DE Trial Results

Platooning
Extended Sensors

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Outline of Measurements and Results

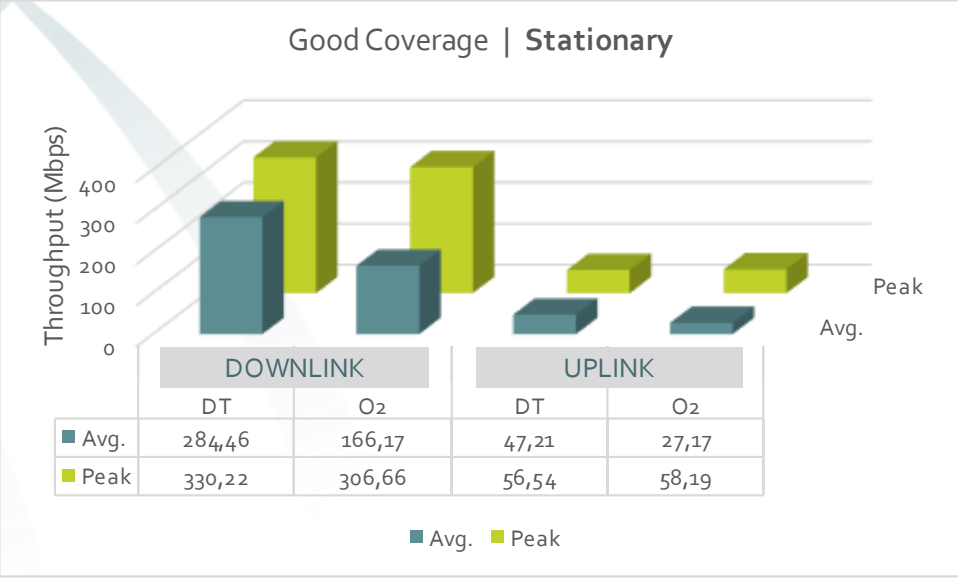
- **Scenario-agnostic tests of 5G networks at DE trial site**
- **User Story Testing & Demo Video**

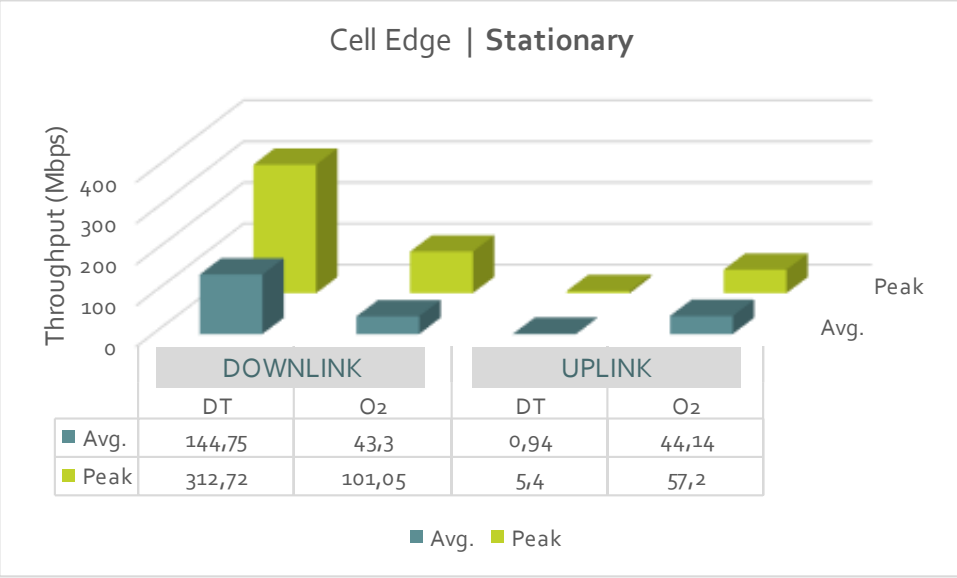
Test Scenarios	Network flows under test	Involved entities
Platooning with edge support	Platooning Control Messages (PCM)	platoon Leader ⇔ follower
	Edge Dynamic Map (EDM) messages	eRSU ⇔ platoon leader
Extended sensors with surround view	Video stream	vehicle ⇔ vehicle
	MQTT messages	vehicle ⇔ MEC

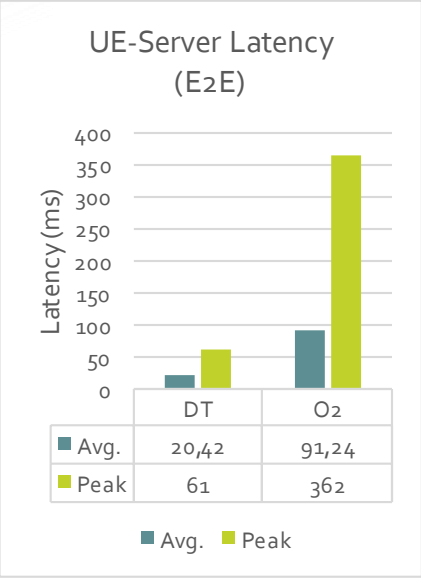
- **Selected KPIs**

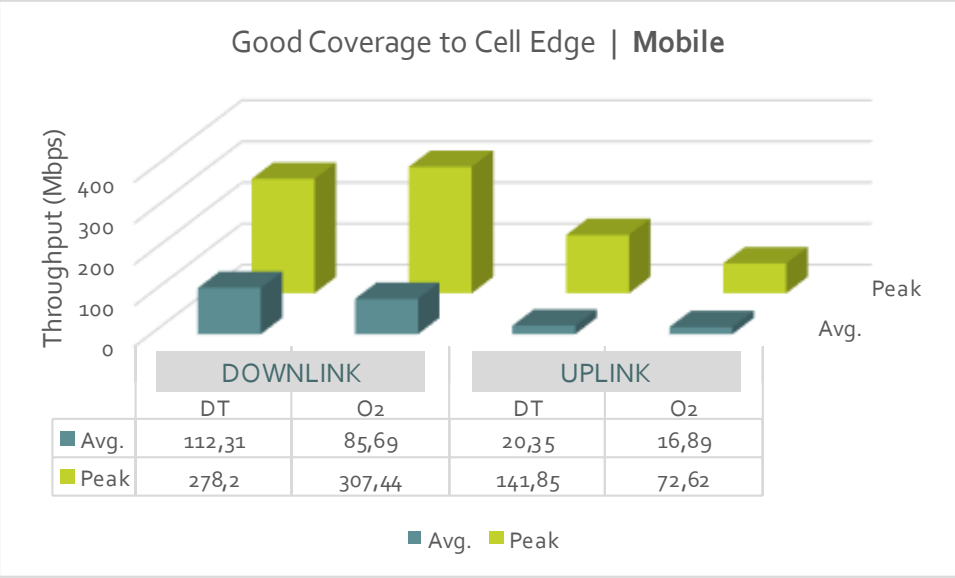
  Throughput, Latency (E2E Delay), Reliability (Packet Loss)

Scenario-Agnostic Test Case Results at DE TS









Details in 5G-MOBIX deliverable D3.7
(to be published soon)

