

# Predictive Quality of Service for Automated Driving Systems

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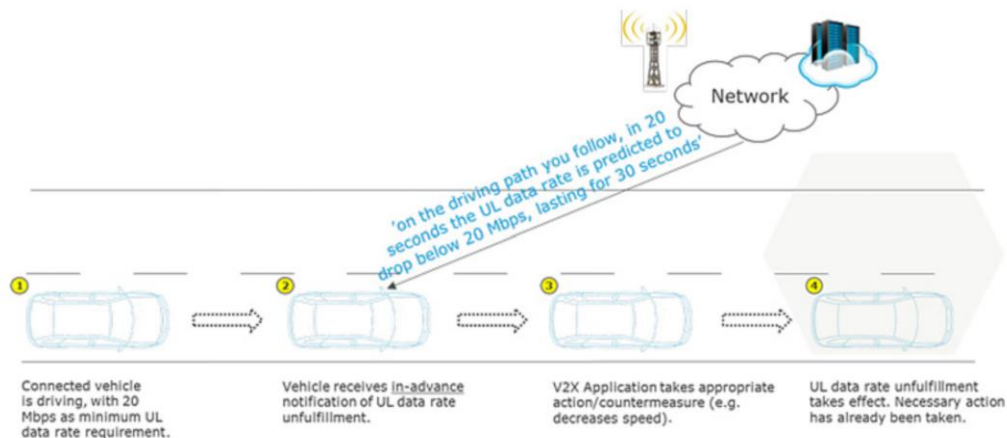
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- Outlook and Conclusions

# Predictive QoS - Background

- First introduced for V2X communication
- V2X applications can operate with different configurations (automation level, inter-vehicle gap, etc.)
- Application may need to adjust configuration in case of QoS change
- Sudden adjustment may affect the service continuity, comfort, and safety
- Applications benefit from early QoS change notification for graceful adaptation

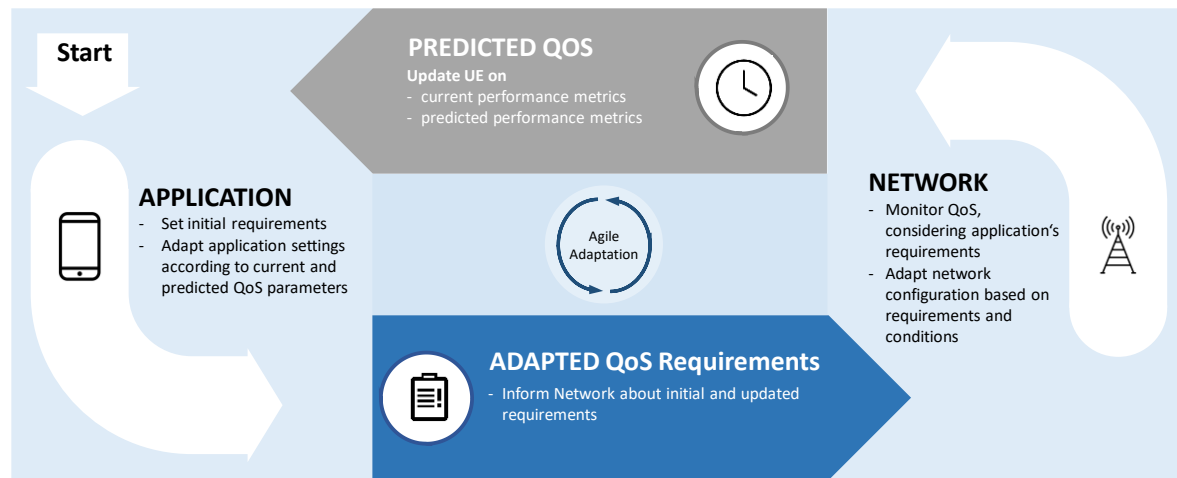


Source: 5GAA Whitepaper "Making 5G Proactive and Predictive for the Automotive Industry"

