5G-MOBIX French Trial Site's results and lessons learnt on 5G for CAM

FR Site contributions to the Cross Borders Issues

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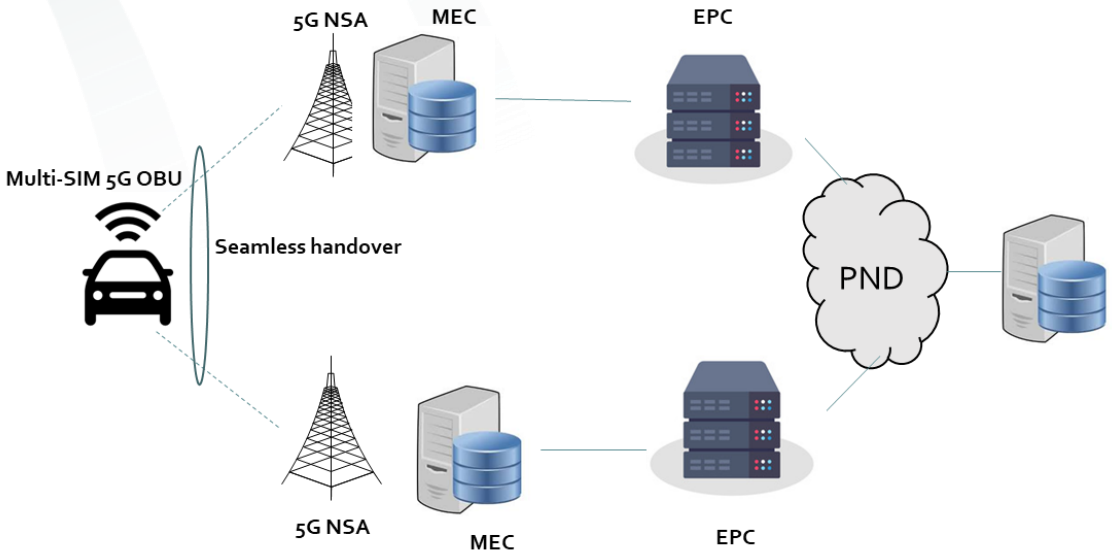
Overview of FR Test Cases

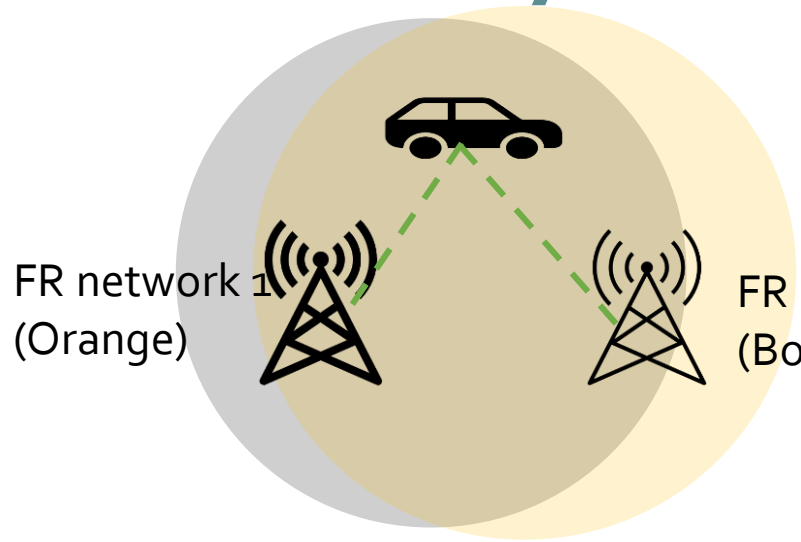
Category	Cross-Border Issues	Solutions	Tests Cases & Scenarios
Telecom & Application	NSA Roaming Interruption Session & Service Continuity Low Coverage Area	Handover using an NSA network Multi-modem / multi-SIM modem Use of satellite solution	Single-SIM and Multi-SIM Connectivity with different technologies & networks
Telecom	mmWave Appplicability	mmWave 5G NSA network	User Story: Infrastructure -assisted advanced driving 4G / 5G sub 6GHz / 5G mmWave
Application	Dynamic QoS Continuity	Predictive QoS	QoS adaptation to performances changes due to roaming/handover

Results of Multi-SIM Connectivity

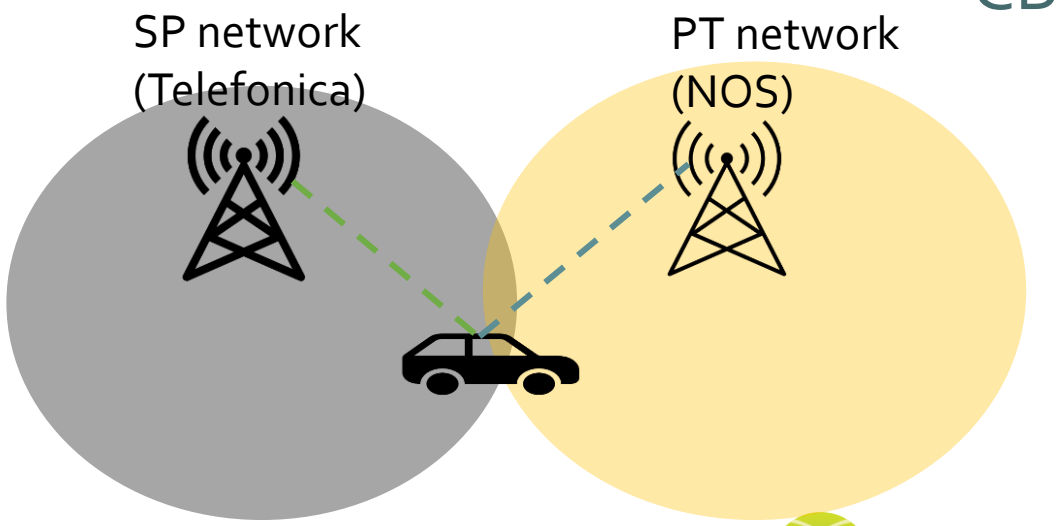
- Scenarios



FR TS



CBC



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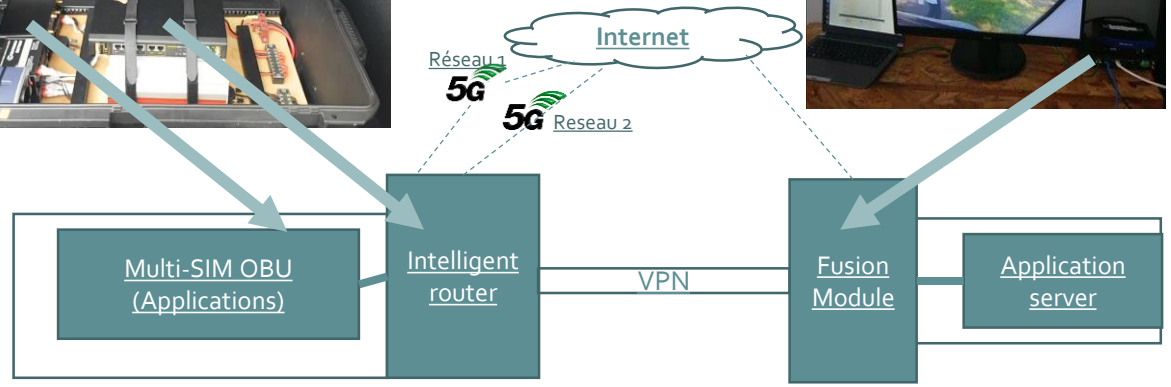
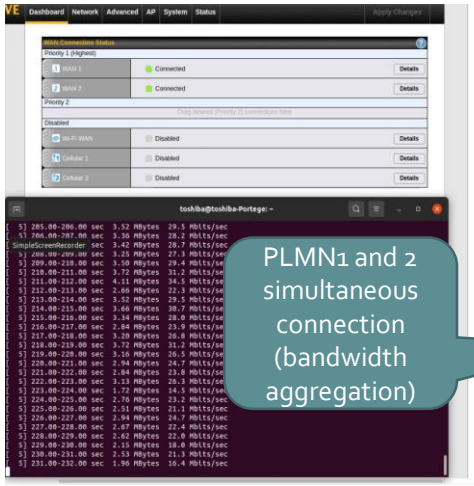
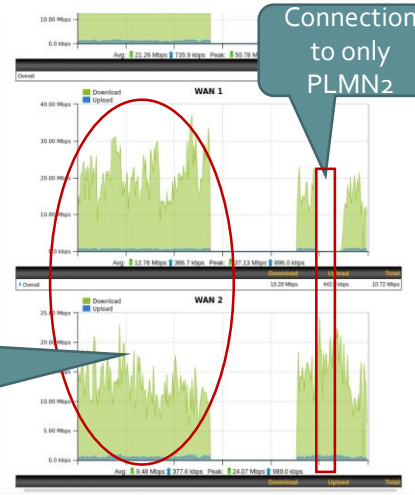
Multi-SIM Connectivity Solution

- Connected Vehicle with intelligent router
  - Simultaneous connection with two 5G Networks
    - Reduction (suppression) of the delay associated with roaming/handover
  - Aggregation of multiple connexions
    - Increase of throughput
- MEC / Cloud Server
  - Fusion of the received data
  - Reodering of packets send to applications.