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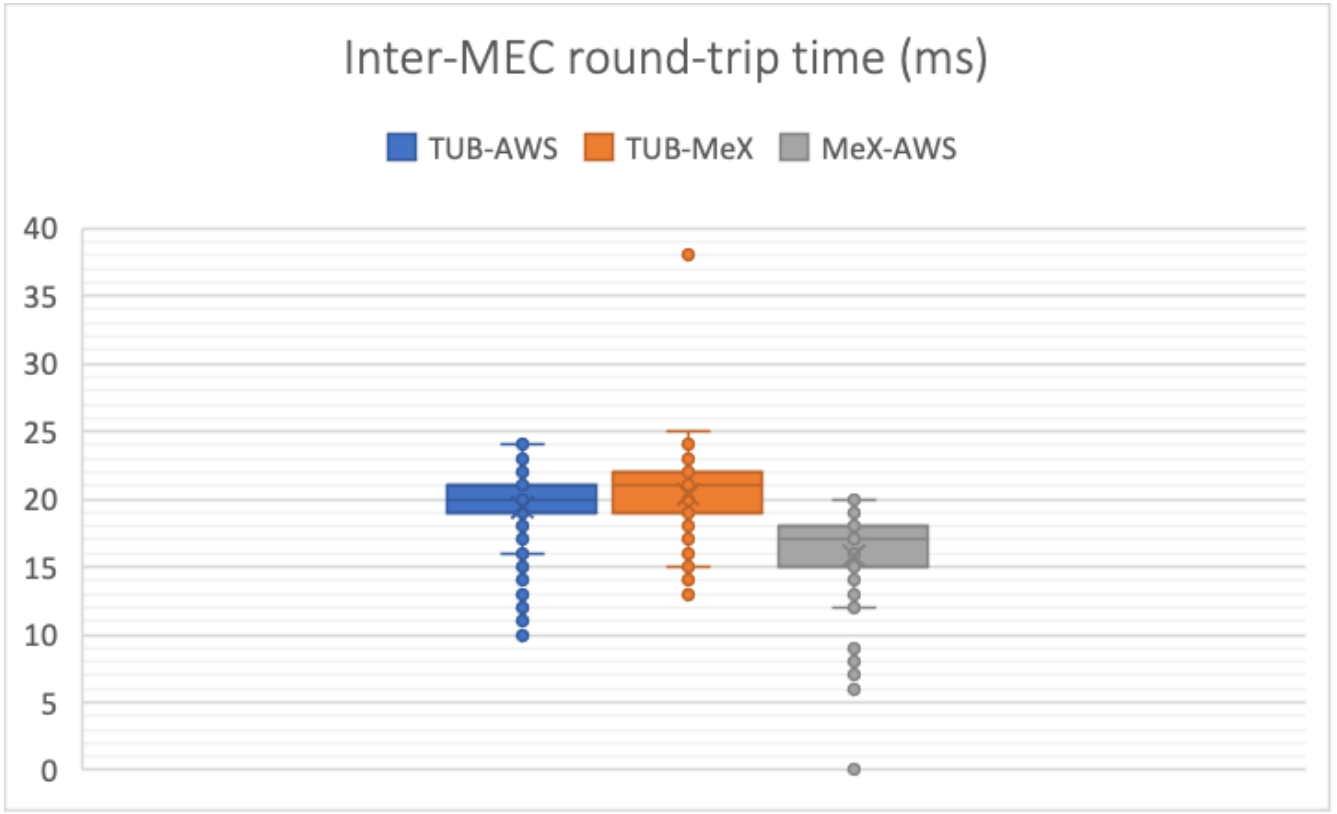
Agnostic Test Case: TUB MEC to MeX MEC

RTT between experimental MEC @ TUB and commercial MobiledgeX (DT) MEC Berlin Node

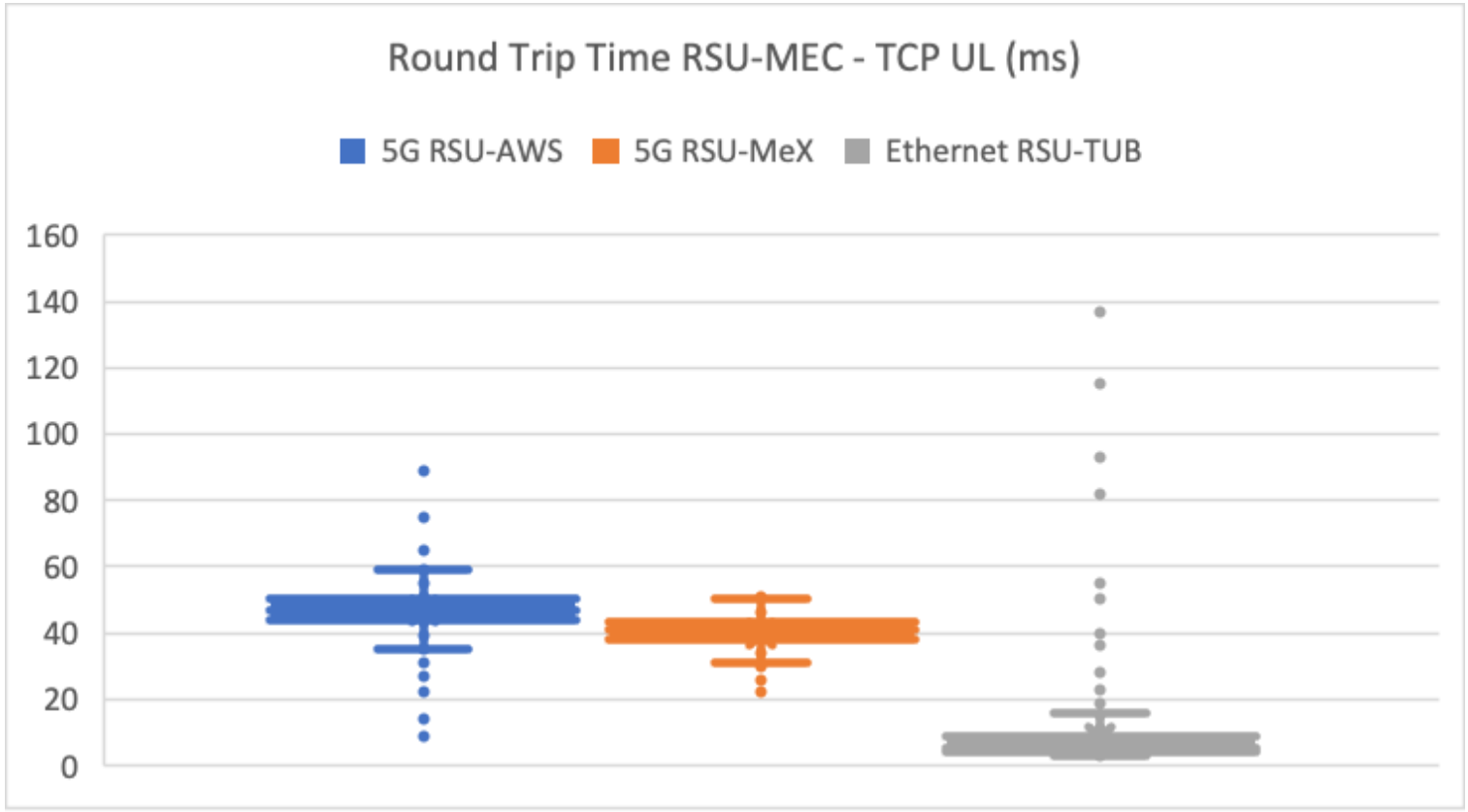


Measured RTT characterizes the induced delay caused by the communication between MEC nodes

- E.g., due to MEC Broker applications hosted on each MEC infrastructure, exchanging V2X application data relevant for the users of the other MEC node
- The "interconnection" of MECs can be realized, e.g., via direct peering, dedicated fiber, or via Internet
- The TUB-MeX interconnection is via Internet (but massively overprovisioned connection via DFN)

Agnostic Test Case: RSU to MEC

RTT between eRSU @ TUB and MEC Nodes / Cloud



This agnostic test shows the impact of different RSU-MEC connection options on the RTT

- 5G RSU is connected to AWS cloud, AWS datacenter is located in Paris
- 5G RSU and MobiledgeX MEC are connected within Deutsche Telekom 5G NSA network, MEC cloudlet location is Berlin
- TUB MEC is in the same large-scale campus ethernet network as the eRSU

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DEMO VIDEO (~4 min.)

