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V2X-supported automated driving in modern 4G networks

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Abstract—**With connected and automated vehicles and remote-controlled driving, available 4G/5G network capacity performance is the key issue. Wide bandwidth allows vehicles to receive and send real-time sensor data to a MEC (Mobile edge computing) server or remote controller. Wide download bandwidth doesn't ensure low latency with vital data, e.g. control commands or camera image. The main difference between 4G and 5G cellular networks is the capability to ensure wide bandwidth for uploading data from a vehicle to a MEC server but also low and predictable latency. This article studies baseline measurements conducted in the modern 4G network, taking into account the expected 5G features. This publication introduces the results from the VTT automated vehicle in the KPN (Dutch landline and mobile telecommunications company) cellular test-network at the automotive test-track between Helmond and Eindhoven, the Netherlands. The tests are carried out to understand potential performance improvements when updating 4G network to 5G network for autonomous vehicles. Measurements are taken by using two MQTT servers. The local MQTT server is the MEC server in the KPN network. The second reference server is located at VTT's premises in Finland. This publication shows that 4G technology performance is not sufficient even in a dedicated test network with a controlled amount of simultaneous users.**

Keywords—Automated driving; Connectivity; 5G networks; sensors; mobility; LTE; latency

I. INTRODUCTION

At this moment, automated driving is considered to be an interaction between a driver and an autonomous vehicle, where the driver is observing vehicle behaviour behind the steering wheel or remotely. When an autonomous system fails, e.g. due to lack of a lane marking for a camera system or positioning accuracy, the driver can take control of the vehicle if needed. One way to cover these situations is to use additional information from the background system through a cellular network or C-V2X communication [1],[6]. Backup information can include correction for positioning, e.g. a list of positioning landmarks or the vehicle can send sensor data to the network server for a more accurate sensor analysis. 5G networks enable autonomous vehicles to receive real-time warnings on incidents and dangerous situations, with low latency. At the same time, vehicles can also send their own sensor data and observed incident information to other road users [2]. Through the use of MEC (Mobile Edge Computing) servers, which control the traffic between vehicles, latencies can be decreased.

One challenge with electric vehicles, compared to traditional gasoline vehicles, is the limited range caused by battery technology. Automated driving requires high-quality perception data from sensors and calculation power inside the vehicle. With traditional ICE vehicles, additional power consumption caused by autonomous systems can be more easily taken into account (e.g. fast refuelling) than with electric vehicles. One way to solve the power limitation is to decide on the level of data processing with car computers [4]. The 5G network allows the sending of data to MEC servers for power-consuming processing.

In this paper, the main focus is to benchmark the existing KPN cellular test-network and its capabilities for automated driving. The network is dedicated only for controlled network testing, although the network has a gateway to the public internet. With public 4G networks, a reliable benchmark is not possible due to the uncontrolled number of users and amount of data. A separate 4G network provides an ideal base level of measurements to compare the difference between 4G and 5G networks.

II. MEASUREMENT METHODS

A. Measurement software

Performance measurements were made using two separate MQTT brokers. MQTT (Message Queuing Telemetry Transport) protocol was selected because it provides good topic-based communication instead of addressing. The MQTT publisher can send data to a selected broker and the subscriber can listen to messages from the broker on a dedicated topic. For latency measurement, this allows the sending of messages to one broker in a selected part of the network. In these measurements, two brokers were used: one inside the KPN network as a MEC server and one outside as a remote server.

The VTT DTRA (Data transfer analyser) tool was used to perform the measurements, see Fig. 1. The software sends MQTT packages with a pre-selected payload size and interval. With these measurements, two separate MQTT brokers were selected: one from Finland at the VTT premises and one inside the KPN network as MEC.

