Latency Assesment for CAM services over 5G

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Abstract*—Cooperative, connected and automated mobility relies, among others, on the exchange of messages between vehicles. Certain applications have strict requirements on message latency. 5G-MOBIX is developing uses cases that will use 5G networks to enable communication among vehicles, road infrastructure and remote ITS centers. These use cases will be tested in cross-border corridors. New methods to evaluate the latency of the messages have to be developed. This paper presents two solutions to assess latency in two locations (Lisbon and Málaga) for C-ITS messages. The test scenario is an alternative to the more traditional C-ITS, as it uses TCP/UDP over IP in a Public Land Mobile Network (PLMN) network, using 5G networks. Additionally, the use of Message Queuing Telemetry Transport (MQTT) as a dissemination broker is also evaluated. The results show the network performance in terms of latency that ITS applications may expect in real 5G Non-Stand Alone (NSA) networks.

***Keywords*—5G, vehicular communications, C-ITS, ITS messages, MQTT, QoS, Latency.**

I. Introduction

Wireless vehicular communications applications aim to provide an efficient, safe and secure transport protocol. IEEE 802.11p-based radio technology was the first route taken to standardize vehicle communications, leading to Dedicated Short-Range Communications (DSRC), in the USA, followed by the Cooperative Intelligent Transport Systems (C-ITS), in Europe. Both DSRC and C ITS use the 5.9 GHz band. Shortly afterwards, 3GPP initiated the standardization of cellular-based vehicular communications (C-V2X) based on LTE and later 5G NR and introduced the side-link communication (PC5) concept to allow vehicles to communicate directly without cellular network support. The cellular option allows to take advantage of network operator's investment which could partner with roadside operators or other service providers to develop enhanced services. This paper explores another approach, still based on cellular networks, using regular data links instead of the C-V2X channels and protocol stack. Two different 5G networks are used to perform the tests.

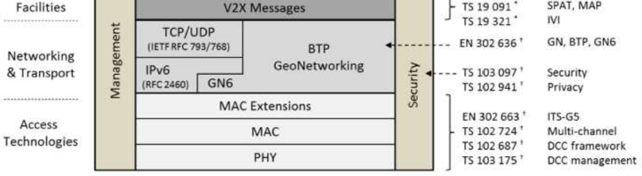

Fig. 1. *C-ITS protocol stack (extracted from [1])*

C-ITS full protocol stack is shown in Fig. 1. For the network and transport layers, the initial focus is on the BTP and GeoNetworking protocols. The possibility of using TCP or UDP over IP for the access layer to transport V2X messages was considered from the beginning (Fig. 1). This network stack and the MQTT broker is used because, at the moment, it is the only one available in the network under assessment.

Common cooperative, connected, and automated mobility applications in Europe will use the Cooperative Awareness Message (CAM) and Decentralized Environmental Notification Message (DENM) protocols/messages to report relevant information about the vehicle (e.g., location, speed, etc.). Other specialized traffic streams might be used to support video and other information for remote vehicle teleoperation. Several use cases have been defined which impose requirements on the maximum latencies, with the most stringent uses cases being the emergency services (such as pre-crash warning), requiring 50 ms, while most other require a maximum latency of 100 ms [2].

5G-MOBIX is a H2020 European project developing various uses cases in cross-border scenarios. While addressing the various elements (network, vehicles, road infrastructure, etc.) needed to demonstrate the uses cases, the consortium is engaged in testing relevant KPIs related to those use cases. As part of this effort, tools are being developed in order to extract metrics for calculating KPIs and some preliminary tests have been performed on 5G networks. This work focuses on latency although other measurements such as IPG may be relevant for some applications [3].

II. Latency assessment method

Two different methods are proposed to assess the latency on real 5G networks.

A. Method 1: Synthetic traffic over UDP transport protocol

UDP protocol is envisioned to be commonly used in cellular communications to stream data such as video. The utilized test method consists of the transmission of a continuous flow of packets over UDP and the measurement of the delay since each packet is transmitted by one node of the communication until it is received at the other node.

