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Piloting of 5G and satellite communications for road safety services

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Abstract

5G networks offer low latency and increased bandwidth, compared to 4G networks, and hence are very interesting for time critical services, such as road safety. The Celtic-Next 5G-SAFE-PLUS project is researching how 5G technologies and related enablers, such as multi-access edge computing (MEC), can be used for improving road safety. Furthermore, especially in remote and rural areas, hybrid communications, using both 5G and satellite communications, can provide continuous network coverage for delivering road safety services. This paper describes the progress done during the project in the development and evaluation of 5G-enabled services for road weather and safety in the context of two use cases.

Keywords:

Cooperative, Connected and Automated Driving; Pilots, Trials and Tests; 5G; Satcom; Road Safety.

Introduction

5G networks offer low latency and increased bandwidth, compared to 3G and 4G networks, and hence are very interesting for time critical services, such as road safety. Vehicle-to-everything (V2X) communications have been researched for several years, and the first deployments, using IEEE 802.11 based ITS-G5 are ongoing. The first services, which are currently deployed, are warnings about hazardous events, signalized intersection information and in-vehicle signage. The second generation of services will also involve more time critical services, such as cooperative perception of objects on the road. The use of ITS-G5 requires however large investments, which is for countries like Finland, with a vast road network and low population density, resource inefficient. Making benefit of the existing cellular and new 5G networks, the infrastructure cost can be decreased. Furthermore, the use of edge computing, such as ETSI Multi-access Edge Computing (MEC), allows for shortening the message transmission path between vehicles, and hence to further reduce latency.

In areas not covered by 5G and other terrestrial networks, satellite communications may provide a solution for delivering road safety services and information to connected vehicles. The current cost of satellite receivers is still very high, but with the advent of new Low Earth Orbit (LEO) satellite networks, such as OneWeb and Starlink, the costs are expected to decrease dramatically. In addition, 5G and beyond networks are evolving towards more seamless integration of terrestrial and non-terrestrial networks, including satellites. Thus, it is expected that this will be a viable approach for delivering road safety and other connected vehicle services in the future.

This paper describes work that we have performed in the framework of the Celtic-Next 5G-SAFE-PLUS project. The main objective of the overall project is to study and refine novel 5G-inspired use cases for the automotive vertical sector and to analyse the resulting requirements and business models for connectivity and services. On top of the defined communication infrastructure, the project is aiming to design and develop advanced road weather and safety services to vehicles, road users, based on vehicular sensor data, telematics, and meteorological systems.

Within the framework of the 5G-SAFE-PLUS project, we have piloted two use cases, namely:

1. Hybrid communications, using 5G and satellite communications for receiving an obstacle warning: In this pilot, the multi-access router in the vehicle uses either 5G or satellite communications, dependent on terrestrial 5G network availability, for receiving a warning about an obstacle on the road.
2. Transmission of safety critical messages between road users via 5G and MEC: In this pilot, a vulnerable road user (VRU) along the road is detected by a static roadside detection unit placed along the side of the road, and the information is shared over 5G and MEC to two vehicles, which are approaching the VRU from opposite directions.

In this paper, we present the development and evaluation of these two use cases, using real networks, equipment, and vehicles.

Pilot system architecture and setup

Figure 1 shows the overall system architecture used in the pilot. The tests are performed in a VTT-operated 5G test network that is physically located in the cities of Oulu and Sodankylä in Finland for the core and radio access network parts, respectively. The test network has two 5G non-standalone (NSA) base stations in Sodankylä and a MEC server that is collocated with the 5G core network in Oulu. The distance between the cities of Oulu and Sodankylä is about 270 km. The V2X message broker used in the pilot is running on the MEC server. The V2X broker implements a publish/subscribe protocol for the V2X message transfer using MQTT. For the satellite link, Iridium Certus is used.

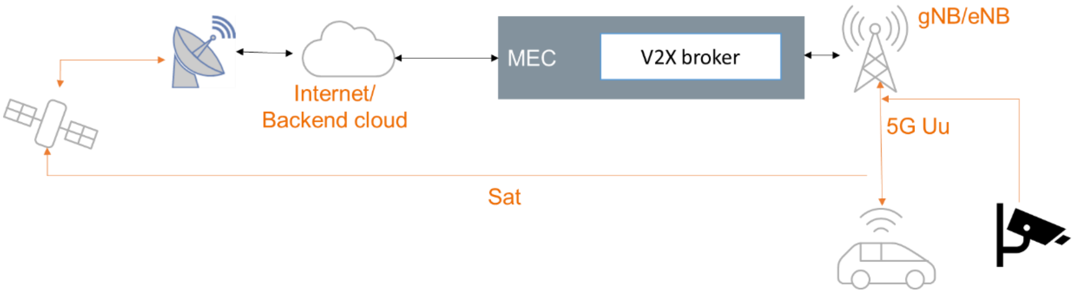

Figure 1 – Pilot system architecture.