A longer, more detailed version is also available publicly:

https://youtu.be/5bOuVYIUIwE

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eRSU-Assisted Platooning Trials

2 Network Flows

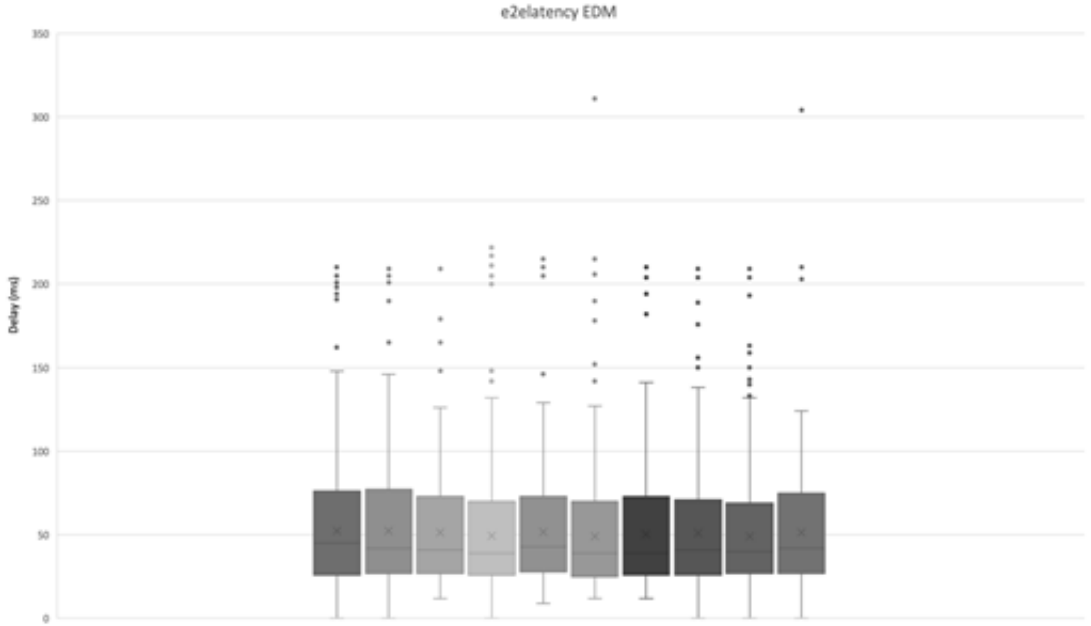
- Edge Dynamic Map (EDM) messages
  - eRSU ⇔ platooning leader
  - Sensors, cameras, etc.
- ETSI-Ensemble style Platooning Protocol[1] messages
  - Platooning leader ⇔ follower
  - CAM, PMM (Platoon join and leave)
  - PCM (Platoon Control Messages)

3 Different Configurations

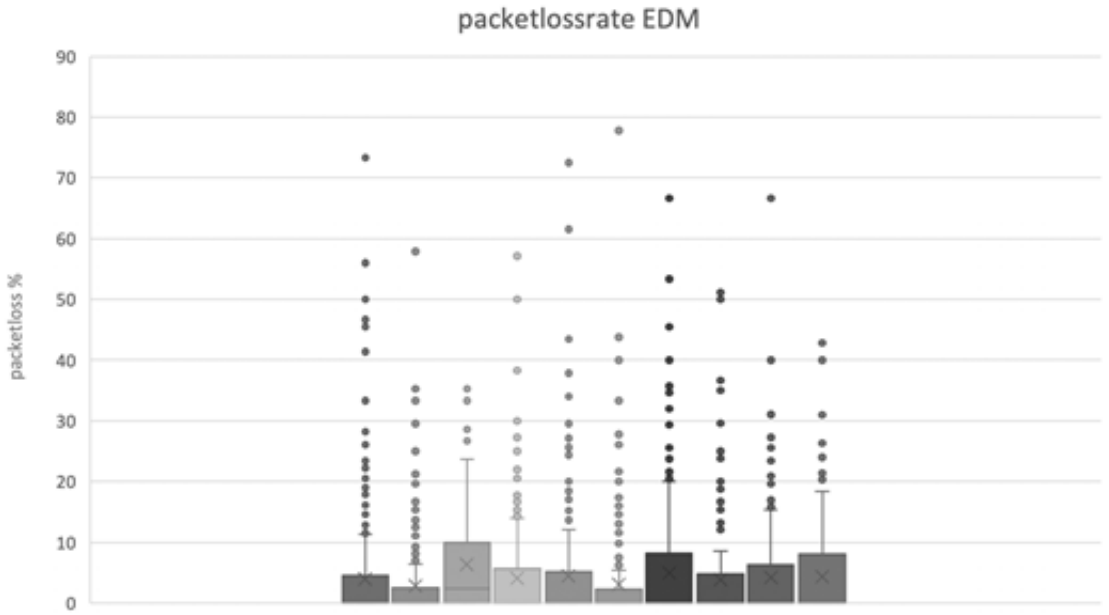
- Full PC5
  - Both flows via PC5 interface
- Full Uu
  - Both flows via Uu interface
- Hybrid
  - EDM flow via Uu, platoon flow via PC5

