double        maximum;
  double        minimum;
  double        mean;
  double        variance;
```

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```
};

typedef sequence<LatencyStatistics> LatencyStatisticsSeq;

local interface DataReaderEx : DDS::DataReader {
  /// Obtain a sequence of statistics summaries.
  void get_latency_stats( inout LatencyStatisticsSeq stats);

  /// Clear any intermediate statistical values.
  void reset_latency_stats();

  /// Statistics gathering enable state.
  attribute boolean statistics_enabled;
};
```

To gather this statistical summary data you will need to use the extended interface. You can do so simply by dynamically casting the OpenDDS data reader pointer and calling the operations directly. In the following example, we assume that reader is initialized correctly by calling `DDS::Subscriber::create_datareader()`:

```
DDS::DataReader_var reader;
// ...

// To start collecting new data.
dynamic_cast<OpenDDS::DCPS::DataReaderImpl*>(reader.in())->
  reset_latency_stats();
dynamic_cast<OpenDDS::DCPS::DataReaderImpl*>(reader.in())->
  statistics_enabled(true);

// ...

// To collect data.
OpenDDS::DCPS::LatencyStatisticsSeq stats;
dynamic_cast<OpenDDS::DCPS::DataReaderImpl*>(reader.in())->
  get_latency_stats(stats);
for (unsigned long i = 0; i < stats.length(); ++i)
{
  std::cout << "stats[" << i << "]:" << std::endl;
  std::cout << "         n = " << stats[i].n << std::endl;
  std::cout << "       max = " << stats[i].maximum << std::endl;
  std::cout << "       min = " << stats[i].minimum << std::endl;
  std::cout << "      mean = " << stats[i].mean << std::endl;
  std::cout << "  variance = " << stats[i].variance << std::endl;
}
```

ENTITY_FACTORY

The ENTITY_FACTORY policy controls whether entities are automatically enabled when they are created. Below is the IDL related to the Entity Factory QoS policy:

```
struct EntityFactoryQosPolicy {
  boolean autoenable_created_entities;
};
```

This policy can be applied to entities that serve as factories for other entities and controls whether or not entities created by those factories are automatically enabled upon creation. This policy can be applied to the domain participant factory (as a factory for domain participants), domain participant (as a factory for publishers, subscribers, and topics), publisher (as a factory for data writers), or subscriber (as a factory for data readers). The default value for the autoenable_created_entities member is true, indicating that entities are automatically enabled when they are created. Applications that wish to explicitly enable entities some time after they are created should set the value of the autoenable_created_entities member of this policy to false and apply the policy to the appropriate factory entities. The application must then manually enable the entity by calling the entity's enable() operation.

The value of this policy may be changed at any time. Changes to this policy affect only entities created after the change.

PRESENTATION

The PRESENTATION QoS policy controls how changes to instances by publishers are presented to data readers. It affects the relative ordering of these changes and the scope of this ordering. Additionally, this policy introduces the concept of coherent change sets. Here is the IDL for the Presentation QoS:

```
enum PresentationQosPolicyAccessScopeKind {
  INSTANCE_PRESENTATION_QOS,
  TOPIC_PRESENTATION_QOS,
  GROUP_PRESENTATION_QOS
};

struct PresentationQosPolicy {
  PresentationQosPolicyAccessScopeKind access_scope;
  boolean coherent_access;
  boolean ordered_access;
};
```

The scope of these changes (access_scope) specifies the level in which an application may be made aware:

- INSTANCE_PRESENTATION_QOS (the default) indicates that changes occur to instances independently. Instance access essentially acts as a no-op with respect to coherent_access and ordered_access. Setting either of these values to true has no observable affect within the subscribing application.
- TOPIC_PRESENTATION_QOS indicates that accepted changes are limited to all instances within the same data reader or data writer.
- GROUP_PRESENTATION_QOS indicates that accepted changes are limited to all instances within the same publisher or subscriber.

Coherent changes (coherent_access) allow one or more changes to an instance be made available to an associated data reader as a single change. If a data reader does not receive the entire set of coherent changes made by a publisher, then none of the changes are made available. The semantics of coherent changes are similar in nature to those found in transactions provided by many relational databases. By default, coherent_access is false.

Changes may also be made available to associated data readers in the order sent by the publisher (`ordered_access`). This is similar in nature to the `DESTINATION_ORDER` QoS policy, however `ordered_access` permits data to be ordered independently of instance ordering. By default, `ordered_access` is `false`.

Note: This policy controls the ordering and scope of samples made available to the subscriber, but the subscriber application must use the proper logic in reading samples to guarantee the requested behavior. For more details, see Section 2.2.2.5.1.9 of the Version 1.4 DDS Specification.

DESTINATION_ORDER

The `DESTINATION_ORDER` QoS policy controls the order in which samples within a given instance are made available to a data reader. If a history depth of one (the default) is specified, the instance will reflect the most recent value written by all data writers to that instance. Here is the IDL for the Destination Order Qos:

```
enum DestinationOrderQosPolicyKind {
  BY_RECEPTION_TIMESTAMP_DESTINATIONORDER_QOS,
  BY_SOURCE_TIMESTAMP_DESTINATIONORDER_QOS
};

struct DestinationOrderQosPolicy {
  DestinationOrderQosPolicyKind kind;
};
```

The `BY_RECEPTION_TIMESTAMP_DESTINATIONORDER_QOS` value (the default) indicates that samples within an instance are ordered in the order in which they were received by the data reader. Note that samples are not necessarily received in the order sent by the same data writer. To enforce this type of ordering, the `BY_SOURCE_TIMESTAMP_DESTINATIONORDER_QOS` value should be used.

The `BY_SOURCE_TIMESTAMP_DESTINATIONORDER_QOS` value indicates that samples within an instance are ordered based on a timestamp provided by the data writer. It should be noted that if multiple data writers write to the same instance, care should be taken to ensure that clocks are synchronized to prevent incorrect ordering on the data reader.

WRITER_DATA_LIFECYCLE

The `WRITER_DATA_LIFECYCLE` QoS policy controls the lifecycle of data instances managed by a data writer. Here is the IDL for the Writer Data Lifecycle QoS policy:

```
struct WriterDataLifecycleQosPolicy {
  boolean autodispose_unregistered_instances;
};
```

When `autodispose_unregistered_instances` is set to `true` (the default), a data writer disposes an instance when it is unregistered. In some cases, it may be desirable to prevent an instance from being disposed when an instance is unregistered. This policy could, for example, allow an `EXCLUSIVE` data writer to gracefully defer to the next data writer without affecting the instance state. Deleting a data writer implicitly unregisters all of its instances prior to deletion.

READER_DATA_LIFECYCLE

The READER_DATA_LIFECYCLE QoS policy controls the lifecycle of data instances managed by a data reader. Here is the IDL for the Reader Data Lifecycle QoS policy:

```
struct ReaderDataLifecycleQosPolicy {
  Duration_t autopurge_nowriter_samples_delay;
  Duration_t autopurge_disposed_samples_delay;
};
```

Normally, a data reader maintains data for all instances until there are no more associated data writers for the instance, the instance has been disposed, or the data has been taken by the user.

In some cases, it may be desirable to constrain the reclamation of these resources. This policy could, for example, permit a late-joining data writer to prolong the lifetime of an instance in fail-over situations.

The autopurge_nowriter_samples_delay controls how long the data reader waits before reclaiming resources once an instance transitions to the NOT_ALIVE_NO_WRITERS state. By default, autopurge_nowriter_samples_delay is infinite.

The autopurge_disposed_samples_delay controls how long the data reader waits before reclaiming resources once an instance transitions to the NOT_ALIVE_DISPOSED state. By default, autopurge_disposed_samples_delay is infinite.

TIME_BASED_FILTER

The TIME_BASED_FILTER QoS policy controls how often a data reader may be interested in changes in values to a data instance. Here is the IDL for the Time Based Filter QoS:

```
struct TimeBasedFilterQosPolicy {
  Duration_t minimum_separation;
};
```

An interval (minimum_separation) may be specified on the data reader. This interval defines a minimum delay between instance value changes; this permits the data reader to throttle changes without affecting the state of the associated data writer. By default, minimum_separation is zero, which indicates that no data is filtered. This QoS policy does not conserve bandwidth as instance value changes are still sent to the subscriber process. It only affects which samples are made available via the data reader.

OWNERSHIP

The OWNERSHIP policy controls whether more than one Data Writer is able to write samples for the same data-object instance. Ownership can be EXCLUSIVE or SHARED. Below is the IDL related to the Ownership QoS policy:

```
enum OwnershipQosPolicyKind {
  SHARED_OWNERSHIP_QOS,
  EXCLUSIVE_OWNERSHIP_QOS
};

struct OwnershipQosPolicy {
  OwnershipQosPolicyKind kind;
};
```

If the kind member is set to SHARED_OWNERSHIP_QOS, more than one Data Writer is allowed to update the same data-object instance. If the kind member is set to EXCLUSIVE_OWNERSHIP_QOS, only one Data Writer is allowed to update

a given data-object instance (i.e., the Data Writer is considered to be the *owner* of the instance) and associated Data Readers will only see samples written by that Data Writer. The owner of the instance is determined by value of the OWNERSHIP_STRENGTH policy; the data writer with the highest value of strength is considered the owner of the data-object instance. Other factors may also influence ownership, such as whether the data writer with the highest strength is "alive" (as defined by the LIVELINESS policy) and has not violated its offered publication deadline constraints (as defined by the DEADLINE policy).

OWNERSHIP_STRENGTH

The OWNERSHIP_STRENGTH policy is used in conjunction with the OWNERSHIP policy, when the OWNERSHIP kind is set to EXCLUSIVE. Below is the IDL related to the Ownership Strength QoS policy:

```
struct OwnershipStrengthQosPolicy {
  long value;
};
```

The value member is used to determine which Data Writer is the *owner* of the data-object instance. The default value is zero.

1.3.3 Policy Example

The following sample code illustrates some policies being set and applied for a publisher.

```
DDS::DataWriterQos dw_qos;
pub->get_default_datawriter_qos (dw_qos);

dw_qos.history.kind = DDS::KEEP_ALL_HISTORY_QOS;

dw_qos.reliability.kind = DDS::RELIABLE_RELIABILITY_QOS;
dw_qos.reliability.max_blocking_time.sec = 10;
dw_qos.reliability.max_blocking_time.nanosec = 0;

dw_qos.resource_limits.max_samples_per_instance = 100;

DDS::DataWriter_var dw =
  pub->create_datawriter(topic,
                         dw_qos,
                         0,   // No listener
                         OpenDDS::DCPS::DEFAULT_STATUS_MASK);
```

This code creates a publisher with the following qualities:

- HISTORY set to Keep All
- RELIABILITY set to Reliable with a maximum blocking time of 10 seconds
- The maximum samples per instance resource limit set to 100

This means that when 100 samples are waiting to be delivered, the writer can block up to 10 seconds before returning an error code. These same QoS settings on the Data Reader side would mean that up to 100 unread samples are queued by the framework before any are rejected. Rejected samples are dropped and the SampleRejectedStatus is updated.

1.4 Conditions and Listeners

1.4.1 Introduction

The DDS specification defines two separate mechanisms for notifying applications of DCPS communication status changes. Most of the status types define a structure that contains information related to the change of status and can be detected by the application using conditions or listeners. The different status types are described in *Communication Status Types*.

Each entity type (domain participant, topic, publisher, subscriber, data reader, and data writer) defines its own corresponding listener interface. Applications can implement this interface and then attach their listener implementation to the entity. Each listener interface contains an operation for each status that can be reported for that entity. The listener is asynchronously called back with the appropriate operation whenever a qualifying status change occurs. Details of the different listener types are discussed in *Listeners*.

Conditions are used in conjunction with Wait Sets to let applications synchronously wait on events. The basic usage pattern for conditions involves creating the condition objects, attaching them to a wait set, and then waiting on the wait set until one of the conditions is triggered. The result of wait tells the application which conditions were triggered, allowing the application to take the appropriate actions to get the corresponding status information. Conditions are described in greater detail in *Conditions*.

1.4.2 Communication Status Types

Each status type is associated with a particular entity type. This section is organized by the entity types, with the corresponding statuses described in subsections under the associated entity type.

Most of the statuses below are plain communication statuses. The exceptions are `DATA_ON_READERS` and `DATA_AVAILABLE` which are read statuses. Plain communication statuses define an IDL data structure. Their corresponding section below describes this structure and its fields. The read statuses are simple notifications to the application which then reads or takes the samples as desired.

Incremental values in the status data structure report a change since the last time the status was accessed. A status is considered accessed when a listener is called for that status or the status is read from its entity.

Fields in the status data structure with a type of `InstanceHandle_t` identify an entity (topic, data reader, data writer, etc.) by the instance handle used for that entity in the Built-In-Topics.

Topic Status Types

Inconsistent Topic Status

The `INCONSISTENT_TOPIC` status indicates that a topic was attempted to be registered that already exists with different characteristics. Typically, the existing topic may have a different type associated with it. The IDL associated with the Inconsistent Topic Status is listed below:

```
struct InconsistentTopicStatus {
  long total_count;
  long total_count_change;
};
```

The `total_count` value is the cumulative count of topics that have been reported as inconsistent. The `total_count_change` value is the incremental count of inconsistent topics since the last time this status was accessed.

Subscriber Status Types

Data On Readers Status

The DATA_ON_READERS status indicates that new data is available on some of the data readers associated with the subscriber. This status is considered a read status and does not define an IDL structure. Applications receiving this status can call `get_datareaders()` on the subscriber to get the set of data readers with data available.

Data Reader Status Types

Sample Rejected Status

The SAMPLE_REJECTED status indicates that a sample received by the data reader has been rejected. The IDL associated with the Sample Rejected Status is listed below:

```
enum SampleRejectedStatusKind {
  NOT_REJECTED,
  REJECTED_BY_INSTANCES_LIMIT,
  REJECTED_BY_SAMPLES_LIMIT,
  REJECTED_BY_SAMPLES_PER_INSTANCE_LIMIT
};

struct SampleRejectedStatus {
  long total_count;
  long total_count_change;
  SampleRejectedStatusKind last_reason;
  InstanceHandle_t last_instance_handle;
};
```

The `total_count` value is the cumulative count of samples that have been reported as rejected. The `total_count_change` value is the incremental count of rejected samples since the last time this status was accessed. The `last_reason` value is the reason the most recently rejected sample was rejected. The `last_instance_handle` value indicates the instance of the last rejected sample.

Liveliness Changed Status

The LIVELINESS_CHANGED status indicates that there have been liveliness changes for one or more data writers that are publishing instances for this data reader. The IDL associated with the Liveliness Changed Status is listed below:

```
struct LivelinessChangedStatus {
  long alive_count;
  long not_alive_count;
  long alive_count_change;
  long not_alive_count_change;
  InstanceHandle_t last_publication_handle;
};
```

The `alive_count` value is the total number of data writers currently active on the topic this data reader is reading. The `not_alive_count` value is the total number of data writers writing to the data reader's topic that are no longer asserting their liveliness. The `alive_count_change` value is the change in the alive count since the last time the status was accessed. The `not_alive_count_change` value is the change in the not alive count since the last time the status was accessed. The `last_publication_handle` is the handle of the last data writer whose liveliness has changed.

Requested Deadline Missed Status

The REQUESTED_DEADLINE_MISSED status indicates that the deadline requested via the Deadline QoS policy was not respected for a specific instance. The IDL associated with the Requested Deadline Missed Status is listed below:

```
struct RequestedDeadlineMissedStatus {
  long total_count;
  long total_count_change;
  InstanceHandle_t last_instance_handle;
};
```

The total_count value is the cumulative count of missed requested deadlines that have been reported. The total_count_change value is the incremental count of missed requested deadlines since the last time this status was accessed. The last_instance_handle value indicates the instance of the last missed deadline.

Requested Incompatible QoS Status

The REQUESTED_INCOMPATIBLE_QOS status indicates that one or more QoS policy values that were requested were incompatible with what was offered. The IDL associated with the Requested Incompatible QoS Status is listed below:

```
struct QosPolicyCount {
  QosPolicyId_t policy_id;
  long count;
};

typedef sequence<QosPolicyCount> QosPolicyCountSeq;

struct RequestedIncompatibleQosStatus {
  long total_count;
  long total_count_change;
  QosPolicyId_t last_policy_id;
  QosPolicyCountSeq policies;
};
```

The total_count value is the cumulative count of times data writers with incompatible QoS have been reported. The total_count_change value is the incremental count of incompatible data writers since the last time this status was accessed. The last_policy_id value identifies one of the QoS policies that was incompatible in the last incompatibility detected. The policies value is a sequence of values that indicates the total number of incompatibilities that have been detected for each QoS policy.

Data Available Status

The DATA_AVAILABLE status indicates that samples are available on the data writer. This status is considered a read status and does not define an IDL structure. Applications receiving this status can use the various take and read operations on the data reader to retrieve the data.

Sample Lost Status

The SAMPLE_LOST status indicates that a sample has been lost and never received by the data reader. The IDL associated with the Sample Lost Status is listed below:

```
struct SampleLostStatus {
  long total_count;
  long total_count_change;
};
```

The total_count value is the cumulative count of samples reported as lost. The total_count_change value is the incremental count of lost samples since the last time this status was accessed.

Subscription Matched Status

The SUBSCRIPTION_MATCHED status indicates that either a compatible data writer has been matched or a previously matched data writer has ceased to be matched. The IDL associated with the Subscription Matched Status is listed below:

```
struct SubscriptionMatchedStatus {
  long total_count;
  long total_count_change;
  long current_count;
  long current_count_change;
  InstanceHandle_t last_publication_handle;
};
```

The total_count value is the cumulative count of data writers that have compatibly matched this data reader. The total_count_change value is the incremental change in the total count since the last time this status was accessed. The current_count value is the current number of data writers matched to this data reader. The current_count_change value is the change in the current count since the last time this status was accessed. The last_publication_handle value is a handle for the last data writer matched.

Data Writer Status Types

Liveliness Lost Status

The LIVELINESS_LOST status indicates that the liveliness that the data writer committed through its Liveliness QoS has not been respected. This means that any connected data readers will consider this data writer no longer active.The IDL associated with the Liveliness Lost Status is listed below:

```
struct LivelinessLostStatus {
  long total_count;
  long total_count_change;
};
```

The total_count value is the cumulative count of times that an alive data writer has become not alive. The total_count_change value is the incremental change in the total count since the last time this status was accessed.

Offered Deadline Missed Status

The OFFERED_DEADLINE_MISSED status indicates that the deadline offered by the data writer has been missed for one or more instances. The IDL associated with the Offered Deadline Missed Status is listed below:

```
struct OfferedDeadlineMissedStatus {
  long total_count;
  long total_count_change;
  InstanceHandle_t last_instance_handle;
};
```

The total_count value is the cumulative count of times that deadlines have been missed for an instance. The total_count_change value is the incremental change in the total count since the last time this status was accessed. The last_instance_handle value indicates the last instance that has missed a deadline.

Offered Incompatible QoS Status

The OFFERED_INCOMPATIBLE_QOS status indicates that an offered QoS was incompatible with the requested QoS of a data reader. The IDL associated with the Offered Incompatible QoS Status is listed below:

```
struct QosPolicyCount {
  QosPolicyId_t policy_id;
  long count;
};
typedef sequence<QosPolicyCount> QosPolicyCountSeq;

struct OfferedIncompatibleQosStatus {
  long total_count;
  long total_count_change;
  QosPolicyId_t last_policy_id;
  QosPolicyCountSeq policies;
};
```

The total_count value is the cumulative count of times that data readers with incompatible QoS have been found. The total_count_change value is the incremental change in the total count since the last time this status was accessed. The last_policy_id value identifies one of the QoS policies that was incompatible in the last incompatibility detected. The policies value is a sequence of values that indicates the total number of incompatibilities that have been detected for each QoS policy.

Publication Matched Status

The PUBLICATION_MATCHED status indicates that either a compatible data reader has been matched or a previously matched data reader has ceased to be matched. The IDL associated with the Publication Matched Status is listed below:

```
struct PublicationMatchedStatus {
  long total_count;
  long total_count_change;
  long current_count;
  long current_count_change;
  InstanceHandle_t last_subscription_handle;
};
```

The `total_count` value is the cumulative count of data readers that have compatibly matched this data writer. The `total_count_change` value is the incremental change in the total count since the last time this status was accessed. The `current_count` value is the current number of data readers matched to this data writer. The `current_count_change` value is the change in the current count since the last time this status was accessed. The `last_subscription_handle` value is a handle for the last data reader matched.

1.4.3 Listeners

Each entity defines its own listener interface based on the statuses it can report. Any entity's listener interface also inherits from the listeners of its owned entities, allowing it to handle statuses for owned entities as well. For example, a subscriber listener directly defines an operation to handle Data On Readers statuses and inherits from the data reader listener as well.

Each status operation takes the general form of `on_<status_name>(<entity>, <status_struct>)`, where `<status_name>` is the name of the status being reported, `<entity>` is a reference to the entity the status is reported for, and `<status_struct>` is the structure with details of the status. Read statuses omit the second parameter. For example, here is the operation for the Sample Lost status:

```
void on_sample_lost(in DataReader the_reader, in SampleLostStatus status);
```

Listeners can either be passed to the factory function used to create their entity or explicitly set by calling `set_listener()` on the entity after it is created. Both of these functions also take a status mask as a parameter. The mask indicates which statuses are enabled in that listener. Mask bit values for each status are defined in DdsDcpsInfrastructure.idl:

```
module DDS {
  typedef unsigned long StatusKind;
  typedef unsigned long StatusMask; // bit-mask StatusKind

  const StatusKind INCONSISTENT_TOPIC_STATUS        = 0x0001 << 0;
  const StatusKind OFFERED_DEADLINE_MISSED_STATUS   = 0x0001 << 1;
  const StatusKind REQUESTED_DEADLINE_MISSED_STATUS = 0x0001 << 2;
  const StatusKind OFFERED_INCOMPATIBLE_QOS_STATUS  = 0x0001 << 5;
  const StatusKind REQUESTED_INCOMPATIBLE_QOS_STATUS= 0x0001 << 6;
  const StatusKind SAMPLE_LOST_STATUS               = 0x0001 << 7;
  const StatusKind SAMPLE_REJECTED_STATUS           = 0x0001 << 8;
  const StatusKind DATA_ON_READERS_STATUS           = 0x0001 << 9;
  const StatusKind DATA_AVAILABLE_STATUS            = 0x0001 << 10;
  const StatusKind LIVELINESS_LOST_STATUS           = 0x0001 << 11;
  const StatusKind LIVELINESS_CHANGED_STATUS        = 0x0001 << 12;
  const StatusKind PUBLICATION_MATCHED_STATUS       = 0x0001 << 13;
  const StatusKind SUBSCRIPTION_MATCHED_STATUS      = 0x0001 << 14;
};
```

Simply do a bit-wise "or" of the desired status bits to construct a mask for your listener. Here is an example of attaching a listener to a data reader (for just Data Available statuses):

```
DDS::DataReaderListener_var listener (new DataReaderListenerImpl);
// Create the Datareader
DDS::DataReader_var dr = sub->create_datareader(
  topic,
  DATAREADER_QOS_DEFAULT,
  listener,
  DDS::DATA_AVAILABLE_STATUS);
```

Here is an example showing how to change the listener using `set_listener()`:

```
dr->set_listener(listener,
                 DDS::DATA_AVAILABLE_STATUS | DDS::LIVELINESS_CHANGED_STATUS);
```

When a plain communication status changes, OpenDDS invokes the most specific relevant listener operation. This means, for example, that a data reader's listener would take precedence over the subscriber's listener for statuses related to the data reader.

A common "gotcha" when using `set_listener` is that the listener is not invoked immediately. Instead, the listener will be invoked for the next status change. Consequently, usages of `set_listener` should 1) invoke the listener manually after calling `set_listener` and 2) ensure that the listener methods are thread safe.

The following sections define the different listener interfaces. For more details on the individual statuses, see *Communication Status Types*.

Topic Listener

```
interface TopicListener : Listener {
  void on_inconsistent_topic(in Topic the_topic,
                             in InconsistentTopicStatus status);
};
```

Data Writer Listener

```
interface DataWriterListener : Listener {
  void on_offered_deadline_missed(in DataWriter writer,
                                  in OfferedDeadlineMissedStatus status);
  void on_offered_incompatible_qos(in DataWriter writer,
                                   in OfferedIncompatibleQosStatus status);
  void on_liveliness_lost(in DataWriter writer,
                          in LivelinessLostStatus status);
  void on_publication_matched(in DataWriter writer,
                              in PublicationMatchedStatus status);
};
```

Publisher Listener

```
interface PublisherListener : DataWriterListener {
};
```

Data Reader Listener

```
interface DataReaderListener : Listener {
  void on_requested_deadline_missed(in DataReader the_reader,
                                    in RequestedDeadlineMissedStatus status);
  void on_requested_incompatible_qos(in DataReader the_reader,
                                     in RequestedIncompatibleQosStatus status);
  void on_sample_rejected(in DataReader the_reader,
                          in SampleRejectedStatus status);
  void on_liveliness_changed(in DataReader the_reader,
                             in LivelinessChangedStatus status);
  void on_data_available(in DataReader the_reader);
  void on_subscription_matched(in DataReader the_reader,
                               in SubscriptionMatchedStatus status);
  void on_sample_lost(in DataReader the_reader,
                      in SampleLostStatus status);
};
```

Subscriber Listener

```
interface SubscriberListener : DataReaderListener {
  void on_data_on_readers(in Subscriber the_subscriber);
};
```

Domain Participant Listener

```
interface DomainParticipantListener : TopicListener,
                                      PublisherListener,
                                      SubscriberListener {
};
```

1.4.4 Conditions

The DDS specification defines four types of condition:

- Status Condition
- Read Condition
- Query Condition
- Guard Condition

Status Condition

Each entity has a status condition object associated with it and a `get_statuscondition()` operation that lets applications access the status condition. Each condition has a set of enabled statuses that can trigger that condition. Attaching one or more conditions to a wait set allows application developers to wait on the condition's status set. Once an enabled status is triggered, the wait call returns from the wait set and the developer can query the relevant status condition on the entity. Querying the status condition resets the status.

Status Condition Example

This example enables the Offered Incompatible QoS status on a data writer, waits for it, and then queries it when it triggers. The first step is to get the status condition from the data writer, enable the desired status, and attach it to a wait set:

```
DDS::StatusCondition_var cond = data_writer->get_statuscondition();
cond->set_enabled_statuses(DDS::OFFERED_INCOMPATIBLE_QOS_STATUS);

DDS::WaitSet_var ws = new DDS::WaitSet;
ws->attach_condition(cond);
```

Now we can wait ten seconds for the condition:

```
DDS::ConditionSeq active;
DDS::Duration_t ten_seconds = {10, 0};
int result = ws->wait(active, ten_seconds);
```

The result of this operation is either a timeout or a set of triggered conditions in the active sequence:

```
if (result == DDS::RETCODE_TIMEOUT) {
  cout << "Wait timed out" << std::endl;
} else if (result == DDS::RETCODE_OK) {
  DDS::OfferedIncompatibleQosStatus incompatibleStatus;
  data_writer->get_offered_incompatible_qos(incompatibleStatus);
  // Access status fields as desired...
}
```

Developers have the option of attaching multiple conditions to a single wait set as well as enabling multiple statuses per condition.

Additional Condition Types

The DDS specification also defines three other types of conditions: read conditions, query conditions, and guard conditions. These conditions do not directly involve the processing of statuses but allow the integration of other activities into the condition and wait set mechanisms. These are other conditions are briefly described here. For more information see the DDS specification or the OpenDDS tests in tests/.

Read Conditions

Read conditions are created using the data reader and the same masks that are passed to the read and take operations. When waiting on this condition, it is triggered whenever samples match the specified masks. Those samples can then be retrieved using the `read_w_condition()` and `take_w_condition()` operations which take the read condition as a parameter.

Query Conditions

Query conditions are a specialized form of read conditions that are created with a limited form of an SQL-like query. This allows applications to filter the data samples that trigger the condition and then are read use the normal read condition mechanisms. See *Query Condition* for more information about query conditions.

Guard Conditions

The guard condition is a simple interface that allows the application to create its own condition object and trigger it when application events (external to OpenDDS) occur.

1.5 Content-Subscription Profile

1.5.1 Introduction

The Content-Subscription Profile of DDS consists of three features which enable a data reader's behavior to be influenced by the content of the data samples it receives. These three features are:

- Content-Filtered Topic
- Query Condition
- Multi Topic

The content-filtered topic and multi topic interfaces inherit from the `TopicDescription` interface (and not from the `Topic` interface, as the names may suggest).

Content-filtered topic and query condition allow filtering (selection) of data samples using a SQL-like parameterized query string. Additionally, query condition allows sorting the result set returned from a data reader's `read()` or `take()` operation. Multi topic also has this selection capability as well as the ability to aggregate data from different data writers into a single data type and data reader.

If you are not planning on using the Content-Subscription Profile features in your application, you can configure OpenDDS to remove support for it at build time (*Content-Subscription Profile*).

1.5.2 Content-Filtered Topic

The domain participant interface contains operations for creating and deleting a content-filtered topic. Creating a content-filtered topic requires the following parameters:

- Name

  Assigns a name to this content-filtered topic which could later be used with the `lookup_topicdescription()` operation.

- Related topic

  Specifies the topic that this content-filtered topic is based on. This is the same topic that matched data writers will use to publish data samples.

- Filter expression

  An SQL-like expression (*Filter Expressions*) which defines the subset of samples published on the related topic that should be received by the content-filtered topic's data readers.

- Expression parameters

  The filter expression can contain parameter placeholders. This argument provides initial values for those parameters. The expression parameters can be changed after the content-filtered topic is created (the filter expression cannot be changed).

Once the content-filtered topic has been created, it is used by the subscriber's `create_datareader()` operation to obtain a content-filtering data reader. This data reader is functionally equivalent to a normal data reader except that incoming data samples which do not meet the filter expression's criteria are dropped.

Filter expressions are first evaluated at the publisher so that data samples which would be ignored by the subscriber can be dropped before even getting to the transport. This feature can be turned off with `-DCPSPublisherContentFilter 0` or the equivalent setting in the `[common]` section of the configuration file. The behavior of non-default `DEADLINE` or `LIVELINESS` QoS policies may be affected by this policy. Special consideration must be given to how the "missing" samples impact the QoS behavior, see the document in `docs/design/CONTENT_SUBSCRIPTION`.

Note: RTPS_UDP transport does not always do Writer-side filtering. It does not currently implement transport level filtering, but may be able to filter above the transport layer.

Filter Expressions

The formal grammar for filter expressions is defined in Annex A of the DDS specification. This section provides an informal summary of that grammar. Query expressions (*Query Expressions*) and topic expressions (*Topic Expressions*) are also defined in Annex A.

Filter expressions are combinations of one or more predicates. Each predicate is a logical expression taking one of two forms:

- `<arg1> <RelOp><arg2>`
- – `arg1` and `arg2` are arguments which may be either a literal value (integer, character, floating-point, string, or enumeration), a parameter placeholder of the form `%n` (where n is a zero-based index into the parameter sequence), or a field reference.
  - At least one of the arguments must be a field reference, which is the name of an IDL struct field, optionally followed by any number of '.' and another field name to represent nested structures.
  - `RelOp` is a relational operator from the list: =, >, >=, <, <=, <>, and `like`. `like` is a wildcard match using `%` to match any number of characters and _ to match a single character.
  - Examples of this form of predicate include: `a = 'z'`, `b <> 'str'`, `c < d`, `e = 'enumerator'`, `f >= 3.14e3`, `27 > g`, `h <> i`, `j.k.l like %0`
- <arg1> [NOT] BETWEEN <arg2> AND <arg3>
- – In this form, argument 1 must be a field reference and arguments 2 and 3 must each be a literal value or parameter placeholder.

Any number of predicates can be combined through the use of parenthesis and the Boolean operators `AND`, `OR`, and `NOT` to form a filter expression.

Expression Parameters

Expression parameters allow more flexibility since the filter can effectively change at runtime. To use expression parameters, add parameter placeholders in the filter expression wherever a literal would be used. For example, an expression to select all samples that have a string field with a fixed value (`m = 'A'`) could instead use a placeholder which would be written as `m = %0`. Placeholders consist of a percent sign followed by a decimal integer between 0 and 99 inclusive.

Using a filter that contains placeholders requires values for each placeholder which is used in the expression to be provided by the application in the corresponding index of the expression parameters sequence (placeholder %0 is sequence[0]). The application can set the parameter sequence when the content-filtered topic is created (`create_contentfilteredtopic`) or after it already exists by using `set_expression_parameters`. A valid value for each used placeholder must be in the parameters sequence whenever the filter is evaluated, for example when a data reader using the content-filtered topic is enabled.

The type used for the parameters sequence in the DDS-DCPS API is a sequence of strings. The application must format this string based on how the parameter is used:

- For a number (integer or floating point), provide the decimal representation in the same way it would appear as a C++ or Java literal.
- For a character or string, provide the character(s) directly without quoting
- For an enumerated type, provide one of the enumerators as if it was a string

Filtering and Dispose/Unregister Samples

DataReaders without filtering can see samples with the `valid_data` field of SampleInfo set to false. This happens when the matching DataWriter disposes or unregisters the instance. Content filtering (whether achieved through Content-Filtered Topics, Query Conditions, or Multi Topics) will filter such samples when the filter expression explicitly uses key fields. Filter expressions that don't meet that criteria will result in no such samples passing the filter.

Content-Filtered Topic Example

The code snippet below creates a content-filtered topic for the Message type. First, here is the IDL for Message:

```
module Messenger {
  @topic
  struct Message {
    long id;
  };
};
```

Next we have the code that creates the data reader:

```
CORBA::String_var type_name = message_type_support->get_type_name();
DDS::Topic_var topic = dp->create_topic("MyTopic",
                                        type_name,
                                        TOPIC_QOS_DEFAULT, 0, 0);
DDS::ContentFilteredTopic_var cft =
  participant->create_contentfilteredtopic("MyTopic-Filtered",
                                           topic,
                                           "id > 1",
                                           StringSeq());
DDS::DataReader_var dr =
```

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```
  subscriber->create_datareader(cft,
                                DATAREADER_QOS_DEFAULT, 0, 0);
```

The data reader 'dr' will only receive samples that have values of 'id' greater than 1.

1.5.3 Query Condition

The query condition interface inherits from the read condition interface, therefore query conditions have all of the capabilities of read conditions along with the additional capabilities described in this section. One of those inherited capabilities is that the query condition can be used like any other condition with a wait set (*Conditions*).

The `DataReader` interface contains operations for creating (`create_querycondition`) and deleting (`delete_readcondition`) a query condition. Creating a query condition requires the following parameters:

- Sample, view, and instance state masks

  These are the same state masks that would be passed to `create_readcondition()`, `read()`, or `take()`.

- Query expression

  An SQL-like expression (see *Query Expressions*) describing a subset of samples which cause the condition to be triggered. This same expression is used to filter the data set returned from a `read_w_condition()` or `take_w_condition()` operation. It may also impose a sort order (`ORDER BY`) on that data set.

- Query parameters

  The query expression can contain parameter placeholders. This argument provides initial values for those parameters. The query parameters can be changed after the query condition is created (the query expression cannot be changed).

A particular query condition can be used with a wait set (`attach_condition`), with a data reader (`read_w_condition`, `take_w_condition`, `read_next_instance_w_condition`, `take_next_instance_w_condition`), or both. When used with a wait set, the `ORDER BY` clause has no effect on triggering the wait set. When used with a data reader's `read*()` or `take*()` operation, the resulting data set will only contain samples which match the query expression and they will be ordered by the `ORDER BY` fields, if an `ORDER BY` clause is present.

Query Expressions

Query expressions are a super set of filter expressions (*Filter Expressions*). Following the filter expression, the query expression can optionally have an `ORDER BY` keyword followed by a comma-separated list of field references. If the `ORDER BY` clause is present, the filter expression may be empty. The following strings are examples of query expressions:

- m > 100 ORDER BY n
- ORDER BY p.q, r, s.t.u
- NOT v LIKE 'z%'

Query expressions can use parameter placeholders in the same way that filter expressions (for content-filtered topics) use them. See *Expression Parameters* for details.

Query Condition Example

The following code snippet creates and uses a query condition for a type that uses struct 'Message' with field 'key' (an integral type).

```
DDS::QueryCondition_var dr_qc =
  dr->create_querycondition(DDS::ANY_SAMPLE_STATE,
                            DDS::ANY_VIEW_STATE,
                            DDS::ALIVE_INSTANCE_STATE,
                            "key > 1",
                            DDS::StringSeq());
DDS::WaitSet_var ws = new DDS::WaitSet;
ws->attach_condition(dr_qc);
DDS::ConditionSeq active;
DDS::Duration_t three_sec = {3, 0};
DDS::ReturnCode_t ret = ws->wait(active, three_sec);
  // error handling not shown
ws->detach_condition(dr_qc);
MessageDataReader_var mdr = MessageDataReader::_narrow(dr);
MessageSeq data;
DDS::SampleInfoSeq infoseq;
ret = mdr->take_w_condition(data, infoseq, DDS::LENGTH_UNLIMITED, dr_qc);
  // error handling not shown
dr->delete_readcondition(dr_qc);
```

Any sample received with `key <= 1` would neither trigger the condition (to satisfy the wait) nor be returned in the 'data' sequence from `take_w_condition()`.

1.5.4 Multi Topic

Multi topic is a more complex feature than the other two Content-Subscription features, therefore describing it requires some new terminology.

The `MultiTopic` interface inherits from the `TopicDescription` interface, just like `ContentFilteredTopic` does. A data reader created for the multi topic is known as a "multi topic data reader." A multi topic data reader receives samples belonging to any number of regular topics. These topics are known as its "constituent topics." The multi topic has a DCPS data type known as the "resulting type." The multi topic data reader implements the type-specific data reader interface for the resulting type. For example, if the resulting type is Message, then the multi topic data reader can be narrowed to the `MessageDataReader` interface.

The multi topic's topic expression (*Topic Expressions*) describes how the distinct fields of the incoming data (on the constituent topics) are mapped to the fields of the resulting type.

The domain participant interface contains operations for creating and deleting a multi topic. Creating a multi topic requires the following parameters:

- Name

  Assigns a name to this multi topic which could later be used with the `lookup_topicdescription()` operation.

- Type name

  Specifies the resulting type of the multi topic. This type must have its type support registered before creating the multi topic.

- Topic expression (also known as subscription expression)

An SQL-like expression (*Topic Expressions*) which defines the mapping of constituent topic fields to resulting type fields. It can also specify a filter (`WHERE` clause).

- Expression parameters

  The topic expression can contain parameter placeholders. This argument provides initial values for those parameters. The expression parameters can be changed after the multi topic is created (the topic expression cannot be changed).

Once the multi topic has been created, it is used by the subscriber's `create_datareader()` operation to obtain a multi topic data reader. This data reader is used by the application to receive the constructed samples of the resulting type. The manner in which these samples are constructed is described in *How Resulting Samples are Constructed*.

Topic Expressions

Topic expressions use a syntax that is very similar to a complete SQL query:

```
SELECT <aggregation> FROM <selection> [WHERE <condition>]
```

- The aggregation can be either a * or a comma separated list of field specifiers. Each field specifier has the following syntax:
- – <constituent_field> [[AS] <resulting_field>]]
  - `constituent_field` is a field reference (*Filter Expressions*) to a field in one of the constituent topics (which topic is not specified).
  - The optional resulting_field is a field reference to a field in the resulting type. If present, the `resulting_field` is the destination for the constituent_field in the constructed sample. If absent, the `constituent_field` data is assigned to a field with the same name in the resulting type. The optional `AS` has no effect.
  - If a * is used as the aggregation, each field in the resulting type is assigned the value from a same-named field in one of the constituent topic types.
- The selection lists one or more constituent topic names. Topic names are separated by a "join" keyword (all 3 join keywords are equivalent):
- – <topic> [{NATURAL INNER | NATURAL | INNER NATURAL} JOIN <topic>]...
  - Topic names must contain only letters, digits, and dashes (but may not start with a digit).
  - The natural join operation is commutative and associative, thus the order of topics has no impact.
  - The semantics of the natural join are that any fields with the same name are treated as "join keys" for the purpose of combining data from the topics in which those keys appear. The join operation is described in more detail in subsequent sections.
- The condition has the exact same syntax and semantics as the filter expression (*Filter Expressions*). Field references in the condition must match field names in the resulting types, not field names in the constituent topic types. The condition in the topic expression can use parameter placeholders in the same way that filter expressions (for content-filtered topics) use them. See *Expression Parameters* for details.

Usage Notes

Join Keys and DCPS Data Keys

The concept of DCPS data keys (`@key`) has already been discussed in *Defining Data Types with IDL*. Join keys for the multi topic are a distinct but related concept.

A join key is any field name that occurs in the struct for more than one constituent topic. The existence of the join key enforces a constraint on how data samples of those topics are combined into a constructed sample (*How Resulting Samples are Constructed*). Specifically, the value of that key must be equal for those data samples from the constituent topics to be combined into a sample of the resulting type. If multiple join keys are common to the same two or more topics, the values of all keys must be equal in order for the data to be combined.

The DDS specification requires that join key fields have the same type. Additionally, OpenDDS imposes two requirements on how the IDL must define DCPS data keys to work with multi topics:

1. Each join key field must also be a DCPS data key for the types of its constituent topics.
2. The resulting type must contain each of the join keys, and those fields must be DCPS data keys for the resulting type.

The example in *IDL and Topic Expression* meets both of these requirements. Note that it is not necessary to list the join keys in the aggregation (`SELECT` clause).

How Resulting Samples are Constructed

Although many concepts in multi topic are borrowed from the domain of relational databases, a real-time middleware such as DDS is not a database. Instead of processing a batch of data at a time, each sample arriving at the data reader from one of the constituent topics triggers multi-topic-specific processing that results in the construction of zero, one, or many samples of the resulting type and insertion of those constructed samples into the multi topic data reader.

Specifically, the arrival of a sample on constituent topic "`A`" with type "`TA`" results in the following steps in the multi topic data reader (this is a simplification of the actual algorithm):

1. A sample of the resulting type is constructed, and fields from `TA` which exist in the resulting type and are in the aggregation (or are join keys) are copied from the incoming sample to the constructed sample.
2. Each topic `B` which has at least one join key in common with `A` is considered for a join operation. The join reads `READ_SAMPLE_STATE` samples on topic `B` with key values matching those in the constructed sample. The result of the join may be zero, one, or many samples. Fields from `TB` are copied to the resulting sample as described in step 1.
3. Join keys of topic "`B`" (connecting it to other topics) are then processed as described in step 2, and this continues to all other topics that are connected by join keys.
4. Any constituent topics that were not visited in steps 2 or 3 are processed as "cross joins" (also known as cross-product joins). These are joins with no key constraints.
5. If any constructed samples result, they are inserted into the multi topic data reader's internal data structures as if they had arrived via the normal mechanisms. Application listeners and conditions are notified.

Use with Subscriber Listeners

If the application has registered a subscriber listener for read condition status changes (`DATA_ON_READERS_STATUS`) with the same subscriber that also contains a multi topic, then the application must invoke `notify_datareaders()` in its implementation of the subscriber listener's `on_data_on_readers()` callback method. This requirement is necessary because the multi topic internally uses data reader listeners, which are preempted when a subscriber listener is registered.

Multi Topic Example

This example is based on the example topic expression used in Annex A section A.3 of the DDS specification. It illustrates how the properties of the multi topic join operation can be used to correlate data from separate topics (and possibly distinct publishers).

IDL and Topic Expression

Often times we will use the same string as both the topic name and topic type. In this example we will use distinct strings for the type names and topic names, in order to illustrate when each is used.

Here is the IDL for the constituent topic data types:

```
@topic
struct LocationInfo {
  @key unsigned long flight_id;
  long x;
  long y;
  long z;
};

@topic
struct PlanInfo {
  @key unsigned long flight_id;
  string flight_name;
  string tailno;
};
```

Note that the names and types of the key fields match, so they are designed to be used as join keys. The resulting type (below) also has that key field.

Next we have the IDL for the resulting data type:

```
@topic
struct Resulting {
  @key unsigned long flight_id;
  string flight_name;
  long x;
  long y;
  long height;
};
```

Based on this IDL, the following topic expression can be used to combine data from a topic `Location` which uses type `LocationInfo` and a topic `FlightPlan` which uses type `PlanInfo`:

```
SELECT flight_name, x, y, z AS height FROM Location NATURAL JOIN FlightPlan WHERE height
↪< 1000 AND x <23
```

Taken together, the IDL and the topic expression describe how this multi topic will work. The multi topic data reader will construct samples which belong to instances keyed by `flight_id`. The instance of the resulting type will only come into existence once the corresponding instances are available from both the `Location` and `FlightPlan` topics. Some other domain participant or participants within the domain will publish data on those topics, and they don't even need to be aware of one another. Since they each use the same `flight_id` to refer to flights, the multi topic can correlate the incoming data from disparate sources.

Creating the Multi Topic Data Reader

Creating a data reader for the multi topic consists of a few steps. First the type support for the resulting type is registered, then the multi topic itself is created, followed by the data reader:

```
ResultingTypeSupport_var ts_res = new ResultingTypeSupportImpl;
ts_res->register_type(dp, "");
CORBA::String_var type_name = ts_res->get_type_name();
DDS::MultiTopic_var mt =
  dp->create_multitopic("MyMultiTopic",
                        type_name,
                        "SELECT flight_name, x, y, z AS height "
                          "FROM Location NATURAL JOIN FlightPlan "
                          "WHERE height < 1000 AND x<23",
                        DDS::StringSeq());
DDS::DataReader_var dr =
  sub->create_datareader(mt,
                         DATAREADER_QOS_DEFAULT,
                         NULL,
                         OpenDDS::DCPS::DEFAULT_STATUS_MASK);
```

Reading Data with the Multi Topic Data Reader

From an API perspective, the multi topic data reader is identical to any other typed data reader for the resulting type. This example uses a wait set and a read condition in order to block until data is available.