PLMN1 and 2 simultaneous connection (bandwidth aggregation)



Connection to only PLMN2

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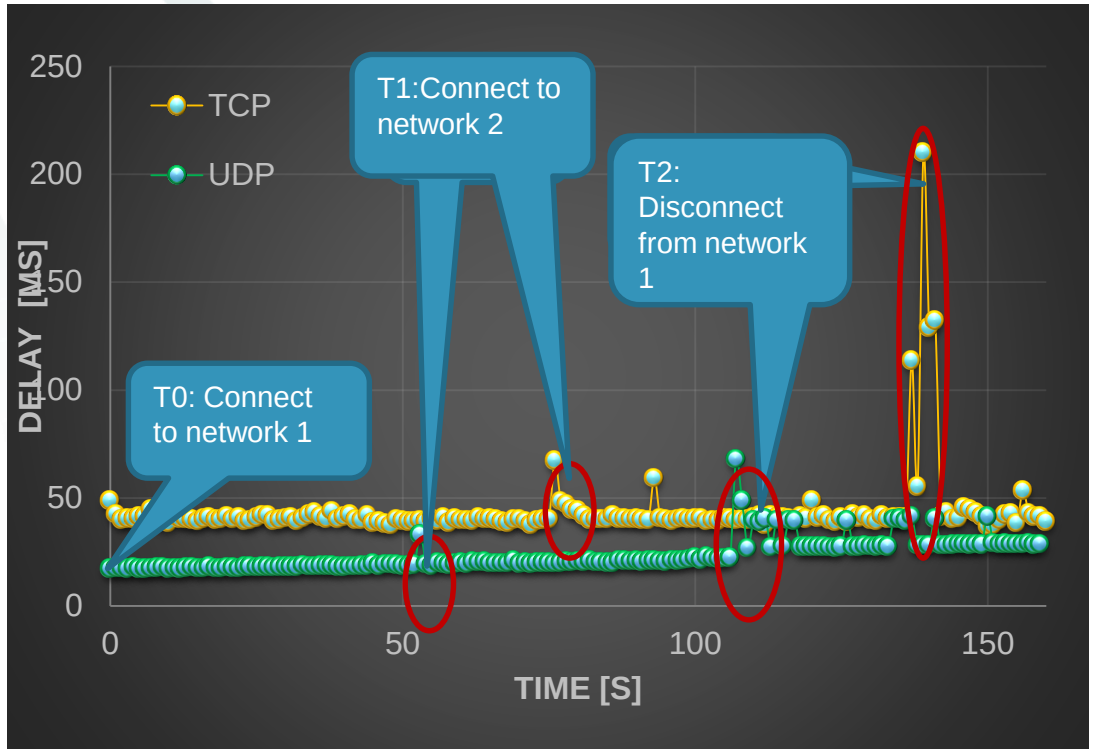
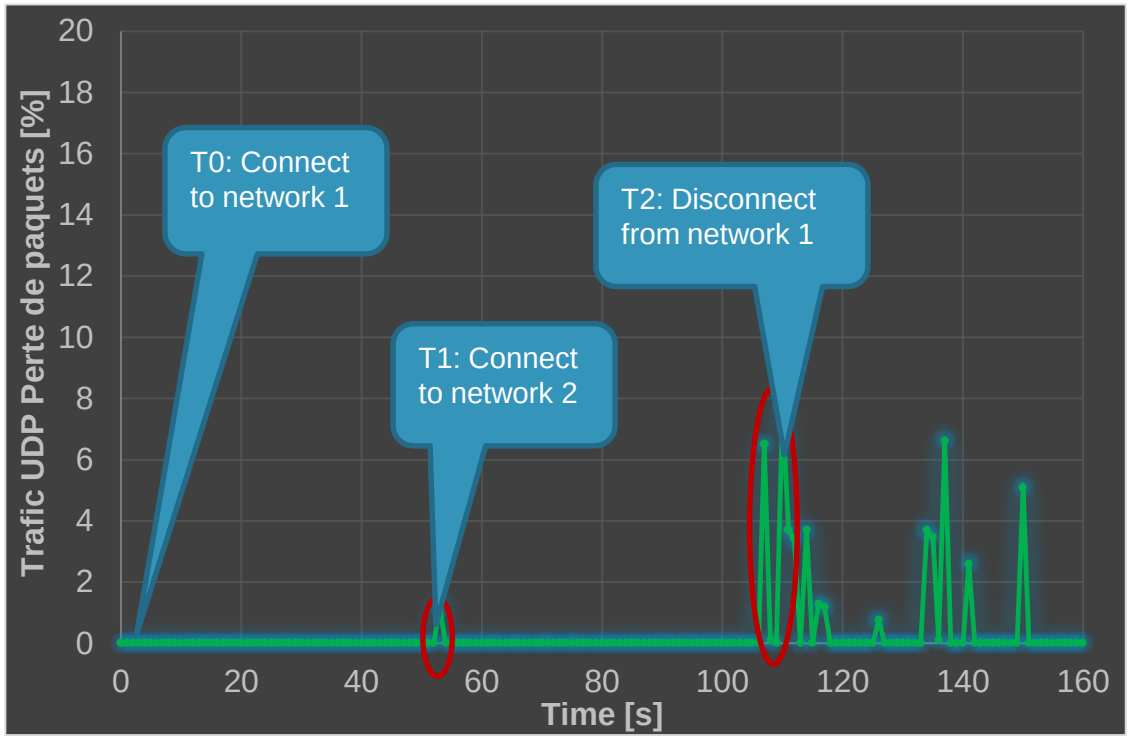
Tests in France

- To : 1st SIM connected to network 1
- T1 : 2nd SIM connected to network 2
  - Packets send to both interfaces.
- T2 : 1st SIM disconnected to network 1



Delay penalty:

- 30 ms for UDP flow
- 150 ms for TCP flow



- 1% -6% penalty for packet loss

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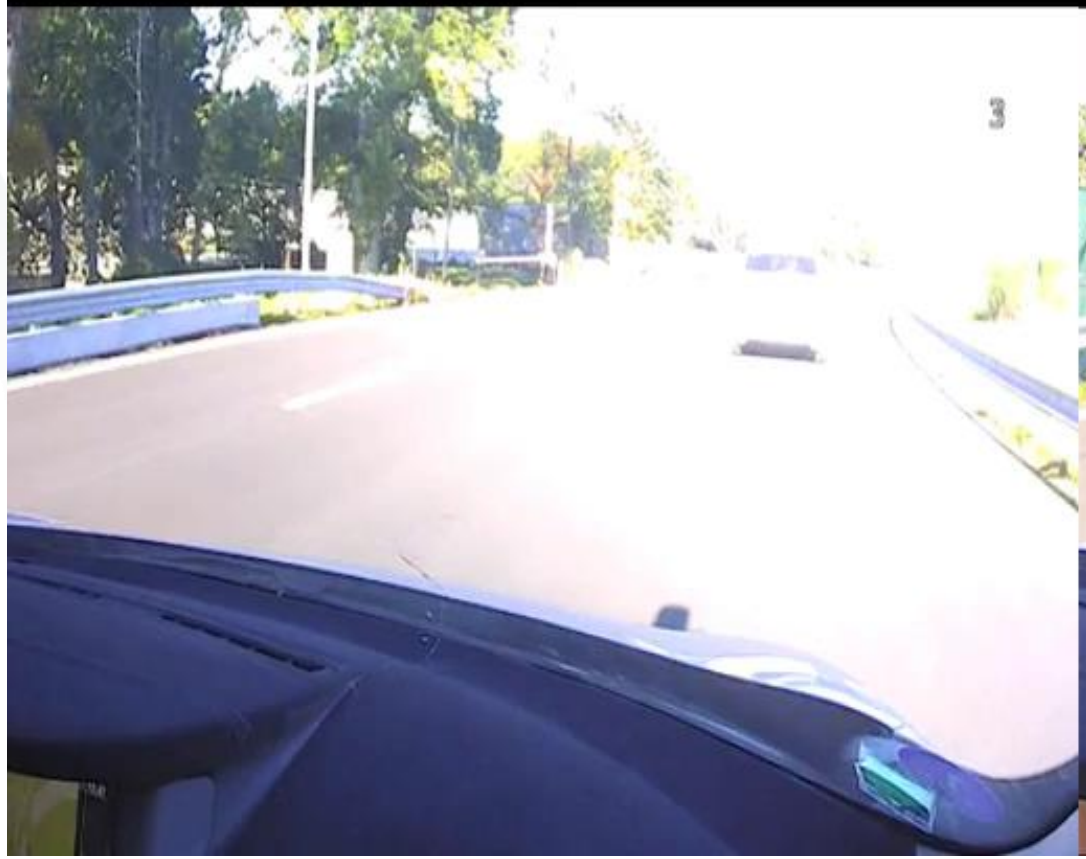
FR-TS Seamless handover test

