Automating the Evaluation of Interoperability Effectiveness in Heterogeneous IoT Systems

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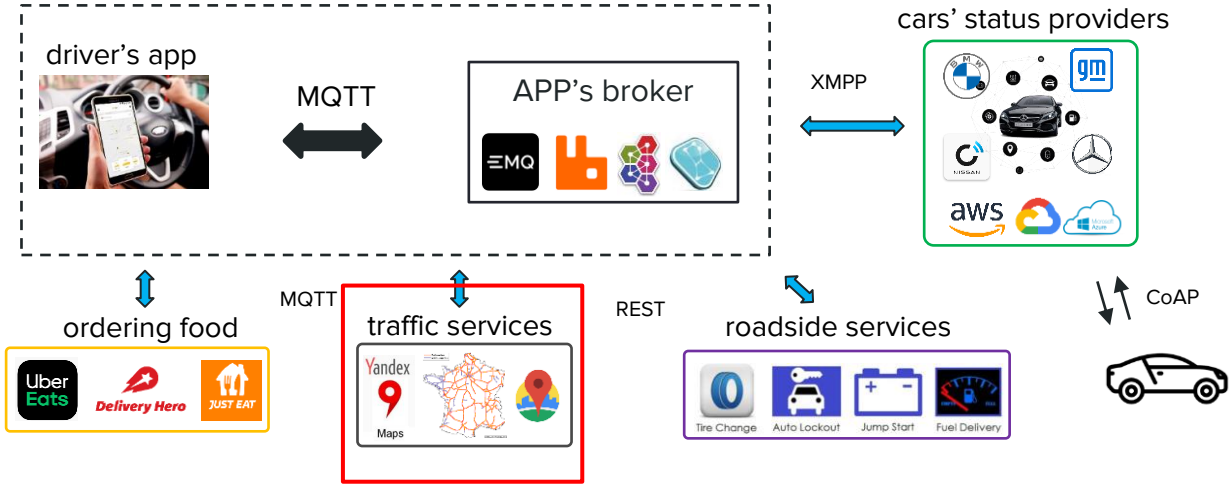
Motivating Scenario

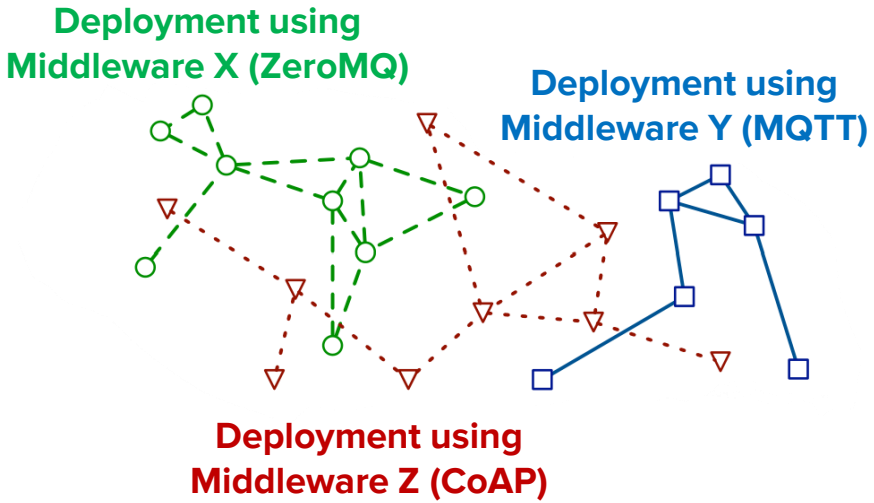
- Internet of Vehicle (IoV)-based Highway System
  - Digital services to improve driving experience & public safety



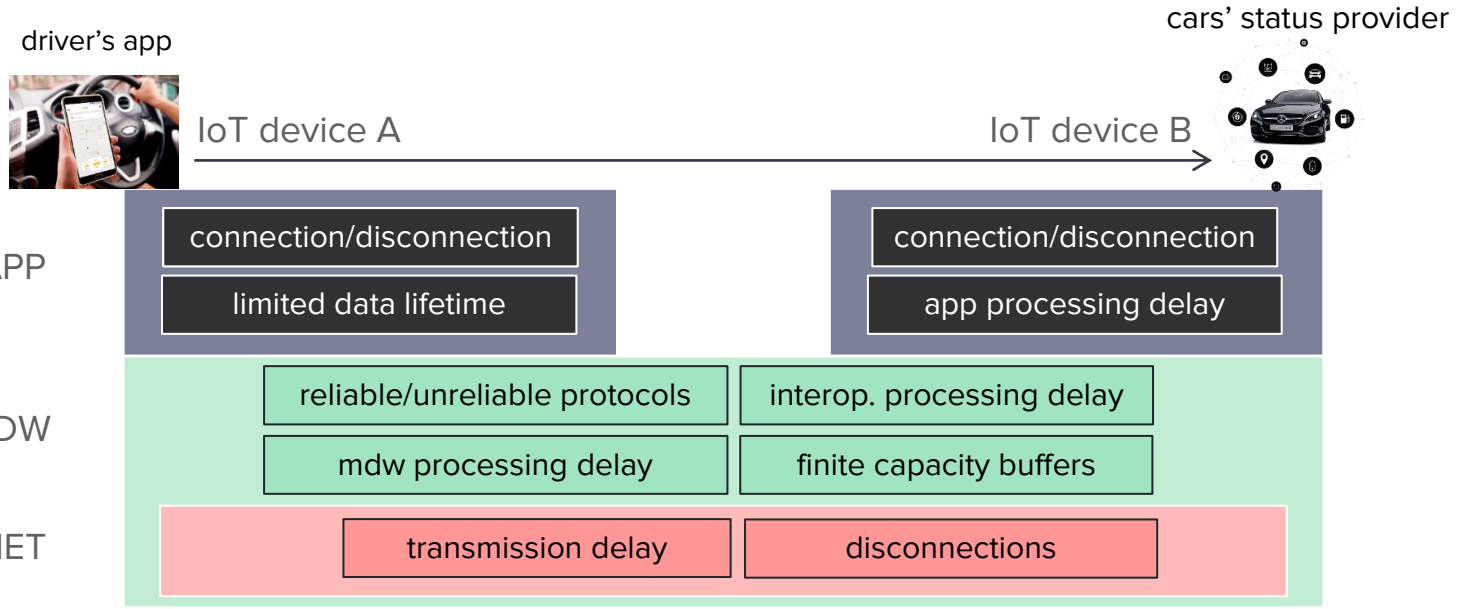
- IoV applications require:
  - Data exchange between heterogeneous on-vehicle devices using diverse *reliable/unreliable delivery mechanisms*
  - Satisfying low latency requirements given *obsolete data & intermittent connectivity*

