An Autonomous and Dynamic Coordination and Discovery Service for Wide-Area Peer-to-peer Publish/Subscribe

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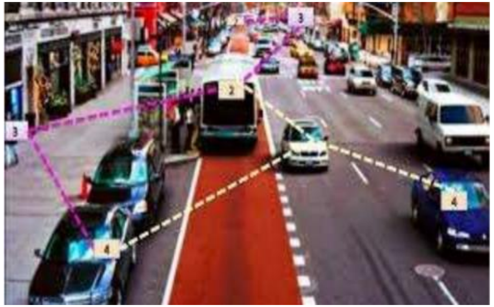
Data Distribution Needs for IIoT

- IIoT applications are highly distributed and mission-critical
- Requiring:
  - Geographically distributed data dissemination
  - Strict Quality of Service (QoS) guarantees:
    - Reliability
    - Durability
    - Timeliness
    - Security



- **Publish/Subscribe** communication paradigm is well suited for IIoT application needs as it provides **scalable and decoupled data delivery** among communicating peers.

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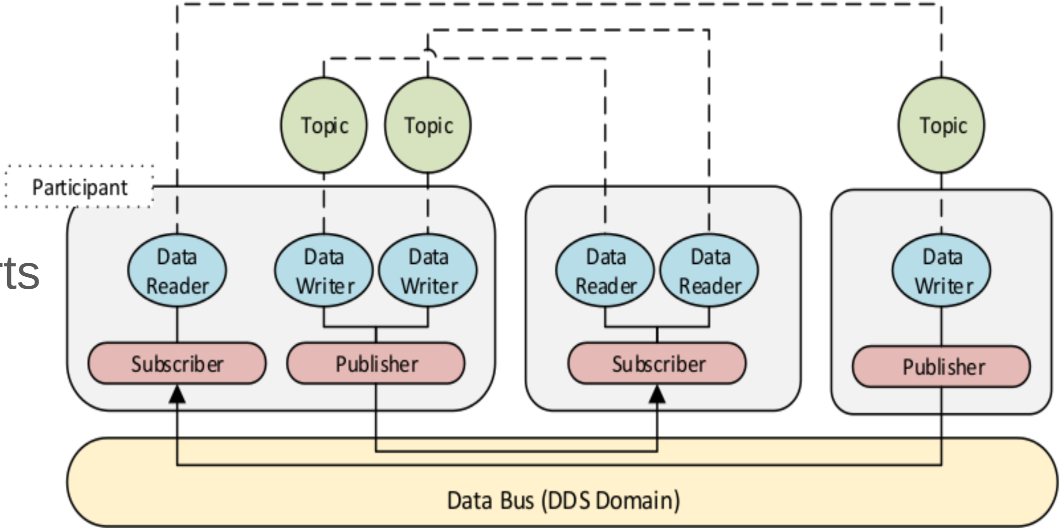
OMG Data Distribution Service (DDS): Publish/Subscribe standard for IIoT

- OMG DDS is a **data-centric, anonymous, topic-based** publish/subscribe standard.
- **Peer-to-Peer** architecture supports **low-latency** and **scalable** data delivery.
- Configurable **QoS policies**:
  - **Reliability, Durability, Deadline, Liveliness, Ownership, Lifespan, History, Resource Limits,** etc.



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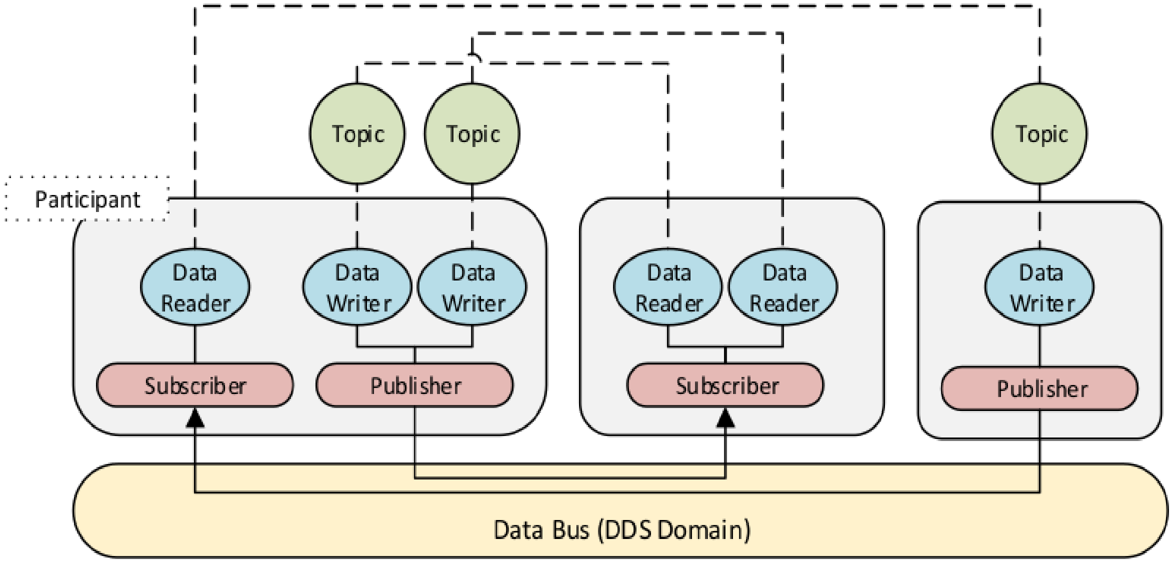
OMG DDS: Limitations for WAN-Scale Use