Transmitted video



Received video

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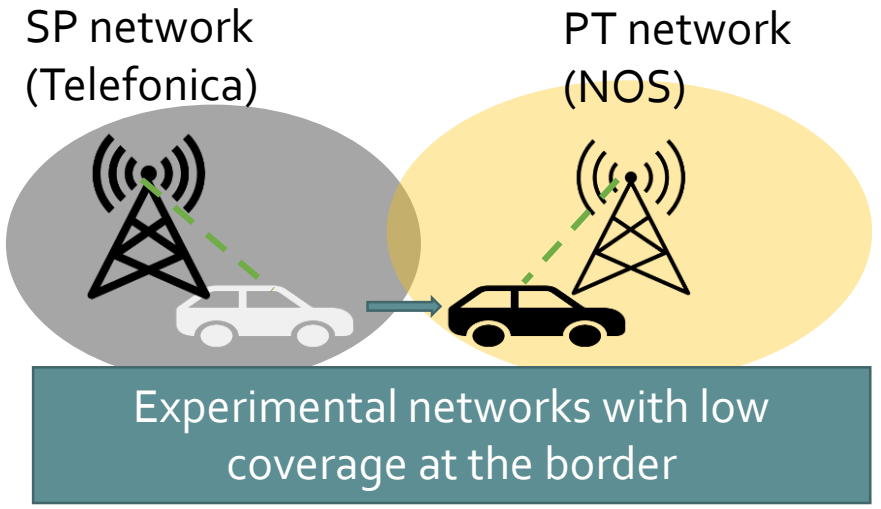
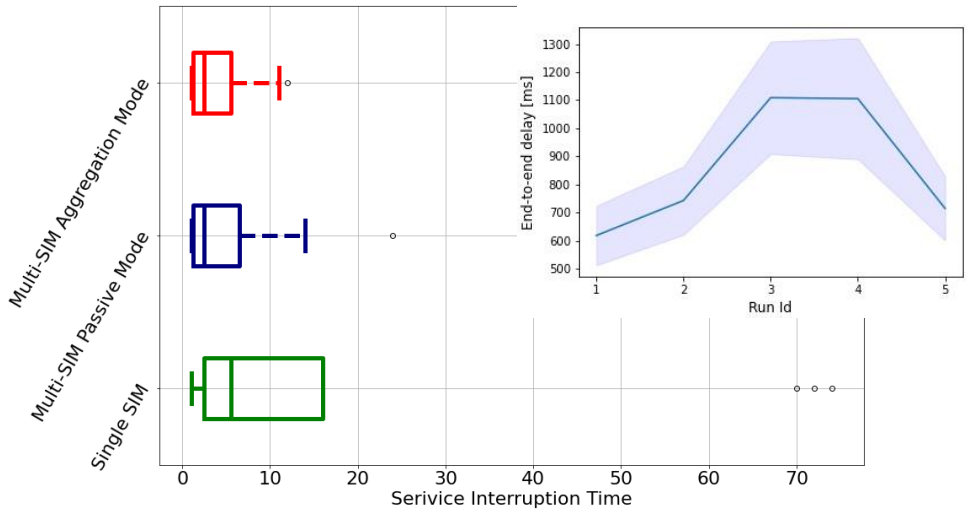
Test in Spain-Portugal Cross-Border Corridor

- CV is installed with an intelligent router which interfaces double SIM 5G OBU: the first SIM from Telefonica, and the second SIM from NOS.
  - CV are sends UDP flows to a server at 10Mbps to a data fusion server installed in France
- **Results**
  - Multi-sim connectivity with link aggregation provides the highest performance for service continuity
  - Given good network conditions, multi-sim connectivity can ensure service availability
  - Important impact related to the location of the monitoring server on the delay





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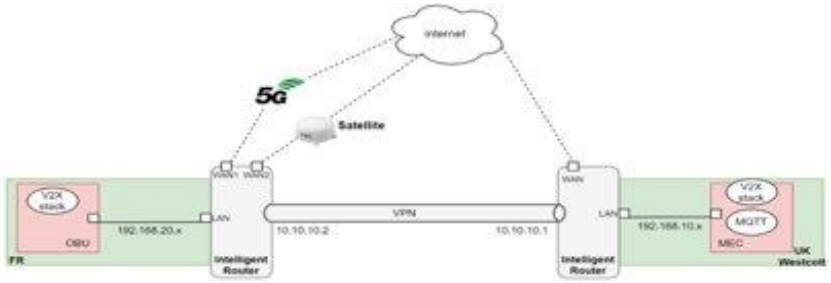
Usage of satellite technology

- Iridium Certus LEO Constellation
  - Thales Iridium Certus-350 Land Mobile (up to 500 kbps)
  - Worldwide coverage almost 100 % (inc. Polar regions)
- Vehicle with on-board equipment
  - 5G on-board unit
  - Satellite terminal
  - Intelligent router
- **Results**
  - Satellite communication should be used in a back-up solution when terrestrial 5G technology is not available
  - Higher latency (few hundreds ms) and some packets loss have been experienced
  - When used with multi-SIM modem, connectivity with VPN server can be maintained



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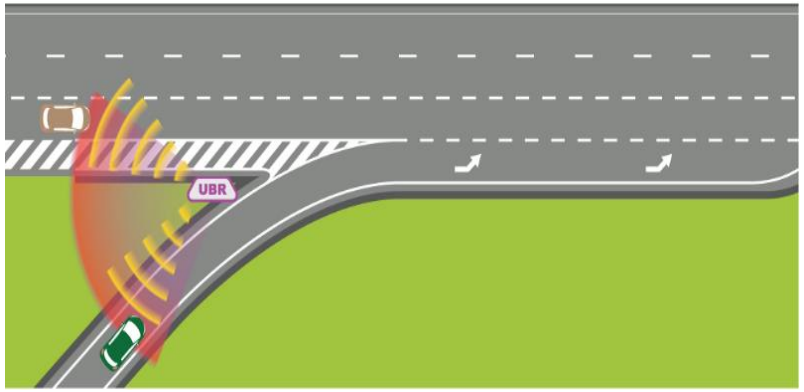
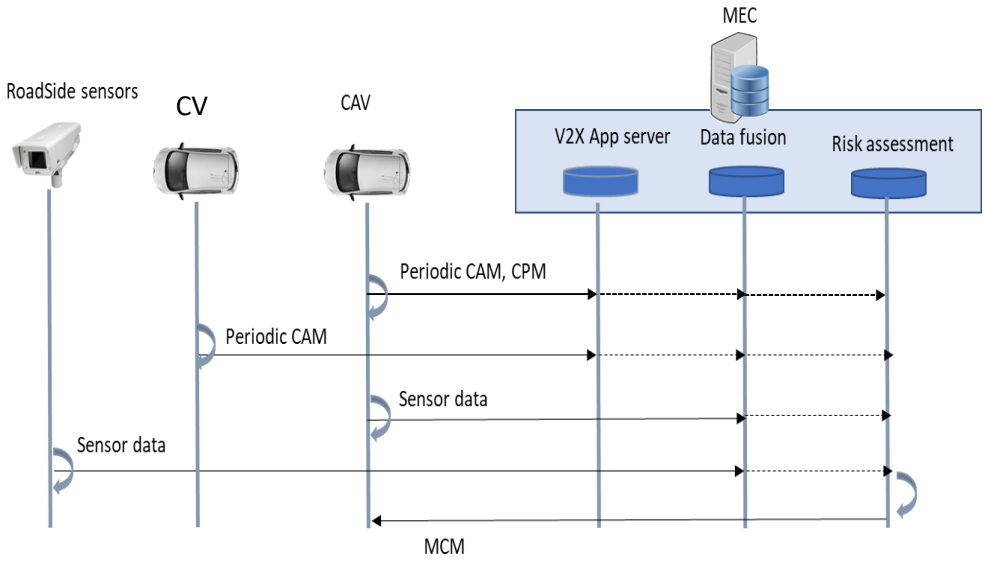
User Story: Infrastructure -assisted advanced driving