Problem Statement

- A variety of constituent systems
  - independently deployed
  - use proprietary Middleware protocols, APIs + data formats
  - use different QoS mechanisms
  - co-exist in shared physical spaces
- Challenges:
  - **heterogeneity** makes it difficult to **design**, **maintain** & **adapt** integrated IoT systems
  - system developers are **overwhelmed** with the amount of knowledge they need to acquire
  - No solutions to **evaluate integration effectiveness** for opportunistic interaction with other systems



IoT Interactions across Multiple Layers



MQTT subscriber :

- pub/sub
- topic

functional semantics

CoAP server :

- push-based
- resource

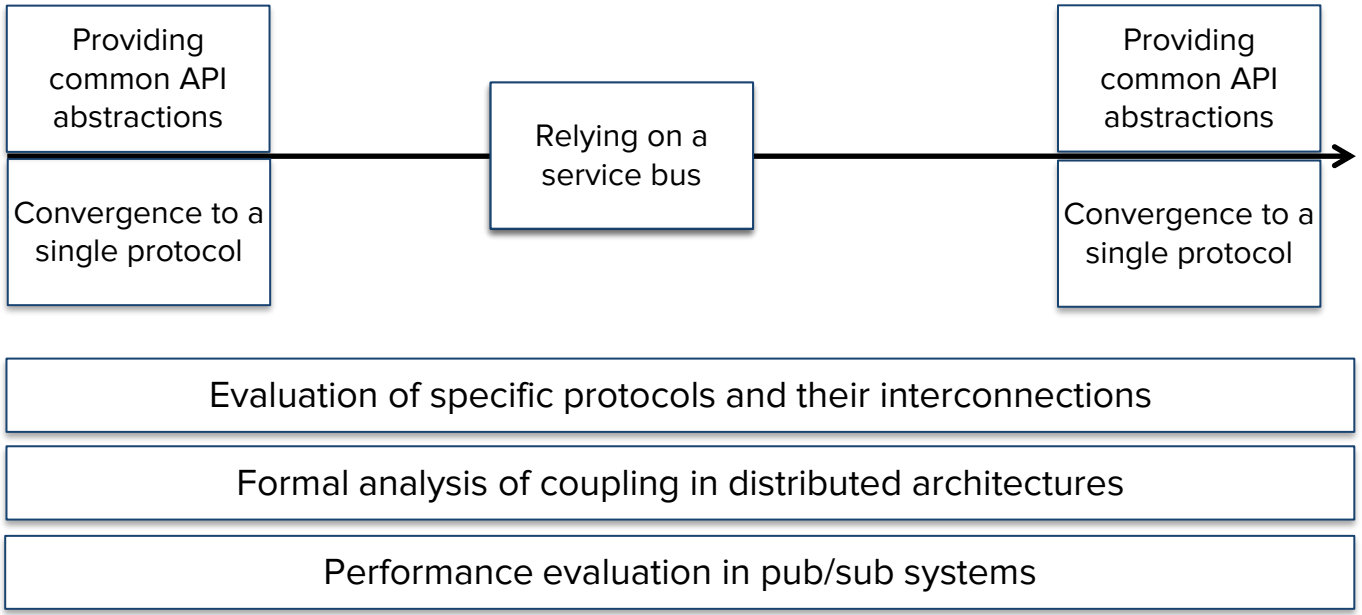
- data feeds lifetime
- reliable

QoS semantics

- mobile connectivity
- unreliable

➢ **How to map these semantics ?**

Existing approaches



- **How to enable interoperability in the IoT ?**
- **What is the end-to-end QoS of the interconnection ?**

Proposed solution

driver's app

systematic solution to interoperability

end-to-end performance analysis

cars' status provider

MQTT subscriber :		CoAP server:
• pub/sub • topic	*functional semantics*	• push-based • resource
• data feeds lifetime • reliable	*QoS semantics*	• mobile connectivity • unreliable

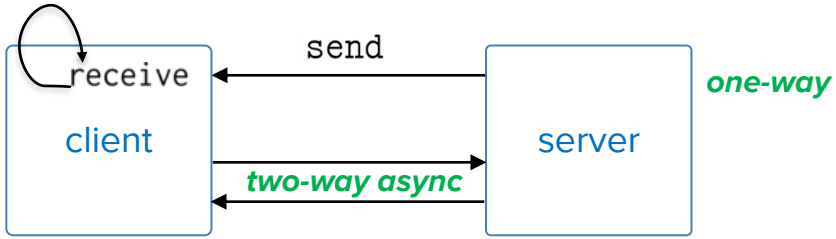
- **Systematic solution to interoperability**:
  mediator synthesis to enable functional middleware-layer interoperability.
- **End-to-end performance modeling & analysis**:
  QoS models to evaluate the interoperability effectiveness.