```
DDS::WaitSet_var ws = new DDS::WaitSet;
DDS::ReadCondition_var rc =
  dr->create_readcondition(DDS::ANY_SAMPLE_STATE,
                           DDS::ANY_VIEW_STATE,
                           DDS::ANY_INSTANCE_STATE);
ws->attach_condition(rc);
DDS::Duration_t infinite = {DDS::DURATION_INFINITE_SEC,
                            DDS::DURATION_INFINITE_NSEC};
DDS::ConditionSeq active;
ws->wait(active, infinite); // error handling not shown
ws->detach_condition(rc);
ResultingDataReader_var res_dr = ResultingDataReader::_narrow(dr);
ResultingSeq data;
DDS::SampleInfoSeq info;
res_dr->take_w_condition(data, info, DDS::LENGTH_UNLIMITED, rc);
```

1.6 Built-In Topics

1.6.1 Introduction

In OpenDDS, Built-In-Topics are created and published by default to exchange information about DDS participants operating in the deployment. When OpenDDS is used in a centralized discovery approach using the `DCPSInfoRepo` service, the Built-In-Topics are published by this service. For DDSI-RTPS discovery, the internal OpenDDS implementation instantiated in a process populates the caches of the Built-In Topic DataReaders. See *Configuring for DDSI-RTPS Discovery* for a description of RTPS discovery configuration.

The IDL struct `BuiltinTopicKey_t` is used by the Built-In Topics. This structure contains an array of 16 octets (bytes) which corresponds to an InfoRepo identifier or a DDSI-RTPS GUID.

1.6.2 Built-In Topics for DCPSInfoRepo Configuration

When starting the `DCPSInfoRepo` a command line option of `-NOBITS` may be used to suppress publication of built-in topics.

Four separate topics are defined for each domain. Each is dedicated to a particular entity (domain participant *DCPSParticipant Topic*, topic *DCPSParticipant Topic*, data writer *DCPSPublication Topic*, data reader *DCPSSubscription Topic*) and publishes instances describing the state for each entity in the domain.

Subscriptions to built-in topics are automatically created for each domain participant. A participant's support for Built-In-Topics can be toggled via the `DCPSBit` configuration option (see the table in *Common Configuration Options*) (Note: this option cannot be used for RTPS discovery). To view the built-in topic data, simply obtain the built-in Subscriber and then use it to access the Data Reader for the built-in topic of interest. The Data Reader can then be used like any other Data Reader.

See *Built-In Topic Subscription Example* for an example showing how to read from a built-in topic.

If you are not planning on using Built-in-Topics in your application, you can configure OpenDDS to remove Built-In-Topic support at build time. Doing so can reduce the footprint of the core DDS library by up to 30%. See *Disabling the Building of Built-In Topic Support* for information on disabling Built-In-Topic support.

1.6.3 DCPSParticipant Topic

The `DCPSParticipant` topic publishes information about the Domain Participants of the Domain. Here is the IDL that defines the structure published for this topic:

```
struct ParticipantBuiltinTopicData {
  BuiltinTopicKey_t key;
  UserDataQosPolicy user_data;
};
```

Each Domain Participant is defined by a unique key and is its own instance within this topic.

1.6.4 DCPSTopic Topic

Note: OpenDDS does not support this Built-In-Topic when configured for RTPS discovery.

The `DCPSTopic` topic publishes information about the topics in the domain. Here is the IDL that defines the structure published for this topic:

```
struct TopicBuiltinTopicData {
  BuiltinTopicKey_t key;
  string name;
  string type_name;
  DurabilityQosPolicy durability;
  QosPolicy deadline;
  LatencyBudgetQosPolicy latency_budget;
  LivelinessQosPolicy liveliness;
  ReliabilityQosPolicy reliability;
  TransportPriorityQosPolicy transport_priority;
  LifespanQosPolicy lifespan;
  DestinationOrderQosPolicy destination_order;
  HistoryQosPolicy history;
  ResourceLimitsQosPolicy resource_limits;
  OwnershipQosPolicy ownership;
  TopicDataQosPolicy topic_data;
};
```

Each topic is identified by a unique key and is its own instance within this built-in topic. The members above identify the name of the topic, the name of the topic type, and the set of QoS policies for that topic.

1.6.5 DCPSPublication Topic

The `DCPSPublication` topic publishes information about the Data Writers in the Domain. Here is the IDL that defines the structure published for this topic:

```
struct PublicationBuiltinTopicData {
  BuiltinTopicKey_t key;
  BuiltinTopicKey_t participant_key;
  string topic_name;
  string type_name;
  DurabilityQosPolicy durability;
  DeadlineQosPolicy deadline;
  LatencyBudgetQosPolicy latency_budget;
  LivelinessQosPolicy liveliness;
  ReliabilityQosPolicy reliability;
  LifespanQosPolicy lifespan;
  UserDataQosPolicy user_data;
  OwnershipStrengthQosPolicy ownership_strength;
  PresentationQosPolicy presentation;
  PartitionQosPolicy partition;
  TopicDataQosPolicy topic_data;
  GroupDataQosPolicy group_data;
};
```

Each Data Writer is assigned a unique key when it is created and defines its own instance within this topic. The fields above identify the Domain Participant (via its key) that the Data Writer belongs to, the topic name and type, and the various QoS policies applied to the Data Writer.

1.6.6 DCPSSubscription Topic

The `DCPSSubscription` topic publishes information about the Data Readers in the Domain. Here is the IDL that defines the structure published for this topic:

```
struct SubscriptionBuiltinTopicData {
  BuiltinTopicKey_t key;
  BuiltinTopicKey_t participant_key;
  string topic_name;
  string type_name;
  DurabilityQosPolicy durability;
  DeadlineQosPolicy deadline;
  LatencyBudgetQosPolicy latency_budget;
  LivelinessQosPolicy liveliness;
  ReliabilityQosPolicy reliability;
  DestinationOrderQosPolicy destination_order;
  UserDataQosPolicy user_data;
  TimeBasedFilterQosPolicy time_based_filter;
  PresentationQosPolicy presentation;
  PartitionQosPolicy partition;
  TopicDataQosPolicy topic_data;
  GroupDataQosPolicy group_data;
};
```

Each Data Reader is assigned a unique key when it is created and defines its own instance within this topic. The fields above identify the Domain Participant (via its key) that the Data Reader belongs to, the topic name and type, and the various QoS policies applied to the Data Reader.

1.6.7 Built-In Topic Subscription Example

The following code uses a domain participant to get the built-in subscriber. It then uses the subscriber to get the Data Reader for the `DCPSParticipant` topic and subsequently reads samples for that reader.

```
Subscriber_var bit_subscriber = participant->get_builtin_subscriber();
DDS::DataReader_var dr =
  bit_subscriber->lookup_datareader(BUILT_IN_PARTICIPANT_TOPIC);
DDS::ParticipantBuiltinTopicDataDataReader_var part_dr =
  DDS::ParticipantBuiltinTopicDataDataReader::_narrow(dr);

DDS::ParticipantBuiltinTopicDataSeq part_data;
DDS::SampleInfoSeq infos;
DDS::ReturnCode_t ret = part_dr->read(part_data, infos, 20,
                                      DDS::ANY_SAMPLE_STATE,
                                      DDS::ANY_VIEW_STATE,
                                      DDS::ANY_INSTANCE_STATE);

// Check return status and read the participant data
```

The code for the other built-in topics is similar.

1.6.8 OpenDDS-specific Built-In Topics

OpenDDSParticipantLocation Topic

The Built-In Topic "OpenDDSParticipantLocation" is published by the DDSI-RTPS discovery implementation to give applications visibility into the details of how each remote participant is connected over the network. If the RtpsRelay (*The RtpsRelay*) and/or IETF ICE (*Interactive Connectivity Establishment (ICE) for RTPS*) are enabled, their usage is reflected in the OpenDDSParticipantLocation topic data. The topic type ParticipantLocationBuiltinTopicData is defined in dds/OpenddsDcpsExt.idl in the `OpenDDS::DCPS` module:

- `guid` (key) – The GUID of the remote participant. Also, a key into the DCPSParticipant topic.
- `location` – A bit-mask indicating which fields are populated.
- `change_mask` – A bit-mask indicating which fields changed.
- `local_addr` – SPDP address of the remote participant for a local connection.
- `local_timestamp` – Time that `local_addr` was set.
- `ice_addr` – SPDP address of the remote participant for an ICE connection.
- `ice_timestamp` – Time that `ice_addr` was set.
- `relay_addr` – SPDP address of the remote participant using the RtpsRelay.
- `relay_timestamp` – Time that `relay_addr` was set.
- `local6_addr, local6_timestamp, ice6_addr, ice6_timestamp, relay6_addr,` and `relay6_timestamp`– Are the IPV6 equivalents.

OpenDDSConnectionRecord Topic

The Built-In Topic "OpenDDSConnectionRecord" is published by the DDSI-RTPS discovery implementation and RTPS_UDP transport implementation to give applications visibility into the details of a participant's connection to an RtpsRelay instance. Security must be enabled in the build of OpenDDS (*Building OpenDDS with Security Enabled*) to use this topic.

The topic type ConnectionRecord is defined in dds/OpenddsDcpsExt.idl in the `OpenDDS::DCPS` module:

- `guid` (key) – The GUID of the remote participant. Also, a key into the DCPSParticipant topic.
- `address` (key) – The address of the remote participant.
- `protocol` (key) – The method used to determine connectivity. Currently, "RtpsRelay:STUN" is the only supported protocol.
- `latency` – A measured round-trip latency for protocols that support it.

OpenDDSInternalThread Topic

The Built-In Topic "OpenDDSInternalThread" is published when OpenDDS is configured with DCPSThreadStatusInterval (*Common Configuration Options*). When enabled, the DataReader for this Built-In Topic will report the status of threads created and managed by OpenDDS within the current process. The timestamp associated with samples can be used to determine the health (responsiveness) of the thread.

The topic type InternalThreadBuiltinTopicData is defined in dds/OpenddsDcpsExt.idl in the `OpenDDS::DCPS` module:

- `thread_id` (key) – A string identifier for the thread.
- `utilization` – Estimated utilization of this thread (0.0-1.0).

1.7 Run-time Configuration

1.7.1 Configuration Approach

OpenDDS includes a file-based configuration framework for configuring global options and options related to specific publishers and subscribers such as discovery and transport configuration. OpenDDS also allows configuration via the command line for a limited number of options and via a configuration API. This section summarizes the configuration options supported by OpenDDS.

OpenDDS configuration is concerned with three main areas:

1. **Common Configuration Options** – configure the behavior of DCPS entities at a global level. This allows separately deployed processes in a computing environment to share common settings for the specified behavior (e.g. all readers and writers should use RTPS discovery).
2. **Discovery Configuration Options** – configure the behavior of the discovery mechanism(s). OpenDDS supports multiple approaches for discovering and associating writers and readers as detailed in *Discovery Configuration*.
3. **Transport Configuration Options** – configure the Extensible Transport Framework (ETF) which abstracts the transport layer from the DCPS layer of OpenDDS. Each pluggable transport can be configured separately.

The configuration file for OpenDDS is a human-readable ini-style text file. *Table 7-1* shows a list of the available configuration section types as they relate to the area of OpenDDS that they configure.

Table Configuration File Sections

Focus Area	File Section Title
Global Settings	`[common]`

Discovery	`[domain]`
	`[repository]`
	`[rtps_discovery]`

Static Discovery	`[endpoint]`
	`[topic]`
	`[datawriterqos]`
	`[datareaderqos]`
	`[publisherqos]`
	`[subscriberqos]`

Transport	`[config]` `[transport]`

For each of the section types with the exception of `[common]`, the syntax of a section header takes the form of `[section type/instance]`. For example, a `[repository]` section type would always be used in a configuration file like so:

`[repository/repo_1]` where `repository` is the section type and `repo_1` is an instance name of a repository configuration. How to use instances to configure discovery and transports is explained further in *Discovery Configuration* and *Transport Configuration*.

The `-DCPSConfigFile` command-line argument can be used to pass the location of a configuration file to OpenDDS. For example:

Windows:

```
publisher -DCPSConfigFile pub.ini
```

Unix:

```
./publisher -DCPSConfigFile pub.ini
```

Command-line arguments are passed to the service participant singleton when initializing the domain participant factory. This is accomplished by using the `TheParticipantFactoryWithArgs` macro:

```
#include <dds/DCPS/Service_Participant.h>

int main(int argc, char* argv[])
{
  DDS::DomainParticipantFactory_var dpf =
    TheParticipantFactoryWithArgs(argc, argv);
  // ...
}
```

To set a default configuration file to load, use `TheServiceParticipant->default_configuration_file(ACE_TCHAR* path)`, like in the following example:

```
#include <dds/DCPS/Service_Participant.h>

int main(int argc, char* argv[])
{
  TheServiceParticipant->default_configuration_file(ACE_TEXT("pub.ini"));

  DDS::DomainParticipantFactory_var dpf =
    TheParticipantFactoryWithArgs(argc, argv);
  // ...
}
```

`pub.ini` would be used unless `-DCPSConfigFile` is passed to override the default configuration file.

The `Service_Participant` class also provides methods that allow an application to configure the DDS service. See the header file dds/DCPS/Service_Participant.h for details.

The following subsections detail each of the configuration file sections and the available options related to those sections.

1.7.2 Common Configuration Options

The `[common]` section of an OpenDDS configuration file contains options such as the debugging output level, the location of the `DCPSInfoRepo` process, and memory preallocation settings. A sample `[common]` section follows:

```
[common]
DCPSDebugLevel=0
DCPSInfoRepo=localhost:12345
DCPSLivelinessFactor=80
DCPSChunks=20
DCPSChunksAssociationMultiplier=10
DCPSBitLookupDurationMsec=2000
DCPSPendingTimeout=30
```

It is not necessary to specify every option.

Option values in the `[common]` section with names that begin with "`DCPS`" can be overridden by a command-line argument. The command-line argument has the same name as the configuration option with a "`-`" prepended to it. For example:

```
subscriber -DCPSInfoRepo localhost:12345
```

The following table summarizes the [common] configuration options:

Table Common Configuration Options

Option	Description	Default
DCPSBit=[1|0]	Toggle Built-In-Topic support.	1
DCPSBitLookupDurationMsec=msec	The maximum duration in milliseconds that the framework will wait for latent Built-In Topic information when retrieving BIT data given an instance handle. The participant code may get an instance handle for a remote entity before the framework receives and processes the related BIT information. The framework waits for up to the given amount of time before it fails the operation.	2000
DCPSBitTransportIPAddress=addr	IP address identifying the local interface to be used by tcp transport for the Built-In Topics. **NOTE**: This property is only applicable to a DCPSInfoRepo configuration.	INADDR_ANY
DCPSBitTransportPort=port	Port used by the tcp transport for Built-In Topics.If the default of '0' is used, the operating system will choose a port to use. **NOTE**: This property is only applicable to a DCPSInfoRepo configuration.	0
DCPSChunks=n	Configurable number of chunks that a data writer's and reader's cached allocators will preallocate when the RESOURCE_LIMITS QoS value is infinite. When all of the preallocated chunks are in use, OpenDDS allocates from the heap.	20

continues on next page

Table 1.1 – continued from previous page

Option	Description	Default
DCPSChunkAssociationMultiplier=N	Multiplier for the DCPSChunks or resource_limits.max_samples value to determine the total number of shallow copy chunks that are pre-allocated. Set this to a value greater than the number of connections so the preallocated chunk handles do not run out. A sample written to multiple data readers will not be copied multiple times but there is a shallow copy handle to that sample used to manage the delivery to each data reader. The size of the handle is small so there is not great need to set this value close to the number of connections.	10
DCPSDebugLevel=n	Integer value that controls the amount of debug information the DCPS layer prints. Valid values are 0 through 10.	0
ORBLogFile=filename	Change log message destination to the file specified, which is opened in appending mode. See the note below this table regarding the ORB prefix.	None: use standard error
ORBVerboseLogging=[0|1|2]	Add a prefix to each log message, using a format defined by the ACE library: 0 – no prefix 1 – verbose "lite": adds timestamp and priority 2 – verbose: in addition to "lite" has host name, PID, program name See the note below this table regarding the ORB prefix.	0
DCPSDefaultAddress=addr	Default value for the host portion of local_address for transport instances containing a local_address. Only applied when DCPSDefaultAddress is set to a non-empty value and no local_address is specified in the transport. Other subsystems (such as DDSI-RTPS Discovery) use DCPSDefaultAddress as a default value as well.	

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Table 1.1 – continued from previous page

Option	Description	Default
DCPSDefaultDiscovery=[DEFAULT_REPO| DEFAULT_RTPS| DEFAULT_STATIC| user-defined configuration instance name]	Specifies a discovery configuration to use for any domain not explicitly configured. DEFAULT_REPO translates to using the DCPSInfoRepo. DEFAULT_RTPS specifies the use of RTPS for discovery. DEFAULT_STATIC specifies the use of static discovery. See *Discovery Configuration* for details about configuring discovery.	DEFAULT_REPO
DCPSGlobalTransportConfig=name	Specifies the name of the transport configuration that should be used as the global configuration. This configuration is used by all entities that do not otherwise specify a transport configuration. A special value of $file uses a transport configuration that includes all transport instances defined in the configuration file.	The default configuration is used as described in *Overview*
DCPSInfoRepo=objref	Object reference for locating the DCPS Information Repository. This can either be a full CORBA IOR or a simple host:port string.	file://repo.ior
DCPSLivelinessFactor=n	Percent of the liveliness lease duration after which a liveliness message is sent. A value of 80 implies a 20% cushion of latency from the last detected heartbeat message.	80
DCPSLogLevel= none| error| warning| notice| info| debug	General logging control. See *Logging* for details.	warning
DCPSMonitor=[0|1]	Use the OpenDDS_monitor library to publish data on monitoring topics (see dds/monitor/README).	0
DCPSPendingTimeout=sec	The maximum duration in seconds a data writer will block to allow unsent samples to drain on deletion. By default, this option blocks indefinitely.	0
DCPSPersistentDataDir=path	The path on the file system where durable data will be stored. If the directory does not exist it will be created automatically.	OpenDDS-durable-data-dir

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Table 1.1 – continued from previous page

Option	Description	Default
DCPSPublisherContentFilter=[1|0]	Controls the filter expression evaluation policy for content filtered topics. When enabled (1), the publisher may drop any samples, before handing them off to the transport when these samples would have been ignored by all subscribers.	1
DCPSSecurity=[0|1]	This setting is only available when OpenDDS is compiled with DDS Security enabled. If set to 1, enable DDS Security framework and built-in plugins. Each Domain Participant using security must be created with certain QoS policy values. See *DDS Security*: DDS Security for more information.	0
DCPSSecurityDebug=CAT[,CAT...]	This setting is only available when OpenDDS is compiled with DDS Security enabled. This controls the security debug logging granularity by category. See *Security Debug Logging* for details.	0
DCPSSecurityDebugLevel=n	This setting is only available when OpenDDS is compiled with DDS Security enabled. This controls the security debug logging granularity by debug level. See *Security Debug Logging* for details.	N/A
DCPSSecurityFakeEncryption=[0|1]	This setting is only available when OpenDDS is compiled with DDS Security enabled. This option, when set to 1, disables all encryption by making encryption and decryption no-ops. OpenDDS still generates keys and performs other security bookkeeping, so this option is useful for debugging the security infrastructure by making it possible to manually inspect all messages.	0
DCPSTransportDebugLevel=n	Integer value that controls the amount of debug information the transport layer prints. See *Transport Layer Debug Logging* for details.	0
pool_size=n_bytes	Size of safety profile memory pool, in bytes.	41943040 (40 MiB)
pool_granularity=n_bytes	Granularity of safety profile memory pool in bytes. Must be multiple of 8.	8

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Table 1.1 – continued from previous page

Option	Description	Default
`Scheduler=[ SCHED_RR| SCHED_FIFO| SCHED_OTHER]`	Selects the thread scheduler to use. Setting the scheduler to a value other than the default requires privileges on most systems. A value of `SCHED_RR`, `SCHED_FIFO`, or `SCHED_OTHER` can be set. `SCHED_OTHER` is the default scheduler on most systems; `SCHED_RR` is a round robin scheduling algorithm; and `SCHED_FIFO` allows each thread to run until it either blocks or completes before switching to a different thread.	SCHED_OTHER
`scheduler_slice=usec`	Some operating systems, such as SunOS, require a time slice value to be set when selecting schedulers other than the default. For those systems, this option can be used to set a value in microseconds.	`none`
`DCPSBidirGIOP=[0|1]`	Use TAO's BiDirectional GIOP feature for interaction with the DCPSInfoRepo. With BiDir enabled, fewer sockets are needed since the same socket can be used for both client and server roles.	`1`
`DCPSThreadStatusInterval=sec`	Enable internal thread status reporting (*OpenDDSInternalThread Topic*) using the specified reporting interval, in seconds.	`0 (disabled)`

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Table 1.1 – continued from previous page

Option	Description	Default
DCPSTypeObjectEncoding=[Normal | WriteOldFormat | ReadOldFormat]	Before version 3.18, OpenDDS had a bug in the encoding used for TypeObject (from XTypes) and related data types. If this application needs to be compatible with an application built with an older OpenDDS (that has XTypes), select one of WriteOldFormat or ReadOldFormat. Using WriteOldFormat means that the TypeInformation written by this application will be understood by legacy applications. Using WriteOldFormat or ReadOldFormat means that TypeInformation written in the legacy format will be understood by this application. These options are designed to enable a phased migration from the incorrect implementation (pre-3.18) to a compliant one. In the first phase, legacy applications can coexist with WriteOldFormat. In the second phase (once all legacy applications have been upgraded), WriteOldFormat can communicate with ReadOldFormat. In the final phase (once all WriteOldFormat applications have been upgraded), ReadOldFormat applications can be transitioned to Normal.	Normal

The DCPSInfoRepo option's value is passed to CORBA::ORB::string_to_object() and can be any Object URL type understandable by TAO (file, IOR, corbaloc, corbaname). A simplified endpoint description of the form <host>:<port> is also accepted. It is equivalent to corbaloc::<host>:<port>/DCPSInfoRepo.

Certain options that begin with "ORB" instead of "DCPS" are listed in the table above. They are named differently since they are inherited from TAO. The options starting with "ORB" listed in this table are implemented directly by OpenDDS (not passed to TAO) and are supported either on the command line (using a "-" prefix) or in the configuration file. Other command-line options that begin with "-ORB" are passed to TAO's ORB_init if DCPSInfoRepo discovery is used.

The DCPSChunks option allows application developers to tune the amount of memory preallocated when the RESOURCE_LIMITS are set to infinite. Once the allocated memory is exhausted, additional chunks are allocated/deallocated from the heap. This feature of allocating from the heap when the preallocated memory is exhausted provides flexibility but performance will decrease when the preallocated memory is exhausted.

1.7.3 Discovery Configuration

In DDS implementations, participants are instantiated in application processes and must discover one another in order to communicate. A DDS implementation uses the feature of domains to give context to the data being exchanged between DDS participants in the same domain. When DDS applications are written, participants are assigned to a domain and need to ensure their configuration allows each participant to discover the other participants in the same domain.

OpenDDS offers a centralized discovery mechanism, a peer-to-peer discovery mechanism, and a static discovery mechanism. The centralized mechanism uses a separate service running a `DCPSInfoRepo` process. The RTPS peer-to-peer mechanism uses the DDSI-RTPS discovery protocol standard to achieve non-centralized discovery. The static discovery mechanism uses the configuration file to determine which writers and readers should be associated and uses the underlying transport to determine which writers and readers exist. A number of configuration options exist to meet the deployment needs of DDS applications. Except for static discovery, each mechanism uses default values if no configuration is supplied either via the command line or configuration file.

The following sections show how to configure the advanced discovery capabilities. For example, some deployments may need to use multiple `DCPSInfoRepo` services or DDSI-RTPS discovery to satisfy interoperability requirements.

Domain Configuration

An OpenDDS configuration file uses the `[domain]` section type to configure one or more discovery domains with each domain pointing to a discovery configuration in the same file or a default discovery configuration. OpenDDS applications can use a centralized discovery approach using the `DCPSInfoRepo` service or a peer-to-peer discovery approach using the RTPS discovery protocol standard or a combination of the two in the same deployment. The section type for the `DCPSInfoRepo` method is `[repository]` and the section type for an RTPS discovery configuration is `[rtps_discovery]`. The static discovery mechanism does not have a dedicated section. Instead, users are expected to refer to the `DEFAULT_STATIC` instance. A single domain can refer to only one type of discovery section.

See *Configuring Applications for DCPSInfoRepo* for configuring InfoRepo Discovery, *Configuring for DDSI-RTPS Discovery* for configuring RTPS Discovery, and *Configuring for Static Discovery* for configuring Static Discovery.

Ultimately a domain is assigned an integer value and a configuration file can support this in two ways. The first is to simply make the instance value the integer value assigned to the domain as shown here:

```
[domain/1]
DiscoveryConfig=DiscoveryConfig1
(more properties...)
```

Our example configures a single domain identified by the domain keyword and followed by an instance value of `/1`. The instance value after the slash in this case is the integer value assigned to the domain. An alternative syntax for this same content is to use a more recognizable (friendly) name instead of a number for the domain name and then add the `DomainId` property to the section to give the integer value. Here is an example:

```
[domain/books]
DomainId=1
DiscoveryConfig=DiscoveryConfig1
```

The domain is given a friendly name of books. The `DomainId` property assigns the integer value of `1` needed by a DDS application reading the configuration. Multiple domain instances can be identified in a single configuration file in this format.

Once one or more domain instances are established, the discovery properties must be identified for that domain. The `DiscoveryConfig` property must either point to another section that holds the discovery configuration or specify one of the internal default values for discovery (e.g. `DEFAULT_REPO`, `DEFAULT_RTPS`, or `DEFAULT_STATIC`). The instance

name in our example is DiscoveryConfig1. This instance name must be associated with a section type of either [repository] or [rtps_discovery].

Here is an extension of our example:

```
[domain/1]
DiscoveryConfig=DiscoveryConfig1

[repository/DiscoveryConfig1]
RepositoryIor=host1.mydomain.com:12345
```

In this case our domain points to a [repository] section which is used for an OpenDDS DCPSInfoRepo service. See *Configuring Applications for DCPSInfoRepo* for more details.

There are going to be occasions when specific domains are not identified in the configuration file. For example, if an OpenDDS application assigns a domain ID of 3 to its participants and the above example does not supply a configuration for domain id of 3 then the following can be used:

```
[common]
DCPSInfoRepo=host3.mydomain.com:12345
DCPSDefaultDiscovery=DEFAULT_REPO

[domain/1]
DiscoveryConfig=DiscoveryConfig1

[repository/DiscoveryConfig1]
RepositoryIor=host1.mydomain.com:12345
```

The DCPSDefaultDiscovery property tells the application to assign any participant that doesn't have a domain id found in the configuration file to use a discovery type of DEFAULT_REPO which means "use a DCPSInfoRepo service" and that DCPSInfoRepo service can be found at host3.mydomain.com:12345.

As shown in *Table 7-2* the DCPSDefaultDiscovery property has three other values that can be used. The DEFAULT_RTPS constant value informs participants that don't have a domain configuration to use RTPS discovery to find other participants. Similarly, the DEFAULT_STATIC constant value informs the participants that don't have a domain configuration to use static discovery to find other participants.

The final option for the DCPSDefaultDiscovery property is to tell an application to use one of the defined discovery configurations to be the default configuration for any participant domain that isn't called out in the file. Here is an example:

```
[common]
DCPSDefaultDiscovery=DiscoveryConfig2

[domain/1]
DiscoveryConfig=DiscoveryConfig1

[repository/DiscoveryConfig1]
RepositoryIor=host1.mydomain.com:12345

[domain/2]
DiscoveryConfig=DiscoveryConfig2

[repository/DiscoveryConfig2]
RepositoryIor=host2.mydomain.com:12345
```

By adding the DCPSDefaultDiscovery property to the [common] section, any participant that hasn't been assigned to a domain id of 1 or 2 will use the configuration of DiscoveryConfig2. For more explanation of a similar configuration for RTPS discovery see *Configuring for DDSI-RTPS Discovery*.

Here are the available properties for the [domain] section.

Table Domain Section Configuration Properties

Option	Description
DomainId=n	An integer value representing a Domain being associated with a repository.
DomainRepoKey=K	Key value of the mapped repository (Deprecated. Provided for backward compatibility).
DiscoveryConfig=config instance name	A user defined string that refers to the instance name of a [repository] or [rtps_discovery] section in the same configuration file or one of the internal default values (DEFAULT_REPO, DEFAULT_RTPS, or DEFAULT_STATIC). (Also see the DCPSDefaultDiscovery property in *Table 7-2*)
DefaultTransportConfig=config	A user defined string that refers to the instance name of a [config] section. See *Transport Configuration*.

Configuring Applications for DCPSInfoRepo

An OpenDDS DCPSInfoRepo is a service on a local or remote node used for participant discovery. Configuring how participants should find DCPSInfoRepo is the purpose of this section. Assume for example that the DCPSInfoRepo service is started on a host and port of myhost.mydomain.com:12345. Applications can make their OpenDDS participants aware of how to find this service through command line options or by reading a configuration file.

In our Getting Started example from 2.1.7, "Running the Example" the executables were given a command line parameter to find the DCPSInfoRepo service like so:

```
publisher -DCPSInfoRepo file://repo.ior
```

This assumes that the DCPSInfoRepo has been started with the following syntax:

Windows:

```
%DDS_ROOT%\bin\DCPSInfoRepo -o repo.ior
```

Unix:

```
$DDS_ROOT/bin/DCPSInfoRepo -o repo.ior
```

The DCPSInfoRepo service generates its location object information in this file and participants need to read this file to ultimately connect. The use of file based IORs to find a discovery service, however, is not practical in most production environments, so applications instead can use a command line option like the following to simply point to the host and port where the DCPSInfoRepo is running.

```
publisher -DCPSInfoRepo myhost.mydomain.com:12345
```

The above assumes that the DCPSInfoRepo has been started on a host (myhost.mydomain.com) as follows:

Windows:

```
%DDS_ROOT%\bin\DCPSInfoRepo -ORBListenEndpoints iiop://:12345
```

Unix:

```
$DDS_ROOT/bin/DCPSInfoRepo -ORBListenEndpoints iiop://:12345
```

If an application needs to use a configuration file for other settings, it would become more convenient to place discovery content in the file and reduce command line complexity and clutter. The use of a configuration file also introduces the opportunity for multiple application processes to share common OpenDDS configuration. The above example can easily be moved to the [common] section of a configuration file (assume a file of pub.ini):

```
[common]
DCPSInfoRepo=myhost.mydomain.com:12345
```

The command line to start our executable would now change to the following:

```
publisher -DCSPConfigFile pub.ini
```

A configuration file can specify domains with discovery configuration assigned to those domains. In this case the RepositoryIor property is used to take the same information that would be supplied on a command line to point to a running DCPSInfoRepo service. Two domains are configured here:

```
[domain/1]
DiscoveryConfig=DiscoveryConfig1

[repository/DiscoveryConfig1]
RepositoryIor=myhost.mydomain.com:12345

[domain/2]
DiscoveryConfig=DiscoveryConfig2

[repository/DiscoveryConfig2]
RepositoryIor=host2.mydomain.com:12345
```

The DiscoveryConfig property under [domain/1] instructs all participants in domain 1 to use the configuration defined in an instance called DiscoveryConfig1. In the above, this is mapped to a [repository] section that gives the RepositoryIor value of myhost.mydomain.com:12345.

Finally, when configuring a DCPSInfoRepo the DiscoveryConfig property under a domain instance entry can also contain the value of DEFAULT_REPO which instructs a participant using this instance to use the definition of the property DCPSInfoRepo wherever it has been supplied. Consider the following configuration file as an example:

```
[common]
DCPSInfoRepo=localhost:12345

[domain/1]
DiscoveryConfig=DiscoveryConfig1

[repository/DiscoveryConfig1]
RepositoryIor=myhost.mydomain.com:12345

[domain/2]
DiscoveryConfig=DEFAULT_REPO
```

In this case any participant in domain 2 would be instructed to refer to the discovery property of DCPSInfoRepo, which is defined in the [common] section of our example. If the DCPSInfoRepo value is not supplied in the [common] section, it could alternatively be supplied as a parameter to the command line like so:

```
publisher -DCPSInfoRepo localhost:12345 -DCPSConfigFile pub.ini
```

This sets the value of DCPSInfoRepo such that if participants reading the configuration file pub.ini encounters DEFAULT_REPO, there is a value for it. If DCPSInfoRepo is not defined in a configuration file or on the command line, then the OpenDDS default value for DCPSInfoRepo is file://repo.ior. As mentioned prior, this is not likely to be the most useful in production environments and should lead to setting the value of DCPSInfoRepo by one of the means described in this section.

Configuring for Multiple DCPSInfoRepo Instances

The DDS entities in a single OpenDDS process can be associated with multiple DCPS information repositories (DCPSInfoRepo).

The repository information and domain associations can be configured using a configuration file, or via application API. Internal defaults, command line arguments, and configuration file options will work as-is for existing applications that do not want to use multiple DCPSInfoRepo associations.

See *Figure 7-1* for an example of a process that uses multiple DCPSInfoRepo repositories. Processes A and B are typical application processes that have been configured to communicate with one another and discover one another in InfoRepo_1. This is a simple use of basic discovery. However, an additional layer of context has been applied with the use of a specified domain (Domain 1). DDS entities (data readers/data writers) are restricted to communicate to other entities within that same domain. This provides a useful method of separating traffic when needed by an application. Processes C and D are configured the same way, but operate in Domain 2 and use InfoRepo_2. The challenge comes when you have an application process that needs to use multiple domains and have separate discovery services. This is Process E in our example. It contains two subscribers, one subscribing to publications from InfoRepo_1 and the other subscribing to publications in InfoRepo_2. What allows this configuration to work can be found in the configE.ini file.

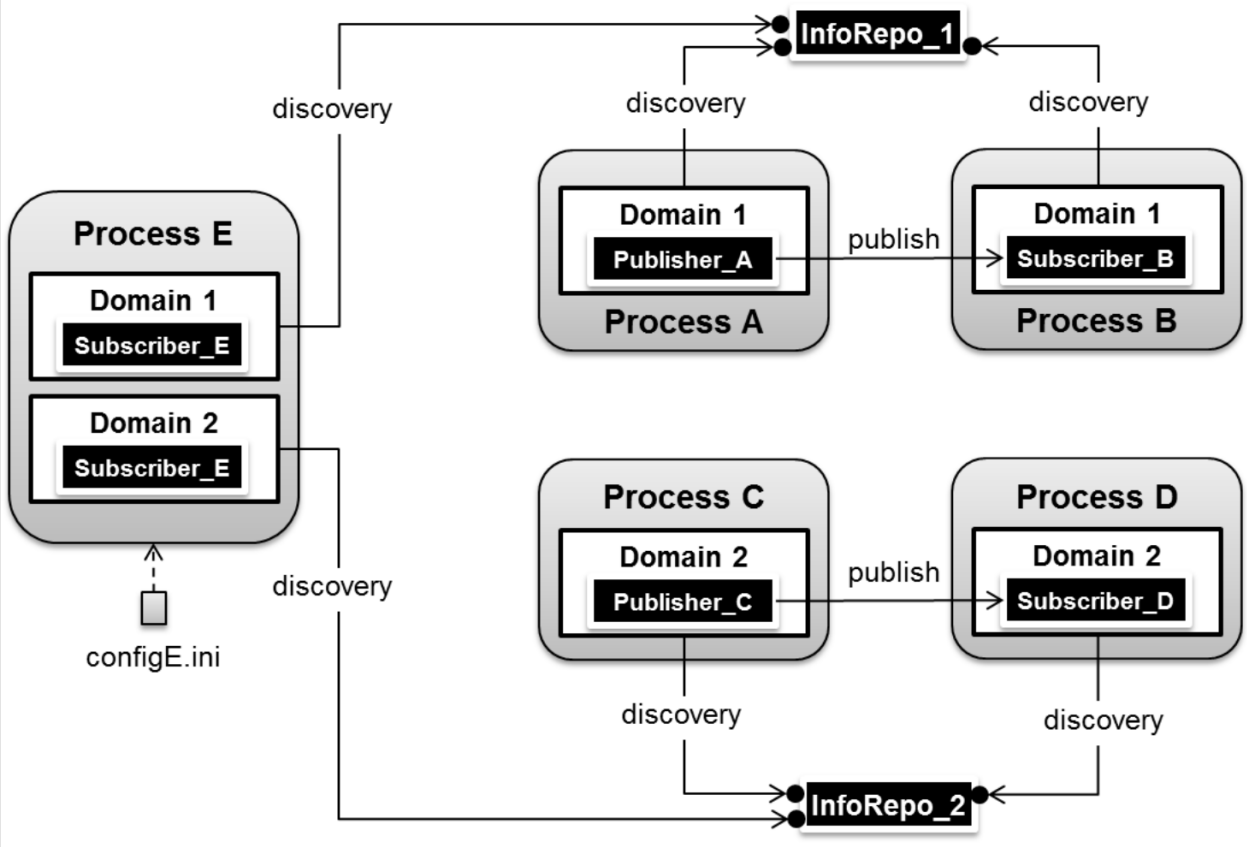

Figure Multiple DCPSInfoRepo Configuration

We will now look at the configuration file (referred to as `configE.ini`) to demonstrate how Process `E` can communicate to both domains and separate `DCPSInfoRepo` services. For this example we will only show the discovery aspects of the configuration and not show transport content.

```
configE.ini
[domain/1]
DiscoveryConfig=DiscoveryConfig1

[repository/DiscoveryConfig1]
RepositoryIor=host1.mydomain.com:12345

[domain/2]
DiscoveryConfig=DiscoveryConfig2

[repository/DiscoveryConfig2]
RepositoryIor=host2.mydomain.com:12345
```

When Process `E` in *Figure 7-1* reads in the above configuration it finds the occurrence of multiple domain sections. As described in Section each domain has an instance integer and a property of `DiscoveryConfig` defined.

For the first domain (`[domain/1]`), the `DiscoveryConfig` property is supplied with the user-defined name of `DiscoveryConfig1` value. This property causes the OpenDDS implementation to find a section title of either `repository` or `rtps_discovery` and an instance name of `DiscoveryConfig1`. In our example, a `[repository/DiscoveryConfig1]` section title is found and this becomes the discovery configuration for domain instance `[domain/1]` (integer value 1). The section found now tells us that the address of the `DCPSInfoRepo` that this domain should use can be found by using the `RepositoryIor` property value. In particular it is `host1.mydomain.com`

and port `12345`. The values of the `RepositoryIor` can be a full CORBA IOR or a simple `host:port` string.

A second domain section title `[domain/2]` is found in this configuration file along with it's corresponding repository section `[repository/DiscoveryConfig2]` that represents the configuration for the second domain of interest and the `InfoRepo_2` repository. There may be any number of repository or domain sections within a single configuration file.

Note: Domains not explicitly configured are automatically associated with the default discovery configuration.

Note: Individual DCPSInfoRepos can be associated with multiple domains, however domains cannot be shared between multiple DCPSInfoRepos.

Here are the valid properties for a `[repository]` section.

Table Multiple repository configuration sections

Option	Description
`RepositoryIor=ior`	Repository IOR or host:port.
`RepositoryKey=key`	Unique key value for the repository. (Deprecated. Provided for backward compatibility)

Configuring for DDSI-RTPS Discovery

The OMG DDSI-RTPS specification gives the following simple description that forms the basis for the discovery approach used by OpenDDS and the two different protocols used to accomplish the discovery operations. The excerpt from the OMG DDSI-RTPS specification Section 8.5.1 is as follows:

"The RTPS specification splits up the discovery protocol into two independent protocols:

1. Participant Discovery Protocol

2. Endpoint Discovery Protocol

A Participant Discovery Protocol (PDP) specifies how Participants discover each other in the network. Once two Participants have discovered each other, they exchange information on the Endpoints they contain using an Endpoint Discovery Protocol (EDP). Apart from this causality relationship, both protocols can be considered independent."

The configuration options discussed in this section allow a user to specify property values to change the behavior of the Simple Participant Discovery Protocol (SPDP) and/or the Simple Endpoint Discovery Protocol (SEDP) default settings.

DDSI-RTPS can be configured for a single domain or for multiple domains as was done in *Configuring for Multiple DCPSInfoRepo Instances*.

A simple configuration is achieved by specifying a property in the `[common]` section of our example configuration file.

```
[common]
DCPSDefaultDiscovery=DEFAULT_RTPS
```

All default values for DDSI-RTPS discovery are adopted in this form. A variant of this same basic configuration is to specify a section to hold more specific parameters of RTPS discovery. The following example uses the `[common]` section to point to an instance of an `[rtps_discovery]` section followed by an instance name of `TheRTPSConfig` which is supplied by the user.

```
[common]
DCPSDefaultDiscovery=TheRTPSConfig

[rtps_discovery/TheRTPSConfig]
ResendPeriod=5
```

The instance `[rtps_discovery/TheRTPSConfig]` is now the location where properties that vary the default DDSI-RTPS settings get specified. In our example the `ResendPeriod=5` entry sets the number of seconds between periodic announcements of available data readers / data writers and to detect the presence of other data readers / data writers on the network. This would override the default of 30 seconds.

If your OpenDDS deployment uses multiple domains, the following configuration approach combines the use of the `[domain]` section title with `[rtps_discovery]` to allow a user to specify particular settings by domain. It might look like this:

```
[common]
DCPSDebugLevel=0

[domain/1]
DiscoveryConfig=DiscoveryConfig1

[rtps_discovery/DiscoveryConfig1]
ResendPeriod=5

[domain/2]
DiscoveryConfig=DiscoveryConfig2

[rtps_discovery/DiscoveryConfig2]
ResendPeriod=5
SedpMulticast=0
```

Some important implementation notes regarding DDSI-RTPS discovery in OpenDDS are as follows:

1. Domain IDs should be between 0 and 231 (inclusive) due to the way UDP ports are assigned to domain IDs. In each OpenDDS process, up to 120 domain participants are supported in each domain.
2. OpenDDS's multicast transport (*IP Multicast Transport Configuration Options*) does not work with RTPS Discovery due to the way GUIDs are assigned (a warning will be issued if this is attempted).

The OMG DDSI-RTPS specification details several properties that can be adjusted from their defaults that influence the behavior of DDSI-RTPS discovery. Those properties, along with options specific to OpenDDS's RTPS Discovery implementation, are listed in *Table 7-5*.

Table RTPS Discovery Configuration Options

Option	Description	Default
`ResendPeriod=sec`	The number of seconds that a process waits between the announcement of participants (see section 8.5.3 in the OMG DDSI-RTPS specification for details).	`30`
`MinResendDelay=msec`	The minimum time in milliseconds between participant announcements.	`100`

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Table 1.2 – continued from previous page

Option	Description	Default
QuickResendRatio=frac	Tuning parameter that configures local SPDP resends as a fraction of the resend period.	0.1
LeaseDuration=sec	Sent as part of the participant announcement. It tells the peer participants that if they don't hear from this participant for the specified duration, then this participant can be considered "not alive."	300
LeaseExtension=sec	Extends the lease of discovered participants by the set amount of seconds. Useful on spotty connections to reduce load on the RtpsRelay.	0
PB=port	Port Base number. This number sets the starting point for deriving port numbers used for Simple Endpoint Discovery Protocol (SEDP). This property is used in conjunction with DG, PG, D0 (or DX), and D1 to construct the necessary Endpoints for RTPS discovery communication. (see section 9.6.1.1 in the OMG DDSI-RTPS specification in how these Endpoints are constructed)	7400
DG=n	An integer value representing the Domain Gain. This is a multiplier that assists in formulating Multicast or Unicast ports for RTPS.	250
PG=n	An integer that assists in configuring SPDP Unicast ports and serves as an offset multiplier as participants are assigned addresses using the formula: PB + DG * domainId + d1 + PG * participantId (see section 9.6.1.1 in the OMG DDSI-RTPS specification in how these Endpoints are constructed)	2
D0=n	An integer value that assists in providing an offset for calculating an assignable port in SPDP Multicast configurations. The formula used is: PB + DG * domainId + d0 (see section 9.6.1.1 in the OMG DDSI-RTPS specification in how these Endpoints are constructed)	0

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Table 1.2 – continued from previous page

Option	Description	Default
D1=n	An integer value that assists in providing an offset for calculating an assignable port in SPDP Unicast configurations. The formula used is: PB + DG * domainId + d1 + PG * participantId (see section 9.6.1.1 in the OMG DDSI-RTPS specification in how these Endpoints are constructed)	10
SpdpRequestRandomPort=[0|1]	Use a random port for SPDP.	0
SedpMaxMessageSize=n	Set the maximum SEDP message size. The default is the maximum UDP message size. See max_message_size in table 7-17.	65466
SedpMulticast=[0|1]	A boolean value (0 or 1) that determines whether Multicast is used for the SEDP traffic. When set to 1, Multicast is used. When set to zero (0) Unicast for SEDP is used.	1
SedpLocalAddress=addr:[port]	Configure the transport instance created and used by SEDP to bind to the specified local address and port. In order to leave the port unspecified, it can be omitted from the setting but the trailing : must be present.	System default address
SpdpLocalAddress=addr[:port]	Address of a local interface, which will be used by SPDP to bind to that specific interface.	DCPSDefaultAddress, or IPADDR_ANY
SedpAdvertisedLocalAddress= addr:[port]	Sets the address advertised by SEDP. Typically used when the participant is behind a firewall or NAT. In order to leave the port unspecified, it can be omitted from the setting but the trailing : must be present.	
SedpSendDelay=msec	Time in milliseconds for a built-in (SEDP) Writer to wait before sending data.	10
SedpHeartbeatPeriod=msec	Time in milliseconds for a built-in (SEDP) Writer to announce the availability of data.	200
SedpNakResponseDelay=msec	Time in milliseconds for a built-in (SEDP) Writer to delay the response to a negative acknowledgment.	100

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Table 1.2 – continued from previous page

Option	Description	Default
DX=n	An integer value that assists in providing an offset for calculating a port in SEDP Multicast configurations. The formula used is: PB + DG * domainId + dx This is only valid when SedpMulticast=1. This is an OpenDDS extension and not part of the OMG DDSI-RTPS specification.	2
SpdpSendAddrs= [host:port],[host:port]...	A list (comma or whitespace separated) of host:port pairs used as destinations for SPDP content. This can be a combination of Unicast and Multicast addresses.	
MaxSpdpSequenceMsgResetChecks=n	Remove a discovered participant after this number of SPDP messages with earlier sequence numbers.	3
PeriodicDirectedSpdp=[0|1]	A boolean value that determines whether directed SPDP messages are sent to all participants once every resend period. This setting should be enabled for participants that cannot use multicast to send SPDP announcements, e.g., an RtpsRelay.	0
UndirectedSpdp=[0|1]	A boolean value that determines whether undirected SPDP messages are sent. This setting should be disabled for participants that cannot use multicast to send SPDP announcements, e.g., an RtpsRelay.	1
InteropMulticastOverride= group_address	A network address specifying the multicast group to be used for SPDP discovery. This overrides the interoperability group of the specification. It can be used, for example, to specify use of a routed group address to provide a larger discovery scope.	239.255.0.1
TTL=n	The value of the Time-To-Live (TTL) field of multicast datagrams sent as part of discovery. This value specifies the number of hops the datagram will traverse before being discarded by the network. The default value of 1 means that all data is restricted to the local network subnet.	1

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Table 1.2 – continued from previous page

Option	Description	Default
`MulticastInterface=iface`	Specifies the network interface to be used by this discovery instance. This uses a platform-specific format that identifies the network interface. On Linux systems this would be something like eth `0`. If this value is not configured, the Common Configuration value `DCPSDefaultAddress` is used to set the multicast interface.	The system default interface is used
`GuidInterface=iface`	Specifies the network interface to use when determining which local MAC address should appear in a GUID generated by this node.	The system / ACE library default is used
`SpdpRtpsRelayAddress=host:port`	Specifies the address of the RtpsRelay for SPDP messages. See *The RtpsRelay*.	
`SpdpRtpsRelaySendPeriod=period`	Specifies the interval between SPDP announcements sent to the RtpsRelay. See *The RtpsRelay*.	30 seconds
`SedpRtpsRelayAddress=host:port`	Specifies the address of the RtpsRelay for SEDP messages. See *The RtpsRelay*.	
`RtpsRelayOnly=[0|1]`	Only send RTPS message to the RtpsRelay (for debugging). See *The RtpsRelay*.	0
`UseRtpsRelay=[0|1]`	Send messages to the RtpsRelay. Messages will only be sent if SpdpRtpsRelayAddress and/or SedpRtpsRelayAddress is set. See *The RtpsRelay*.	0
`SpdpStunServerAddress=host:port`	Specifies the address of the STUN server to use for SPDP when using ICE. See *Interactive Connectivity Establishment (ICE) for RTPS*	
`SedpStunServerAddress=host:port`	Specifies the address of the STUN server to use for SEDP when using ICE. See *Interactive Connectivity Establishment (ICE) for RTPS*.	
`UseIce=[0|1]`	Enable or disable ICE for both SPDP and SEDP. See *Interactive Connectivity Establishment (ICE) for RTPS*.	0
`IceTa=msec`	Minimum interval between ICE sends. See *Interactive Connectivity Establishment (ICE) for RTPS*.	50
`IceConnectivityCheckTTL=sec`	Maximum duration of connectivity check. See *Interactive Connectivity Establishment (ICE) for RTPS*.	300

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Table 1.2 – continued from previous page

Option	Description	Default
`IceChecklistPeriod=sec`	Attempt to cycle through all of the connectivity checks for a candidate in this amount of time. See *Interactive Connectivity Establishment (ICE) for RTPS*.	10
`IceIndicationPeriod=sec`	Send STUN indications to peers to maintain NAT bindings at this period. See *Interactive Connectivity Establishment (ICE) for RTPS*.	15
`IceNominatedTTL=sec`	Forget a valid candidate if an indication is not received in this amount of time. See *Interactive Connectivity Establishment (ICE) for RTPS*.	300
`IceServerReflexiveAddressPeriod=sec`	Send messages to the STUN server at this period. See *Interactive Connectivity Establishment (ICE) for RTPS*.	30
`IceServerReflexiveIndicationCount=int`	Send this many indications before sending a new binding request to the STUN server. See *Interactive Connectivity Establishment (ICE) for RTPS*.	10
`IceDeferredTriggeredCheckTTL=sec`	Purge deferred checks after this amount of time. See *Interactive Connectivity Establishment (ICE) for RTPS*.	300
`IceChangePasswordPeriod=sec`	Change the ICE password after this amount of time. See *Interactive Connectivity Establishment (ICE) for RTPS*.	300
`MaxAuthTime=sec`	Set the maximum time for authentication with DDS Security.	300
`AuthResendPeriod=sec`	Resend authentication messages after this amount of time. It is a floating point value, so fractions of a second can be specified.	1
`SecureParticipantUserData=[0|1]`	If DDS Security is enabled, the Participant's USER_DATA QoS is omitted from unsecured discovery messages.	`0`

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Table 1.2 – continued from previous page

Option	Description	Default
`UseXTypes=[ no|0| minimal|1| complete|2 ]`	Enables discovery extensions from the XTypes specification. Participants exchange top-level type information in endpoint announcements and extended type information using the Type Lookup Service. `minimal` or `1` uses `MinimalTypeObject` and `complete` or `2` uses `CompleteTypeObject` if available. See *Representing Types with TypeObject and DynamicType* for more information on `CompleteTypeObject` and its use in the dynamic binding.	`minimal`
`TypeLookupServiceReplyTimeout=msec`	If a request is sent to a peer's Type Lookup Service (see UseXTypes above), wait up to this duration (in milliseconds) for a reply.	`5000` `(5 seconds)`
`SedpResponsiveMode=[0|1]`	Causes the built-in SEDP endpoints to send additional messages which may reduce latency.	0
`SedpPassiveConnectDuration=msec`	Sets the duration that a passive endpoint will wait for a connection.	60000 (1 minute)
`SendBufferSize=bytes`	Socket send buffer size for both SPDP and SEDP. A value of zero indicates that the system default value is used.	0
`RecvBufferSize=bytes`	Socket receive buffer size for both SPDP and SEDP. A value of zero indicates that the system default value is used.	0
`MaxParticipantsInAuthentication=N`	If DDS Security is enabled, this option (when set to a positive number) limits the number of peer participants that can be concurrently in the process of authenticating – that is, not yet completed authentication.	0 (unlimited)
`SedpReceivePreallocatedMessageBlocks=N`	Configure the receive_preallocated_message_blocks attribute of SEDP's transport. See *Configuration Options Common to All Transports*.	0 (use default)
`SedpReceivePreallocatedDataBlocks=N`	Configure the receive_preallocated_data_blocks attribute of SEDP's transport. See *Configuration Options Common to All Transports*.	0 (use default)

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Table 1.2 – continued from previous page

Option	Description	Default
`CheckSourceIp=[0|1]`	Incoming participant announcements (SPDP) are checked to verify that their source IP address matches one of: • An entry in the metatraffic locator list • The configured RtpsRelay (if any) • An ICE AgentInfo parameter Announcements that don't match any of these are dropped if this check is enabled.	1 (enabled)

Note: If the environment variable `OPENDDS_RTPS_DEFAULT_D0` is set, its value is used as the `D0` default value.

Additional DDSI-RTPS Discovery Features

The DDSI_RTPS discovery implementation creates and manages a transport instance – specifically an object of class `RtpsUdpInst`. In order for applications to access this object and enable advanced features (*Additional RTPS_UDP Features*), the `RtpsDiscovery` class provides the method `sedp_transport_inst(domainId, participant)`.

Configuring for Static Discovery

Static discovery may be used when a DDS domain has a fixed number of processes and data readers/writers that are all known *a priori*. Data readers and writers are collectively known as *endpoints*. Using only the configuration file, the static discovery mechanism must be able to determine a network address and the QoS settings for each endpoint. The static discovery mechanism uses this information to determine all potential associations between readers and writers. A domain participant learns about the existence of an endpoint through hints supplied by the underlying transport.

Note: Currently, static discovery can only be used for endpoints using the RTPS UDP transport.

Static discovery introduces the following configuration file sections: `[topic/*]`,``[datawriterqos/]``, ``[datareaderqos/]``, `[publisherqos/*]`, `[subscriberqos/*]`, and `[endpoint/*]`. The `[topic/*]` (*Table 7-6*) section is used to introduce a topic. The `[datawriterqos/*]` (*Table 7-7*), `[datareaderqos/*]` (*Table 7-8*), `[publisherqos/*]` (*Table 7-9*), and `[subscriberqos/*]` (*Table 7-10*) sections are used to describe a QoS of the associated type. The `[endpoint/*]` (*Table 7-11*) section describes a data reader or writer.

Data reader and writer objects must be identified by the user so that the static discovery mechanism can associate them with the correct `[endpoint/*]` section in the configuration file. This is done by setting the `user_data` of the `DomainParticipantQos` to an octet sequence of length 6. The representation of this octet sequence occurs in the `participant` value of an `[endpoint/*]` section as a string with two hexadecimal digits per octet. Similarly, the `user_data` of the `DataReaderQos` or `DataWriterQos` must be set to an octet sequence of length 3 corresponding to the `entity` value in the `[endpoint/*]` section. For example, suppose the configuration file contains the following:

```
[topic/MyTopic]
type_name=TestMsg::TestMsg

[endpoint/MyReader]
type=reader
topic=MyTopic
config=MyConfig
domain=34
participant=0123456789ab
entity=cdef01

[config/MyConfig]
transports=MyTransport

[transport/MyTransport]
transport_type=rtps_udp
use_multicast=0
local_address=1.2.3.4:30000
```

The corresponding code to configure the `DomainParticipantQos` is:

```
DDS::DomainParticipantQos dp_qos;
domainParticipantFactory->get_default_participant_qos(dp_qos);
dp_qos.user_data.value.length(6);
dp_qos.user_data.value[0] = 0x01;
dp_qos.user_data.value[1] = 0x23;
dp_qos.user_data.value[2] = 0x45;
dp_qos.user_data.value[3] = 0x67;
dp_qos.user_data.value[4] = 0x89;
dp_qos.user_data.value[5] = 0xab;
```

The code to configure the DataReaderQos is similar:

```
DDS::DataReaderQos qos;
subscriber->get_default_datareader_qos(qos);
qos.user_data.value.length(3);
qos.user_data.value[0] = 0xcd;
qos.user_data.value[1] = 0xef;
qos.user_data.value[2] = 0x01;
```

The domain id, which is 34 in the example, should be passed to the call to `create_participant`.

In the example, the endpoint configuration for `MyReader` references `MyConfig` which in turn references `MyTransport`. Transport configuration is described in *Transport Configuration*. The important detail for static discovery is that at least one of the transports contains a known network address (`1.2.3.4:30000`). An error will be issued if an address cannot be determined for an endpoint. The static discovery implementation also checks that the QoS of a data reader or data writer object matches the QoS specified in the configuration file.

Table [topic/*] Configuration Options

Option	Description	Default
`name=string`	The name of the topic.	`Instance name of section`
`type_name=string`	Identifier which uniquely defines the sample type. This is typically a CORBA interface repository type name.	`Required`

Table [datawriterqos/*] Configuration Options

Option	Description	Default
durability.kind=[VOLATILE|TRANSIENT_LOCAL]	See *DURABILITY*.	See *Table 3-5*.
deadline.period.sec=[numeric|DURATION_INFINITE_SEC]	See *DEADLINE*.	See *Table 3-5*.
deadline.period.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *DEADLINE*.	See *Table 3-5*.
latency_budget.duration.sec=[numeric|DURATION_INFINITE_SEC]	See *LATENCY_BUDGET*.	See *Table 3-5*.
latency_budget.duration.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *LATENCY_BUDGET*.	See *Table 3-5*.
liveliness.kind=[AUTOMATIC| MANUAL_BY_TOPIC| MANUAL_BY_PARTICIPANT]	See *LIVELINESS*.	See *Table 3-5*.
liveliness.lease_duration.sec=[numeric|DURATION_INFINITE_SEC]	See *LIVELINESS*.	See *Table 3-5*.
liveliness.lease_duration.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *LIVELINESS*.	See *Table 3-5*.
reliability.kind=[BEST_EFFORT|RELIABILE]	See *RELIABILITY*.	See *Table 3-5*.
reliability.max_blocking_time.sec=[numeric|DURATION_INFINITE_SEC]	See *RELIABILITY*.	See *Table 3-5*.
reliability.max_blocking_time.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *RELIABILITY*.	See *Table 3-5*.
destination_order.kind=[BY_SOURCE_TIMESTAMP| BY_RECEPTION_TIMESTAMP]	See *DESTINATION_ORDER*.	See *Table 3-5*.
history.kind=[KEEP_LAST|KEEP_ALL]	See *HISTORY*.	See *Table 3-5*.
history.depth=numeric	See *HISTORY*.	See *Table 3-5*.
resource_limits.max_samples=numeric	See *RESOURCE_LIMITS*.	See *Table 3-5*.
resource_limits.max_instances=numeric	See *RESOURCE_LIMITS*.	See *Table 3-5*.
resource_limits.max_samples_per_instance= numeric	See *RESOURCE_LIMITS*.	See *Table 3-5*.
transport_priority.value=numeric	See *TRANSPORT_PRIORITY*.	See *Table 3-5*.
lifespan.duration.sec=[numeric|DURATION_INFINITE_SEC]	See *LIFESPAN*.	See *Table 3-5*.
lifespan.duration.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *LIFESPAN*.	See *Table 3-5*.
ownership.kind=[SHARED|EXCLUSIVE]	See *OWNERSHIP*.	See *Table 3-5*.
ownership_strength.value=numeric	See *OWNERSHIP_STRENGTH*.	See *Table 3-5*.

Table [datareaderqos/*] Configuration Options

Option	Description	Default
durability.kind=[VOLATILE|TRANSIENT_LOCAL]	See *DURABILITY*.	See *Table 3-6*.
deadline.period.sec=[numeric|DURATION_INFINITE_SEC]	See *DEADLINE*.	See *Table 3-6*.
deadline.period.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *DEADLINE*.	See *Table 3-6*.
latency_budget.duration.sec=[numeric|DURATION_INFINITE_SEC]	See *LATENCY_BUDGET*.	See *Table 3-6*.
latency_budget.duration.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *LATENCY_BUDGET*.	See *Table 3-6*.
liveliness.kind=[AUTOMATIC| MANUAL_BY_TOPIC| MANUAL_BY_PARTICIPANT]	See *LIVELINESS*.	See *Table 3-6*.
liveliness.lease_duration.sec=[numeric|DURATION_INFINITE_SEC]	See *LIVELINESS*.	See *Table 3-6*.
liveliness.lease_duration.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *LIVELINESS*.	See *Table 3-6*.
reliability.kind=[BEST_EFFORT|RELIABILE]	See *RELIABILITY*.	See *Table 3-6*.
reliability.max_blocking_time.sec=[numeric|DURATION_INFINITE_SEC]	See *RELIABILITY*.	See *Table 3-6*.
reliability.max_blocking_time.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *RELIABILITY*.	See *Table 3-6*.
destination_order.kind=[BY_SOURCE_TIMESTAMP| BY_RECEPTION_TIMESTAMP]	See *DESTINATION_ORDER*.	See *Table 3-6*.
history.kind=[KEEP_LAST|KEEP_ALL]	See *HISTORY*.	See *Table 3-6*.
history.depth=numeric	See *HISTORY*.	See *Table 3-6*.
resource_limits.max_samples=numeric	See *RESOURCE_LIMITS*.	See *Table 3-6*.
resource_limits.max_instances=numeric	See *RESOURCE_LIMITS*.	See *Table 3-6*.
resource_limits.max_samples_per_instance= numeric	See *RESOURCE_LIMITS*.	See *Table 3-6*.
time_based_filter.minimum_separation.sec=[numeric|DURATION_INFINITE_SEC]	See *TIME_BASED_FILTER*.	See *Table 3-6*.
time_based_filter.minimum_separation.nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *TIME_BASED_FILTER*.	See *Table 3-6*.
reader_data_lifecycle. autopurge_nowriter_samples_delay. sec=[numeric|DURATION_INFINITE_SEC]	See *READER_DATA_LIFECYCLE*.	See *Table 3-6*.
reader_data_lifecycle. autopurge_nowriter_samples_delay. nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *READER_DATA_LIFECYCLE*.	See *Table 3-6*.
reader_data_lifecycle. autopurge_dispose_samples_delay.sec=[numeric|DURATION_INFINITE_SEC]	See *READER_DATA_LIFECYCLE*.	See *Table 3-6*.
reader_data_lifecycle. autopurge_dispose_samples_delay. nanosec=[numeric|DURATION_INFINITE_NANOSEC]	See *READER_DATA_LIFECYCLE*.	See *Table 3-6*.

Table [publisherqos/*] Configuration Options

Option	Description	Default
`presentation.access_scope=[INSTANCE|TOPIC|GROUP]`	See *PRESENTATION*.	See *Table 3-3*.
`presentation.coherent_access=[true|false]`	See *PRESENTATION*.	See *Table 3-3*.
`presentation.ordered_access=[true|false]`	See *PRESENTATION*.	See *Table 3-3*.
`partition.name=name0,name1,...`	See *PARTITION*.	See *Table 3-3*.

Table [subscriberqos/*] Configuration Options

Option	Description	Default
`presentation.access_scope=[INSTANCE|TOPIC|GROUP]`	See *PRESENTATION*.	See *Table 3-4*.
`presentation.coherent_access=[true|false]`	See *PRESENTATION*.	See *Table 3-4*.
`presentation.ordered_access=[true|false]`	See *PRESENTATION*.	See *Table 3-4*.
`partition.name=name0,name1,...`	See *PARTITION*.	See *Table 3-4*.

Table [endpoint/*] Configuration Options

Option	Description	Default
`domain=numeric`	Domain id for endpoint in range 0-231. Used to form GUID of endpoint.	Required
`participant=hexstring`	String of 12 hexadecimal digits. Used to form GUID of endpoint. All endpoints with the same domain/participant combination should be in the same process.	Required
`entity=hexstring`	String of 6 hexadecimal digits. Used to form GUID of endpoint. The combination of domain/participant/entity should be unique.	Required
`type=[reader|writer]`	Determines if the entity is a data reader or data writer.	Required
`topic=name`	Refers to a `[topic/*]` section.	Required
`datawriterqos=name`	Refers to a `[datawriterqos/*]` section.	See *Table 3-5*.
`datareaderqos=name`	Refers to a `[datareaderqos/*]` section.	See *Table 3-6*.
`publisherqos=name`	Refers to a `[publisherqos/*]` section.	See *Table 3-3*.
`subscriberqos=name`	Refers to a `[subscriberqos/*]` section.	See *Table 3-4*.
`config`	Refers to a transport configuration in a `[config/*]` section. This is used to determine a network address for the endpoint.	

1.7.4 Transport Configuration

Beginning with OpenDDS 3.0, a new transport configuration design has been implemented. The basic goals of this design were to:

- Allow simple deployments to ignore transport configuration and deploy using intelligent defaults (with no transport code required in the publisher or subscriber).
- Enable flexible deployment of applications using only configuration files and command line options.

- Allow deployments that mix transports within individual data writers and writers. Publishers and subscribers negotiate the appropriate transport implementation to use based on the details of the transport configuration, QoS settings, and network reachability.
- Support a broader range of application deployments in complex networks.
- Support optimized transport development (such as collocated and shared memory transports - note that these are not currently implemented).
- Integrate support for the `RELIABILITY` QoS policy with the underlying transport.
- Whenever possible, avoid dependence on the ACE Service Configurator and its configuration files.

Unfortunately, implementing these new capabilities involved breaking of backward compatibility with OpenDDS transport configuration code and files from previous releases. See docs/OpenDDS_3.0_Transition.txt for information on how to convert your existing application to use the new transport configuration design.

Overview

Transport Concepts

This section provides an overview of the concepts involved in transport configuration and how they interact.

Each data reader and writer uses a *Transport Configuration* consisting of an ordered set of *Transport Instances*. Each Transport Instance specifies a Transport Implementation (i.e. tcp, udp, multicast, shmem, or rtps_udp) and can customize the configuration parameters defined by that transport. Transport Configurations and Transport Instances are managed by the *Transport Registry* and can be created via configuration files or through programming APIs.

Transport Configurations can be specified for Domain Participants, Publishers, Subscribers, Data Writers, and Data Readers. When a Data Reader or Writer is enabled, it uses the most specific configuration it can locate, either directly bound to it or accessible through its parent entity. For example, if a Data Writer specifies a Transport Configuration, it always uses it. If the Data Writer does not specify a configuration, it tries to use that of its Publisher or Domain Participant in that order. If none of these entities have a transport configuration specified, the *Global Transport Configuration* is obtained from the Transport Registry. The Global Transport Configuration can be specified by the user via either configuration file, command line option, or a member function call on the Transport Registry. If not defined by the user, a default transport configuration is used which contains all available transport implementations with their default configuration parameters. If you don't specifically load or link in any other transport implementations, OpenDDS uses the tcp transport for all communication.

How OpenDDS Selects a Transport

Currently, the behavior for OpenDDS is that Data Writers actively connect to Data Readers, which are passively awaiting those connections. Data Readers "listen" for connections on each of the Transport Instances that are defined in their Transport Configuration. Data Writers use their Transport Instances to "connect" to those of the Data Readers. Because the logical connections discussed here don't correspond to the physical connections of the transport, OpenDDS often refers to them as *Data Links*.

When a Data Writer tries to connect to a Data Reader, it first attempts to see if there is an existing data link that it can use to communicate with that Data Reader. The Data Writer iterates (in definition order) through each of its Transport Instances and looks for an existing data link to the Transport Instances that the reader defined. If an existing data link is found it is used for all subsequent communication between the Data Writer and Reader.

If no existing data link is found, the Data Writer attempts to connect using the different Transport Instances in the order they are defined in its Transport Configuration. Any Transport Instances not "matched" by the other side are skipped. For example, if the writer specifies udp and tcp transport instances and the reader only specifies tcp, the udp transport instance is ignored. Matching algorithms may also be affected by QoS parameters, configuration of the instances, and

other specifics of the transport implementation. The first pair of Transport Instances that successfully "connect" results in a data link that is used for all subsequent data sample publication.

Configuration File Examples

The following examples explain the basic features of transport configuration via files and describe some common use cases. These are followed by full reference documentation for these features.

Single Transport Configuration

The simplest way to provide a transport configuration for your application is to use the OpenDDS configuration file. Here is a sample configuration file that might be used by an application running on a computer with two network interfaces that only wants to communicate using one of them:

```
[common]
DCPSGlobalTransportConfig=myconfig

[config/myconfig]
transports=mytcp

[transport/mytcp]
transport_type=tcp
local_address=myhost
```

This file does the following (starting from the bottom up):

1. Defines a transport instance named `mytcp` with a transport type of tcp and the local address specified as `myhost`, which is the host name corresponding to the network interface we want to use.
2. Defines a transport configuration named `myconfig` that uses the transport instance `mytcp` as its only transport.
3. Makes the transport configuration named `myconfig` the global transport configuration for all entities in this process.

A process using this configuration file utilizes our customized transport configuration for all Data Readers and Writers created by it (unless we specifically bind another configuration in the code as described in *Using Multiple Configurations*).

Using Mixed Transports

This example configures an application to primarily use multicast and to "fall back" to tcp when it is unable to use multicast. Here is the configuration file:

```
[common]
DCPSGlobalTransportConfig=myconfig

[config/myconfig]
transports=mymulticast,mytcp

[transport/mymulticast]
transport_type=multicast
```

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```
[transport/mytcp]
transport_type=tcp
```

The transport configuration named `myconfig` now includes two transport instances, `mymulticast` and `mytcp`. Neither of these transport instances specify any parameters besides transport_type, so they use the default configuration of these transport implementations. Users are free to use any of the transport-specific configuration parameters that are listed in the following reference sections.

Assuming that all participating processes use this configuration file, the application attempts to use multicast to initiate communication between data writers and readers. If the initial multicast communication fails for any reason (possibly because an intervening router is not passing multicast traffic) tcp is used to initiate the connection.

Using Multiple Configurations

For many applications, one configuration is not equally applicable to all communication within a given process. These applications must create multiple Transport Configurations and then assign them to the different entities of the process.

For this example consider an application hosted on a computer with two network interfaces that requires communication of some data over one interface and the remainder over the other interface. Here is our configuration file:

```
[common]
DCPSGlobalTransportConfig=config_a

[config/config_a]
transports=tcp_a

[config/config_b]
transports=tcp_b

[transport/tcp_a]
transport_type=tcp
local_address=hosta

[transport/tcp_b]
transport_type=tcp
local_address=hostb
```

Assuming `hosta` and `hostb` are the host names assigned to the two network interfaces, we now have separate configurations that can use tcp on the respective networks. The above file sets the "`A`" side configuration as the default, meaning we must manually bind any entities we want to use the other side to the "`B`" side configuration.

OpenDDS provides two mechanisms to assign configurations to entities:

- Via source code by attaching a configuration to an entity (reader, writer, publisher, subscriber, or domain participant)
- Via configuration file by associating a configuration with a domain

Here is the source code mechanism (using a domain participant):

```
DDS::DomainParticipant_var dp =
        dpf->create_participant(MY_DOMAIN,
                                PARTICIPANT_QOS_DEFAULT,
                                DDS::DomainParticipantListener::_nil(),
```

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```
                                    OpenDDS::DCPS::DEFAULT_STATUS_MASK);

OpenDDS::DCPS::TransportRegistry::instance()->bind_config("config_b", dp);
```

Any Data Writers or Readers owned by this Domain Participant should now use the "B" side configuration.

Note: When directly binding a configuration to a data writer or reader, the `bind_config` call must occur before the reader or writer is enabled. This is not an issue when binding configurations to Domain Participants, Publishers, or Subscribers. See *ENTITY_FACTORY* for details on how to create entities that are not enabled.

Transport Registry Example

OpenDDS allows developers to also define transport configurations and instances via C++ APIs. The `OpenDDS::DCPS::TransportRegistry` class is used to construct `OpenDDS::DCPS::TransportConfig` and `OpenDDS::DCPS::TransportInst` objects. The `TransportConfig` and `TransportInst` classes contain public data member corresponding to the options defined below. This section contains the code equivalent of the simple transport configuration file described in . First, we need to include the correct header files:

```
#include <dds/DCPS/transport/framework/TransportRegistry.h>
#include <dds/DCPS/transport/framework/TransportConfig.h>
#include <dds/DCPS/transport/framework/TransportInst.h>
#include <dds/DCPS/transport/tcp/TcpInst.h>

using namespace OpenDDS::DCPS;
```

Next we create the transport configuration, create the transport instance, configure the transport instance, and then add the instance to the configuration's collection of instances:

```
TransportConfig_rch cfg = TheTransportRegistry->create_config("myconfig");
TransportInst_rch inst = TheTransportRegistry->create_inst("mytcp", // name
                                                           "tcp");  // type

// Must cast to TcpInst to get access to transport-specific options
TcpInst_rch tcp_inst = dynamic_rchandle_cast<TcpInst>(inst);
tcp_inst->local_address_str_ = "myhost";

// Add the inst to the config
cfg->instances_.push_back(inst);
```

Lastly, we can make our newly defined transport configuration the global transport configuration:

```
TheTransportRegistry->global_config(cfg);
```

This code should be executed before any Data Readers or Writers are enabled.

See the header files included above for the full list of public data members and member functions that can be used. See the option descriptions in the following sections for a full understanding of the semantics of these settings.

Stepping back and comparing this code to the original configuration file from, the configuration file is much simpler than the corresponding C++ code and has the added advantage of being modifiable at run-time. It is easy to see why we recommend that almost all applications should use the configuration file mechanism for transport configuration.

Transport Configuration Options

Transport Configurations are specified in the OpenDDS configuration file via sections with the format of `[config/<name>]`, where `<name>` is a unique name for that configuration within that process. The following table summarizes the options when specifying a transport configuration:

Table Transport Configuration Options

Option	Description	Default
`transports=inst1[, inst2][, ...]`	Ordered list of transport instance names that this configuration will utilize. This field is required for every transport configuration.	none
`swap_bytes=[0|1]`	A value of 0 causes DDS to serialize data in the source machine's native endianness; a value of 1 causes DDS to serialize data in the opposite endianness. The receiving side will adjust the data for its endianness so there is no need to match this option between machines. The purpose of this option is to allow the developer to decide which side will make the endian adjustment, if necessary.	`0`
`passive_connect_duration=[milliseconds]`	Time duration (in milliseconds) for initial passive connection establishment. A value of zero would wait indefinitely (not recommended).	`10000` (10 sec)

The `passive_connect_duration` option is typically set to a non-zero, positive integer. Without a suitable connection timeout, the subscriber endpoint can potentially enter a state of deadlock while waiting for the remote side to initiate a connection. Because there can be multiple transport instances on both the publisher and subscriber side, this option needs to be set to a high enough value to allow the publisher to iterate through the combinations until it succeeds.

In addition to the user-defined configurations, OpenDDS can implicitly define two transport configurations. The first is the default configuration and includes all transport implementations that are linked into the process. If none are found, then only tcp is used. Each of these transport instances uses the default configuration for that transport implementation. This is the global transport configuration used when the user does not define one.

The second implicit transport configuration is defined whenever an OpenDDS configuration file is used. It is given the same name as the file being read and includes all the transport instances defined in that file, in the alphabetical order of their names. The user can most easily utilize this configuration by specifying the `DCPSGlobalTransportConfiguration=$file` option in the same file. The $file value always binds to the implicit file configuration of the current file.

Transport Instance Options

Transport Instances are specified in the OpenDDS configuration file via sections with the format of `[transport/<name>]`, where `<name>` is a unique name for that instance within that process. Each Transport Instance must specify the `transport_type` option with a valid transport implementation type. The following sections list the other options that can be specified, starting with those options common to all transport types and following with those specific to each transport type.

When using dynamic libraries, the OpenDDS transport libraries are dynamically loaded whenever an instance of that type is defined in a configuration file. When using custom transport implementations or static linking, the application developer is responsible for ensuring that the transport implementation code is linked with their executables.

Configuration Options Common to All Transports

The following table summarizes the transport configuration options that are common to all transports:

Table Common Transport Configuration Options

Option	Description	Default
`transport_type=type`	Type of the transport; the list of available transports can be extended programmatically via the transport framework. tcp, udp, multicast, shmem, and rtps_udp are included with OpenDDS.	none
`queue_messages_per_pool=n`	When backpressure is detected, messages to be sent are queued. When the message queue must grow, it grows by this number.	`10`
`queue_initial_pools=n`	The initial number of pools for the backpressure queue. The default settings of the two backpressure queue values preallocate space for 50 messages (5 pools of 10 messages).	`5`
`max_packet_size=n`	The maximum size of a transport packet, including its transport header, sample header, and sample data.	`2147481599`
`max_samples_per_packet=n`	Maximum number of samples in a transport packet.	`10`
`optimum_packet_size=n`	Transport packets greater than this size will be sent over the wire even if there are still queued samples to be sent. This value may impact performance depending on your network configuration and application nature.	`4096` (4 KiB)
`thread_per_connection=[0|1]`	Enable or disable the thread per connection send strategy. By default, this option is disabled.	`0`
`datalink_release_delay=msec`	The datalink release_delay is the delay (in milliseconds) for datalink release after no associations. Increasing this value may reduce the overhead of re-establishment when reader/writer associations are added and removed frequently.	`10000` (10 sec)
`receive_preallocated_message_blocks=n`	Set to a positive number to override the number of message blocks that the allocator reserves memory for eagerly (on startup).	`0` (use default)
`receive_preallocated_data_blocks=n`	Set to a positive number to override the number of data blocks that the allocator reserves memory for eagerly (on startup).	`0` (use default)

Enabling the `thread_per_connection` option will increase performance when writing to multiple data readers on different process as long as the overhead of thread context switching does not outweigh the benefits of parallel writes. This balance of network performance to context switching overhead is best determined by experimenting. If a machine has multiple network cards, it may improve performance by creating a transport for each network card.

TCP/IP Transport Configuration Options

There are a number of configurable options for the tcp transport. A properly configured transport provides added resilience to underlying stack disturbances. Almost all of the options available to customize the connection and reconnection strategies have reasonable defaults, but ultimately these values should to be chosen based upon a careful study of the quality of the network and the desired QoS in the specific DDS application and target environment.

The local_address option is used by the peer to establish a connection. By default, the TCP transport selects an ephemeral port number on the NIC with the FQDN (fully qualified domain name) resolved. Therefore, you may wish to explicitly set the address if you have multiple NICs or if you wish to specify the port number. When you configure inter-host communication, the local_address can not be localhost and should be configured with an externally visible address (i.e. 192.168.0.2), or you can leave it unspecified in which case the FQDN and an ephemeral port will be used.

FQDN resolution is dependent upon system configuration. In the absence of a FQDN (e.g. `example.opendds.org`),

OpenDDS will use any discovered short names (e.g. example). If that fails, it will use the name resolved from the loopback address (e.g. localhost).

Note: OpenDDS IPv6 support requires that the underlying ACE/TAO components be built with IPv6 support enabled. The local_address needs to be an IPv6 decimal address or a FQDN with port number. The FQDN must be resolvable to an IPv6 address.

The `tcp` transport exists as an independent library and needs to be linked in order to use it. When using a dynamically-linked build, OpenDDS automatically loads the transport library whenever it is referenced in a configuration file or as the default transport when no other transports are specified.

When the `tcp` library is built statically, your application must link directly against the library. To do this, your application must first include the proper header for service initialization: `<dds/DCPS/transport/tcp/Tcp.h>`.

You can also configure the publisher and subscriber transport implementations programatically, as described in *Transport Registry Example*. Configuring subscribers and publishers should be identical, but different addresses/ports should be assigned to each Transport Instance.

The following table summarizes the transport configuration options that are unique to the `tcp` transport:

Table TCP/IP Configuration Options

Option	Description	Default
`active_connect_timeout_msec`	The time period (milliseconds) for the active connection side to wait for the connection to be established. If not connected within this period then the on_publication_lost() callbacks will be called.	`5000` (5 sec)
`conn_retry_attempts`	Number of reconnect attempts before giving up and calling the on_publication_lost() and on_subscription_lost() callbacks.	`3`
`conn_retry_initial_delay`	Initial delay (milliseconds) for reconnect attempt. As soon as a lost connection is detected, a reconnect is attempted. If this reconnect fails, a second attempt is made after this specified delay.	`500`
`conn_retry_backoff_multiplier`	The backoff multiplier for connection tries. After the initial delay described above, subsequent delays are determined by the product of this multiplier and the previous delay. For example, with a conn_retry_initial_delay of 500 and a conn_retry_backoff_multiplier of 1.5, the second reconnect attempt will be 0.5 seconds after the first retry connect fails; the third attempt will be 0.75 seconds after the second retry connect fails; the fourth attempt will be 1.125 seconds after the third retry connect fails.	`2.0`
`enable_nagle_algorithm`	Enable or disable the TCP Nagle's algorithm. By default, it is disabled. Enabling the Nagle's algorithm may increase throughput at the expense of increased latency.	`0`
`local_address`	Host and port of the connection acceptor. The default value is the FQDN and port 0, which means the OS will choose the port. If only the host is specified and the port number is omitted, the ':' is still required on the host specifier.	`fqdn:0`
`max_output_pause_period`	Maximum period (milliseconds) of not being able to send queued messages. If there are samples queued and no output for longer than this period then the connection will be closed and `on_*_lost()` callbacks will be called. The default value of zero means that this check is not made.	`0`
`passive_reconnect_duration`	The time period (milliseconds) for the passive connection side to wait for the connection to be reconnected. If not reconnected within this period then the `on_*_lost()` callbacks will be called.	`2000` (2 sec)
`pub_address`	Override the address sent to peers with the configured string. This can be used for firewall traversal and other advanced network configurations.	

TCP/IP Reconnection Options

When a TCP/IP connection gets closed OpenDDS attempts to reconnect. The reconnection process is (a successful reconnect ends this sequence):

- Upon detecting a lost connection immediately attempt reconnect.
- If that fails, then wait `conn_retry_initial_delay` milliseconds and attempt reconnect.
- While we have not tried more than `conn_retry_attempts`, wait (previous wait time * `conn_retry_backoff_multiplier`) milliseconds and attempt to reconnect.

UDP/IP Transport Configuration Options

The `udp` transport is a bare bones transport that supports best-effort delivery only. Like `tcp`, `local_address`, it supports both IPv4 and IPv6 addresses.

`udp` exists as an independent library and therefore needs to be linked and configured like other transport libraries. When using a dynamic library build, OpenDDS automatically loads the library when it is referenced in a configuration file. When the `udp` library is built statically, your application must link directly against the library. Additionally, your application must also include the proper header for service initialization: <dds/DCPS/transport/udp/Udp.h>.

The following table summarizes the transport configuration options that are unique to the `udp` transport:

Table UDP/IP Configuration Options

Option	Description	Default
`local_address`	Host and port of the listening socket. Defaults to a value picked by the underlying OS. The port can be omitted, in which case the value should end in ":".	`fqdn:0`
`send_buffer_size`	Local send buffer size in bytes for UDP payload.	Platform value of `ACE_DEFAULT_MAX_SOCKET_BUFSIZ`
`rcv_buffer_size`	Local receive buffer size in bytes for UDP payload.	Platform value of `ACE_DEFAULT_MAX_SOCKET_BUFSIZ`

IP Multicast Transport Configuration Options

The `multicast` transport provides unified support for best-effort and reliable delivery based on a transport configuration parameter.

Best-effort delivery imposes the least amount of overhead as data is exchanged between peers, however it does not provide any guarantee of delivery. Data may be lost due to unresponsive or unreachable peers or received in duplicate.

Reliable delivery provides for guaranteed delivery of data to associated peers with no duplication at the cost of additional processing and bandwidth. Reliable delivery is achieved through two primary mechanisms: 2-way peer handshaking and negative acknowledgment of missing data. Each of these mechanisms are bounded to ensure deterministic behavior and is configurable to ensure the broadest applicability possible for user environments.

`multicast` supports a number of configuration options:

The `default_to_ipv6` and `port_offset` options affect how default multicast group addresses are selected. If `default_to_ipv6` is set to "1" (enabled), then the default IPv6 address will be used (`[FF01::80]`). The `port_offset` option determines the default port used when the group address is not set and defaults to `49152`.

The `group_address` option may be used to manually define a multicast group to join to exchange data. Both IPv4 and IPv6 addresses are supported. As with `tcp`, OpenDDS IPv6 support requires that the underlying ACE/TAO components be built with IPv6 support enabled.

On hosts with multiple network interfaces, it may be necessary to specify that the multicast group should be joined on a specific interface. The option `local_address` can be set to the IP address of the local interface that will receive multicast traffic.

If reliable delivery is desired, the `reliable` option may be specified (the default). The remainder of configuration options affect the reliability mechanisms used by the `multicast` transport:

The `syn_backoff`, `syn_interval`, and `syn_timeout` configuration options affect the handshaking mechanism. `syn_backoff` is the exponential base used when calculating the backoff delay between retries. The `syn_interval` option defines the minimum number of milliseconds to wait before retrying a handshake. The `syn_timeout` defines the maximum number of milliseconds to wait before giving up on the handshake.

Given the values of `syn_backoff` and `syn_interval`, it is possible to calculate the delays between handshake attempts (bounded by `syn_timeout`):

```
delay = syn_interval * syn_backoff ^ number_of_retries
```

For example, if the default configuration options are assumed, the delays between handshake attempts would be: 0, 250, 1000, 2000, 4000, and 8000 milliseconds respectively.

The `nak_depth`, `nak_interval`, and `nak_timeout` configuration options affect the Negative Acknowledgment mechanism. `nak_depth` determines the maximum number of datagrams retained by the transport to service incoming repair requests. The `nak_interval` configuration option defines the minimum number of milliseconds to wait between repair requests. This interval is randomized to prevent potential collisions between similarly associated peers. The *maximum* delay between repair requests is bounded to double the minimum value.

The `nak_timeout` configuration option defines the maximum amount of time to wait on a repair request before giving up.

The `nak_delay_intervals` configuration option defines the number of intervals between naks after the initial nak.

The `nak_max` configuration option limits the maximum number of times a missing sample will be nak'ed. Use this option so that naks will be not be sent repeatedly for unrecoverable packets before `nak_timeout`.

Currently, there are a couple of requirements above and beyond those already mandated by the ETF when using this transport:

- *At most*, one DDS domain may be used per multicast group;
- A given participant may only have a single `multicast` transport attached per multicast group; if you wish to send and receive samples on the same multicast group in the same process, independent participants must be used.

`multicast` exists as an independent library and therefore needs to be linked and configured like other transport libraries. When using a dynamic library build, OpenDDS automatically loads the library when it is referenced in a configuration file. When the `multicast` library is built statically, your application must link directly against the library. Additionally, your application must also include the proper header for service initialization: `<dds/DCPS/transport/multicast/Multicast.h>`.

The following table summarizes the transport configuration options that are unique to the `multicast` transport:

Table IP Multicast Configuration Options

Option	Description	Default
default_to_ipv6=[0|1]	Enable IPv6 default group address selection. By default, this option is disabled.	0
group_address=host:port	The multicast group to join to send/receive data.	224.0.0.128:<port>, [FF01::80]:<port>
local_address=host:port	Use the address of a local network interface which is used to join the multicast group.	
nak_delay_intervals=n	The number of intervals between naks after the initial nak.	4
nak_depth=n	The number of datagrams to retain in order to service repair requests (reliable only).	32
nak_interval=msec	The minimum number of milliseconds to wait between repair requests (reliable only).	500
nak_max=n	The maximum number of times a missing sample will be nak'ed.	3
nak_timeout=msec	The maximum number of milliseconds to wait before giving up on a repair response (reliable only).	30000 (30 sec)
port_offset=n	Used to set the port number when not specifying a group address. When a group address is specified, the port number within it is used. If no group address is specified, the port offset is used as a port number. This value should not be set less than 49152.	49152
rcv_buffer_size=n	The size of the socket receive buffer in bytes. A value of zero indicates that the system default value is used.	0
reliable=[0|1]	Enables reliable communication.	1
syn_backoff=n	The exponential base used during handshake retries; smaller values yield shorter delays between attempts.	2.0
syn_interval=msec	The minimum number of milliseconds to wait between handshake attempts during association.	250
syn_timeout=msec	The maximum number of milliseconds to wait before giving up on a handshake response during association. The default is 30 seconds.	30000 (30 sec)
ttl=n	The value of the time-to-live (ttl) field of any datagrams sent. The default value of one means that all data is restricted to the local network.	1
async_send=[0|1]	Send datagrams using Async I/O (on platforms that support it efficiently).	

RTPS_UDP Transport Configuration Options

The OpenDDS implementation of the OMG DDSI-RTPS (`formal/2014-09-01`) specification includes the transport protocols necessary to fulfill the specification requirements and those needed to be interoperable with other DDS implementations. The `rtps_udp` transport is one of the pluggable transports available to a developer and is necessary for interoperable communication between implementations. This section will discuss the options available to the developer for configuring OpenDDS to use this transport.

To provide an RTPS variant of the single configuration example from *Single Transport Configuration*, the configuration file below simply introduces the `myrtps` transport and modifies the `transport_type` property to the value `rtps_udp`. All other items remain the same.

```
[common]
DCPSGlobalTransportConfig=myconfig

[config/myconfig]
transports=myrtps

[transport/myrtps]
transport_type=rtps_udp
local_address=myhost
```

To extend our examples to a mixed transport configuration as shown in *Using Mixed Transports*, below shows the use of an `rtps_udp` transport mixed with a `tcp` transport. The interesting pattern that this allows for is a deployed OpenDDS application that can be, for example, communicating using `tcp` with other OpenDDS participants while communicating in an interoperability configuration with a non-OpenDDS participant using `rtps_udp`.

```
[common]
DCPSGlobalTransportConfig=myconfig

[config/myconfig]
transports=mytcp,myrtps

[transport/myrtps]
transport_type=rtps_udp

[transport/mytcp]
transport_type=tcp
```

Some implementation notes related to using the `rtps_udp` transport protocol are as follows:

1. `WRITER_DATA_LIFECYCLE` (8.7.2.2.7) notes that the same Data sub-message should dispose and unregister an instance. OpenDDS may use two Data sub-messages.
2. RTPS transport instances can not be shared by different Domain Participants.
3. Transport auto-selection (negotiation) is partially supported with RTPS such that the `rtps_udp` transport goes through a handshaking phase only in reliable mode.

Table RTPS_UDP Configuration Options

Option	Description	Default
use_multicast=[0|1]	The rtps_udp transport can use Unicast or Multicast. When set to 0 (false) the transport uses Unicast, otherwise a value of 1 (true) will use Multicast.	1
multicast_group_address =network_address	When the transport is set to multicast, this is the multicast network address that should be used. If no port is specified for the network address, port 7401 will be used.	239.255.0.2:7401
multicast_interface=iface	Specifies the network interface to be used by this transport instance. This uses a platform-specific format that identifies the network interface. On Linux systems this would be something like eth0. If this value is not configured, the Common Configuration value DCPSDefaultAddress is used to set the multicast interface.	The system default interface is used
local_address=addr:[port]	Bind the socket to the given address and port. Port can be omitted but the trailing ":" is required.	System default
ipv6_local_address = addr:[port]	Bind the socket to the given address and port. Port can be omitted but the trailing ":" is required.	System default
advertised_address= addr:[port]	Set the address advertised by the transport. Typically used when the participant is behind a firewall or NAT. Port can be omitted but the trailing ":" is required.	
ipv6_advertised_address = addr:[port]	Set the address advertised by the transport. Typically used when the participant is behind a firewall or NAT. Port can be omitted but the trailing ":" is required.	
send_delay=*msec*	Time in milliseconds for an RTPS Writer to wait before sending data.	10
nak_depth=n	The number of data samples to retain in order to service repair requests (reliable only).	32
nak_response_delay=*msec*	Protocol tuning parameter that allows the RTPS Writer to delay the response (expressed in milliseconds) to a request for data from a negative acknowledgment. (see table 8.47 in the OMG DDSI-RTPS specification)	200
heartbeat_period=*msec*	Protocol tuning parameter that specifies in milliseconds how often an RTPS Writer announces the availability of data. (see table 8.47 in the OMG DDSI-RTPS specification)	1000 (1 sec)
ResponsiveMode =[0|1]	Causes reliable writers and readers to send additional messages which may reduce latency.	0
max_message_size=n	The maximum message size. The default is the maximum UDP message size.	65466
ttl=n	The value of the time-to-live (ttl) field of any multicast datagrams sent. This value specifies the number of hops the datagram will traverse before being discarded by the network. The default value of 1 means that all data is restricted to the local network subnet.	1
DataRtpsRelayAddress=host:port	Address and port of the RtpsRelay for RTPS messages. See *The RtpsRelay*.	
RtpsRelayOnly=[0|1]	Send RTPS message to the RtpsRelay (for debugging). See *The RtpsRelay*.	0
UseRtpsRelay=[0|1]	Send messages to the RtpsRelay. Messages will only be sent if DataRtpsRelayAddress is set. See *The RtpsRelay*.	0
DataStunServerAddress=host:port	Address and port of the STUN server to use for RTPS when using ICE. See *Interactive Connectivity Establishment (ICE) for RTPS*.	
UseIce=[0|1]	Enable or disable ICE for this transport instance. See *Interactive Connectivity Establishment (ICE) for RTPS*.	0

Additional RTPS_UDP Features

The RTPS_UDP transport implementation has capabilities that can only be enabled by API. These features cannot be enabled using configuration files.

The `RtpsUdpInst` class has a method `count_messages(bool flag)` via inheritance from `TransportInst`. With count_messages enabled, the transport will track various counters and make them available to the application using the method `append_transport_statistics(TransportStatisticsSequence& seq)`. The elements of that sequence are defined in IDL: `OpenDDS::DCPS::TransportStatistics` and detailed in the tables below.

TransportStatistics

Type	Name	Description
string	transport	The name of the transport.
MessageCountSequence	message_count	Set of message counts grouped by remote address. See the MessageCount table below.
GuidCountSequence	writer_resend_count	Map of counts indicating how many times a local writer has resent a data sample. Each element in the sequence is a structure containing a GUID and a count.
GuidCountSequence	reader_nack_count	Map of counts indicating how many times a local reader has requested a sample to be resent.

MessageCount

Type	Name	Description
Locator_t	locator	A byte array containing an IPv4 or IPv6 address.
MessageCountKind	kind	Key indicating the type of message count for transports that use multiple protocols.
boolean	relay	Indicates that the locator is a relay.
unsigned long	send_count	Number of messages sent to the locator.
unsigned long	send_bytes	Number of bytes sent to the locator.
unsigned long	send_fail_count	Number of sends directed at the locator that failed.
unsigned long	send_fail_bytes	Number of bytes directed at the locator that failed.
unsigned long	recv_count	Number of messages received from the locator.
unsigned long	recv_bytes	Number of bytes received from the locator.

Shared-Memory Transport Configuration Options

The following table summarizes the transport configuration options that are unique to the `shmem` transport. This transport type is supported Unix-like platforms with POSIX/XSI shared memory and on Windows platforms. The shared memory transport type can only provide communication between transport instances on the same host. As part of transport negotiation (*Using Mixed Transports*), if there are multiple transport instances available for communication between hosts, the shared memory transport instances will be skipped so that other types can be used.

Table Shared-Memory Transport Configuration Options

Option	Description	Default
`pool_size=bytes`	The size of the single shared-memory pool allocated.	`16777216 (16 MiB)`
`datalink_control_size=bytes`	The size of the control area allocated for each data link. This allocation comes out of the shared-memory pool defined by pool_size.	`4096 (4 KiB)`
`host_name=host`	Override the host name used to identify the host machine.	Uses fully qualified domain name

1.7.5 Discovery and Transport Configuration Templates

OpenDDS supports dynamic configuration of RTPS discovery and transports by means of configuration templates in OpenDDS configuration files. This feature adds 3 optional file sections, `[DomainRange]`, `[transport_template]`, and `[Customization]`, as well as a new transport property, `instantiation_rule`, which specifies when transport instances are created. Configuration templates are processed at application startup; however, creation of domain, discovery, and transport objects is deferred until a participant is created in a corresponding domain.

A traditional OpenDDS application with 5 participants in different domains will have a config.ini file with 5 separate but nearly identical `[domain]` sections. The same functionality can be accomplished with a single `[DomainRange/1-5]` section using templates.

`[Customization]` sections can be used in `[rtps_discovery]` template sections to add the domain ID to the multicast override address. This creates a unique address for each domain. `[Customization]` sections can also be used with `[transport_template]` sections to modify the transport multicast group addresses and address ports by domain ID. The `[transport_template]` rule, `instantiation_rule=per_participant`, configures OpenDDS to create a separate transport instance for each domain participant. This allows applications to have multiple participants per domain when using RTPS.

Configuring Discovery for a Set of Similar Domains

Domain range sections are similar to domain sections and use the same configuration properties with 3 notable differences.

- Domain ranges must have a beginning and end domain, such as

  `[DomainRange/1-5]`.

- Domain ranges use the `DiscoveryTemplate` property rather than the `DiscoveryConfig` property to denote the corresponding `[rtps_discovery]` section.
- Domain ranges can have an optional `Customization` property that maps to a named `[Customization]` section

See *Example Config.ini* for a `[DomainRange]` example.

Configuring a Set of Similar Transports

Transport template sections are specified as `[transport_template/name]`. They are similar to `[transport]` sections and use the same configuration properties as well as an optional `Customization` property that maps to a named `[Customization]` section. To associate a transport template with a domain range in a configuration file, set the `DCPSGlobalTransportConfig` property in the `[common]` section to the name of the `[config]` whose transports property is the name of the transport template. For example, for a global config setting

```
[common]
DCPSGlobalTransportConfig=primary_config
```

a corresponding config could be

```
[config/primary_config]
transports=auto_config_rtps
```

and the partial transport template would be

```
[transport_template/auto_config_rtps]
transport_type=rtps_udp
```

Domain participants that belong to a domain that is configured by a template can bind to non-global transport configurations using the `bind_config` function. See *Using Multiple Configurations* for a discussion of `bind_config`.

If the `[transport_template]` sets the property `instantiation_rule=per_participant`, a separate transport instance will be created for each participant in the domain.

See *Example Config.ini* for a `[transport_template]` example.

Adding Customizations

`[Customization]` sections can modify the InteropMulticastOverride property in [rtps_discovery] sections and the multicast_group_address property in `[transport_template]` sections.

- `InteropMulticastOverride=AddDomainId` adds the domain id to the last octet of the `InteropMulticastOverride` address
- `multicast_group_address=add_domain_id_to_ip_addr` adds the domain ID to the last octet of the multicast group address
- `multicast_group_address=add_domain_id_to_port` uses the domain ID in the port calculation for the multicast group address

Example Config.ini

The following is an example configuration file for domains 2 through 10. It includes customizations to add the domain ID to the discovery `InteropMulticastOverride` address and customizations to add the domain ID to the transport's multicast group IP address and port.

