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5G Vertical Use Cases and Trials of Transportation

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***Abstract*— The 5G networks are still being deployed in many countries creating new business opportunities. 5G networks allow us to include new features and deliver new levels of system capacity and efficiency such as higher speed connectivity, ultra low latency connectivity, improved security, distributed networks, virtualized networks and so on. They enable us to have new use cases and scenarios such as automated vehicles, smart city, eHealth, and so on. In this paper, 5G vertical use cases and large scale trials of transportation undertaken at the EU 5G-HEART project trial sites across Europe are introduced. Four representative transport use cases are validated in the 5G-HEART project. They are as follows: (1) Platooning that drives a group of vehicles together, (2) Autonomous driving that avoids collision and achieves safer driving and better traffic efficiency, (3) Remote driving support that allows an user or cloud software to control vehicles remotely, and (4) Vehicle data services that provides us with a better vehicle services by interconnecting various third-party data to autonomous vehicles using 5G networks. User requirements and KPIs are analyzed for 5G transportation use cases. The selected results of 5G-HEART transportation vertical trials are presented.

***Index Terms*— 5G use cases, Transport vertical trials, Platooning, Autonomous driving, Remote driving, Vehicle data services, eMBB, URLLC, mMTC**

I. Introduction

THE 5G networks are still being deployed in many countries creating new business opportunities. 5G networks allow us to include new network features and deliver new levels of system capacity and efficiency such as higher speed connectivity, ultra-low latency connectivity, improved security, distributed networks, virtualized networks and so on. They enable us to have new use cases and scenarios such as automated vehicle, smart city, eHealth, and so on. 5G vertical use cases will establish a robust ecosystem through cross-industry collaboration.

There are already many 5G use cases developed by academy and industry. They are now being demonstrated. In [1], the performance measurements of 5G networks are presented. They tested traffic profiles derived from real use-cases, RAN configuration effects, and the empirical benefits [1]. In [2], WiFi6 and 5G tests are evaluated under simplified 5G test environment. In this paper, we introduce 5G vertical use cases and large scale trials of transportation in EU. 5G HEalth AquacultuRe and Transport validation trials (5G-HEART) project [3] validates 5G vertical use cases and trials using EU ICT-17 platforms and two national 5G test platforms. The target use cases are healthcare, transportation and aquaculture. In order to perform large scale vertical trials, we face diverse technical challenges on 5G networks.

5G-HEART will validate 5G vertical use cases and trials in the domain of healthcare, transportation and aquaculture. Based on an iterative process, 5G vertical use case scenarios and trials are revised during each trialling phase, the business analysis is performed during the project, and the discussions within the consortium and the feedback are received from the stakeholders and the owners of the utilised 5G testbeds. In particular, International Telecommunications Union (ITU) has three main generic application services for 5G systems: enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and massive Machine-Type Communications (mMTC). The main objective of 5G systems is how much 5G system can support them. 5G-HEART validates these application services across Europe. The use cases and trials evaluation undertaken in this paper was performed for the 5G systems deployments at the 5G-HEART project trial sites in Finland, Norway, UK, Greece, and Netherlands. A variety of transportation use cases were considered for evaluating and validating 5G systems.

The remaining parts of this paper are as follows: In section II, 5G transportation vertical trials and use cases that are performed in 5G-HEART are described. In section III, user requirements and KPIs of transportation use cases are analyzed. In section IV, the selected 5G trial results are introduced. Section V contains the conclusion and summary.

II. 5G Vertical Use cases of Transportation

5G is expected to satisfy the requirements of various use cases of the transportation industry through advanced wireless connectivity and automation, which would lay a foundation for a high level of autonomous vehicles. Four representative transportation use cases have been considered in this paper. We label each use case scenario with Tn for transportation and Sn for scenario where n is an identifier number. Transportation use case scenarios of 5G-HEART are summarized as follows:

- T1 Platooning includes three use case scenarios such as T1S1 and T1S2 "High bandwidth in-vehicle situational awareness and see-through for Platooning" and T1S3 "Dynamic channel management for traffic progression".
- T2 Autonomous and assisted driving includes four use cases scenarios such as T2S1 and T2S2 "Smart junctions and network assisted & cooperative collision avoidance (CoCA)",

T2S3 “QoS for advanced driving”, and T2S4 “Human tachograph”.