Measurement software collects timestamps from the vehicle's GNSS (Global Navigation Satellite System) and adds a timestamp to every MQTT message at the message publishing time. The MQTT package is sent to the MQTT broker, where the DTRA tool reads the same message back and adds a GNSS timestamp at the time of the subscribing message. With sending and receiving timestamps, DTRA calculates values for network performance. The measurement process can be adjusted with sending the interval and MQTT message payload size. With the increasing interval and MQTT message payload size, the network can be loaded with data over network capability.

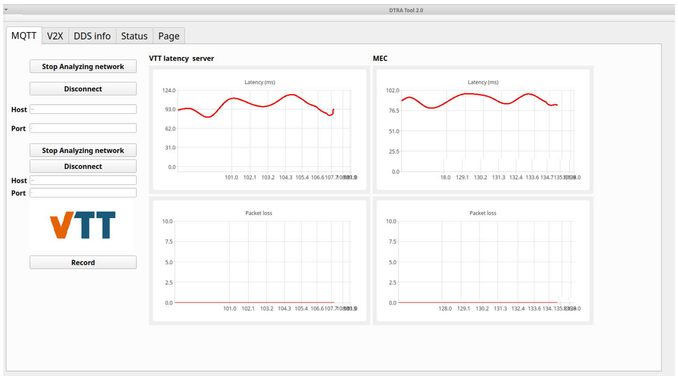


Fig. 1. VTT DTRA network measurement tool with online latency and lost MQTT package counters.

B. Hardware

For the measurements, the Sierra 4G LTE MP70 router was used. The router and 4G antennas were installed on the VTT autonomous vehicle, called Martti, see Fig. 2. In addition to communication hardware, an accurate timestamp and the location were received with ublox ZED-F9P GNSS. During the test runs, the manual driving mode was used, but the sensor systems and network communications were enabled to deliver data to the 5G network. The speed of the vehicle was kept static, following speed limitations on the road section.

Fig. 2. 4G and GNSS antenna setup on roof of the test vehicle Martti with V2X capable antennas.

III. TEST ARRANGEMENT

The test site in Helmond consists of an optimised 4G network, covering the A270 and N270 between Eindhoven and Helmond. The network is covering a highway, motorway and an urban road with several controlled intersections. For the 4G network, the production sites are used in a shared RAN mode. Multi-Operator Core Network (MOCN) is used to share the Radio Access Network (RAN). The base stations are configured with two MNO's: 1. Production (20408) and 2. Test (20469), see Fig. 3.

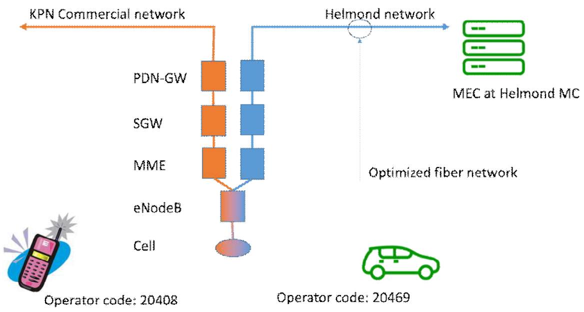


Fig. 3. KPN Commercial network and Helmond network structure with MEC server.

In total, six base stations are covering the road, see Fig 4. With this setup, we have actual production traffic using the same Radio Access Network (RAN). The test network, however, has an MEC facility at the metro core close to the base stations, where traffic is broken out. This way, users (typically vehicles) can use the services running at the MEC facility close by.

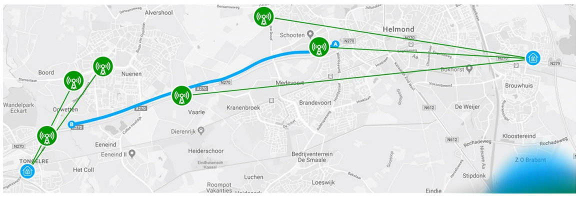


Fig. 4. Six base stations visualized with test route.

