Analysis of the Advanced Message Queuing Protocol (AMQP) and comparison with the Real-Time Publish Subscribe Protocol (DDS-RTPS Interoperability Protocol)

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Background: AMQP

- AMQP = Advanced Message Queuing Protocol

  A protocol to communicate between clients and messaging middleware servers (brokers)

- A protocol developed by an industry consortia:
  - IONA
  - JP Morgan
  - RedHat
  - 29West
  - Others

- The goals are:
  - Support Messaging semantics of financial industry
  - Provide needed performance to financial industry
  - Be extensible to new queuing and routing
  - Allow service to be programmed by the application

- High-level Requirements:
  - To accommodate existing messaging API standards (for example, Sun's JMS)
  - To allow complete configuration of server wiring via the protocol

- Low-level Design Requirements:
  - To be compact, using a binary encoding that packs and unpacks rapidly
  - To handle messages of any size without significant limit
  - To carry multiple channels across a single connection
  - To be longlived, with no significant inbuilt limitations
  - To allow asynchronous command pipelining

Background: DDS-RTPS

- DDS-RTPS = Data-Distribution Service Real-Time Publish Subscriber Protocol

  The standard protocol used by the OMG Data-Distribution Service Specification

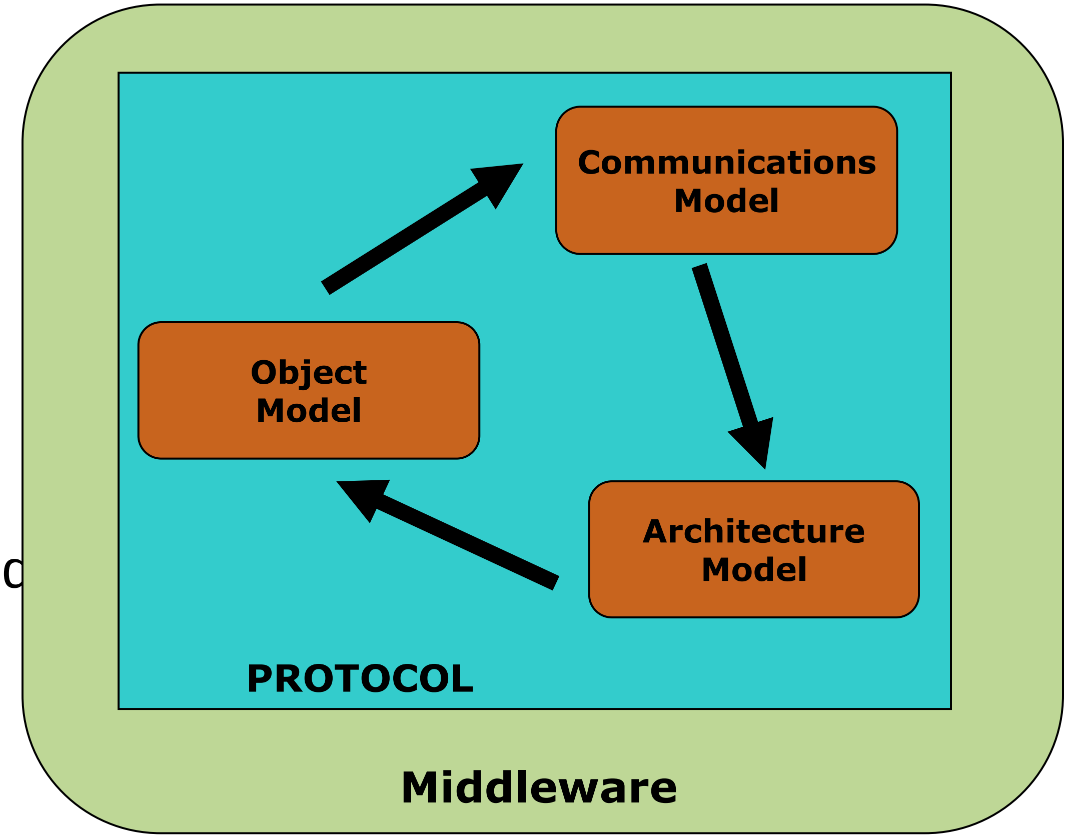
- An OMG standard developed and supported by middleware vendors and users:
  - RTI, PrismTech, THALES, SELEX, NSWC-DD, MITRE, OCI, MilSOFT, etc.
- The goals are:
  - Support Real-Time Publish-Subscribe Middleware
  - Deliver high performance and scale to large systems
  - Support packet based unrealizable transports, including multicast
  - Support Quality of Service
  - Provide for forward and backwards compatibility
  - Provide automatic discovery
- High-level Requirements:
  - To accommodate the OMG DDS specification and all its Qos
- Low-level Design Requirements:
  - To be compact, using a binary encoding that packs and unpacks rapidly
  - To handle messages of any size without significant limit
  - To carry multiple channels across a single connection
  - To be longlived, with no significant inbuilt limitations
  - To allow asynchronous command pipelining

Agenda

- Middleware Models and Protocols
  - Service Models
  - Protocol
- Comparison
  - Communications Model
  - Object Model
  - Architecture Model
  - Protocol
- Conclusion

Middleware = Service Model + Protocol

- Service model composed of:
  - Communications model
  - Object Model
  - Architecture model
- All these interact
- The service model and protocol are also coupled



Communications Model

Architecture Model

Object Model

PROTOCOL

Middleware

Protocols cannot be compared in isolation!
They must be compared in the context of the service model

Middleware Service Model

Service Model = Communications Model
+ Object Model
+ Architecture Model

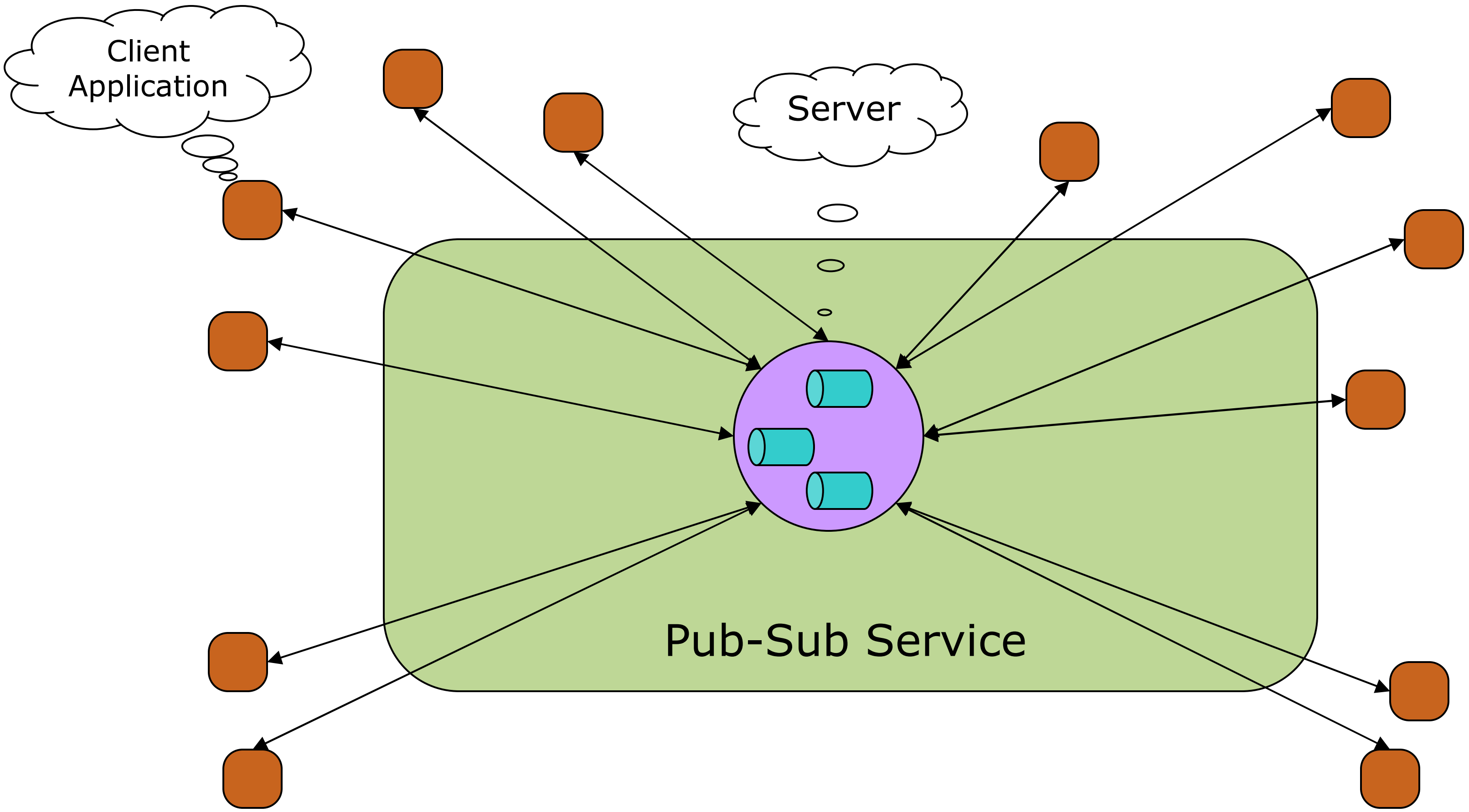
- Communications Model:
  - Abstract model of how applications interact:
    - Queue Based
    - Data-Distribution
    - Replicated Data
    - Distributed Transactions
    - Remote Method Invocation
- Object Model
  - Middleware entities the application uses to interact with the service:
    - Queues, Publishers, Domains, Caches, Federations, Remote Objects…
- Architecture Model
  - Centralized, Brokered, Peer-to-Peer