**Core idea behind PQoS: Network informs the V2X application of expected/estimated QoS change before the change occurs**




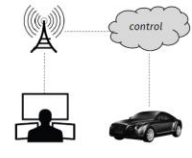
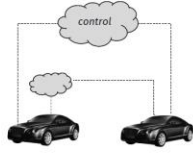
# PQoS: Application ↔ Network Interaction

- PQoS aims to **predict, adapt, and inform**
  - **Predict** network behavior ahead of time
  - **Adapt** network behavior in order to better support the application
  - **Inform** application on current and predicted metrics



VW, DT, Huawei, White Paper  
“AQoS: Agile Quality-of-Service Adaptation:  
An Enabler for Advanced Connected-Vehicle  
Applications”, (2018 Jan)

# Exemplary PQoS Use Cases in V2X and IIoT

KPI	IIoT Applications		V2X Applications			
	<i>Closed-loop control</i>	<i>Mobile robot control</i>	<i>HD map collecting and sharing</i>	<i>Teleoperated driving</i>	<i>High-density platooning</i>	
Services						
	guarantee safe interaction between production machinery and human operators	interconnect several robots over a large area to fulfill a common task	build an HD map of the environment to improve safety and provide optimal route selection	control of vehicles by a remote operator (either human or software)	enable vehicles to travel in close proximity at high speeds to decrease fuel consumption	
Latency [ms]	150	From 1 to 500	≤ 100	≤ 50	from 10 to 25	
Reliability [%]	from 99.9999 to 99.999999	> 99.9999	99	99 (uplink) 99.999 (downlink)	from 90 to 99.99	
Data rate	very low	30/50 Mbps	up to 500 Mbps for HD sensor data	30/50 Mbps	30/50 Mbps	
P Q O S	Role of predictions	prevent harm to human operators in case of malfunctions	improve productivity	ensure reliable services	guarantee a minimum safety level at all times	ensure continuous operation (even without connectivity)
	Prediction window	milliseconds	seconds/minutes	minutes/hours	seconds/minutes	seconds/minutes

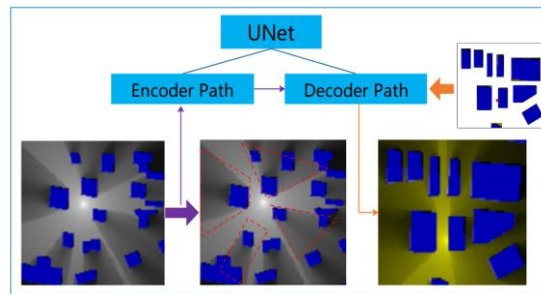
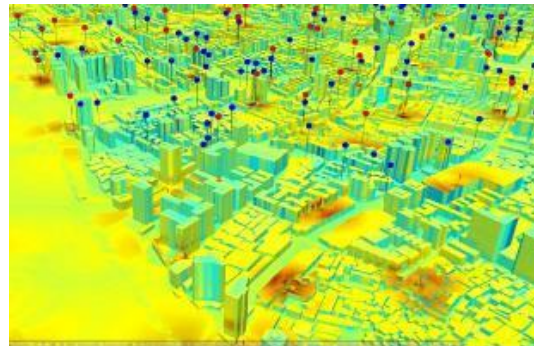
# Selected PQoS Techniques

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- Radio map prediction
- Predictive scheduling
- Decreased Application Downtime