- Current technology limitations restrict the use of DDS to a single LAN:
  - DDS uses **multicast for discovery**
  - **NAT/Firewall** use prevents data distribution across LANs.
  - Existing **broker-based** solutions to bridge DDS LANs:
    - **Not Scalable**: Require **manual configuration**
    - Require **invasive changes** to the application code
    - **Lack autonomous and dynamic discovery and coordination** service to interconnect peers across multiple networks



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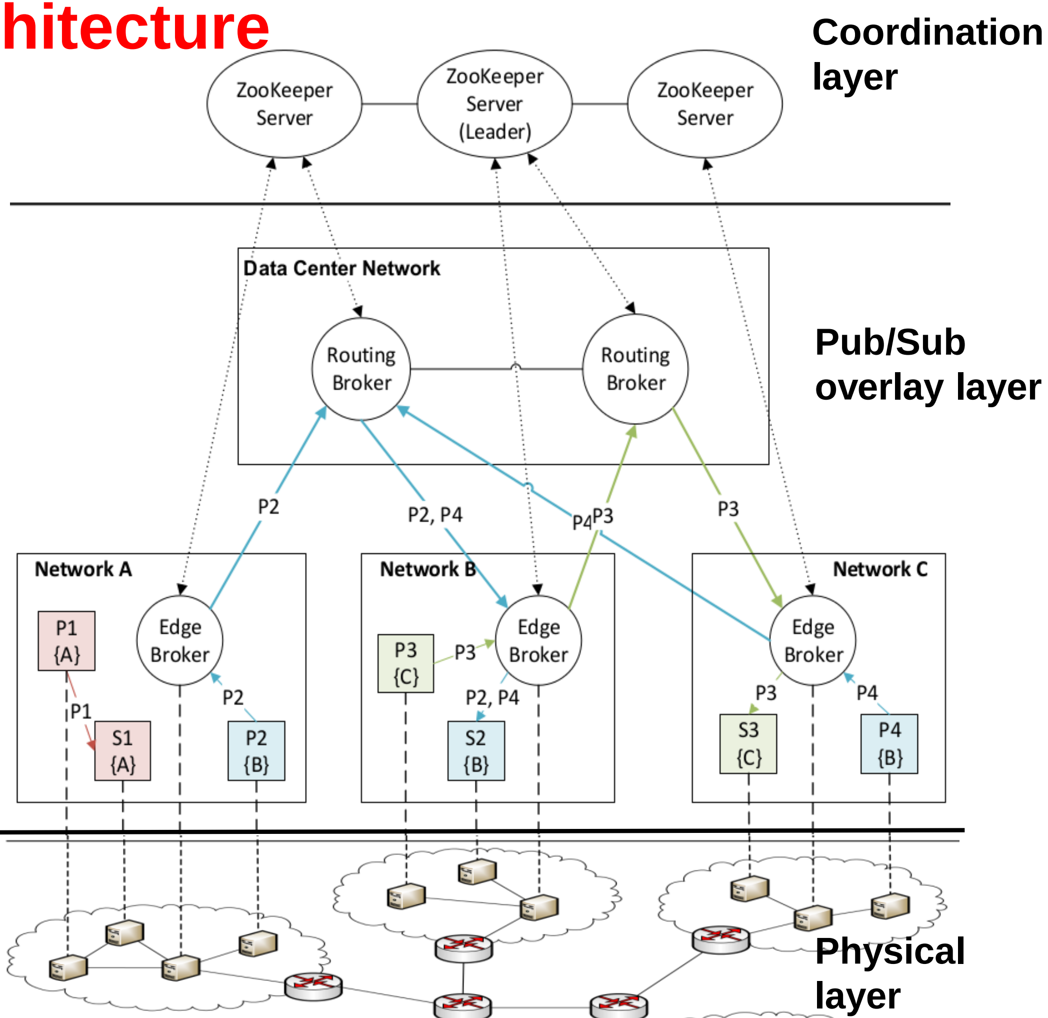
In Summary

A readily available, rapidly deployable, and non-invasive middleware solution to autonomously discover and interconnect DDS peers at WAN-scale does not exist.

PubSubCoord:Solution Architecture

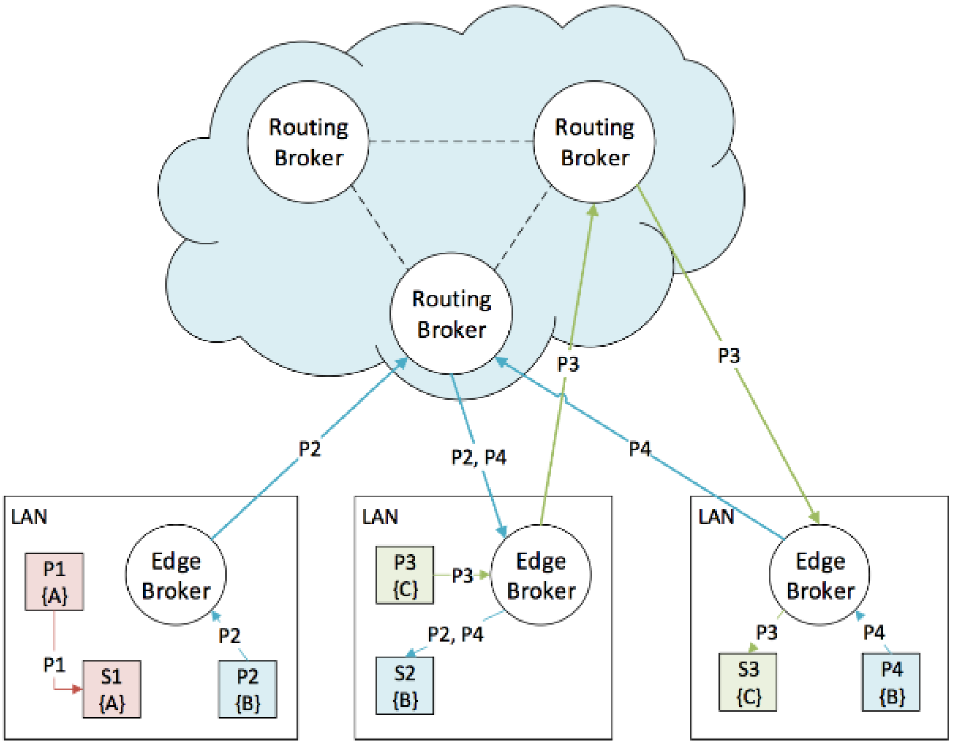
- **2-Level Broker architecture** for low latency (**maximum 2-hop**) dissemination.
  - **Edge Broker Layer:** serves as a **gateway** for locally connected endpoints in a LAN
  - **Routing Broker Layer:** serves as a **mediator** to route data between edge brokers according to assigned and matched topics
- **Coordination layer** is responsible for autonomous discovery and data routing between brokers.