B. Method 2: Synthetic CAM and DENM messages through a MQTT broker

Many connectivity solutions in the automotive industry today are using MQTT to support applications following the publish-subscribe paradigm. It thus seems natural to use this infrastructure to transport V2X CAM and DENM messages. These messages are transmitted by devices – On-Board Units

(OBU) installed on vehicles or Fixed Side Units (FSU) installed on a near road side edge computing infrastructure – to a MQTT broker where one of the ends of the communication subscribes to a service in order to receive the messages that other nodes, or itself, sends.

The test solution builds synthetic V2X messages (transmitted every 500 ms) to a broker which broadcasts the messages to other vehicles. Both the uplink latency (vehicle to broker) and end-end (vehicle to vehicle) are measured.

III. Measurement Platforms

Two measurement platforms have been used in 5G-MOBIX. For the UDP latency measurements, the TACS4 Performance testing platform, developed by DEKRA has been used at Malaga, on Telefonica 5G network. For the MQTT latency measurements the ISEL QoS Network Performance Evaluation (IQ-NPE) was used on the NOS 5G network at Lisbon.

A. DEKRA TACS4 Performance testing platform

It is a comprehensive standalone application that autonomously delivers concurrent performance testing and user experience analytics access networks for voice and data services. More information available at [4]. It just requires a smartphone where TACS4-Mobile app runs, and a TACS4 agent software running at a selected point of the network. Measurements are locally accessible at the smartphone and can be forwarded to a web server for further processing. This test system is composed of three elements:

- TACS4-Mobile: Mobile application (a.k.a. App) to be installed on devices that participate in the test scenario. It exchanges data traffic with other TACS4-Agents. It manages the test scenario.
- TACS4-Agent: Computer multi-user and multi-platform software to be installed in the data endpoints or nodes which participate in the test scenario. It exchanges data traffic with the TACS mobile app.
- TACS4-Web: HTML5 application for tests results collection, extended data analytics (e.g., KPI aggregation from test data from different days, devices, etc.). It also allows TACS4-Mobile remote management. It is hosted in a DEKRA secured data centre.

The general architecture is depicted in Fig. 2. TACS4-Agents have client and server functionality and can create data streams to measure the throughput between the two ends in one or both directions.

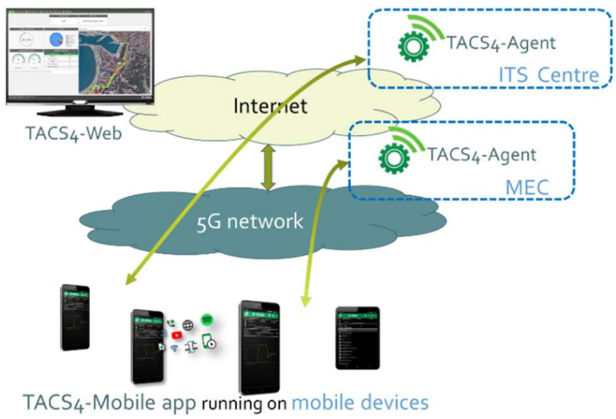

Fig. 2. *Generic TACS4 Performance test solution overview*

The control connections are performed thought the 5G network before the tests starts and after it finishes, so the control does not interfere with the results. An algorithm is used to synchronize the time reference at both ends.

B. ISEL QoS Network Performance Evaluation (IQ-NPE)

An in-house developed tool, thoroughly describe in [5], the ISEL QoS Network Performance Evaluation (IQ-NPE) is used to generate ITS messages and measure latency. The IQ-NPE system, presented in Fig. 3, is based on a set of QoS probes, On-Board Units (OBUs) and Fixed Side Units (FSUs) and a centralized management platform. These devices are used to perform QoS tests over a 5G network, according to different Use Case (UC) and User Story (US), as well as agnostic scenarios [5].