[1]https://platooningensemble.eu/

Full PC5 Test Case Results - EDM Flow



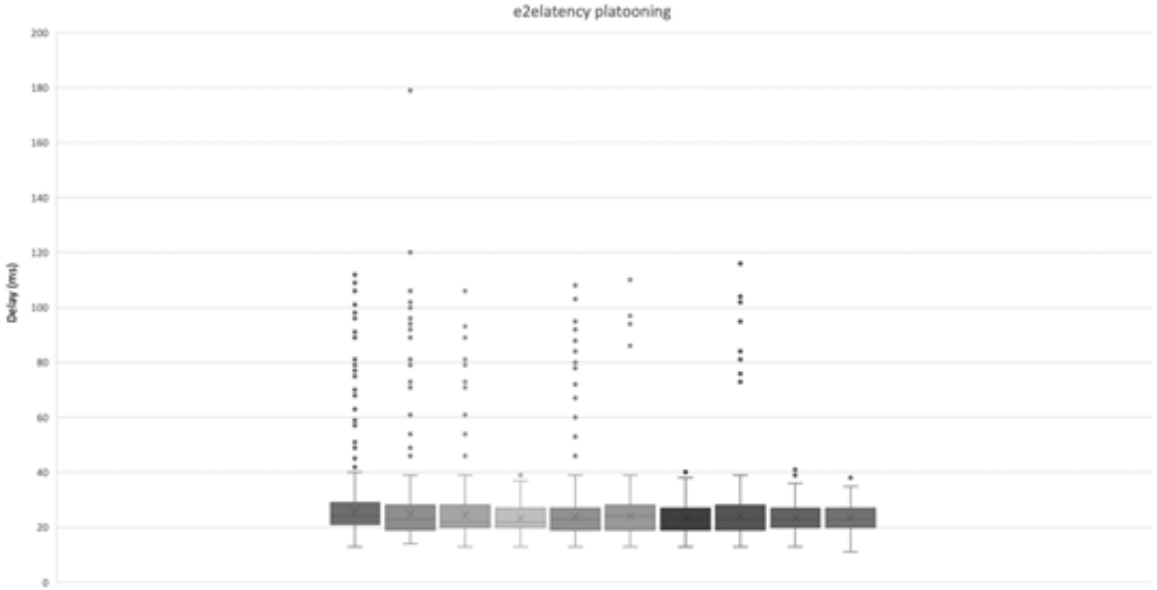
# total samples	**Mean**	Median	Std. Deviation
35055	**51,20**	41	30,02
Max	Min	CI 95%	Percentile 95
210	0	0,31	105

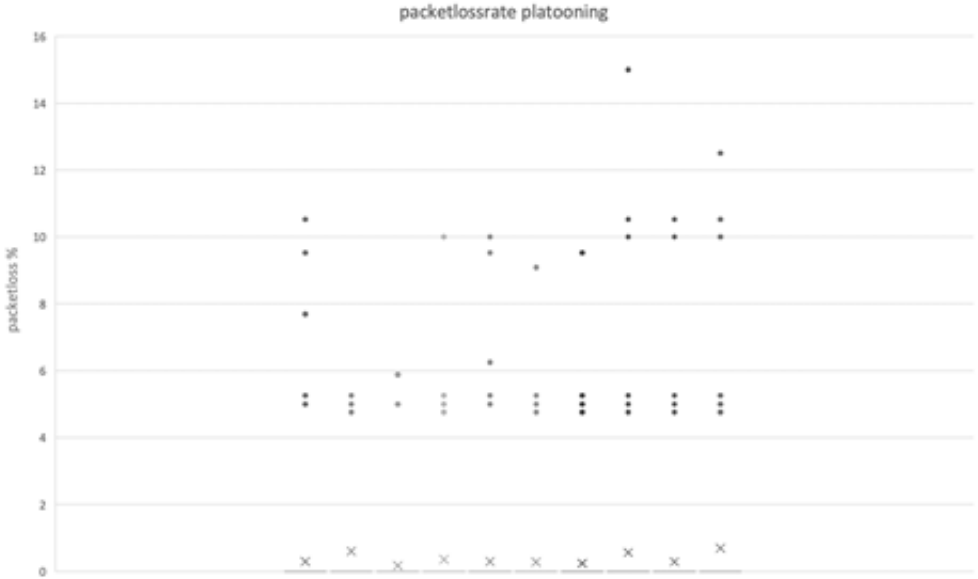


# total samples	**Mean**	Median	Std. Deviation
40956	**4,34**	0	7,91
Max	Min	CI 95%	Percentile 95
77,78	0	0,08	20,45

In the EDM flow over PC5, e2e latency and packet loss highly fluctuate depending on the distance and line of sight between RSU and OBU