• T3 Remote driving support has one use case scenario :T3S1 “Tele-operated support (TeSo)”.

• T4 Vehicle data services contain seven use case scenarios such as T4S1 “Vehicle prognostics”, T4S2 “over the air (OTA) updates”, T4S3 “Smart traffic corridors”, T4S4 “Location-based advertising”, T4S6 “Vehicle sourced HD mapping”, T4S7 “Environmental services”.

A. T1S1 and T1S2 Use Case Scenario in Surrey, UK.

In the use case of platooning, drivers will feel more secure and comfortable if they can know what happens in front of a lead car. This requirement can be satisfied by the see-through function. Using 5G wireless communication technology and the see-through function, the lead vehicle can provide a see-through view to the vehicles behind. The see-through technology for platooning will bring many benefits on traffic flow efficiency. Drivers in a group of vehicles can see the front scene via an Augmented Reality (AR) video and have communication with the group of vehicles. In addition, the event or object detection can be performed. The information can be delivered to the vehicles for improved safety by anticipating maneuvers of the lead vehicle.

B. T1S3 Use Case Scenario in Surrey, UK.

Vehicle platooning services require a low-latency and high-reliability connectivity in order to keep their smooth management and operation. Due to a fast moving vehicle, Doppler effect is harmful to wireless communications system in high-speed vehicle. The fast fading channel and spatial-temporal variation of the dynamic channels should be consider in this use case scenario. We can no longer use conventional broadcasting service. In addition, availability of the wireless channel may vary according to locations and environments. In the various platooning services, wireless channels for Vehicle-to-everything (V2X) communications should be dynamically allocated in terms of the location, speed and weather of the platoons.

C. T2S1 Use Case Scenario as trial track in Groningen, Netherlands.

When 5G V2X communications are deployed, vehicles can communicate with other vehicles and exchange vehicle status data such as speed, location, and direction. The cooperative collision avoidance scheme provides a driver with warnings message or situation awareness displays using the collected data about the neighboring vehicles status. In this use case scenario, we focus on safety information with low latency at intersections and the traffic efficiency. The time critical safety information includes the accurate traffic signal, vehicle location and speed information as well as information of Vulnerable Road Users (VRUs).

D. T2S2 Use Case Scenario as simulation track in Surrey, UK.

This is a simulation track about the Cooperative Collision Avoidance (CoCA) use case scenario. We focus on cooperative occupancy maps for efficient traffic management at different driving conditions and environments such as overtaking, lane changing, exiting or entering motorways and so on. In this use case scenario, the CoCA provides us with network-assisted safety information for autonomous vehicles. 5G networks make them announce collision risks, other vehicles locations, and vulnerable pedestrians on the road.

E. T2S3 Use Case Scenario in Surrey, UK.

This use case scenario covers the appropriate driving mode selection. The driving mode can be characterized by the Level of Automation (LoA) reflecting the technology matureness and affecting the performance of automated vehicles. Each driving mode has pros-and-cons. If we use an inappropriate driving mode, it causes collisions or traffic hazards. For example, autonomous driving is allowed only on certain conditions or strategic roads and it is prevented on other conditions or roads. Thus, the most suitable LoA should be founded in terms of the operating conditions and environments of the vehicle.

F. T2S4 Use Case Scenario in Oulu, Finland.

In T2S4 use case scenario, a wearable human tachograph is developed. It provides us with assessment about the drivers’ physiological status. Wearable sensor devices as a smart watch are worn continuously and important information is analyzed for fatigue of drivers. The level of alertness and fitness-to-drive information for drivers can be advised by analyzing the physiological information including stress level, sleep history, physical activity, and so on. In addition, sensors of smart watch can detect and analyze real-time physiological information of the driver. Based on both historical data and real-time physiological data, we could analyze them and produce more valuable information for the fleet driving management of busses and trucks.