Centralized Broker Pub-Sub Service

One central server materializes all middleware entities

All traffic flows via server

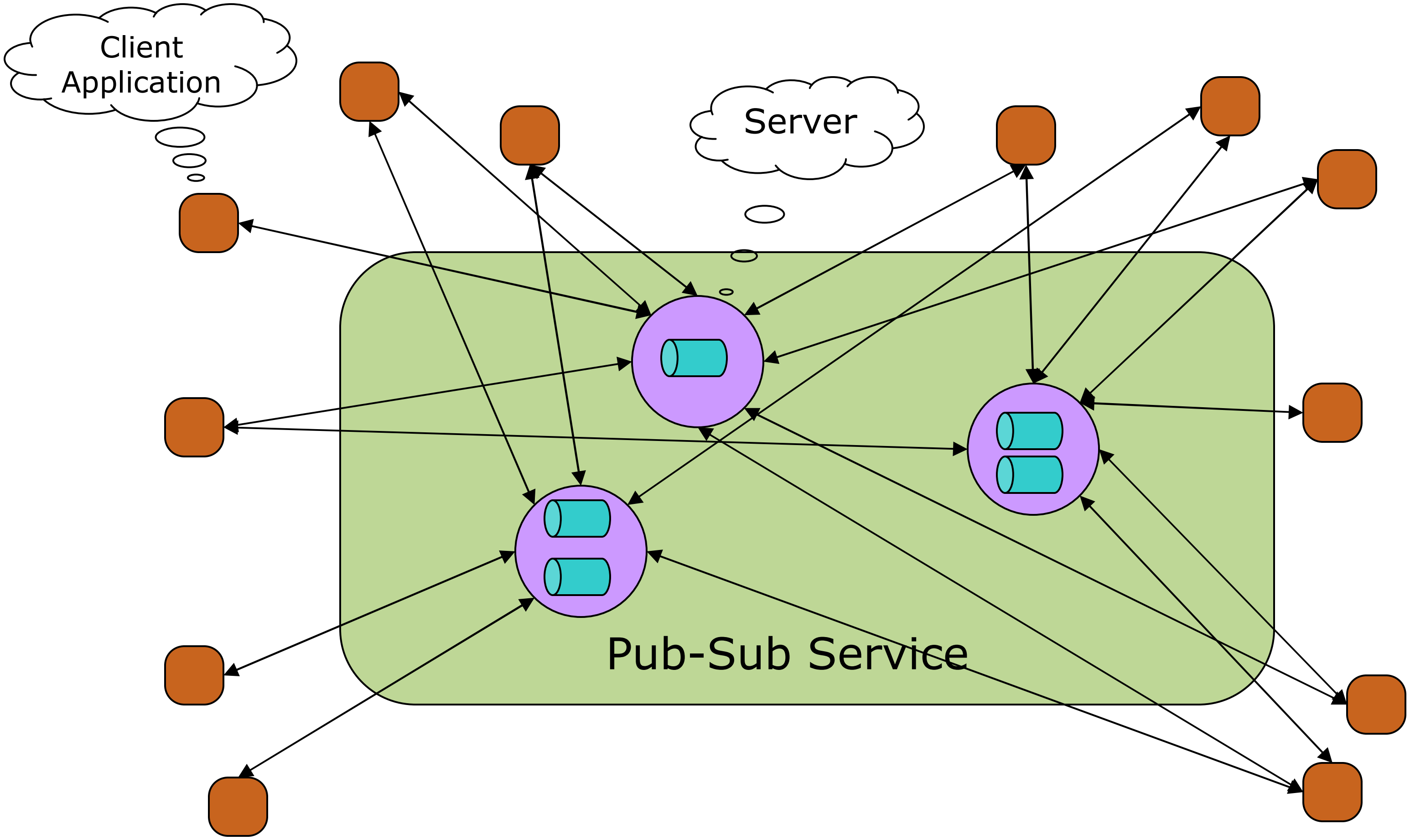
E.g. “naïve” implementations of JMS, CORBA Notification, etc.



Centralized Multi-Broker Pub-Sub Service

Each Queue/Topic Can be placed on a different Server

E.g. Better implementations of JMS, CORBA Notification, etc.