```
[common]
DCPSGlobalTransportConfig=the_config

[DomainRange/2-10]
DiscoveryTemplate=DiscoveryConfigTemplate

[Customization/discovery_customization]
InteropMulticastOverride=AddDomainId

[Customization/transport_customization]
multicast_group_address=add_domain_id_to_ip_addr,add_domain_id_to_port

[rtps_discovery/DiscoveryConfigTemplate]
InteropMulticastOverride=239.255.4.0
Customization=discovery_customization
SedpMulticast=1
```

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```
[config/the_config]
transports=auto_config_rtps

[transport_template/auto_config_rtps]
transport_type=rtps_udp
instantiation_rule=per_participant
Customization=transport_customization
multicast_group_address=239.255.2.0
```

1.7.6 Logging

By default, the OpenDDS framework will only log serious errors and warnings that can't be conveyed to the user in the API. An OpenDDS user may increase the amount of logging via the log level and debug logging via controls at the DCPS, Transport, or Security layers.

The default destination of these log messages is the process's standard error stream. See *Table 7-2 Common Configuration Options* for options controlling the destination and formatting of log messages.

The highest level logging is controlled by the general log levels listed in the following table.

Table : Log Levels

Level	Values	Description
Error	DCPSLogLevel: error log_level: Log_Level::Error ACE_Log_Priority:LM_ERROR	Logs issues that may prevent OpenDDS from functioning properly or functioning as configured.
Warning	DCPSLogLevel: warning log_level: Log_Level::Warning ACE_Log_Priority:LM_WARNING	Log issues that should probably be addressed, but don't prevent OpenDDS from functioning. This is the default.
Notice	DCPSLogLevel: notice log_level: Log_Level::Notice ACE_Log_Priority:LM_NOTICE	Logs details of issues that are returned to the user via the API, for example through a DDS::ReturnCode_t.
Info	DCPSLogLevel: info log_level: Log_Level::Info ACE_Log_Priority:LM_INFO	Logs a small amount of basic information, such as the version of OpenDDS being used.
Debug	DCPSLogLevel: debug log_level: Log_Level::Debug ACE_Log_Priority:LM_DEBUG	This level doesn't directly control any logging but will enable at least DCPS and security debug level 1. For backwards compatibility, setting DCPS debug logging to greater than zero will set this log level. Setting the log level to below this level will disable all debug logging.

The log level can be set a number of ways. To do it with command line arguments, pass:

```
-DCPSLogLevel notice
```

Using a configuration file option is similar:

```
DCPSLogLevel=notice
```

Doing this from code can be done using an enumerator or a string:

```
OpenDDS::DCPS::log_level.set(OpenDDS::DCPS::LogLevel::Notice);
OpenDDS::DCPS::log_level.set_from_string("notice");
```

Passing invalid levels to the text-based methods will cause warning messages to be logged unconditionally, but will not cause the `DomainParticipantFactory` to fail to initialize.

DCPS Layer Debug Logging

Debug logging in the DCPS layer of OpenDDS is controlled by the `DCPSDebugLevel` configuration option and command-line option. It can also be set in application code using:

```
OpenDDS::DCPS::set_DCPS_debug_level(level)
```

The *level* defaults to a value of 0 and has values of 0 to 10 as defined below:

- 0 – debug logging is disabled
- 1 - logs that should happen once per process
- 2 - logs that should happen once per DDS entity
- 4 - logs that are related to administrative interfaces
- 6 - logs that should happen every Nth sample write/read
- 8 - logs that should happen once per sample write/read
- 10 - logs that may happen more than once per sample write/read

Transport Layer Debug Logging

OpenDDS transport debug layer logging is controlled via the `DCPSTransportDebugLevel` configuration option. For example, to add transport layer logging to any OpenDDS application that uses `TheParticipantFactoryWithArgs`, add the following option to the command line:

```
-DCPSTransportDebugLevel level
```

The transport layer logging level can also be configured by setting the variable:

```
OpenDDS::DCPS::Transport_debug_level = level;
```

Valid transport logging levels range from 0 to 5 with increasing verbosity of output.

Note: Transport logging level 6 is available to generate system trace logs. Using this level is not recommended as the amount of data generated can be overwhelming and is mostly of interest only to OpenDDS developers. Setting the logging level to 6 requires defining the `DDS_BLD_DEBUG_LEVEL` macro to 6 and rebuilding OpenDDS.

There are additional debug logging options available through the `transport_debug` object that are separate from the logging controlled by the transport debug level. For the moment this can only be configured using C++; for example:

```
OpenDDS::DCPS::transport_debug.log_progress = true;
```

Table Transport Debug Logging Categories

Option	Description
log_progress	Log progress for RTPS entity discovery and association.
log_dropped_messages	Log received RTPS messages that were dropped.
log_nonfinal_messages	Log non-final RTPS messages send or received. Useful to gauge lost messages and resends.
log_fragment_storage	Log fragment reassembly process for transports where that applies. Also logged when the transport debug level is set to the most verbose.
log_remote_counts	Log number of associations and pending associations of RTPS entities.

Security Debug Logging

When OpenDDS is compiled with security enabled, debug logging for security can be enabled using DCPSecurityDebug (*Table 7-2 Common Configuration Options*). Security logging is divided into categories, although DCPSSecurityDebugLevel is also provided, which controls the categories in a similar manner and using the same scale as DCPSDebugLevel.

Table Security Debug Logging Categories

Option	Debug Level	Description
N/A	0	The default. Security related messages are not logged.
access_error	1	Log errors from permission and governance file parsing.
new_entity_error	1	Log security-related errors that prevented a DDS entity from being created.
cleanup_error	1	Log errors from cleaning up DDS entities in the security plugins.
access_warn	2	Log warnings from permission and governance file parsing.
auth_warn	3	Log warnings from the authentication and handshake that happen when two secure participants discover each other.
encdec_error	3	Log errors from the encryption and decryption of RTPS messages.
new_entity_warn	3	Log security-related warnings from creating a DDS entity.
bookkeeping	4	Log generation of crypto handles and keys for local DDS entities and tracking crypto handles and keys for remote DDS entities.
auth_debug	4	Log debug information from the authentication and handshake that happen when two secure participants discover each other.
encdec_warn	4	Log warnings from the encryption and decryption of RTPS messages.
encdec_debug	8	Log debug information from the encryption and decryption of RTPS messages.
showkeys	9	Log the whole key when generating it, receiving it, and using it.
chlookup	10	Very verbosely prints the steps being taken when looking up a crypto handle for decrypting. This is most useful to see what keys a participant has.
all	10	Enable all the security related logging.

Categories are passed to DCPSecurityDebug using a comma limited list:

```
-DCPSSecurityDebug=access_warn,showkeys
```

Unknown categories will cause warning messages, but will not cause the DomainParticipantFactory to fail to initialize.

Like the other debug levels, security logging can also be programmatically configured. All the following are equivalent:

```
OpenDDS::DCPS::security_debug.access_warn = true;
OpenDDS::DCPS::security_debug.set_debug_level(1);
OpenDDS::DCPS::security_debug.parse_flags(ACE_TEXT("access_warn"));
```

1.8 opendds_idl

opendds_idl is one of the code generators used in the process of building OpenDDS and OpenDDS applications. It can be used in a number of different ways to customize how source code is generated from IDL files. See *Processing the IDL* for an overview of the default usage pattern.

The OpenDDS IDL compiler is invoked using the `opendds_idl` executable, located in bin/ (on the `PATH`). It parses a single IDL file and generates the serialization and key support code that OpenDDS requires to marshal and demarshal the types described in the IDL file, as well as the type support code for the data readers and writers. For each IDL file processed, such as `xyz.idl`, it generates three files: `xyzTypeSupport.idl`, `xyzTypeSupportImpl.h`, and `xyzTypeSupportImpl.cpp`. In the typical usage, `opendds_idl` is passed a number of options and the IDL file name as a parameter. For example,

```
opendds_idl [options...] Foo.idl
```

Subsequent sections describe all of the command-line options and the ways that `opendds_idl` can be used to generate alternate mappings.

1.8.1 opendds_idl Command Line Options

The following table summarizes the options supported by `opendds_idl`.

Table opendds_idl Command Line Options

Option	Description	Default
`-v`	Enables verbose execution	Quiet execution
`-h`	Prints a help (usage) message and exits	N/A
`-V`	Prints version numbers of both TAO and OpenDDS	N/A
`--idl-version VERSION`	Set the version of IDL to use.	4
`--list-idl-versions`	List the versions of IDL at least partially supported.	N/A
`--syntax-only`	Just check syntax of input files, exiting after parsing.	Goes on to generate code
`-Wb,export_macro=macro`	Export macro used for generating C++ implementation code. `--export` is equivalent to `-Wb, export_macro`	No export macro used
`-Wb,export_include=file`	Additional header to `#include` in generated code — this header `#defines` the export macro	No additional include
`-Wb,pch_include=file`	Pre-compiled header file to include in generated C++ files	No pre-compiled header included
`-Dname[=value]`	Define a preprocessor macro	N/A
`-Idir`	Add `dir` to the preprocessor include path	N/A
`-o outputdir`	Output directory where `opendds_idl` should place the generated files.	The current directory

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Table 1.3 – continued from previous page

Option	Description	Default
`-Wb,java`	Enable OpenDDS Java Bindings for generated TypeSupport implementation classes	No Java support
`-Gitl`	Generates "Intermediate Type Language" descriptions of datatypes. These files are used by the Wireshark dissector or other external applications.	Not generated
`-GfaceTS`	Generates FACE (Future Airborne Capability Environment) Transport Services API	Not generated
`-Gv8`	Generate type support for converting data samples to/from V8 JavaScript objects `-Wb,v8` is an alternative form of this option	Not generated
`-Grapidjson`	Generate type support for converting data samples to/from RapidJSON objects	Not generated
`-Gxtypes-complete`	Generate complete XTypes TypeObjects which can be used to provide type information to applications that don't have compile-time knowledge of the IDL. See *Dynamic Language Binding*.	Only minimal TypeObjects are generated
`-Lface`	Generates IDL-to-C++ mapping for FACE	Not generated
`-Lspcpp`	Generates IDL-to-C++ mapping for Safety Profile	Not generated
`-Lc++11`	Generates IDL-to-C++11 mapping	Not generated
`-Wb,tao_include_prefix=s`	Prefix the string *s* to #include directives meant to include headers generated by `tao_idl`	N/A
`-St`	Suppress generation of IDL TypeCodes when one of the `-L` options are present.	IDL TypeCodes generated

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Table 1.3 – continued from previous page

Option	Description	Default
`--unknown-annotations VAL`	For IDL version 4, control the reaction to unknown annotations. The options are: • `warn-once`, the default, warn once per annotation with the same name. • `warn-all`, warn for every use of an unknown annotation. • `error`, similar to `warn-all`, but causes the compiler to exit with an error status when finished. • `ignore`, ignore all unknown annotations.	`warn-once`
`--no-dcps-data-type-warnings`	Don't warn about `#pragma DCPS_DATA_TYPE`	Warnings are issued, use annotations to silence them
`--[no-]default-nested`	Un-annotated types/modules are treated as nested. See *Topic Types vs. Nested Types* for details.	Types are nested by default.
`--default-extensibility`	Set the default XTypes extensibility. Can be `final`, `appendable` or `mutable`. See *Extensibility* for details.	`appendable`
`--default-enum-extensibility-zero`	Do not set the type flags for enums. This flag is for simulating the behavior of previous versions of OpenDDS.	
`--default-autoid VAL`	Set the default XTypes auto member-id assignment strategy: sequential or hash – see *@autoid(value)*	`sequential`
`--default-try-construct VAL`	Set the default XTypes try-construct strategy: `discard`, `use-default`, or `trim` – see *Customizing XTypes per-member*	`discard`
`--old-typeobject-encoding`	Use the pre-3.18 encoding of `TypeObject`s when deriving `TypeIdentifier`s	Use standard encoding
`--old-typeobject-member-order`	Use the pre-3.24 struct and union member order for `TypeObject`s, which is ordered by member id instead of declared order. See 3.24.0 news entry for more info.	Use standard declared order

The code generation options allow the application developer to use the generated code in a wide variety of environments. Since IDL may contain preprocessing directives (`#include`, `#define`, etc.), the C++ preprocessor is invoked by `opendds_idl`. The `-I` and `-D` options allow customization of the preprocessing step. The `-Wb,export_macro` option lets you add an export macro to your class definitions. This is required if the generated code is going to reside

in a shared library and the compiler (such as Visual C++ or GCC) uses the export macro (`dllexport` on Visual C++ / overriding hidden visibility on GCC). The `-Wb,pch_include` option is required if the generated implementation code is to be used in a project that uses precompiled headers.

1.8.2 Using the IDL-to-C++11 Mapping

The IDL-to-C++11 Mapping is a separate specification from the OMG. Like the "classic" IDL-to-C++ Mapping, IDL-to-C++11 describes how IDL constructs (structs, sequences, unions, etc.) should appear in C++. Since the IDL-to-C++11 Mapping assumes a C++11 (or higher) compiler and standard library, the code generated is easier to use and looks more natural to C++ developers who are not familiar with the classic mapping. For example, IDL strings, arrays, and sequences map to their equivalents in the `std` namespace: `string`, `array`, and `vector`. All of the details of the mapping are spelled out in the specification document (available at https://www.omg.org/spec/CPP11), however the easiest way to get started with the mapping is to generate code from IDL and examine the generated header file.

In the default mode of `opendds_idl` (as described in *Processing the IDL*), responsibility for generating the language mapping is delegated to `tao_idl` (using the IDL-to-C++ classic mapping). In this case, `opendds_idl` is only responsible for generating the OpenDDS-specific additions such as `TypeSupport.idl` and the marshal/demarshal functions.

Contrast this with using `opendds_idl` for IDL-to-C++11. In this case, `opendds_idl` takes over responsibility for generating the language mapping. This is indicated by the `-Lc++11` command-line option.

Starting with a user-written file `Foo.idl`, running "`opendds_idl -Lc++11<other options> Foo.idl`" generates these output files:

- `FooTypeSupport.idl`
  - IDL local interfaces for `*TypeSupport`, `*DataWriter`, `*DataReader`
- `FooC.h`
  - IDL-to-C++11 language mapping
- `FooTypeSupportImpl.h and .cpp`
  - Additional source code needed for OpenDDS

FooTypeSupport.idl is the same as it was when using the classic mapping. After it's generated by `opendds_idl`, it needs to be processed by `tao_idl` to generate `FooTypeSupportC.h`, `FooTypeSupportC.inl`, and `FooTypeSupportC.cpp`.

Unlike when using the classic mapping, `Foo.idl` is not processed by `tao_idl`.

`Foo.idl` can contain the following IDL features:

- modules, typedefs, and constants
- basic types
- constructed types: enums, structs and unions
  - Note that setting a union value through a modifier method automatically sets the discriminator. In cases where there are multiple possible values for the discriminator, a 2-argument modifier method is provided. Using this is preferred to using `_d()`.
  - If you chose to use the `_d()` method of the generated union types, take note that it can only be used to set a value that selects the same union member as the one that's currently selected. OpenDDS treats this as a precondition (it is not checked within the implementation).
- strings (narrow and wide), sequences, and arrays
  - Bounded strings and sequences are supported, but bounds checks are not currently enforced. Due to this limitation, distinct types are not used for bounded instantiations.

- annotations – see *Defining Data Types with IDL*
- #includes of IDL files that are also used with the IDL-to-C++11 mapping

When using MPC to generate projects, the `opendds_cxx11` base project should be used to inherit the correct settings for code generation. If the generated code will be part of a shared library, use the `-Wb,export_include` option (in addition to `-Wb,export_macro`) so that the generated headers have an `#include` for the export header.

When using CMake to generate projects, see the CMake module documentation included in the OpenDDS repository (`docs/cmake.md`).

1.9 The DCPS Information Repository

1.9.1 DCPS Information Repository Options

The table below shows the command line options for the `DCPSInfoRepo` server:

Table DCPS Information Repository Options

Option	Description	Default
`-o file`	Write the IOR of the `DCPSInfo` object to the specified file	`repo.ior`
`-NOBITS`	Disable the publication of built-in topics	Built-in topics are published
`-a address`	Listening address for built-in topics (when built-in topics are published).	Random port
`-z`	Turn on verbose transport logging	Minimal transport logging.
`-r`	Resurrect from persistent file	1 (true)
`-FederationId <id>`	Unique identifier for this repository within any federation. This is supplied as a 32 bit decimal numeric value.	N/A
`-FederateWith <ref>`	Repository federation reference at which to join a federation. This is supplied as a valid CORBA object reference in string form: stringified IOR, file: or corbaloc: reference string.	N/A
`-?`	Display the command line usage and exit	N/A

OpenDDS clients often use the IOR file that `DCPSInfoRepo` outputs to locate the service. The `-o` option allows you to place the IOR file into an application-specific directory or file name. This file can subsequently be used by clients with the `file://` IOR prefix.

Applications that do not use built-in topics may want to disable them with `-NOBITS` to reduce the load on the server. If you are publishing the built-in topics, then the `-a` option lets you pick the listen address of the tcp transport that is used for these topics.

Using the `-z` option causes the invocation of many transport-level debug messages. This option is only effective when the DCPS library is built with the `DCPS_TRANS_VERBOSE_DEBUG` environment variable defined.

The `-FederationId` and `-FederateWith` options are used to control the federation of multiple `DCPSInfoRepo` servers into a single logical repository. See *Repository Federation* for descriptions of the federation capabilities and how to use these options.

File persistence is implemented as an ACE Service object and is controlled via service config directives. Currently available configuration options are:

Table InfoRepo persistence directives

Options	Description	Defaults
`-file`	Name of the persistent file	`InforepoPersist`
`-reset`	Wipe out old persistent data.	`0` (false)

The following directive:

```
static PersistenceUpdater_Static_Service "-file info.pr -reset 1"
```

will persist `DCPSInfoRepo` updates to local file `info.pr`. If a file by that name already exists, its contents will be erased. Used with the command-line option `-r`, the `DCPSInfoRepo` can be reincarnated to a prior state. When using persistence, start the `DCPSInfoRepo` process using a TCP fixed port number with the following command line option. This allows existing clients to reconnect to a restarted InfoRepo.

```
-ORBListenEndpoints iiop://:<port>
```

1.9.2 Repository Federation

Note: Repository federation should be considered an experimental feature.

Repository Federation allows multiple DCPS Information Repository servers to collaborate with one another into a single federated service. This allows applications obtaining service metadata and events from one repository to obtain them from another if the original repository is no longer available.

While the motivation to create this feature was the ability to provide a measure of fault tolerance to the DDS service metadata, other use cases can benefit from this feature as well. This includes the ability of initially separate systems to become federated and gain the ability to pass data between applications that were not originally reachable. An example of this would include two platforms which have independently established internal DDS services passing data between applications; at some point during operation the systems become reachable to each other and federating repositories allows data to pass between applications on the different platforms.

The current federation capabilities in OpenDDS provide only the ability to statically specify a federation of repositories at startup of applications and repositories. A mechanism to dynamically discover and join a federation is planned for a future OpenDDS release.

OpenDDS automatically detects the loss of a repository by using the `LIVELINESS` Quality of Service policy on a Built-in Topic. When a federation is used, the `LIVELINESS` QoS policy is modified to a non-infinite value. When `LIVELINESS` is lost for a Built-in Topic an application will initiate a failover sequence causing it to associate with a different repository server. Because the federation implementation currently uses a Built-in Topic `ParticipantDataDataReaderListener` entity, applications should not install their own listeners for this topic. Doing so would affect the federation implementation's capability to detect repository failures.

The federation implementation distributes repository data within the federation using a reserved DDS domain. The default domain used for federation is defined by the constant `Federator::DEFAULT_FEDERATIONDOMAIN`.

Currently only static specification of federation topology is available. This means that each DCPS Information Repository, as well as each application using a federated DDS service, needs to include federation configuration as part of its configuration data. This is done by specifying each available repository within the federation to each participating process and assigning each repository to a different key value in the configuration files as described in *Configuring for Multiple DCPSInfoRepo Instances*.

Each application and repository must include the same set of repositories in its configuration information. Failover sequencing will attempt to reach the next repository in numeric sequence (wrapping from the last to the first) of the repository key values. This sequence is unique to each application configured, and should be different to avoid overloading any individual repository.

Once the topology information has been specified, then repositories will need to be started with two additional command line arguments. These are shown in *Table 9-1*. One, `-FederationId <value>`, specifies the unique identifier for a repository within the federation. This is a 32 bit numeric value and needs to be unique for all possible federation topologies.

The second command line argument required is `-FederateWith <ref>`. This causes the repository to join a federation at the <ref> object reference after initialization and before accepting connections from applications.

Only repositories which are started with a federation identification number may participate in a federation. The first repository started should not be given a `-FederateWith` command line directive. All others are required to have this directive in order to establish the initial federation. There is a command line tool (`federation`) supplied that can be used to establish federation associations if this is not done at startup. See *Federation Management* for a description. It is possible, with the current static-only implementation, that the failure of a repository before a federation topology is entirely established could result in a partially unusable service. Due to this current limitation, it is highly recommended to always establish the federation topology of repositories prior to starting the applications.

Federation Management

A new command line tool has been provided to allow some minimal run-time management of repository federation. This tool allows repositories started without the `-FederateWith` option to be commanded to participate in a federation. Since the operation of the federated repositories and failover sequencing depends on the presence of connected topology, it is recommended that this tool be used before starting applications that will be using the federated set of repositories.

The command is named `repoctl` and is located in the bin/ directory. It has a command format syntax of:

```
repoctl <cmd> <arguments>
```

Where each individual command has its own format as shown in *Table 9-3*. Some options contain endpoint information. This information consists of an optional host specification, separated from a required port specification by a colon. This endpoint information is used to create a CORBA object reference using the corbaloc: syntax in order to locate the 'Federator' object of the repository server.

Table repoctl Repository Management Command

Command	Syntax	Description
`join`	`repoctl join <target> <peer> [ <federation domain> ]`	Calls the <peer> to join <target> to the federation. <federation domain> is passed if present, or the default Federation Domain value is passed.
`leave`	`repoctl leave <target>`	Causes the <target> to gracefully leave the federation, removing all managed associations between applications using <target> as a repository with applications that are not using <target> as a repository.
`shutdown`	`repoctl shutdown <target>`	Causes the <target> to shutdown without removing any managed associations. This is the same effect as a repository which has crashed during operation.
`kill`	`repoctl kill <target>`	Kills the <target> repository regardless of its federation status.
`help`	`repoctl help`	Prints a usage message and quits.

A join command specifies two repository servers (by endpoint) and asks the second to join the first in a federation:

```
repoctl join 2112 otherhost:1812
```

This generates a CORBA object reference of `corbaloc::otherhost:1812/Federator` that the federator connects to and invokes a join operation. The join operation invocation passes the default Federation Domain value (because we did not specify one) and the location of the joining repository which is obtained by resolving the object reference `corbaloc::localhost:2112/Federator`.

A full description of the command arguments are shown in *Table 9-4*.

Table Federation Management Command Arguments

Option	Description
<target>	This is endpoint information that can be used to locate the `Federator::Manager` CORBA interface of a repository which is used to manage federation behavior. This is used to command leave and shutdown federation operations and to identify the joining repository for the join command.
<peer>	This is endpoint information that can be used to locate the `Federator::Manager` CORBA interface of a repository which is used to manage federation behavior. This is used to command join federation operations.
<federation domain>	This is the domain specification used by federation participants to distribute service metadata amongst the federated repositories. This only needs to be specified if more than one federation exists among the same set of repositories, which is currently not supported. The default domain is sufficient for single federations.

Federation Example

To illustrate the setup and use of a federation, this section walks through a simple example that establishes a federation and a working service that uses it.

This example is based on a two repository federation, with the simple Message publisher and subscriber from *Using DCPS* configured to use the federated repositories.

Configuring the Federation Example

There are two configuration files to create for this example one each for the message publisher and subscriber.

The Message Publisher configuration `pub.ini` for this example is as follows:

```
[common]
DCPSDebugLevel=0

[domain/information]
DomainId=42
DomainRepoKey=1

[repository/primary]
RepositoryKey=1
RepositoryIor=corbaloc::localhost:2112/InfoRepo

[repository/secondary]
RepositoryKey=2
RepositoryIor=file://repo.ior
```

Note that the `DCPSInfo` attribute/value pair has been omitted from the `[common]` section. The user domain is 42, so that domain is configured to use the primary repository for service metadata and events.

The `[repository/primary]` and `[repository/secondary]` sections define the primary and secondary repositories to use within the federation (of two repositories) for this application. The `RepositoryKey` attribute is an internal key value used to uniquely identify the repository (and allow the domain to be associated with it, as in the preceding `[domain/information]` section). The `RepositoryIor` attributes contain string values of resolvable object references to reach the specified repository. The primary repository is referenced at port 2112 of the `localhost` and is expected to be available via the TAO `IORTable` with an object name of `/InfoRepo`. The secondary repository is expected to provide an IOR value via a file named `repo.ior` in the local directory.

The subscriber process is configured with the `sub.ini` file as follows:

```
[common]
DCPSDebugLevel=0

[domain/information]
DomainId=42
DomainRepoKey=1

[repository/primary]
RepositoryKey=1
RepositoryIor=file://repo.ior

[repository/secondary]
RepositoryKey=2
RepositoryIor=corbaloc::localhost:2112/InfoRepo
```

Note that this is the same as the `pub.ini` file except the subscriber has specified that the repository located at port 2112 of the `localhost` is the secondary and the repository located by the `repo.ior` file is the primary. This is opposite of the assignment for the publisher. It means that the publisher is started using the repository at port 2112 for metadata and events while the subscriber is started using the repository located by the IOR contained in the file. In each case, if a repository is detected as unavailable the application will attempt to use the other repository if it can be reached.

The repositories do not need any special configuration specifications in order to participate in federation, and so no files are required for them in this example.

Running the Federation Example

The example is executed by first starting the repositories and federating them, then starting the application publisher and subscriber processes the same way as was done in the example of *Running the Example*.

Start the first repository as:

```
$DDS/bin/DCPSInfoRepo -o repo.ior -FederationId 1024
```

The `-o repo.ior` option ensures that the repository IOR will be placed into the file as expected by the configuration files. The `-FederationId 1024` option assigns the value 1024 to this repository as its unique id within the federation.

Start the second repository as:

```
$DDS/bin/DCPSInfoRepo \
  -ORBListenEndpoints iiop://localhost:2112 \
  -FederationId 2048 -FederateWith file://repo.ior
```

Note that this is all intended to be on a single command line. The `-ORBListenEndpoints iiop://localhost:2112` option ensures that the repository will be listening on the port that the previous configuration files are expecting. The `-FederationId 2048` option assigns the value 2048 as the repositories unique id within the federation. The

`-FederateWith file://repo.ior` option initiates federation with the repository located at the IOR contained within the named file - which was written by the previously started repository.

Once the repositories have been started and federation has been established (this will be done automatically after the second repository has initialized), the application publisher and subscriber processes can be started and should execute as they did for the previous example in *Running the Example*.

1.10 Java Bindings

1.10.1 Introduction

OpenDDS provides JNI bindings. Java applications can make use of the complete OpenDDS middleware just like C++ applications.

See the java/INSTALL file for information on getting started, including the prerequisites and dependencies.

Java versions 9 and up use the Java Platform Module System. To use OpenDDS with one of these Java versions, set the MPC feature java_pre_jpms to 0. OpenDDS's configure script will attempt to detect the Java version and set this automatically.

See the java/FAQ file for information on common issues encountered while developing applications with the Java bindings.

1.10.2 IDL and Code Generation

The OpenDDS Java binding is more than just a library that lives in one or two .jar files. The DDS specification defines the interaction between a DDS application and the DDS middleware. In particular, DDS applications send and receive messages that are strongly-typed and those types are defined by the application developer in IDL.

In order for the application to interact with the middleware in terms of these user-defined types, code must be generated at compile-time based on this IDL. C++, Java, and even some additional IDL code is generated. In most cases, application developers do not need to be concerned with the details of all the generated files. Scripts included with OpenDDS automate this process so that the end result is a native library (`.so` or `.dll`) and a Java library (`.jar` or just a `classes` directory) that together contain all of the generated code.

Below is a description of the generated files and which tools generate them. In this example, `Foo.idl` contains a single struct `Bar` contained in module `Baz` (IDL modules are similar to C++ namespaces and Java packages). To the right of each file name is the name of the tool that generates it, followed by some notes on its purpose.

Table Generated files descriptions

File	Generation Tool
`Foo.idl`	Developer-written description of the DDS sample type
`Foo{C,S}.{h,inl,cpp}`	`tao_idl`: C++ representation of the IDL
`FooTypeSupport.idl`	`opendds_idl`: DDS type-specific interfaces
`FooTypeSupport{C,S}.{h,inl,cpp}`	`tao_idl`
`Baz/BarSeq{Helper,Holder}.java`	`idl2jni`
`Baz/BarData{Reader,Writer}*.java`	`idl2jni`
`Baz/BarTypeSupport*.java`	`idl2jni` (except TypeSupportImpl, see below)
`FooTypeSupportJC.{h,cpp}`	`idl2jni`: JNI native method implementations
`FooTypeSupportImpl.{h,cpp}`	`opendds_idl`: DDS type-specific C++ impl.
`Baz/BarTypeSupportImpl.java`	`opendds_idl`: DDS type-specific Java impl.
`Baz/Bar*.java`	`idl2jni`: Java representation of IDL struct
`FooJC.{h,cpp}`	`idl2jni`: JNI native method implementations

Foo.idl:

```
module Baz {
  @topic
  struct Bar {
    long x;
  };
};
```

1.10.3 Setting up an OpenDDS Java Project

These instructions assume you have completed the installation steps in the java/INSTALL document, including having the various environment variables defined.

- Start with an empty directory that will be used for your IDL and the code generated from it. java/tests/messenger/messenger_idl/ is set up this way.
- Create an IDL file describing the data structure you will be using with OpenDDS. See `Messenger.idl` for an example. This file will contain at least struct/union annotated with `@topic`. For the sake of these instructions, we will call the file `Foo.idl`.
- The C++ generated classes will be packaged in a shared library to be loaded at run-time by the JVM. This requires the packaged classes to be exported for external visibility. ACE provides a utility script for generating the correct export macros. The script usage is shown here:

Unix:

```
$ACE_ROOT/bin/generate_export_file.pl Foo > Foo_Export.h
```

Windows:

```
%ACE_ROOT%\bin\generate_export_file.pl Foo > Foo_Export.h
```

- Create an MPC file, Foo.mpc, from this template:

```
project: dcps_java {
  idlflags += -Wb,stub_export_include=Foo_Export.h \
    -Wb,stub_export_macro=Foo_Export
  dcps_ts_flags += -Wb,export_macro=Foo_Export
  idl2jniflags += -Wb,stub_export_include=Foo_Export.h \
    -Wb,stub_export_macro=Foo_Export
  dynamicflags += FOO_BUILD_DLL

  specific {
    jarname = DDS_Foo_types
  }

 TypeSupport_Files {
    Foo.idl
  }
}
```

You can leave out the specific {...} block if you do not need to create a jar file. In this case you can directly use the Java .class files which will be generated under the classes subdirectory of the current directory.

- Run MPC to generate platform-specific build files.

Unix:

```
$ACE_ROOT/bin/mwc.pl -type gnuace
```

Windows:

```
%ACE_ROOT%\bin\mwc.pl -type [CompilerType]
```

CompilerType can be any supported MPC type (such as "vs2019")

Make sure this is running ActiveState Perl or Strawberry Perl.

- Compile the generated C++ and Java code

Unix:

```
make
```

Windows:

Build the generated .``sln`` (Solution) file using your preferred method. This can be either the Visual Studio IDE or one of the command-line tools. If you use the IDE, start it from a command prompt using `devenv` so that it inherits the environment variables. Command-line tools for building include ms `build` and invoking the IDE (`devenv`) with the appropriate arguments.

When this completes successfully you have a native library and a Java `.jar` file. The native library names are as follows:

Unix:

```
libFoo.so
```

Windows:

```
Foo.dll (Release) or Food.dll (Debug)
```

You can change the locations of these libraries (including the `.jar` file) by adding a line such as the following to the `Foo.mpc` file:

```
libout = $(PROJECT_ROOT)/lib
```

where `PROJECT_ROOT` can be any environment variable defined at build-time.

- You now have all of the Java and C++ code needed to compile and run a Java OpenDDS application. The generated `.jar` file needs to be added to your `classpath`, along with the `.jar` files that come from OpenDDS (in the lib directory). The generated C++ library needs to be available for loading at run-time:

Unix:

Add the directory containing `libFoo.so` to the `LD_LIBRARY_PATH`.

Windows:

Add the directory containing `Foo.dll` (or `Food.dll`) to the `PATH`. If you are using the debug version (`Food.dll`) you will need to inform the OpenDDS middleware that it should not look for `Foo.dll`. To do this, add `-Dopendds.native.debug=1` to the Java VM arguments.

See the publisher and subscriber directories in java/tests/messenger/ for examples of publishing and subscribing applications using the OpenDDS Java bindings.

- If you make subsequent changes to `Foo.idl`, start by re-running MPC (step #5 above). This is needed because certain changes to `Foo.idl` will affect which files are generated and need to be compiled.

1.10.4 A Simple Message Publisher

This section presents a simple OpenDDS Java publishing process. The complete code for this can be found at java/tests/messenger/publisher/TestPublisher.java. Uninteresting segments such as imports and error handling have been omitted here. The code has been broken down and explained in logical subsections.

Initializing the Participant

DDS applications are boot-strapped by obtaining an initial reference to the Participant Factory. A call to the static method `TheParticipantFactory.WithArgs()` returns a Factory reference. This also transparently initializes the C++ Participant Factory. We can then create Participants for specific domains.

```
public static void main(String[] args) {

    DomainParticipantFactory dpf =
        TheParticipantFactory.WithArgs(new StringSeqHolder(args));
    if (dpf == null) {
      System.err.println ("Domain Participant Factory not found");
      return;
    }
    final int DOMAIN_ID = 42;
    DomainParticipant dp = dpf.create_participant(DOMAIN_ID,
      PARTICIPANT_QOS_DEFAULT.get(), null, DEFAULT_STATUS_MASK.value);
    if (dp == null) {
      System.err.println ("Domain Participant creation failed");
      return;
    }
```

Object creation failure is indicated by a null return. The third argument to `create_participant()` takes a Participant events listener. If one is not available, a null can be passed instead as done in our example.

Registering the Data Type and Creating a Topic

Next we register our data type with the `DomainParticipant` using the `register_type()` operation. We can specify a type name or pass an empty string. Passing an empty string indicates that the middleware should simply use the identifier generated by the IDL compiler for the type.

```
MessageTypeSupportImpl servant = new MessageTypeSupportImpl();
if (servant.register_type(dp, "") != RETCODE_OK.value) {
  System.err.println ("register_type failed");
  return;
}
```

Next we create a topic using the type support servant's registered name.

```
Topic top = dp.create_topic("Movie Discussion List",
                            servant.get_type_name(),
                            TOPIC_QOS_DEFAULT.get(), null,
                            DEFAULT_STATUS_MASK.value);
```

Now we have a topic named "*Movie Discussion List*" with the registered data type and default QoS policies.

Creating a Publisher

Next, we create a publisher:

```
Publisher pub = dp.create_publisher(
  PUBLISHER_QOS_DEFAULT.get(),
  null,
  DEFAULT_STATUS_MASK.value);
```

Creating a DataWriter and Registering an Instance

With the publisher, we can now create a DataWriter:

```
DataWriter dw = pub.create_datawriter(
  top, DATAWRITER_QOS_DEFAULT.get(), null, DEFAULT_STATUS_MASK.value);
```

The `DataWriter` is for a specific topic. For our example, we use the default `DataWriter` QoS policies and a null `DataWriterListener`.

Next, we narrow the generic `DataWriter` to the type-specific `DataWriter` and register the instance we wish to publish. In our data definition IDL we had specified the subject_id field as the key, so it needs to be populated with the instance id (99 in our example):

```
MessageDataWriter mdw = MessageDataWriterHelper.narrow(dw);
Message msg = new Message();
msg.subject_id = 99;
int handle = mdw.register(msg);
```

Our example waits for any peers to be initialized and connected. It then publishes a few messages which are distributed to any subscribers of this topic in the same domain.

```
msg.from = "OpenDDS-Java";
msg.subject = "Review";
msg.text = "Worst. Movie. Ever.";
msg.count = 0;
int ret = mdw.write(msg, handle);
```

1.10.5 Setting up the Subscriber

Much of the initialization code for a subscriber is identical to the publisher. The subscriber needs to create a participant in the same domain, register an identical data type, and create the same named topic.

```
public static void main(String[] args) {

    DomainParticipantFactory dpf =
        TheParticipantFactory.WithArgs(new StringSeqHolder(args));
    if (dpf == null) {
      System.err.println ("Domain Participant Factory not found");
      return;
    }
    DomainParticipant dp = dpf.create_participant(42,
      PARTICIPANT_QOS_DEFAULT.get(), null, DEFAULT_STATUS_MASK.value);
```

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```
    if (dp == null) {
      System.err.println("Domain Participant creation failed");
      return;
    }

    MessageTypeSupportImpl servant = new MessageTypeSupportImpl();
                    if (servant.register_type(dp, "") != RETCODE_OK.value) {
      System.err.println ("register_type failed");
      return;
    }
    Topic top = dp.create_topic("Movie Discussion List",
                                servant.get_type_name(),
                                TOPIC_QOS_DEFAULT.get(), null,
                                DEFAULT_STATUS_MASK.value);
```

Creating a Subscriber

As with the publisher, we create a subscriber:

```
Subscriber sub = dp.create_subscriber(
  SUBSCRIBER_QOS_DEFAULT.get(), null, DEFAULT_STATUS_MASK.value);
```

Creating a DataReader and Listener

Providing a `DataReaderListener` to the middleware is the simplest way to be notified of the receipt of data and to access the data. We therefore create an instance of a `DataReaderListenerImpl` and pass it as a `DataReader` creation parameter:

```
DataReaderListenerImpl listener = new DataReaderListenerImpl();
 DataReader dr = sub.create_datareader(
   top, DATAREADER_QOS_DEFAULT.get(), listener,
   DEFAULT_STATUS_MASK.value);
```

Any incoming messages will be received by the Listener in the middleware's thread. The application thread is free to perform other tasks at this time.

1.10.6 The DataReader Listener Implementation

The application defined `DataReaderListenerImpl` needs to implement the specification's `DDS.DataReaderListener` interface. OpenDDS provides an abstract class `DDS._DataReaderListenerLocalBase`. The application's listener class extends this abstract class and implements the abstract methods to add application-specific functionality.

Our example `DataReaderListener` stubs out most of the Listener methods. The only method implemented is the message available callback from the middleware:

```
public class DataReaderListenerImpl extends DDS._DataReaderListenerLocalBase {

    private int num_reads_;
```

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```
    public synchronized void on_data_available(DDS.DataReader reader) {
        ++num_reads_;
        MessageDataReader mdr = MessageDataReaderHelper.narrow(reader);
        if (mdr == null) {
          System.err.println ("read: narrow failed.");
          return;
        }
```

The Listener callback is passed a reference to a generic `DataReader`. The application narrows it to a type-specific `DataReader`:

```
MessageHolder mh = new MessageHolder(new Message());
SampleInfoHolder sih = new SampleInfoHolder(new SampleInfo(0, 0, 0,
    new DDS.Time_t(), 0, 0, 0, 0, 0, 0, 0, false));
int status  = mdr.take_next_sample(mh, sih);
```

It then creates holder objects for the actual message and associated `SampleInfo` and takes the next sample from the `DataReader`. Once taken, that sample is removed from the `DataReader`'s available sample pool.

```
        if (status == RETCODE_OK.value) {

          System.out.println ("SampleInfo.sample_rank = "+ sih.value.sample_rank);
          System.out.println ("SampleInfo.instance_state = "+
                              sih.value.instance_state);

          if (sih.value.valid_data) {

            System.out.println("Message: subject    = " + mh.value.subject);
            System.out.println("         subject_id = " + mh.value.subject_id);
            System.out.println("         from       = " + mh.value.from);
            System.out.println("         count      = " + mh.value.count);
            System.out.println("         text       = " + mh.value.text);
            System.out.println("SampleInfo.sample_rank = " +
                               sih.value.sample_rank);
          }
          else if (sih.value.instance_state ==
                     NOT_ALIVE_DISPOSED_INSTANCE_STATE.value) {
            System.out.println ("instance is disposed");
          }
          else if (sih.value.instance_state ==
                     NOT_ALIVE_NO_WRITERS_INSTANCE_STATE.value) {
            System.out.println ("instance is unregistered");
          }
          else {
            System.out.println ("DataReaderListenerImpl::on_data_available: "+
                                "received unknown instance state "+
                                sih.value.instance_state);
          }

        } else if (status == RETCODE_NO_DATA.value) {
          System.err.println ("ERROR: reader received DDS::RETCODE_NO_DATA!");
        } else {
```

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```
            System.err.println ("ERROR: read Message: Error: "+ status);
        }
    }

}
```

The `SampleInfo` contains meta-information regarding the message such as the message validity, instance state, etc.

1.10.7 Cleaning up OpenDDS Java Clients

An application should clean up its OpenDDS environment with the following steps:

```
dp.delete_contained_entities();
```

Cleans up all topics, subscribers and publishers associated with that `Participant`.

```
dpf.delete_participant(dp);
```

The `DomainParticipantFactory` reclaims any resources associated with the `DomainParticipant`.