- Scenario
- 1 CAV driving on main road
  - Send CAM / CPM to MEC installed in infrastructure
- 1 Vehicle on insertion lane
  - Detected by roadside sensor
- V2X applications installed in MEC to assist CAV in driving tasks
  - Fusion of data messages and assessment of situation and lane merging
- MEC sends trajectory recommendation to CAV via MCM
  - Indicated lane change when conflicts detected with other vehicle





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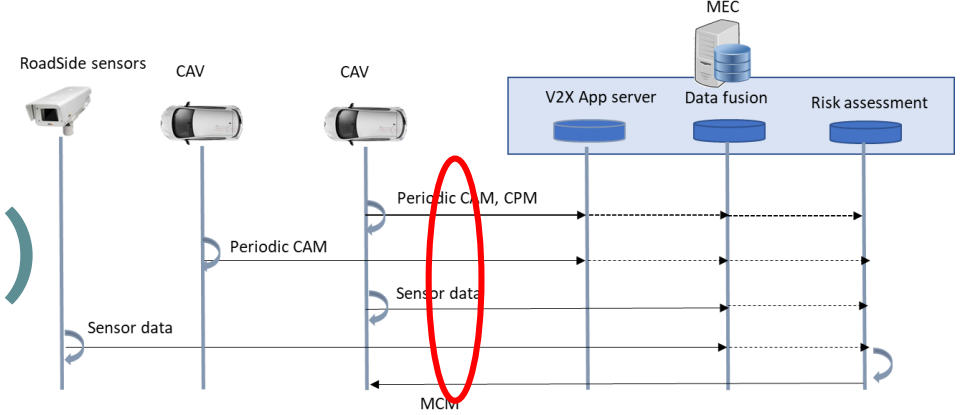
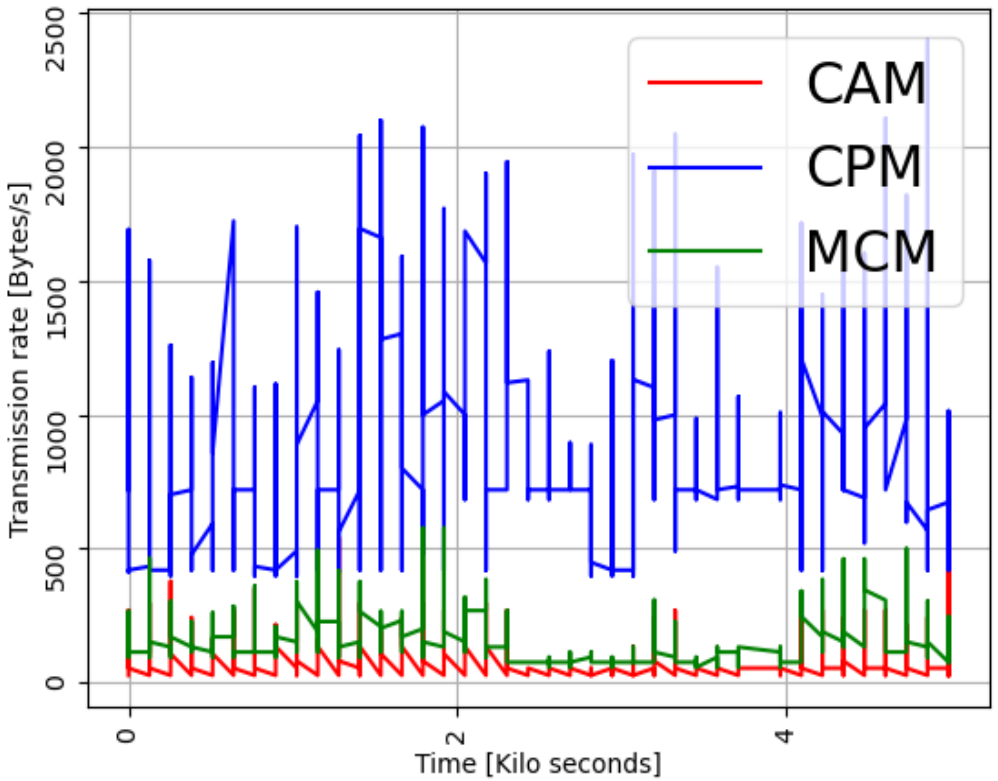
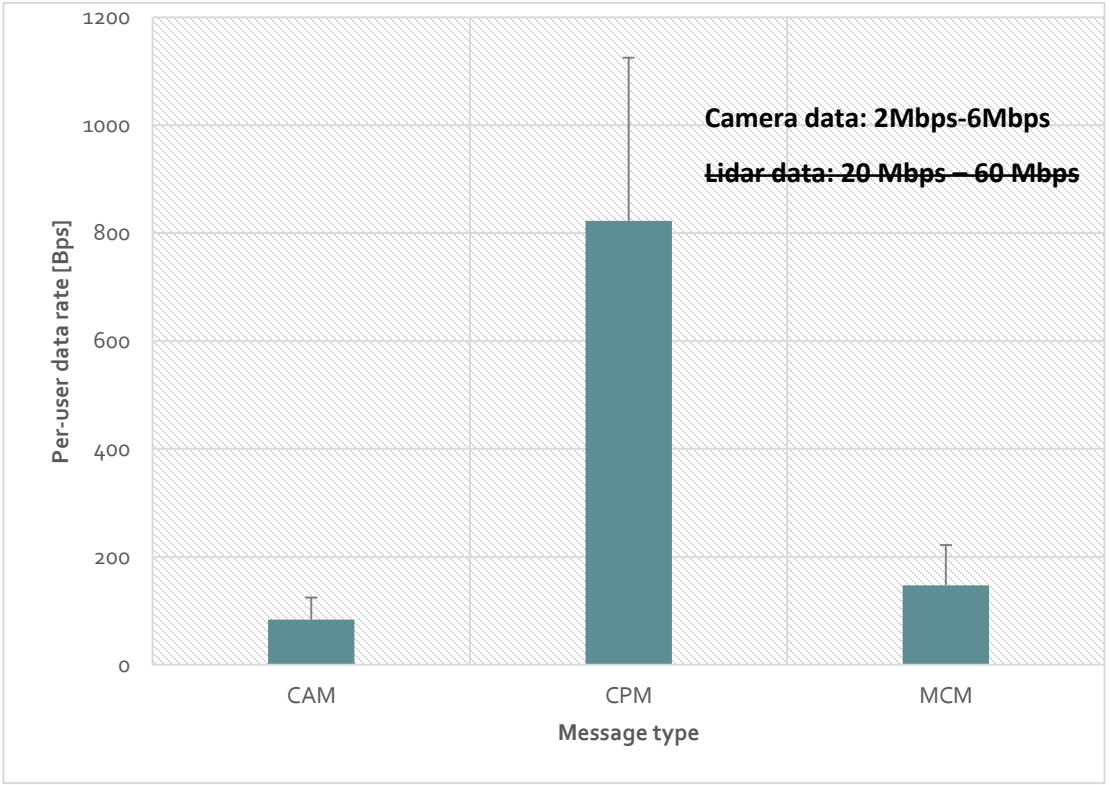
Throughput of V2X Communication (3 vehicles)