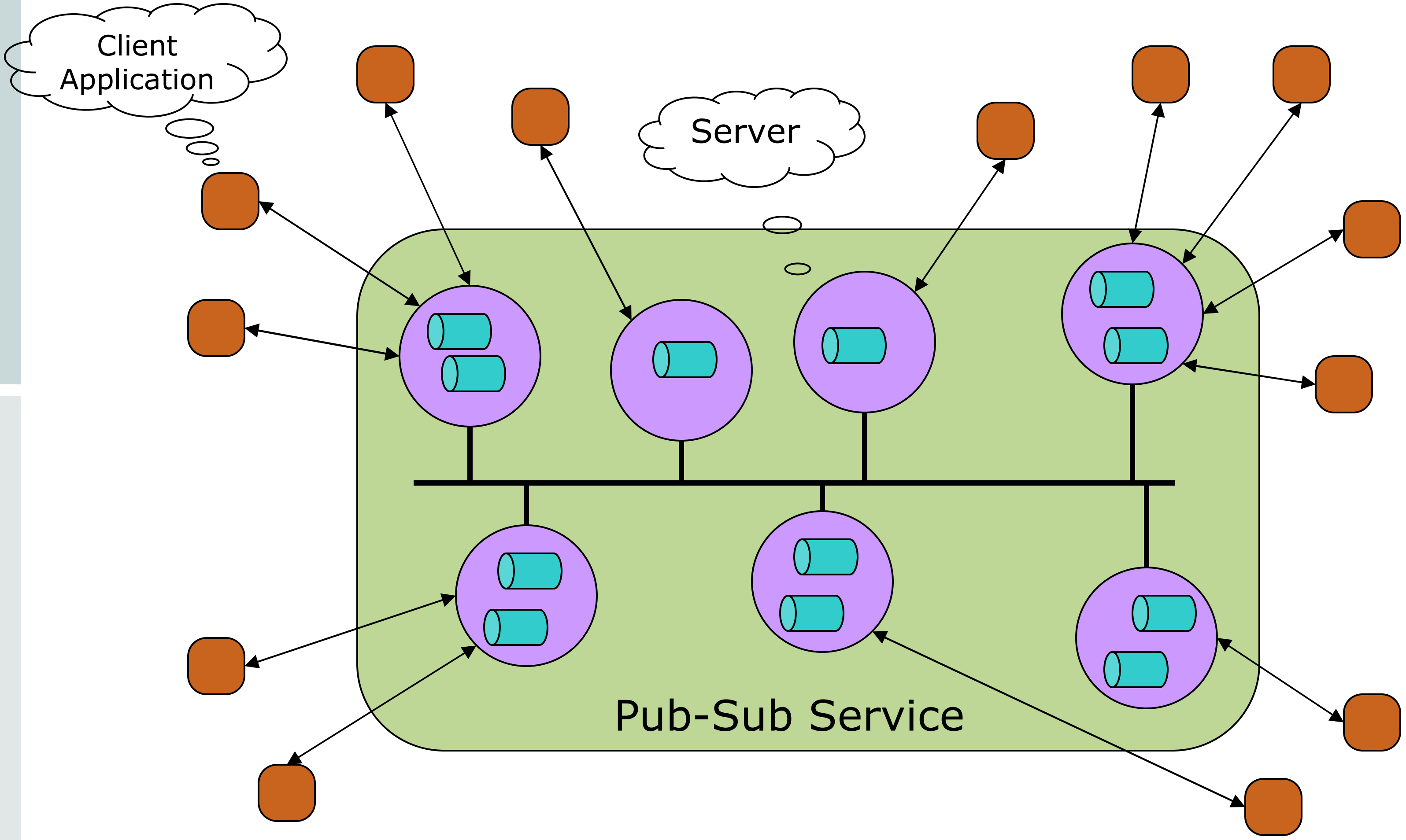


De-centralized Brokered Pub-Sub Service

App uses messaging or RMI to interact with Service Access points

Pub-Sub Service distributes messages internally between servers

Internally PS-Service can be peer-to-peer, hub-and-spoke, multicast, etc.

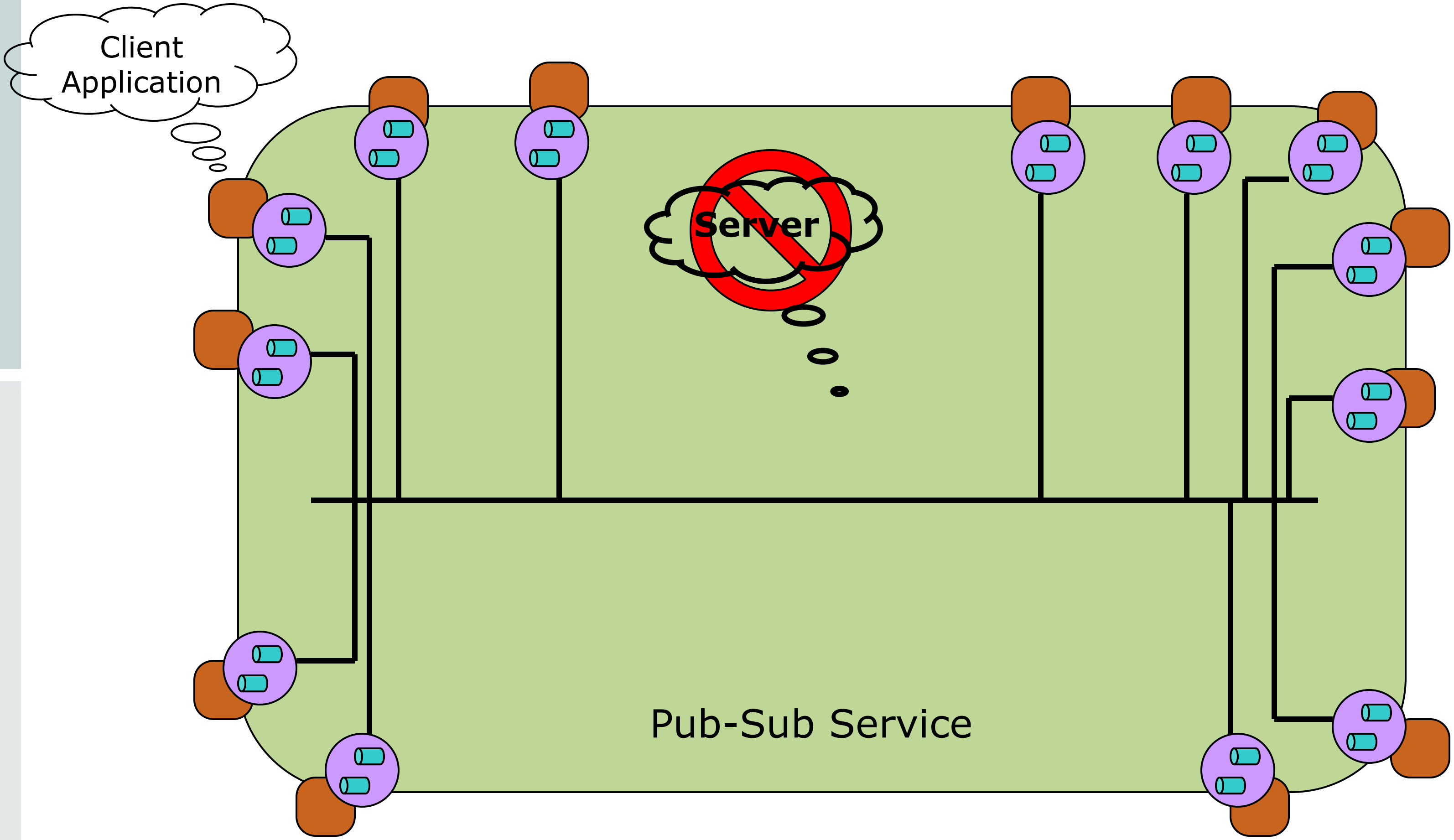


De-Centralized Unbrokered Pub-Sub Service

App links (binds) directly with the Pub-Sub service

Queuing occurs locally on each client

Clients communicate peer-to-peer



Service Model Architecture Examples

Model	*Examples*
Centralized *Brokered*	Typical JMS implementations
Centralized *Multi-Brokered*	Better JMS implementations CORBA event & notification service
De-centralized Brokered	TIBCO RendezVous TIBCO SmartSockets IBM WebSphere MQ (MQSeries) using client connection
De-centralized *Un-brokered* *(Peer-to-peer)*	Most DDS implementations: RTI DDS, OpenSplice, Tao-DDS IBM WebSphere MQ (MQSeries) using Binding connection

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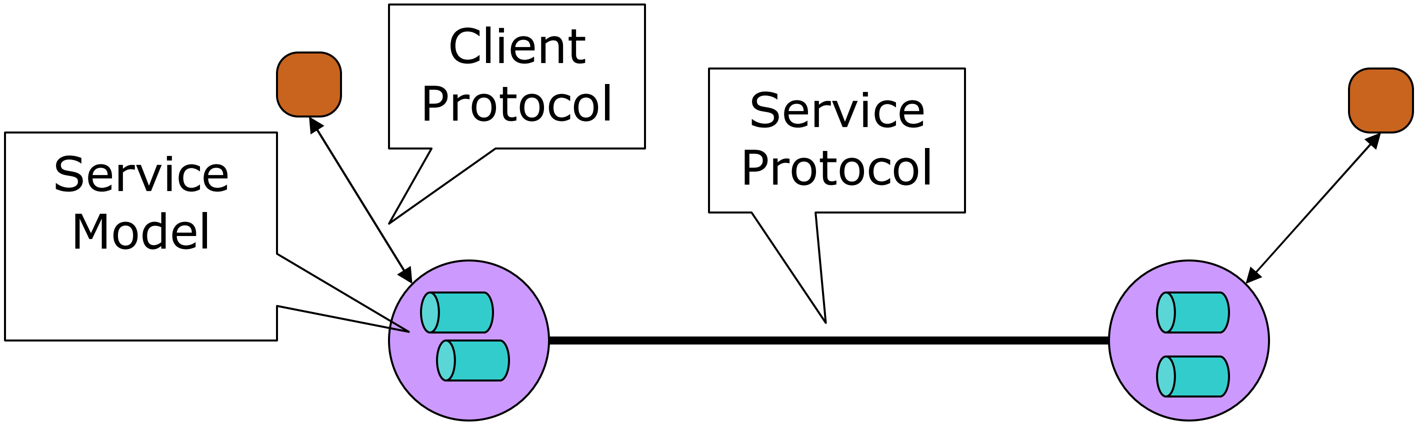
Service Model and Protocol relationship



Client Protocol

Service Protocol

Service Model

- There are interactions between the service model and the Protocol
- A Brokered Service model requires 2 protocols:
  - Client Protocol (used by client applications)
  - Service Protocol (used between the Brokers)
- A fully peer-to-peer middleware requires only one protocol