G. T3S1 Use Case Scenario in Surry, UK.

Tele-operated support (TeSo) enables us to control a vehicle remotely by either a cloud computing software or a human. Autonomous driving requires many sensors and algorithms for path finding, object detection and identification, vehicle control and so on. Remote driving requirements controlled by a human have much lower than autonomous driving requirements. Ambient information of this use case scenario is transmitted and visualized to the remote user. In this use case scenario, a vehicle can travel in a public area, equipped with high definition (HD) video cameras and multiple sensors. Using vehicle’s instrumentation data on the driving condition and real-time video stream, an user in a remote location can monitor the car status and control the steering wheel and speed of the vehicle. TeSo can be considered on-demand if there is a request of the driver for remote support.

H. T4S1 Use Case Scenario in Oulu, Finland.

Vehicle prognostics allows us to have key information about the reliability of vehicle parts and equipment. It can report the failure and reduce the risk of vehicles. In addition, it can predict when parts or equipment will no longer perform normally. A Road Side Unit (RSU) can typically access the

Internet. It can collect any passing vehicle information and report to remote diagnosis service centres. If they receive a specific message such as repair notification, this vehicle service can be connected to local repair centres. We can obtain a proper vehicle service in time and reduce the potential risk of vehicles by analyzing data from the vehicle status periodically.

I. T4S2 Use Case Scenario in Oulu, Finland

An over-the-air (OTA) update is a method about delivery of new software, or other data via wireless connectivity. They are delivered from a cloud server to a connected vehicle via 5G networks. It is similar to an update mechanism of smartphone or laptop. Engine Control Unit (ECU) is a key hardware module with corresponding software module in a vehicle. It can control key electronic functions about the vehicle engine system. It is highly related to safety related functions from the steering wheel to the brake system. In particular, ECU of automated driving as a key function of the vehicle is getting more important. It should be securely managed and possibly need to update software regularly.

J. T4S3 Use Case Scenario in Surry, UK.

The smart traffic corridor enables a driver to be aware of upcoming accidents, obstacles and other information. It will be helpful for alleviating traffic congestion, improving traffic efficiency, and achieving air pollution. It requires to integrate multiple technologies to operate this use case properly. In this use case scenario, we focus on minimizing air pollution. In particular, urban areas suffer from air pollution. Passenger vehicles are a major air pollution contributor. Thus, we focus on a path finding and navigation service in order to reduce the air pollution for the Air Quality Management Areas (AQMAs). From this use case scenario, we can minimize the vehicle's emissions as well as simultaneously reduce the travel cost and time for the driver.

K. T4S4 Use Case Scenario in Surrey, UK.

If vehicles and passengers information is readily available and there is a request from them, location-based services can be provided by streaming content, advertising locally or providing traffic guidance to vehicles and users. In particular, it will be useful in specific business models such as car-sharing. The car-sharing is a business model of car hiring where people hire a car for short periods of time. Cars are not owned by individual person and the start and destination of the journey may change in terms of the passengers and conditions.

L. T4S5 Use Case Scenario in Surry, UK.

The multiple use case scenarios sometimes need to operate simultaneously inside a vehicle. 5G network slicing technique enables us to have multiplexing of independent virtualized networks on the same physical network infrastructure using Software Defined Networking (SDN) and Network Function Virtualization (NFV). Each slicing is an independent and isolated network to satisfy diverse requirement by a particular use case scenario. It allows us to form customized support simultaneously. It may often conflict requirements between them. We can customize a logical independent network on the same physical network infrastructure. Different End-to-End (E2E) slices enable us to support the various V2X applications and services operating inside a vehicle.

M. T4S6 Use Case Scenario in Surrey, UK.

Multiple self-driving and mapping companies have already produced High-Definition (HD) maps. However, it is not a matured technique. They do not contain the richness of information and accuracy is not high. They are iteratively making these HD maps better but there is a lack of standardization between various providers and consumers. British Standards Institution (BSI) with Ordnance Survey, UK investigate this topic. The HD maps creation and management will be a key function in the autonomy protocols of automated vehicles.