# Radio Maps

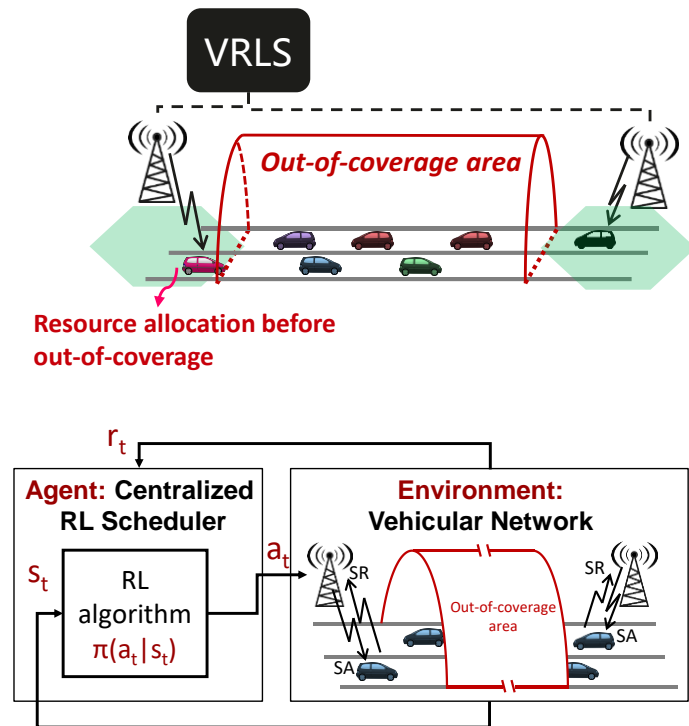
- “Base layer” for PQoS
- Measuring or predicting radio signal parameters (e.g., SNR, RSRP, ...)
- Use radio map to predict app-level QoS
- Methods
  - Measurements (pros: accuracy; cons: costly, not adaptive)
  - Simulations (pros: adaptive; cons: complexity)
  - ML-based methods (e.g., [1]) (pros: inference speed; cons: needs large training dataset)



[1] Levie, R., Yapar, Ç., Kutyniok, G., & Caire, G. (2021). RadioUNet: Fast radio map estimation with convolutional neural networks. *IEEE Transactions on Wireless Communications*

# Predictive Scheduling

- Using network information to predictively assign resources
- Use case: prescheduling for out-of-coverage (OOC) areas
- Vehicular Reinforcement Learning scheduler (VRLS) learns scheduling assignments in OOC based on feedback from vehicles



[2] T. Sahin, R. Khalili, M. Boban, A. Wolisz: 'VRLS: A Unified Reinforcement Learning Scheduler for Vehicle-to-Vehicle Communications', IEEE VTC-Fall, 2019.

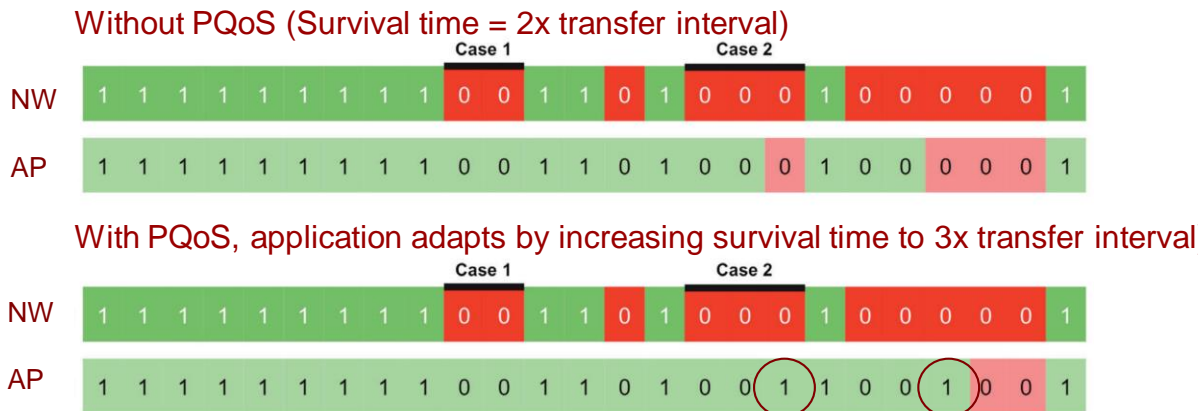


# Application-level PQoS Technique: Decreased Application Downtime

- Predictive QoS enables **application to take actions** before application goes into “Down” mode
- Network service status: “Up” (QoS requirement fulfilled: green) and “Down” (not fulfilled: red)
- Application status: **Normal mode** (green) and **Down mode** (red)
- **Survival time**: time that application can “survive” without network service