The messages exchanged in the pilot are based on ETSI Release 2 messages, namely Collective Perception Message (CPM) and Manoeuvre Coordination Message (MCM), for which standardization is finalized in 2023. In the pilots, the CPM messages are according to ETSI TR 103 562 V2.1.1, the MCM messages are based on the specifications from the TRANSAID project. The messages are coded according to ASN.1/UPER and transmitted using MQTT protocol to the V2X broker.

In the pilots, we used the following equipment, which are also illustrated in Figure 2:

- Connected and Automated Vehicle "Martti": a VW Touareg, which has been updated for automated driving through addition of electronic actuators. The vehicle is equipped with a set of environmental sensors and 5G-enabled on-board unit (OBU). In the pilots, two modems are used: a Huawei CPE for the low-latency tests and the Goodmill Systems multi-access router for the hybrid communication tests. The Goodmill Systems router contains a Sierra Wireless modem, which allows the connectivity to 5G. In addition, the router was connected to an Iridium Certus modem for the satellite connectivity.
- Connected Motorcycle "Jarno". The motorcycle is equipped with an OBU, including a 5G Huawei CPE modem.
- A detection unit, consisting of a LiDAR, camera, GNSS, and a 5G modem (Huawei CPE). The unit detects and classifies objects using YOLO, calculates the position of the object using LiDAR and composes and publishes CPMs with data on the detected objects.

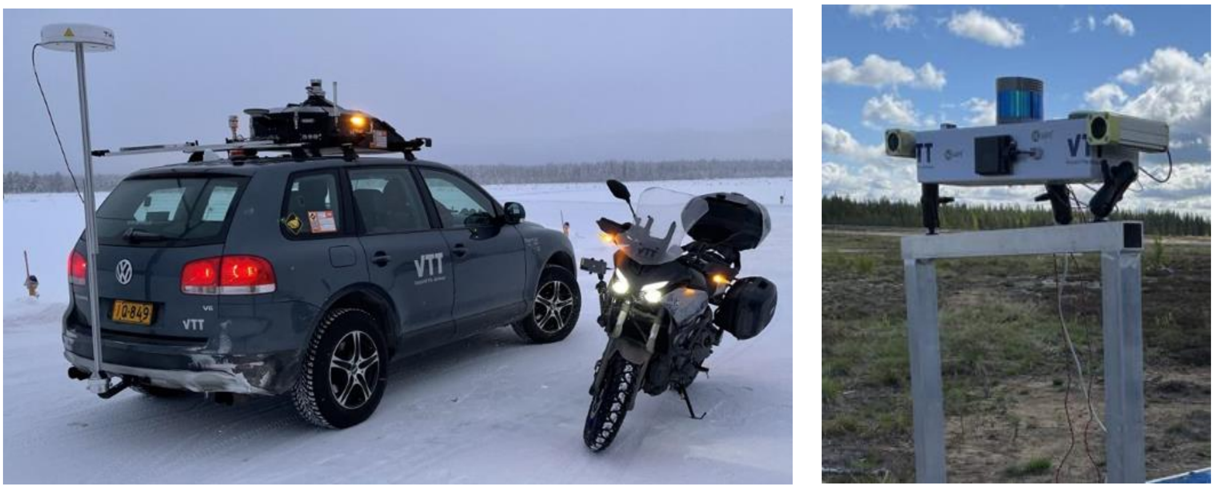

Figure 2 – Automated vehicle "Martti", with Iridium Certus receiver, Connected motorcycle "Jarno" and detection unit.