The IQ-NPE system collects and processes performance parameters obtained from the probes, and calculates the Key Performance Indicators (KPI) identified in [7]. The system architecture is composed by the following components:

- ISEL QoS On Board Unit (IQ-OBU), which is an hardware and software probe to be installed on vehicles to generate either synthetic traffic or standard ITS messages, and collect performance measurements at different Points Control and Observation (PCO).
- ISEL QoS Fixed Side Unit (IQ-FSU), which is a software agent to be installed on Mobile Edge Computing (MEC), as well as at the ITS centres. The IQ-FSU will be used to generate traffic and collect performance measurements on the network side, on both downlink and uplink traffic flows.
- ISEL QoS Management System (IQ-MS), which is a centralised software platform used to manage the probes, including probe and test plan configuration, and real-time visualization. It will also be responsible for collection of all performance assessment results obtained during test trials.

The system uses out-of-band control connections, based on legacy 3G/4G cellular networks, to manage the QoS Probes installed on vehicles, in order to avoid traffic interference on the 5G access network interface. Depending on the test type, traffic flows can be generated/received by IQ-OBUs, as well as IQ-FSUs.

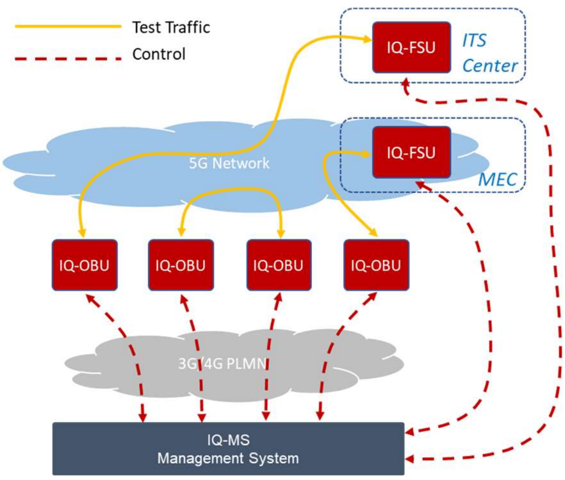

Fig. 3. *IQ-NPE system architecture*

IV. RESULTS

This section presents preliminary results to evaluate the latency performance obtained within the scope of 5G-MOBIX project to evaluate latency performance using directly UDP protocol and transmitting synthetic V2X messages thought the use of a MQTT broker.

UDP latency measurements have been performed by the DEKRA team at Malaga vehicle test track site, on Telefonica NSA 5G network using DEKRA Performance testing platform.

ISEL team has performed V2X over MQTT latency measurements on the NOS 5G network at Lisbon using ISEL QoS Network Performance Evaluation (IQ-NPE) tool.

A. *Synthetic traffic over UDP transport protocol*

The tests included UDP DL and UDP UL measurements at a fixed position (as a first approach to avoid mobility issues), and at different communication rates ranging from 0.5 to 4 Mbps in uplink direction, and from 5 to 35 Mbps in downlink direction. Each test lasted 10 minutes and latency and network conditions results were collected. Mobility results will be addressed in a near future.

The radio signal strength conditions on both the LTE carrier (RSRP) and 5G carrier (SS-RSRP) and the signal quality on the LTE carrier (RSRQ) and the 5G carrier (SS-RSRQ) were collected (see Fig 4). Chipset logging capabilities at the mobile device were used to extract the information. The chipset log information was also analysed to ensure all transmissions during the measurements took place on the 5G carrier.

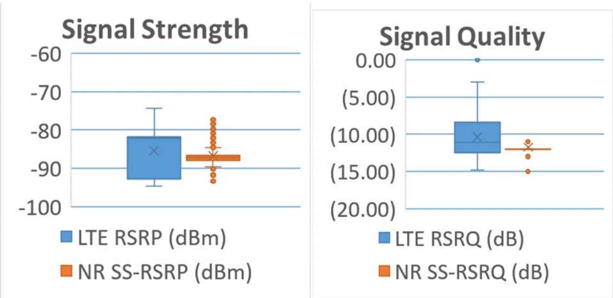

Fig. 4. *Signal strength and Signal quality measurement*

Latency measured as the One-Way Delay (OWD) of the UDP downlink transmission at data rates of 5, 10, 15, 25 and 35 Mbps is shown in the boxplot in Fig. 5.