Overview

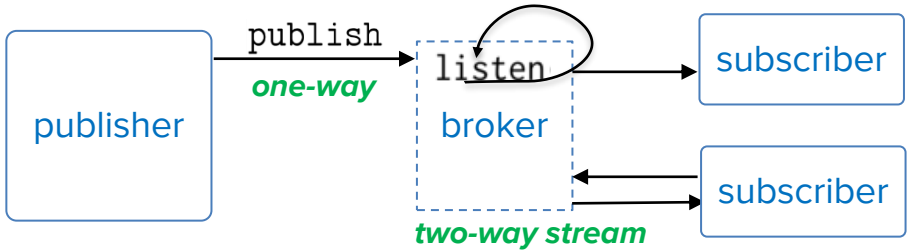
1. Interaction Paradigms for Data Exchange in the IoT
2. Modeling QoS Semantics of IoT interactions using PerfMPs
3. QoS-aware composition for evaluating interoperability effectiveness
4. Evaluation results
5. Conclusion & Future work

Core Interaction Paradigms

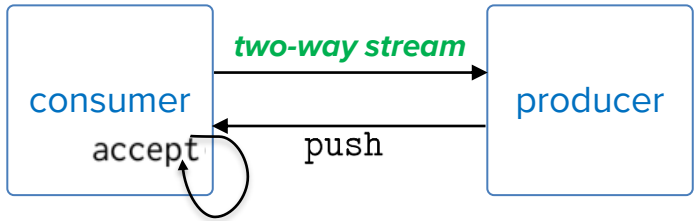
Client/Server (CS) – CoAP, DPWS, etc.



Publish/Subscribe (PS) – MQTT, AMQP, etc.



Data/Streaming (DS) – Websockets, etc.



Data eXchange (DeX) API

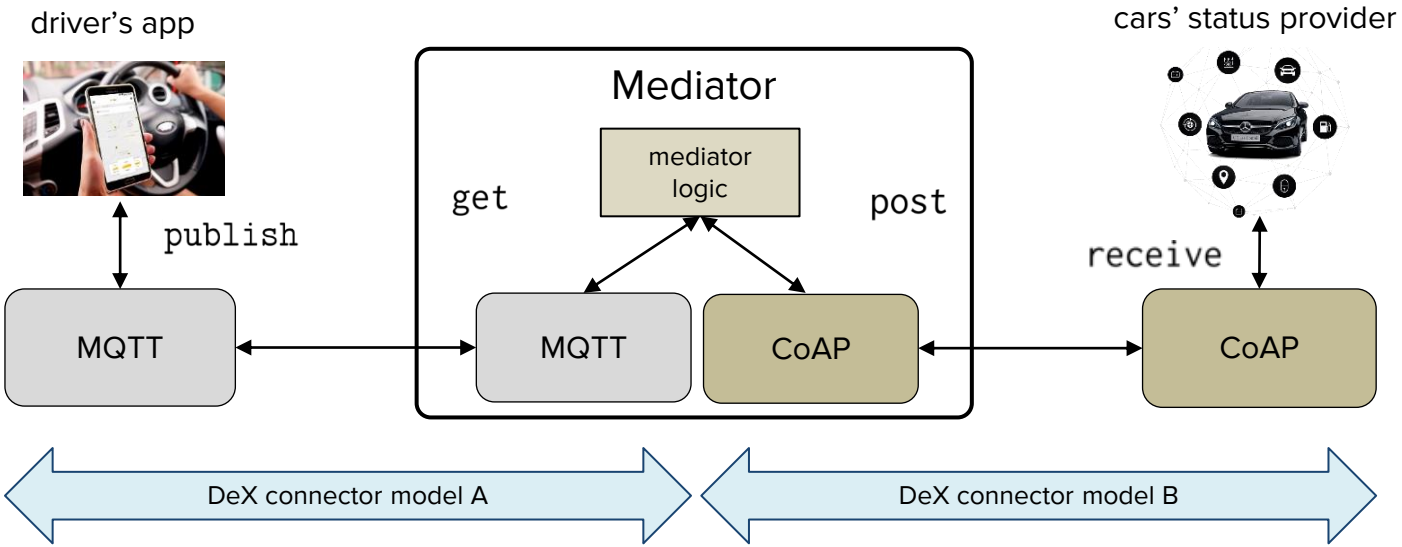
- one-way
- two-way async
- two-way sync
- two-way stream

each interaction is represented as combination of **post** and **get** primitives