```
TheServiceParticipant.shutdown();
```

Shuts down the `ServiceParticipant`. This cleans up all OpenDDS associated resources. Cleaning up these resources is necessary to prevent the `DCPSInfoRepo` from forming associations between endpoints which no longer exist.

1.10.8 Configuring the Example

OpenDDS offers a file-based configuration mechanism. The syntax of the configuration file is similar to a Windows INI file. The properties are divided into named sections corresponding to common and individual transports configuration.

The Messenger example has common properties for the `DCPSInfoRepo` objects location and the global transport configuration:

```
[common]
DCPSInfoRepo=file://repo.ior
DCPSGlobalTransportConfig=$file
```

and a transport instance section with a transport type property:

```
[transport/1]
transport_type=tcp
```

The `[transport/1]` section contains configuration information for the transport instance named "1". It is defined to be of type `tcp`. The global transport configuration setting above causes this transport instance to be used by all readers and writers in the process.

See *Run-time Configuration* for a complete description of all OpenDDS configuration parameters.

1.10.9 Running the Example

To run the Messenger Java OpenDDS application, use the following commands:

```
$DDS_ROOT/bin/DCPSInfoRepo -o repo.ior

$JAVA_HOME/bin/java -ea -cp classes:$DDS_ROOT/lib/i2jrt.jar:$DDS_ROOT/lib/OpenDDS_DCPS.
↪jar:classes TestPublisher -DCPSConfigFile pub_tcp.ini

$JAVA_HOME/bin/java -ea -cp classes:$DDS_ROOT/lib/i2jrt.jar:$DDS_ROOT/lib/OpenDDS_DCPS.
↪jar:classes TestSubscriber -DCPSConfigFile sub_tcp.ini
```

The `-DCPSConfigFile` command-line argument passes the location of the OpenDDS configuration file.

1.10.10 Java Message Service (JMS) Support

OpenDDS provides partial support for JMS version 1.1. Enterprise Java applications can make use of the complete OpenDDS middleware just like standard Java and C++ applications.

See the `INSTALL` file in the java/jms/ directory for information on getting started with the OpenDDS JMS support, including the prerequisites and dependencies.

1.11 Modeling SDK

The OpenDDS Modeling SDK is a modeling tool that can be used by the application developer to define the required middleware components and data structures as a UML model and then generate the code to implement the model using OpenDDS. The generated code can then be compiled and linked with the application to provide seamless middleware support to the application.

1.11.1 Overview

Model Capture

UML models defining DCPS elements and policies along with data definitions are captured using the graphical model capture editors included in the Eclipse plug-ins. The elements of the UML models follow the structure of the DDS UML Platform Independent Model (PIM) defined in the DDS specification (OMG: `formal/2015-04-10`).

Opening a new OpenDDS model within the plug-ins begins with a top level main diagram. This diagram includes any package structures to be included in the model along with the local QoS policy definitions, data definitions, and DCPS elements of the model. Zero or more of the policy or data definition elements can be included. Zero or one DCPS elements definition can be included in any given model.

Figure Graphical modeling of the data definitions

Creating separate models for QoS policies only, data definitions only, or DCPS elements only is supported. References to other models allows externally defined models to be included in a model. This allows sharing of data definitions and QoS policies among different DCPS models as well as including externally defined data in a new set of data definitions.

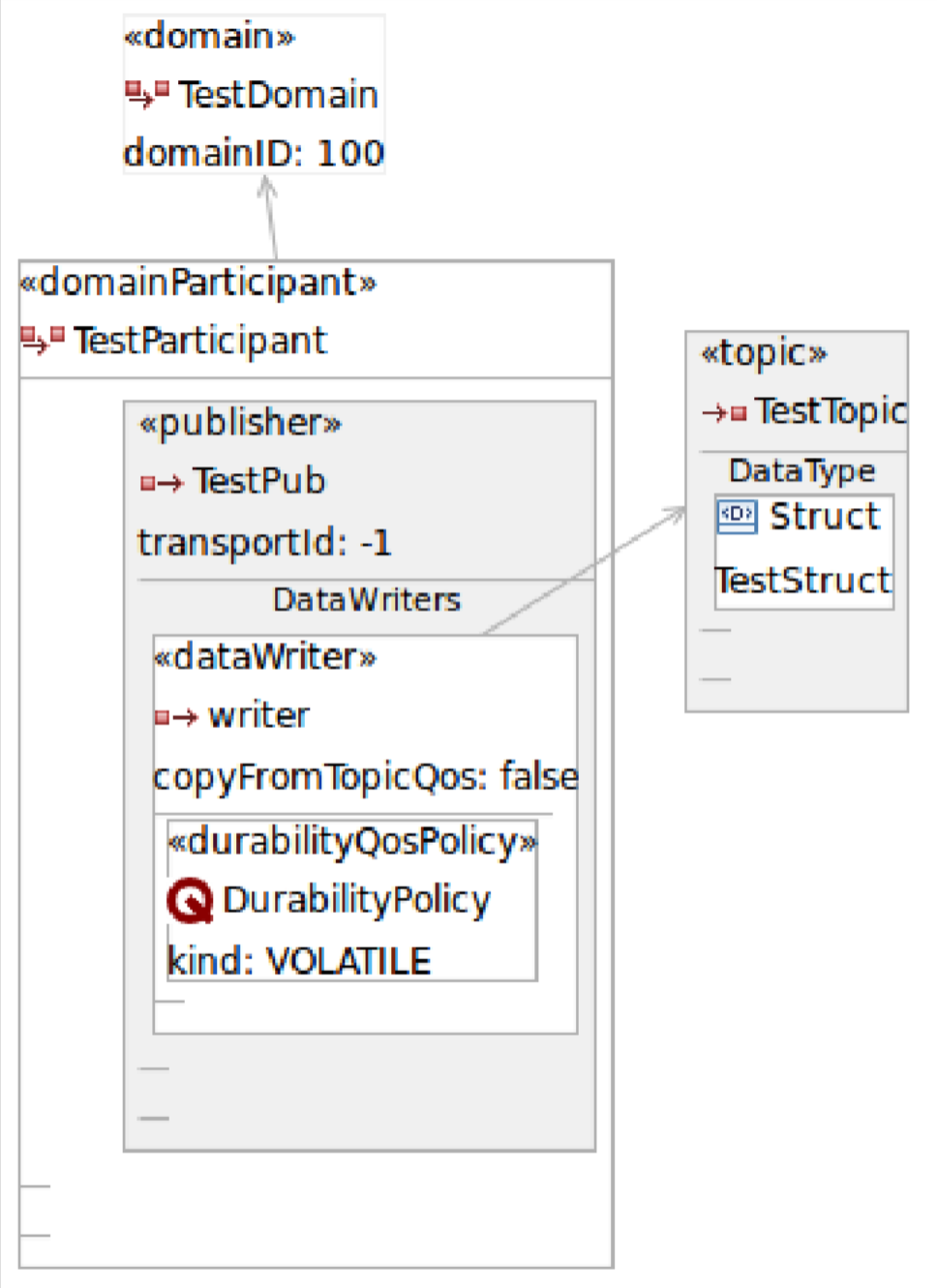

Figure Graphical modeling of the DCPS entities

Code Generation

Once models have been captured, source code can be generated from them. This source code can then be compiled into link libraries providing the middleware elements defined in the model to applications that link the library. Code generation is done using a separate forms based editor.

Specifics of code generation are unique to the individual generation forms and are kept separate from the models for which generation is being performed. Code generation is performed on a single model at a time and includes the ability to tailor the generated code as well as specifying search paths to be used for locating resources at build time.

It is possible to generate model variations (distinct customizations of the same model) that can then be created within the same application or different applications. It is also possible to specify locations to search for header files and link libraries at build time. See *Generated Code* for details.

Programming

In order to use the middleware defined by models, applications need to link in the generated code. This is done through header files and link libraries. Support for building applications using the MPC portable build tool is included in the generated files for a model. See *Developing Applications* for details.

1.11.2 Installation and Getting Started

Unlike the OpenDDS Middleware which is compiled from source code by the developer, the compiled Modeling SDK is available for download via an Eclipse Update Site.

Prerequisites

- Java Runtime Environment (JRE)
- Eclipse IDE

Installation

1. From Eclipse, open the Help menu and select Install New Software.

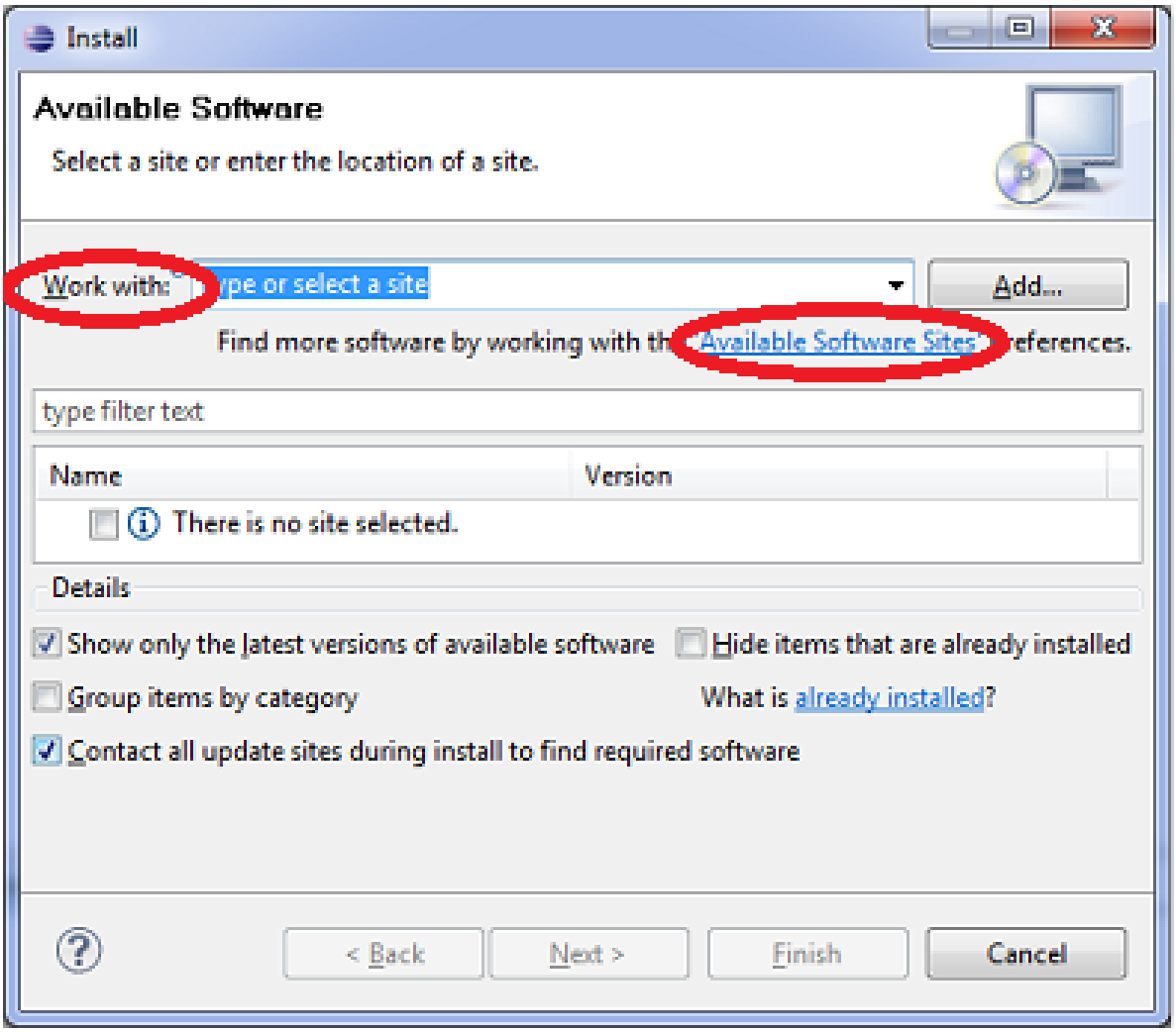

Figure Eclipse Software Installation Dialog

- Click the hyperlink for Available Software Sites.
- The standard `eclipse.org` sites (Eclipse Project Updates and Galileo) should be enabled. If they are disabled, enable them now.
- Add a new Site entry named OpenDDS with URL http://download.opendds.org/modeling/eclipse_44/
- Click OK to close the Preferences dialog and return to the Install dialog.
- In the "Work with" combo box, select the new entry for OpenDDS.
- Select the "OpenDDS Modeling SDK" and click Next.
- Review the "Install Details" list and click Next. Review the license, select Accept (if you do accept it), and click Finish.
- Eclipse will download the OpenDDS plug-ins and various plug-ins from `eclipse.org` that they depend on. There will be a security warning because the OpenDDS plug-ins are not signed. There also may be a prompt to accept a certificate from `eclipse.org`.

- Eclipse will prompt the user to restart in order to use the newly installed software.

Getting Started

The OpenDDS Modeling SDK contains an Eclipse Perspective. Open it by going to the Window menu and selecting Open Perspective -> Other -> OpenDDS Modeling.

To get started using the OpenDDS Modeling SDK, see the help content installed in Eclipse. Start by going to the Help menu and selecting Help Contents. There is a top-level item for "`OpenDDS Modeling SDK Guide`" that contains all of the OpenDDS-specific content describing the modeling and code generation activities.

1.11.3 Developing Applications

In order to build an application using the OpenDDS Modeling SDK, one must understand a few key concepts. The concepts concern:

1. The support library
2. Generated model code
3. Application code

Modeling Support Library

The OpenDDS Modeling SDK includes a support library, found at tools/modeling/codegen/model. This support library, when combined with the code generated by the Modeling SDK, greatly reduces the amount of code needed to build an OpenDDS application.

The support library is a C++ library which is used by an OpenDDS Modeling SDK application. Two classes in the support library that most developers will need are the Application and Service classes.

The Application Class

The `OpenDDS::Model::Application` class takes care of initialization and finalization of the OpenDDS library. It is required for any application using OpenDDS to instantiate a single instance of the `Application` class, and further that the `Application` object not be destroyed while communicating using OpenDDS.

The `Application` class initializes the factory used to create OpenDDS participants. This factory requires the user-provided command line arguments. In order to provide them, the `Application` object must be provided the same command line arguments.

The Service Class

The `OpenDDS::Model::Service` class is responsible for the creation of OpenDDS entities described in an OpenDDS Modeling SDK model. Since the model can be generic, describing a much broader domain than an individual application uses, the Service class uses lazy instantiation to create OpenDDS entities.

In order to properly instantiate these entities, it must know:

- The relationships among the entities
- The transport configuration used by entities

Generated Code

The OpenDDS Modeling SDK generates model-specific code for use by an OpenDDS Modeling SDK application. Starting with a .codegen file (which refers to an `.opendds` model file), the files described in *Table 11-1*. The process of generating code is documented in the Eclipse help.

Table Generated Files

File Name	Description
`<ModelName>.idl`	Data types from the model's `DataLib`
`<ModelName>_T.h`	C++ class from the model's `DcpsLib`
`<ModelName>_T.cpp`	C++ implementation of the model's `DcpsLib`
`<ModelName>.mpc`	MPC project file for the generated C++ library
`<ModelName>.mpb`	MPC base project for use by the application
`<ModelName>_paths.mpb`	MPC base project with paths, see *Dependencies Between Models*
`<ModelName>Traits.h`	Transport configuration from the .codegen file
`<ModelName>Traits.cpp`	Transport configuration from the .codegen file

The DCPS Model Class

The DCPS library models relationships between DDS entities, including `Topics`, `DomainParticipants`, `Publishers`, `Subscribers`, `DataWriters` and `DataReaders`, and their corresponding Domains.

For each DCPS library in your model, the OpenDDS Modeling SDK generates a class named after the DCPS library. This DCPS model class is named after the DCPS library, and is found in the `<ModelName>_T.h` file in the code generation target directory.

The model class contains an inner class, named Elements, defining enumerated identifiers for each DCPS entity modeled in the library and each type referenced by the library's Topics. This Elements class contains enumeration definitions for each of:

- DomainParticipants
- Types
- Topics
- Content Filtered Topics
- Multi Topics
- Publishers
- Subscribers
- Data Writers
- Data Readers

In addition, the DCPS model class captures the relationships between these entities. These relationships are used by the Service class when instantiating DCPS entities.

The Traits Class

Entities in a DCPS model reference their transport configuration by name. The Model Customization tab of the Codegen file editor is used to define the transport configuration for each name.

There can be more than one set of configurations defined for a specific code generation file. These sets of configurations are grouped into instances, each identified by a name. Multiple instances may be defined, representing different deployment scenarios for models using the application.

For each of these instances, a `Traits` class is generated. The traits class provides the transport configuration modeled in the Codegen editor for a specific transport configuration name.

The Service Typedef

The Service is a template which needs two parameters: (1) the entity model, in the DCPS model `Elements` class, (2) transport configuration, in a `Traits` class. The OpenDDS Modeling SDK generates one typedef for each combination of DCPS library and transport configuration model instance. The typedef is named `<InstanceName><DCPSLibraryName>Type`.

Data Library Generated Code

From the data library, IDL is generated, which is processed by the IDL compilers. The IDL compilers generate type support code, which is used to serialize and deserialize data types.

QoS Policy Library Generated Code

There are no specific compilation units generated from the QoS policy library. Instead, the DCPS library stores the QoS policies of the entities it models. This QoS policy is later queried by the Service class, which sets the QoS policy upon entity creation.

Application Code Requirements

Required headers

The application will need to include the `Traits` header, in addition to the `Tcp.h` header (for static linking). These will include everything required to build a publishing application. Here is the `#include` section of an example publishing application, `MinimalPublisher.cpp`.

```
#ifdef ACE_AS_STATIC_LIBS
#include <dds/DCPS/transport/tcp/Tcp.h>
#endif

#include "model/MinimalTraits.h"
```

Exception Handling

It is recommended that Modeling SDK applications catch both `CORBA::Exception` objects and `std::exception` objects.

```
int ACE_TMAIN(int argc, ACE_TCHAR* argv[])
{
  try {
    // Create and use OpenDDS Modeling SDK (see below)
  } catch (const CORBA::Exception& e) {
    // Handle exception and return non-zero
  } catch (const OpenDDS::DCPS::Transport::Exception& te) {
    // Handle exception and return non-zero
  } catch (const std::exception& ex) {
    // Handle exception and return non-zero
  }
  return 0;
}
```

Instantiation

As stated above, an OpenDDS Modeling SDK application must create an `OpenDDS::Model::Application` object for the duration of its lifetime. This `Application` object, in turn, is passed to the constructor of the Service object specified by one of the typedef declarations in the traits headers.

The service is then used to create OpenDDS entities. The specific entity to create is specified using one of the enumerated identifiers specified in the `Elements` class. The Service provides this interface for entity creation:

```
DDS::DomainParticipant_var participant(Elements::Participants::Values part);
DDS::TopicDescription_var topic(Elements::Participants::Values part,
                                Elements::Topics::Values topic);
DDS::Publisher_var publisher(Elements::Publishers::Values publisher);
DDS::Subscriber_var subscriber(Elements::Subscribers::Values subscriber);
DDS::DataWriter_var writer(Elements::DataWriters::Values writer);
DDS::DataReader_var reader(Elements::DataReaders::Values reader);
```

It is important to note that the service also creates any required intermediate entities, such as `DomainParticipants`, `Publishers`, `Subscribers`, and `Topics`, when necessary.

Publisher Code

Using the `writer()` method shown above, `MinimalPublisher.cpp` continues:

```
int ACE_TMAIN(int argc, ACE_TCHAR* argv[])
{
  try {
    OpenDDS::Model::Application application(argc, argv);
    MinimalLib::DefaultMinimalType model(application, argc, argv);

    using OpenDDS::Model::MinimalLib::Elements;
    DDS::DataWriter_var writer = model.writer(Elements::DataWriters::writer);
```

What remains is to narrow the `DataWriter` to a type-specific data writer, and send samples.

```
data1::MessageDataWriter_var msg_writer =
  data1::MessageDataWriter::_narrow(writer);
data1::Message message;
// Populate message and send
message.text = "Worst. Movie. Ever.";
DDS::ReturnCode_t error = msg_writer->write(message, DDS::HANDLE_NIL);
if (error != DDS::RETCODE_OK) {
  // Handle error
}
```

In total our publishing application, `MinimalPublisher.cpp`, looks like this:

```
#ifdef ACE_AS_STATIC_LIBS
#include <dds/DCPS/transport/tcp/Tcp.h>
#endif

#include "model/MinimalTraits.h"

int ACE_TMAIN(int argc, ACE_TCHAR* argv[])
{
  try {
    OpenDDS::Model::Application application(argc, argv);
    MinimalLib::DefaultMinimalType model(application, argc, argv);

    using OpenDDS::Model::MinimalLib::Elements;
    DDS::DataWriter_var writer = model.writer(Elements::DataWriters::writer);

    data1::MessageDataWriter_var msg_writer =
      data1::MessageDataWriter::_narrow(writer);
    data1::Message message;
    // Populate message and send
    message.text = "Worst. Movie. Ever.";
    DDS::ReturnCode_t error = msg_writer->write(message, DDS::HANDLE_NIL);
    if (error != DDS::RETCODE_OK) {
      // Handle error
    }
  } catch (const CORBA::Exception& e) {
    // Handle exception and return non-zero
  } catch (const std::exception& ex) {
    // Handle exception and return non-zero
  }
  return 0;
}
```

Note this minimal example ignores logging and synchronization, which are issues that are not specific to the OpenDDS Modeling SDK.

Subscriber Code

The subscriber code is much like the publisher. For simplicity, OpenDDS Modeling SDK subscribers may want to take advantage of a base class for Reader Listeners, called `OpenDDS::Modeling::NullReaderListener`. The `NullReaderListener` implements the entire `DataReaderListener` interface and logs every callback.

Subscribers can create a listener by deriving a class from `NullReaderListener` and overriding the interfaces of interest, for example on_data_available.

```
#ifdef ACE_AS_STATIC_LIBS
#include <dds/DCPS/transport/tcp/Tcp.h>
#endif

#include "model/MinimalTraits.h"
#include <model/NullReaderListener.h>

class ReaderListener : public OpenDDS::Model::NullReaderListener {
public:
  virtual void on_data_available(DDS::DataReader_ptr reader)
    ACE_THROW_SPEC((CORBA::SystemException)) {
    data1::MessageDataReader_var reader_i =
      data1::MessageDataReader::_narrow(reader);

    if (!reader_i) {
      // Handle error
      ACE_OS::exit(-1);
    }

    data1::Message msg;
    DDS::SampleInfo info;

    // Read until no more messages
    while (true) {
      DDS::ReturnCode_t error = reader_i->take_next_sample(msg, info);
      if (error == DDS::RETCODE_OK) {
        if (info.valid_data) {
          std::cout << "Message: " << msg.text.in() << std::endl;
        }
      } else {
        if (error != DDS::RETCODE_NO_DATA) {
          // Handle error
        }
        break;
      }
    }
  }
};
```

In the main function, create a data reader from the service object:

```
DDS::DataReader_var reader = model.reader(Elements::DataReaders::reader);
```

Naturally, the `DataReaderListener` must be associated with the data reader in order to get its callbacks.

```
DDS::DataReaderListener_var listener(new ReaderListener);
reader->set_listener(listener, OpenDDS::DCPS::DEFAULT_STATUS_MASK);
```

The remaining subscriber code has the same requirements of any OpenDDS Modeling SDK application, in that it must initialize the OpenDDS library through an `OpenDDS::Modeling::Application` object, and create a Service object with the proper DCPS model Elements class and traits class.

An example subscribing application, `MinimalSubscriber.cpp`, follows.

```
#ifdef ACE_AS_STATIC_LIBS
#include <dds/DCPS/transport/tcp/Tcp.h>
#endif

#include "model/MinimalTraits.h"
#include <model/NullReaderListener.h>

class ReaderListener : public OpenDDS::Model::NullReaderListener {
public:
  virtual void on_data_available(DDS::DataReader_ptr reader)
  ACE_THROW_SPEC((CORBA::SystemException)) {
    data1::MessageDataReader_var reader_i =
      data1::MessageDataReader::_narrow(reader);

    if (!reader_i) {
      // Handle error
      ACE_OS::exit(-1);
    }

    data1::Message msg;
    DDS::SampleInfo info;

    // Read until no more messages
    while (true) {
      DDS::ReturnCode_t error = reader_i->take_next_sample(msg, info);
      if (error == DDS::RETCODE_OK) {
        if (info.valid_data) {
          std::cout << "Message: " << msg.text.in() << std::endl;
        }
      } else {
        if (error != DDS::RETCODE_NO_DATA) {
          // Handle error
        }
        break;
      }
    }
  }
};

int ACE_TMAIN(int argc, ACE_TCHAR* argv[])
{
  try {
    OpenDDS::Model::Application application(argc, argv);
    MinimalLib::DefaultMinimalType model(application, argc, argv);
```

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```
    using OpenDDS::Model::MinimalLib::Elements;

    DDS::DataReader_var reader = model.reader(Elements::DataReaders::reader);

    DDS::DataReaderListener_var listener(new ReaderListener);
    reader->set_listener(listener, OpenDDS::DCPS::DEFAULT_STATUS_MASK);

    // Call on_data_available in case there are samples which are waiting
    listener->on_data_available(reader);

    // At this point the application can wait for an exteral "stop" indication
    // such as blocking until the user terminates the program with Ctrl-C.

  } catch (const CORBA::Exception& e) {
    e._tao_print_exception("Exception caught in main():");
    return -1;
  } catch (const std::exception& ex) {
    // Handle error
    return -1;
  }
  return 0;
}
```

MPC Projects

In order to make use of the OpenDDS Modeling SDK support library, OpenDDS Modeling SDK MPC projects should inherit from the dds_model project base. This is in addition to the dcpsexe base from which non-Modeling SDK projects inherit.

```
project(*Publisher) : dcpsexe, dds_model {
  // project configuration
}
```

The generated model library will generate an MPC project file and base project file in the target directory, and take care of building the model shared library. OpenDDS modeling applications must both (1) include the generated model library in their build and (2) ensure their projects are built after the generated model libraries.

```
project(*Publisher) : dcpsexe, dds_model {
  // project configuration
  libs  += Minimal
  after += Minimal
}
```

Both of these can be accomplished by inheriting from the model library's project base, named after the model library.

```
project(*Publisher) : dcpsexe, dds_model, Minimal {
  // project configuration
}
```

Note that the `Minimal.mpb` file must now be found by MPC during project file creation. This can be accomplished through the -include command line option.

Using either form, the MPC file must tell the build system where to look for the generated model library.

```
project(*Publisher) : dcpsexe, dds_model, Minimal {
  // project configuration
  libpaths += model
}
```

This setting based upon what was provided to the Target Folder setting in the Codegen file editor.

Finally, like any other MPC project, its source files must be included:

```
Source_Files {
  MinimalPublisher.cpp
}
```

The final MPC project looks like this for the publisher:

```
project(*Publisher) : dcpsexe, dds_model, Minimal {
  exename   = publisher
  libpaths += model

  Source_Files {
    MinimalPublisher.cpp
  }
}
```

And similar for the subscriber:

```
project(*Subscriber) : dcpsexe, dds_model, Minimal {
  exename   = subscriber
  libpaths += model

  Source_Files {
    MinimalSubscriber.cpp
  }
}
```

Dependencies Between Models

One final consideration — the generated model library could itself depend on other generated model libraries. For example, there could be an external data type library which is generated to a different directory.

This possibility could cause a great deal of maintenance of project files, as models change their dependencies over time. To help overcome this burden, the generated model library records the paths to all of its externally referenced model libraries in a separate MPB file named `<ModelName>_paths.mpb`. Inheriting from this paths base project will inherit the needed settings to include the dependent model as well.

Our full MPC file looks like this:

```
project(*Publisher) : dcpsexe, dds_model, Minimal, Minimal_paths {
  exename   = publisher
  libpaths += model

  Source_Files {
```

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```
    MinimalPublisher.cpp
  }
}

project(*Subscriber) : dcpsexe, dds_model, Minimal, Minimal_paths {
  exename   = subscriber
  libpaths += model

  Source_Files {
    MinimalSubscriber.cpp
  }
}
```

1.12 Alternate Interfaces to Data

The DDS-DCPS approach to data transfer using synchronization of strongly-typed caches (DataWriter and DataReader) is not appropriate for all applications. Therefore OpenDDS provides two different alternate interface approaches which are described in this section. These are not defined by OMG specifications and may change in future releases of OpenDDS, including minor updates. The two approaches are:

- Recorder and Replayer
  - These interfaces allow the application to create untyped stand-ins for DataReaders and/or DataWriters
  - Recorder can be used with the Dynamic Language Binding XTypes features (*Dynamic Language Binding*) to access typed data samples through a reflection-based API
- Observer
  - Observers play a role similar to the spec-defined Listeners (attached to DataReaders and/or DataWriters). Unlike the Listeners, Observers don't need to interact with the DataReader/Writer caches to access the data samples.

The XTypes Dynamic Language Binding (*Dynamic Language Binding*) provides a set of related features that can be used to create DataWriters and DataReaders that work with a generic data container (DynamicData) instead of a specific IDL-generated data type.

1.12.1 Recorder and Replayer

The Recorder feature of OpenDDS allows applications to record samples published on arbitrary topics without any prior knowledge of the data type used by that topic. Analogously, the Replayer feature allows these recorded samples to by re-published back into the same or other topics. What makes these features different from other Data Readers and Writers are their ability to work with any data type, even if unknown at application build time. Effectively, the samples are treated as if each one contains an opaque byte sequence.

The purpose of this section is to describe the public API for OpenDDS to enable the recording/replaying use-case.

API Structure

Two new user-visible classes (that behave somewhat like their DDS Entity counterparts) are defined in the `OpenDDS::DCPS` namespace, along with the associated Listener interfaces. Listeners may be optionally implemented by the application. The `Recorder` class acts similarly to a `DataReader` and the `Replayer` class acts similarly to a `DataWriter`.

Both `Recorder` and `Replayer` make use of the underlying OpenDDS discovery and transport libraries as if they were `DataReader` and `DataWriter`, respectively. Regular OpenDDS applications in the domain will "see" the `Recorder` objects as if they were remote `DataReader` s and `Replayers` as if they were `DataWriter` s.

Usage Model

The application creates any number of `Recorder` s and `Replayer` s as necessary. This could be based on using the Built-In Topics to dynamically discover which topics are active in the Domain. Creating a `Recorder` or `Replayer` requires the application to provide a topic name and type name (as in `DomainParticipant::create_topic()`) and also the relevant QoS data structures. The `Recorder` requires SubscriberQos and DataReaderQos whereas the `Replayer` requires PublisherQos and DataWriterQos. These values are used in discovery's reader/writer matching. See the section on QoS processing below for how the `Recorder` and `Replayer` use QoS. Here is the code needed to create a recorder:

```
OpenDDS::DCPS::Recorder_var recorder =
     service_participant->create_recorder(domain_participant,
                                          topic.in(),
                                          sub_qos,
                                          dr_qos,
                                          recorder_listener);
```

Data samples are made available to the application via the `RecorderListener` using a simple "one callback per sample" model. The sample is delivered as an `OpenDDS::DCPS::RawDataSample` object. This object includes the timestamp for that data sample as well as the marshaled sample value. Here is a class definition for a user-defined Recorder Listener.

```
class MessengerRecorderListener : public OpenDDS::DCPS::RecorderListener
{
public:
  MessengerRecorderListener();

  virtual void on_sample_data_received(OpenDDS::DCPS::Recorder*,
                                       const OpenDDS::DCPS::RawDataSample& sample);

  virtual void on_recorder_matched(OpenDDS::DCPS::Recorder*,
                                   const DDS::SubscriptionMatchedStatus& status );

};
```

The application can store the data wherever it sees fit (in memory, file system, database, etc.). At any later time, the application can provide that same sample to a `Replayer` object configured for the same topic. It's the application's responsibility to make sure the topic types match. Here is an example call that replays a sample to all readers connected on a replayer's topic:

```
replayer->write(sample);
```

Because the stored data is dependent on the definition of the data structure, it can't be used across different versions of OpenDDS or different versions of the IDL used by the OpenDDS participants.

QoS Processing

The lack of detailed knowledge about the data sample complicates the use of many normal DDS QoS properties on the `Replayer` side. The properties can be divided into a few categories:

- Supported
- – Liveliness
  – Time-Based Filter
  – Lifespan
  – Durability (transient local level, see details below)
  – Presentation (topic level only)
  – Transport Priority (pass-thru to transport)
- Unsupported
- – Deadline (still used for reader/writer match)
  – History
  – Resource Limits
  – Durability Service
  – Ownership and Ownership Strength (still used for reader/writer match)
- Affects reader/writer matching and Built-In Topics but otherwise ignored
- – Partition
  – Reliability (still used by transport negotiation)
  – Destination Order
  – Latency Budget
  – User/Group Data

Durability details

On the `Recorder` side, transient local durability works just the same as any normal `DataReader`. Durable data is received from matched `DataWriter` s. On the `Replayer` side there are some differences. As opposed to the normal DDS `DataWriter`, `Replayer` is not caching/storing any data samples (they are simply sent to the transport). Because instances are not known, storing data samples according to the usual History and Resource Limits rules is not possible. Instead, transient local durability can be supported with a "pull" model whereby the middleware invokes a method on the `ReplayerListener` when a new remote `DataReader` is discovered. The application can then call a method on the `Replayer` with any data samples that should be sent to that newly-joined `DataReader`. Determining which samples these are is left to the application.

Recorder With XTypes Dynamic Language Binding

The Recorder class includes support for the Dynamic Language Binding from XTypes (*Dynamic Language Binding*). Type information for each matched DataWriter (that supports XTypes complete TypeObjects) is stored in the Recorder. Users can call Recorder::get_dynamic_data, passing a RawDataSample to get back a DynamicData object which includes type information – see DynamicData::type().

A tool called "inspect," uses the Recorder and Dynamic Language Binding allow for the printing of any type, so long as the topic name, type name, and domain ID are known. The DataWriter must include code generation for complete TypeObjects. See tools/inspect/Inspect.cpp for this tool's source code. It can be used as a standalone tool or an example for developing your own applications using these APIs.

1.12.2 Observer

To observe the most important events happening within OpenDDS, applications can create classes that derive from the Observer abstract base class (in dds/DCPS/Observer.h). The design of Observer is intended to allow applications to have a single Observer object observing many Entities, however this is flexible to allow many different use cases. The following events can be observed:

- DataWriter/Reader enabled, deleted
- DataWriter/Reader QoS changed
- DataWriter/Reader peer associated, disassociated
- DataWriter sample sent
- DataReader sample received (enters the cache), read, taken

Attaching Observers to Entities

Entity is the spec-defined base interface of the following types:

- DataWriter, DataReader
  - As seen above in *Observer*, the Observer events originate in the DataWriter and DataReader Entities
- DomainParticipant, Publisher, Subscriber
  - Among their other roles, these Entities act as containers (either directly or indirectly) for DataWriters and DataReaders.
  - If a smaller-scoped Entity (such as a DataWriter) has no Observer for the event in question, its containing Entity (in this example, a Publisher) is checked for an Observer.
- Topic
  - Although it is an Entity, no Observer events are generated by Topics or Entities they contain (since they don't contain any Entities)

The class EntityImpl (in dds/DCPS/EntityImpl.h) is OpenDDS's base class for all Entity types. EntityImpl includes public methods for Observer registration: set_observer and get_observer. These methods are not part of the IDL interfaces, so invoking them the requires a cast to the implementation (Impl) of Entity.

```
DDS::DataWriter_var dw = /* ... */;
EntityImpl* entity = dynamic_cast<EntityImpl*>(dw.in());
Observer_rch observer = make_rch<MyObserver>();
entity->set_observer(observer, Observer::e_SAMPLE_SENT);
```

Note that since the Observer class as an internal (not IDL) interface, it uses the "RCH" (Reference Counted Handle) smart pointer classes. Observer itself inherits from RcObject, and uses of Observer-derived classes should use the RcHandle template and its associated functions, as in the example above. See dds/DCPS/RcHandle_T.h for details.

Writing Observer-Derived Classes

The virtual methods in the Observer class are divided into 3 groups based on the general category of events they observe:

1. Operations on the observed Entity itself
2. - on_enabled, on_deleted, on_qos_changed
   - The only parameter to these methods is the Entity, so the Observer implementation can use the public methods on the Entity.
3. Events relating to associating with remote matched endpoints
   - on_associated, on_disassociated
   - In addition to the Entity, the Observer implementation receives a GUID_t structure which is the internal representation of remote Entity identity. The GUID_t values from on_associated could be stored or logged to correlate them with the values from on_disassociated.
4. Events relating to data samples moving through the system
   - on_sample_sent, on_sample_received, on_sample_read, on_sample_taken
5. - In addition to the Entity, the Observer implementation receives an instance of the Sample structure. The definition of this structure is nested within Observer. See below for details.

The Observer::Sample structure

The Observer::Sample structure contains the following fields:

- instance and instance_state
  - Describe the instance that this sample belongs to, using the spec-defined types
- timestamp and sequence_number
  - Attributes of the sample itself: timestamp uses a spec-defined type whereas sequence_number uses the OpenDDS internal type for DDSI-RTPS 64-bit sequence numbers.
- data and data_dispatcher
  - Since Observer is an un-typed interface, the contents of the data sample itself are represented only as a void pointer
  - Implementations that need to process this data can use the data_dispatcher object to interpret it. See the class definition of ValueDispatcher in dds/DCPS/ValueDispatcher.h for more details.

1.13 Safety Profile

1.13.1 Overview

The Safety Profile configuration allows OpenDDS to be used in environments that have a restricted set of operating system and standard library functions available and that require dynamic memory allocation to occur only at system start-up.

OpenDDS Safety Profile (and the corresponding features in ACE) were developed for the Open Group's FACE specification, edition 2.1. It can be used along with the support for FACE Transport Services to create FACE-conformant DDS applications, or it can be used by general DDS applications that are not written to the FACE Transport Services APIs. This latter use-case is described by this section of the developer's guide. For more information on the former use-case see the file FACE/README.txt in the source distribution.

1.13.2 Safety Profile Subset of OpenDDS

The following features of OpenDDS are not available when it is configured for Safety Profile:

- DCPSInfoRepo and its associated libraries and tools
- Transport types: tcp, udp, multicast, shared memory
  - The rtps_udp transport type is available (uses UDP unicast or multicast)
- OpenDDS Monitor library and monitoring GUI

When developing the Safety Profile, the following DDS Compliance Profiles were disabled:

- content_subscription
- ownership_kind_exclusive
- object_model_profile
- persistence_profile

See *Disabling the Building of Compliance Profile Features* for more details on compliance profiles. It is possible that enabling any of these compliance profiles in a Safety Profile build will result in a compile-time or run-time error.

To build OpenDDS Safety Profile, pass the command line argument "–safety-profile" to the configure script along with any other arguments needed for your platform or configuration. When safety profile is enabled in the configure script, the four compliance profiles listed above default to disabled. See *Installation* and the `INSTALL.md` file in the source distribution for more information about the configure script.

1.13.3 Safety Profile Configurations of ACE

OpenDDS uses ACE as its platform abstraction library, and in OpenDDS's Safety Profile configuration, one of the following safety profile configurations must be enabled in ACE:

- FACE Safety Base (always uses the memory pool)
- FACE Safety Extended with Memory Pool
- FACE Safety Extended with Standard C++ Dynamic Allocation

OpenDDS's configure script will automatically configure ACE. Pass the command line argument "–safety-profile=base" to select the Safety Base profile. Otherwise a "–safety-profile" (no equals sign) configuration will default to Safety Extended with Memory Pool.

The Safety Extended with Standard C++ Dynamic Allocation configuration is not automatically generated by the configure script, but the file "build/target/ACE_wrappers/ace/config.h" can be edited after it is generated by configure (and before running make). Remove the macro definition for ACE_HAS_ALLOC_HOOKS to disable the memory pool.

ACE's safety profile configurations have been tested on Linux and on LynxOS-178 version 2.3.2+patches. Other platforms may work too but may require additional configuration.

1.13.4 Run-time Configurable Options

The memory pool used by OpenDDS can be configured by setting values in the [common] section of the configuration file. See *Common Configuration Options* and the pool_size and pool_granularity rows of table *Table 7-2*.

1.13.5 Running ACE and OpenDDS Tests

After configuring and building OpenDDS Safety Profile, note that there are two sub-directories of the top level that each contain some binary artifacts:

- build/host has the build-time code generators tao_idl and opendds_idl
- build/target has the run-time libraries for safety profile ACE and OpenDDS and the OpenDDS tests

Therefore, testing needs to be relative to the build/target sub-directory. Source-in the generated file `build/target/setenv.sh` to get all of the needed environment variables.

ACE tests are not built by default, but once this environment is set up all it takes to build them is generating makefiles and running make:

1. `cd $ACE_ROOT/tests`
2. `$ACE_ROOT/bin/mwc.pl -type gnuace`
3. `make`

Run ACE tests by changing to the $ACE_ROOT/tests directory and using run_test.pl. Pass any "-Config XYZ" options required for your configuration (use run_test.pl -h to see the available Config options).

Run OpenDDS tests by changing to the $DDS_ROOT and using bin/auto_run_tests.pl. Pass "-Config OPENDDS_SAFETY_PROFILE", "-Config SAFETY_BASE" (if using safety base), "-Config RTPS", and -Config options corresponding to each disabled compliance profile, by default: "-Config DDS_NO_OBJECT_MODEL_PROFILE -Config DDS_NO_OWNERSHIP_KIND_EXCLUSIVE -Config DDS_NO_PERSISTENCE_PROFILE -Config DDS_NO_CONTENT_SUBSCRIPTION".

Alternatively, an individual test can be run using run_test.pl from that test's directory. Pass the same set of -Config options to run_test.pl.

1.13.6 Using the Memory Pool in Applications

When the Memory Pool is enabled at build time, all dynamic allocations made by code in OpenDDS or in ACE (methods invoked by OpenDDS) go through the pool. Since the pool is a general purpose dynamic allocator, it may be desirable for application code to use the pool too. Since these APIs are internal to OpenDDS, they may change in future releases.

The class `OpenDDS::DCPS::MemoryPool` (dds/DCPS/MemoryPool.h) contains the pool implementation. However, most client code shouldn't interact directly with it. The class `OpenDDS::DCPS::SafetyProfilePool` (dds/DCPS/SafetyProfilePool.h) adapts the pool to the ACE_Allocator interface. `OpenDDS::DCPS::PoolAllocator<T>` (dds/DCPS/PoolAllocator.h) adapts the pool to the C++ Allocator concept (C++03). Since the PoolAllocator is stateless, it depends on the ACE_Allocator's singleton. When

OpenDDS is configured with the memory pool, ACE_Allocator's singleton instance will point to an object of class SafetyProfilePool.

Application code that makes use of C++ Standard Library classes can either use PoolAllocator directly, or make use of the macros defined in PoolAllocator.h (for example OPENDDS_STRING).

Application code that allocates raw (untyped) buffers of dynamic memory can use SafetyProfilePool either directly or via the ACE_Allocator::instance() singleton.

Application code that allocates objects from the heap can use the PoolAllocator<T> template.

Classes written by the application developer can derive from PoolAllocationBase (see PoolAllocationBase.h) to inherit class-scoped operators new and delete, thus redirecting all dynamic allocation of these classes to the pool.

1.14 DDS Security

1.14.1 Building OpenDDS with Security Enabled

Prior to utilizing DDS Security, OpenDDS must be built to include security elements into the resulting libraries. The following instructions show how this is to be completed on various platforms.

Prerequisites

OpenDDS includes an implementation of the OMG DDS Security 1.1 specification. Building OpenDDS with security enabled requires the following dependencies:

1. Xerces-C++ v3.x
2. OpenSSL v1.0.2+, v1.1, or v3.0.1+ (1.1 is preferred)
3. Google Test (only required if building OpenDDS tests)
    - If you are using OpenDDS from a git repository, Google Test is provided as a git submodule. Make sure to enable submodules with the `--recursive` option to git clone.
4. CMake (required if building OpenDDS tests and building Google Test and other dependencies from source).

General Notes on Using OpenDDS Configure Script with DDS Security:

1. DDS Security is disabled by default, enable it with `--security`
2. OpenDDS tests are disabled by default, enable them with `--tests`
    - Disabling tests skips the Google Test and CMake dependencies
    - If tests are enabled, the configure script can run CMake and build Google Test

Building OpenDDS with Security on Windows

Using Microsoft vcpkg

Microsoft vcpkg is a "C++ Library Manager for Windows, Linux, and macOS" which helps developers build/install dependencies. Although it is cross-platform, this guide only discusses vcpkg on Windows.

As of this writing, vcpkg is only supported on Visual Studio 2015 Update 3 and later versions; if using an earlier version of Visual Studio, skip down to the manual setup instructions later in this section.

- If OpenDDS tests will be built, install CMake or put the one that comes with Visual Studio on the `PATH` (see `Common7\IDE\CommonExtensions\Microsoft\CMake`).

- If you need to obtain and install vcpkg, navigate to *https://github.com/Microsoft/vcpkg* and follow the instructions to obtain vcpkg by cloning the repository and bootstrapping it.
- Fetch and build the dependencies; by default, vcpkg targets x86 so be sure to specify the x64 target if required by specifying it when invoking vcpkg install, as shown here:

```
vcpkg install openssl:x64-windows xerces-c:x64-windows
```

- Configure OpenDDS by passing the openssl and xerces3 switches. As a convenience, it can be helpful to set an environment variable to store the path since it is the same location for both dependencies.

```
set VCPKG_INSTALL=c:\path\to\vcpkg\installed\x64-windows
configure --security --openssl=%VCPKG_INSTALL% --xerces3=%VCPKG_INSTALL%
```

- Compile with msbuild or by launching Visual Studio from this command prompt so it inherits the correct environment variables and building from there.

```
msbuild /m DDS_TAOv2_all.sln
```

Manual Build

Note: For all of the build steps listed here, check that each package targets the same architecture (either 32-bit or 64-bit) by compiling all dependencies within the same type of Developer Command Prompt.

Compiling OpenSSL

Official OpenSSL instructions can be found here.

1. Install Perl and add it to the Path environment variable. For this guide, ActiveState is used.
2. Install Netwide Assembler (NASM). Click through the latest stable release and there is a win32 and win64 directory containing executable installers. The installer does not update the Path environment variable, so a manual entry (`%LOCALAPPDATA%\bin\NASM`) is necessary.
3. Download the required version of OpenSSL by cloning the repository.
4. Open a Developer Command Prompt (32-bit or 64-bit depending on the desired target architecture) and change into the freshly cloned openssl directory.
5. Run the configure script and specify a required architecture (`perl Configure VC-WIN32` or `perl Configure VC-WIN64A`).
6. Run `nmake`
7. Run `nmake install`

Note: If the default OpenSSL location is desired, which will be searched by OpenDDS, open the "Developer Command Prompt" as an administrator before running the install. It will write to `C:\Program Files` or `C:\Program Files (x86)` depending on the architecture.

Compiling Xerces-C++ 3

Official Xerces instructions can be found here.

1. Download/extract the Xerces source files.
2. Create a cmake build directory and change into it (from within the Xerces source tree).

```
mkdir build
cd build
```

3. Run cmake with the appropriate generator. In this case Visual Studio 2017 with 64-bit is being used so:

```
cmake -G "Visual Studio 15 2017 Win64" ..
```

4. Run cmake again with the build switch and install target (this should be done in an administrator command-prompt to install in the default location as mentioned above).

```
cmake --build . --target install
```

Configuring and Building OpenDDS:

1. Change into the OpenDDS root folder and run configure with security enabled.
   - If the default location was used for OpenSSL and Xerces, configure should automatically find the dependencies:

```
configure --security
```

2. If a different location was used (assuming environment variables `NEW_SSL_ROOT` and `NEW_XERCES_ROOT` point to their respective library directories):

```
configure --security --openssl=%NEW_SSL_ROOT% \
  --xerces3=%NEW_XERCES_ROOT%
```

3. Compile with msbuild (or by opening the solution file in Visual Studio and building from there).

```
msbuild /m DDS_TAOv2_all.sln
```

Building OpenDDS with Security on Linux

Xerces-C++ and OpenSSL may be installed using the system package manager, or built from source. If using the system package manager (that is, headers can be found under `/usr/include`), invoke the configure script with the –security option. If Xerces-C++ and/or OpenSSL are built from source or installed in a custom location, also provide the `--xerces3=/foo` and `--openssl=/bar` command line options.

Building OpenDDS with Security on macOS

Xerces-C++ and OpenSSL may be installed using homebrew or another developer-focused package manager, or built from source. The instructions above for Linux also apply to macOS but the package manager will not install directly in `/usr` so make sure to specify the library locations to the configure script.

Building OpenDDS with Security for Android

See the `docs/android.md` file included in the OpenDDS source code.

1.14.2 Architecture of the DDS Security Specification

The DDS Security specification defines plugin APIs for Authentication, Access Control, and Cryptographic operations. These APIs provide a level of abstraction for DDS implementations as well as allowing for future extensibility and version control. Additionally, the specification defines Built-In implementations of each of these plugins, which allows for a baseline of functionality and interoperability between DDS implementations. OpenDDS implements these Built-In plugins, and this document assumes that the Built-In plugins are being used. Developers using OpenDDS may also implement their own custom plugins, but those efforts are well beyond the scope of this document.

1.14.3 Terms and Background Info

DDS Security uses current industry standards and best-practices in security. As such, this document makes use of several security concepts which may warrant additional research by OpenDDS users.

Term Group	References
Public Key Cryptography (including Private Keys)	• Public Key Cryptography • RSA • Elliptic Curve Cryptography
Public Key Certificate	• Public Key Certificate • Certificate Authority • X.509 • PEM
Signed Documents	• Digital Signature

Table

1.14.4 Required DDS Security Artifacts

Per-Domain Artifacts

These are shared by all participants within the secured DDS Domain:

- Identity CA Certificate
- Permissions CA Certificate (may be same as Identity CA Certificate)
- Governance Document
- Signed by Permissions CA using its private key

Per-Participant Artifacts

These are specific to the individual Domain Participants within the DDS Domain:

- Identity Certificate and its Private Key
- Issued by Identity CA (or a CA that it authorized to act on its behalf)
- Permissions Document
- Contains a "subject name" which matches the participant certificate's Subject
- Signed by Permissions CA using its private key

1.14.5 Required OpenDDS Configuration

The following configuration steps are required to enable OpenDDS Security features:

1. Select RTPS Discovery and the RTPS-UDP Transport; because DDS Security only works with these configurations, both must be specified for any security-enabled participant.
2. Enable OpenDDS security-features, which can be done two ways:
   - Via API: "`TheServiceParticipant->set_security(true);`" or
   - Via config file: "`DCPSSecurity=1`" in the `[common]` section.

DDS Security Configuration via PropertyQosPolicy

When the application creates a DomainParticipant object, the DomainParticipantQos passed to the `create_participant()` method now contains a PropertyQosPolicy object which has a sequence of name-value pairs. The following properties must be included to enable security. Except where noted, these values take the form of a URI starting with either the scheme "file:" followed by a filesystem path (absolute or relative) or the scheme "data:" followed by the literal data.

Name	Value	Notes
`dds.sec.auth.identity_ca`	Certificate PEM file	Can be the same as `permissions_ca`
`dds.sec.access.permissions_ca`	Certificate PEM file	Can be the `same as identity_ca`
`dds.sec.access.governance`	Signed XML (.p7s)	Signed by `permissions_ca`
`dds.sec.auth. identity_certificate`	Certificate PEM file	Signed by `identity_ca`
`dds.sec.auth.private_key`	Private Key PEM file	Private key for `identity_certificate`
`dds.sec.auth.password`	Private Key Password (not a URI)	Optional, Base64 encoded
`dds.sec.access.permissions`	Signed XML (.p7s)	Signed by `permissions_ca`

Table

PropertyQosPolicy Example Code

Below is an example of code that sets the DDS Participant QoS's PropertyQoSPolicy in order to configure DDS Security.