Performance evaluation and results

In this section, we present selected results obtained from running a set of pre-defined test cases for the two piloted use cases. In the performance evaluation, we used the pilot setup and equipment described in the previous section. During the tests, we measured the communication performance of delivering the road safety messages using both application-level and data link level Quality of Service (QoS) measurement tools in order to have a comprehensive view of the performance. For the application-level measurements, we used either our own proprietary tool, developed for measuring CPM and MCM message transmission performance end-to-end, and a logging script that was run both at the V2X broker and message receiver side. For the data link-level measurements, we used the commercial QoS measurement tool by Kaitotek, called Qosium. Depending on the test case, the measurements included either the whole message delivery path, that is, "from detection unit to V2X broker/MEC to automated vehicle", or only a part of it, namely, the "from the V2X broker/MEC to the automated vehicle" portion. The testing took place on 12-15th of December 2022 on a winter vehicle test track in Sodankylä, that is equipped with the earlier mentioned 5G test network operated by VTT. The conditions during the testing were quite arctic with sub-zero temperatures ranging from -15 to -28C and intermittent snow fall. We describe the results obtained from the two piloted use cases in the following sections.

'Hybrid connectivity' use case results

The hybrid connectivity tests included measurements of the downlink one-way network delay between the V2X broker/MEC and "Martti" vehicle. The measurements were done using both the 5G network and the satellite network thanks to using the Goodmill Systems multi-access router in the vehicle's side. The measurements were executed in two steps as described in the following.

First, static tests were performed. During the static 15-minute test, the "Martti" vehicle was in a fixed position and was connected to the V2X broker for CPM messages reception. For these tests, the multi-access router was executing an automatic script that allowed to "force" handover and change the active connection (i.e., the connection, which is currently used for the data transfer) between the 5G and satellite links. The results of the static tests were collected using the Qosium network performance measurement tool in combination with the application-level MQTT message logging script. The Qosium measurement results are illustrated in Figure 3. Qosium gathers and measures the through-traffic with application layer packets, and MQTT logging script records the timestamp of sent and received MQTT messages, from which the delay calculation can be made.

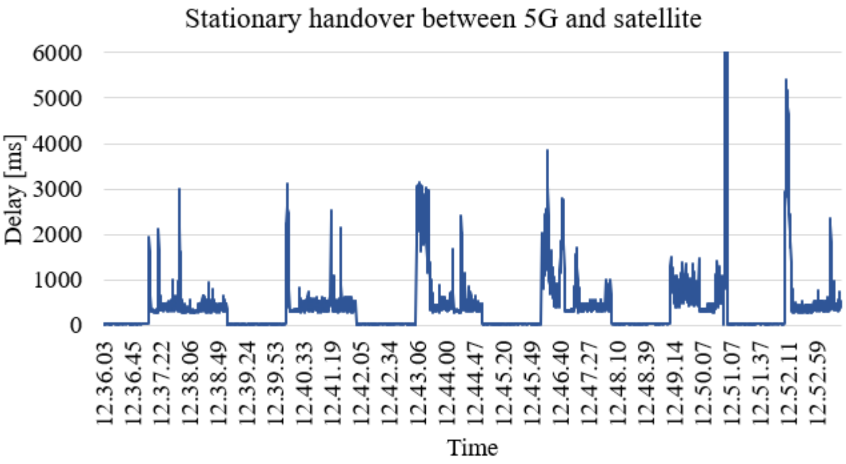

Figure 3 One-way network delay of CPM message delivery at data link layer from the V2X broker to the vehicle during the stationary 15-minute test where handovers are "forced" between 5G and satellite networks.

Next, driving tests were performed. The aim of the driving tests was to understand how seamless the handover is between two networks and what are the delay variations in a real scenario. In these tests, the car was driving out of the coverage area of the 5G network, turning, and coming back to the initial position. The Goodmill Systems router is constantly monitoring the quality and availability of the 5G and satellite networks and makes the decision on handover based on that as well as the enforced handover policies. The results of the driving tests were collected using the Qosium network measurement tool in combination with the MQTT logging script. A packet trace collected during the test using tcpdump was also analysed with Wireshark afterwards. The results are illustrated in Figure 4. Furthermore, the average and median delay values from both the tests are summarized in Table 1.