N. T4S7 Use Case Scenario in Surrey, UK.

There will be huge numbers of environmental sensors at both vehicles and roadside units. However, data are not consolidated and integrated efficiently. They are not efficiently used at specific applications and services for which each sensor is deployed. Using 5G networks and new opportunity for massive connectivity and analysis, it is possible to consolidate roadside sensor data and use the in different use case scenarios.

III. User Requirements KPI analysis of Transport Vertical Use cases

In 5G systems, connectivity between vehicles, infrastructure, cloud networks, and pedestrians is important to improve the safety and reliability of autonomous vehicles in the overall transportation system. We analyse user requirements and key performance indicators (KPIs) for the 5G-HEART transportation use case scenarios that is described in section II [4,10]. Table 1 summarizes the user requirements of selected transportation use cases.

Table 1. User requirements of selected transportation use cases

Requirements	T2S1	T2S4	T3S1	T4S6
Video Transmission	n/a	n/a	15 Mbps/chan-nel or stream (HD video)	15 Mbps/chan-nel or stream
Data Reception (DL)	10 Mbps	<10 Mbps	1-5 Mbps	10 Mbps
Data Transmission (UL)	10 Mbps	<10 Mbps	1-5 Mbps	1 Mbps
Voice Communicati on	n/a	n/a	128 Kbps UL/DL	n/a
Mobility	Maximum 160 km/h	50-200 Km/h	0-50 Km/h (urban) 0-100 Km/h (sub-urban) 0-250 Km/h (motoways)	0-200 Km/h
Location Information	±0,5 meters	±0,5 meters	±0.5 meters (urban) to ±4 meters (sub-urban and motoways)	±0,5 meters
Edge Computing	User Perception	User Perception	User Perception	n/a

Edge Storage	User Perception	User Perception	User Perception	n/a
Latency level	5 msec	5 msec	5 to 20 msec	100 msec
Traffic and Service Type	Mixture of Sustained 10 Mbps and Bursty 10 MByte bursts	Sustained: 10 Mbps (wearables data) Bursty: 10 Mbps (history data) Sporadic: 1 Mbps (synchronisa-tion)	Sustained 15-20 Mbps	Sustained 1 Mbps
Reliability/Availability	99.999%	99.99%	99.999%	99.99%
Area Dependent Interactivity	Density of 1 UE / 10 m^2 and 1.000 transactions/sec	Density of 1 UE / 10 m^2 and 1.000 transactions/sec	Density of 1 UE/15 m^2 and 200 transactions/sec	Density of 1 UE/25m^2 and 1 UE/m^2 with 1.000 transactions/sec
Security/Privacy level	Public	Confidential	Confidential	Public

Figure 1 illustrates the KPIs of transportation vertical use cases. As we can observe Figure 1, the most important KPIs are mobility, latency, location accuracy, and Uplink (UL) – Downlink (DL) throughput in terms of how much they characterize the majority of the scenarios. Apart from that, use case scenario T2S4 includes additionally a high interactivity requirement. Considering area traffic capacity, the requirements are low to medium for all scenarios. More precisely, the most stringent value is imposed by T4S2.

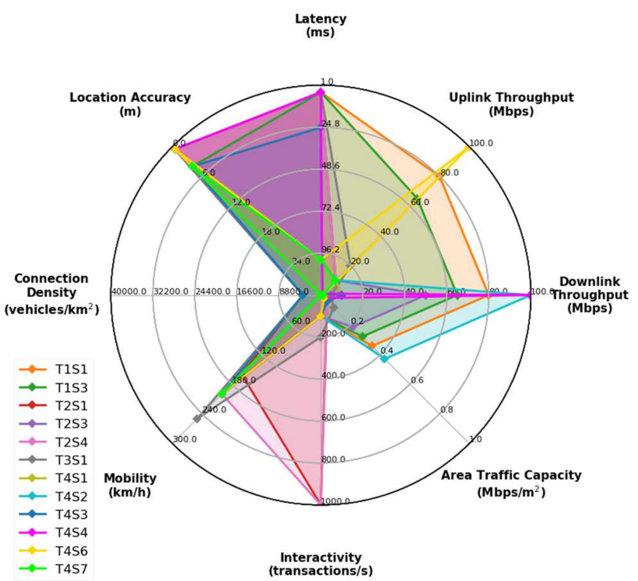


Figure 1 Network KPI requirements of transport vertical.