PubSubCoord: Data Dissemination

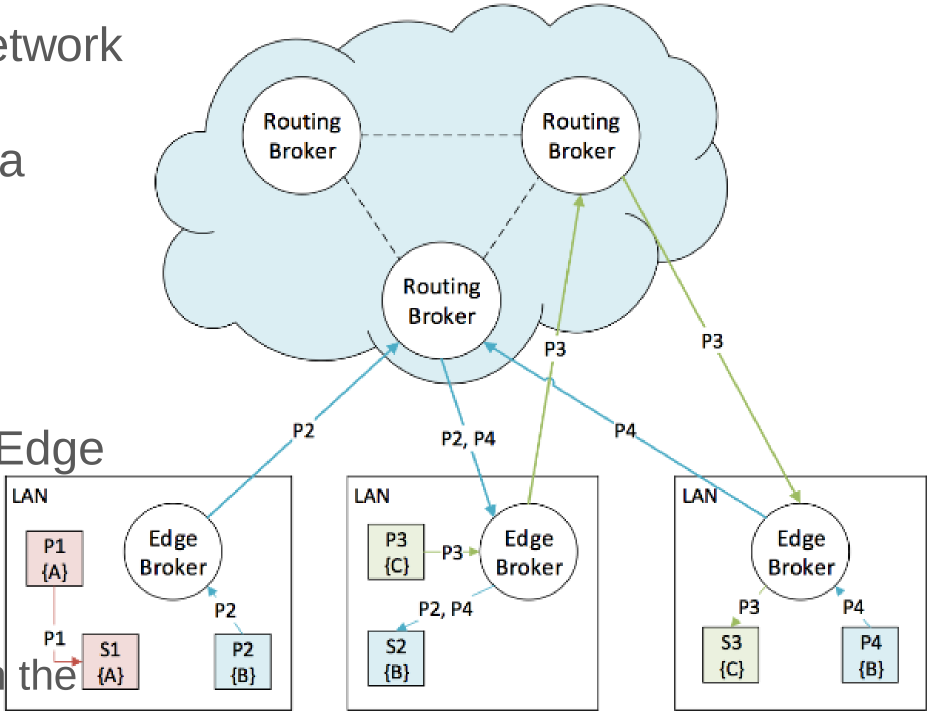
- **Local Communication at the Edge:**
  - ➢ P1 and S1 are interested in topic A. Since they reside in the same network, they communicate via **UDP-based unicast without incurring a hop to the routing broker layer**.

- **Communication across networks via Routing Broker layer:**
  - ➢ P2, P4, and S2 are interested in topic B but are deployed in different networks, so their **communications are routed through a routing broker** that is responsible for topic B.



Benefits of PubSubCoord Design

- ❖ Low-latency (maximum 2-hop) data dissemination over the broker overlay network
- ❖ Load balancing at routing broker layer via elastic autoscaling
- ❖ Easy state maintenance
- ❖ Failed Edge Brokers do not affect other Edge Brokers.
- ❖ Efficient intra-LAN dissemination
  - ➢ traffic that is local is not allowed to reach the routing brokers
  - ➢ local dissemination is handled by the edge brokers themselves thereby avoiding round-trip WAN latencies



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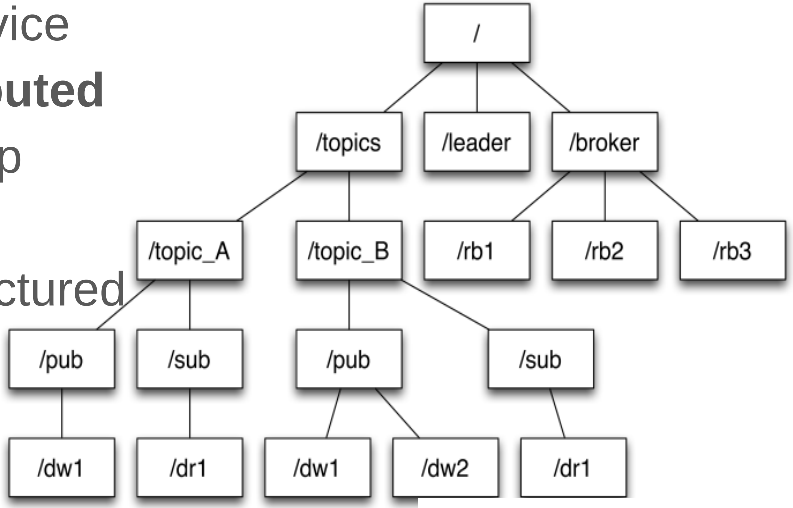
PubSubCoord Design: Coordination Layer