```
// DDS Security artifact file locations
const char auth_ca_file[] = "file:identity_ca_cert.pem";
const char perm_ca_file[] = "file:permissions_ca_cert.pem";
const char id_cert_file[] = "file:test_participant_01_cert.pem";
const char id_key_file[] = "file:test_participant_01_private_key.pem";
const char governance_file[] = "file:governance_signed.p7s";
const char permissions_file[] = "file:permissions_01_signed.p7s";

// DDS Security property names
const char DDSSEC_PROP_IDENTITY_CA[] = "dds.sec.auth.identity_ca";
const char DDSSEC_PROP_IDENTITY_CERT[] = "dds.sec.auth.identity_certificate";
const char DDSSEC_PROP_IDENTITY_PRIVKEY[] = "dds.sec.auth.private_key";
const char DDSSEC_PROP_PERM_CA[] = "dds.sec.access.permissions_ca";
const char DDSSEC_PROP_PERM_GOV_DOC[] = "dds.sec.access.governance";
const char DDSSEC_PROP_PERM_DOC[] = "dds.sec.access.permissions";

void append(DDS::PropertySeq& props, const char* name, const char* value)
{
  const DDS::Property_t prop = {name, value, false /*propagate*/};
  const unsigned int len = props.length();
  props.length(len + 1);
  props[len] = prop;
}

int main(int argc, char* argv[])
{
  DDS::DomainParticipantFactory_var dpf =
    TheParticipantFactoryWithArgs(argc, argv);

  // Start with the default Participant QoS
  DDS::DomainParticipantQos part_qos;
  dpf->get_default_participant_qos(part_qos);

  // Add properties required by DDS Security
  DDS::PropertySeq& props = part_qos.property.value;
  append(props, DDSSEC_PROP_IDENTITY_CA, auth_ca_file);
  append(props, DDSSEC_PROP_IDENTITY_CERT, id_cert_file);
  append(props, DDSSEC_PROP_IDENTITY_PRIVKEY, id_key_file);
  append(props, DDSSEC_PROP_PERM_CA, perm_ca_file);
  append(props, DDSSEC_PROP_PERM_GOV_DOC, governance_file);
  append(props, DDSSEC_PROP_PERM_DOC, permissions_file);

  // Create the participant
  participant = dpf->create_participant(4, // DomainID
                                        part_qos,
                                        0, // No listener
                                        OpenDDS::DCPS::DEFAULT_STATUS_MASK);
```

Identity Certificates and Certificate Authorities

All certificate inputs to OpenDDS, including self-signed CA certificates, are expected to be an X.509 v3 certificate in PEM format for either a 2048-bit RSA key or a 256-bit Elliptic Curve key (using the prime256v1 curve).

Identity, Permissions, and Subject Names

The "subject_name" element for a signed permissions XML document must match the "Subject:" field provided by the accompanying Identity Certificate which is transmitted during participant discovery, authentication, and authorization. This ensures that the permissions granted by the Permissions CA do, in fact, correspond to the identity provided.

Examples in the OpenDDS Source Code Repository

Examples to demonstrate how the DDS Security features are used with OpenDDS can be found in the OpenDDS GitHub repository.

The following table describes the various examples and where to find them in the source tree.

Example	Source Location
C++ application that configures security QoS policies via command-line parameters	tests/DCPS/Messenger/publisher.cpp
Identity CA Certificate (along with private key)	tests/security/certs/identity/identity_ca_cert.pem
Permissions CA Certificate (along with private key)	tests/security/certs/permissions/permissions_ca_cert.pem
Participant Identity Certificate (along with private key)	tests/security/certs/identity/test_participant_01_cert.pem
Governance XML Document (alongside signed document)	tests/DCPS/Messenger/governance.xml
Permissions XML Document (alongside signed document)	tests/DCPS/Messenger/permissions_1.xml

Table

Using OpenSSL Utilities for OpenDDS

To generate certificates using the openssl command, a configuration file "openssl.cnf" is required (see below for example commands). Before proceeding, it may be helpful to review OpenSSL's manpages to get help with the file format. In particular, configuration file format and ca command's documentation and configuration file options.

An example OpenSSL CA-Config file used in OpenDDS testing can be found here: tests/security/certs/identity/identity_ca_openssl.cnf

Creating Self-Signed Certificate Authorities

Generate a self-signed 2048-bit RSA CA:

```
openssl genrsa -out ca_key.pem 2048
openssl req -config openssl.cnf -new -key ca_key.pem -out ca.csr
openssl x509 -req -days 3650 -in ca.csr -signkey ca_key.pem -out ca_cert.pem
```

Generate self-signed 256-bit Elliptic Curve CA:

```
openssl ecparam -name prime256v1 -genkey -out ca_key.pem
openssl req -config openssl.cnf -new -key ca_key.pem -out ca.csr
openssl x509 -req -days 3650 -in ca.csr -signkey ca_key.pem -out ca_cert.pem
```

Creating Signed Certificates with an Existing CA

Generate a signed 2048-bit RSA certificate:

```
openssl genrsa -out cert_1_key.pem 2048
openssl req -new -key cert_1_key.pem -out cert_1.csr
openssl ca -config openssl.cnf -days 3650 -in cert_1.csr -out cert_1.pem
```

Generate a signed 256-bit Elliptic Curve certificate:

```
openssl ecparam -name prime256v1 -genkey -out cert_2_key.pem
openssl req -new -key cert_2_key.pem -out cert_2.csr
openssl ca -config openssl.cnf -days 3650 -in cert_2.csr -out cert_2.pem
```

Signing Documents with SMIME

Sign a document using existing CA & CA private key:

```
openssl smime -sign -in doc.xml -text -out doc_signed.p7s -signer ca_cert.pem -inkey ca_
↪private_key.pem
```

1.14.6 Domain Governance Document

The signed governance document is used by the DDS Security built-in access control plugin in order to determine both per-domain and per-topic security configuration options for specific domains. For full details regarding the content of the governance document, see the OMG DDS Security specification section 9.4.1.2.

Global Governance Model

It's worth noting that the DDS Security Model expects the governance document to be globally shared by all participants making use of the relevant domains described within the governance document. Even if this is not the case, the local participant will verify incoming authentication and access control requests as if the remote participant shared the same governance document and accept or reject the requests accordingly.

Key Governance Elements

Domain Id Set

A list of domain ids and/or domain id ranges of domains impacted by the current domain rule. The syntax is the same as the domain id set found in the governance document.

The set is made up of <id> tags or <id_range> tags. An <id> tag simply contains the domain id that are part of the set. An <id_range> tag can be used to add multiple ids at once. It must contain a <min> tag to say where the range starts and may also have a <max> tag to say where the range ends. If the <max> tag is omitted then the set includes all valid domain ids starting at <min>.

If the domain rule or permissions grant should to apply to all domains, use the following:

```
<domains>
  <id_range><min>0</min></id_range>
</domains>
```

If there's a need to be selective about what domains are chosen, here's an annotated example:

```
<domains>
  <id>2</id>
  <id_range><min>4</min><max>6</max></id_range> <!-- 4, 5, 6 -->
  <id_range><min>10</min></id_range> <!-- 10 and onward -->
</domains>
```

Governance Configuration Types

The following types and values are used in configuring both per-domain and per-topic security configuration options. We summarize them here to simplify discussion of the configuration options where they're used, found below.

Boolean

A boolean value indicating whether a configuration option is enabled or not. Recognized values are: `TRUE/true/1` or `FALSE/false/0.`

ProtectionKind

The method used to protect domain data (message signatures or message encryption) along with the ability to include origin authentication for either protection kind. Currently, OpenDDS doesn't implement origin authentication. So while the "_WITH_ORIGIN_AUTHENTICATION" options are recognized, the underlying configuration is unsupported. Recognized values are: `{NONE, SIGN, ENCRYPT,SIGN_WITH_ORIGIN_AUTHENTICATION`, or `ENCRYPT_WITH_ORIGIN_AUTHENTICATION}`

BasicProtectionKind

The method used to protect domain data (message signatures or message encryption). Recognized values are: `{NONE, SIGN, or ENCRYPT}`

FnmatchExpression

A wildcard-capable string used to match topic names. Recognized values will conform to POSIX `fnmatch()` function as specified in POSIX 1003.2-1992, Section B.6.

Domain Rule Configuration Options

The following XML elements are used to configure domain participant behaviors.

Element	Type	Description
<allow_unauthenticated_participants>	Boolean	A boolean value which determines whether to allow unauthenticated participants for the current domain rule
<enable_join_access_control>	Boolean	A boolean value which determines whether to enforce domain access controls for authenticated participants
<discovery_protection_kind>	ProtectionKind	The discovery protection element specifies the protection kind used for the built-in DataWriter(s) and DataReader(s) used for secure endpoint discovery messages
<liveliness_protection_kind>	ProtectionKind	The liveliness protection element specifies the protection kind used for the built-in DataWriter and DataReader used for secure liveliness messages
<rtps_protection_kind>	BasicProtectionKind	Indicate the desired level of protection for the whole RTPS message. Very little RTPS data exists outside the "metadata protection" envelope (see topic rule configuration options), and so for most use cases topic-level "data protection" or "metadata protection" can be combined with discovery protection and/or liveliness protection in order to secure domain data adequately. One item that is not secured by "metadata protection" is the timestamp, since RTPS uses a separate InfoTimestamp submessage for this. The timestamp can be secured by using <rtps_protection_kind>

Table

Topic Rule Configuration Options

The following XML elements are used to configure topic endpoint behaviors:

<topic_expression> : **FnmatchExpression**

A wildcard-capable string used to match topic names. See description above. A "default" rule to catch all previously unmatched topics can be made with: <topic_expression>*</topic_expression>

<enable_discovery_protection> : **Boolean**

Enables the use of secure discovery protections for matching user topic announcements.

<enable_read_access_control> : **Boolean**

Enables the use of access control protections for matching user topic DataReaders.

<enable_write_access_control> : **Boolean**

Enables the use of access control protections for matching user topic DataWriters.

<metadata_protection_kind> : **ProtectionKind**

Specifies the protection kind used for the RTPS SubMessages sent by any DataWriter and DataReader whose associated Topic name matches the rule's topic expression.

<data_protection_kind> : **BasicProtectionKind**

Specifies the basic protection kind used for the RTPS SerializedPayload SubMessage element sent by any DataWriter whose associated Topic name matches the rule's topic expression.

Governance XML Example

```
<?xml version="1.0" encoding="utf-8"?>
<dds xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation=
↪"http://www.omg.org/spec/DDS- Security/20170801/omg_shared_ca_domain_governance.xsd">
  <domain_access_rules>
    <domain_rule>
      <domains>
        <id>0</id>
        <id_range>
          <min>10</min>
          <max>20</max>
        </id_range>
      </domains>
<allow_unauthenticated_participants>FALSE</allow_unauthenticated_participants>
      <enable_join_access_control>TRUE</enable_join_access_control>
      <rtps_protection_kind>SIGN</rtps_protection_kind>
      <discovery_protection_kind>ENCRYPT</discovery_protection_kind>
      <liveliness_protection_kind>SIGN</liveliness_protection_kind>
      <topic_access_rules>
        <topic_rule>
          <topic_expression>Square*</topic_expression>
          <enable_discovery_protection>TRUE</enable_discovery_protection>
          <enable_read_access_control>TRUE</enable_read_access_control>
```

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```
          <enable_write_access_control>TRUE</enable_write_access_control>
          <metadata_protection_kind>ENCRYPT</metadata_protection_kind>
          <data_protection_kind>ENCRYPT</data_protection_kind>
        </topic_rule>
        <topic_rule>
          <topic_expression>Circle</topic_expression>
          <enable_discovery_protection>TRUE</enable_discovery_protection>
          <enable_read_access_control>FALSE</enable_read_access_control>
          <enable_write_access_control>TRUE</enable_write_access_control>
          <metadata_protection_kind>ENCRYPT</metadata_protection_kind>
          <data_protection_kind>ENCRYPT</data_protection_kind>
        </topic_rule>
        <topic_rule>
          <topic_expression>Triangle</topic_expression>
          <enable_discovery_protection>FALSE</enable_discovery_protection>
          <enable_read_access_control>FALSE</enable_read_access_control>
          <enable_write_access_control>TRUE</enable_write_access_control>
          <metadata_protection_kind>NONE</metadata_protection_kind>
          <data_protection_kind>NONE</data_protection_kind>
        </topic_rule>
        <topic_rule>
          <topic_expression>*</topic_expression>
          <enable_discovery_protection>TRUE</enable_discovery_protection>
          <enable_read_access_control>TRUE</enable_read_access_control>
          <enable_write_access_control>TRUE</enable_write_access_control>
          <metadata_protection_kind>ENCRYPT</metadata_protection_kind>
          <data_protection_kind>ENCRYPT</data_protection_kind>
        </topic_rule>
      </topic_access_rules>
    </domain_rule>
  </domain_access_rules>
</dds>
```

1.14.7 Participant Permissions Document

The signed permissions document is used by the DDS Security built-in access control plugin in order to determine participant permissions to join domains and to create endpoints for reading, writing, and relaying domain data. For full details regarding the content of the permissions document, see the OMG DDS Security specification section 9.4.1.3.

Key Permissions Elements

Grants

Each permissions file consists of one or more permissions grants. Each grant bestows access control privileges to a single subject name for a limited validity period.

Subject Name

Each grant's subject name is intended to match against a corresponding identity certificate's "subject" field. In order for permissions checks to successfully validate for both local and remote participants, the supplied identity certificate subject name must match the subject name of one of the grants included in the permissions file.

Validity

Each grant's validity section contains a start date and time (<not_before>) and an end date and time (<not_after>) to indicate the period of time during which the grant is valid.

The format of the date and time, which is like ISO-8601, must take one of the following forms:

- YYYY-MM-DDThh:mm:ss
  - Example: 2020-10-26T22:45:30
- YYYY-MM-DDThh:mm:ssZ
  - Example:2020-10-26T22:45:30Z
- YYYY-MM-DDThh:mm:ss+hh:mm
  - Example:2020-10-26T23:45:30+01:00
- YYYY-MM-DDThh:mm:ss-hh:mm
  - Example:2020-10-26T16:45:30-06:00

All fields shown must include leading zeros to fill out their full width, as shown in the examples. YYYY-MM-DD is the date and hh:mm:ss is the time in 24-hour format. The date and time must be able to be represented by the time_t (C standard library) type of the system. The seconds field can also include a variable length fractional part, like 00.0 or 01.234, but it will be ignored because time_t represents a whole number of seconds. Examples #1 and #2 are both interpreted to be using UTC. To put the date and time in a local time, a time zone offset can to be added that says how far the local timezone is ahead of (using '+' as in example #3) or behind (using '-' as in example #4) UTC at that date and time.

Allow / Deny Rules

Grants will contain one or more allow / deny rules to indicate which privileges are being applied. When verifying that a particular operation is allowed by the supplied grant, rules are checked in the order they appear in the file. If the domain, partition, and (when implemented) data tags for an applicable topic rule match the operation being verified, the rule is applied (either allow or deny). Otherwise, the next rule is considered. Special Note: If a grant contains any allow rule that matches a given domain (even one with no publish / subscribe / relay rules), the grant may be used to join a domain with join access controls enabled.

Default Rule

The default rule is the rule applied if none of the grant's allow rules or deny rules match the incoming operation to be verified.

Domain Id Set

Every allow or deny rule must contain a set of domain ids to which it applies. The syntax is the same as the domain id set found in the governance document. See *Key Governance Elements* for details.

Publish / Subscribe / Relay Rules (PSR rules)

Every allow or deny rule may optionally contain a list of publish, subscribe, or relay rules bestowing privileges to publish, subscribe, or relay data (respectively). Each rule applies to a collection of topics in a set of partitions with a particular set of data tags. As such, each rule must then meet these three conditions (topics, partitions, and (when implemented) data tags) in order to apply to a given operation. These conditions are governed by their relevant subsection, but the exact meaning and default values will vary depending on the both the PSR type (publish, subscribe, relay) as well as whether this is an allow rule or a deny rule. Each condition is summarized below. See the DDS Security specification for full details. OpenDDS does not currently support relay-only behavior and consequently ignores allow and deny relay rules for both local and remote entities. Additionally, OpenDDS does not currently support data tags, and so the data tag condition applied is always the "default" behavior described below.

Topic List

The list of topics and/or topic expressions for which a rule applies. Topic names and expressions are matched using POSIX fnmatch() rules and syntax. If the triggering operation matches any of the topics listed, the topic condition is met. The topic section must always be present for a PSR rule, so there there is no default behavior.

Partition List

The partitions list contains the set of partition names for which the parent PSR rule applies. Similarly to topics, partition names and expressions are matched using POSIX `fnmatch()` rules and syntax. For "allow" PSR rules, the DDS entity of the associated triggering operation must be using a strict subset of the partitions listed for the rule to apply. When no partition list is given for an "allow" PSR rule, the "empty string" partition is used as the default value. For "deny" PSR rules, the rule will apply if the associated DDS entity is using any of the partitions listed. When no partition list is given for a "deny" PSR rule, the wildcard expression "*" is used as the default value.

Data Tags List

Data tags are an optional part of the DDS Security specification and are not currently implemented by OpenDDS. If they were implemented, the condition criteria for data tags would be similar to partitions. For "allow" PSR rules, the DDS entity of the associated triggering operation must be using a strict subset of the data tags listed for the rule to apply. When no data tag list is given for an "allow" PSR rule, the empty set of data tags is used as the default value. For "deny" PSR rules, the rule will apply if the associated DDS entity is using any of the data tags listed. When no data tag list is given for a "deny" PSR rule, the set of "all possible tags" is used as the default value.

Permissions XML Example

```
<?xml version="1.0" encoding="UTF-8"?>
<dds xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation=
↪"http://www.omg.org/spec/DDS-Security/20170801/omg_shared_ca_permissions.xsd">
  <permissions>
    <grant name="ShapesPermission">
      <subject_name>emailAddress=cto@acme.com, CN=DDS Shapes Demo, OU=CTO Office, O=ACME␣
↪Inc., L=Sunnyvale, ST=CA, C=US</subject_name>
      <validity>
        <not_before>2015-10-26T00:00:00</not_before>
        <not_after>2020-10-26T22:45:30</not_after>
      </validity>
      <allow_rule>
        <domains>
          <id>0</id>
        </domains>
      </allow_rule>
      <deny_rule>
        <domains>
          <id>0</id>
        </domains>
        <publish>
          <topics>
            <topic>Circle1</topic>
          </topics>
        </publish>
        <publish>
          <topics>
            <topic>Square</topic>
          </topics>
          <partitions>
```

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```
            <partition>A_partition</partition>
          </partitions>
        </publish>
        <subscribe>
          <topics>
            <topic>Square1</topic>
          </topics>
        </subscribe>
        <subscribe>
          <topics>
            <topic>Tr*</topic>
          </topics>
          <partitions>
            <partition>P1*</partition>
          </partitions>
        </subscribe>
      </deny_rule>
      <default>DENY</default>
    </grant>
  </permissions>
</dds>
```

1.14.8 DDS Security Implementation Status

The following DDS Security features are not implemented in OpenDDS.

1. Optional parts of the DDS Security v1.1 specification
   - Ability to write a custom plugin in C or in Java (C++ is supported)
   - Logging Plugin support
   - Built-in Logging Plugin
   - Data Tagging
2. Use of RTPS KeyHash for encrypted messages
   - OpenDDS doesn't use KeyHash, so it meets the spec requirements of not leaking secured data through KeyHash
3. Immutability of Publisher's Partition QoS, see OMG Issue DDSSEC12-49 (Member Link)
4. Use of multiple plugin configurations (with different Domain Participants)
5. CRL (**RFC 5280**) and OCSP (**RFC 2560**) support
6. Certain plugin operations not used by built-in plugins may not be invoked by middleware
7. Origin Authentication
8. PKCS#11 for certificates, keys, passwords
9. Relay as a permissions "action" (Publish and Subscribe are supported)
10. Legacy matching behavior of permissions based on Partition QoS (9.4.1.3.2.3.1.4 in spec)
11. 128-bit AES keys (256-bit is supported)
12. Configuration of Built-In Crypto's key reuse (within the DataWriter) and blocks-per-session

13. Signing (without encrypting) at the payload level, see OMG Issue DDSSEC12-59 (Member Link)

1.15 Internet-Enabled RTPS

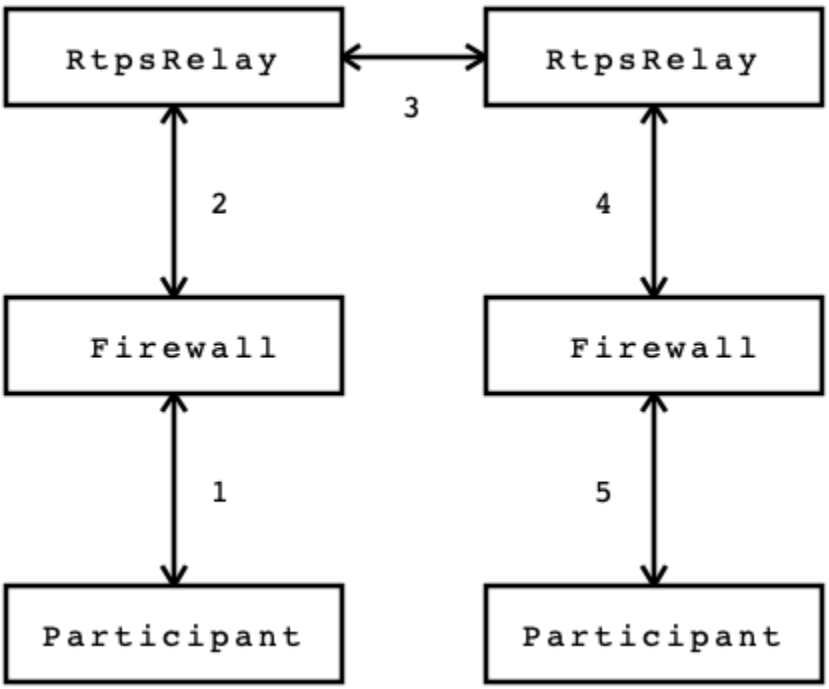
1.15.1 Overview

Like any specification, standard, or system, RTPS was designed with certain assumptions. Two of these assumptions severely limit the ability to use RTPS in modern network environments. First, RTPS, or more specifically, SPDP uses multicast for discovery. Multicast is not supported on the public Internet which precludes the use of RTPS for Internet of Things (IoT) applications and Industrial Internet of Things (IIoT) applications. Second, SPDP and SEDP advertise locators (IP and port pairs) for endpoints (DDS readers and writer). If the participant is behind a firewall that performs network address translation, then the locators advertised by the participant are useless to participants on the public side of the firewall.

This section describes different tools and techniques for getting around these limitations. First, we introduce the *RtpsRelay* as a service for forwarding RTPS messages according to application-defined groups. The RtpsRelay can be used to connect participants that are deployed in environments that don't support multicast and whose packets are subject to NAT. Second, we introduce Interactive Connection Establishment (ICE) for RTPS. Adding ICE to RTPS is an optimization that allows participants that are behind firewalls that perform NAT to exchange messages directly. ICE requires a back channel for distributing discovery information and is typically used with the RtpsRelay.

1.15.2 The RtpsRelay

The RtpsRelay is designed to allow participants to exchange RTPS datagrams when separated by a firewall that performs network address translation (NAT) and/or a network that does not support multicast like the public Internet. The RtpsRelay supports both IPv4 and IPv6. A participant that uses an RtpsRelay Instance is a *client* of that instance. Each RtpsRelay instance contains two participants: the *Application Participant* and the *Relay Participant*. The Application Participant runs in the domain of the application. The RtpsRelay reads the built-in topics to discover Participants, DataReaders, and DataWriters. It then shares this information with other RtpsRelay instances using the Relay Participant. Each RtpsRelay instance maintains a map of associated readers and writers. When a client sends an RTPS datagram to its RtpsRelay instance, the RtpsRelay instance uses the association table to forward the datagram to other clients and other RtpsRelay instances so that they can deliver it to their clients. Clients send RTPS datagrams via unicast which is generally supported and compatible with NAT. The RtpsRelay can be used in lieu of or in addition to conventional RTPS discovery.



The preceding diagram illustrates how the RtpsRelay can be used to connect participants that are behind firewalls that may be performing NAT. First, a Participant sends an RTPS datagram to its associated RtpsRelay (1). This datagram is intercepted by the firewall, the source address and port are replaced by the external IP address and port of the firewall, and then the datagram is sent to the RtpsRelay (2). The relationship between the source address and external IP address and port selected by the firewall is called a NAT binding. The RtpsRelay instance forwards the datagram to other RtpsRelay instances (3). The RtpsRelays then forward the datagram to all of the destination participants (4). Firewalls on the path to the participants intercept the packet and replace the destination address (which is the external IP and port of the firewall) with the address of the Participant according to a previously created NAT binding (5).

The RTPS implementation in OpenDDS uses a port for SPDP, a port for SEDP, and a port for conventional RTPS messages. The relay mirrors this idea and exposes three ports to handle each type of traffic.

To keep NAT bindings alive, clients send STUN binding requests and indications periodically to the RtspRelay ports. Participants using ICE may use these ports as a STUN server for determining a server reflexive address. The timing parameters for the periodic messages are controlled via the ICE configuration variables for server reflexive addresses.

Using the RtpsRelay

Support for the RtpsRelay is activated via configuration. See *Table 7-5 RTPS Discovery Configuration Options* and *Table 7-17 RTPS_UDP Configuration Options*. As an example:

```
[common]
DCPSGlobalTransportConfig=$file

[domain/4]
DiscoveryConfig=rtps

[rtps_discovery/rtps]
SpdpRtpsRelayAddress=1.2.3.4:4444
SedpRtpsRelayAddress=1.2.3.4:4445
```

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```
UseRtpsRelay=1

[transport/the_rtps_transport]
transport_type=rtps_udp
DataRtpsRelayAddress=1.2.3.4:4446
UseRtpsRelay=1
```

Each participant should use a single RtpsRelay instance due to the way NAT bindings work. Most firewalls will only forward packets received from the destination address that was originally used to create the NAT binding. That is, if participant A is interacting with relay A and participant B is interacting with relay B, then a message from A to B must go from A to relay A, to relay B, and finally to B. Relay A cannot send directly to B since that packet will not be accepted by the firewall.

Usage

The RtpsRelay itself is an OpenDDS application. The source code is located in `tools/rtpsrelay`. Security must be enabled to build the RtpsRelay. See *Building OpenDDS with Security Enabled*. Each RtpsRelay process has a set of ports for exchanging RTPS messages with the participants called the "vertical" ports and a set of ports for exchanging RTPS messages with other relays called the "horizontal" ports.

The RtpsRelay contains an embedded webserver called the meta discovery server. The webserver has the following endpoints:

- `/config`

  Responds with configured content and content type. See -MetaDiscovery options below. Potential client participants can download the necessary configuration from this endpoint.

- `/healthcheck`

  Responds with HTTP 200 (OK) or 503 (Service Unavailable) if thread monitoring is enabled and the RtpsRelay is not admitting new client participants. Load balancers can use this endpoint to route new client participants to an available RtpsRelay instance.

The command-line options for the RtpsRelay:

- `-Id STRING`

  The Id option is mandatory and is a unique id associated with all topics published by the relay.

- `-HorizontalAddress ADDRESS`

  Determines the base network address used for receiving RTPS message from other relays. By default, the relay listens on the first IP network and uses port 11444 for SPDP messages, 11445 for SEDP messages, and 11446 for data messages.

- `-VerticalAddress ADDRESS`

  Determines the base network address used for receiving RTPS messages from the participants. By default, the relay listens on 0.0.0.0:4444 for SPDP messages, 0.0.0.0:4445 for SEDP messages, and 0.0.0.0.4446 for data messages.

- `-RelayDomain DOMAIN`

  Sets the DDS domain used by the Relay Participant. The default is 0.

- `-ApplicationDomain DOMAIN`

  Sets the DDS domain used by the Application Participant. The default is 1.

- `-UserData STRING`

  Set the contents of the Application Participant's UserData QoS policy to the provided string.

- `-BufferSize INTEGER`

  Send of send and receive buffers in bytes

- `-Lifespan SECONDS`

  RtpsRelay will only forward a datagram to a client if it has received a datagram from the client in this amount of time. Otherwise, participant is marked as not alive. The default is 60 seconds.

- `-InactivePeriod SECONDS`

  RtpsRelay will mark participant as not active if does not receive a datagram from the client in this amount of time. The default is 60 seconds.

- `-AllowEmptyPartitions 0|1`

  Allow client participants with no partitions. Defaults to 1 (true).

- `-IdentityCA PATH`

  `-PermissionsCA PATH`

  `-IdentityCertificate PATH`

  `-IdentityKey PATH`

  `-Governance PATH`

  `-Permissions PATH`

  Provide paths to the DDS Security documents. Requires a security-enabled build.

- `-RestartDetection 0|1`

  Setting RestartDetction to 1 causes the relay to track clients by the first 6 bytes of their RTPS GUID and source IP address and clean up older sessions with the same key. The default is 0 (false).

- `-LogWarnings0|1`

  `-LogDiscovery0|1`

  `-LogActivity0|1`

  Enable/disable logging of the various event types.

- `-LogRelayStatistics SECONDS`

  `-LogHandlerStatistics SECONDS`

  `-LogParticipantStatistics SECONDS`

  Write statistics for the various event types to the log at the given interval, defaults to 0 (disabled).

- `-PublishRelayStatistics SECONDS`

  `-PublishHandlerStatistics SECONDS`

  `-PublishParticipantStatistics SECONDS`

  Configure the relay to publish usage statistics on DDS topics at the given interval, defaults to 0 (disabled).

- `-LogThreadStatus 0|1`

  Log the status of the threads in the RtpsRelay, defaults to 0 (disabled).

- `-ThreadStatusSafetyFactor INTEGER`

  Restart if thread monitoring is enabled and a thread has not checked in for this many reporting intervals, default 3.

- `-UtilizationLimit DECIMAL`

  If thread monitoring is enabled, the RtpsRelay will not accept to new client participants if the CPU utilization of any thread is above this limit, default .95.

- `-PublishRelayStatus SECONDS`

  `-PublishRelayStatusLiveliness SECONDS`

  Setting PublishRelayStatus to a positive integer causes the relay to publish its status at that interval. Setting PublishRelayStatusLiveliness to a positive integer causes the relay to set the liveliness QoS on the relay status topic.

- `-MetaDiscoveryAddress ADDRESS`

  Listening address for the meta discovery server, default 0.0.0.0:8080.

- `-MetaDiscoveryContentType CONTENT-TYPE`

  The HTTP content type to report for the meta discovery config endpoint, default application/json.

- `-MetaDiscoveryContentPath PATH`

  `-MetaDiscoveryContent CONTENT`

  The content returned by the meta discovery config endpoint, default {}. If a path is specified, the content of the file will be used.

- `-MaxAddrSetSize INTEGER`

  The maximum number addresses that the RtpsRelay will maintain for a client participant, defaults to 0 (infinite).

- `-RejectedAddressDuration SECONDS`

  Amount of time to reject messages from client participants that show suspicious behavior, e.g., those that send messages from the RtpsRelay back to the RtpsRelay. The default is 0 (disabled).

Deployment Considerations

Running an RtpsRelay relay cluster with RTPS in the cloud leads to a bootstrapping problem since multicast is not supported in the cloud. One option is to not use RTPS for discovery. Another option is to run a single well-known relay that allows the other relays to discover each other. A third option is to use a program translates multicast to unicast.

RTPS uses UDP which typically cannot be load balanced effectively due to the way NAT bindings work. Consequently, each RtpsRelay server must have a public IP address. Load balancing can be achieved by having the participants choose a relay according to a load balancing policy. To illustrate, each relay could also run an HTTP server which does nothing but serve the public IP address of the relay. These simple web servers would be exposed via a centralized load balancer. A participant, then, could access the HTTP load balancer to select a relay.

1.15.3 Interactive Connectivity Establishment (ICE) for RTPS

Interactive Connectivity Establishment (ICE) is protocol for establishing connectivity between a pair of hosts that are separated by at least one firewall that performs network address translation. ICE can be thought of as an optimization for situations that require an RtpsRelay. The success of ICE depends on the firewall(s) that separate the hosts.

The ICE protocol has three steps. First, a host determines its public IP address by sending a STUN binding request to a public STUN server. The STUN server sends a binding success response that contains the source address of the request. If the host has a public IP address, then the address returned by STUN will match the IP address of the host. Otherwise, the address will be the public address of the outermost firewall. Second, the hosts generate and exchange candidates (which includes the public IP address determined in the first step) using a side channel. A candidate is an IP and port that responds to STUN messages and sends datagrams. Third, the hosts send STUN binding requests to the candidates in an attempt to generate the necessary NAT bindings and establish connectivity.

For OpenDDS, ICE can be used to potentially establish connectivity between SPDP endpoints, SEDP endpoints, and ordinary RTPS endpoints. SPDP is used as the side channel for SEDP and SEDP is used as the side channel for the ordinary RTPS endpoints. To this, we added two parameters to the RTPS protocol for sending general ICE information and ICE candidates and added the ability to execute the ICE protocol and process STUN messages to the RTPS transports.

ICE is defined in IETF RFC 8445. ICE utilizes the STUN protocol that is defined in IETF RFC 5389. The ICE implementation in OpenDDS does not use TURN servers.

ICE is enabled through configuration. The minimum configuration involves setting the `UseIce` flag and providing addresses for the STUN servers. See *Table 7-5 RTPS Discovery Configuration Options* and *Table 7-17 RTPS_UDP Configuration Options* for details.

```
[common]
DCPSGlobalTransportConfig=$file
DCPSDefaultDiscovery=DEFAULT_RTPS

[transport/the_rtps_transport]
transport_type=rtps_udp
DataRtpsRelayAddress=5.6.7.8:4446
UseIce=1
DataStunServerAddress=1.2.3.4:3478

[domain/42]
DiscoveryConfig=DiscoveryConfig1
[rtps_discovery/DiscoveryConfig1]
SpdpRtpsRelayAddress=5.6.7.8:4444
SedpRtpsRelayAddress=5.6.7.8:4445
UseIce=1
SedpStunServerAddress=1.2.3.4:3478
```

1.15.4 Security Considerations

The purpose of this section is to inform users about potential security issues when using OpenDDS. Users of OpenDDS are encouraged to perform threat modeling, security reviews, assessments, testing, etc. to ensure that their applications meet their security objectives.

Use DDS Security

Most applications have common objectives with respect to data security:

- Authentication - The identity of every process that participates in the DDS domain can be established.
- Authorization - Only authorized writers of a topic may generate samples for a topic and only authorized readers may consume samples for a topic.
- Integrity - The content of a sample cannot be altered without detection.
- Privacy - The content of a sample cannot be read by an unauthorized third party.

If an application is subject to any of these security objectives, then it should use the DDS Security features described in *DDS Security*. Using a non-secure discovery mechanism or a non-secure transport leaves the application exposed to data security breaches.

Understand the Weaknesses of (Secure) RTPS Discovery

Secure RTPS Discovery has a behavior that can be exploited to launch a denial of service attack (see https://www.cisa.gov/news-events/ics-advisories/icsa-21-315-02). Basically, an attacker can send a fake SPDP message to a secure participant which will cause it to begin authentication with a non-existent participant. The authentication messages are repeated resulting in amplification. An attacker could manipulate a group of secure participants to launch a denial of service attack against a specific host or group of hosts. RTPS (without security) has the same vulnerability except that messages come from the other builtin endpoints. For this reason, consider the mitigation features below before making an OpenDDS participant publicly accessible.

The weakness in RTPS Discovery can be mitigated but currently does not have a solution. OpenDDS includes the following features for mitigation:

- Compare the source IP of the SPDP message to the locators. For most applications, the locators advertised by SPDP should match the source IP of the SPDP message.
  - See CheckSourceIp in *Table 7-5 RTPS Discovery Configuration Options*
- Use the participant lease time from secure discovery and bound it otherwise. By default, OpenDDS will attempt authentication for the participant lease duration specified in the SPDP message. However, this data can't be trusted so a smaller maximum lease time can be specified to force authentication or discovery to terminate before the lease time.
  - See MaxAuthTime in *Table 7-5 RTPS Discovery Configuration Options*
- Limit the number of outstanding secure discoveries. The number of discovered but not-yet-authenticated participants is capped when using secure discovery.
  - See MaxParticipantsInAuthentication in *Table 7-5 RTPS Discovery Configuration Options*

Run Participants in a Secure Network

One approach to a secure application without DDS Security is to secure it at the network layer instead of the application layer. A physically secure network satisfies this by construction. Another approach is to use a virtual private network (VPN) or a secure overlay. These approaches have a simple security model when compared to DDS Security and are not interoperable.

1.16 XTypes

1.16.1 Overview

The DDS specification defines a way to build distributed applications using a data-centric publish and subscribe model. In this model, publishing and subscribing applications communicate via Topics and each Topic has a data type. An assumption built into this model is that all applications agree on data type definitions for each Topic that they use. This assumption is not practical as systems must be able to evolve while remaining compatible and interoperable.

The DDS XTypes (Extensible and Dynamic Topic Types) specification loosens the requirement on applications to have a common notion of data types. Using XTypes, the application developer adds IDL annotations that indicate where the types may vary between publisher and subscriber and how those variations are handled by the middleware.

OpenDDS implements the XTypes specification version 1.3 at the Basic Conformance level, with a partial implementation of the Dynamic Language Binding. Some features described by the specification are not yet implemented in OpenDDS - those are noted in *Unimplemented Features*. This includes IDL annotations that are not yet implemented (*Annotations*). See *Differences from the specification* for situations where the implementation of XTypes in OpenDDS departs from or infers something about the specification. Specification issues have been raised for these situations.

1.16.2 Features

Extensibility

There are 3 kinds of extensibility for types:

Appendable
: Appendable denotes a constructed type which may have additional members added onto or removed from the end, but not both at the same time. Appendable is the default extensibility. A type can be explicitly marked as appendable with the *@appendable* annotation.

Mutable
: Mutable denotes a constructed type that allows for members to be added, removed, and reordered so long as the keys and the required members of the sender and receiver remain. Mutable extensibility is accomplished by assigning a stable identifier to each member. A type can be marked as mutable with the *@mutable* annotation.

Final
: Final denotes a constructed type that can not add, remove, or reorder members. This can be considered a non-extensible constructed type, with behavior similar to that of a type created before XTypes. A type can be marked as final with the *@final* annotation.

The default extensibility can be changed with the *–default-extensibility* opendds_idl option.

Structs, unions, and enums are the only types which can use any of the extensibilities.

The default extensibility for enums is "appendable" and is not governed by `--default-extensibility`. TypeObjects for received enums that do not set any flags are treated as a wildcard.

Assignability

Assignability describes the ability of values of one type to be coerced to values of a possibility different type.

Assignability between the type of a writer and reader is checked as part of discovery. If the types are assignable but not identical, then the *"try construct"* mechanism will be used to coerce values of the writer's type to values of the reader's type.

In order for two constructed types to be assignable they must

- Have the same extensibility.
- Have the same set of keys.

Each member of a constructed type has an identifier. This identifier may be assigned automatically or explicitly.

Union assignability depends on two dimensions. First, unions are only assignable if their discriminators are assignable. Second, for any branch label or default that exists in both unions, the members selected by that branch label must be assignable.

Interoperability with non-XTypes Implementations

Communication with a non-XTypes DDS (either an older OpenDDS or another DDS implementation which has RTPS but not XTypes 1.2+) requires compatible IDL types and the use of RTPS Discovery. Compatible IDL types means that the types are structurally equivalent and serialize to the same bytes using XCDR version 1.

Additionally, the XTypes-enabled participant needs to be set up as follows:

- Types cannot use mutable extensibility
- Data Writers must have their Data Representation QoS policy set to `DDS::XCDR_DATA_REPRESENTATION`
- Data Readers must include `DDS::XCDR_DATA_REPRESENTATION` in the list of data representations in their Data Representation QoS (true by default)

Data Representation shows how to change the data representation. *XCDR1 Support* details XCDR1 support.

Dynamic Language Binding

Before the XTypes specification, all DDS applications worked by mapping the topic's data type directly into the programming language and having the data handling APIs such as read, write, and take, all defined in terms of that type. As an example, topic type A (an IDL structure) caused code generation of IDL interfaces ADataWriter and ADataReader while topic type B generated IDL interfaces BDataWriter and BDataReader. If an application attempted to pass an object of type A to the BDataWriter, a compile-time error would occur (at least for statically typed languages including C++ and Java). Advantages to this design include efficiency and static type safety, however, the code generation required by this approach is not desirable for every DDS application.

The XTypes Dynamic Language Binding defines a generic data container DynamicData and the interfaces DynamicDataWriter and DynamicDataReader. Applications can create instances of DynamicDataWriter and DynamicDataReader that work with various topics in the domain without needing to incorporate the generated code for those topics' data types. The system is still type safe but the type checks occur at runtime instead of at compile time. The Dynamic Language Binding is described in detail in *Dynamic Language Binding*.

1.16.3 Examples and Explanation

Suppose you are in charge of deploying a set of weather stations that publish temperature, pressure, and humidity. The following examples show how various features of XTypes may be applied to address changes in the schema published by the weather station. Specifically, without XTypes, one would either need to create a new type with its own DataWriters/DataReaders or update all applications simultaneously. With proper planning and XTypes, one can simply modify the existing type (within limits) and writers and readers using earlier versions of the topic type will remain compatible with each other and be compatible with writers and readers using new versions of the topic type.

Mutable Extensibility

The type published by the weather stations can be made extensible with the `@mutable` annotation:

```
// Version 1
@topic
@mutable
struct StationData {
  short temperature;
  double pressure;
  double humidity;
};
```

Suppose that some time in the future, a subset of the weather stations are upgraded to monitor wind speed and direction:

```
enum WindDir {N, NE, NW, S, SE, SW, W, E};
// Version 2
@topic
@mutable
struct StationData {
  short temperature;
  double pressure;
  double humidity;
  short wind_speed;
  WindDir wind_direction;
};
```

When a Version 2 writer interacts with a Version 1 reader, the additional fields will be ignored by the reader. When a Version 1 writer interacts with a Version 2 reader, the additional fields will be initialized to a "logical zero" value for its type (empty string, `FALSE` boolean) - see Table 9 of the XTypes specification for details.

Assignability

The first and second versions of the `StationData` type are *assignable* meaning that it is possible to construct a version 2 value from a version 1 value and vice-versa. The assignability of non-constructed types (e.g., integers, enums, strings) is based on the types being identical or identical up to parameterization, i.e., bounds of strings and sequences may differ. The assignability of constructed types like structs and unions is based on finding corresponding members with assignable types. Corresponding members are those that have the same id.

A type marked as `@mutable` allows for members to be added, removed, or reordered so long as member ids are preserved through all of the mutations.

Member IDs

Member ids are assigned using various annotations. A policy for a type can be set with either `@autoid(SEQUENTIAL)` or `@autoid(HASH)`:

```
// Version 3
@topic
@mutable
@autoid(SEQUENTIAL)
struct StationData {
  short temperature;
  double pressure;
  double humidity;
};

// Version 4
@topic
@mutable
@autoid(HASH)
struct StationData {
  short temperature;
  double pressure;
  double humidity;
};
```

`SEQUENTIAL` causes ids to be assigned based on the position in the type. `HASH` causes ids to be computed by hashing the name of the member. If no `@autoid` annotation is specified, the policy is `SEQUENTIAL`.

Suppose that Version 3 was used in the initial deployment of the weather stations and the decision was made to switch to `@autoid(HASH)` when adding the new fields for wind speed and direction. In this case, the ids of the pre-existing members can be set with `@id`:

```
enum WindDir {N, NE, NW, S, SE, SW, W, E};

// Version 5
@topic
@mutable
@autoid(HASH)
struct StationData {
  @id(0) short temperature;
  @id(1) double pressure;
  @id(2) double humidity;
  short wind_speed;
  WindDir wind_direction;
};
```

See the *Member ID assignment* for more details.

Appendable Extensibility

Mutable extensibility requires a certain amount of overhead both in terms of processing and network traffic. A more efficient but less flexible form of extensibility is appendable Appendable is limited in that members can only be added to or removed from the end of the type. With appendable, the initial version of the weather station IDL would be:

```
// Version 6
@topic
@appendable
struct StationData {
  short temperature;
  double pressure;
  double humidity;
};
```

And the subsequent addition of the wind speed and direction members would be:

```
enum WindDir {N, NE, NW, S, SE, SW, W, E};

// Version 7
@topic
@appendable
struct StationData {
  short temperature;
  double pressure;
  double humidity;
  short wind_speed;
  WindDir wind_direction;
};
```

As with mutable, when a Version 7 Writer interacts with a Version 6 Reader, the additional fields will be ignored by the reader. When a Version 6 Writer interacts with a Version 7 Reader, the additional fields will be initialized to default values based on Table 9 of the XTypes specification.

Appendable is the default extensibility.

Final Extensibility

The third kind of extensibility is final. Annotating a type with `@final` means that it will not be compatible with (assignable to/from) a type that is structurally different. The `@final` annotation can be used to define types for pre-XTypes compatibility or in situations where the overhead of mutable or appendable is unacceptable.

Try Construct

From a reader's perspective, there are three possible scenarios when attempting to initialize a member. First, the member type is identical to the member type of the reader. This is the trivial case the value from the writer is copied to the value for the reader. Second, the writer does not have the member. In this case, the value for the reader is initialized to a default value based on Table 9 of the XTypes specification (this is the "logical zero" value for the type). Third, the type offered by the writer is assignable but not identical to the type required by the reader. In this case, the reader must try to construct its value from the corresponding value provided by the writer.

Suppose that the weather stations also publish a topic containing station information:

```
typedef string<8> StationID;
typedef string<256> StationName;

// Version 1
@topic
@mutable
struct StationInfo {
  @try_construct(TRIM) StationID station_id;
  StationName station_name;
};
```

Eventually, the pool of station IDs is exhausted so the IDL must be refined as follows:

```
typedef string<16> StationID;
typedef string<256> StationName;

// Version 2
@topic
@mutable
struct StationInfo {
  @try_construct(TRIM) StationID station_id;
  StationName station_name;
};
```

If a Version 2 writer interacts with a Version 1 reader, the station ID will be truncated to 8 characters. While perhaps not ideal, it will still allow the systems to interoperate.

There are two other forms of try-construct behavior. Fields marked as `@try_construct(USE_DEFAULT)` will receive a default value if value construction fails. In the previous example, this means the reader would receive an empty string for the station ID if it exceeds 8 characters. Fields marked as `@try_construct(DISCARD)` cause the entire sample to be discarded. In the previous example, the Version 1 reader will never see a sample from a Version 2 writer where the original station ID contains more than 8 characters. `@try_construct(DISCARD)` is the default behavior.

1.16.4 Data Representation

Data representation is the way a data sample can be encoded for transmission. Writers can only encode samples using one data representation, but readers can accept multiple data representations. Data representation can be XML, XCDR1, XCDR2, or unaligned CDR.

XML
: This isn't currently supported and will be ignored.

  The `DataRepresentationId_t` value is `DDS::XML_DATA_REPRESENTATION`

  The annotation is *@OpenDDS::data_representation(XML)*.

XCDR1
: This is the pre-XTypes standard CDR extended with XTypes features. Support is limited to non-XTypes features, see *XCDR1 Support* for details.

  The `DataRepresentationId_t` value is `DDS::XCDR_DATA_REPRESENTATION`

  The annotation is *@OpenDDS::data_representation(XCDR1)*.

XCDR2
: This is default for writers when using the RTPS-UDP transport and should be preferred in most cases. It is a more robust and efficient version of XCDR1.

The `DataRepresentationId_t` value is `DDS::XCDR2_DATA_REPRESENTATION`

The annotation is *@OpenDDS::data_representation(XCDR2)*.

Unaligned CDR

This is a OpenDDS-specific encoding that is the default for writers using only non-RTPS-UDP transports. It can't be used by a DataWriter using the RTPS-UDP transport.

The `DataRepresentationId_t` value is `OpenDDS::DCPS::UNALIGNED_CDR_DATA_REPRESENTATION`

The annotation is *@OpenDDS::data_representation(UNALIGNED_CDR)*.

Data representation is a QoS policy alongside the other QoS options. Its listed values represent allowed serialized forms of the data sample. The DataWriter and DataReader need to have at least one matching data representation for communication between them to be possible.

The default value of the `DataRepresentationQosPolicy` is an empty sequence. For RTPS-UDP this is interpreted as XCDR2 for DataWriters and accepting XCDR1 and XCDR2 for DataReaders. For other transports it's interpreted as Unaligned CDR for DataWriters and accepting XCDR1, XCDR2, and Unaligned CDR for DataReaders. A writer or reader without an explicitly-set `DataRepresentationQosPolicy` will therefore be able to communicate with another reader or writer which is compatible with XCDR2. The example below shows a possible configuration for an XCDR1 DataWriter.

```
DDS::DataWriterQos qos;
pub->get_default_datawriter_qos(qos);
qos.representation.value.length(1);
qos.representation.value[0] = DDS::XCDR_DATA_REPRESENTATION;
DDS::DataWriter_var dw = pub->create_datawriter(topic, qos, 0, 0);
```

Note that the IDL constant used for XCDR1 is `XCDR_DATA_REPRESENTATION` (without the digit).

In addition to a DataWriter/DataReader QoS setting for data representation, each type defined in IDL can have its own data representation specified via an annotation. This value restricts which data representations can be used for that type. A DataWriter/DataReader must have at least one data representation in common with the type it uses.

The default value for an unspecified data representation annotation is to allow all forms of serialization.

The type's set of allowed data representations can be specified by the user in IDL with the notation: `@OpenDDS::data_representation(XCDR2)` where XCDR2 is replaced with the specific data representation.

1.16.5 Type Consistency Enforcement

TypeConsistencyEnforcementQosPolicy

The Type Consistency Enforcement QoS policy lets the application fine-tune details of how types may differ between writers and readers. The policy only applies to data readers. This means that each reader can set its own policy for how its type may vary from the types of the writers that it may match.

There are six members of the `TypeConsistencyEnforcementQosPolicy` struct defined by XTypes, but OpenDDS only supports setting one of them: `ignore_member_names`. All other members should be kept at their default values.

`ignore_member_names` defaults to `FALSE` so member names (along with member IDs, see *Member ID assignment*) are significant for type compatibility. Changing this to `TRUE` means that only member IDs are used for type compatibility.

Type Compatibility

When a reader/writer match is happening, type consistency enforcement checks that the two types are compatible according to the type objects if they are available. This check will not happen if OpenDDS has been *configured not to generate or use type objects* or if the remote DDS doesn't support type objects. The full type object compatibility check is too detailed to reproduce here. It can be found in section 7.2.4 of the XTypes 1.3 specification. In general though two topic types and their nested types are compatible if:

- Extensibilities of shared types match
- Extensibility rules haven't been broken, for example:
  - Changing a `@final` struct
  - Adding a member in the middle of an `@appendable` struct
- Length bounds of strings and sequences are the same or greater
- Lengths of arrays are exactly the same
- The keys of the types match exactly
- Shared member IDs match when required, like when they are final or are being used as keys

If the type objects are compatible then the match goes ahead. If one or both type objects are not available, then OpenDDS falls back to checking the names each entity's `TypeSupport` was given. This is the name passed to the `register_type` method of a `TypeSupport` object or if that string is empty then the name of the topic type in IDL.

An interesting side effect of these rules is when type objects are always available, then the topic type names passed to `register_type` are only used within that process. This means they can be changed and remote readers and writers will still match, assuming the new name is used consistently within the process and the types are still compatible.

1.16.6 IDL Annotations

Indicating Which Types Can Be Topic Types

@topic

Applies To: struct or union type declarations

The topic annotation marks a topic type for samples to be transmitted from a publisher or received by a subscriber. A topic type may contain other topic and non-topic types. See *Defining Data Types with IDL* for more details.