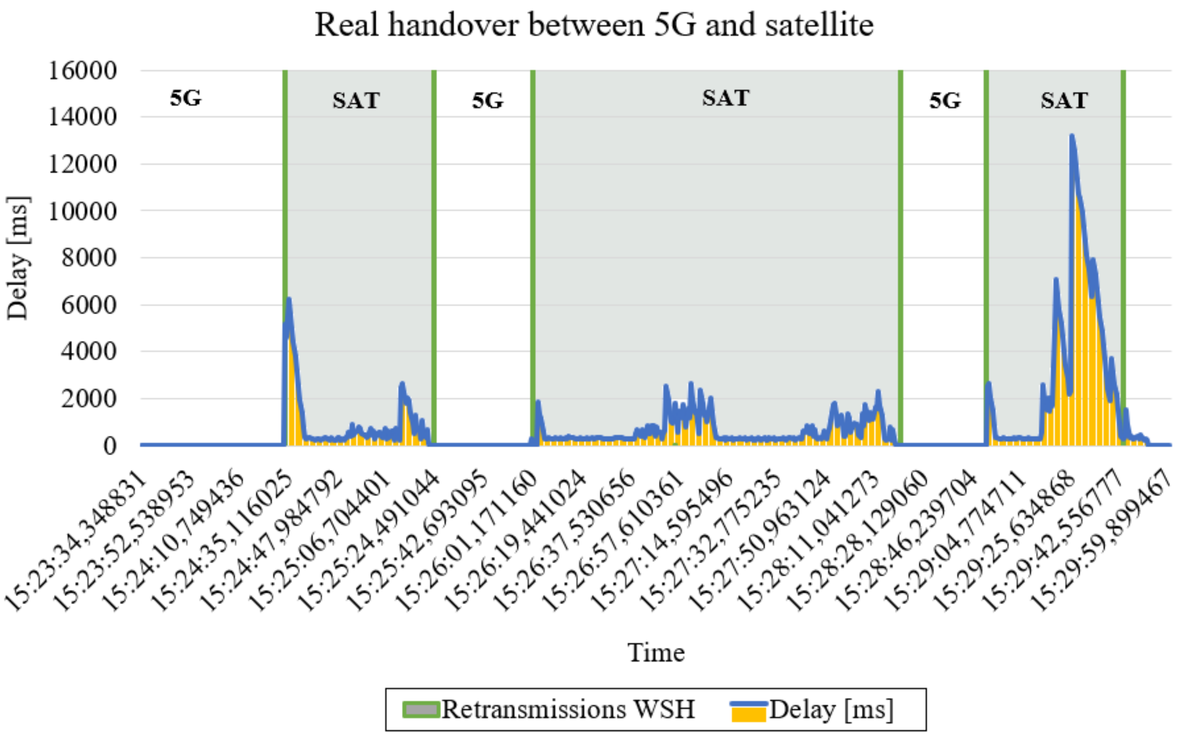

Figure 4 Real handover test between 5G and satellite networks during CPM reception by the vehicle. Blue and yellow lines are indicating an application layer delay based on the calculations from MQTT logs. Green bars show the periods of time with packet retransmissions reported by Wireshark (WSH). When connected to 5G network, there are no retransmissions.

Table 1 Comparison of averaged and median delay values of CPM reception measured from the V2X broker to the vehicle by Qosium and the MQTT logging script.

Static tests				
Network	MQTT average	Qosium average	MQTT median	Qosium median
5G	18.59 ms	18,45 ms	18.44 ms	18.27 ms
Satellite	909.40 ms	736.06 ms	401.85 ms	442.12 ms
Driving tests				
5G	21.12 ms	20.00 ms	18.46 ms	20 ms
Satellite	1266.70 ms	650.54 ms	398.12 ms	308.94 ms

The results indicate very good delay performance when the 5G network is used and sufficient delay values for the CPM perception over the satellite link. In general, the average network delay using the satellite connectivity stayed under 0.8 seconds during long 15 minutes static tests and under 0.7 seconds during moving tests. It is important to notice that TCP retransmissions during the transmission over the satellite link contribute to the application-level delay. Also, high delay peaks detected while using the satellite connection. Several factors contribute to the delay peaks, such as satellite movement relatively to the vehicle movement, as well as possible obstacles such as foliage. Moreover, it is important to notice that when the satellite is farther from the user equipment, latency increases.

‘Transmission of safety critical messages via 5G and MEC’ use case results

In the scenario tested, a VRU along the road is detected by the detection unit (Figure 2 – Automated vehicle “Martti”, with Iridium Certus receiver, Connected motorcycle “Jarno” and detection unit.). An automated vehicle approaches the VRU and overtakes the VRU if there is no oncoming vehicle (in the test a connected motorcycle) is approaching. CPM is used for detecting the objects and MCM for negotiation between the automated vehicle and the motorcycle. Both the vehicle and the detection unit were equipped with a Huawei 5G CPE router. The use case was evaluated in the 5G test network in Sodankylä in cold weather in December 2022 and in February 2023.