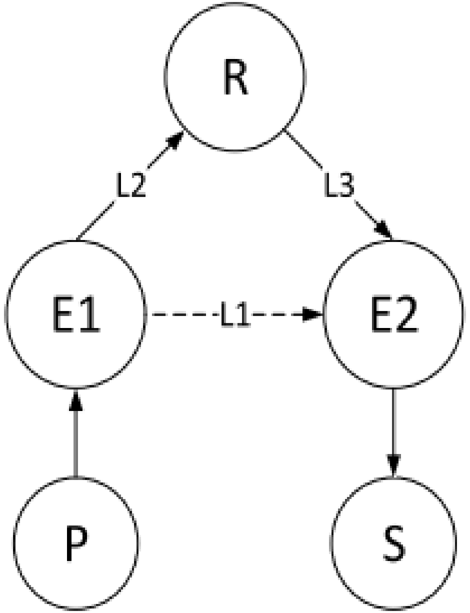
- PubSubCoord uses a coordination layer comprising an **ensemble of ZooKeeper servers,** which help brokers discover each other and build broker overlay networks
- **Zookeeper** is a centralized and replicated service which provides **generic constructs** for **distributed coordination.** Example: Leader election, group membership, locks, etc.
  - **Znodes:** Data Model of Zookeeper is structured like a file system comprising of znodes- **Zookeeper data object** (path and data)
  - **Watch Mechanism:** notifies a client of ZooKeeper of a change to a znode that is being watched by that client.

PubSubCoord Data Model



PubSubCoord Design: QoS Optimization

- In case of **congested, slow or lossy WAN links** over the two-hop route connecting Edge brokers via a Routing broker, PubSubCoord supports **Deadline-Aware overlays**, which **directly interconnect two Edge-Brokers:**
  - **Improves reliability and latency** by providing an additional one hop path, directly interconnecting two edge brokers
  - Leveraged by pub/sub streams that require **stringent assurance and deadline-driven data delivery.**
  - **Uses DDS deadline QoS** that expresses the maximum duration within which a sample has to be updated.



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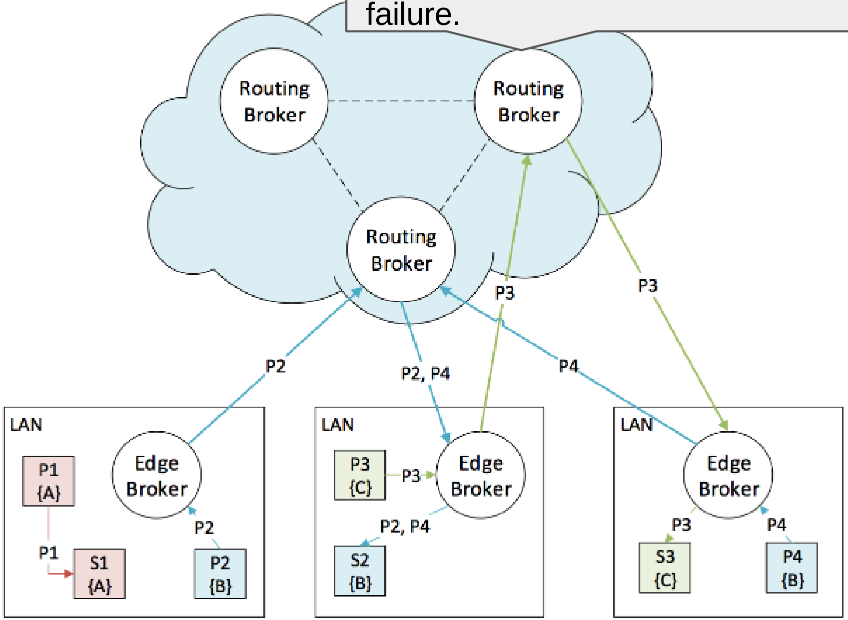
PubSubCoord Design: Load Balancing & Fault Tolerance

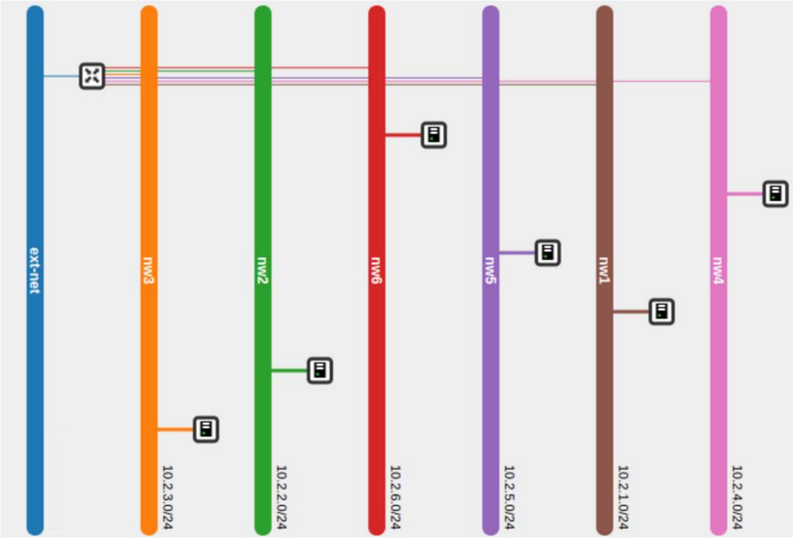
- **Load Balancing:** Leader Routing Broker distributes topics among worker Routing Brokers. Example: **least loaded routing broker** in terms of number of topics, CPU/network utilization, etc.
- **Fault Tolerance:** Leader Routing Broker **reassigns topics handled by a failed broker to another worker** Routing broker to avoid service cessation. ZooKeeper's watch mechanism is used to notify the appropriate edge brokers to update their paths to the right routing broker.