@nested

Applies To: struct or union type declarations

The `@nested` annotation marks a type that will always be contained within another. This can be used to prevent a type from being used as in a topic. One reason to do so is to reduce the amount of code generated for that type.

@default_nested

Applies To: modules

The `@default_nested(TRUE)` or `@default_nested(FALSE)` sets the default nesting behavior for a module. Types within a module marked with `@default_nested(FALSE)` can still set their own behavior with `@nested`.

Specifying allowed Data Representations

If there are `@OpenDDS::data_representation` annotations are on the topic type, then the representations are limited to ones the specified in the annotations, otherwise all representations are allowed. Trying to create a reader or writer with the disallowed representations will result in an error. See *Data Representation* for more information.

@OpenDDS::data_representation(XML)

Applies To: topic types

Limitations: XML is not currently supported

@OpenDDS::data_representation(XCDR1)

Applies To: topic types

Limitations: XCDR1 doesn't support XTypes features See *Data Representation* for details

@OpenDDS::data_representation(XCDR2)

Applies To: topic types

XCDR2 is currently the recommended data representation for most cases.

@OpenDDS::data_representation(UNALIGNED_CDR)

Applies To: topic types

Limitations: OpenDDS specific, can't be used with RTPS-UDP, and doesn't support XTypes features See *Data Representation* for details

Standard @data_representation

`tao_idl` doesn't support bitset, which the standard `@data_representation` requires. Instead use `@OpenDDS::data_representation` which is similar, but doesn't support bitmask value chaining like `@data_representation(XCDR|XCDR2)`. The equivalent would require two separate annotations:

```
@OpenDDS::data_representation(XCDR1)
@OpenDDS::data_representation(XCDR2)
```

Determining Extensibility

The extensibility annotations can explicitly define the *extensibility* of a type. If no extensibility annotation is used, then the type will have the default extensibility. This will be *appendable* unless the *–default-extensibility opendds_idl* option is to override the default.

@mutable

Alias: `@extensibility(MUTABLE)`

Applies To: type declarations

This annotation indicates a type may have non-key or non-must-understand members removed. It may also have additional members added.

@appendable

Alias: `@extensibility(APPENDABLE)`

Applies To: type declarations

This annotation indicates a type may have additional members added or members at the end of the type removed.

Limitations: Appendable is not currently supported when XCDR1 is used as the data representation.

@final

Alias: `@extensibility(FINAL)`

Applies To: type declarations

This annotation marks a type that cannot be changed and still be compatible. Final is most similar to pre-XTypes.

Customizing XTypes per-member

Try Construct annotations dictate how members of one object should be converted from members of a different but assignable object. If no try construct annotation is added, it will default to discard.

@try_construct(USE_DEFAULT)

Applies to: structure and union members, sequence and array elements

The use_default try construct annotation will set the member whose deserialization failed to a default value which is determined by the XTypes specification. Sequences will be of length 0, with the same type as the original sequence. Primitives will be set equal to 0. Strings will be replaced with the empty string. Arrays will be of the same length but have each element set to the default value. Enums will be set to the first enumerator defined.

@try_construct(TRIM)

Applies to: structure and union members, sequence and array elements

The trim try construct annotation will, if possible, shorten a received value to one fitting the receiver's bound. As such, trim only makes logical sense on bounded strings and bounded sequences.

@try_construct(DISCARD)

Applies to: structure and union members, sequence and array elements

The discard try construct annotation will "throw away" the sample if an element fails to deserialize.

Member ID assignment

If no explicit id annotation is used, then member IDs will automatically be assigned sequentially.

@id(value)

Applies to: structure and union members

`value` is an unsigned 32-bit integer which assigns that member's ID.

@autoid(value)

Applies to: module declarations, structure declarations, union declarations

The autoid annotation can take two values, `HASH` or `SEQUENTIAL`. `SEQUENTIAL` states that the identifier shall be computed by incrementing the preceding one. `HASH` states that the identifier should be calculated with a hashing algorithm - the input to this hash is the member's name. `HASH` is the default value of `@autoid`.

@hashid(value)

Applies to: structure and union members

The `@hashid` sets the identifier to the hash of the `value` parameter, if one is specified. If the `value` parameter is omitted or is the empty string, the member's name is used as if it was the `value`.

Determining the Key Fields of a Type

@key

Applies to: structure members, union discriminator

The `@key` annotation marks a member used to determine the Instances of a topic type. See *Keys* for more details on the general concept of a Key. For XTypes specifically, two types can only be compatible if each contains the members that are keys within the other.

1.16.7 Dynamic Language Binding

For an overview of the Dynamic Language Binding, see *Dynamic Language Binding*. This section describes the features of the Dynamic Language Binding that OpenDDS supports.

There are two main usage patterns supported:

- Applications can receive DynamicData from a Recorder object (*Recorder and Replayer*)
- Applications can use XTypes DynamicDataWriter and/or DynamicDataReader (*DynamicDataWriters and DynamicDataReaders*)

To use DynamicDataWriter and/or DynamicDataReader for a given topic, the data type definition for that topic must be available to the local DomainParticipant. There are a few ways this can be achieved, see *Obtaining DynamicType and Registering TypeSupport* for details.

Representing Types with TypeObject and DynamicType

In XTypes, the types of the peers may not be identical, as in the case of appendable or mutable extensibility. In order for a peer to be aware of its remote peer's type, there must be a way for the remote peer to communicate its type. TypeObject is an alternative to IDL for representing types, and one of the purposes of TypeObject is to communicate the peers' types.

There are two classes of TypeObject: MinimalTypeObject and CompleteTypeObject. A MinimalTypeObject object contains minimal information about the type that is sufficient for a peer to perform type compatibility checking. However, MinimalTypeObject may not contain all information about the type as represented in the corresponding user IDL file. In cases where the complete information about the type is required, CompleteTypeObject should be used. When XTypes is enabled, peers communicate their TypeObject information during the discovery process automatically. Internally, the local and received TypeObjects are stored in a TypeLookupService object, which is shared between the entities in the same DomainParticipant.

In the Dynamic Language Binding, each type is represented using a DynamicType object, which has a TypeDescriptor object that describes all the information needed to correctly process the type. Likewise, each member in a type is represented using a DynamicTypeMember object, which has a MemberDescriptor object that describes any information needed to correctly process the type member. DynamicType is converted from the corresponding CompleteTypeObject internally by the system.

Enabling Use of CompleteTypeObjects

To enable use of `CompleteTypeObject` s needed for the dynamic binding, they must be generated and OpenDDS must be configured to use them. To generate them, *-Gxtypes-complete* must be passed to `opendds_idl` (*opendds_idl Command Line Options*). For MPC, this can be done by adding this to the opendds_idl arguments for idl files in the project, like this:

```
TypeSupport_Files {
  dcps_ts_flags += -Gxtypes-complete
  Messenger.idl
}
```

To do the same for CMake:

```
OPENDDS_TARGET_SOURCES(target
  Messenger.idl
  OPENDDS_IDL_OPTIONS -Gxtypes-complete
)
```

Once set up to be generated, OpenDDS has to be configured to send and receive the `CompleteTypeObject` s. This can be done by setting the *UseXTypes* RTPS discovery configuration option (*Configuring for DDSI-RTPS Discovery*) or programmatically using the `OpenDDS::RTPS::RtpsDiscovery::use_xtypes()` setter methods.

Interpreting Data Samples with DynamicData

Together with DynamicType, DynamicData allows users to interpret a received data sample and read individual fields from it. Each DynamicData object is associated with a type, represented by a DynamicType object, and the data corresponding to an instance of that type. Consider the following example:

```
@appendable
struct NestedStruct {
  @id(1) short s_field;
};

@topic
@mutable
struct MyStruct {
  @id(1) long l_field;
  @id(2) unsigned short us_field;
  @id(3) float f_field;
  @id(4) NestedStruct nested_field;
  @id(5) sequence<unsigned long> ul_seq_field;
  @id(6) double d_field[10];
};
```

The samples for MyStruct are written by a normal, statically-typed DataWriter. The writer application needs to have the IDL-generated code including the "complete" form of TypeObjects. Use a command-line option to opendds_idl to enable CompleteTypeObjects since the default is to generate MinimalTypeObjects (*opendds_idl Command Line Options*).

One way to obtain a DynamicData object representing a data sample received by the participant is using the Recorder and RecorderListener classes (*Recorder and Replayer*). Recorder's get_dynamic_data can be used to construct a DynamicData object for each received sample from the writer. Internally, the CompleteTypeObjects received from discovering that writer are converted to DynamicTypes and they are then used to construct the DynamicData objects. Once a DynamicData object for a MyStruct sample is constructed, its members can be read as described in the following sections. Another way to obtain a DynamicData object is from a DynamicDataReader (*Creating and Using a DynamicDataWriter or DynamicDataReader*).

Reading Basic Types

DynamicData provides methods for reading members whose types are basic such as integers, floating point numbers, characters, boolean. See the XTypes specification for a complete list of basic types for which DynamicData provides an interface. To call a correct method for reading a member, we need to know the type of the member as well as its id. For our example, we first want to get the number of members that the sample contains. In these examples, the `data` object is an instance of DynamicData.

```
DDS::UInt32 count = data.get_item_count();
```

Then, each member's id can be read with `get_member_id_at_index`. The input for this function is the index of the member in the sample, which can take a value from `0` to `count - 1`.

```
XTypes::MemberId id = data.get_member_id_at_index(0);
```

The `MemberDescriptor` for the corresponding member then can be obtained as follows.

```
XTypes::MemberDescriptor md;
DDS::ReturnCode_t ret = data.get_descriptor(md, id);
```

The returned `MemberDescriptor` allows us to know the type of the member. Suppose id is 1, meaning that the member at index 0 is `l_field`, we now can get its value.

```
DDS::Int32 int32_value;
ret = data.get_int32_value(int32_value, id);
```

After the call, `int32_value` contains the value of the member `l_field` from the sample. The method returns `DDS::RETCODE_OK` if successful.

Similarly, suppose we have already found out the types and ids of the members `us_field` and `f_field`, their values can be read as follows.

```
DDS::UInt16 uint16_value;
ret = data.get_uint16_value(uint16_value, 2); // Get the value of us_field
DDS::Float32 float32_value;
ret = data.get_float32_value(float32_value, 3); // Get the value of f_field
```

Reading Collections of Basic Types

Besides a list of methods for getting values of members of basic types, DynamicData also defines methods for reading sequence members. In particular, for each method that reads value from a basic type, there is a counterpart that reads a sequence of the same basic type. For instance, `get_int32_value` reads the value from a member of type `int32/long`, and `get_int32_values` reads the value from a member of type `sequence<int32>`. For the member `ul_seq_field` in our example, its value can be read as follows.

```
DDS::UInt32Seq my_ul_seq;
ret = data.get_uint32_values(my_ul_seq, id); // id is 5
```

Because `ul_seq_field` is a sequence of unsigned 32-bit integers, the `get_uint32_values` method is used. Again, the second argument is the id of the requested member, which is 5 for `ul_seq_field`. When successful, `my_ul_seq` contains values of all elements of the member `ul_seq_field` in the sample.

To get the values of the array member `d_field`, we first need to create a separate DynamicData object for it, and then read individual elements of the array using the new DynamicData object.

```
XTypes::DynamicData array_data;
DDS::ReturnCode_t ret = data.get_complex_value(array_data, id); // id is 6

const DDS::UInt32 num_items = array_data.get_item_count();
for (DDS::UInt32 i = 0; i < num_items; ++i) {
  const XTypes::MemberId my_id = array_data.get_member_id_at_index(i);
  DDS::Float64 my_double;
  ret = array_data.get_float64_value(my_double, my_id);
}
```

In the example code above, `get_item_count` returns the number of elements of the array. Inside the for loop, the index of each element is converted to an id within the array using `get_member_id_at_index`. Then, this id is used to

read the element's value into `my_double`. Note that the second parameter of the interfaces provided by DynamicData must be the id of the requested member. In case of collection, elements are considered members of the collection. However, the collection element doesn't have a member id. And thus, we need to convert its index into an id before calling a get_*_value (or get_*_values) method.

Reading Members of More Complex Types

For a more complex member such as a nested structure or union, the discussed DynamicData methods are not suitable. And thus, users first need to get a new DynamicData object that represents the sole data of the member with get_complex_value. This new DynamicData object can then be used to get the values of the inner members of the nested member. For example, a DynamicData object for the nested_field member of the MyStruct sample can be obtained as follows.

```
XTypes::DynamicData nested_data;
DDS::ReturnCode_t ret = data.get_complex_value(nested_data, id); // id is 4
```

Recall that nested_field has type NestedStruct which has one member s_field with id 1. Now the value of s_field can be read from nested_data using get_int16_value, since s_field has type short.

```
DDS::Int16 my_short;
ret = nested_data.get_int16_value(my_short, id); // id is 1
```

The get_complex_value method is also suitable for any other cases where the value of a member cannot be read directly using the get_*_value or get_*_values methods. As an example, suppose we have a struct MyStruct2 defined as follows.

```
@appendable
struct MyStruct2 {
  @id(1) sequence<NestedStruct> seq_field;
};
```

And suppose we already have a DynamicData object, called data, that represents a sample of MyStruct2. To read the individual elements of seq_field, we first get a new DynamicData object for the seq_field member.

```
XTypes::DynamicData seq_data;
DDS::ReturnCode_t ret = data.get_complex_value(seq_data, id); // id is 1
```

Since the elements of seq_field are structures, for each of them we create another new DynamicData object to represent it, which can be used to read its member.

```
const DDS::UInt32 num_elems = seq_data.get_item_count();
for (DDS::UInt32 i = 0; i < num_elems; ++i) {
  const XTypes::MemberId my_id = seq_data.get_member_id_at_index(i);
  XTypes::DynamicData elem_data; // Represent each element.
  ret = seq_data.get_complex_value(elem_data, my_id);
  DDS::Int16 my_short;
  ret = elem_data.get_int16_value(my_short, 1);
}
```

Populating Data Samples With DynamicData

DynamicData objects can be created by the application and populated with data so that they can be used as data samples which are written to a DynamicDataWriter (*Creating and Using a DynamicDataWriter or DynamicDataReader*).

To create a DynamicData object, use the DynamicDataFactory API defined by the XTypes spec:

```
DDS::DynamicData_var dynamic =
  DDS::DynamicDataFactory::get_instance()->create_data(type);
```

Like other data types defined by IDL interfaces (for example, the `*TypeSupportImpl` types), the "dynamic" object's lifetime is managed with a smart pointer - in this case `DDS::DynamicData_var`.

The "type" input parameter to `create_data()` is an object that implements the `DDS::DynamicType` interface. The DynamicType representation of any type that's supported as a topic data type is available from its corresponding TypeSupport object (*Obtaining DynamicType and Registering TypeSupport*) using the `get_type()` operation. Once the application has access to that top-level type, the DynamicType interface can be used to obtain complete information about the type including nested and referenced data types. See the file dds/DdsDynamicData.idl in OpenDDS for the definition of the DynamicType and related interfaces.

Once the application has created the DynamicData object, it can be populated with data members of any type. The operations used for this include the DynamicData operations named "set_*" for the various data types. They are analogous to the "get_*" operations that are described in *Interpreting Data Samples with DynamicData*. When populating the DynamicData of complex data types, use get_complex_value() (*Reading Members of More Complex Types*) to navigate from DynamicData representing containing types to DynamicData representing contained types.

Setting the value of a member of a DynamicData union using a `set_*` method implicitly 1) activates the branch corresponding to the member and 2) sets the discriminator to a value corresponding to the active branch. After a branch has been activated, the value of the discriminator can be changed using a `set_*` method. However, the new value of the discriminator must correspond to the active branch. To set the discriminator, use `DISCRIMINATOR_ID` as the member id for the call to `set_*` (see dds/DCPS/XTypes/TypeObject.h).

Unions start in an "empty" state meaning that no branch is active. At the point of serialization, the middleware will treat an empty union according to the following procedure. The discriminator is assumed to have the default value for the discriminator type and all members are assumed to have the default value for their type. There are three possibilities. First, the discriminator selects a non-default branch in which case the serialized union will have the default discriminator value and the default value for the implicitly selected member; Second, the discriminator selects a default branch in which case the serialized union will have the default discriminator value and the default value for the default branch member. Third, the discriminator selects no branch (and a default branch is not defined) in which case the serialized union will have the default discriminator only.

DynamicDataWriters and DynamicDataReaders

DynamicDataWriters and DataReaders are designed to work like any other DataWriter and DataReader except that their APIs are defined in terms of the DynamicData type instead of a type generated from IDL. Each DataWriter and DataReader has an associated Topic and that Topic has a data type (represented by a TypeSupport object). Behavior related to keys, QoS policies, discovery and built-in topics, DDS Security, and transport is not any different for a DynamicDataWriter or DataReader. One exception is that in the current implementation, Content-Subscription features (*Content-Subscription Profile*) are not supported for DynamicDataWriters and DataReaders.

Obtaining DynamicType and Registering TypeSupport

OpenDDS currently supports two usage patterns for obtaining a TypeSupport object that can be used with the Dynamic Language Binding:

- Dynamically load a library that has the IDL-generated code
- Get the DynamicType of a peer DomainParticipant that has CompleteTypeObjects

The XTypes specification also describes how an application can construct a new type at runtime, but this is not yet implemented in OpenDDS.

To use a shared library (`*.dll` on Windows, `*.so` on Linux, `*.dylib` on macOS, etc.) as a type support plug-in, an application simply needs to load the library into its process. This can be done with the ACE cross-platform support library that OpenDDS itself uses, or using a platform-specific function like LoadLibrary or dlopen. The application code does not need to include any generated headers from this IDL. This makes the type support library a true plug-in, meaning it can be loaded into an application that had no knowledge of it when that application was built.

Once the shared library is loaded, an internal singleton class in OpenDDS called Registered_Data_Types can be used to obtain a reference to the TypeSupport object.

```
DDS::TypeSupport_var ts_static = Registered_Data_Types->lookup(0, "TypeName");
```

This TypeSupport object `ts_static` is not registered with the DomainParticipant and is not set up for the Dynamic Language Binding. But, crucially, it does have the DynamicType object that we'll need to set up a second TypeSupport object which is registered with the DomainParticipant.

```
DDS::DynamicType_var type = ts_static->get_type();
DDS::DynamicTypeSupport_var ts_dynamic = new DynamicTypeSupport(type);
DDS::ReturnCode_t ret = ts_dynamic->register_type(participant, "");
```

Now the type support object `ts_dynamic` can be used in the usual DataWriter/DataReader setup sequence (creating a Topic first, etc.) but the created DataWriters and DataReaders will be DynamicDataWriters and DynamicDataReaders (*Creating and Using a DynamicDataWriter or DynamicDataReader*).

The other approach to obtaining TypeSupport objects for use with the Dynamic Language Binding is to have DDS discovery's built-in endpoints get TypeObjects from remote domain participants. To do this, use the `get_dynamic_type` method on the singleton `Service_Participant` object.

```
DDS::DynamicType_var type; // NOTE: passed by reference below
DDS::ReturnCode_t ret = TheServiceParticipant->get_dynamic_type(type, participant, key);
```

The two input parameters to `get_dynamic_type` are the `participant` (an object reference to the DomainParticipant that will be used to register our TypeSupport and create Topics, DataWriters, and/or DataReders) and the `key` which is the `DDS::BuiltinTopicKey_t` that identifies the remote entity which has the data type that we'll use. This key can be obtained from the Built-In Publications topic (which identifies remote DataWriters) or the Built-In Subscriptions topic (which identifies remote DataReaders). See *Built-In Topics* for details on using the Built-In Topics.

The type obtained from `get_dynamic_type` can be used to create and register a TypeSupport object.

```
DDS::DynamicTypeSupport_var ts_dynamic = new DynamicTypeSupport(type);
DDS::ReturnCode_t ret = ts_dynamic->register_type(participant, "");
```

Creating and Using a DynamicDataWriter or DynamicDataReader

Following the steps in *Obtaining DynamicType and Registering TypeSupport*, a DynamicTypeSupport object is registered with the domain participant. The type name used to register with the participant may be the default type name (used when an empty string is passed to the `register_type` operation), or some other type name. If the default type name was used, the application can access that name by invoking the `get_type_name` operation on the TypeSupport object.

The registered type name is then used as one of the input parameters to `create_topic`, just like when creating a topic for the Plain (non-Dynamic) Language Binding. Once a Topic object exists, create a DataWriter or DataReader using this Topic. They can be narrowed to the DynamicDataWriter or DynamicDataReader IDL interface:

```
DDS::DynamicDataWriter_var w = DDS::DynamicDataWriter::_narrow(writer);
DDS::DynamicDataReader_var r = DDS::DynamicDataReader::_narrow(reader);
```

The IDL interfaces are defined in dds/DdsDynamicTypeSupport.idl in OpenDDS. They provides the same operations as any other DataWriter or DataReader, but with DynamicData as their data type. See *Populating Data Samples With DynamicData* for details on creating DynamicData objects for use with the DynamicDataWriter interface. See *Interpreting Data Samples with DynamicData* for details on using DynamicData objects obtained from the DynamicDataReader interface.

Limitations of the Dynamic Language Binding

The Dynamic Language Binding doesn't currently support:

- Access from Java applications
- Content-Subscription Profile features (Content-Filtered Topics, Multi Topics, Query Conditions)
- XCDRv1 Data Representation
- Constructing types at runtime

1.16.8 Unimplemented Features

OpenDDS implements the XTypes specification version 1.3 at the Basic Conformance level, with a partial implementation of the Dynamic Language Binding (supported features of which are described in *Dynamic Language Binding*). Specific unimplemented features listed below. The two optional profiles, XTypes 1.1 Interoperability (XCDR1) and XML, are not implemented.

XCDR1 Support

Pre-XTypes standard CDR is fully supported, but the XTypes-specific features are not fully supported and should be avoided. Types can be marked as final or appendable, but all types should be treated as if they were final. Nothing should be marked as mutable. Readers and writers of topic types that are mutable or contain nested types that are mutable will fail to initialize.

Type System

- IDL map type
- IDL bitmask type
- Struct and union inheritance

Annotations

IDL4 defines many standardized annotations and XTypes uses some of them. The Annotations recognized by XTypes are in Table 21 in XTypes 1.3. Of those listed in that table, the following are not supported in OpenDDS. They are listed in groups defined by the rows of that table. Some annotations in that table, and not listed here, can only be used with new capabilities of the Type System (*Type System*).

- Struct members
  - `@optional`
  - `@must_understand`
  - `@non_serialized`
- Struct or union members
  - `@external`
- Enums
  - `@bit_bound`
  - `@default_literal`
  - `@value`
- `@verbatim`
- `@data_representation`
  - See *Standard @data_representation* for details.

1.16.9 Differences from the specification

- Inconsistent topic status isn't set for reader/reader or writer/writer in non-XTypes use cases
- Define the encoding and extensibility used by Type Lookup Service (Member Link)
- Enums must have the same "bit bound" to be assignable (Member Link)
- Default data representation is XCDR2 (Member Link)
- Type Lookup Service when using DDS Security (Member Link)
- Anonymous types in Strongly Connected Components (Member Link)
- Meaning of ignore_member_names in TypeConsistencyEnforcement (Member Link)

1.17 Common Terms

1.17.1 Environment Variables

ACE_ROOT

Root of the ACE source tree or installation prefix being used.

DDS_ROOT

Root of the OpenDDS source tree or installation prefix being used.

TAO_ROOT

Root of the TAO source tree or installation prefix being used.

CHAPTER

TWO

INTERNAL DOCUMENTATION

This documentation are for those who want to contribute to OpenDDS and those who are just curious!

2.1 OpenDDS Development Guidelines

This document organizes our current thoughts around development guidelines in a place that's readable and editable by the overall user and maintainer community. It's expected to evolve as different maintainers get a chance to review and contribute to it.

Although ideally all code in the repository would already follow these guidelines, in reality the code has evolved over many years by a diverse group of developers. At one point an automated re-formatter was run on the codebase, migrating from the GNU C style to the current, more conventional style, but automated tools can only cover a subset of the guidelines.

2.1.1 Repository

The repository is hosted on Github at OpenDDS/OpenDDS and is open for pull requests.

2.1.2 Automated Build Systems

Pull requests will be tested automatically and full CI builds of the master branch can be found at http://scoreboard.ociweb.com/oci-dds.html.

See *Running Tests* for how tests are run in general. See *GitHub Actions Summary and FAQ* for how building and testing is done with GitHub Actions.

2.1.3 Doxygen

Doxygen is run on OpenDDS regularly. There are two hosted versions of this:

- Latest Release
  - Based on the current release of OpenDDS.
- Master
  - Based on the master branch in the repository. To access it, go to the scoreboard and click the green "Doxygen" link near the top.
  - Depending on the activity in the repository this might be unstable because of the time it takes to get the updated Doxygen on to the web sever. Prefer latest release unless working with newer code.

See *Documenting Code for Doxygen* to see how to take advantage of Doxygen when writing code in OpenDDS.

2.1.4 Dependencies

- MPC is the build system, used to configure the build and generate platform specific build files (Makefiles, VS solution files, etc.).
- ACE is a library used for cross-platform compatibility, especially networking and event loops. It is used both directly and through TAO.
- TAO is a C++ CORBA implementation built on ACE.
  - It's used to communicate with DCPSInfoRepo, which is one option for Discovery.
  - TAO's data types and support for the OMG IDL-to-C++ mapping are also used in the End User DDS API.
  - The TAO IDL compiler is used internally and by the end user to allow OpenDDS to use user-defined IDL types as topic data.
- Perl is an interpreted language used in the configure script, the tests, and any other scripting in OpenDDS codebase.
- Google Test is required for OpenDDS tests. By default, CMake will be used to build a specific version of Google Test that we have as a submodule. An appropriate prebuilt or system Google Test can also be used.

See docs/dependencies.md for all dependencies and details on how these are used in OpenDDS.

2.1.5 Text File Formatting

All text files in the source code repository follow a few basic rules. These apply to C++ source code, Perl scripts, MPC files, and any other plaintext file.

- A text file is a sequence of lines, each ending in the "end-of-line" character (AKA Unix line endings).
- Based on this rule, all files end with the end-of-line character.
- The character before end-of-line is a non-whitespace character (no trailing whitespace).
- Tabs are not used.
  - One exception, MPC files may contain literal text that's inserted into Makefiles which could require tabs.
  - In place of a tab, use a set number of spaces (depending on what type of file it is, C++ uses 2 spaces).
- Keep line length reasonable. I don't think it makes sense to strictly enforce an 80-column limit, but overly long lines are harder to read. Try to keep lines to roughly 80 characters.

2.1.6 C++ Standard

The base C++ standard used in OpenDDS is C++03. There are some optional features that are only built when a newer C++ standard level is used. See uses of the MPC feature no_cxx11 and the base project opendds_cxx11.mpb. Avoid using implementation-defined extensions (including `#pragma`). Exceptions are: * `#pragma once` which only impacts preprocessing and is understood across all supported compilers, or harmlessly ignored if not understood * `#pragma pack` can only be used on POD structs to influence alignment/padding

Use the C++ standard library as much as possible. The standard library should be preferred over ACE, which in turn should be preferred over system-specific libraries. The C++ standard library includes the C standard library by reference, making those identifiers available in namespace std. Using C's standard library identifiers in namespace std is preferred over the global namespace – `#include <cstring>` instead of `#include <string.h>`. Not all supported

platforms have standard library support for wide characters (`wchar_t`) but this is rarely needed. Preprocessor macro `DDS_HAS_WCHAR` can be used to detect those platforms.

2.1.7 C++ Coding Style

- C++ code in OpenDDS must compile under the compilers listed in the `README.md` file.
- Commit code in the proper style from the start, so follow-on commits to adjust style don't clutter history.
- C++ source code is a plaintext file, so the guidelines in "Text File Formatting" apply.
- A modified Stroustrup style is used (see tools/scripts/style).
  - Warning: not everything in tools/scripts/style represents the current guidelines.
- Sometimes the punctuation characters are given different names, this document will use:
  - Parentheses `( )`
  - Braces `{ }`
  - Brackets `[ ]`

Example

```
template<typename T>
class MyClass : public Base1, public Base2 {
public:
  bool method(const OtherClass& parameter, int idx = 0) const;
};

template<typename T>
bool MyClass<T>::method(const OtherClass& parameter, int) const
{
  if (parameter.foo() > 42) {
    return member_data_;
  } else {
    for (int i = 0; i < some_member_; ++i) {
      other_method(i);
    }
    return false;
  }
}
```

Punctuation

The punctuation placement rules can be summarized as:

- Open brace appears as the first non-whitespace character on the line to start function definitions.
- Otherwise the open brace shares the line with the preceding text.
- Parentheses used for control-flow keywords (`if`, `while`, `for`, `switch`) are separated from the keyword by a single space.
- Otherwise parentheses and brackets are not preceded by spaces.

Whitespace

- Each "tab stop" is two spaces.
- Namespace scopes that span most or all of a file do not cause indentation of their contents.
- Otherwise lines ending in `{` indicate that subsequent lines should be indented one more level until `}`.
- Continuation lines (when a statement spans more than one line) can either be indented one more level, or indented to nest "under" an `(` or similar punctuation.
- Add space around binary operators and after commas: `a + b, c`
- Do not add space around parentheses for function calls, a properly formatted function call looks like `func(arg1, arg2, arg3);`
- Do not add space around brackets for indexing, instead it should look like: `mymap[key]`
- For code that includes multiple braces appearing together in the same expression (such as initializer lists), there are two approved styles: * spaces between braces and their enclosed (non-empty) sub-expression: `const GUID_t GUID_UNKNOWN = { { 0 }, { { 0 }, 0 } };` or `{ a + b, {} }` * no such spaces: `const GUID_t GUID_UNKNOWN = {{0}, {{0}, 0}};` or `{a + b, {}}`
- Do not add extra spaces to make syntax elements (that span lines/statements) line up; this only causes unnecessary changes in adjacent lines as the code evolves.
- In general, do not add extra spaces unless doing so is covered by the rules above.

Language Usage

- Add braces following control-flow keywords even when they are optional.
- `this->` is not used unless required for disambiguation or to access members of a template-dependent base class.
- Declare local variables at the latest point possible.
- `const` is a powerful tool that enables the compiler to help the programmer find bugs. Use `const` everywhere possible, including local variables.
- Modifiers like `const` appear left of the types they modify, like: `const char* cstring = ...`. `char const*` is equivalent but not conventional.
- For function arguments that are not modified by the callee, pass by value for small objects (8 bytes?) and pass by const-reference for everything else.
- Arguments unused by the implementation have no names (in the definition that is, the declarations still have names), or a `/*commented-out*/` name.
- Use `explicit` constructors unless implicit conversions are intended and desirable.
- Use the constructor initializer list and make sure its order matches the declaration order.
- Prefer pre-increment/decrement (`++x`) to post-increment/decrement (`x++`) for both objects and non-objects.
- All currently supported compilers use the template inclusion mechanism. Thus function/method template definitions may not be placed in normal `*.cpp` files, instead they can go in `_T.cpp` (which are `#included` and not separately compiled), or directly in the `*.h`. In this case, `*_T.cpp` takes the place of `*.inl` (except it is always inlined). See ACE for a description of `*.inl` files.

Pointers and References

Pointers and references go along with the type, not the identifier. For example:

```
int* intPtr = &someInt;
```

Watch out for multiple declarations in one statement. `int* c, b;` does not declare two pointers! It's best just to break these into separate statements:

```
int* c;
int* b;
```

In code targeting C++03, `0` should be used as the null pointer. For C++11 and later, `nullptr` should be used instead. `NULL` should never be used.

Naming

(For library code that the user may link to)

- Preprocessor macros visible to user code must begin with `OPENDDS_`
- C++ identifiers are either in top-level namespace `DDS` (OMG spec defined) or `OpenDDS` (otherwise)
- Within the `OpenDDS` namespace there are some nested namespaces:
  - `DCPS`: anything relating to the implementation of the DCPS portion of the DDS spec
  - `RTPS`: types directly tied to the RTPS spec
  - `Federator`: DCPSInfoRepo federation
  - `FileSystemStorage`: reusable component for persistent storage
- Naming conventions
  - `ClassesAreCamelCaseWithInitialCapital`
  - `methodsAreCamelCaseWithInitialLower` OR `methods_are_lower_case_with_underscores`
  - `member_data_use_underscores_and_end_with_an_underscore_`
  - `ThisIsANamespaceScopedOrStaticClassMemberConstant`

Comments

- Add comments only when they will provide MORE information to the reader.
- Describing the code verbatim in comments doesn't add any additional information.
- If you start out implementation with comments describing what the code will do (or pseudocode), review all comments after implementation is done to make sure they are not redundant.
- Do not add a comment before the constructor that says `// Constructor`. We know it's a constructor. The same note applies to any redundant comment.

Documenting Code for Doxygen

Doxygen is run on the codebase with each change in master and each release. This is a simple guide showing the way of documenting in OpenDDS.

Doxygen supports multiple styles of documenting comments but this style should be used in non-trivial situations:

```
/**
 * This sentence is the brief description.
 *
 * Everything else is the details.
 */
class DoesStuff {
// ...
};
```

For simple things, a single line documenting comment can be made like:

```
/// Number of bugs in the code
unsigned bug_count = -1; // Woops
```

The extra * on the multiline comment and / on the single line comment are important. They inform Doxygen that comment is the documentation for the following declaration.

If referring to something that happens to be a namespace or other global object (like DDS, OpenDDS, or RTPS), you should precede it with a %. If not it will turn into a link to that object.

For more information, see the Doxygen manual.

Preprocessor

- If possible, use other language features things like inlining and constants instead of the preprocessor.
- Prefer `#ifdef` and `#ifndef` to `#if defined` and `#if !defined` when testing if a single macro is defined.
- Leave parentheses off preprocessor operators. For example, use `#if defined X && defined Y` instead of `#if defined(X) && defined(Y)`.
- As stated before, preprocessor macros visible to user code must begin with `OPENDDS_`.
- See section *C++ Standard* above for notes on `#pragma`.
- Ignoring the header guard if there is one, preprocessor statements should be indented using two spaces starting at the pound symbol, like so:

```
#if defined X && defined Y
#  if X > Y
#    define Z 1
#  else
#    define Z 0
#  endif
#else
#  define Z -1
#endif
```

Includes

Order

As a safeguard against headers being dependant on a particular order, includes should be ordered based on a hierarchy going from local headers to system headers, with spaces between groups of includes. Generated headers from the same directory should be placed last within these groups. This order can be generalized as the following:

1. Pre-compiled header if it is required for a `.cpp` file by Visual Studio.
2. The corresponding header to the source file (`Foo.h` if we were in `Foo.cpp`).
3. Headers from the local project.
4. Headers from external OpenDDS-based libraries.
5. Headers from dds/DCPS.
6. `dds/*C.h` Headers
7. Headers from external TAO-based libraries.
8. Headers from TAO.
9. Headers from external ACE-based libraries.
10. Headers from ACE.
11. Headers from external non-ACE-based libraries.
12. Headers from system and C++ standard libraries.

There can be exceptions to this list. For example if a header from ACE or the system library was needed to decide if another header should be included.

Path

Headers should only use local includes (`#include "foo/Foo.h"`) if the header is relative to the file. Otherwise system includes (`#include <foo/Foo.h>`) should be used to make it clear that the header is on the system include path.

In addition to this, includes for a file that will always be relative to the including file should have a relative include path. For example, a `dds/DCPS/bar.cpp` should include `dds/DCPS/bar.h` using `#include "bar.h"`, not `#include <dds/DCPS/bar.h>` and especially not `#include "dds/DCPS/bar.h"`.

Example

For a `Doodad.cpp` file in dds/DCPS, the includes could look like:

```
#include <DCPS/DdsDcps_pch.h>

#include "Doodad.h"

#include <ace/config-lite.h>
#ifndef ACE_CPP11
#  include "ConditionVariable.h"
#endif
#include "ReactorTask.h"
#include "transport/framework/DataLink.h"
```

(continues on next page)

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```
#include <dds/DdsDcpsCoreC.h>

#include <tao/Version.h>

#include <ace/Version.h>

#include <openssl/openssl.h>

#include <unistd.h>
#include <stdlib.h>
```

2.1.8 Initialization

Note that OpenDDS applications require ACE to be initialized to work correctly. For many OpenDDS applications, `ACE::init()` and `ACE::fini()` will be called automatically, either by interaction with the ACE or TAO libraries, or due to ACE's redefinition of executable entry points (e.g. `main`) which wrap normal execution with calls to those functions. However, be advised that on some platforms, the helper macros to catch entry points may change names to suit compiler options. For example, for Visual C++ builds on Windows with wide-character support enabled, the helper macro changes from `main` to `wmain`. Applications either need to handle these differences in order to correctly ensure initialization or they need to use an entrypoint helper macro such as `ACE_TMAIN` which isn't vulnerable to this issue.

2.1.9 Time

Measurements of time can be broken down into two basic classes: A specific point in time (Ex: 00:00 January 1, 1970) and a length or duration of time without context (Ex: 134 Seconds). In addition, a computer can change its clock while a program is running, which could mess up any time lapses being measured. To solve this problem, operating systems provide what's called a monotonic clock that runs independently of the normal system clock.

ACE can provide monotonic clock time and has a class for handling time measurements, `ACE_Time_Value`, but it doesn't differentiate between specific points in time and durations of time. It can differentiate between the system clock and the monotonic clock, but it does so poorly. OpenDDS provides three classes that wrap `ACE_Time_Value` to fill these roles: `TimeDuration`, `MonotonicTimePoint`, and `SystemTimePoint`. All three can be included using dds/DCPS/TimeTypes.h. Using `ACE_Time_Value` is discouraged unless directly dealing with ACE code which requires it and using `ACE_OS::gettimeofday()` or `ACE_Time_Value().now()` in C++ code in dds/DCPS treated as an error by the `lint.pl` linter script.

`MonotonicTimePoint` should be used when tracking time elapsed internally and when dealing with `ACE_Time_Values` being given by the `ACE_Reactor` in OpenDDS. `ACE_Conditions`, like all ACE code, will default to using system time. Therefore the `Condition` class wraps it and makes it so it always uses monotonic time like it should. Like `ACE_OS::gettimeofday()`, referencing `ACE_Condition` in dds/DCPS will be treated as an error by `lint.pl`.

More information on using monotonic time with ACE can be found here.

`SystemTimePoint` should be used when dealing with the DDS API and timestamps on incoming and outgoing messages.

2.1.10 Logging

ACE Logging

Logging is done via ACE's logging macro functions, `ACE_DEBUG` and `ACE_ERROR`, defined in `ace/Log_Msg.h`. The logging macros arguments to both are:

- A `ACE_Log_Priority` value
  - This is an enum defined in `ace/Log_Priority.h` to say what the priority or severity of the message is.
- The format string
  - This is similar to the format string for the standard `printf`, where it substitutes sequences starting with `%`, but the format of theses sequences is different. For example `char*` values are substituted using `%C` instead of `%s`. See the documenting comment for `ACE_Log_Msg::log` in `ace/Log_Msg.h` for what the format of the string is.
- The variable number of arguments
  - Like `printf` the variable arguments can't be whole objects, like a `std::string` value. In the case of `std::string`, the format and arguments would look like: `"%C", a_string.c_str()`.

Note that all the `ACE_DEBUG` and `ACE_ERROR` arguments must be surrounded by two sets of parentheses.

```
ACE_DEBUG((LM_DEBUG, "Hello, %C!\n", "world"));
```

ACE logs to `stderr` by default on conventional platforms, but can log to other places.

Usage in OpenDDS

Logging Conditions and Priority

In OpenDDS `ACE_DEBUG` and `ACE_ERROR` are used directly most of the time, but sometimes they are used indirectly, like with the transport framework's `VDBG` and `VDBG_LVL`. They also should be conditional on one of the logging control systems in OpenDDS. See section 7.6 of the OpenDDS Developer's Guide for user perspective.

The logging conditions are as follows:

Message Kind	Macro	Priority	Condition
Unrecoverable error	`ACE_ERROR`	`LM_ERROR`	`log_level >= LogLevel::Error`
Unreportable recoverable error	`ACE_ERROR`	`LM_WARNING`	`log_level >= LogLevel::Warning`
Reportable recoverable error	`ACE_ERROR`	`LM_NOTICE`	`log_level >= LogLevel::Notice`
Informational message	`ACE_DEBUG`	`LM_INFO`	`log_level >= LogLevel::Info`
Debug message	`ACE_DEBUG`	`LM_DEBUG`	Based on `DCPS_debug_level` or one of the other debug systems *listed below*[1]

An *unrecoverable error* indicates that OpenDDS is in a state where it cannot function as intended. This may be the result of a defect, misconfiguration, or interference.

A *recoverable error* indicates that OpenDDS could not perform a desired action but remains in a state where it can function as intended.

[1] Debug messages don't rely on both *LogLevel::Debug* and a debug control system. The reason is that it results in a simpler check and the log level already loosely controls all the debug control systems. See the *LogLevel::set* function in dds/DCPS/debug.cpp for exactly what it does.

A *reportable error* indicates that OpenDDS can report the error via the API through something like an exception or return value.

An *informational message* gives high level information mostly at startup, like the version of OpenDDS being used.

A *debug message* gives lower level information, such as if a message is being sent. These are directly controlled by one of a few debug logging control systems.

- `DCPS_debug_level` should be used for all debug logging that doesn't fall under the other systems. It is an unsigned integer value which ranges from 0 to 10. See dds/DCPS/debug.h for details.
- `Transport_debug_level` should be used in the transport layer. It is an unsigned integer value which ranges from 0 to 6. See dds/DCPS/transport/framework/TransportDebug.h for details.
- `security_debug` should be used for logging in related to DDS Security. It is an object with `bool` members that make up categories of logging messages that allow fine control. See dds/DCPS/debug.h for details.

For number-based conditions like `DCPS_debug_level` and `Transport_debug_level`, the number used should be the log level the message starts to become active at. For example for `DCPS_debug_level >= 6` should be used instead of `DCPS_debug_level > 5`.

Message Content

- Log messages should take the form:

```
(%P|%t) [ERROR:|WARNING:|NOTICE:|INFO:] FUNCTION_NAME: MESSAGE\n
```

  - Use `ERROR:`, `WARNING:`, `NOTICE:`, and `INFO:` if using the corresponding log priorities.
  - `CLASS_NAME::METHOD_NAME` should be used instead of just the function name if it's part of a class. It's at the developer's discretion to come up with a meaningful name for members of overload sets, templates, and other more complex cases.
  - `security_debug` and `transport_debug` log messages should indicate the category name, for example:

```
if (security_debug.access_error) {
  ACE_ERROR((LM_ERROR, "(%P|%t) ERROR: {access_error} example_function: Hello,␣
↪World!\n"));
}
```

- Format strings should not be wrapped in `ACE_TEXT`. We shouldn't go out of our way to replace it in existing logging points, but it should be avoided it in new ones.
  - `ACE_TEXT`'s purpose is to wrap strings and characters in `L` on builds where `uses_wchar=1`, so they become the wide versions.
  - While not doing it might result in a performance hit for character encoding conversion at runtime, the builds where this happens are rare, so it's outweighed by the added visual noise to the code and the possibility of bugs introduced by improper use of `ACE_TEXT`.
- Avoid new usage of `ACE_ERROR_RETURN` in order to not hide the return statement within a macro.

Examples

```
if (log_level >= LogLevel::Error) {
  ACE_ERROR((LM_ERROR, "(%P|%t) ERROR: example_function: Hello, World!\n"));
}

if (log_level >= LogLevel::Warning) {
  ACE_ERROR((LM_WARNING, "(%P|%t) WARNING: example_function: Hello, World!\n"));
}

if (log_level >= LogLevel::Notice) {
  ACE_ERROR((LM_NOTICE, "(%P|%t) NOTICE: example_function: Hello, World!\n"));
}

if (log_level >= LogLevel::Info) {
  ACE_DEBUG((LM_INFO, "(%P|%t) INFO: example_function: Hello, World!\n"));
}

if (DCPS_debug_level >= 1) {
  ACE_DEBUG((LM_DEBUG, "(%P|%t) example_function: Hello, World!\n"));
}
```

2.2 Documentation Guidelines

This Sphinx-based documentation is hosted on Read the Docs and can be located here. It can also be built locally. To do this follow the steps in the following section.

2.2.1 Building

Run docs/build.py, passing the kinds of documentation desired. Multiple kinds can be passed, and they are documented in the following sections.

Requirements

The script requires Python 3.6 or later and an internet connection if the script needs to download dependencies or check the validity of external links.

You might receive a message like this when running for the first time:

```
build.py: Creating venv...
The virtual environment was not created successfully because ensurepip is not
available.  On Debian/Ubuntu systems, you need to install the python3-venv
package using the following command.

    apt install python3.9-venv
```

If you do, then follow the directions it gives, remove the `docs/.venv` directory, and try again.

HTML

HTML documentation can be built and viewed using `./docs/build.py -o html`. If it was built successfully, then the front page will be at `./docs/_build/html/index.html`.

A single page variant is also available using `./docs/build.py -o singlehtml` If it was built successfully, then the page will be at `./docs/_build/singlehtml/index.html`.

PDF

Note: This has additional dependencies on LaTeX that are documented here.

PDF documentation can be built and viewed using `./docs/build.py -o pdf`. If it was built successfully, then the PDF file will be at `./docs/_build/latex/opendds.pdf`.

Dash

Documentation can be built for Dash, Zeal, and other Dash-compatible applications using doc2dash. The command for this is `./docs/build.py dash`. This will create a `docs/_build/OpenDDS.docset` directory that must be manually moved to where other docsets are stored.

Strict Checks

`docs/build.py strict` will promote Sphinx warnings to errors and check to see if links resolve to a valid web page.

Note: The documentation includes dynamic links to files in the GitHub repo created by *ghfile*. These links will be invalid until the git commit they were built under is pushed to a Github fork of OpenDDS. This also means running will cause those links to marked as broken. A workaround for this is to pass `-c master` or another commit, branch, or tag that is desired.

Building Manually

It is recommended to use `build.py` to build the documentation as it will handle dependencies automatically. If necessary though, Sphinx can be ran directly.

To build the documentation the dependencies need to be installed first. Run this from the `docs` directory to do this:

```
pip3 install -r requirements.txt
```

Then `sphinx-build` can be ran. For example to build the HTML documentation:

```
sphinx-build -M html . _build
```

2.2.2 RST/Sphinx Usage

- See Sphinx reStructuredText Primer for basic RST usage.
- Inline code such as class names like `DataReader` and other symbolic text such as commands like `ls` should use double backticks: ``` ``TEXT`` ```. This distinguishes it as code, makes it easier to distinguish characters, and reduces the chance of needing to escape characters if they happen to be special for RST.
- One sentence per line should be perfered. This makes it easier to see what changed in a `git diff` or GitHub PR and easier to move sentences around in editors like Vim. It also avoids inconsistencies involving what the maximum line length is. This might make it more annoying to read the documentation raw, but that's not the intended way to do so anyway.

Special Links

There are a few shortcuts for linking to GitHub and OMG that are custom to OpenDDS. These come in the form of RST roles and are implemented in docs/sphinx_extensions/links.py.

ghfile

```
:ghfile:`README.md`

:ghfile:`the \`\`README.md\`\` File <README.md>`

:ghfile:`the support section of the \`\`README.md\`\` File <README.md#support>`

:ghfile:`check out the available support <README.md#support>`
```

Turns into:

README.md#support

README.md

the `README.md` File

the support section of the `README.md` File

check out the available support

The path passed must exist, be relative to the root of the repository, and will have to be committed, if it's not already. If there is a URL fragment in the path, like `README.md#support`, then it will appear in the link URL.

It will try to point to the most specific version of the file:

- If `-c` or `--gh-links-commit` was passed to `build.py`, then it will use the commit, branch, or tag that was passed along with it.
- Else if the OpenDDS is a release it will calculate the release tag and use that.
- Else if the OpenDDS is in a git repository it will use the commit hash.
- Else it will use `master`.

ghissue

```
:ghissue:`213`

:ghissue:`this is the issue <213>`

:ghissue:`this is **the issue** <213>`
```

Turns into:

Issue #213 on GitHub

this is the issue

this is **the issue**

ghpr

```
:ghpr:`1`

:ghpr:`this is the PR <1>`

:ghpr:`this is **the PR** <1>`
```

Turns into:

Pull Request #1 on GitHub

this is the PR

this is **the PR**

omgissue

```
:omgissue:`DDSXTY14-29`

:omgissue:`this is the issue <DDSXTY14-29>`

:omgissue:`this is **the issue** <DDSXTY14-29>`
```

Turns into:

OMG Issue DDSXTY14-29 (Member Link)

this is the issue (Member Link)

this is **the issue** (Member Link)

2.3 Unit Tests

2.3.1 The Goals of Unit Testing

The primary goal of a unit test is to provide informal evidence that a piece of code performs correctly. An alternative to unit testing is writing formal proofs. However, formal proofs are difficult, expensive, and unmaintainable given the changing nature of software. Unit tests, while necessarily incomplete, are a practical alternative.

Unit tests document how to use various algorithms and data structures and serve as an informal set of requirements. As such, a unit test should be developed with the idea that it will serve as a reference for future developers. Clarity in unit tests serve to accomplish their primary goal of establishing correctness. That is, a unit test that is difficult to understand casts doubt that the code being tested is correct. Consequently, unit tests should be clear and concise.

The confidence one has in a piece of code is often related to the number of code paths explored in it. This is often approximated by "code coverage." That is, one can run the unit test with a coverage tool to see which code paths were exercised by the unit test. Code with higher coverage tends to have fewer bugs because the tester has often considered various corner-cases. Consequently, unit tests should aim for high code coverage.

Unit tests should be executed frequently to provide developers with instant feedback. This applies to the feature under development and the system as a whole. That is, developers should frequently execute all of the unit tests to make sure they haven't broken functionality elsewhere in the system. The more frequently the tests are run, the smaller the increment of development and the easier it is to identify a breaking change. Thus, unit tests should execute quickly.

Code that is difficult to test will most likely be difficult to use. Code that is difficult to use correctly will lead to bugs in code that uses it. Consequently, unit tests are vital to the design of useful software as developing a unit test provides feedback on the design of the code under test. Often, when developing a unit test, one will find parts of the design that can be improved.

Unit tests should promote and not inhibit development. A robust set of unit tests allows a developer to aggressively refactor since the correctness of the system can be checked after the refactoring. However, unit tests do produce drag on development since they must be maintained as the code evolves. Thus, it is important that the unit test code be properly maintained so that they are an asset and not a liability.

Some of the goals mentioned above are in conflict. Adding code to increase coverage may make the tests less maintainable, slower, and more difficult to understand. The following metrics can be generated to measure the utility of the unit tests:

- Code coverage
- Test compilation time
- Test execution time
- Test code size vs. code size
- Defect rate vs. code coverage (Are bugs appearing in code that is not tested as well?)

2.3.2 Unit Test Organization

The most basic unit when testing is the *test case*. A test case typically has four phases.

1. Setup - The system is initialized to a known state.
2. Exercise - The code under test is invoked.
3. Check - The resulting state of the system and outputs are checked.
4. Teardown - Any resources allocated in the test are deallocated.

Test cases are grouped into a *test suite*.

Test suites are organized into *a test plan*.

We adopt file boundaries for organizing the unit tests for OpenDDS. That is, the unit tests for a file group `dds/DCPS/SomeFile.(h|cpp)` will be located in `tests/unit-tests/dds/DCPS/SomeFile.cpp`. The file `tests/unit-tests/dds/DCPS/SomeFile.cpp` is a test suite containing all of the test cases for `dds/DCPS/SomeFile.(h|cpp)`. The test plan for OpenDDS will execute all of the test suites under tests/unit-tests. When the complete test plan takes too much time to execute, it will be sub-divided along module boundaries.

In regards to coverage, the coverage of `dds/DCPS/SomeFile.(h|cpp)` is measured by executing the tests in its test suite `tests/unit-tests/dds/DCPS/SomeFile.cpp`. The purpose of this is to avoid indirect testing where a piece of code may get full coverage without ever being intentionally tested.

2.3.3 Unit Test Scope

A unit test should be completely deterministic with respect to the code paths that it exercises. This means the test code must have control over all relevant inputs, i.e., inputs that influence the code paths. To illustrate, the current time is relevant when testing algorithms that perform date related functions, e.g., code that is conditioned on a certificate being expired, while it is not relevant if it is only used when printing log messages. Sources of non-determinism include time, random numbers, schedulers, and the network. A dependency on the time is typically mitigated by mocking the service that return the time. Random numbers can be handled the same way. A unit test should never sleep. Avoiding schedulers means a unit test should not have multiple processes and should not have multiple threads unless they cannot impact the code paths being tested. The network can be avoided by defining a suitable abstraction and mocking.

Code that relies on event dispatching may use a mock dispatcher to control the sequence of events. One design that makes it possible to unit test in this way is to organize a module as a set of atomic event handlers around a plain old data structure core. The core should be easy to test. Event handlers are called for timers, I/O readiness, and method calls into the module. Event handlers update the core and can perform I/O and call into other modules. Inter-module calls are problematic in that they create the possibility for deadlock and other hazards. In the simplest designs, each module has a single lock that is acquired at the beginning of each event handler. The non-deterministic part of the module can be tested by isolating its dependencies on the operating system and other modules; typically by providing mock objects.

To illustrate the other side of determinism, consider other kinds of tests. Integration tests often use operating system services, e.g., threads and networking, to test partial or whole system functionality. A stress test executes the same code over and over hoping that non-determism results in a different outcome. Performance tests may or may not admit non-determinism and focuses on aggregate behavior as opposed to code-level correctness. Unit tests should focus on code-level correctness.

2.3.4 Isolating Dependencies

More often than not, the code under test will have dependencies on other objects. For each dependency, the test can either pass in a real object or a stand-in. Test stand-ins have a variety of names including mocks, spies, dummies, etc. depending on their function. Some take the position that everything should be mocked. The author takes the position that real objects should be preferred for the following reasons:

- Less code to maintain
- The design of the real objects improves to accommodate testing
- Tests break in a more meaningful way when dependencies change, i.e., over time, a test stand-in may no longer behave in a realistic way

However, there are cases when a test stand-in is justified:

- It is difficult to configure the real object

- The real object lacks the necessary API for testing and adding it cannot be justified

The use of a mock assumes that an interface exists for the stand-in.

2.3.5 Writing a New Unit Test

1. Add the test to the appropriate file under tests/unit-tests.
2. Name the test after the code it is meant to cover. For example, the `tests/unit-tests/dds/DCPS/security/AccessControlBuiltInImpl.cpp` unit test covers the `dds/DCPS/security/AccessControlBuiltInImpl.(h|cpp)` files.
3. Update the tests/unit-tests/UnitTests.mpc file if necessary.

2.3.6 Using GTest

The main unit test driver is based on GTest. GTest provides you with many helpful tools to simplify the writing of unit tests. To use GTest in a test, add `#include <gtest/gtest.h>` to the unit test source file. A basic unit test has the following form

```
TEST(TestModule, TestSubmodule)
{
}
```

All tests in a unit test source file must have the same TestModule which is name of the unit under test with underscores, e.g., `dds_DCPS_security_AccessControlBuiltInImpl`. This naming convention is required for intentional unit test coverage. The TestSubmodule can be any identifier, however, it should typical describe the class, function, or scenario being tested.

Each test contains evaluators. The most common evaluators are `EXPECT_EQ`, `EXPECT_TRUE`, `EXPECT_FALSE`.