- Comparison of **network (NW)** and **application (AP)** failures with and without PQoS

- With PQoS, application can **gracefully degrade** the performance without going into “Down” mode



Modified from: 5G-ACIA whitepaper “Key 5G Use Cases and Requirements”

# PQoS in Prestandardization

- V2X: 5GAA Whitepaper “Making 5G Proactive and Predictive for the Automotive Industry”
- IIoT: 5G-ACIA Whitepaper “5G for Automation in Industry: Primary use cases, functions and service requirements”

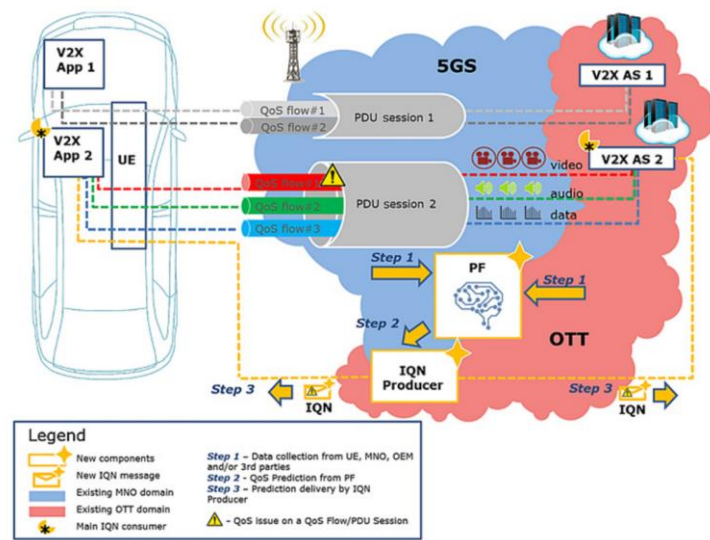
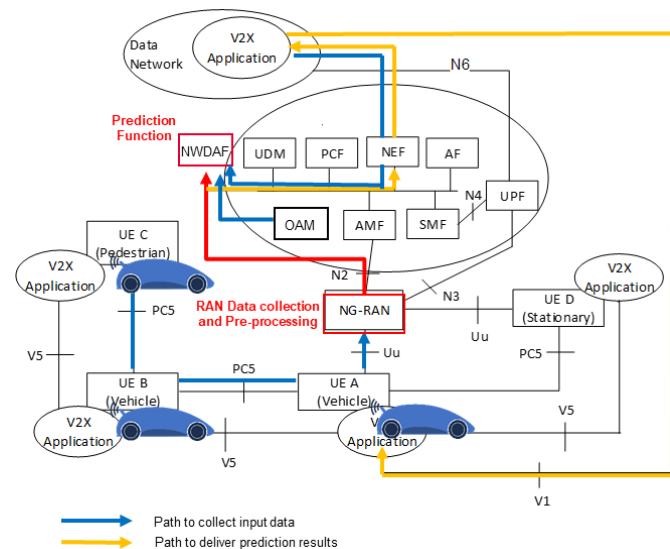


Figure 3-1: Predictive QoS in the 5GS

Source: 5GAA Whitepaper “Making 5G Proactive and Predictive for the Automotive Industry”