Protocol layers: Middleware perspective (proposed)

Layer 6
Application operations

Layer 5
Middleware operations

Layer 4
Reliability, Flow Control, Packet Assembly

Layer 3
Packet delivery & routing

The existing middleware perspectives are inadequate to model middleware protocols:

The 7-layer OSI model:

- **Has layers with very limited functionality: (Session Presentation)**
- **Considers TCP and UDP both "layer 4 concepts"**

The 5-layer TCP/IP model:

- **Combines all layers above Transport into single "Application Layer"**
- **Considers TCP and UDP equivalent**

Some protocols may expand multiple layers

Protocol layers (Middleware perspective)

Layer 6
Application operations

Invoke Operations with known semantics
Send messages to queues
Pub/Sub specific topics

Multi-layer protocols

Layer 5
Middleware operations

HTTP
GIOP
SOAP
FTP
TLS

DTLS
STUN

A middleware protocol at this Level must operate on top of a Layer4 protocol like TCP

Layer 4
Reliability, Flow Control, Packet Assembly

SCTP
TCP
RTP
PGM

DTLS
STUN

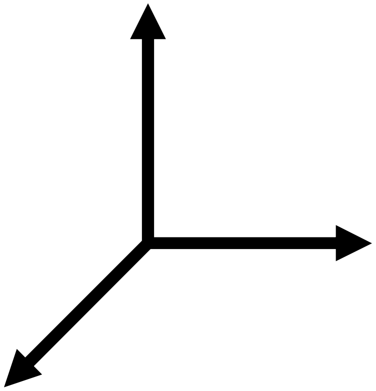
A middleware protocol at this Level can operate on top of UDP or Multicast

Layer 3
Packet delivery & routing

UDP
IP
IP Multicast

Middleware Comparison Dimensions

Service Model:
- Communication Model
- Object Model
- Architecture Model (+ required brokers)



Protocol:
- Layer
- Features
- Transport Assumptions
- Overhead

Impact/Capabilities:
- Features: Reliability, Persistence, QoS, Batching
- Impact:
  - Deployment
  - Performance (protocol overhead, #intermediaries)
  - Robustness (failure conditions)

AMQP vs. DDS-RTPS

Aspect	**AMQP**	**DDS-RTPS**
Communications *(service model)*	Message Queues Globally addressable queues	Data Distribution Global Data Space
Object Model *(service model)*	AMQ Broker Exchange Binding Queue Routing Key	DomainParticipant Topic Publisher Subscriber DataWriter DataReader
Architecture *(service model)*	Clients and Brokers Queues Centralized in Brokers	Peer-to-Peer No Intermediaries
Protocol	AMQP – Layer 5 only (only middleware actions)	RTPS – Layer 4 and 5 Middleware actions Reliability, Flow control, Fragmentation

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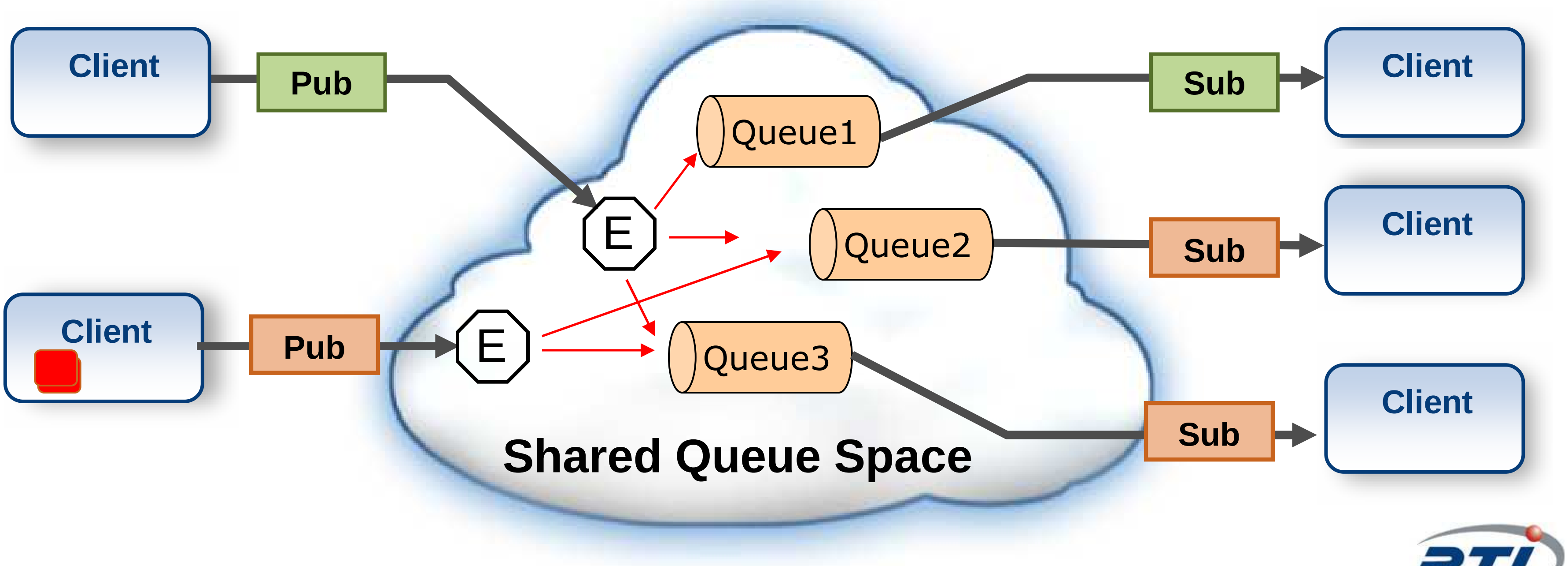
AMQ Service Model: Communication Model

Provides a “**Shared Queue Space**” that is accessible to all interested applications.

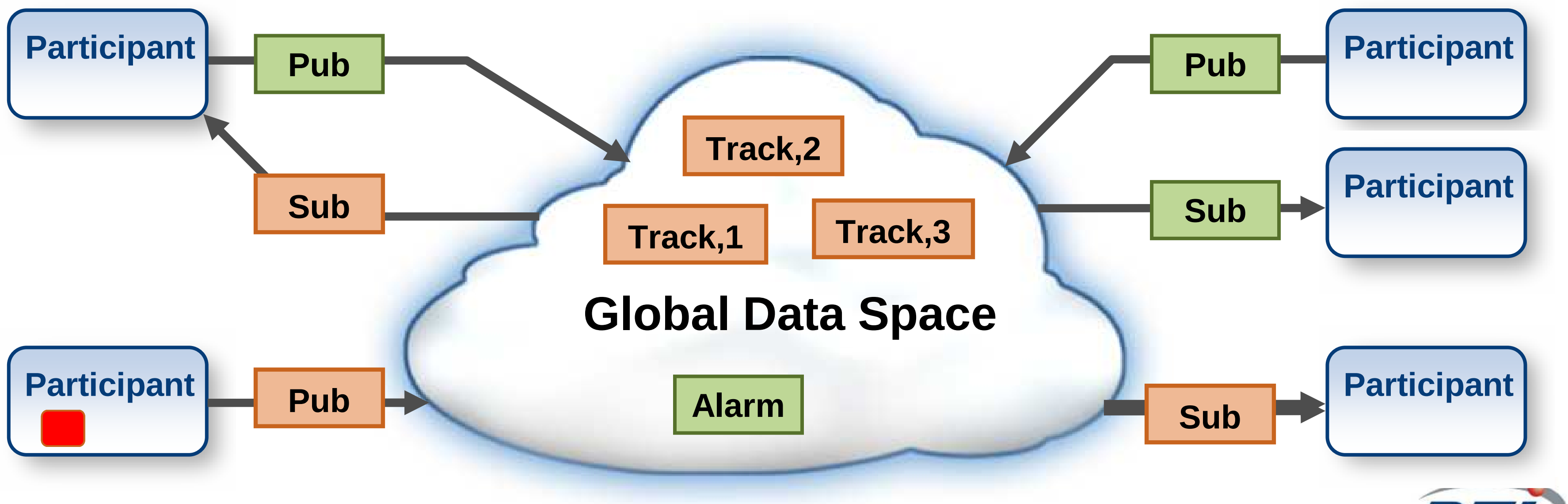
- **Message** are sent to an **Exchange**
- Each message has an associated **Routing Key**
- **Brokers** forward messages to one or more **Queues** based on the **Routing Key**
- Subscriber get messages from **named Queues**
- Only **one subscriber** can get a given message from each **Queue**