IV. 5G Vertical Use Case and Trial Results

In this section, we introduce the field trial results of the selected transportation use case scenario: T2S4 Human tachograph. Earlier results based on the indoor measurements were published in [7].

A. Human tachograph

Fatigue is a serious risk when driving a car. According to the traffic accident investigation boards [5], fatigue is a background factor in one in five fatalities with or between motor vehicles. Most typical fatigue accidents are head-on collisions or driving off the road. The main objective of the human tachograph is to prevent driver's fatigue by analyzing driver's physiological information. The human tachograph includes a key function to track both real-time data (physiological information) and long-term data (sleep and physical activity). The collected data from the human tachograph can be shared with cloud networks with a high level of security and privacy. We can notify to other drivers and vehicles if a potential risk affecting to them is detected. For this purpose, a traffic warning system has been implemented in 5G networks. T2S4 use case scenario can trigger warning messages to other relevant vehicles and road traffic safety systems by analyzing data about human tachograph driver conditions. The human tachograph trial video is linked in the YouTube channel [6].

B. Network architecture and use case scenario

Figure 2 presents the high-level network architecture for the human tachograph use case scenario.

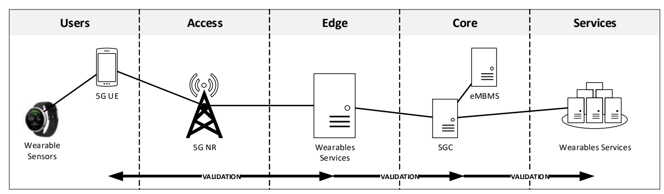


Figure 2. Network architecture and use case scenario of the human tachograph.

The driver monitoring data in the form of live biosignals is collected using wearable sensor devices (heart rate monitors on chest belts and/or sports watches) and streamed to the network in the UL direction using a 5G mobile phone as Gateway (GW) device. The sensing data is received in the edge cloud to be used as a live biosignal data in the driver condition assessment and it is also forwarded to the remote cloud to be used in the long-term analysis. In addition to the live sensor data analysis and visualisation, the edge cloud environment can be used for data fusion between the live and long-term sensor data. Furthermore, the edge cloud environment hosts the warning message triggering framework, which is used to notify the other road users in the area about increased risk caused by driver fatigue. The warning messages are distributed to the road user in the downlink direction of the same 5G cell that is used to collect the wearable sensor data from the professional drivers. As an additional component to the warning messages distribution in 5G NSA networks, the Evolved Multimedia Broadcast Multicast Service (eMBMS) -based multicasting/broadcasting can be used to deliver the notifications to a large group of recipients.

The trial network configuration for T2S4 use case scenario contains the following hardware and software components:

• **Wearable sensor devices:**

o Polar H10 heart rate monitor measures and collects the physiological information including Heart Rate (HR), Electrocardiogram (ECG), and Accelerometer (ACC) and broadcasts them continuously over a Bluetooth Low Energy (BLE) connectivity.

• **UEs:**

o OnePlus 8 Pro for collecting biosignals from Polar H10 smart watch and streaming them to the 5G network. The same phone is also running Nemo Handy SW for debugging purposes.

o Huawei H112-370 5G CPE is used as the 5G UE in the measurements. It is visible as a conventional Ethernet interface for the measurement laptop.

• **eNBs:**

o LTE Frequency Division Duplex (FDD) @ 2.6 GHz (band 7), Bandwidth = 5+10 MHz (anchor for macro 5G gNB).

o LTE FDD @ 2.1 GHz (band 1), Bandwidth = 10 MHz (anchor for pico 5G gNB).

• **gNBs:**

o 5G NR Time Division Duplex (TDD) Rel-15 NSA @ 3.5 GHz (band n78), Bandwidth = 60 MHz.