To break out the traffic at the MEC, CUPS (Control plane and user plane separation) is used. This way, the distance between the base station and the edge facility is limited to around 20 kilometres, and thus latencies are reduced. Edge computing is already possible with 4G; however, with 5G, the capabilities will be extended. Latencies will also be reduced using 5G New Radio (NR). Also, "Session and Service Continuity" (SSC) mode 2 and 3 is introduced in 5 core networks. This will help to always stay connected to an edge, while traversing different edges. Using this, the continuity can be improved by first creating a new PDU (Packet Data Unit) session to a new edge before breaking the old PDU session to the old edge (make before break).

Another way to reduce the latency of the mobile network is by using priorities. It is possible to give priority to both specific data connections, using a specific bearer, or by prioritising traffic for a specific SIM that is used. With the test network in Helmond, it is possible to enable different priority measures. With 5G networks, it is expected that RAN slicing will become available in the future. Currently, with 4G, other measures can be taken. In general, we can say that, when considering the complete chain from the vehicle toward the C-ITS service running on the network, RAN is consuming the largest part of the delay. Taking measures at the RAN can have a significant impact on the overall performance. For the 4G implementation, we have implemented pre-scheduling, by which the UE (User Equipment) will get radio resources scheduled in advance. This will enable the transfer of data in the uplink with less delay. This of course is up to a certain limit. When pre-scheduling too many resources, this can negatively impact other users and the overall efficiency of the network. In the current test, pre-scheduling was enabled for 380 bytes every three resource blocks, with a timeout of 200ms. This means that if for 200ms no uplink traffic was received, no more resource blocks were prescheduled.

Initial tests using a MQTT system at the edge and a MQTT payload of 364 bytes show a round-trip latency of around 20ms average, 14 ms min and 90 ms max. Without prescheduling, the latency is 40 ms average, 26 ms min and 153 ms max.

IV. MEASUREMENTS

The MQTT latency measurements were done at the Helmond test road in the Netherlands. The test track was 2.5 km long from the Automotive campus to the first traffic light to west along motorway N270. The measurements were done with using the VTT DTRA tool on a Linux laptop. Figure 5 shows the test road on the map with latency measurements in milliseconds. Each colour-coded dot contains a measurement with the GNSS location, timestamp, latency value in milliseconds and number of lost packages.

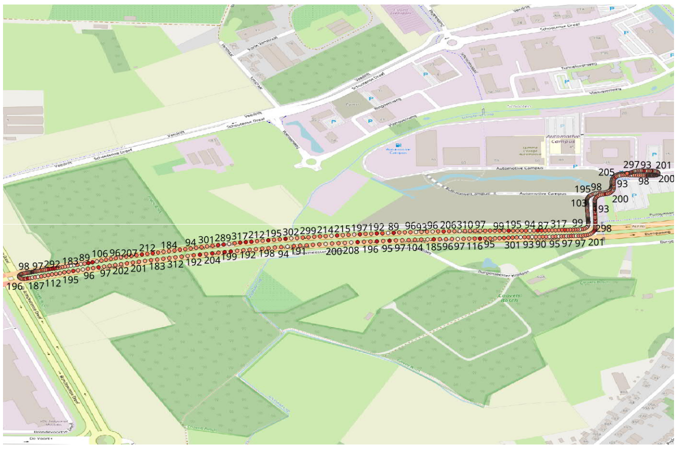


Fig. 5. Test road visualised with LTE latency in millisecond.

The payload of the MQTT message sent to MEC and VTT servers had a size of 200, 400 and 1441 bytes and message interval of 100ms, see Table 1. A test with one payload was repeated on the same route to limit outlier values caused interference from traffic environment.

TABLE I. PARAMETERS FOR TEST SCENARIOS .

Payload size (Bytes)	Test ID	Interval (ms)
200	1	100
	2	
400	1	100
	2	
1441	1	100
	2	

Measured values for network latency in milliseconds were, minimum, maximum, average, jitter and standard deviation. The minimum value gives the optimal delivery latency for measurement, and the maximum is the worst-case delivery time.