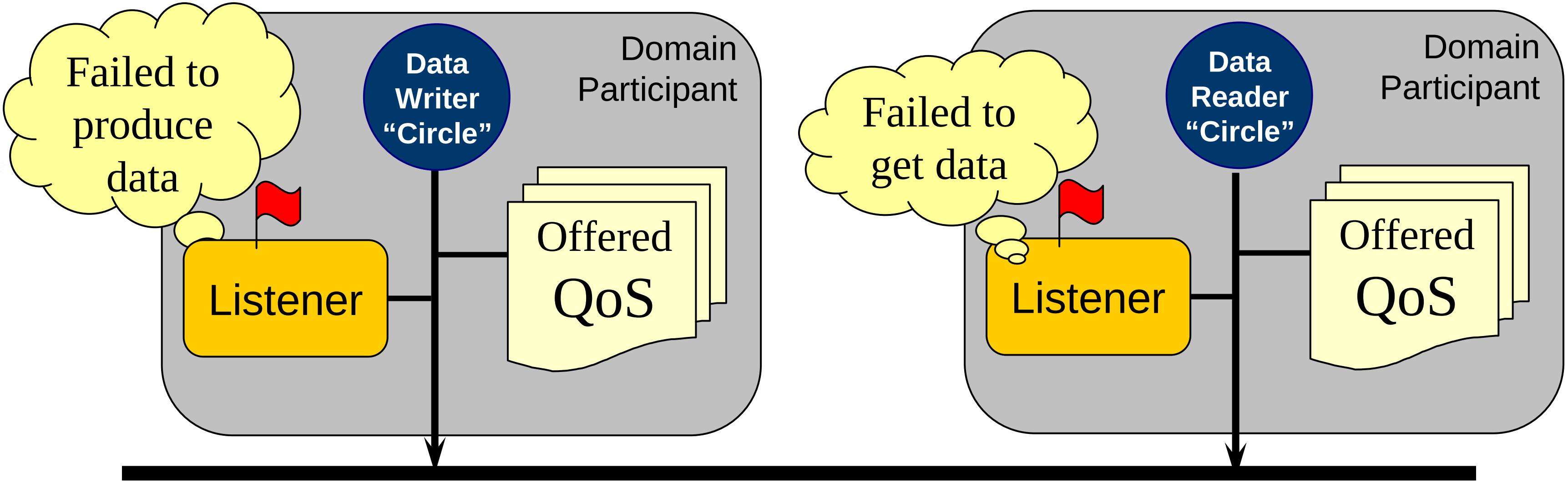
DDS Service Model: Communication Model

Provides a “**Global Data Space**” that is accessible to all interested applications.

- Data objects addressed by **Domain, Topic** and **Key**
- Subscriptions are **decoupled** from Publications
- Contracts established by means of **QoS**
- Automatic **discovery** and **configuration**



DDS Service Model: Communication Model



- Publisher declares information it has and specifies the Topic
  - and the offered QoS contract
  - and an associated listener to be alerted of any significant status changes
- Subscriber declares information it wants and specifies the Topic
  - and the requested QoS contract
  - and an associated listener to be alerted of any significant status changes
- DDS automatically discovers publishers and subscribers
  - DDS ensures QoS matching and alerts of inconsistencies

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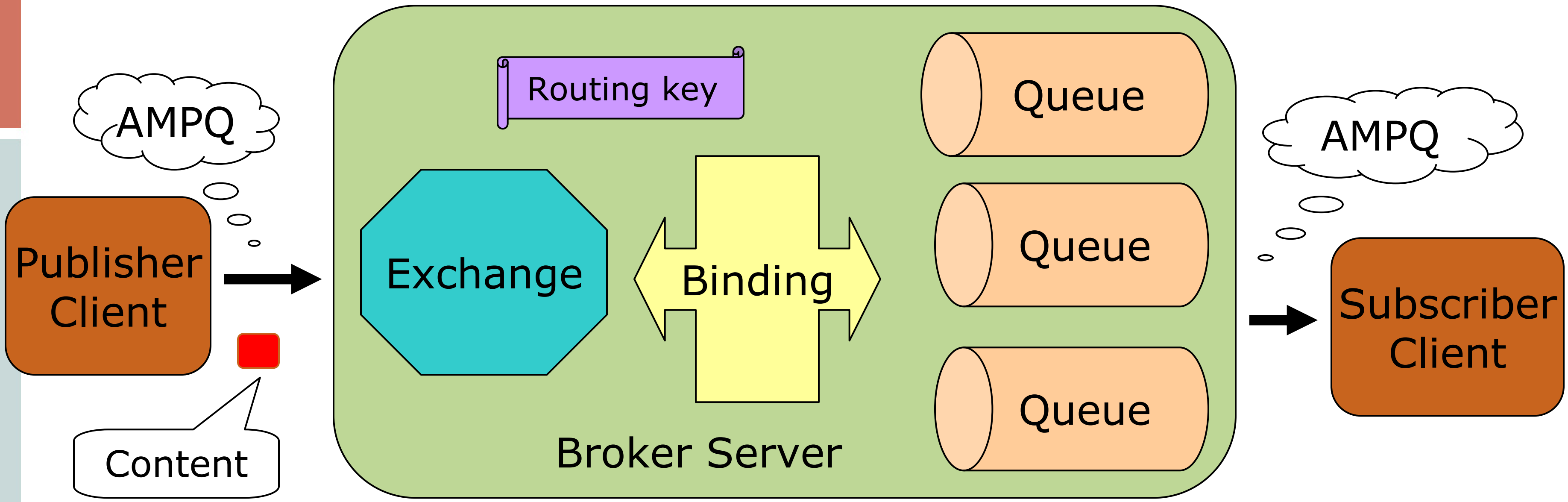
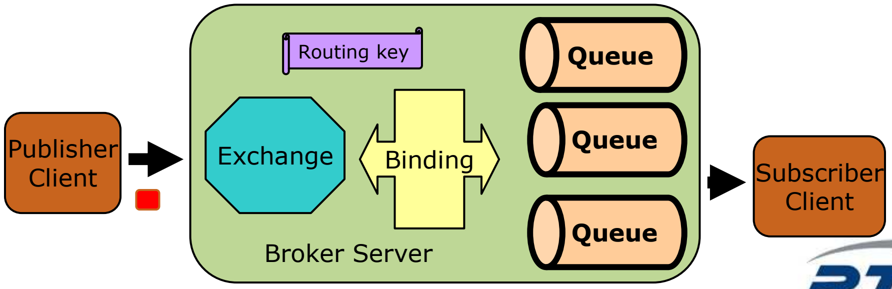
AMQ Service Model : Object Model



- **Exchange** – Receives messages and routes to a set of message queues
- **Queue** – Stores messages until they can be processed by the application(s)
- **Binding** – Routes messages between Exchange and Queue. Configured externally to the application
  - Default binding maps routing-key to Queue name
- **Routing Key** – label used by the exchange to route Content to the queues
- **Content** – Encapsulates application data and provides the methods to send receive, acknowledge, etc.