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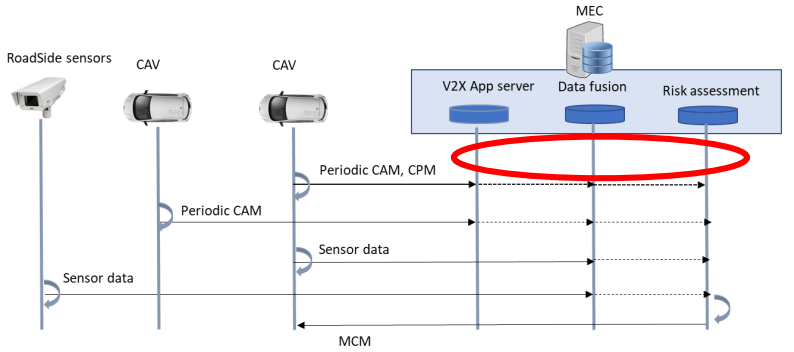
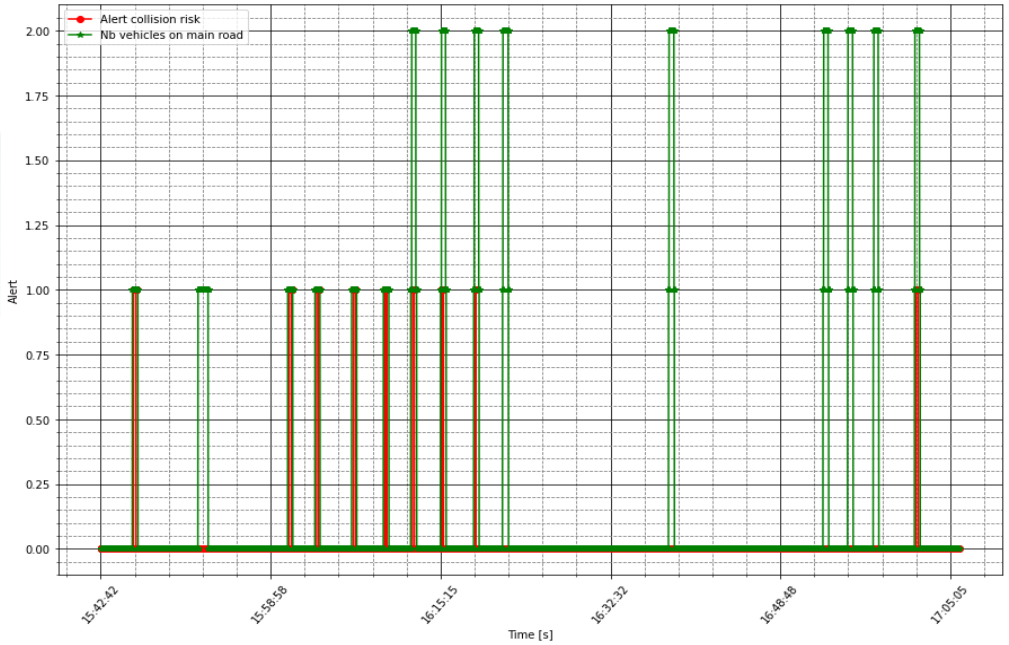
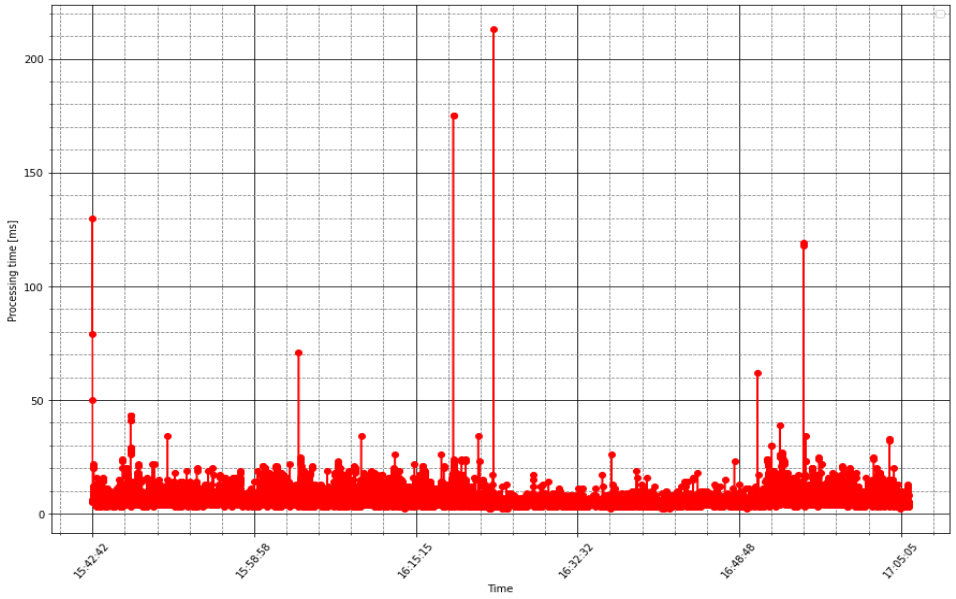
Processing delay in MEC





Monitoring system : extended perception, risk assessment, maneuver coordination



Processing delay on MEC for data fusion and analysis

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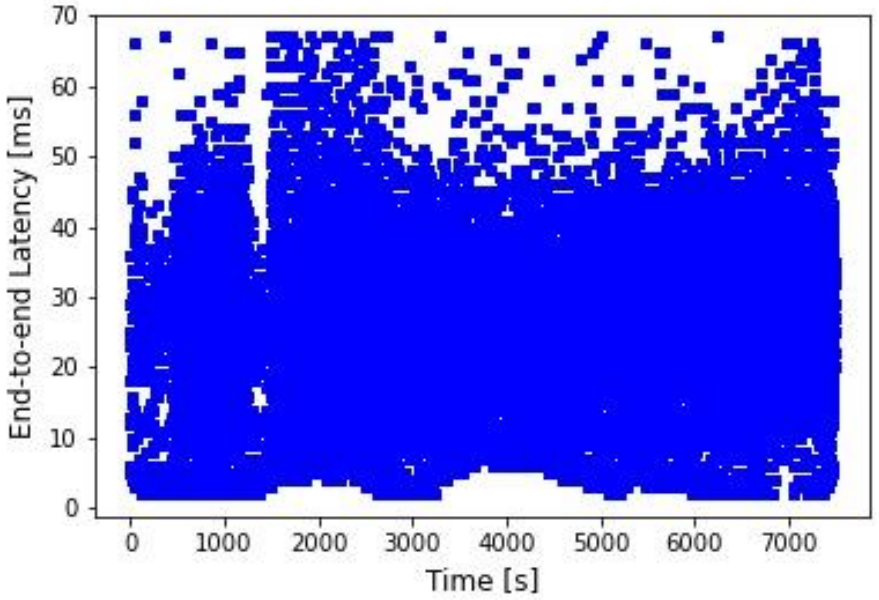
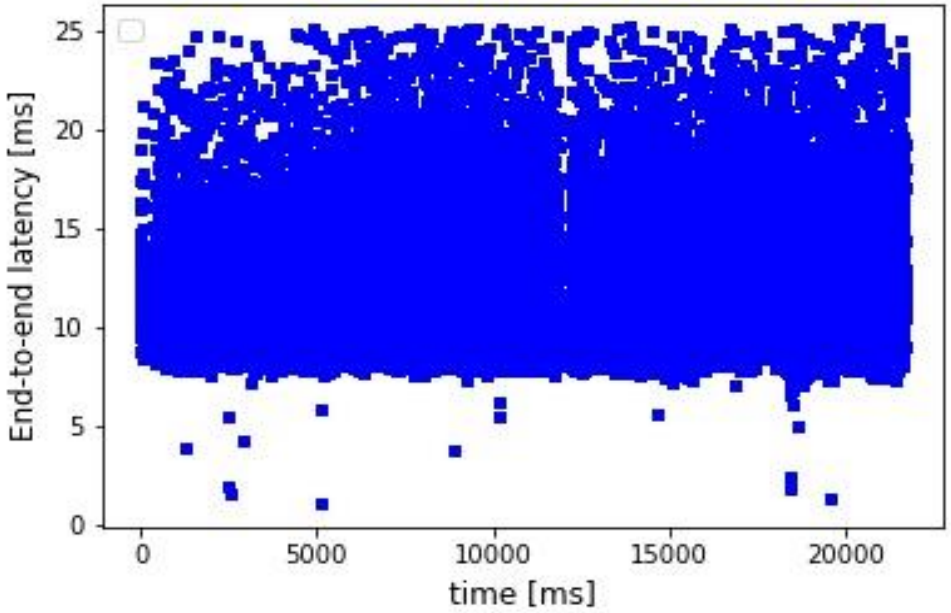
Performance in end-to-end latency

- 4G Technology



  - Average: 29.07 ms
  - Median: 28 ms
  - Standard Deviation: 9.37 ms

- 5G Technology (NSA)