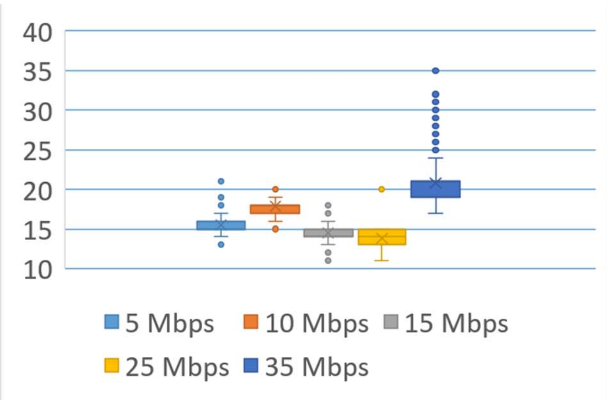

Fig. 5. *One-way-delay OWD (ms) results (UDP DL)*

Fig. 5 shows that the latency values obtained are quite stable and most results range from 13 to 18 ms, independently of the data rate used (best result of 11 ms), but at 35 Mbps, the degradation of the latency parameter is easy to observe. At this data rate, latency ranged from 18 to 22 ms with some measurements reaching values of up to 35 ms.

UDP uplink latency tests were performed at data rates of 0.5, 1, 2 and 4 Mbps and results can be observed in Fig. 6, top side of the figure showing a 'zoomed' view, where the axis limits have been adjusted to display the interquartile range.

The latency values obtained in the UL direction, are around 5 ms higher compared to the DL values. Additionally, high latency outliers appear, which can be related to the uplink scheduler. These outliers happen more frequently as the data rate increases, occurring consistently above 2 Mbps.

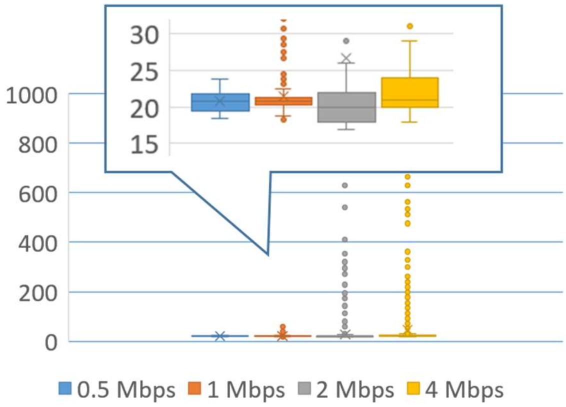

Fig. 6. *One-way-delay results (UDP UL)*

B. *C-ITS messages using MQTT application protocol*

An OBU was placed inside the trunk of a car at a fixed location with four LTE/5G antennas placed on the vehicle's roof, exploiting the MIMO capabilities of the 5G modem used. Synthetic CAM and DENM messages were used. In all the results presented here, a message is generated every 500 ms. Several configurations were tested, namely:

- Three message sizes (200, 400, and 800 bytes).
- Two MQTT broker locations, one in Lisbon, near the test site, and another in London.

Additionally, two message delivering scenarios were tested:

- An OBU publishes to a MQTT broker and subscribes its own message (therefore going through the PLMN two times) mimicking a CAM/V2V communication.
- An FSU publishes to a MQTT broker and an OBU subscribes, mimicking a DENM/I2V communication. In this case, the message will go through the PLMN only once since the FSU is connected to the broker using the internet and not a PLMN radio access.

Several combinations of these variables were evaluated. As these are preliminary results, only the results from a stationary receiver will be shown. Fig. 7.a shows the effect that MQTT QoS (QoS values meaning delivery of message: 0: at most once; 1: at least once; 2: exactly once) has on the latency between the FSU (where the broker is located) and the OBU. The fact that QoS 0 and 1 have the same latency, although counter-intuitive, is justified by the low impact of the subscriber delivery time since, for this test, the broker and the FSU (publisher) are at the same location.

Fig. 7.b shows the effect that QoS has on the message latency between the OBUs (OBU to FSU and back to OBU). As expected, an increase in QoS increases the total latency. From both figures, it can be seen that QoS 0 is suitable for all use cases, with latencies rarely higher than 50 ms, while QoS 1, with latencies below 100 ms, is suitable for all use cases except pre-crash sensing warning. With QoS 2, the latency is always above 100 ms, therefore becoming unsuitable.