post and **get** primitives abstract CS, PS and DS primitives

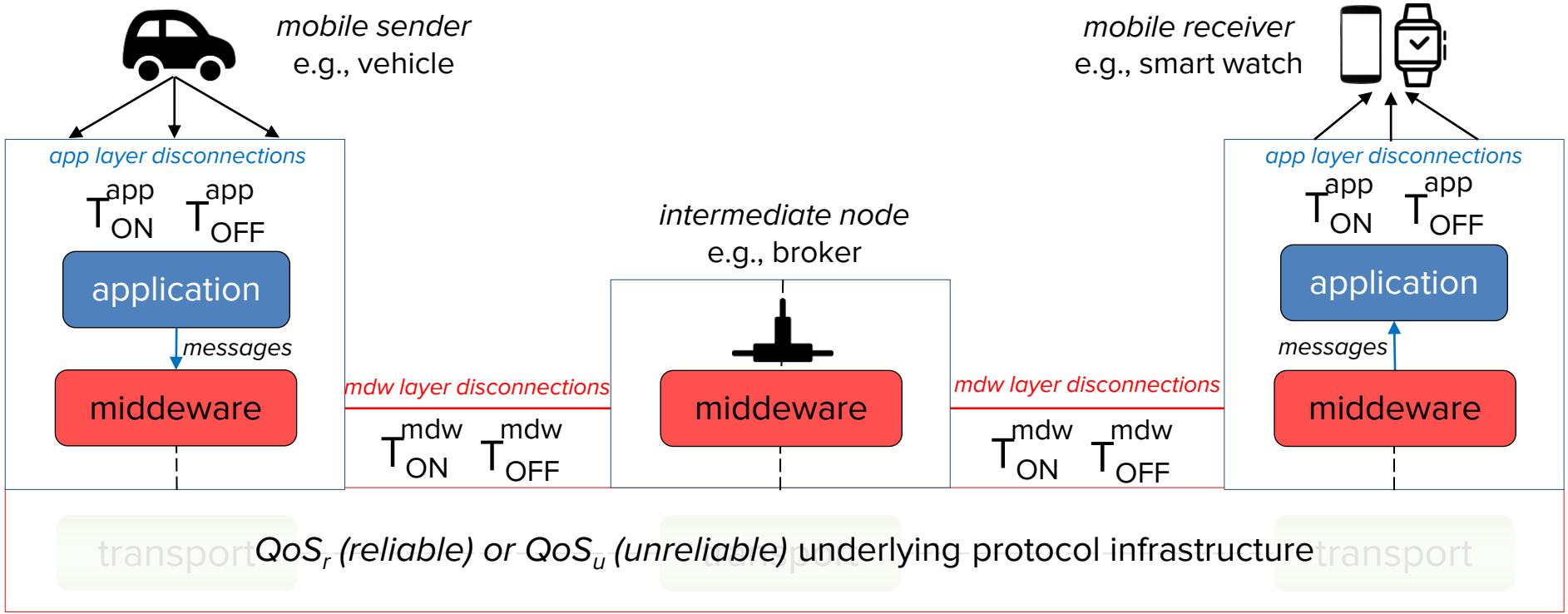
We rely on the DeX abstraction to introduce our middleware protocol interoperability solution[1]

DeX mediators for IoT Interoperability

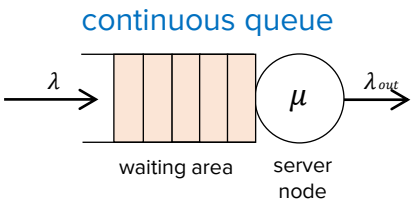


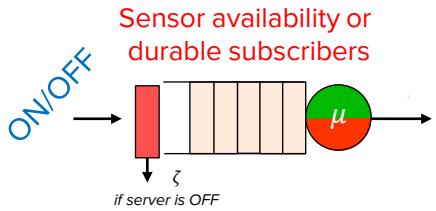
→ What is the end-to-end QoS of this interconnection ?

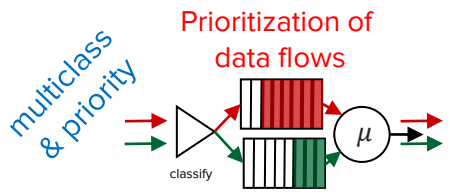
QoS parameters of CS, PS & DS Interactions



How to model QoS semantics?







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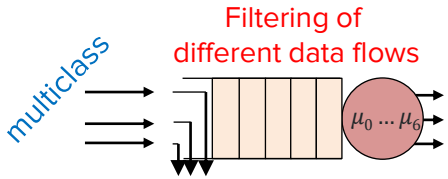
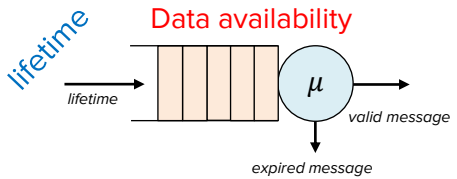
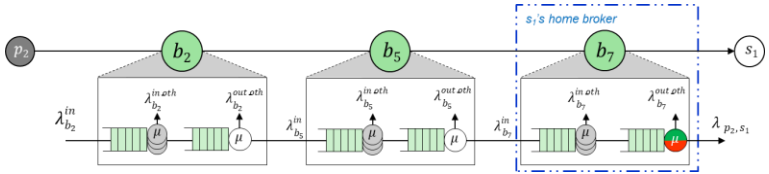




- Model end-to-end path of IoT interactions at the middleware-layer using a combination of different types of queues

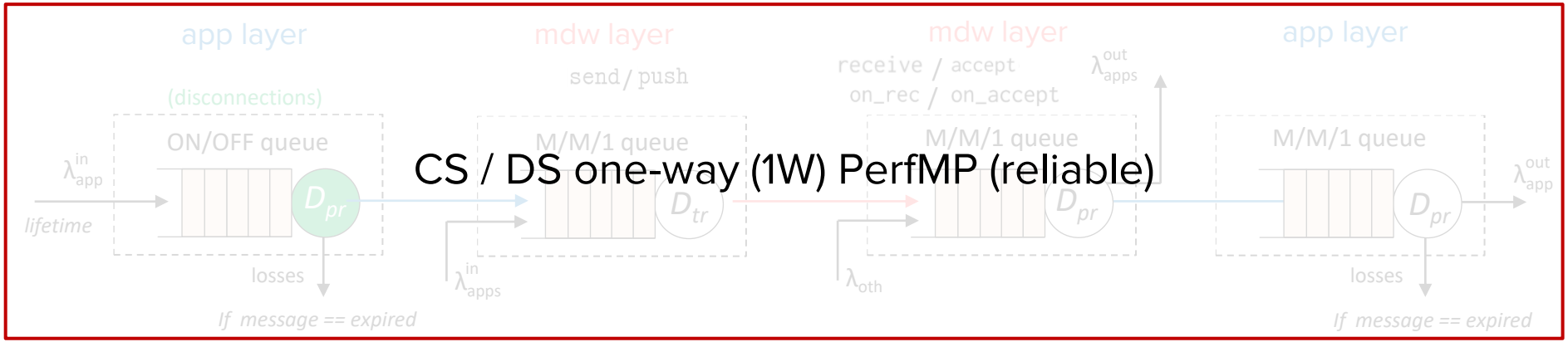


→ Metrics for delivery success rates, end-to-end delay, system utilization, memory, etc.