```
EXPECT_EQ(X, 2)
EXPECT_EQ(Y, 3)
```

This will mark the test as a failure if either `X` does not equal 2, or `Y` does not equal 3.

`EXPECT_TRUE` and `EXPECT_FALSE` are equivalence checks to a boolean value. In the following examples we pass `X` to a function `is_even` that returns true if the passed value is an even number and returns false otherwise.

```
EXPECT_TRUE(is_even(X));
```

This will mark the test as a failure if `is_even(X)` returns false.

```
EXPECT_FALSE(is_even(X));
```

This will mark the test as a failure if `is_even(X)` returns true.

There are more EXPECT_* and ASSERT_*, but these are the most common ones. The difference between EXPECT and ASSERT is that an ASSERT will cease the test upon failure, whereas EXPECTS continue to run. For example if you have multiple `EXPECT_EQ`, they will all always run.

For more information, visit the google test documentation: https://github.com/google/googletest/blob/main/docs/primer.md.

2.3.7 Code Coverage

To enable code coverage, one needs to disable the *dds_non_coverage* feature, e.g., `./configure ... --features=dds_non_coverage=0`.

The script `$DDS_ROOT/tools/scripts/unit_test_coverage.sh` will execute unit tests and generate an intentional unit test coverage report. It can be called with no arguments to generate a report for all of the units or it can be called with a list of units to test. For example, `$DDS_ROOT/tools/scripts/unit_test_coverage.sh dds/DCPS/Serializer`.

2.3.8 Final Word

Ignore anything in this document that prevents you from writing unit tests.

2.4 GitHub Actions Summary and FAQ

2.4.1 Overview

GitHub Actions is the continuous integration solution currently being used to evaluate the readiness of pull requests. It builds OpenDDS and runs the test suite across a wide variety of operation systems and build configurations.

2.4.2 Legend for GitHub Actions Build Names

Operating System

- u20/u22 - Ubuntu 20.04/22.04
- w19/w22 - Windows Server 2019/Windows Server 2022
- m11/m12 - macOS 11/12

See also:

GitHub Runner Images <https://github.com/actions/runner-images>

Build Configuration

- x86 - Windows 32 bit. If not specified, x64 is implied.
- re - Release build. If not specified, Debug is implied.
- clangX/gccY - compiler used to build OpenDDS. If not specified, the default system compiler is used. Windows Server 2019 uses Visual Studio 2019 Windows Server 2022 uses Visual Studio 2022

Build Type

- stat - Static build
- bsafe/esafe - Base Safety/Extended Safety build
- sec - Security build
- asan/tsan - Address/Thread Sanitizer build

Build Options

- o1 - enables `--optimize`
- d0 - enables `--no-debug`
- i0 - enables `--no-inline`
- p1 - enables `--ipv6`
- w1 - enables wide characters
- v1 - enables versioned namespace
- cpp03 - `--std=c++03`
- j/j<N> - Java version default/N
- ace7 - uses ace7tao3 rather than ace6tao2
- xer0 - disables xerces
- qt - enables `--qt`
- ws - enables `--wireshark`
- js0 - enables `--no-rapidjson`
- a1 - enables TAO's Anys using `--features=dds_suppress_anys=0`

Feature Mask

This is a mask in an attempt to keep names shorter.

- FM-08
  - `--no-built-in-topics`
  - `--no-content-subscription`
  - `--no-ownership-profile`
  - `--no-object-model-profile`
  - `--no-persistence-profile`
- FM-1f
  - `--no-built-in-topics`
- FM-2c
  - `--no-content-subscription`
  - `--no-object-model-profile`

  - `--no-persistence-profile`

- FM-2f
  - `--no-content-subscription`
- FM-37
  - `--no-content-filtered-topics`

2.4.3 build_and_test.yml Workflow

Our main workflow which dictates our GitHub Actions run is .github/workflows/build_and_test.yml. It defines jobs, which are the tasks that are run by the CI.

Triggering the Build And Test Workflow

There are a couple ways in which a run of build and test workflow can be started.

Any pull request targeting master will automatically run the OpenDDS workflows. This form of workflow run will simulate a merge between the branch and master.

Push events on branches prefixed `gh_wf_` will trigger workflow runs on the fork in which the branch resides. These fork runs of GitHub Actions can be viewed in the "Actions" tab. Runs of the workflow on forks will not simulate a merge between the branch and master.

Job Types

There are a number of job types that are contained in the file build_and_test.yml. Where possible, a configuration will contain 3 jobs. The first job that is run is *ACE_TAO_*. This will create an artifact which is used later by the OpenDDS build. The second job is *build_*, which uses the previous *ACE_TAO_* job to configure and build OpenDDS. This job will then export an artifact to be used in the third step. The third step is the *test_* job, which runs the appropriate tests for the associated OpenDDS configuration.

Certain builds do not follow this 3 step model. Static and Release builds have a large footprint and therefore cannot fit the entire test suite onto a GitHub Actions runner. As a result, they only build and run a subset of the tests in their final jobs, but then have multiple final jobs to increase test coverage. These jobs are prefixed by:

- *compiler_* (and for some build configurations, *compiler2_*) which runs the tests/DCPS/Compiler tests.
- *unit_* which runs the unit tests located in tests/unit-tests.
- *messenger_* which runs the tests in tests/DCPS/Messenger and tests/DCPS/C++11/Messenger.

To shorten the runtime of the continuous integration, some other builds will not run the test suite.

All builds with safety profile disabled and ownership profile enabled, will run the tests/cmake tests. Test runs which only contain CMake tests are prefixed by `cmake_`.

.lst Files

.lst files contain a list of tests with configuration options that will turn tests on or off. The *test_* jobs pass in tests/dcps_tests.lst. MacOS, Windows 22, Static, and Release builds instead use tests/core_ci_tests.lst. The Thread Sanatizer build uses tests/tsan_tests.lst. This separation of .lst files is due to how excluding all but a few tests in the `dcps_tests.lst` would require adding a new config option to every test we didn't want to run. There is a separate security test list, tests/security/security_tests.lst, which governs the security tests which are run when `--security` is passed to `auto_run_tests.pl`. The last list file used by `build_and_test.yml` is tools/modeling/tests/modeling_tests.lst, which is included by passing `--modeling` to `auto_run_tests.pl`.

To disable a test in GitHub Actions, `!GH_ACTIONS` must be added next to the test in the .lst file. There are similar test blockers which only block for specific GitHub Actions configurations from running marked tests:

- `!GH_ACTIONS_OPENDDS_SAFETY_PROFILE` blocks Safety Profile builds
- `!GH_ACTIONS_M10` blocks the MacOS10 runners

This option currently does nothing because GitHub sees MacOS runners as unresponsive when they attempt to run some of the more intensive tests in dcps_tests.lst.

- `!GH_ACTIONS_ASAN` blocks the Address Sanitizer builds
- `!GH_ACTIONS_W22` blocks the Windows Server 2022 runner

These blocks are necessary because certain tests cannot properly run on GitHub Actions due to how the runners are configured. `-Config GH_ACTIONS` is assumed by `auto_run_tests.pl` when running on GitHub Actions, but the other test configurations must be passed using `-Config`.

See also:

Running Tests
For how `auto_run_tests.pl` and the lst files work in general.

Workflow Checks

The .github/workflows/lint.yml workflow runs .github/workflows/lint_build_and_test.pl, which checks that the .github/workflows/build_and_test.yml workflow has gcc-problem-matcher and msvc-problem-matcher in the correct places.

Running this script requires the YAML CPAN module. As a safety measure, it has some picky rules about how steps are named and ordered. In simplified terms, these rules include:

- If used, the problem matcher must be appropriate for the platform the job is running on.
- The problem matcher must not be declared before steps that are named "setup gtest" or named like "build ACE/TAO". This should reduce any warnings from Google Test or ACE/TAO.
- A problem matcher should be declared before steps that start with "build" or contain "make". These steps should also contain `cmake --build`, `make`, or `msbuild` in their `run` string.

Blocked Tests

Certain tests are blocked from GitHub actions because their failures are either unfixable, or are not represented on the scoreboard. If this is the case, we have to assume that the failure is due to some sort of limitation caused by the GitHub Actions runners.

Only Failing on CI

- tests/DCPS/SharedTransport/run_test.pl multicast
  - Multicast times out waiting for remote peer. Fails on `test_u20_p1_j8_FM-1f` and `test_u20_p1_sec`.
- tests/DCPS/Thrasher/run_test.pl high/aggressive/medium XXXX XXXX
  - The more intense thrasher tests cause consistent failures due to the increased load from ASAN. GitHub Actions fails these tests very consistently compared to the scoreboard which is more intermittent. Fails on `test_u20_p1_asan_sec`.

Failing Both CI and scoreboard

These tests fail on the CI as well as the scoreboard, but will remain blocked on the CI until fixed. Each test has a list of the builds it was failing on before being blocked.

- tests/DCPS/BuiltInTopicTest/run_test.pl
  - `test_u18_esafe_js0`
- tests/DCPS/CompatibilityTest/run_test.pl rtps_disc
  - `test_m10_o1d0_sec`
- tests/DCPS/Federation/run_test.pl
  - `test_u18_w1_sec`
  - `test_u18_j_cft0_FM-37`
  - `test_u18_w1_j_FM-2f`
  - `test_u20_ace7_j_qt_ws_sec`
  - `test_u20_p1_asan_sec`
  - `test_u20_p1_asan_sec`
- tests/DCPS/MultiDPTest/run_test.pl
  - `test_u18_bsafe_js0_FM-1f`
  - `test_u18_esafe_js0`
- tests/DCPS/NotifyTest/run_test.pl
  - `test_u18_esafe_js0`
- tests/DCPS/Reconnect/run_test.pl restart_pub
  - `test_w22_x86_i0_sec`
- tests/DCPS/Reconnect/run_test.pl restart_sub
  - `test_w22_x86_i0_sec`
- tests/DCPS/TimeBasedFilter/run_test.pl -reliable

- `test_u18_bsafe_js0_FM-1f`
- `test_u18_esafe_js0`

Test Results

The tests are run using autobuild which creates a number of output files that are turned into a GitHub artifact. This artifact is processed by the "check results" step which uses the script tools/scripts/autobuild_brief_html_to_text.pl to catch failures and print them in an organized manner. Due to this being a part of the "test" jobs, the results of each run will appear as soon as the job is finished.

Artifacts

Artifacts from the continuous integration run can be downloaded by clicking details on one of the Build & Test runs. Once all jobs are completed, a dropdown will appear on the bar next to "Re-run jobs", called "Artifacts" which lists each artifact that can be downloaded.

Alternatively, clicking the "Summary" button at the top of the list of jobs will list all the available artifacts at the bottom of the page.

Using Artifacts to Replicate Builds

You can download the `ACE_TAO_` and `build_` artifacts then use them for a local build, so long as your operating system is the same as the one on the runner.

1. `git clone` the ACE_TAO branch which is targeted by the build. This is usually going to be `ace6tao2`.
2. `git clone --recursive` the OpenDDS branch on which the CI was run.
3. Merge OpenDDS master into your cloned branch.
4. run `tar xvfJ` from inside the cloned ACE_TAO, targeting the `ACE_TAO_*.tar.xz` file.
5. run `tar xvfJ` from inside the cloned OpenDDS, targeting the `build_*.tar.xz` file.
6. Adjust the setenv.sh located inside OpenDDS to match the new locations for your ACE_TAO, and OpenDDS. The word "runner" should not appear within the setenv.sh once you are finished.

You should now have a working duplicate of the build that was run on GitHub Actions. This can be used for debugging as a way to quickly set up a problematic build.

Using Artifacts to View More Test Information

Tests failures which are recorded on GitHub only contain a brief capture of output surrounding a failure. This is useful for some tests, but it can often be helpful to view more of a test run. This can be done by downloading the artifact for a test step you are viewing. This test step artifact contains a number of files including `output.log_Full.html`. This is the full log of all output from all test runs done for the corresponding job. It should be opened in either a text editor or Firefox, as Chrome will have issues due to the length of the file.

Caching

The OpenDDS workflows create .tar.xz archives of certain build artifacts which can then be up uploaded and shared between jobs (and the user) as part of GitHub Actions' "artifact" API. A cache key comparison made using the relevant git commit SHA will determine whether to rebuild the artifact, or to use the cached artifact.

2.5 Running Tests

2.5.1 Main Test Suite

Building

Tests are not built by default, `--tests` must be passed to the `configure` script. This will build all the tests. There are a few ways to only have specific tests built:

- If using Make, specify the targets instead of leaving it default to the `all` target.
- Run MPC on the test directory and build separately. Make sure to also build the test's dependencies.
- Create a custom workspace with the tests and pass it to the `configure` script using the `--workspace` option. Also make sure to include the test's dependencies.

Running

Note: Make sure *ACE_ROOT* and *DDS_ROOT* are set, which can be done by running `source setenv.sh` on Linux and macOS or `call setenv.cmd` on Windows.

OpenDDS' main suite of tests is ran by the tests/auto_run_tests.pl Perl script that reads lists of tests from files and selectively runs based on how the script has been configured.

For Unixes (Linux, macOS, BSDs, etc)

Run this in *DDS_ROOT*:

```
./bin/auto_run_tests.pl
```

For Windows

Run this in *DDS_ROOT*:

```
bin\auto_run_tests.pl
```

If OpenDDS was built in Release mode add `-ExeSubDir Release`. If it was built as static libraries add `-ExeSubDir Static_Debug` or `-ExeSubDir Static_Release`.

Manual Configuration

Manual configuration is done by passing `-Config`, `-Exclude`, and test list files arguments to the script.

To manually configure what tests to run:

- See the `--list-all-configs` or `--show-all-configs` options to see the existing configurations used by all test list files.
- See the `--list-configs` or `--show-configs` options to see the existing configurations used by specific test list files.
- See the test list files for the tests themselves:
  - tests/dcps_tests.lst
    - This is included by default. Use `--no-dcps` to exclude this list.
    - If `--no-auto-config` was passed, then `--dcps` will have to be passed to include this.
  - tests/security/security_tests.lst
    - Use `--security` to include this list.
  - java/tests/dcps_java_tests.lst
    - Use `--java` to include this list.
  - tools/modeling/tests/modeling_tests.lst
    - Use `--modeling` to include this list.
- In a test list file each of the-space delimited words after the colon determines when the test is ran.
- Passing `-Config RTPS` will run tests that have `RTPS` and leave out tests with `!RTPS`.
- Passing `-Exclude RTPS` will exclude all tests that have `RTPS` in the entry. This option matches using RegEx, so a test with `SUPER_DUPER_RTPS` will also be excluded. It also ignores inverse entries, so it will not exclude a test with `!SUPER_DUPER_RTPS`.
- There are `-Config` options that are added automatically if `--no-auto-config` wasn't passed:
  - `-Config RTPS`
  - `-Config GH_ACTIONS` if running on *GitHub Actions*
  - These are based on the OS `auto_run_tests.pl` is running under:
    - `-Config Win32`
    - `-Config macOS`
    - `-Config Linux`
- Assuming they were built, CMake tests are ran if `--cmake` is passed. This uses CTest, which is a system that is separate from the one previously described.
- See `--help` for all the available options.

Note: For those editing and creating test list files: The `ConfigList` code in ACE can't properly handle mutiple test list entries with the same command. It will run all those entries if the last one will run, even if based on the configs only one entry should run. `auto_run_tests.pl` will warn about this if it's using a test list file that has this problem.

2.6 Bench Performance & Scalability Test Framework

2.6.1 Motivation

The Bench framework (version 2) grew out of a desire to be able to test the performance and scalability of OpenDDS in large and heterogeneous deployments, along with the ability to quickly develop and deploy new test scenarios across a potentially-unspecified number of machines.

2.6.2 Overview

The resulting design of the Bench framework depends on three primary test applications: worker processes, one or more node controllers, and a test controller.

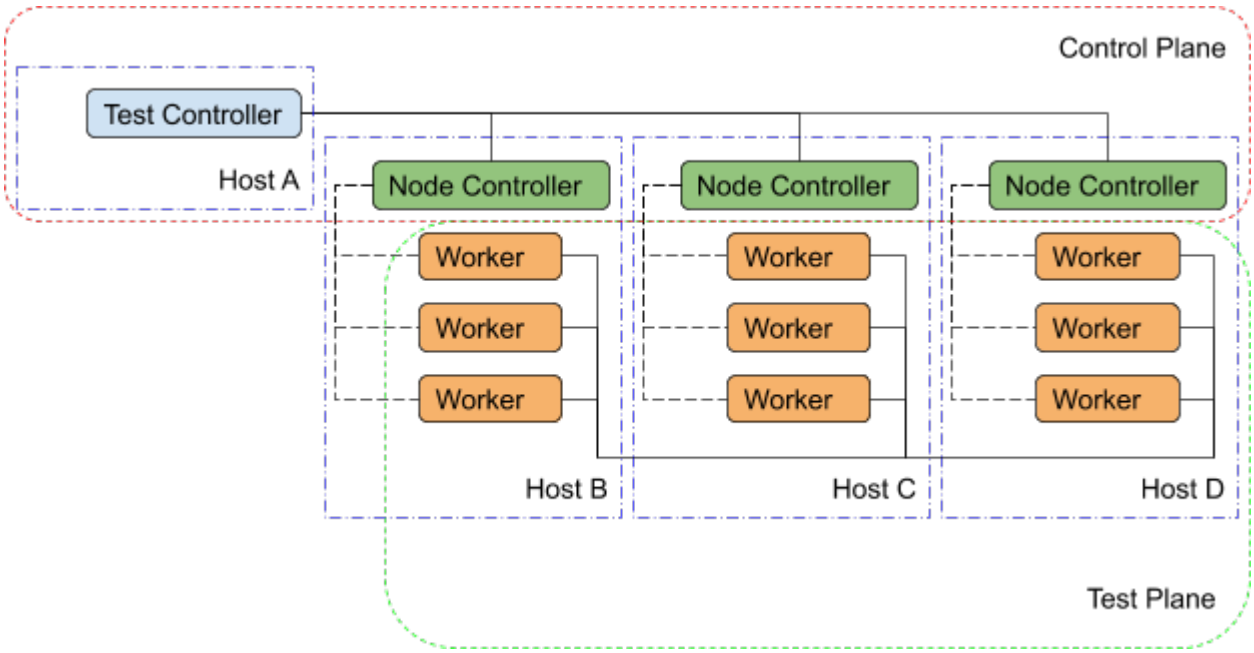

Fig. 2.1: Bench Overview

Worker

The `worker` application, true to its name, performs most of the work associated with any given test scenario. It creates and exercises the DDS entities specified in its configuration file and gathers performance statistics related to discovery, data integrity, and performance. The worker's configuration file contains regions that may be used to represent OpenDDS's configuration sections as well as individual DDS entities and the QoS policies to be for their creation. In addition, the worker configuration contains test timing values and descriptions of test `actions` to be taken (e.g. publishing and forwarding data read from subscriptions). Upon test completion, the worker can write out a report file containing the performance statistics gathered during its run.

Node Controller

Each machine in the test environment will run (at least) one `node_controller` application which acts as a daemon and, upon request from a `test_controller`, will spawn one or more worker processes. Each request will contain the configuration to use for the spawned workers and, upon successful exit, the workers' report files will be read and sent back to the `test_controller` which requested it. Failed workers processes (aborts, crashes) will be noted and have their output logs sent back to the requesting `test_controller`. In addition to collecting worker reports, the node controller also gathers general system resource statistics during test execution (CPU and memory utilization) to be returned to the test controller at the end of the test.

Test Controller

Each execution of the test framework will use a `test_controller` to read in a scenario configuration file (an annotated collection of worker configuration file names) before listening for available `node_controller`'s and parceling out the scenario's worker configurations to the individual `node_controller`'s. The `test_controller` may also optionally adjust certain worker configuration values for the sake of the test (assigning a unique DDS partition to avoid collisions, coordinating worker test times, etc.). After sending the allocated scenario to each of the available node controllers, the test controller waits to receive reports from each of the node controllers. After receiving all the reports, the `test_controller` coalesces the performance statistics from each of the workers and presents the final results to the user (both on screen & in a results file).

2.6.3 Building Bench

Required Features

The primary requirements for building OpenDDS such that Bench also gets built:

- C++11 Support, either with a compiler that defaults to C++11 (or later) support or by manually specifying a compatible standard (e.g. `--std=c++11`)
- RapidJSON present and enabled (`--rapidjson`)
- Tests are being built (`--tests`)

Required Targets

If these elements are present, you can either build the entire test suite (slow) or use these 3 targets (faster), which also cover all the required libraries:

- `Bench_Worker`
- `Bench_node_controller`
- `Bench_test_controller`

2.6.4 Running Bench

Environment Variables

To run Bench executables with dynamically linked or shared libraries, you'll want to make sure the Bench libraries are in your library path.

Linux/Unix

Add `${DDS_ROOT}/performance-tests/bench/lib` to your `LD_LIBRARY_PATH`

Windows

Add `%DDS_ROOT%\performance-tests\bench\lib` to your `PATH`

Assuming *DDS_ROOT* is already set on your system (from the `configure` script or from sourcing `setenv.sh`), there are convenience scripts to do this for you in the performance-tests/bench directory (`set_bench_env[.sh/.cmd]`)

Running a Bench CI Test

In the event that you're debugging a failing Bench CI test, you can use performance-tests/bench/run_test.pl to execute the full scenario without first setting the environment as listed above. This is because the perl script sets the appropriate environment variables automatically before launching its processes (a single `node_controller` in the background, as well as the test controller with the requested scenario). The perl script can be inspected in order to determine which scenarios have been made available in this way. The script can be modified to easily run other available scenarios (see performance-tests/bench/example/config/scenario) against a single node controller with relative ease.

Running Scenarios Manually

Assuming you already have scenario and worker configuration files defined, the general approach to running a scenario is to start one or more `node_controller`s (across one or more hosts) and then execute the test_controller with the desired scenario configuration.

2.6.5 Configuration Files

As a general rule, Bench uses JSON configuration files that directly map onto the C++ Platform Specific Model (PSM) of the IDL found in performance-tests/bench/idl and the IDL used in the DDS specification. This allows the test applications to easily convert between configuration files and the C++ structures used for the configuration of DDS entities.

Scenario Configuration Files

Scenario configuration files are used by the test controller to determine the number and type (configuration) of worker processes required for a particular test scenario. In addition, the scenario file may specify certain sets of workers to be run on the same node by placing them together in a node "prototype" (see below).

IDL Definition

```
struct WorkerPrototype {
  // Filename of the JSON Serialized Bench::WorkerConfig
  string config;
  // Number of workers to spawn using this prototype (Must be >=1)
  unsigned long count;
};

typedef sequence<WorkerPrototype> WorkerPrototypes;

struct NodePrototype {
  // Assign to a node controller with a name that matches this wildcard
  string name_wildcard;
  WorkerPrototypes workers;
  // Number of Nodes to spawn using this prototype (Must be >=1)
  unsigned long count;
  // This NodePrototype must have a Node to itself
  boolean exclusive;
};

typedef sequence<NodePrototype> NodePrototypes;

// This is the root type of the scenario configuration file
struct ScenarioPrototype {
  string name;
  string desc;
  // Workers that must be deployed in sets
  NodePrototypes nodes;
  // Workers that can be assigned to any node
  WorkerPrototypes any_node;
  /*
   * Number of seconds to wait for the scenario to end.
   * 0 means never timeout.
   */
  unsigned long timeout;
};
```

Annotated Example

```
{
  "name": "An Example",
  "desc": "This shows the structure of the scenario configuration",
  "nodes": [
    {
      "name_wildcard": "example_nc_*",
      "workers": [
        {
          "config": "daemon.json",
          "count": 1
        },
        {
          "config": "spawn.json",
          "count": 1
        }
      ],
      "count": 2,
      "exclusive": false
    }
  ],
  "any_node": [
    {
      "config": "master.json",
      "count": 1
    }
  ],
  "timeout": 120
}
```

This scenario configuration will launch 5 worker processes. It will launch 2 pairs of "daemon" / "spawn" processes, with each member of each pair being kept together on the same node (i.e. same `node_controller`). The pairs themselves may be split across nodes, but each "daemon" will be with at least one "spawn" and vice-versa. They may also wind up all together on the same node, depending on the number of available nodes. And finally, one "master" process will be started wherever there is room available.

The "name_wildcard" field is used to filter the `node_controller` instances that can be used to host the nodes in the current node config - only the `node_controller` instances with names matching the wildcard can be used. If the "name_wildcard" is omitted or its value is empty, any `node_controller` can be used. If node "prototypes" are marked exclusive, the test controller will attempt to allocate them exclusively to their own node controllers. If not enough node controllers exist to honor all the exclusive nodes, the test controller will fail with an error message.

Worker Configuration Files

QoS Masking

In a typical DDS application, default QoS objects are often supplied by the entity factory so that the application developer can make required changes locally and not impact larger system configuration choices. As such, the QoS objects found within the JSON configuration file should be treated as a "delta" from the default configuration object of a parent factory class. So while the JSON "qos" element names will directly match the relevant IDL element names, there will also be an additional "qos_mask" element that lives alongside the "qos" element in order to specify which elements apply. For each QoS attribute "attribute" within the "qos" object, there will also be a boolean "has_attribute" within

the "qos_mask" which informs the builder library that this attribute should indeed be applied against the default QoS object supplied by the parent factory class before the entity is created.

IDL Definition

```
struct TimeStamp {
  long sec;
  unsigned long nsec;
};

typedef sequence<string> StringSeq;
typedef sequence<double> DoubleSeq;

enum PropertyValueKind { PVK_TIME, PVK_STRING, PVK_STRING_SEQ, PVK_STRING_SEQ_SEQ, PVK_
↪DOUBLE, PVK_DOUBLE_SEQ, PVK_ULL };
union PropertyValue switch (PropertyValueKind) {
  case PVK_TIME:
    TimeStamp time_prop;
  case PVK_STRING:
    string string_prop;
  case PVK_STRING_SEQ:
    StringSeq string_seq_prop;
  case PVK_STRING_SEQ_SEQ:
    StringSeqSeq string_seq_seq_prop;
  case PVK_DOUBLE:
    double double_prop;
  case PVK_DOUBLE_SEQ:
     DoubleSeq double_seq_prop;
  case PVK_ULL:
    unsigned long long ull_prop;
};

struct Property {
  string name;
  PropertyValue value;
};
typedef sequence<Property> PropertySeq;

struct ConfigProperty {
  string name;
  string value;
};
typedef sequence<ConfigProperty> ConfigPropertySeq;

// ConfigSection

struct ConfigSection {
  string name;
  ConfigPropertySeq properties;
};
typedef sequence<ConfigSection> ConfigSectionSeq;

// Writer
```

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```
struct DataWriterConfig {
  string name;
  string topic_name;
  string listener_type_name;
  unsigned long listener_status_mask;
  string transport_config_name;
  DDS::DataWriterQos qos;
  DataWriterQosMask qos_mask;
};
typedef sequence<DataWriterConfig> DataWriterConfigSeq;

// Reader

struct DataReaderConfig {
  string name;
  string topic_name;
  string listener_type_name;
  unsigned long listener_status_mask;
  PropertySeq listener_properties;
  string transport_config_name;
  DDS::DataReaderQos qos;
  DataReaderQosMask qos_mask;
  StringSeq tags;
};
typedef sequence<DataReaderConfig> DataReaderConfigSeq;

// Publisher

struct PublisherConfig {
  string name;
  string listener_type_name;
  unsigned long listener_status_mask;
  string transport_config_name;
  DDS::PublisherQos qos;
  PublisherQosMask qos_mask;
  DataWriterConfigSeq datawriters;
};
typedef sequence<PublisherConfig> PublisherConfigSeq;

// Subscription

struct SubscriberConfig {
  string name;
  string listener_type_name;
  unsigned long listener_status_mask;
  string transport_config_name;
  DDS::SubscriberQos qos;
  SubscriberQosMask qos_mask;
  DataReaderConfigSeq datareaders;
};
typedef sequence<SubscriberConfig> SubscriberConfigSeq;
```

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```
// Topic

struct ContentFilteredTopic {
  string cft_name;
  string cft_expression;
  DDS::StringSeq cft_parameters;
};

typedef sequence<ContentFilteredTopic> ContentFilteredTopicSeq;

struct TopicConfig {
  string name;
  string type_name;
  DDS::TopicQos qos;
  TopicQosMask qos_mask;
  string listener_type_name;
  unsigned long listener_status_mask;
  string transport_config_name;
  ContentFilteredTopicSeq content_filtered_topics;
};
typedef sequence<TopicConfig> TopicConfigSeq;

// Participant

struct ParticipantConfig {
  string name;
  unsigned short domain;
  DDS::DomainParticipantQos qos;
  DomainParticipantQosMask qos_mask;
  string listener_type_name;
  unsigned long listener_status_mask;
  string transport_config_name;
  StringSeq type_names;
  TopicConfigSeq topics;
  PublisherConfigSeq publishers;
  SubscriberConfigSeq subscribers;
};
typedef sequence<ParticipantConfig> ParticipantConfigSeq;

// TransportInstance

struct TransportInstanceConfig {
  string name;
  string type;
  unsigned short domain;
};
typedef sequence<TransportInstanceConfig> TransportInstanceConfigSeq;

// Discovery

struct DiscoveryConfig {
  string name;
```

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```
  string type; // "rtps" or "repo"
  string ior; // "repo" URI (e.g. "file://repo.ior")
  unsigned short domain;
};
typedef sequence<DiscoveryConfig> DiscoveryConfigSeq;

// Process

struct ProcessConfig {
  ConfigSectionSeq config_sections;
  DiscoveryConfigSeq discoveries;
  TransportInstanceConfigSeq instances;
  ParticipantConfigSeq participants;
};

// Worker

// This is the root structure of the worker configuration
// For the sake of readability, module names have been omitted
// All structures other than this one belong to the Builder module
struct WorkerConfig {
  TimeStamp create_time;
  TimeStamp enable_time;
  TimeStamp start_time;
  TimeStamp stop_time;
  TimeStamp destruction_time;
  PropertySeq properties;
  ProcessConfig process;
  ActionConfigSeq actions;
  ActionReportSeq action_reports;
};
```

Annotated Example

```
{
  "create_time": { "sec": -1, "nsec": 0 },
```

Since the timestamp is negative, this treats the time as relative and waits one second.

```
"enable_time": { "sec": -1, "nsec": 0 },
"start_time": { "sec": 0, "nsec": 0 },
```

Since the time is zero and thus neither absolute nor relative, this treats the time as indefinite and waits for keyboard input from the user.

```
"stop_time": { "sec": -10, "nsec": 0 },
```

Again, a relative timestamp. This time, it waits for 10 seconds for the test actions to run before stopping the test.

```
"destruction_time": { "sec": -1, "nsec": 0 },
```

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```
"process": {
```

This is the primary section where all the DDS entities are described, along with configuration of OpenDDS.

```
"config_sections": [
```

The elements of this section are functionally identical to the sections of an OpenDDS `.ini` file with the same name. Each config section is created programmatically within the worker process using the name provided and made available to the OpenDDS `ServiceParticipant` during entity creation. The example here sets the value of both the `DCPSSecurity` and `DCPSDebugLevel` keys to 0 within the `[common]` section of the configuration.

```
  { "name": "common",
    "properties": [
      { "name": "DCPSDefaultDiscovery",
        "value":"rtps_disc"
      },
      { "name": "DCPSGlobalTransportConfig",
        "value":"$file"
      },
      { "name": "DCPSDebugLevel",
        "value": "0"
      },
      { "name": "DCPSPendingTimeout",
        "value": "3"
      }
    ]
  },
  { "name": "rtps_discovery/rtps_disc",
    "properties": [
      { "name": "ResendPeriod",
        "value": "5"
      }
    ]
  },
  { "name": "transport/rtps_transport",
    "properties": [
      { "name": "transport_type",
        "value": "rtps_udp"
      }
    ]
  }
],
"participants": [
```

The list of participants to create.

```
{ "name": "participant_01",
  "domain": 7,
  "transport_config_name": "rtps_instance_01",
```

The transport config that gets bound to this participant

```
"qos": { "entity_factory": { "autoenable_created_entities": false } },
"qos_mask": { "entity_factory": { "has_autoenable_created_entities": false } },
```

An example of QoS masking. Note that in this example, the boolean flag is `false`, so the QoS mask is not actually applied. In this case, both lines here were added to make switching back and forth between `autoenable_created_entities` easier (simply change the value of the bottom element `"has_autoenable_created_entities"` to `"true"`).

```
"topics": [
```

List of topics to register for this participant

```
{ "name": "topic_01",
  "type_name": "Bench::Data"
```

Note the type name. `"Bench::Data"` is currently the only topic type supported by the Bench framework. That said, it contains a variably sized array of octets, allowing a configurable range of data payload sizes (see write_action below).

```
"content_filtered_topics": [
  {
    "cft_name": "cft_1",
    "cft_expression": "filter_class > %0",
    "cft_parameters": ["2"]
  }
]
```

List of content filtered topics. Note `"cft_name"`. Its value can be used in DataReader `"topic_name"` to use the content filter.

```
   }
 ],
"subscribers": [
```

List of subscribers

```
{ "name": "subscriber_01",
  "datareaders": [
```

List of DataReaders

```
{ "name": "datareader_01",
  "topic_name": "topic_01",
  "listener_type_name": "bench_drl",
  "listener_status_mask": 4294967295,
```

Note the listener type and status mask. `"bench_drl"` is a listener type registered by the Bench Worker application that does most of the heavy lifting in terms of stats calculation and reporting. The mask is a fully-enabled bitmask for all listener events (i.e. `2^32 - 1`).

```
"qos": { "reliability": { "kind": "RELIABLE_RELIABILITY_QOS" } },
"qos_mask": { "reliability": { "has_kind": true } },
```

DataReaders default to best effort QoS, so here we are setting the reader to reliable QoS and flagging the `qos_mask` appropriately in order to get a reliable datareader.

```
"tags": [ "my_topic", "reliable_transport" ]
```

The config can specify a list of tags associated with each data reader. The statistics for each tag is computed in addition to the overall statistics and can be printed out at the end of the run by the `test_controller`.

```
      }
    ]
  }
],
"publishers": [
```

List of publishers within this participant

```
{ "name": "publisher_01",
  "datawriters": [
```

List of DataWriters within this publisher

```
{ "name": "datawriter_01",
```

Note that each DDS entity is given a process-entity-unique name, which can be used below to locate / identify this entity.

```
              "topic_name": "topic_01",
              "listener_type_name": "bench_dwl",
              "listener_status_mask": 4294967295
            }
          ]
        }
      ]
    }
  ]
},
"actions": [
```

A list of worker 'actions' to start once the test 'start' period begins.

```
{
  "name": "write_action_01",
  "type": "write",
```

Current valid types are `"write"`, `"forward"`, and `"set_cft_parameters"`.

```
"writers": [ "datawriter_01" ],
```

Note the datawriter name defined above is passed into the action's writer list. This is used to locate the writer within the process.

```
"params": [
  { "name": "data_buffer_bytes",
```

The size of the octet array within the `Bench::Data` message. Note, actual messages will be slightly larger than this value.

```
  "value": { "$discriminator": "PVK_ULL", "ull_prop": 512 }
},
{ "name": "write_frequency",
```

The frequency with which the write action attempts to write a message. In this case, twice a second.

```
  "value": { "$discriminator": "PVK_DOUBLE", "double_prop": 2.0 }
},
```

```
{ "name": "filter_class_start_value",
  "value": { "$discriminator": "PVK_ULL", "ull_prop": 0 }
},
{ "name": "filter_class_stop_value",
  "value": { "$discriminator": "PVK_ULL", "ull_prop": 0 }
},
{ "name": "filter_class_increment",
  "value": { "$discriminator": "PVK_ULL", "ull_prop": 0 }
}
```

Value range and increment for "`filter_class`" data variable, used when writing data. This variable is an unsigned integer intended to be used for content filtered topics "set_cft_parameters" actions.

```
  ]
},

{ "name": "cft_action_01",
  "type": "set_cft_parameters",
  "params": [
    { "name": "content_filtered_topic_name",
      "value": { "$discriminator": "PVK_STRING", "string_prop": "cft_1" }
    },
    { "name": "max_count",
      "value": { "$discriminator": "PVK_ULL", "ull_prop": 3 }
    },
```

Maximum count of "Set" actions to be taken.

```
{ "name": "param_count",
  "value": { "$discriminator": "PVK_ULL", "ull_prop": 1 }
},
```

Number of parameters to be set

```
{ "name": "set_frequency",
  "value": { "$discriminator": "PVK_DOUBLE", "double_prop": 2.0 }
},
```

The frequency for set action, per second

```
{ "name": "acceptable_param_values",
  "value": { "$discriminator": "PVK_STRING_SEQ_SEQ", "string_seq_seq_prop": [ ["1", "2",
↪"3"] ] }
},
```

Lists of allowed values to set to, for each parameter. Worker will iterate thought the list sequentially unless "random_order" flag (below) is specified

```
        { "name": "random_order",
          "value": { "$discriminator": "PVK_ULL", "ull_prop": 1 }
        }
      ]
  }

  ]
}
```

2.6.6 Detailed Application Descriptions

test_controller

As mentioned above, the `test_controller` application is the application responsible for running test scenarios and, as such, will probably wind up being the application most frequently run directly by testers. The `test_controller` needs network visibility to at least one `node_controller` configured to run on the same domain. It expects, as arguments, the path to a directory containing config files (both scenario & worker) and the name of a scenario configuration file to run (without the `.json` extension). For historical reasons, the config directory is often simply called `example`. The `test_controller` application also supports a number of optional configuration parameters, some of which are described in the section below.

Usage

`test_controller CONFIG_PATH SCENARIO_NAME [OPTIONS]`

`test_controller --help|-h`

This is a subset of the options. Use `--help` option to see all the options.

CONFIG_PATH

Path to the directory of the test configurations and artifacts

SCENARIO_NAME

Name of the scenario file in the test context without the *.json* extension.

--domain N

The DDS Domain to use. The default is 89.

--wait-for-nodes N

The number of seconds to wait for nodes before broadcasting the scenario to them. The default is 10 seconds.

--timeout N

The number of seconds to wait for a scenario to complete. Overrides the value defined in the scenario. If N is 0, there is no timeout.

--override-create-time N

Overwrite individual worker configs to create their DDS entities N seconds from now (absolute time reference)

--override-start-time N

Overwrite individual worker configs to start their test actions (writes & forwards) N seconds from now (absolute time reference)

`--tag` TAG

Specify a tag for which the performance statistics will be printed out (and saved to a results file). Multiple instances of this option can be specified, each for a single tag.

`--json-result-id` ID

Specify a name to store the raw JSON report under. By default, this not enabled. These results will contain the full raw `Bench::TestController` report, including all node controller and worker reports (and DDS entity reports)

node_controller

The node controller application is best thought of as a daemon, though the application can be run both in a long-running `daemon` mode and also a `one-shot` mode more appropriate for testing. The `daemon-exit-on-error` mode additionally has the ability to exit the process every time an error is encountered, which is useful for restarting the application when errors are detected, if run as a part of an OS system environment (systemd, supervisord, etc).

Usage

```
node_controller [OPTIONS] one-shot|daemon|daemon-exit-on-error
```

one-shot

Run a single batch of worker requests (configs > processes > reports) and report the results before exiting. Useful for one-off and local testing.

daemon

Act as a long-running process that continually runs batches of worker requests, reporting the results. Attempts to recover from errors.

daemon-exit-on-error

Act as a long-running process that continually runs batches of worker requests, reporting the results. Does not attempt to recover from errors.

`--domain` N

The DDS Domain to use. The default is 89.

`--name` STRING

Human friendly name for the node. Will be used by the test controller for referring to the node. During allocation of node controllers, the name is used to match against the "name_wildcard" fields of the node configs. Only node controllers whose names match the "name_wildcard" of a given node config can be allocated to that node config. Multiple nodes could have the same name.

worker

The worker application is meant to mimic the behavior of a single arbitrary OpenDDS test application. It uses the Bench builder library along with its JSON configuration file to first configure OpenDDS (including discovery & transports) and then create all required DDS entities using any desired DDS QoS attributes. Additionally, it allows the user to configure several test phase timing parameters, using either absolute or relative times:

- DDS entity creation (`create_time`)
- DDS entity "enabling" (`enable_time`) (only relevant if `autoenable_created_entities` QoS setting is false)
- test actions start time (`start_time`)
- test actions stop time (`stop_time`)

- DDS entity destruction (`destruction_time`)

Finally, it also allows for the configuration and execution of test "actions" which take place between the "start" and "stop" times indicated in configuration.These may make use of the created DDS entities in order to simulate application behavior. At the time of this writing, the three actions are `"write"`, which will write to a datawriter using data of a configurable size and frequency (and maximum count), `"forward"`, which will pass along the data read from one datareader to a datawriter, allowing for more complex test behaviors (including round-trip latency & jitter calculations), and `"set_cft_parameters"`, which will change the content filtered topic parameter values dynamically. In addition to reading a JSON configuration file, the worker is capable of writing a JSON report file that contains various test statistics gathered from listeners attached to the created DDS entities. This report is read by the `node_controller` after the worker process ends and is then sent back to the waiting `test_controller`.

Usage

`worker [OPTIONS] CONFIG_FILE`

`--log` `LOG_FILE`

The log file path. Will log to `stdout` if not passed.

`--report` `REPORT_FILE`

The report file path.

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