 Pico gNB for laboratory trials.

 Macro gNB for field trials with a grid of 6 horizontal beams.

 30 kHz subcarrier spacing corresponding to 0.5 ms slot duration in the numerology of OFDMA systems.

 The configuration is optimised for UL performance with the 3/7 DL/UL time slot ratio and UL proactive scheduling enabled [8].

 The Multiple Input Multiple Output (MIMO) configuration is 4x4 for the DL and 1x4 for the UL.

• **EPC and 5GC:**

o Emulated core network.

• **Wearables services:**

o A Virtual Machine (VM) server collects the streaming sensor data in VTT's edge cloud system.

o A server collects the streaming sensor data and history data in Polar's remote cloud system.

The following software components are utilised in the human tachograph trial setup:

• **Polar Mobile Software Development Kit (SDK)** directly read live data (streamed through BLE) from Polar sensors, including ECG data, ACC data and HR broadcast.

• **Polar Sensor Logger Android application** implements decoding of the H10 BLE signalling using the Polar SDK and visualization of the biosignal measurements. It also includes an MQTT publisher for the measurement and trial purposes. Polar Sensor Logger publishes the sensor data from a smartphone to the brokers at the network edge cloud network in the 5GTN platform and Polar's remote research server.

• **Polar Open Test Application Programming Interface (API)** provides us with a direct information sharing connectivity between the Polar ecosystem and research server as well as between the Polar research server and 5G network edge cloud environment for historical data.

o Estimation of fatigue levels for the day based on user's sleep history (recent sleep amount and timing in relation to circadian rhythm) is calculated on the research server.

o Fatigue level prediction also takes into account daytime napping (not currently available in history data, but through manual notation).

• **MQTT client** (publisher) for publishing the biosignal data packets to the network.

• **MQTT broker** running in the edge cloud for initial reception and forwarding of the published biosignal data packets.

• **MQTT client** (subscriber) for receiving the published biosignal data packets in the network.

C. Verification Methodology

In order to verify that the mobility of the users do not have any significant effect on the results achieved in the laboratory conditions [7], measurements and verification were performed outdoors around the VTT Oulu premises using 5G NR macrocell provided by the test facility. In this case, all the available 5G NR devices synchronized their clocks using the Network Time Protocol (NTP) signal sent from the gNB. The accuracy of mobile NTP synchronization is in the order of 10 ms, which is clearly not enough for any one-way latency measurements with 5G NR. To overcome this issue, we setup an external Global Positioning System (GPS) receiver as a clock reference for the laptop through which the Polar Sensor Logger traffic is forwarded. The setup for the outdoor measurements is shown in Figure 3.