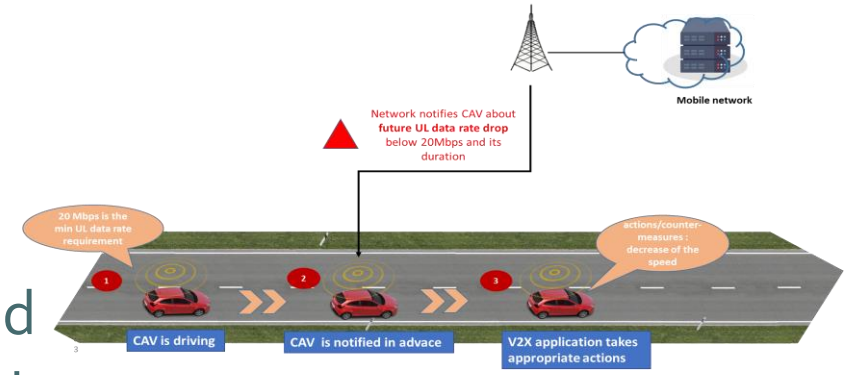


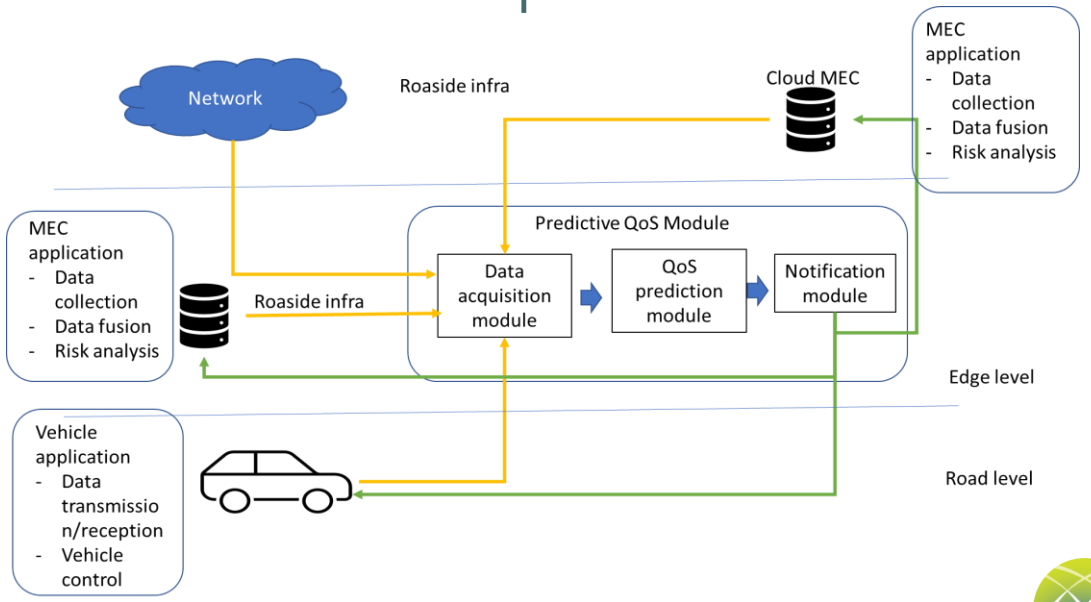
  - Average: 12.15 ms
  - Median : 11.517 ms
  - Standard deviation: 2.885 ms

Potential improvement to come (SA, slicing, URLLC, spectrum with mmWave)

QoS adaptation to performances changes due to roaming/handover

- Predictive QoS modules
  - Installed in MEC at FR TS
  - Predict communication performances based on modeled learned from dataset collected in open road
  - Request users to adapt their behavior via anticipated QoS notification (IQN)





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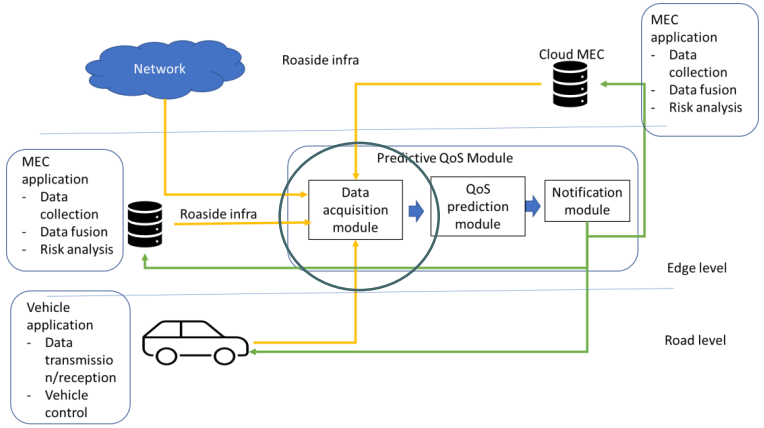
Data acquisition

- Location
  - Versailles
  - Paris
  - Guyancourt
- Modems
  - SIMCOM OBU 5G
  - Téléphone Samsung S21
- Content
  - Timestamps, location, speed
  - Access, network, application KPIs



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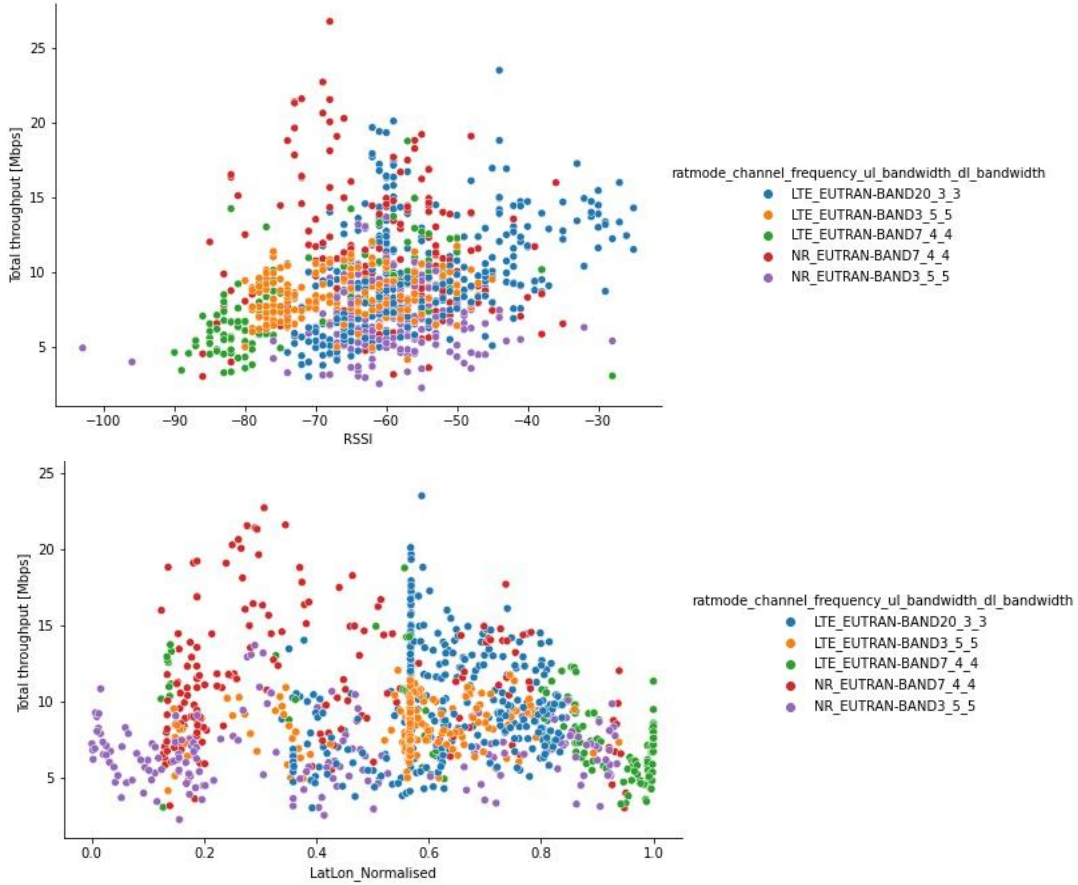
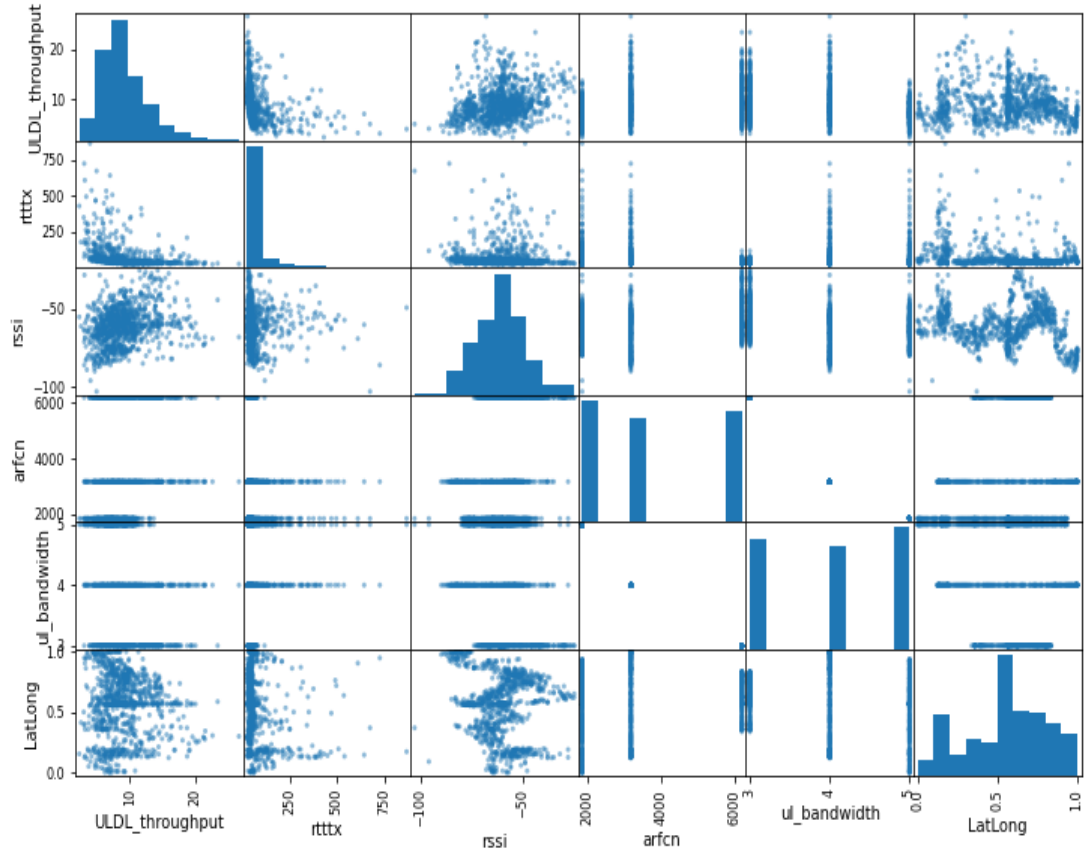
Data analysis