The measurement starts to set-up the message interval and payload size sent to the MQTT broker, see Table 1. Each MQTT message is timestamped and labelled with an increasing ID number. DTRA software listens to the MQTT broker for timestamped packages. When the MQTT package arrives, the DTRA tool compares the timestamp and ID number to the internal counter and PC epoc timestamp. If a received message ID number is different compared to the expected ID number, difference is calculated as number of lost MQTT packages.

V. RESULTS

The measurements were taken using 3 different payload sizes, with two test runs each. The duration of the test drives was around 300ms, depending on the traffic situation and traffic-light timing. The results indicate the behaviour of the LTE networks. Latency can be low for each test drive, around 70-80ms, but maximum latency can reach almost 1.5 seconds. An average latency value is usually between 100-200ms, see table 2.

Figures 6, 7, 8 and 9 show latency measurement related to the vehicle position on the test track. One sample number is the GNSS position on the test track. Figure 6 shows that the latency with the MEC server stays stable, around 100ms, but some samples peak at 600 ms. This shows that with a small payload, the latency stays stable, and these peak values can be filtered out as outliers.

Network latency to the VTT MQTT broker in Fig. 7 shows the effect of the public network on latency times. The network load outside the test network gateway cannot be controlled, causing variable latency over the test track. In this case, peak values can reach even 400 ms.

Network latency of the VTT MQTT broker with a 200-byte payload. Sample numbers are related to vehicle position on the test track. When increasing payload size to 1441 bytes, the test network starts to generate higher peak values over the test track area, see Fig, 8. Overall performance stays around 100ms, but the number of unusable samples (latency > 200ms) are spread all over the test track area.

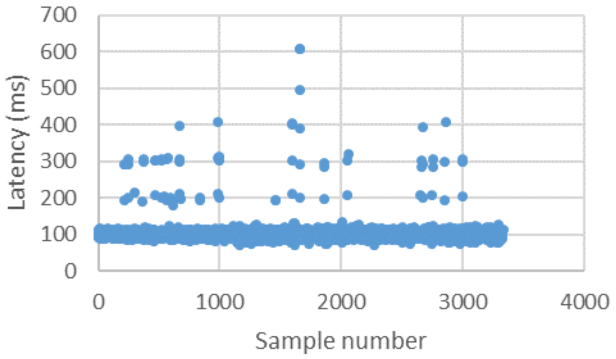


Fig. 6. Network latency to MEC with 200 Bytes payload. Sample numbers are related to vehicle position on test track

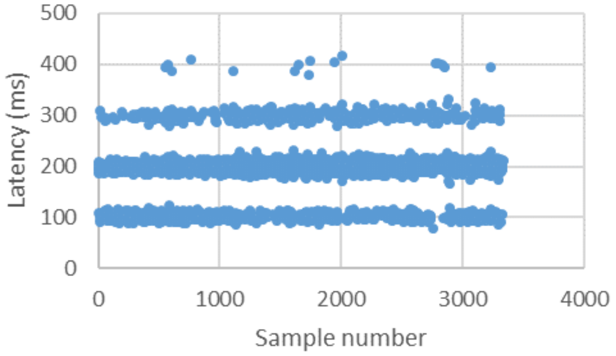


Fig. 7. Network latency to VTT MQTT broker with 200 Bytes payload. Sample numbers are related to vehicle position on test track

With the VTT MQTT broker, increase of payload does not affect the overall result, see Fig 9. Public internet causes uncontrolled latency on packets; therefore, the latency difference between payloads is not visible.