Leader RB performs **load balancing** of topics among worker brokers and **redistribution** of topics on broker failure.



Experiment Setup: Testbed Configuration

- **OpenStack private cloud** comprising **60 physical machines** each with 12 cores and 32 GB of memory.
- **VM configuration:** 1VCPU and 2GB RAM. Edge and Routing broker instances run in their own VM. Multiple publisher and subscriber test applications share a VM.
- Neutron was used to create **120 virtual networks/**LANs.
- **Emulated latencies:** 20 milliseconds roundtrip LAN and 80 milliseconds roundtrip WAN
- **PTP time Synchronization.**
- **RTI Connext 5.1** is used for implementation.



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Experiment Setup: Test application configuration

- ❖ All DDS endpoints are configured with the following **QoS settings:**
  - ➢**RELIABLE reliability QoS:** Reliable data delivery at transport-level
  - ➢**KEEP_ALL history QoS**: Keep all data history in memory
  - ➢**TRANSIENT durability QoS:** Deliver history data for late joiners
  - ➢**LIFESPAN QoS** 60 seconds: Keep data history for 60 seconds

- ❖ Publishers send **64Byte messages every 50 miliseconds**.
- ❖ **5000 messages** are sent per publisher. Only use values only after 1,000 samples since the latency values of initial samples are not consistent due to coordination and discovery overhead
- ❖ **End-to-end latency** was calculated as the time difference between the send timestamp at the publisher and reception timestamp at the subscriber.

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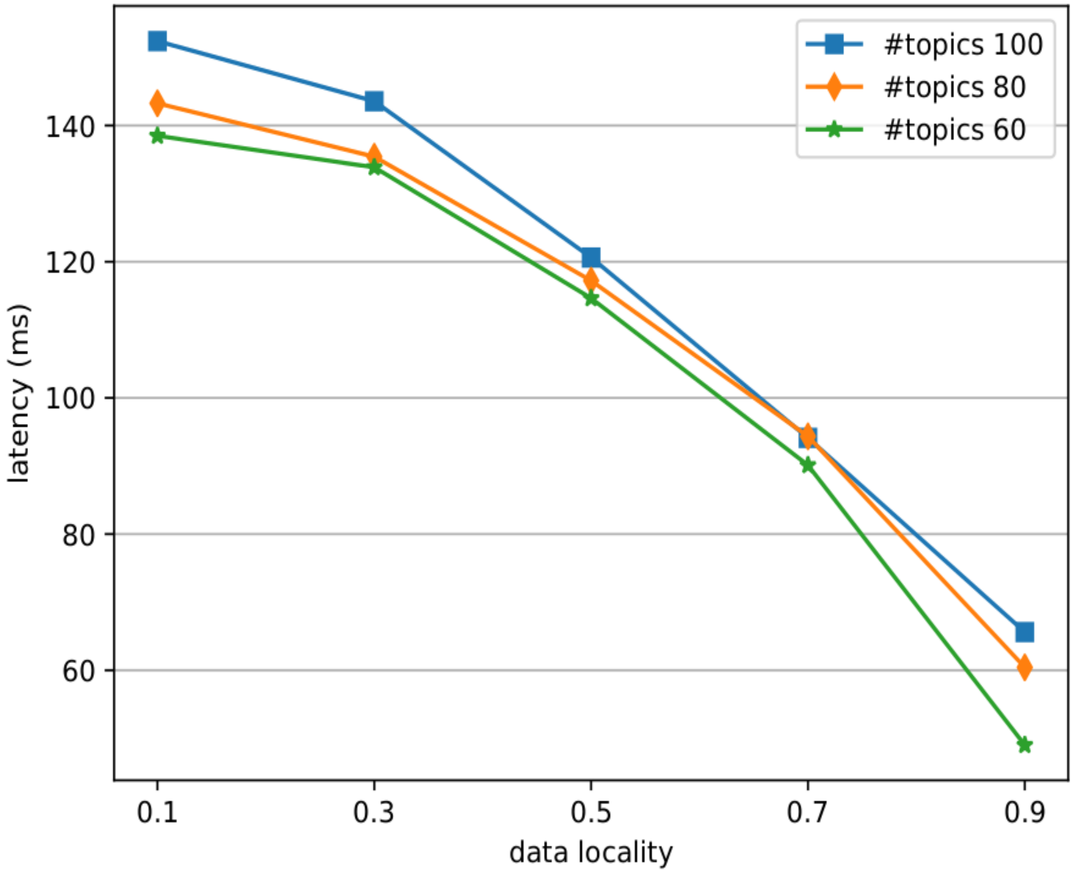
Data Locality Experiment

Edge Broker layer is responsible for dissemination of local traffic thereby preventing WAN latencies.

- ❖ Measure end-to-end latency for different values of **data locality**:
  - ➢ fraction of topics in an isolated network which are local to the network and do not have interested subscribers in another network

- ❖ As the data locality increases, the end-to-end dissemination latency decreases



Scalability Experiment Setup

- 400 VMs were used: 120 VMs for edge brokers; 40 VMs for routing brokers; 40 VMs were used for publishers and 200 VMs for subscribers.
- VM for publishers hosts 25 publisher applications. VM for subscribers hosts 50 subscriber test applications. Thereby, creating a total of 1000 publishers and 10,000 subscribers
- Subscribers in each network are interested in 100 topics out of 1000 topics in the system.