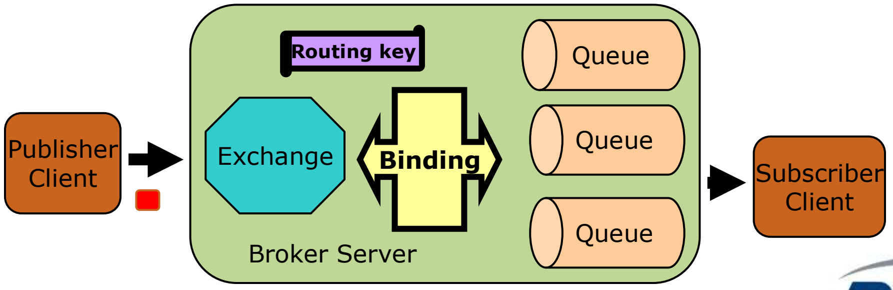
AMQ Queues

- Stores and distributes messages
- Each message delivered to a single client consumer
- Properties (on creation):
  - Name
    - Client Named or Server Named
  - Durable
    - Durable remains present after re-start
      - But may lose non-persistent messages
  - Auto-delete
    - Will auto-delete when all clients have finished using it
  - Private (Exclusive)/Shared
    - Private (Exclusive) ⇔ read by a single consumer



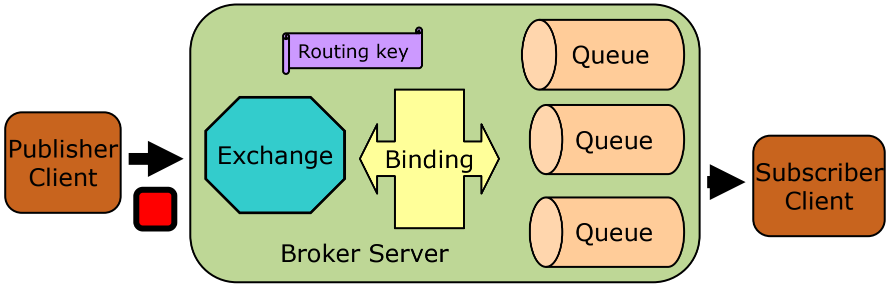
AMQ Binding & Routing Key

- Binding
  - Tells exchange how to route messages:
    Queue.Bind <queue> TO <exchange> WHERE <condition>
- The **<condition>** can involve:
  - Message Properties
  - Header fields
  - Content
  - In most cases uses a single field: the “routing key”
- Routing key = virtual address used in the binding
  - For Point2point routing-key = name of msgQ
  - For Topic PubSub routing-key = topic hierarchy value
  - In other cases routing-key may be combined with msg header and content

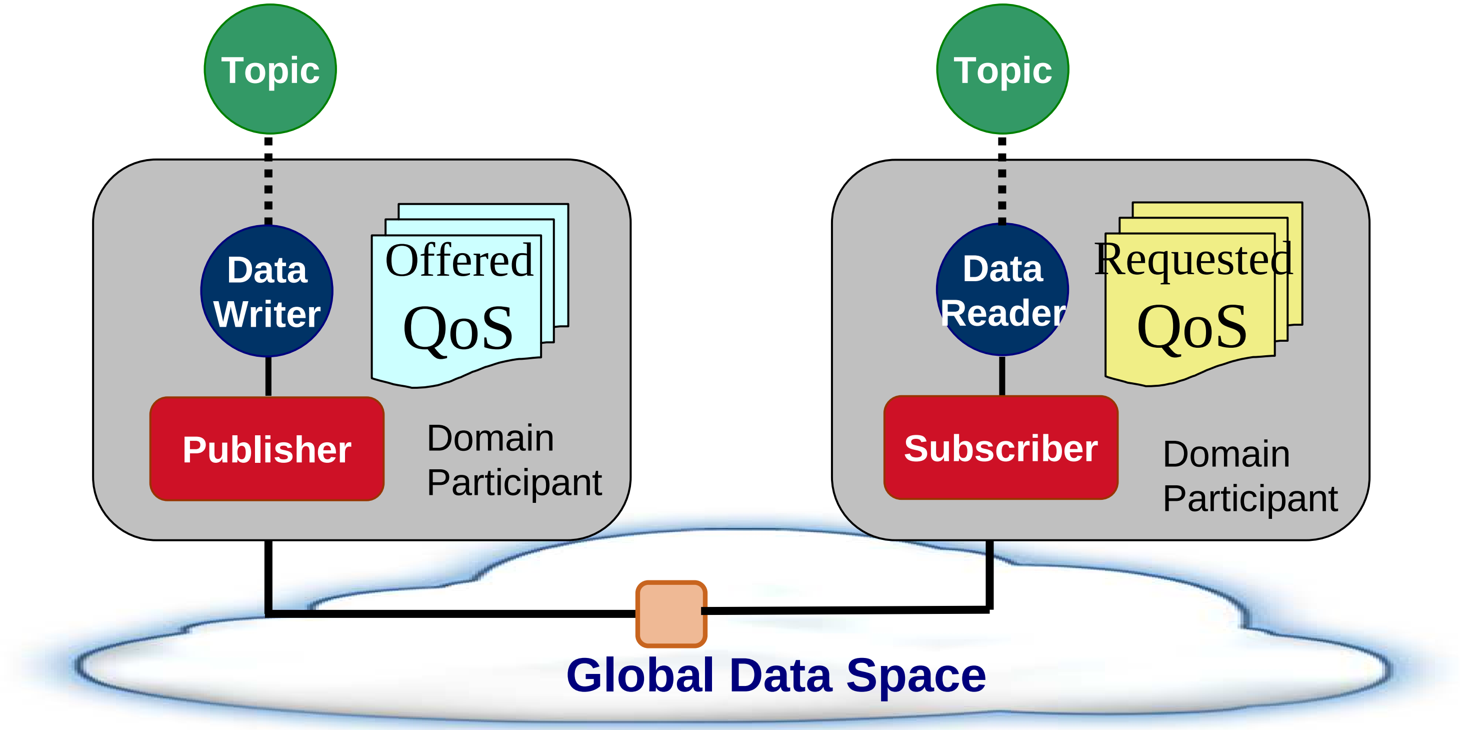


AMQ Content

- Client producer creates message
- Producer fill content, properties and routing information
- Producer sends msg to Exchange
- Exchange route msg to set of Queues. Each is treated as a separate copy (no common identifier)
- Queue passes message to a single consumer if present or else buffers it.
  - Upon ‘delivery’ msg removed from queue.
- 2 kind of acks: Automatic or Explicit
  - Explicit requires app to indicate so for each message



DDS Service Model: Object Model



- **DomainParticipant** – Allows application to join a DDS Domain (Global Data Space)
- **Topic** – A string that addresses a group of objects in the Global Data Space
  - Each Object is identified by a Key (some fields within the object data)
- **Publisher, Subscriber** – Pools resources for DataWriters and DataReaders
- **DataWriter** – Declares intent to publish a Topic and provides type-safe operations to write/send data
- **DataReader** – Declares intent to subscribe to a Topic and provides type-safe operations to read/receive data

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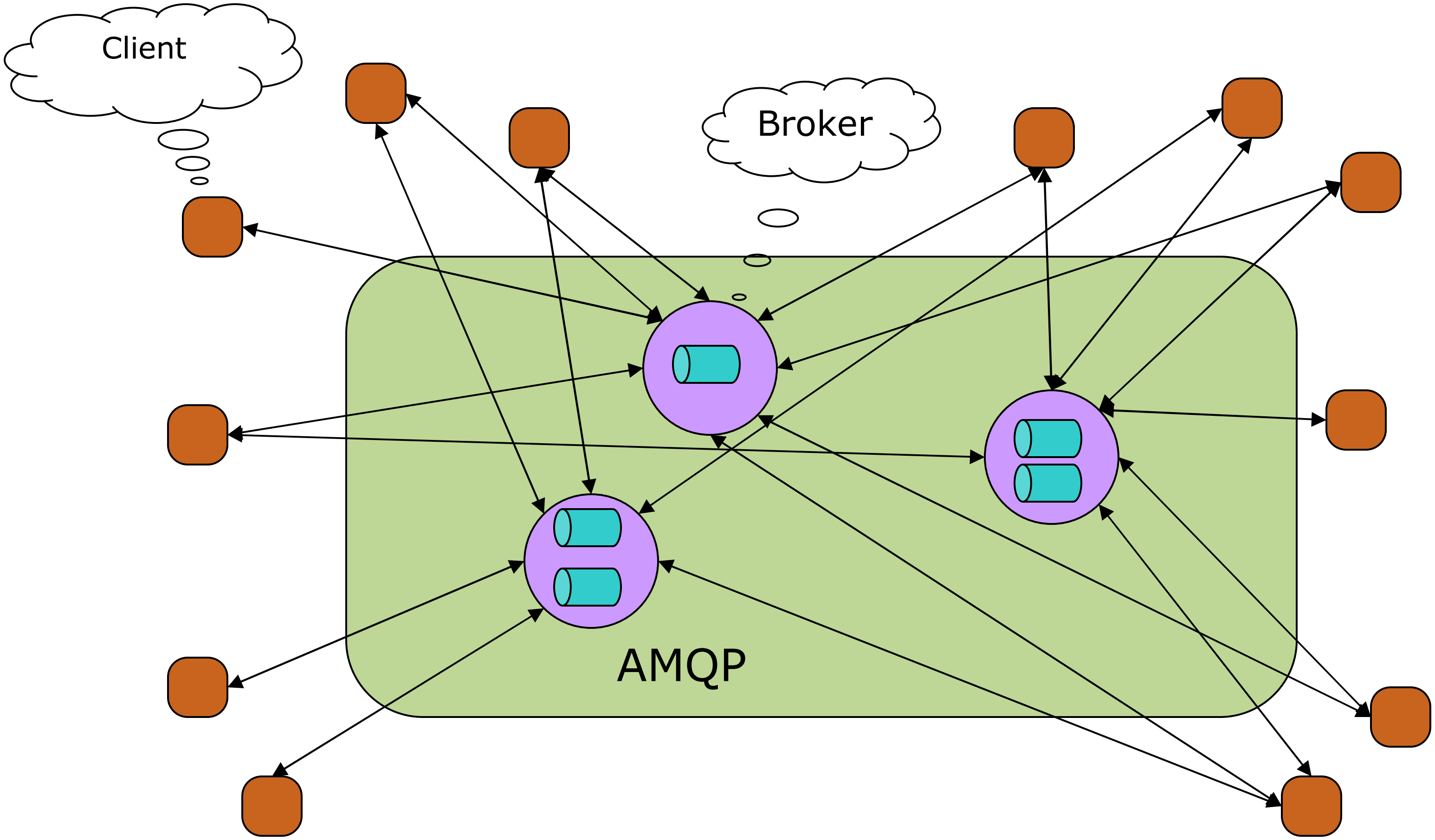
AMQP Service Model : Architecture Model