- QoS prediction do not rely on a parametric model with a unique parameter
- Combined impact of multiple parameters need to be conisdered

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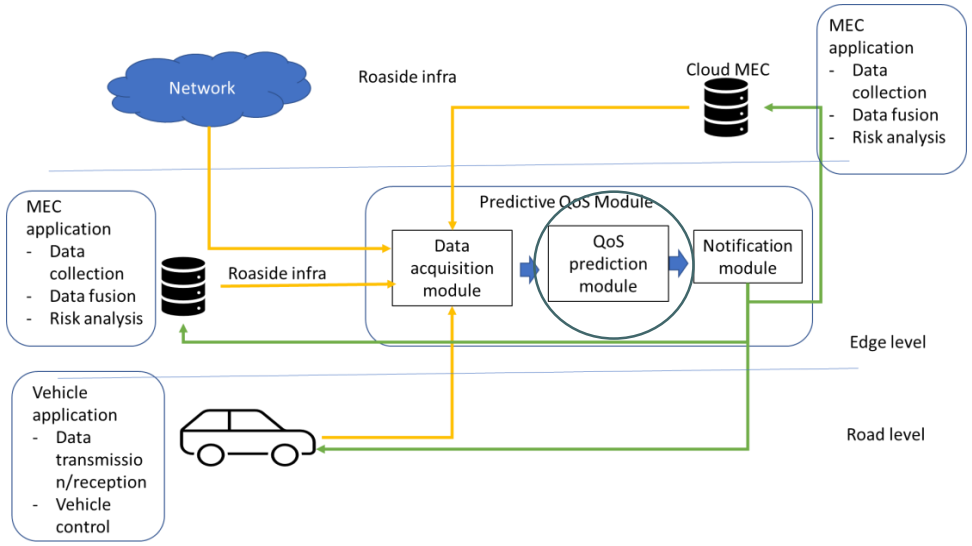
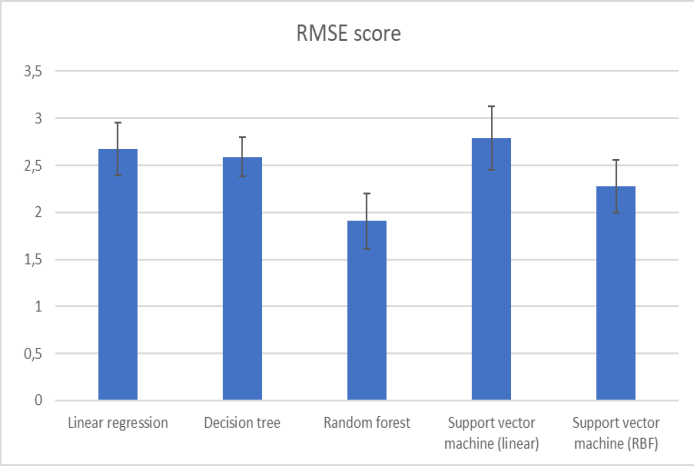
Model learning

- Multiple supervised learning models used
- Based on RMSE score, random forest provides higher performances
- Fine tuning of model needed





Real throughput [Mbps]	Predicted throughput [Mbp
6,996	6,21526
10,574	9,28
7,48	7,04
13,89	13,06
21,519	17,34

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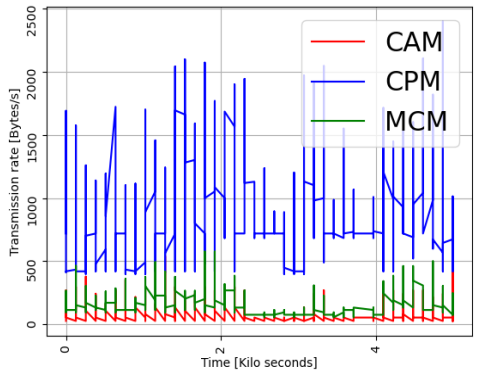
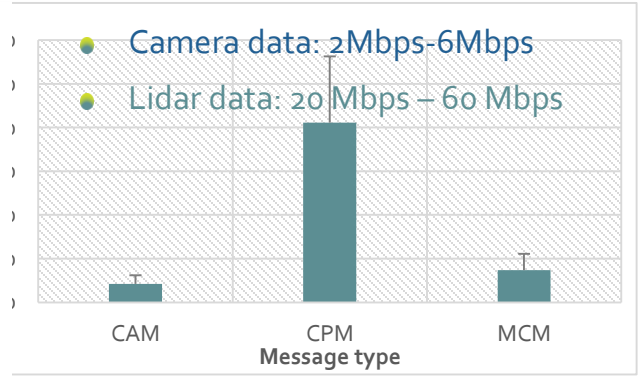
QoS Notification

- Notification of predecited QoS using IQN message specified in FR TS

Element	value	Description
Header		
Destination Port #		Destination vehicle/end user port number
Src Port #		Source Predictive QoS centre port number
Destination Port #		Destination vehicle/end user IP add
Src Port #		Source Predictive QoS centre IP address
Payload		
Action ID	INT	0 : unknown 1 : data rate 2 : speed 3 : XXX
Action Element	INT	0 : unknown 1 : application Id 2 : vehicle control unit 3: XXX
Action Value MIN	Min Double	If Action ID= 1 {min data rate in bps) If Action ID = 2 {min speed in m/s)
Action value MAX	MAX double	If Action ID= 1 {max data rate in bps) If Action ID = 2 {max speed in m/s)
Action start time Actional end time	time time	Start time of the action End time of the action
Action ID	INT	0 : unknown 1 : data rate 2 : speed 3 : XXX
Action Element	INT	0 : uknown 1 : application ID 2 : vehicle control unit 3: XXX
Action Value MIN	Min Double	If Action ID= 1 {min data rate in bps) If Action ID = 2 {min speed in m/s)
Action value MAX	MAX double	If Action ID= 1 {max data rate in bps) If Action ID = 2 {max speed in m/s)
Action start time Actional end time	time time	Start time of the action End time of the action

- What can be controled?
  - V2X messages: low transmission rate
  - Video: required fine adaptation of transmission parameters