Full PC5 Test Case Results - Platooning Flow



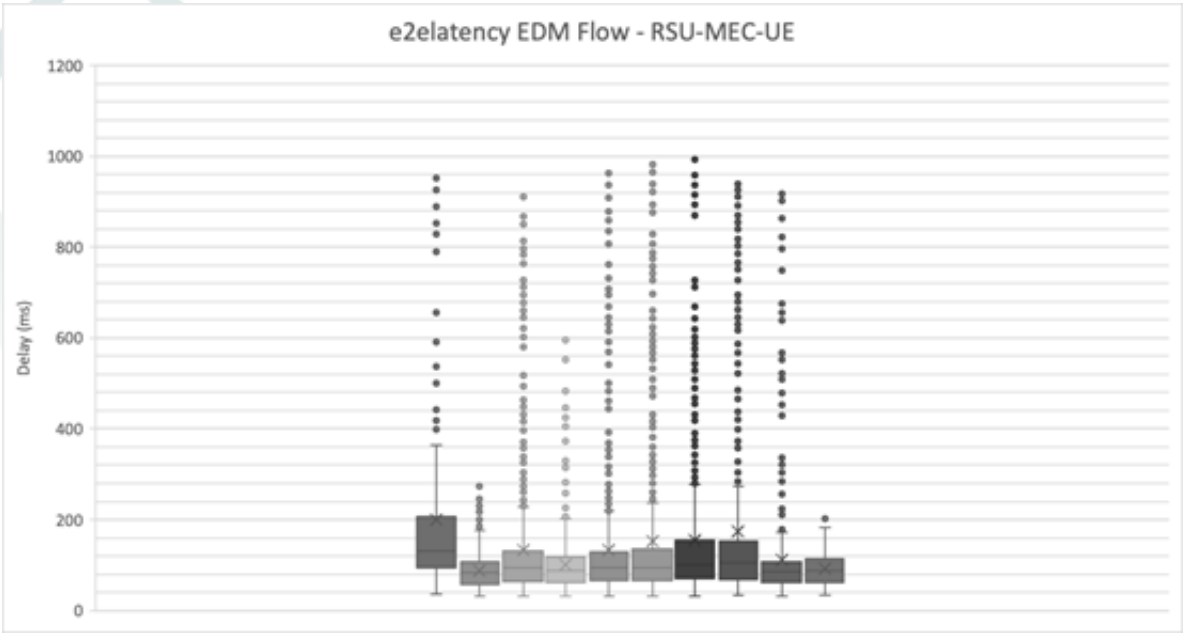


# total samples	**Mean**	Median	Std. Deviation
16715	**24,39**	23	8,29
Max	Min	CI 95%	Percentile 95
179	13	0,13	34

# total samples	**Mean**	Median	Std. Deviation
20763	**0,36**	0	1,51
Max	Min	CI 95%	Percentile 95
15	0	0,021	5

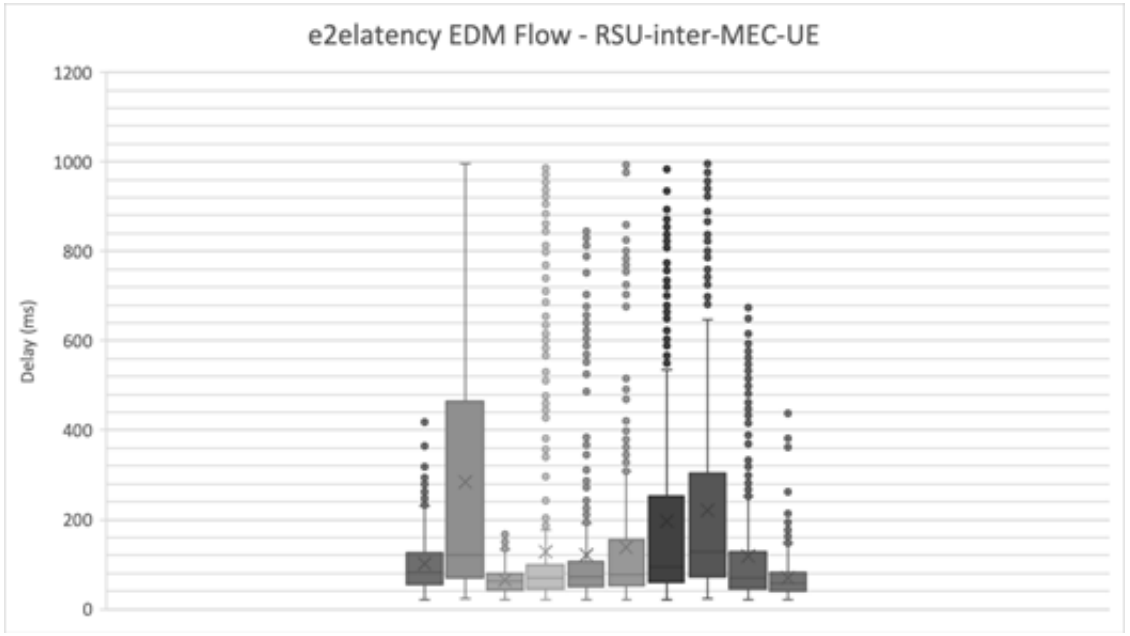
In the platooning flow, both vehicles are very close to each other and Tx-Rx conditions are better; therefore, E2E latency and packet loss values are much lower than those of EDM flow via PC5 interface

Full Uu Test Case Results - EDM Flow



# total samples	**Mean**	Median	Std, Deviation
8060	**131,55**	92,51	141,15
Max.	Min.	CI 95%	Percentile 95
993,3	31,25	3,08	429,21

RSU messages to vehicle via MobiledgeX MEC



# total samples	**Mean**	Median	Std, Deviation
10890	**147,018**	76,49	187,30
Max.	Min.	CI 95%	Percentile 95
996,4	21,07	3,518	620,39

RSU messages to vehicle via TUB MEC & MobiledgeX MEC

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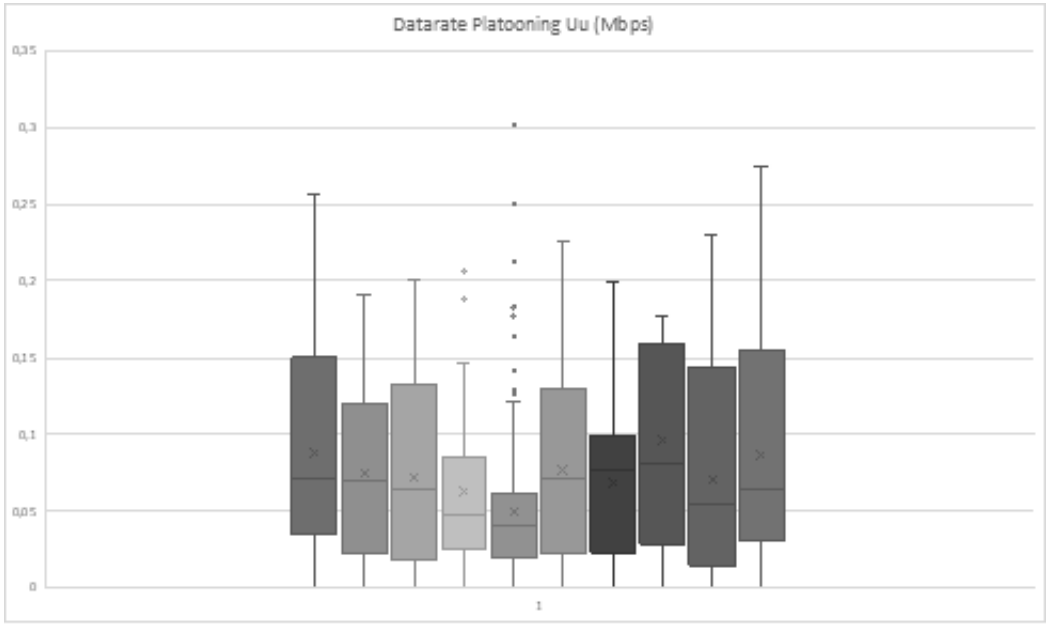
Full Uu Test Case Results - Platooning Flow

# total samples	**Mean**	Median	Std. Deviation
10143	**76,86**	70,65	51,99
Max.	Min.	CI 95%	Percentile 95
1045,85	19,95	1,012	125,73

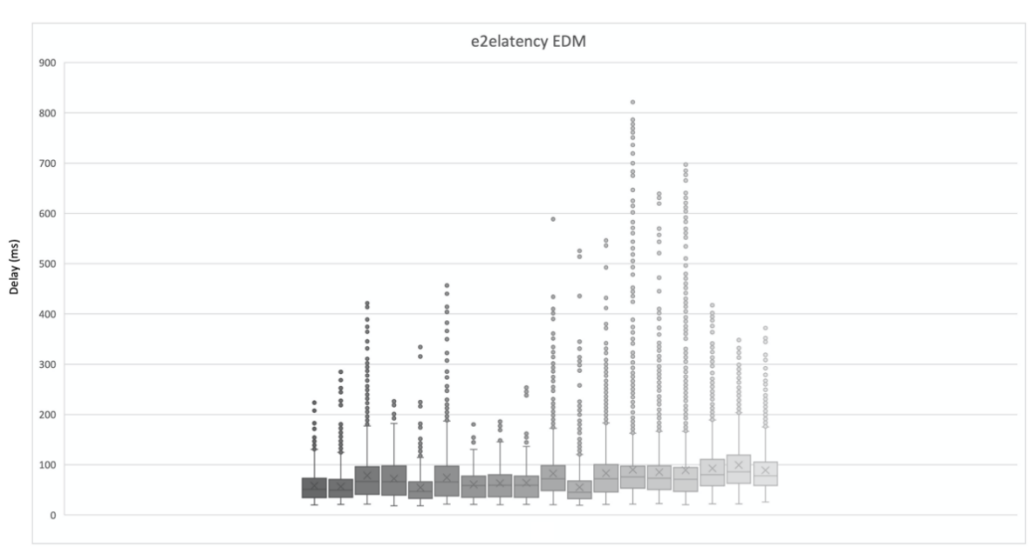
In Uu case, E2e latency is higher compared to PC5, but no packet loss thanks to TCP-based transmission

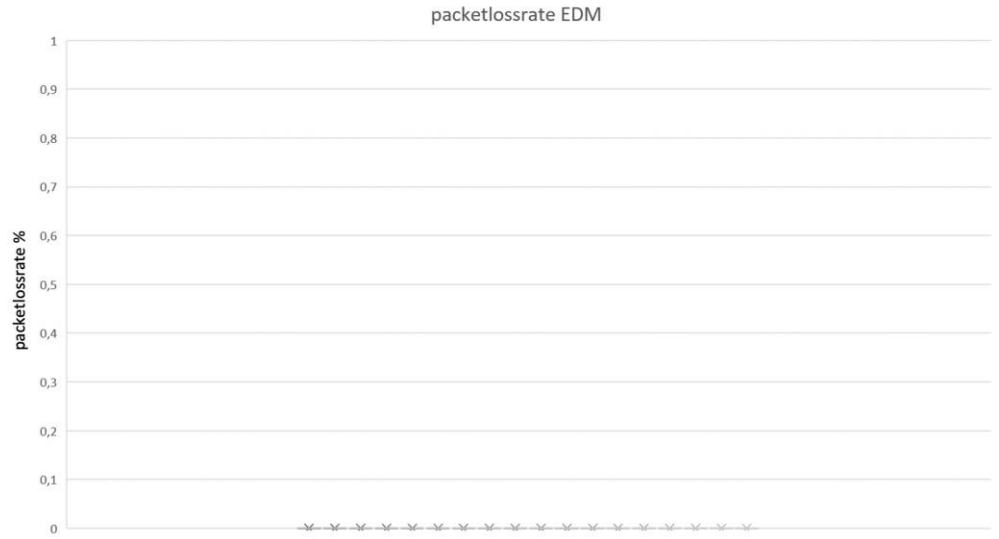


# total samples	**Mean**	Median	Std. Deviation
800	**0,073**	0,055	0,058
Max	Min	CI 95%	Percentile 95
0,301	0,004	0,004	0,176

Reliability KPI not relevant due to TCP; data rate given instead. Very low data rate required for the platoon flow.