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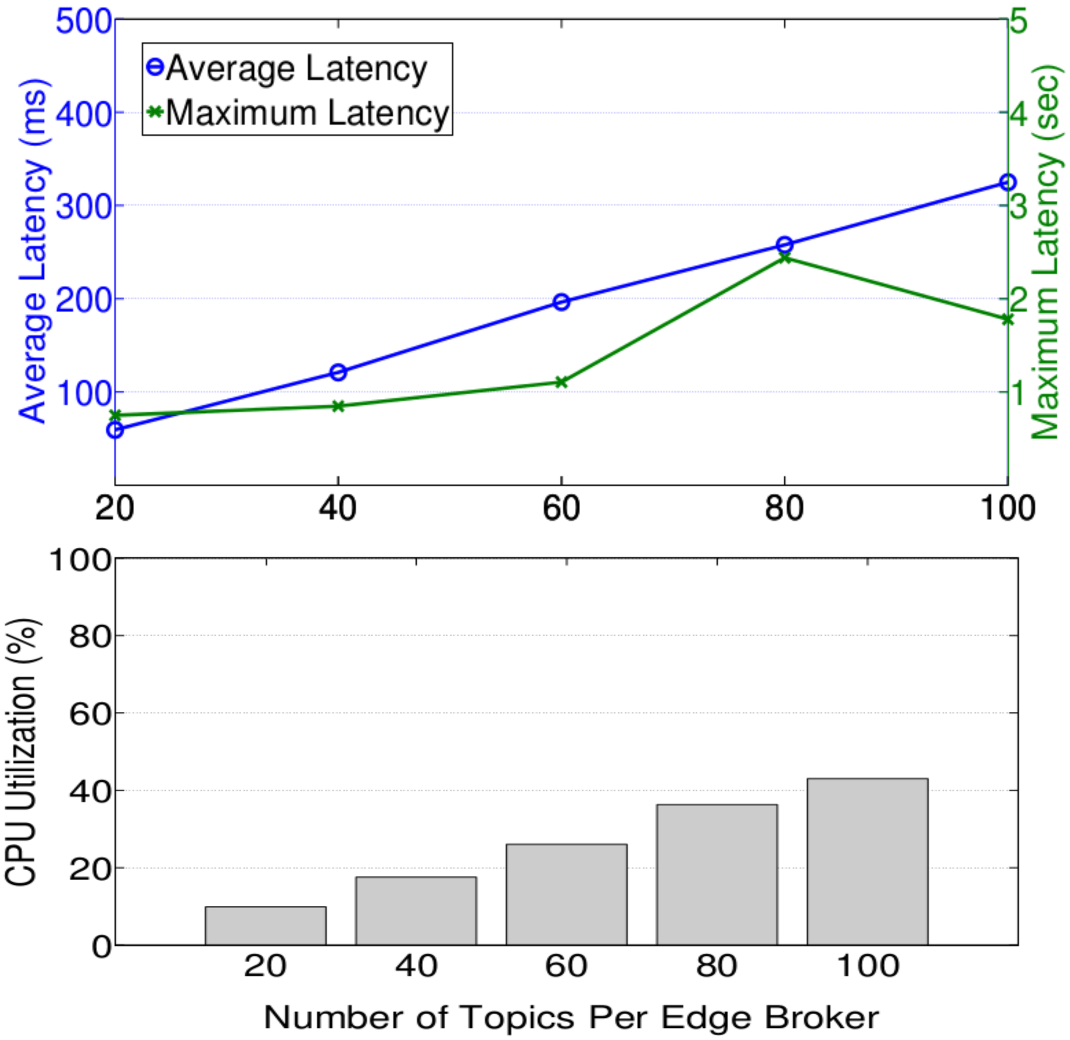
Scalability Experiment: Number of Topics

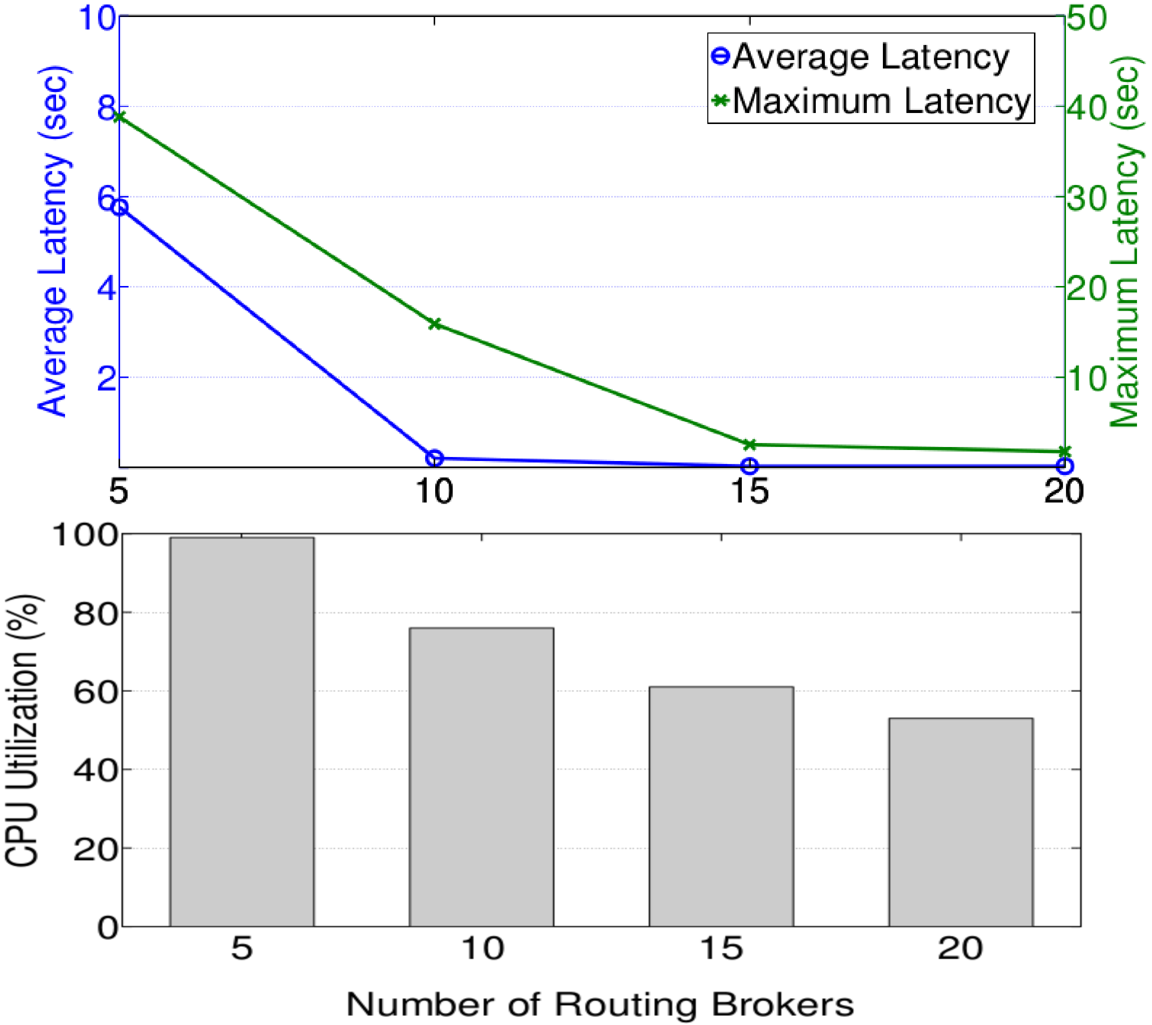
- The computation overhead and end-to-end dissemination latency grows linearly with the number of adopted topics at the Edge Broker.



