Content-based Filtering Discovery Protocol (CFDP): Scalable and Efficient
OMG DDS Discovery Protocol

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Real-Time Innovations (RTI)
Data Distribution Service (DDS)

- DDS is an OMG standard specification for data-centric publish/subscribe middleware
- DDS is deployed in many IoT application domains, including Aerospace & Defense, Healthcare, Energy, Transportation, Control Systems
  - Interoperability
  - Scalability
  - QoS support
DDS Elements & Features

- Domain
- Participant
- DataWriter (DW) and DataReader (DR)
- Topic
- Quality-of-service (QoS)
- Content Filtered Topic (CFT)
DDS Architecture
DDS Discovery Protocol

- OMG DDS Real-Time Publish-Subscribe (RTPS) defines a discovery protocol
  - Participant Discovery Protocol (PDP)
  - Endpoint Discovery Protocol (EDP)
- The DDS RTPS specification describes Simple Discovery Protocol (SDP) as a default discovery protocol
  - Simple Participant Discovery Protocol (SPDP)
  - Simple Endpoint Discovery Protocol (SEDP)
DDS Discovery Protocol Entities

Participant Discovery Phase
- Advertises this Participant
- Discovers other Participants

Endpoint Discovery Phase
- Advertises this Participant's Data Writers and Data Readers
- Discovers this Participant's Data Writers and Data Readers

Participant
- Built-in DataWriter
- Built-in DataReader

Network
- participant DATA
- "DCPSParticipant" built-in topic
- subscription DATA
- "DCPSSubscription" built-in topic
- publication DATA
- "DCPSParticipant" built-in topic
- publication DATA
- "DCPSSubscription" built-in topic
Problem?

• SDP scales poorly as the number of peers and their endpoints increases in a domain

• Why?

  - Each peer sends/receives discovery messages to/from other peers in the same domain

• For a large scale system, substantial network, memory, and computing resources are consumed just for the discovery process

• This overhead degrades discovery completion time and hence overall scalability
Solution

- A new mechanism for scalable DDS discovery called the Content-based Filtering Discovery Protocol (CFDP)

- CFDP employs content-based filtering on the sending peers to filter out unnecessary discovery messages by exchanging filtering expressions that limit the range of interests

- For the implementation, CFDP uses Content Filtered Topic (CFT) for built-in discovery entities
Design of CFDP

• CFDP filters out discovery messages based on topics names and endpoint types

• Utilizes the first phase of SDP called SPDP

• Differs from SDP in the endpoint discovery phase

• Uses built-in entities with CFTs that filter discovery messages on topic names stored in subscription DATA and publication DATA
Design of CFDP

**DP1**
- **Publication Filtering**
  - topic_name MATCH 'A,B,MASK_ALL'
- **Subscription Filtering**
  - topic_name MATCH 'MASK_ALL'

**Publication DATA (DW{B})**

**Subscription DATA (DR{A})**

**DP2**
- **Publication Filtering**
  - topic_name MATCH 'B,MASK_ALL'
- **Subscription Filtering**
  - topic_name MATCH 'A,MASK_ALL'

**Publication DATA (DW{A})**

**Filtered Discovery Message**

**Delivered Discovery Message**
SDP Example

Network Load: 6 transfers for each DP = 18
Memory Load: 6 objects for each DP's DB = 18
CFDP Example

Network Load: 3(DP1) + 4(DP2) + 3(DP3) = 10
Memory Load: 3(DP1) + 4(DP2) + 3(DP3) = 10
CFDP Implementation

• CFDP prototype is implemented at the application-level to avoid non-standard changes to the underlying DDS middleware

• Use provided callback functions (Pluggable Discovery Framework) to exploit required events from the middleware
  - Creation/Deletion events of local DDS entities

• Create built-in DDS entities to exchange discovery events with remote peers
  - Creation/Deletion events of remote DDS entities
Assumption by Practical Limitation

- Our prototype implementation assumes users determine which topics are published or subscribed by participants when participants are created.

- CFDP uses TRANSIENT_LOCAL durability QoS for late joiners, but it does not work properly with using CFT.