Centralized Multi Broker

Each Queue is materialized in a Broker

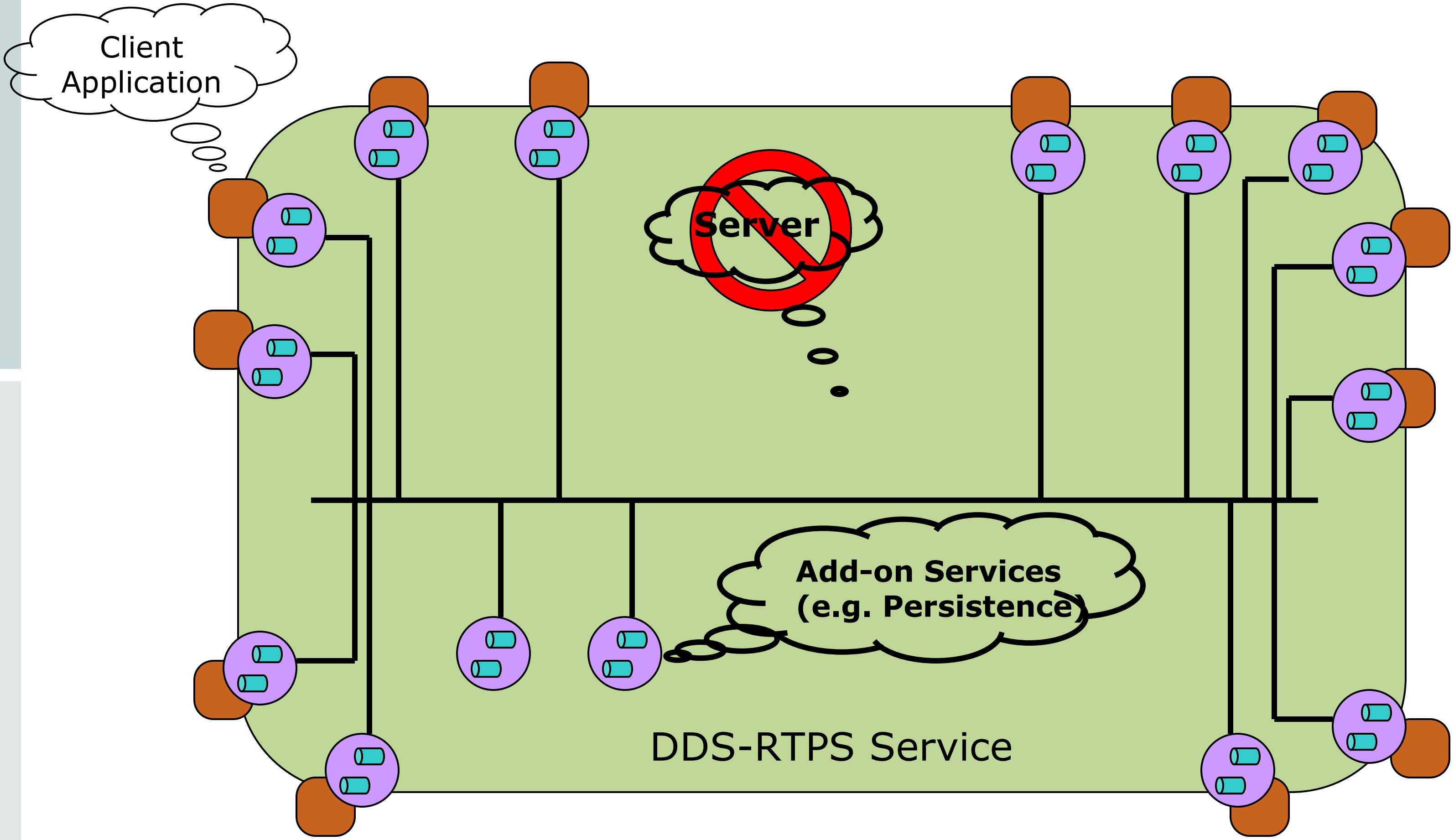


DDS-RTPS: Unbrokered Pub-Sub Service

Unbrokered Peer-to-Peer

Each application links (binds) directly with the Pub-Sub service

“Queuing/Cacheing” occurs locally on each client



Model tradeoffs for RT systems

Model	***Advantages***	***Disadvantages***
Centralized Brokered	Simplest to implement Fewest network connections per client	Single point of failure Server is bottleneck Poor performance Poor predictability Does not scale
Centralized Multi-Brokered	Simple to implement Scales to many Queues	Hard to administer Potentially many connections per client Servers can be bottlenecks Single point of failure for any queue Not scalable to many readers/writers per queue
De-centralized Brokered	Scales to large # queues Scales to large # readers/queue Low number of connections No single points of failure	Worst latency Worst predictability
De-centralized Un-brokered (Peer-to-peer)	Scales to large # queues Scales to large # readers/queue Best latency Best predictability No single points of failure	Most difficult to implement Requires use of UDP to avoid large # connections