Both the end-to-end latency between the detection unit and the vehicle at application level and the traffic between the V2X broker and the vehicle at data link level were logged. TWAMP (Two-Way Active Measurement Protocol) measurements were performed in the test track prior to the tests. The measured Round-trip time has a median of 16 ms. The delay between broker and vehicle on link level has a median of about 9 ms, which is in line with the TWAMP measurements. Table 2 gives an overview of the measurements at link at application level. The median of the end to end latency between detection unit and vehicle for CPMs 36 ms. Figure 5 shows box plots for the end-to-end latency of the CPM from the different experiments. As the difference between the link level and application level measurements is considerable, there is room for reducing the end-to-end latency through optimisation of the application software at both the detection unit and the vehicle.

Table 2. Overview of the latency measurements

Latency (ms)	average	median	95% percentile
one-way broker-vehicle at data link level (Qosium)	10.5 ms	8.9 ms	12 ms
end-to-end latency detection unit-vehicle at application level	37.9 ms	36 ms	58 ms

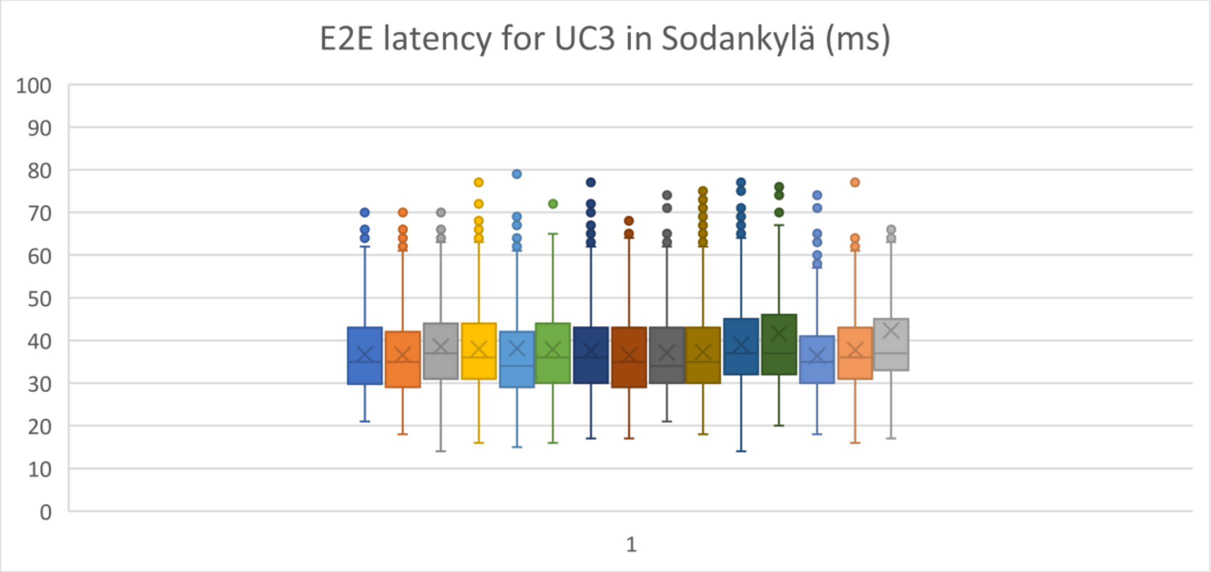

Figure 5. Results of the E2E latency for safety critical message transmission.

Conclusions and way forward

5G and related enablers such as MEC offer lower latency; thus, allowing to use the technology for safety critical services for connected and automated vehicles. In addition, satellite connectivity can be utilized in combination to 5G to improve the availability and reliability of the services in remote and rural areas. The Celtic-Next 5G-SAFE-PLUS project has researched how these novel communication technologies can be used for improving road safety. In this paper, we described the progress done in the development of 5G-enabled road safety services in the 5G-SAFE-PLUS project in the context of two use cases, namely transmission of safety critical messages between road users via 5G and MEC and hybrid connectivity. The use cases were also implemented and evaluated, using real networks, equipment, and vehicles. Selected results obtained from the performance evaluation were presented in this paper. Overall, we were able to successfully demonstrate the new service concepts for connected and automated vehicles during the project. The performance results were promising, although also leaving places for improvement. In addition, considerations on new communication technologies and solutions benefitting connected and automated vehicles in the 5G-Advanced and 6G related R&D&I will be of interest in our future studies.

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