Hybrid Test Case Results - EDM Flow



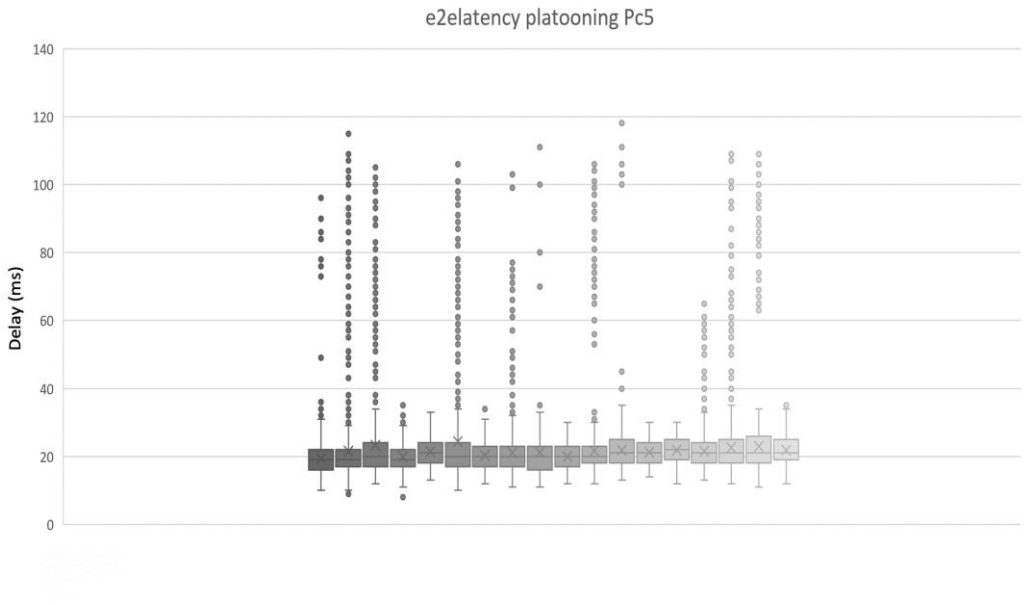


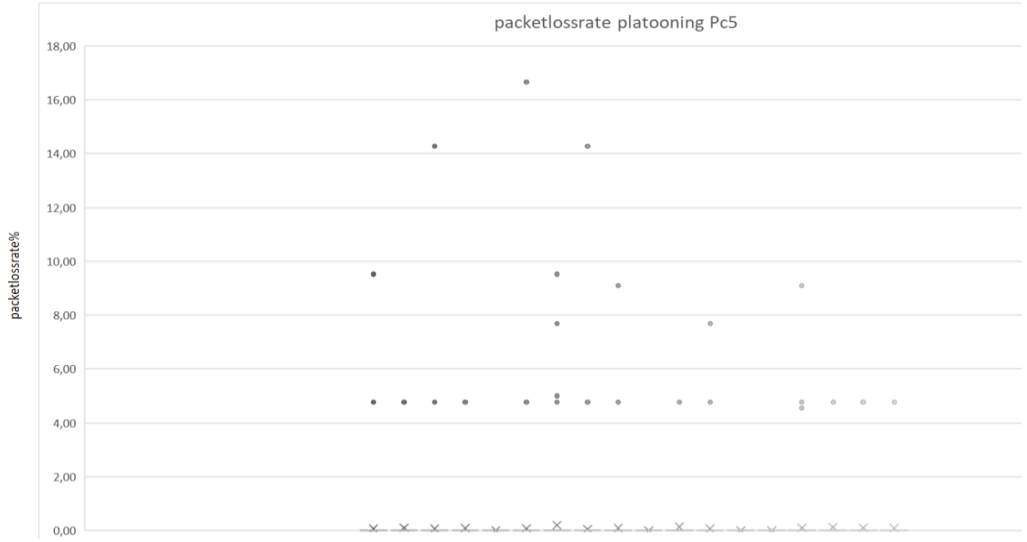
# total samples	**Mean**	Median	Std. Deviation
60391	**75,52**	65,98	54,87
Max	Min	CI 95%	Percentile 95
822,9	18,24	0,44	157,2

# total samples	**Mean**	Median	Std. Deviation
60391	**100%**	100%	0
Max	Min	CI 95%	Percentile 95
100%	100%	100%	100%

E2e latency for EDM flow is lower in hybrid test cases, seemingly due to the elimination of interference with platooning flow

Hybrid Test Case Results - Platooning Flow





# total samples	**Mean**	Median	Std. Deviation
48591	**21,32**	20	8,81
Max	Min	CI 95%	Percentile 95
118	8	0,08	29

# total samples	**Mean**	Median	Std. Deviation
48591	**0,08**	0,00	0,71
Max	Min	CI 95%	Percentile 95
16,66	0,00	0,01	0,00

E2e latency for platooning flow is much better in hybrid test cases, compared to Uu case, thanks to the usage of PC5 interface

Conclusions from Platooning Results

- Platooning results have been obtained in DE TS's large-scale real-world deployment of V2X applications, RSUs, MEC broker applications, etc.
  - Highly dynamic/variable conditions while conducting driving trials in urban environment
  - Especially PC5 Sidelink from roadside infrastructure is susceptible to the dynamics
- Hybrid configuration provides best of both worlds
  - However: The hybrid Platooning V2X application is the most complex application to develop, as it involves the full V2X application layer architecture and distributed components
- In current 5G NSA networks some of the 5G benefits still need to materialize
  - Network Slicing (esp. uRLLC) of 5G SA networks are expected to further improve E2E latency
  - In the current 5G NSA settings …
    - …PC5 is the choice for transmitting time-critical messages
    - …5GUu is the choice for messages with high reliability requirements
- Future hybrid V2X applications will benefit from integration of predictive QoS
  - Drives dynamic decisions on V2X application communication paths for 5GUu/PC5