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```
QoS Prediction Module: timestamp=1650459517, Send IQN command to client ID: 3601, new data rate: 11.74 Mbps
QoS Prediction Module: timestamp=1650459518, Send IQN command to client ID: 3601, new data rate: 11.35 Mbps
QoS Prediction Module: timestamp=1650459519, Send IQN command to client ID: 3601, new data rate: 11.61 Mbps
QoS Prediction Module: timestamp=1650459520, Send IQN command to client ID: 3601, new data rate: 11.44 Mbps
QoS Prediction Module: timestamp=1650459521, Send IQN command to client ID: 3601, new data rate: 11.64 Mbps
QoS Prediction Module: timestamp=1650459522, Send IQN command to client ID: 3601, new data rate: 11.58 Mbps
QoS Prediction Module: timestamp=1650459523, Send IQN command to client ID: 3601, new data rate: 11.73 Mbps
QoS Prediction Module: timestamp=1650459524, Send IQN command to client ID: 3601, new data rate: 11.44 Mbps
QoS Prediction Module: timestamp=1650459525, Send IQN command to client ID: 3601, new data rate: 10.89 Mbps
QoS Prediction Module: timestamp=1650459526, Send IQN command to client ID: 3601, new data rate: 11.64 Mbps
QoS Prediction Module: timestamp=1650459527, Send IQN command to client ID: 3601, new data rate: 11.15 Mbps
QoS Prediction Module: timestamp=1650459528, Send IQN command to client ID: 3601, new data rate: 11.87 Mbps
QoS Prediction Module: timestamp=1650459529, Send IQN command to client ID: 3601, new data rate: 11.82 Mbps
QoS Prediction Module: timestamp=1650459530, Send IQN command to client ID: 3601, new data rate: 11.15 Mbps
QoS Prediction Module: timestamp=1650459531, Send IQN command to client ID: 3601, new data rate: 10.93 Mbps
QoS Prediction Module: timestamp=1650459532, Send IQN command to client ID: 3601, new data rate: 11.47 Mbps
QoS Prediction Module: timestamp=1650459533, Send IQN command to client ID: 3601, new data rate: 11.45 Mbps
QoS Prediction Module: timestamp=1650459534, Send IQN command to client ID: 3601, new data rate: 11.65 Mbps
QoS Prediction Module: timestamp=1650459535, Send IQN command to client ID: 3601, new data rate: 11.53 Mbps
QoS Prediction Module: timestamp=1650459536, Send IQN command to client ID: 3601, new data rate: 9.93 Mbps
QoS Prediction Module: timestamp=1650459537, Send IQN command to client ID: 3601, new data rate: 11.96 Mbps
QoS Prediction Module: timestamp=1650459538, Send IQN command to client ID: 3601, new data rate: 10.7 Mbps
QoS Prediction Module: timestamp=1650459539, Send IQN command to client ID: 3601, new data rate: 8.56 Mbps
QoS Prediction Module: timestamp=1650459540, Send IQN command to client ID: 3601, new data rate: 9.35 Mbps
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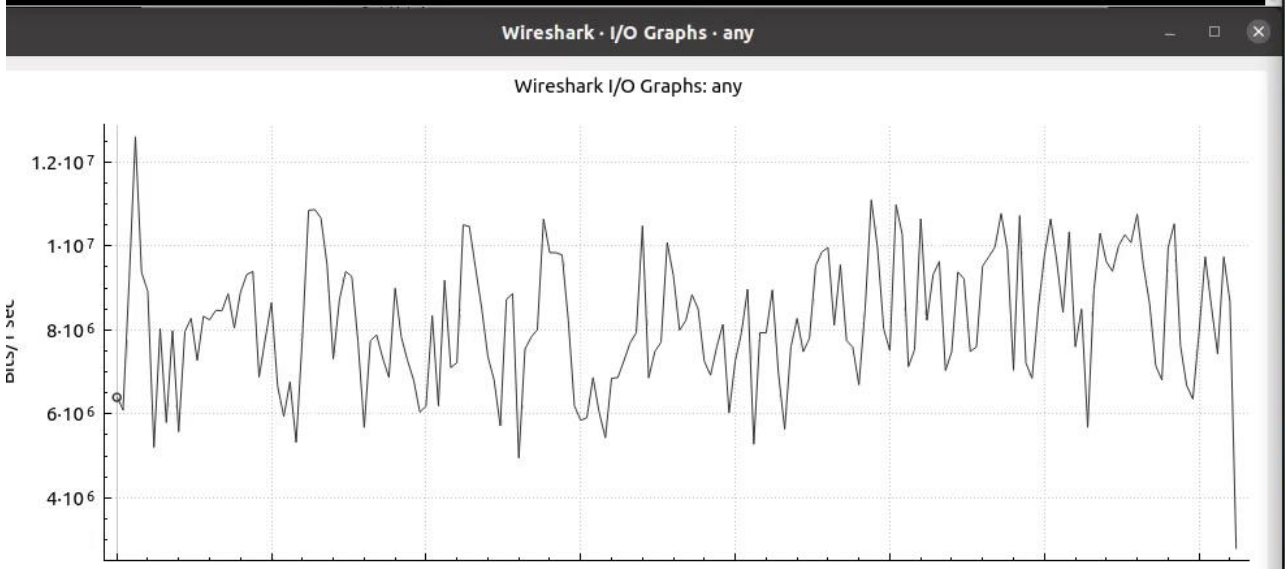


```
QoS Client Module 3601: current position (48.7866, 2.08908), timestamp=1650459485, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7865, 2.08933), timestamp=1650459486, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7865, 2.08945), timestamp=1650459487, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7864, 2.0897), timestamp=1650459488, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7864, 2.08983), timestamp=1650459489, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7863, 2.0901), timestamp=1650459490, IQN received, data rate adaptation to 9 Mbps
QoS Client Module 3601: current position (48.7863, 2.09037), timestamp=1650459491, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7863, 2.0905), timestamp=1650459492, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7862, 2.09077), timestamp=1650459493, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7862, 2.0909), timestamp=1650459494, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7862, 2.09117), timestamp=1650459495, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7861, 2.0913), timestamp=1650459496, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7861, 2.09157), timestamp=1650459497, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7861, 2.0917), timestamp=1650459498, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7861, 2.09197), timestamp=1650459499, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.786, 2.09222), timestamp=1650459500, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.786, 2.09235), timestamp=1650459501, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7859, 2.09262), timestamp=1650459502, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7859, 2.09275), timestamp=1650459503, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7859, 2.09302), timestamp=1650459504, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7859, 2.09315), timestamp=1650459505, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7872, 2.08703), timestamp=1650459506, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7871, 2.08712), timestamp=1650459507, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.787, 2.08732), timestamp=1650459508, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7869, 2.08753), timestamp=1650459509, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7869, 2.08765), timestamp=1650459510, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7868, 2.08792), timestamp=1650459512, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7868, 2.08805), timestamp=1650459512, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7868, 2.08832), timestamp=1650459513, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7867, 2.08845), timestamp=1650459515, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7867, 2.0887), timestamp=1650459515, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7867, 2.08883), timestamp=1650459517, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7866, 2.08908), timestamp=1650459517, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7865, 2.0892), timestamp=1650459518, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7865, 2.08945), timestamp=1650459519, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7864, 2.0897), timestamp=1650459521, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7864, 2.08983), timestamp=1650459521, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7863, 2.0901), timestamp=1650459523, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7863, 2.09023), timestamp=1650459523, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7863, 2.0905), timestamp=1650459525, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7863, 2.09063), timestamp=1650459525, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7862, 2.0909), timestamp=1650459526, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7862, 2.09117), timestamp=1650459527, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7861, 2.0913), timestamp=1650459529, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7861, 2.09157), timestamp=1650459529, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7861, 2.0917), timestamp=1650459530, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7861, 2.09197), timestamp=1650459532, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.786, 2.09208), timestamp=1650459532, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.786, 2.09235), timestamp=1650459534, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.786, 2.09248), timestamp=1650459534, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7859, 2.09275), timestamp=1650459535, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7859, 2.09302), timestamp=1650459537, IQN received, data rate adaptation to 9 Mbps
QoS Client Module 3601: current position (48.7859, 2.09315), timestamp=1650459537, IQN received, data rate adaptation to 11 Mbps
QoS Client Module 3601: current position (48.7872, 2.08703), timestamp=1650459539, IQN received, data rate adaptation to 10 Mbps
QoS Client Module 3601: current position (48.7871, 2.08712), timestamp=1650459539, IQN received, data rate adaptation to 8 Mbps
QoS Client Module 3601: current position (48.787, 2.08732), timestamp=1650459540, IQN received, data rate adaptation to 9 Mbps
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Conclusion

Category	Cross-Border Issues	Solutions	Outcomes
Telecom & Application	NSA Roaming Interruption Session & Service Continuity Low Coverage Area	Handover using an NSA network Multi-modem / multi-SIM modem Use of satellite solution	**Intelligent combination of multiple technologies can be used to ensure service continuity for vehicle applications**
Telecom	mmWave Appplicability	mmWave 5G NSA network	**5G mmWave has potential be used in dedicated areas to support V2X applications** **Only initial experimentation could be done**
Application	Dynamic QoS Continuity	Predictive QoS	**Important to collect data at high resolution with their geolocation** **Adaptation of application configuration to the radio environment can become possible**

Thank you

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