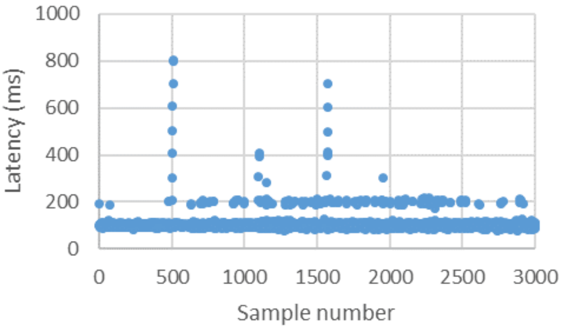


Fig. 8. Network latency to MEC with 1441 Bytes payload. Sample numbers are related to vehicle position on test track

Average latency values shows that minimum latency can stay between 0-80ms but maximum latency can reach almost 1.5 seconds. The average latency value is mainly between 100-200ms, see Table 2. The average latency shows a difference between the VTT and MEC servers. The MEC network server latency stays around 105 ms regardless of the payload. With the VTT server, latency can change 50 ms depending on the payload.

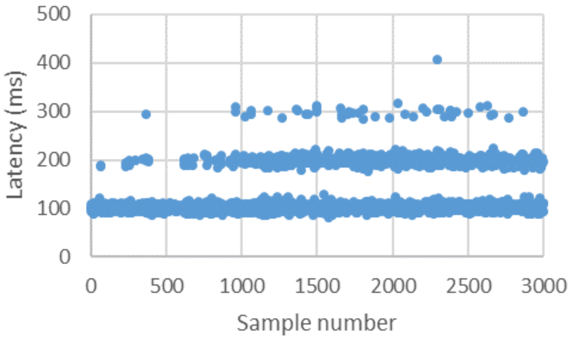
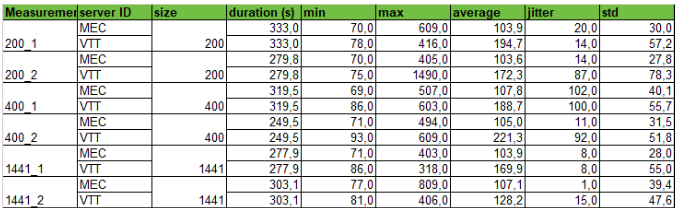


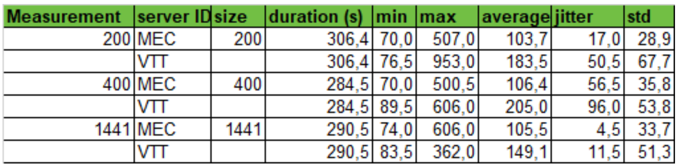
Fig. 9. Network latency to VTT MQTT broker with 1441 Bytes payload. Sample numbers are related to vehicle position on test track

TABLE II. LATENCY MEASUREMENTS WITH MINIMUM, MAXIMUM, AVERAGE, JITTER AND STANDARD DEVIATION VALUES.



Measuremer	server ID	size	duration (s)	min	max	average	jitter	std
200_1	MEC	200	333,0	70,0	609,0	103,9	20,0	30,0
	VTT		333,0	78,0	416,0	194,7	14,0	57,2
200_2	MEC	200	279,8	70,0	405,0	103,6	14,0	27,8
	VTT		279,8	75,0	1490,0	172,3	87,0	78,3
400_1	MEC	400	319,5	69,0	507,0	107,8	102,0	40,1
	VTT		319,5	86,0	603,0	188,7	100,0	55,7
400_2	MEC	400	249,5	71,0	494,0	105,0	11,0	31,5
	VTT		249,5	93,0	609,0	221,3	92,0	51,8
1441_1	MEC	1441	277,9	71,0	403,0	103,9	8,0	28,0
	VTT		277,9	86,0	318,0	169,9	8,0	55,0
1441_2	MEC	1441	303,1	77,0	809,0	107,1	1,0	39,4
	VTT		303,1	81,0	406,0	128,2	15,0	47,6

TABLE III. AVERAGE VALUES BASED ON TABLE II CONTENT.