CS/DS Performance Modeling Pattern (PerfMP)

CoAP server :
- data feeds lifetime
- reliable

CoAP client:
- mobile connectivity
- reliable



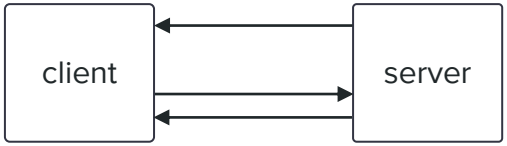
app connection/disconnection

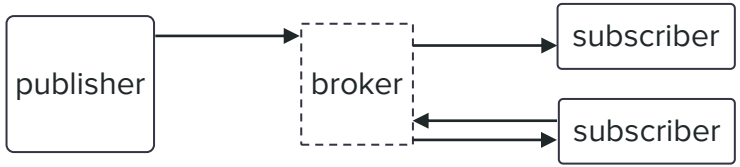
limited data lifetime

net. disconnections

transmission delay

DeX PerfMP of core paradigms





CS/DS-1w

CS-2w async

CS-2w sync

PS-1w

PS-2w stream

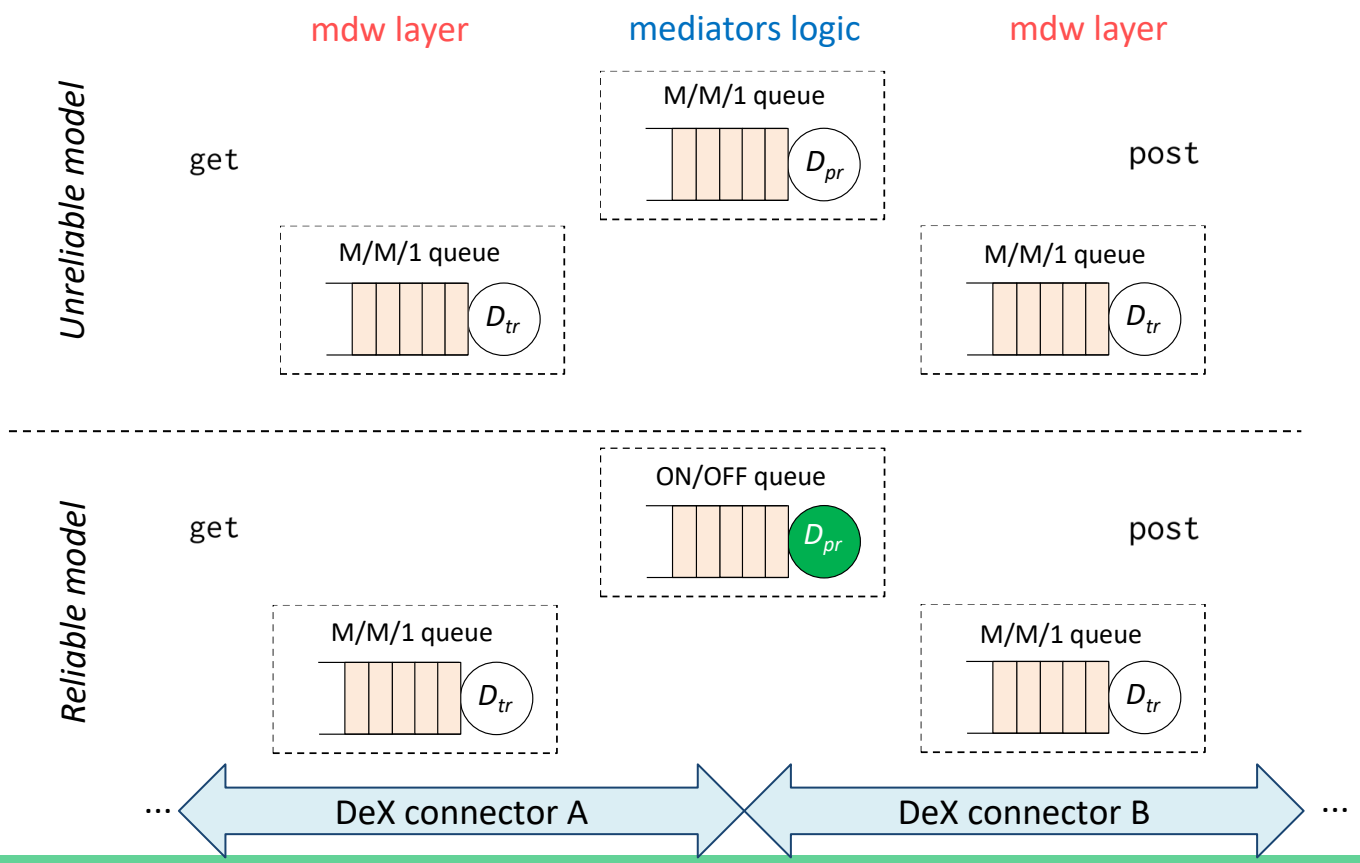
DS-2w stream

→ What about heterogeneous interactions ?