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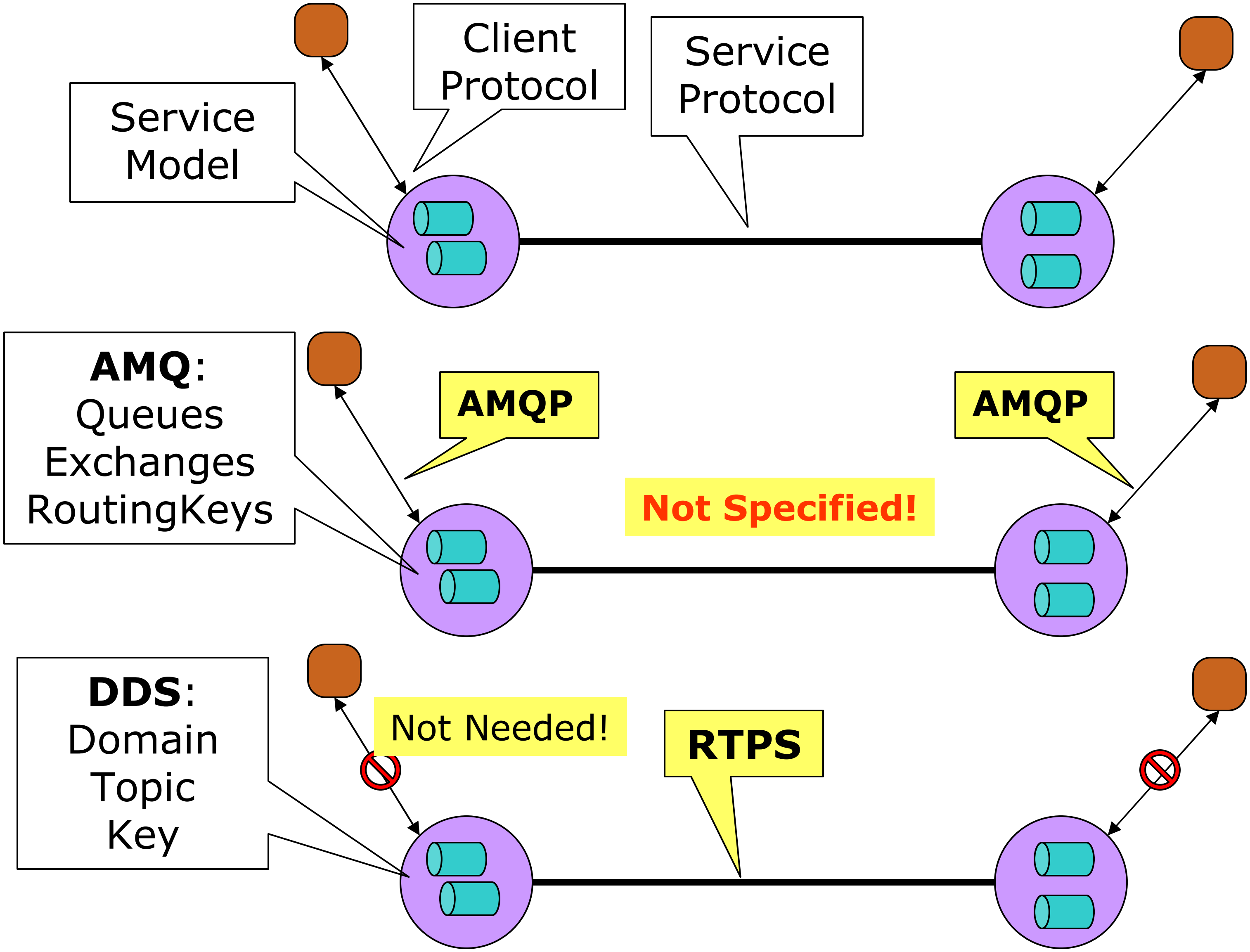
AMQP vs DDS-RTPS Protocols: Scope



Service Model

Client Protocol

Service Protocol

AMQ: Queues Exchanges RoutingKeys

AMQP

AMQP

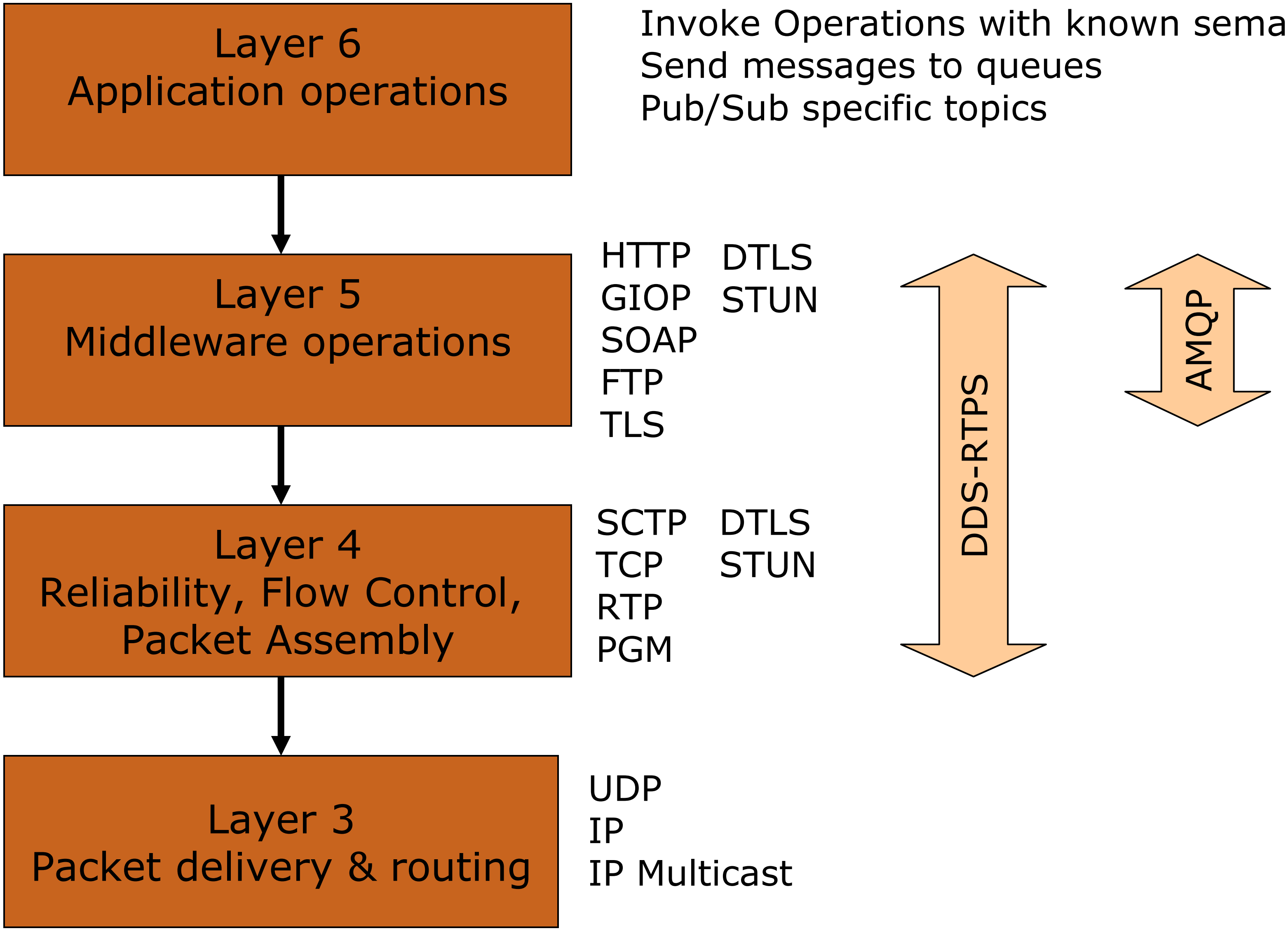
Not Specified!

DDS: Domain Topic Key

Not Needed!

RTPS

AMQP vs DDS-RTPS Protocol: Layers



Layer 6
Application operations

Invoke Operations with known semantics
Send messages to queues
Pub/Sub specific topics

Layer 5
Middleware operations

HTTP
GIOP
SOAP
FTP
TLS

DTLS
STUN

Layer 4
Reliability, Flow Control,
Packet Assembly

SCTP
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PGM

DTLS
STUN

Layer 3
Packet delivery & routing

UDP
IP
IP Multicast

AMQP vs. DDS-RTPS Protocols

Aspect	***AMQP***	***DDS-RTPS***
Reliability	NO: Must be Provided by Transport	YES: Ack and Nack based Configurable Heartbeats
Fragmentation	NO: Must be Provided by Transport	YES: Fragmentation fully supported Reliability supported at the fragment level
Discovery	Not defined by protocol	Defined by protocol
Multiplexed connections, Batching	Yes	Yes
Expected deployment	Up to 500 msgs/sec per broker	Up to 100000 msgs/sec per peer
Transport	Connection-Oriented (Assumes TCP) No UDP, No Multicast	RTPS – Layer 4 and 5 Middleware actions Reliability, Flow control, Fragmentation

Conclusion

- Protocols must be compared in the context of the Middleware Service model they support

- AMQP developed to support a Brokered model.
  - Layer 5 protocol that defines only Client 2 Broker communications
  - Inter-Broker communications undefined
  - Assumers TCP-like transport

- DDS-RTPS developed to support un-brokered fully peer-to-peer model
  - Layer 4 + 5 protocol defines peer-to-peer interactions
  - All communication aspects defined
  - Assumes datagrams only. Supports UDP and Multicast

- DDS-RTPS far more suitable for high-performance and real-time systems
  - No intermediate brokers => better latency and predictability
  - No bottlenecks or single points of failure
  - Supports Multicast and unreliable channels (e.g. wireless links with dropouts)