Measurement	server ID	size	duration (s)	min	max	average	jitter	std
200	MEC	200	306,4	70,0	507,0	103,7	17,0	28,9
	VTT		306,4	76,5	953,0	183,5	50,5	67,7
400	MEC	400	284,5	70,0	500,5	106,4	56,5	35,8
	VTT		284,5	89,5	606,0	205,0	96,0	53,8
1441	MEC	1441	290,5	74,0	606,0	105,5	4,5	33,7
	VTT		290,5	83,5	362,0	149,1	11,5	51,3

VI. FUTURE WORK

The research work described here has been performed in the framework of the EU sponsored 5G-MOBIX project and the Celtic-next 5G-SAFE+ project. The 5G-MOBIX project aims to support mobility of people and automated passenger cars, especially in the cross-border regions. Also 5G-SAFE+ addresses the use of 5G technologies for time-critical road safety services, including Vulnerable Road users such as Powered Two Wheelers (PTW). Low latencies and high bandwidth are essential, especially in fast moving vehicles; therefore, understanding different vehicle features is taken into account. The project is investigating advanced automated driving scenarios, such as the use of Manoeuvre Coordination Service (MCS) for negotiation between automated and connected vehicles, including motorcycles [5]. One of the important target outcomes is to ensure that the latency is sufficient even when driving on the motorway (120 km), and warnings are enabled between the vehicle and motorcycle if overtaking is expected (see 10).

Fig. 10. MCM message exchange between motorcycle and passenger car

The next steps in the project are to perform a test with an updated network to 5G technology. In theory, 5G will increase upload bandwidth for data, decreasing average latency. It should also stabilise latency between samples, decreasing the difference between minimum and maximum latency times. For these measurements, two vehicles with 5G-capable devices are used. In addition to Martti, the KTM motorcycle (Jarno) is used to add load to the network (see Fig. 11). This will help to measure the increase of users and data to 5G network performance.

Fig. 11. The test vehicles - automated passenger car-Martti and motorcycle-Jarno

VII. CONCLUSIONS

This article has shown benchmark results of the 4G/LTE network with different payload sizes. As the results shows, LTE coverage is good at the whole tested road section. It is notable that the test network should cover the whole test road from the Helmond Automotive Campus to Eindhoven. During the tests, the time network hardware issue limited the test area covered by one network cell, see Fig 5.

Results from Table 2 and Table 3 show that latency is not affected on payload size but is changing between measurements. This effect is clearly visible when comparing payloads of 200 bytes and 1441 bytes with the VTT MQTT broker. With 200 bytes, the average latency is 183.5 ms. An increase of payload should also increase latency if bandwidth is limiting the data transfer. In this case, latency decreases to 149.1 ms with a 1441-byte payload.

The results show that a 4G network can perform at a good level for e.g. automated remote driving, providing a minimum latency around 70 ms with different payloads. On the other hand, maximum and average values show that network performance is not stable in the whole network cell area. It is notable that the latency can peak to value 1490 ms, sending data to the VTT MQTT broker, which is considered network failure with time-critical data. With the MEC server, the peak value can reach 809 ms. The average values in Table 2 show the performance between measurements. These values show better performance for time-critical data, e.g. sending and receiving a packet with a 1441-byte payload takes an average of 105 ms for MEC.

In automated driving, one way to find a reference for feasible latency is to compare it to the positioning sample rate. In the Martti vehicle, RTK GNSS was used with a 10 Hz sample rate (1 sample in 100 ms). With lower than 100 ms latency, it’s possible to send sensor and receive sensor data from the MEC network server, e.g. corrected landmark information or analysed sensor samples for a positioning sample from the RTK. When comparing these results with the RTK sample rate, latency with MEC is not usable to provide benefits of edge computing for vehicle positioning.

Theoretically, 5G should increase network performance, but one variable is also network load caused by multiple simultaneous user. As figures 4, 5, 6 and 7 show, separate 4G networks can perform at a good level for automated driving. Peak latency values can be filtered out when using smaller (200 bytes) payloads. When the user number and data amount increase, e.g. the public network, also latency times and peak values, increases. This can also happen with public 5G networks.

ACKNOWLEDGMENT

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