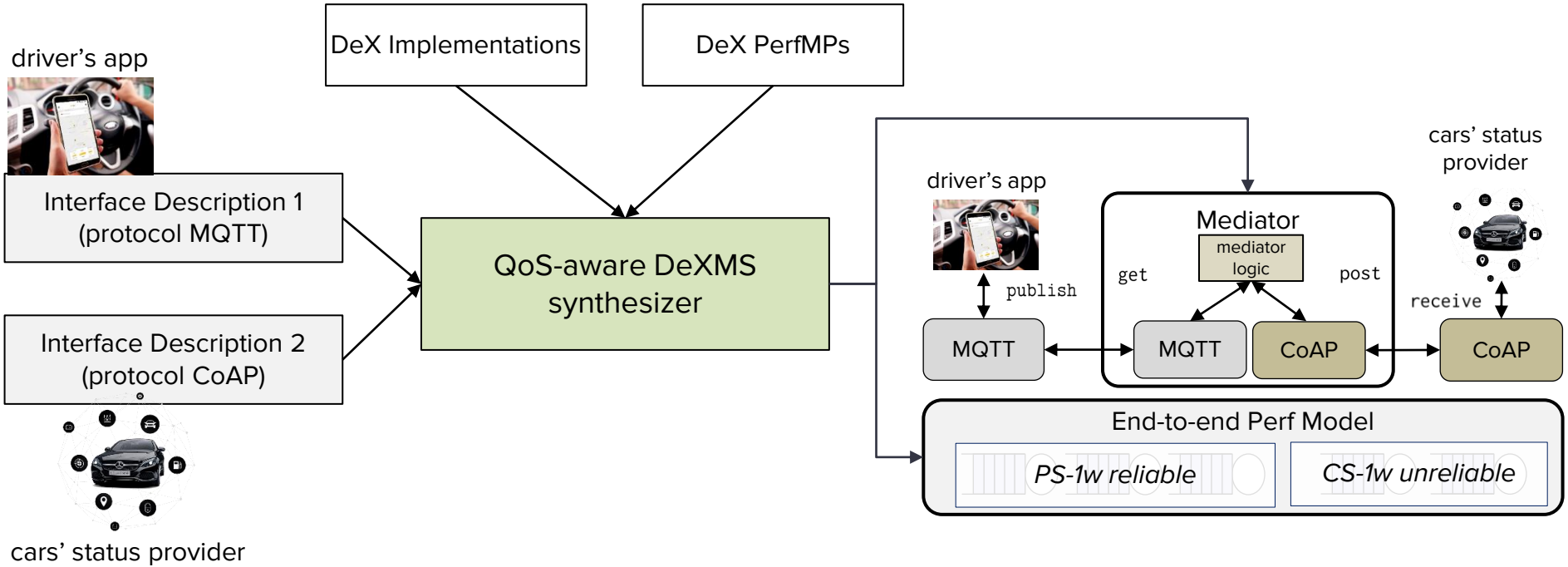
MQTT subscriber :
- data feeds lifetime
- reliable

CoAP server :
- mobile connectivity
- unreliable

PerfMP for DeX Mediators



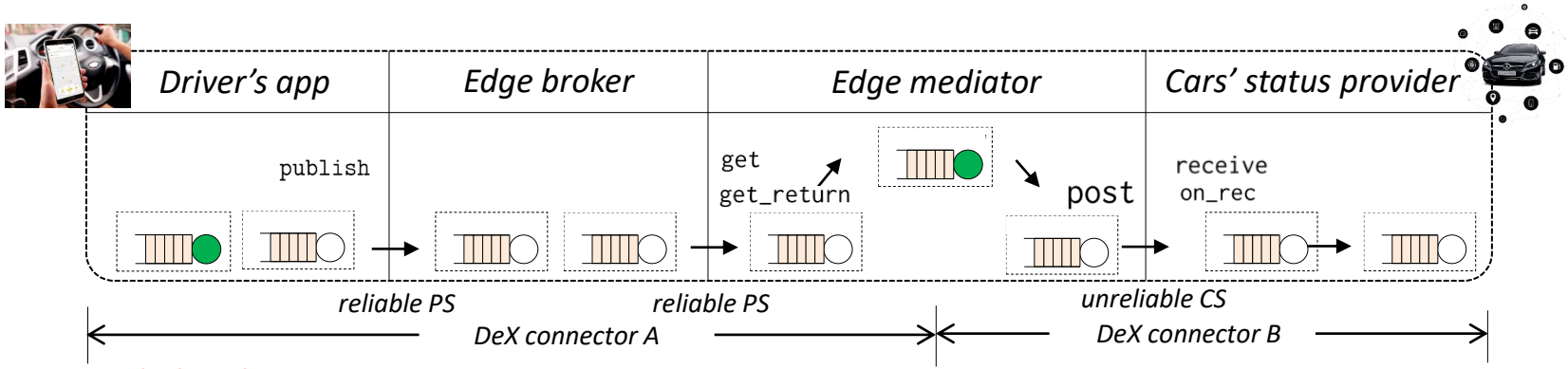
Automated QoS-aware DeX Mediator synthesis



→ How to use end-to-end Perf models in real world scenarios?