Extended Sensors User Story Trials

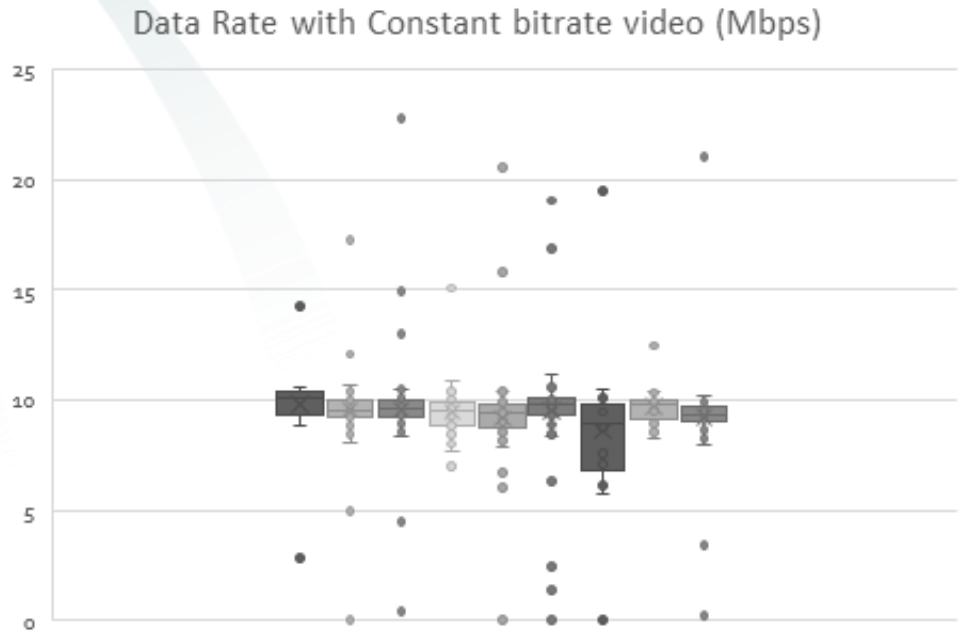
2 Network Flows

- Video stream
  - vehicle ⇔ vehicle
  - 4 different camera feeds, used for surround view generation
- MQTT messages for vehicle discovery service (VDS)
  - vehicle ⇔ MEC
  - VDS feed / VDS query, vehicle peer ID

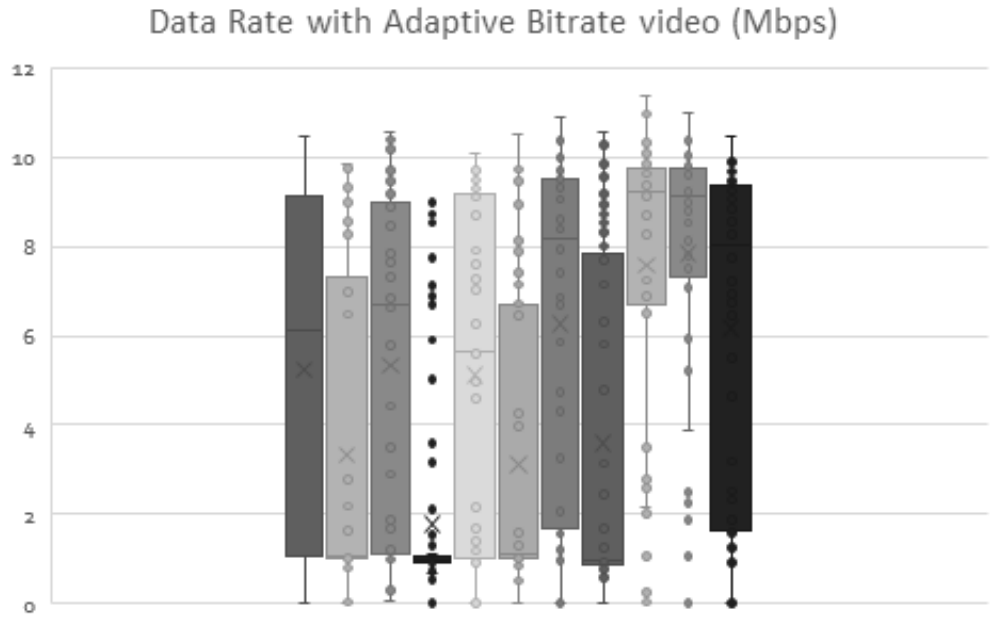
Measurement Focus

- Constant bitrate (CBR) vs. adaptive bitrate (ABR)video streaming analysis --> Data rate & reliability
- MEC-enabled vehicle discovery service --> Latency