Scalability Experiment: RB Load Balancing

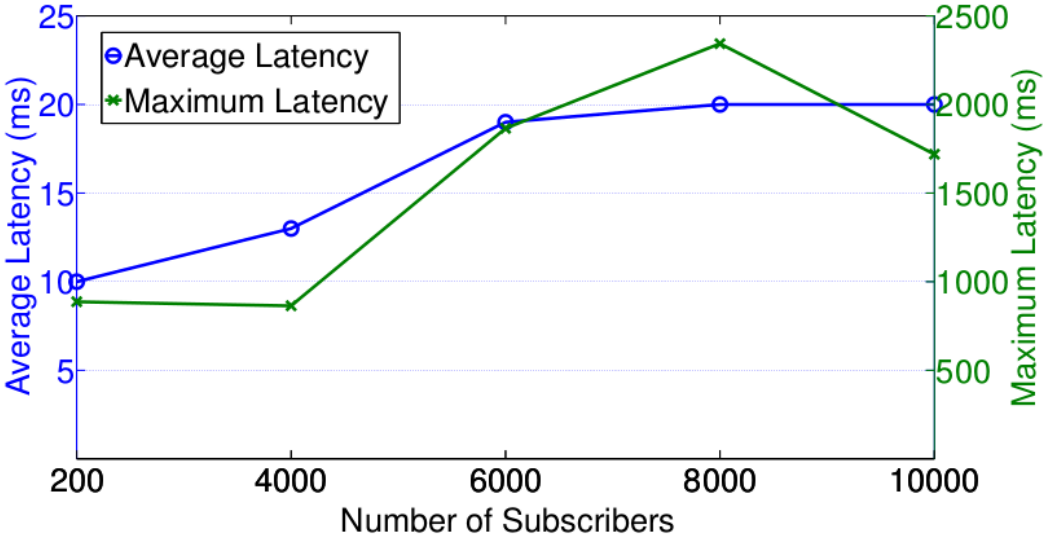
Our solution supports load balancing at the Routing Broker Layer.

- When there are 5 instances of Routing Brokers, the CPU of the routing brokers becomes saturated and latency gets adversely impacted.
- Latency values improve on scaling-up the number of routing brokers to 10.

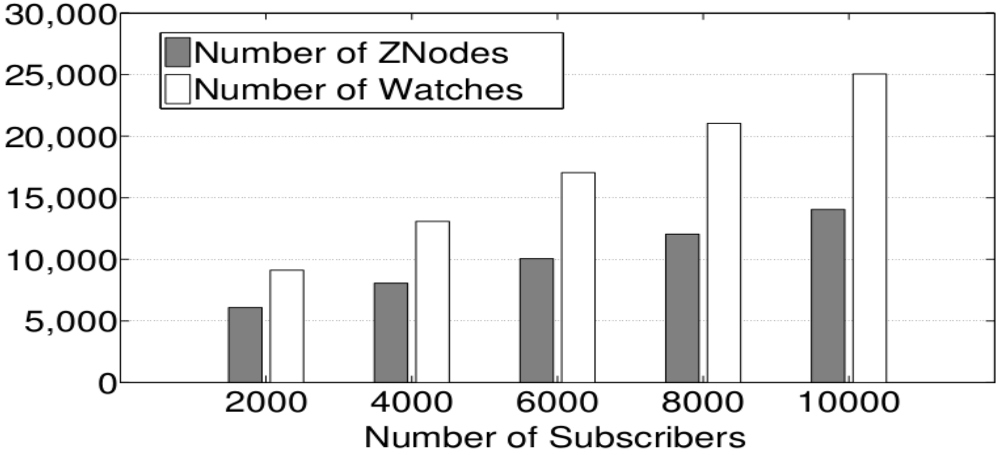


Scalability Experiment: ZK Coordination

To evaluate the scalability of ZK based centralized coordination, the number of simultaneously joining subscribers is increased from 2,000 to 10,000 in steps of 2,000.