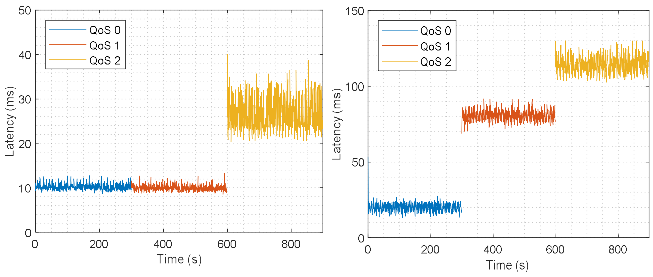

Fig. 7. a) QoS effect on message latency for a stationary vehicle (FSU to OBU), on the left; b) QoS effect on message latency for a stationary vehicle (OBU to OBU), on the right

Fig. 8 shows the effect of the message size. As can be seen, the message size used during the tests does not impact the latency. Considering that most of CAM messages sizes are below 450 bytes 0, the latency could be expected to remain stable.

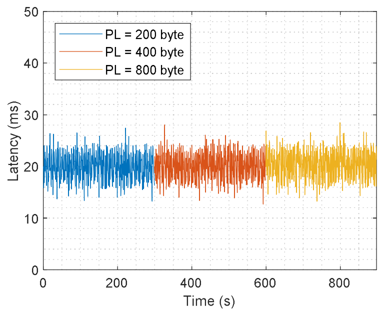

Fig. 8. Payload size effect on latency for a stationary vehicle with QoS 0 and OBU to OBU scenario

Fig. 9 shows the effect broker location. QoS 0 is used. The impact of the larger distance to London's broker location can be clearly seen, as latency values ranging from 2 to 6 times the latency obtained with the local broker are obtained. Also, some latency values exceed the 50 ms required in the strictest used cases. Therefore, the location of the broker in a real implementation must be chosen carefully.

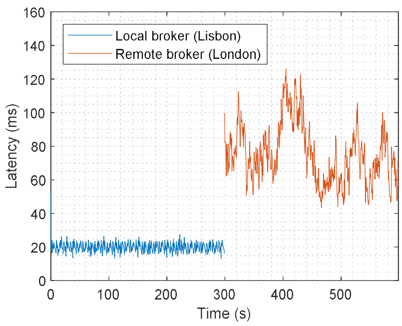

Fig. 9. MQTT broker location effect on latency for a stationary vehicle with QoS 0 and OBU to OBU scenario

V. Conclusions

Two complementary test methods have been proposed to compute the latency of messages used in vehicular communications applications. The test methods seem to be consistent based on the preliminary results. Extensive measurement campaigns should be performed to analyse the impact of the various factors (location of servers/brokers, packet size, influence of existing traffic, impact of mobility, etc.).The measurements performed at the Telefonica network using UDP protocol show uplink latencies around 20 ms and downlink latencies close to 15 ms. Increasing the transmissions rates (above 2 Mbps in uplink and above 30 MHz in downlink) also shows a degradation in latency performance. Most critical are the uplink outliers, which should be characterized so that applications are able to counteract the impact. The replay of these tests has also shown that the values obtained vary between runs, and it needs to be determined which parameters, such as traffic load and data packet size, affect and in which proportion to latency behaviour. The MQTT latency results show the impact on server location/distance and respective latency/jitter variation. Latency values and value dispersion increases when MQTT server is installed in a remote cloud system. MQTT subscriber latency increases when QoS increases, with QoS 2 being unusable for CAM purposes. The MQTT round trip time (publisher to subscriber) for different QoS levels varies around 20, 80 and 120 ms, for 0, 1 and 2 QoS levels, respectively. Therefore, taking the CAM refresh rate, the QoS level 0 should be taken (20 ms).Although the static scenario seems to produce latencies adequate for ITS messages, in a more realistic scenario, mobility will play an important as intra/inter cell handover is expected to introduce extra latencies. This effect will be evaluated in the future.

Acknowledgment

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