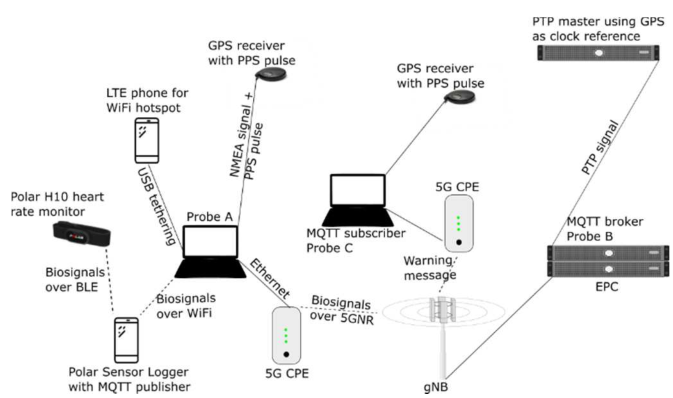


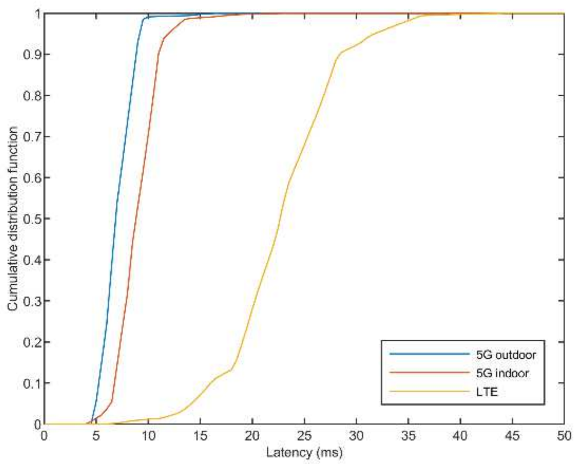
Figure 3. Human tachograph trial setup for the outdoor measurements. PPS: pulse per second, NMEA: National Marine Electronics Association, PTP: precision time protocol.

D. Measurement results

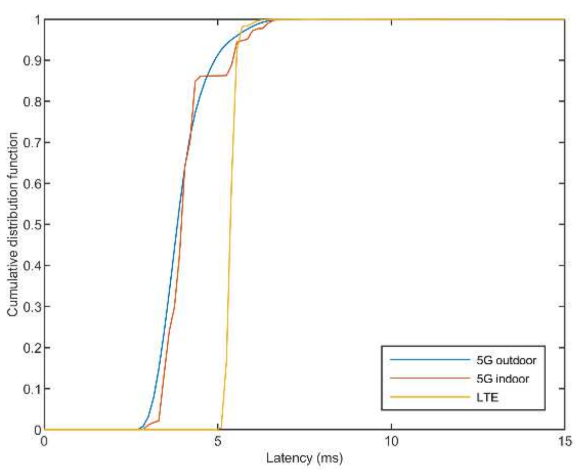
The outdoor measurement is performed around VTT Oulu premises. The maximum vehicle speed during the measurements was 40 km/h. The Cumulative Distribution Function (CDF) of the biosignal reporting latency in the UL direction is shown in Figure 4. Polar Sensor Logger produces multiple data such as 1 heart rate, 2 electrocardiography and 6 accelerometer messages per second resulting in approximately 50 kbps biosignal traffic. The measured average latencies are

7.04 ms, 8.98 ms, and 22.8 ms for 5G outdoor, 5G indoor, and LTE, respectively. The CDF of the warning message delivery latency in the DL is shown in Figure 6. We assume that the warning messages have a similar structure to Cooperative Awareness Messages (CAMs) with a payload of 83 B. The average latencies are 3.96 ms, 4.10 ms, and 5.38 ms for 5G outdoor, 5G indoor, and LTE, respectively.

Average latencies are on a good level fulfilling the requirements for this scenario. However, it is the tail of the latency CDF that defines the reliability of warning message delivery. The reliability results and more discussion can be found from [9].



(a)



(b)

Figure 4. CDF of the biosignal reporting latency in the UL direction (a) and CDF of the warning message delivery latency in the DL direction (b)

V. CONCLUSION AND SUMMARY

The 5G system is the first mobile system supporting multiple use cases and services across multiple vertical industries. Many vertical industries such as healthcare, transportation, food, entertainment, energy, financial, manufacturing are involved in 5G vertical use case developments. In particular, 5G systems will be useful for achieving a high level of automated vehicles by provide advanced connectivity solutions. Automotive and transportation industry considers lots of 5G vertical use cases such as platooning, remote driving, automated lane change, and so on. In this paper, transportation vertical use cases and trials performed by the EU project 5G-HEART are introduced together with example results from a selected trial scenario. 5G-HEART focuses on realising 5G trials and validating 5G KPIs on the vital vertical use-cases of healthcare, transport and aquaculture. The transportation vertical trials comprise four representative use cases. They are divided into multiple scenarios. Four representative use cases are as follows:

• T1 Platooning that drives a group of vehicles together.

• T2 Autonomous driving that avoids collision and achieves safer driving and better traffic efficiency.

• T3 Remote driving support that allows an user or cloud software to control vehicles remotely.

• T4 Vehicle data services that provides us with a better vehicle services by interconnecting various third-party data to autonomous vehicles using 5G networks. The use case scenarios have been performed across Europe. Further trial results have been released in the project website [3].

ACKNOWLEDGEMENT

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