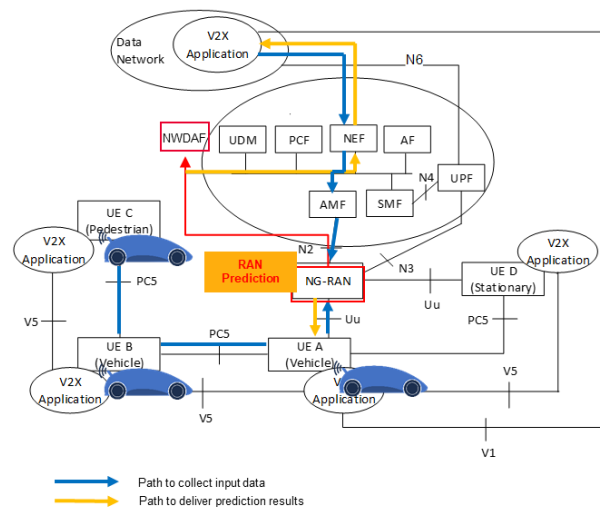
# PQoS in Standardization

- 3GPP SA defined Network Data Analytics Function (NWDAF) in TS 29.520
  - QoS provisioning and policy adjustment
  - Mobility and topology management
  - Sharing of analytics and QoS policy
- 3GPP RAN3: “Study on enhancement for data collection for NR and ENDC” (ongoing)
  - Studies high level principles for RAN AI
  - Assessment of standardization impacts of nodes/functions that provide training and inference data



# Some Open Research Issues

- Q1: How to enable RAN-side PQoS functionalities?
- Q2: How to collect data and update model for different use cases?
- Q3: How can network ensure (near-)deterministic timing requirements for cooperative automated driving?
- Q4: How reliant can a vehicle be on prediction with certain probability (e.g., Throughput > 10 Mbps for next 10 sec with 99% probability)?

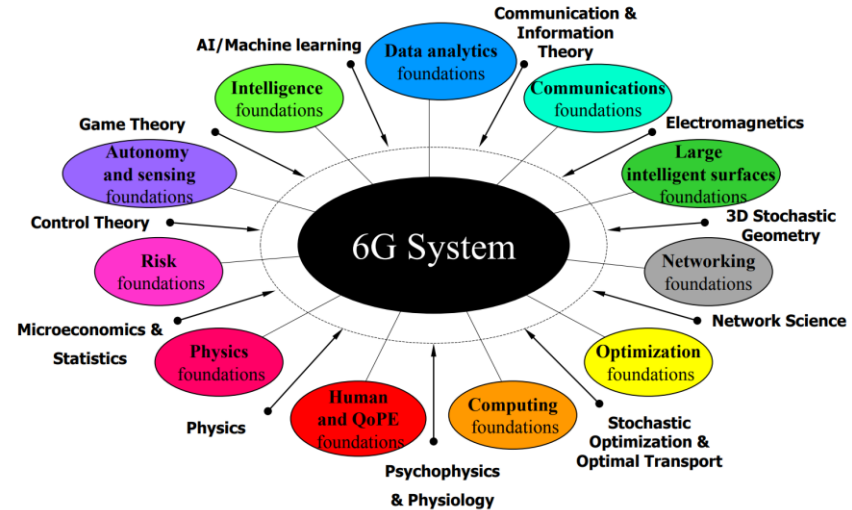


## Why is RAN PQoS needed?

- Avoid high overhead
- Collect highly granular data
- Provide real-time prediction

# Conclusions

- Predictive QoS is a powerful technology and a possible game changer for V2X (and other vertical) use cases requiring reliable and predictable performance
- Strong interest in PQoS from key players in V2X and other verticals (IIoT, eHealth)
- PQoS is a complex concept that involves data analytics, ML, control theory, optimization, ...
- 5G enabled a small subset of PQoS functionalities (predict, inform, no adapt), with many open issues to tackle
- 6G can enable the full suite of PQoS functionalities in both RAN and core



Source: Saad, Walid, Mehdi Bennis, and Mingzhe Chen. "A vision of 6G wireless systems: Applications, trends, technologies, and open research problems." *IEEE network* 34.3 (2019): 134-142.

Thank you

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