Evaluation Results

- JINQS[1] (Java Implementation of a Network-of-Queues Simulation):
  - open source simulator for building queueing networks
- We extend JINQS to implement:
  - ON/OFF queue, reliable/unreliable data exchange, other QoS parameters
  - Our proposed PerfMPs & End-to-end Perf Models
- Evaluate the trade-off between response times delivery success rates for numerous reliable/unreliable interactions in the IoV scenario
- End-to-end Perf Model of IoV scenario:

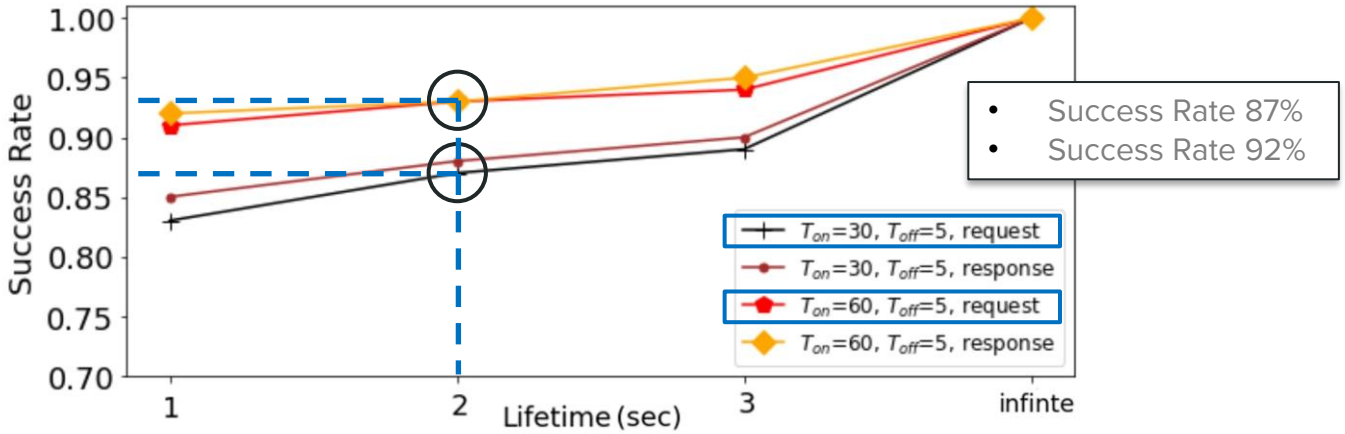


[1] http://wp.doc.ic.ac.uk/ajf/jinqs/

Results: reliable Publisher (1)

# incoming cars : 42 cars / sec
lifetime = 1/2/3 sec / infinite
T_{ON} = 30/60 sec; req/res T_{OFF} = 5 sec
λ_{req} = 130 msg/sec (all cars)
λ_{res} = 250 msg/sec (all cars)
BW car = 3 Mbps upload, 6 Mbps download

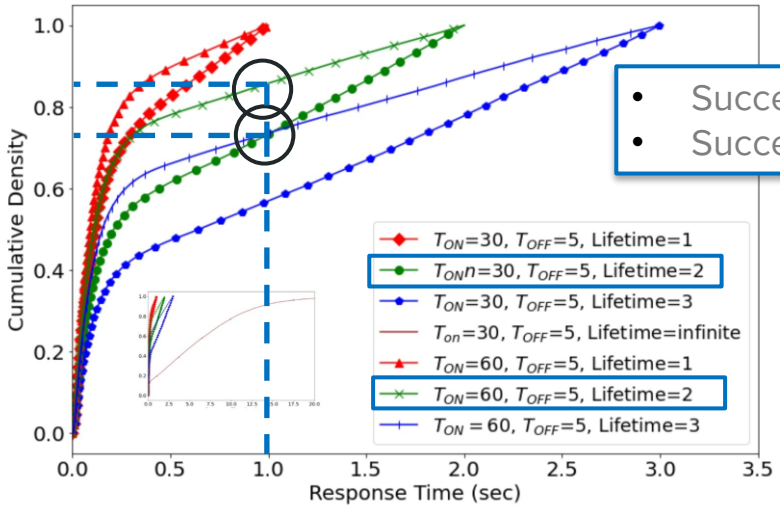
Delivery Success Rates



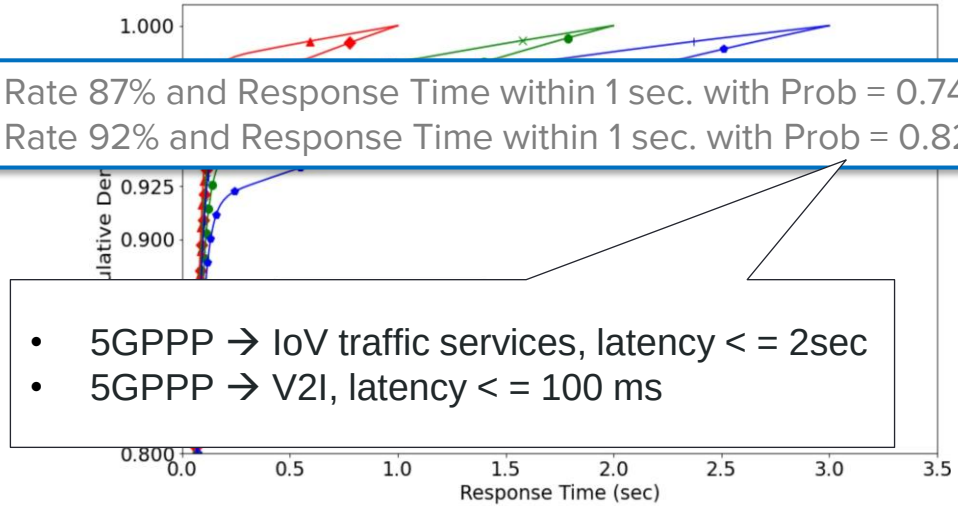
Results: reliable Publisher (2)

# incoming cars : 42 cars / sec
lifetime = 1/2/3 sec / infinite
T_{ON} = 30/60 sec; req/res T_{OFF} = 5 sec
λ_{req} = 130 msg/sec
λ_{res} = 250 msg/sec
BW car = 3 Mbps upload, 6 Mbps download