Extended Sensors Video Streaming Results: Constant Bitrate vs Adaptive Bitrate

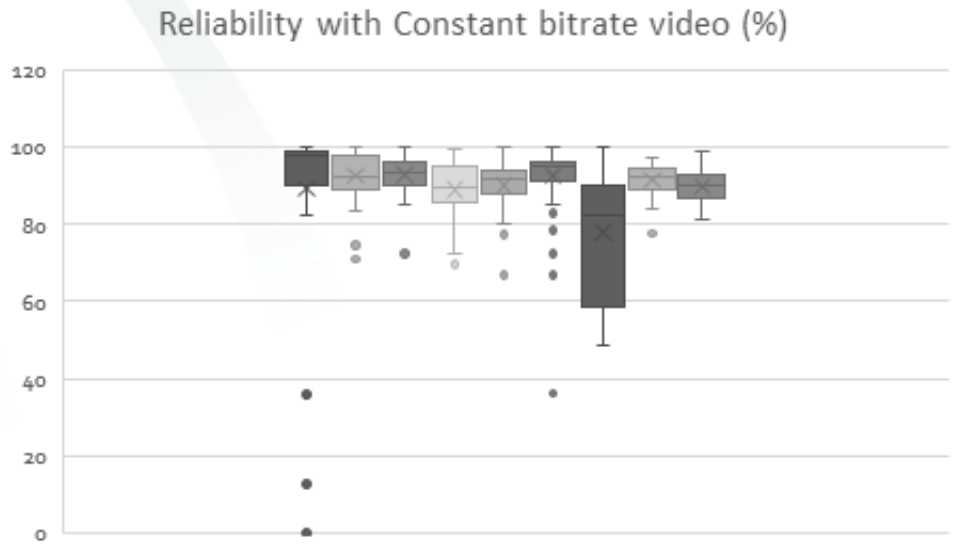


# total samples	Mean	Median	Std. Deviation
423	8.80	9.51	3.24
Max	Min	CI 95%	Percentile 95
22.78	0.004	0.31	10.57

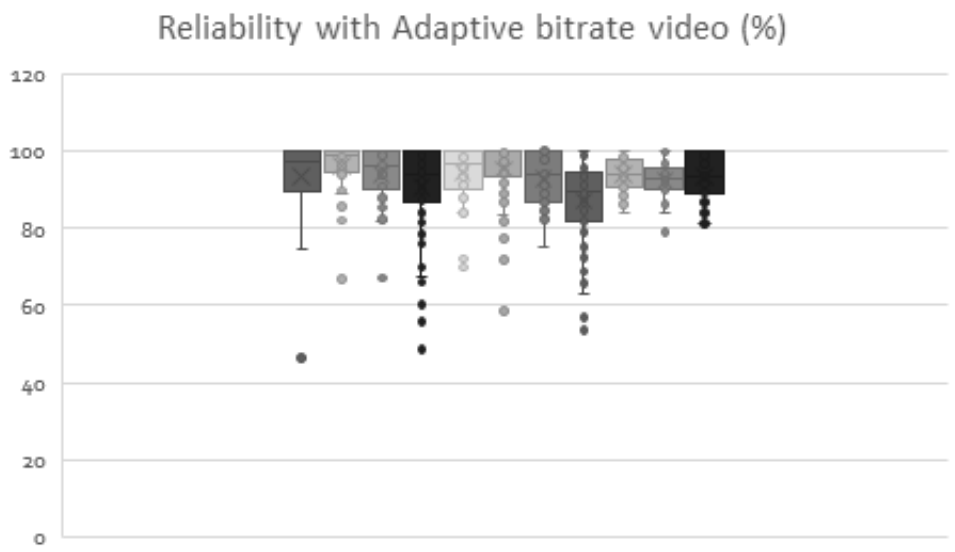


# total samples	Mean	Median	Std. Deviation
575	4.84	3.95	3.86
Max	Min	CI 95%	Percentile 95
11.38	0	0.01	9.97

Extended Sensors Video Streaming Results: Constant Bitrate vs Adaptive Bitrate

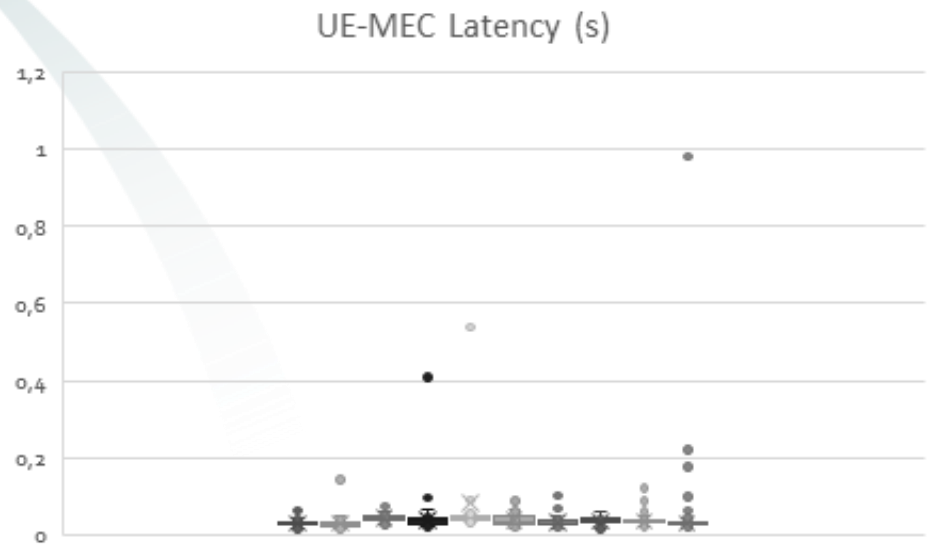


# total samples	Mean	Median	Std. Deviation
423	88.61	92.22	12.75
Max	Min	CI 95%	Percentile 95
100	35.77	0.04	99.99



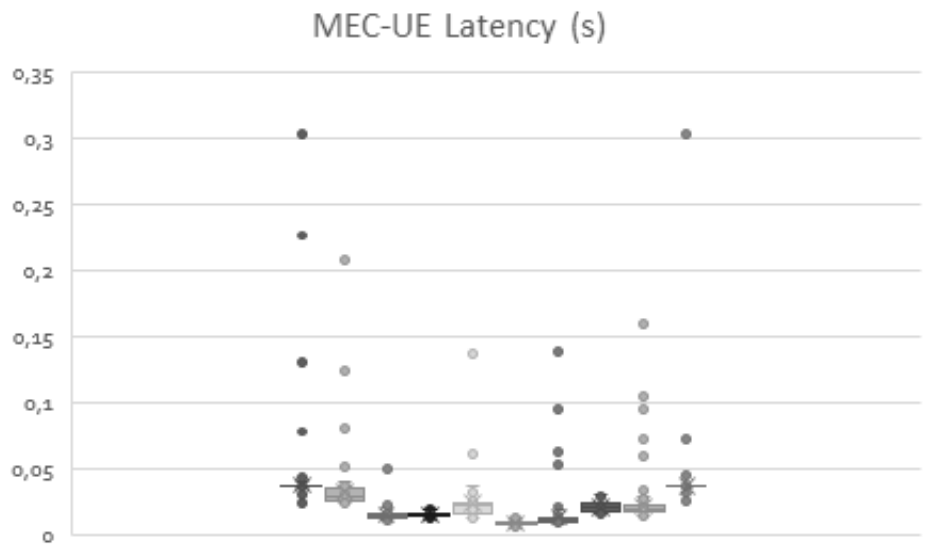
# total samples	Mean	Median	Std. Deviation
575	92.63	94.58	8.68
Max	Min	CI 95%	Percentile 95
100	46.32	0.02	100

Extended Sensors MQTT Messaging Results



# total samples	Mean	Median	Std. Deviation
2847	0.035	0.030	0.038
Max	**Min**	**CI 95%**	**Percentile 95**
0.981	0.014	4.54E-05	0.051

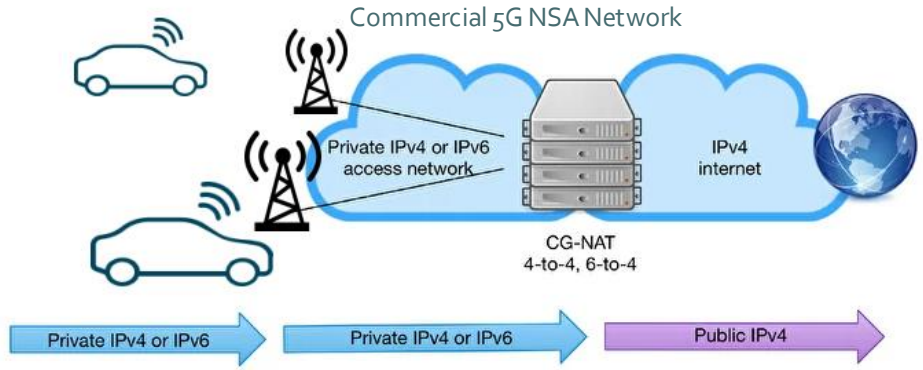
(uplink)



# total samples	Mean	Median	Std. Deviation
2847	0.028	0.034	0.015
Max	**Min**	**CI 95%**	**Percentile 95**
0.302883	0.006	1.79E-05	0.033

(downlink)

Extended Sensors Video Streaming Results & V2X Application Requirements



- Mobile networks currently do not cater for **direct UE<>UE connectivity**, which is a requirement for V2V traffic over 5G Uu
  - Carrier-grade NAT (CGN) prevents direct communication among vehicles
  - Communication not initiated by UEs is blocked by Firewall
  - **Solution 1:** Use specific APN configurations to tailor to V2X applications' needs
  - **Solution 2:** Use NAT traversal at MEC
- V2X Application interruption time (reconnection time) :
  - With Private IPs (i.e. with CGN) and NAT traversal at MEC: 10 seconds approx.
  - With Public IPs: 4-5 seconds approx.

Conclusions from Extended Sensors

- Adaptive bitrate increases reliability (reduced packet loss).
- The use of public IPs on UEs significantly decreases the video streaming application's interruption time when switching modem (~4s vs ~10s).
- The latency of the MQTT messaging between the UE and the MEC (MobiledgeX) is about 30 ms (uplink and downlink), not far from the performance of commercial clouds (e.g., Amazon AWS).
- There is high variability in network performance when testing on open roads using commercial NSA networks.

Thank you

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