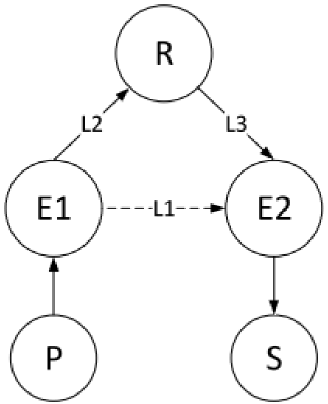
- Time taken by ZK server to respond to a client request, increases from **10ms to 20ms** with increasing number of subscribers.
- Number of znodes and watches increases as the system scales.
- **Overhead of ZooKeeper based centralized coordination service remains acceptable even at scale.**



Deadline Aware Overlay Experiment:

Deadline Aware Overlays are used for topics which have stricter data delivery requirements in case of congested, lossy or slow WAN links.

- ❖ Compare the dissemination latency and broker overhead for deadline-aware multi-path vs single-path overlays under different WAN link configurations:
  - ➢ **A: 30ms delay and no packet loss**
  - ➢ **B: 250 msec delay and 1% packet loss**



Test Cases	**L1**	**L2**	**L3**
Case 1	A	A	A
Case 2	A	A	B
Case 3	A	B	A
Case 4	A	B	B
Case 5	B	A	A
Case 6	B	A	B
Case 7	B	B	A
Case 8	B	B	B

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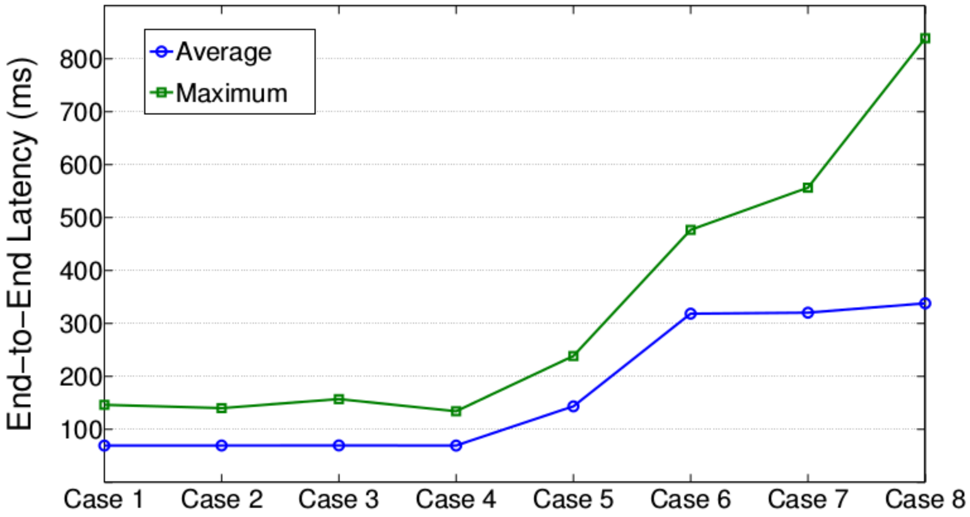
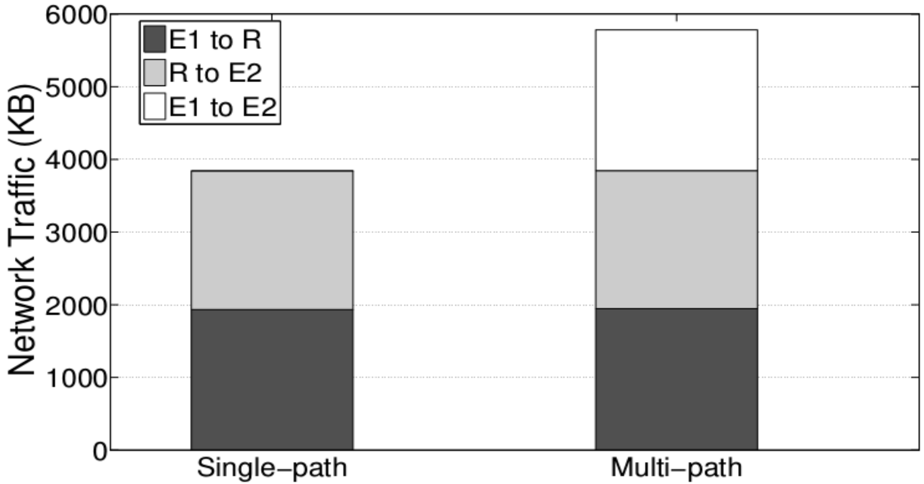
Deadline Aware Overlay Experiment:

- Test cases 1 to 5 for multi-path overlays perform better than single-path overlays.
- Topics with strict delivery requirements can benefit from deadline-aware overlays under adverse WAN link conditions.
- Maintaining multi-path overlays impose additional computation and network transfer overhead at the edge broker





Conclusions

- Presented PubSubCoord which is an autonomous and dynamic coordination and discovery service for WAN-scale DDS applications
- PubSubCoord disseminates data in a scalable manner for systems having many pub/sub endpoints and topics across multiple networks.
- Centralized coordination service like ZooKeeper can serve as a pub/sub control plane for large-scale systems
- Configurable QoS supported by DDS can be used for low-latency data delivery in WANs by building multipath overlays
- **Future work**
  - Effective load balancing algorithms at routing broker layer
  - Experiment with IoT systems (smart transportation)
  - Support for other pub/sub technologies
  - Interoperability
  - Integration with SDN and Time Sensitive Networking

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Thank you.

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