End-to-end response time - requests



End-to-end response time - responses



- Success Rate 87% and Response Time within 1 sec. with Prob = 0.74
- Success Rate 92% and Response Time within 1 sec. with Prob = 0.82

- 5GPPP → IoV traffic services, latency < = 2sec
- 5GPPP → V2I, latency < = 100 ms

Results: unreliable Publisher

# incoming cars : 42 cars / sec
lifetime = 1/2/3 sec / infinite
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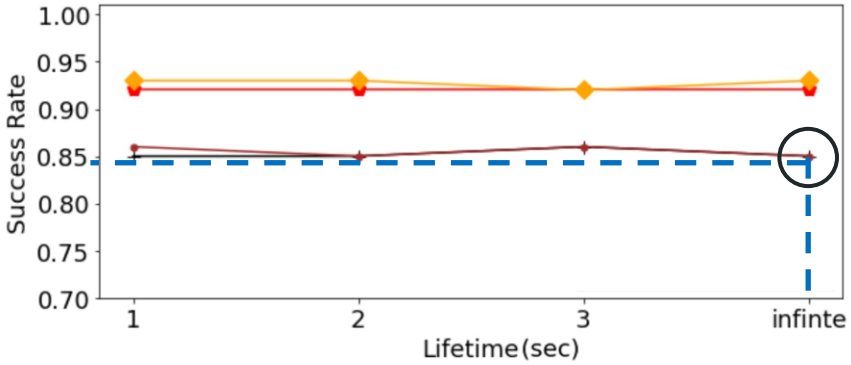
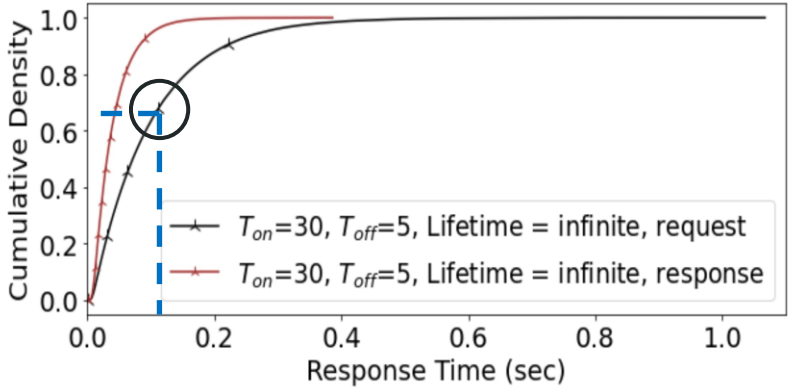


End-to-end response time request & response



- Success Rate 85% and Response Time within 100 ms. with Prob = 0.62

Results: unreliable Publisher

# incoming cars : 42 cars / sec
lifetime = 1/2/3 sec / infinite
T_{ON} = 30 sec; req/res T_{OFF} = 5 sec
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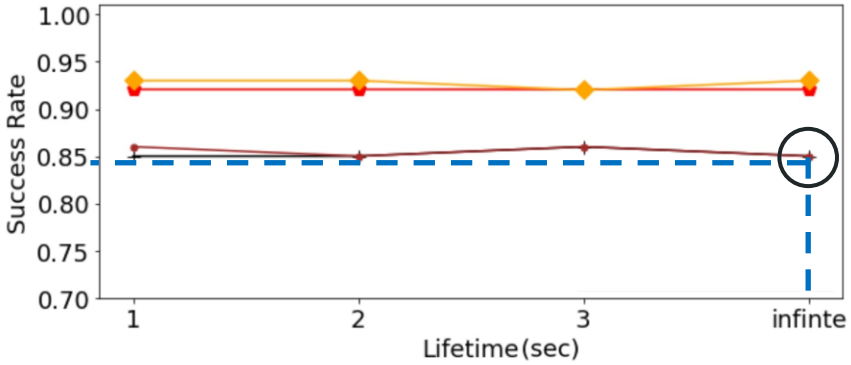
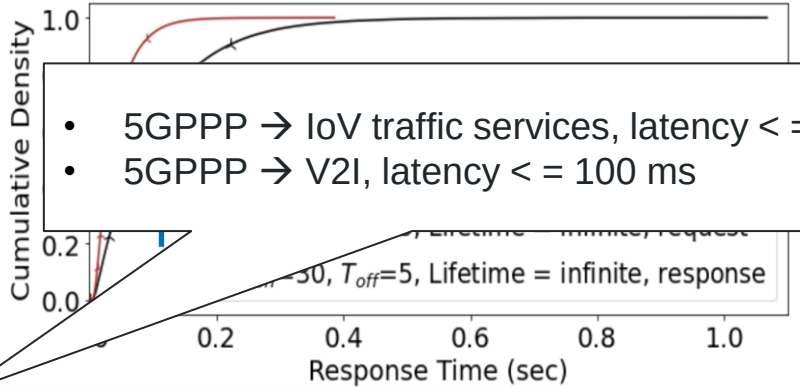
Delivery Success Rates



End-to-end response time request & response



- 5GPPP → IoV traffic services, latency < = 2sec
- 5GPPP → V2I, latency < = 100 ms

- Success Rate 85% and Response Time within 100 ms. with Prob = 0.62

Conclusion & Next steps

- ❖ Performance modeling patterns (PerfMP) to captures the application and middleware layers of IoT interactions
- ❖ QoS-aware DeX Mediator synthesis methodology for evaluating the interoperability effectiveness of IoT interconnections

- ➢ Future work
  - Automate the system tuning process given an IoT use case scenario
  - Introduce PerfMPs for AI-based IoT components for data processing

Thank You!

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