- When a value in a filtering expression of a CFT is changed, the changed value is not reflected in the list of late joiners.
CFDP Callback Functions

- Pluggable Discovery Framework (PDF)
  - Local Endpoint Enabled
  - Local Endpoint Deleted
- Built-in Entities
  - Remote DataWriter Received
  - Remote DataReader Received
CFDP Sequence of DW Creation Event

Peer 1

- CFDP Discovery Plugin
  - CFDPPublication Built-in DataWriter
  - AfterLocalDataWriterEnabledCallback
  - Pluggable Discovery Framework (PDF)

Peer 2

- CFDP Discovery Plugin
  - CFDPPublication Built-in DataReader
  - assert_remote_datawriter
  - Pluggable Discovery Framework (PDF)

STEP 1

STEP 2

publication DATA

STEP 3
SDP Network Usage with Multicast

\[ N_{\text{multi-participant}} = \frac{E}{P} + \frac{E}{P} \cdot (P - 1) \]  \hspace{1cm} (1)

\[ = \frac{E}{P} + E - \frac{E}{P} \]  \hspace{1cm} (2)

\[ = E \]  \hspace{1cm} (3)

\[ N_{\text{multi-total}} = E \cdot P \]  \hspace{1cm} (4)
CFDP Network Usage with Multicast

\[ N_{\text{multi\_participant}} = \frac{E}{P} + \frac{E}{P} \cdot (P - 1) \cdot R \]  \hspace{1cm} (12)

\[ = \frac{E}{P} + E \cdot R - \frac{E}{P} \cdot R \]  \hspace{1cm} (13)

\[ = F \cdot (1 - R) + E \cdot R \]  \hspace{1cm} (14)

\[ \sim E \cdot R \]  \hspace{1cm} (15)

\[ N_{\text{multi\_total}} \sim E \cdot P \cdot R \]  \hspace{1cm} (16)
SDP Network Usage with Unicast

\[ N_{uni\_participant} = \frac{E}{P} \cdot (P - 1) + \frac{E}{P} \cdot (P - 1) \quad (5) \]
\[ = 2 \cdot \frac{E}{P} \cdot (P - 1) \quad (6) \]
\[ \therefore (P - 1) \sim P \quad (7) \]
\[ \sim 2 \cdot E \quad (8) \]

\[ N_{uni\_total} \sim 2 \cdot E \cdot P \quad (9) \]
CFDP Network Usage with Unicast

\[ N_{\text{uni\_participant}} = \frac{E}{P} \cdot (P - 1) \cdot R + \frac{E}{P} \cdot (P - 1) \cdot R \quad (17) \]

\[ = 2 \cdot \frac{E}{P} \cdot (P - 1) \cdot R \quad (18) \]

\[ \sim 2 \cdot E \cdot R \quad (19) \]

\[ N_{\text{uni\_total}} \sim 2 \cdot E \cdot P \cdot R \quad (20) \]
SDP Memory Usage

\[ M_{\text{participant}} = E \]  \hspace{1cm} (10)

\[ M_{\text{total}} = E \cdot P \]  \hspace{1cm} (11)
CFDP Memory Usage

\[
M_{\text{participant}} = \frac{E}{P} + \frac{E}{P} \cdot (P - 1) \cdot R \quad (21)
\]

\[
\sim E \cdot R \quad (22)
\]

\[
M_{\text{total}} \sim E \cdot P \cdot R \quad (23)
\]
Empirical Evaluation

- Discovery Completion Time
  - CFDP vs. SDP (10% matching)

- CPU Usage
  - CFDP vs. SDP (10% matching)
  - CFDP (10%, 30%, 50%)

- Memory & Network Usage
  - CFDP vs. SDP (10%, 50%, 100%)
Empirical Evaluation

• Testbed
  - Six 12-core machines
  - 1Gb Ethernet connected to a single network switch
  - RTI Connext DDS 5.0

• Experiment Setup
  - 480 applications (participants)
  - Each participant has 20 endpoints
  - Default matching ratio is 0.1 (10%)
  - SDP uses multicast and CFDP uses unicast
Discovery Completion Time

- Discovery completion time is defined as the time needed to completely discover all matching endpoints in a domain.
CFDP and SDP CPU Usage

SDP CPU Usage (10% Matching)

CFDP CPU Usage (10% Matching)

CFDP CPU Usage (30% Matching)

CFDP CPU Usage (50% Matching)
Sent/Received Discovery Messages

![Bar chart showing sent, received, and total samples for different scenarios. The chart compares CFDP (10%), SDP (10%), CFDP (50%), and CFDP (100%) scenarios. The y-axis represents the number of samples, ranging from 0 to 10,000. The x-axis lists the scenarios. The chart indicates differences in the number of sent, received, and total samples across different scenarios.]
Discussion

• CFDP is more efficient and scalable than SDP

• CFDP’s current lack of support for multicast can impede scalability

• Instance-based filtering can help to make CFDP scalable in a large-scale system with a small set of topics
Questions?