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EU-China Joint V2X Trial Results

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***Abstract*—This article summarizes the main research and trial results of the 5G-DRIVE project. The European 5G-DRIVE and Chinese 5G Large-Scale Trial projects were twinning projects that aim to design Cellular Vehicle-to-Everything (C-V2X) assisted automated driving use cases and to trial out these use cases in the field experiments under a harmonized trial framework. One of the main objectives was to benchmark C-V2X connectivity between Europe and China. Evaluating the benefits of C-V2X connectivity at urban intersection use cases has been conducted. The main Key Performance Indicators include coverage range at the urban intersection, packet error rate and latencies which depends on antenna height and channel load. The comparison between long-range LTE/5G and short-range C-V2X/PC5 channels has been conducted. C-V2X provides low latencies (< 40 milliseconds in average) and coverage is less than 800 meters. LTE/5G supports longer ranges but it cannot guarantee latencies less than 70 milliseconds, which reduces safe driving speed to 30 km/h to keep the safety-margin at 0,6 meters.**

Keywords; 5G, V2X, automated driving, C-V2X, latency, automated vehicle

I. EXPERIMENTS

In Europe trial sites, there were three test session during fall 2020 (see. Fig. 1). The aim was to review how the automated driving benefits on C-V2X/PC5 connected driving OBUs and networks available partly today and more widely by 2023. The use cases were intersection related since this is one of the most challenging environments in urban areas and especially left turn at four-way intersection is still unsolved automated vehicle scenario. Intersection is associated to 45 % of all accidents in U.S last 10 years [1]. The selected use cases for testing and benchmarking were:

1. Green Light Optimal Speed Advisory (GLOSA)
2. Intelligent intersection

Fig. 1. Trials in the urban intersection

GLOSA is beneficial application for saving fuel of vehicle and there have positive environment footprint [2]. In intelligent intersection use case, object detection was conducted with using road-side camera and sending Cooperative Perception messages (CPM) of variable size over the available networks. Following the harmonized trial framework, the above selected use cases were also performed in Shanghai, China. The selected Key Performance Indicators were: 1) latency / jitter, 2) packet error rate, 3) bandwidth and 4) network coverage.

A. EU experiments

The test route was about 800 m having one intersection. The equipment consist of the following components: 5G-capable Huawei CPE Pro router for the Ue measurements and 5.9 GHz Qualcomm® Cellular Vehicle-to-Everything (C-V2X) Development Platform for the LTE-V2X measurements [3].

Fig. 2 shows the measured latency histograms for LTE-V2X / PC5 based measurements for different package sizes. Message transmis was performed with maximum speed the software allowed (< 5 ms). The aim was to test how message size would influence network channel performance. The observation is that latencies remain reasonable values (less than 45 ms) when messages are less 400 Bytes whereas bigger message size raises latencies about 10 - 30 %.

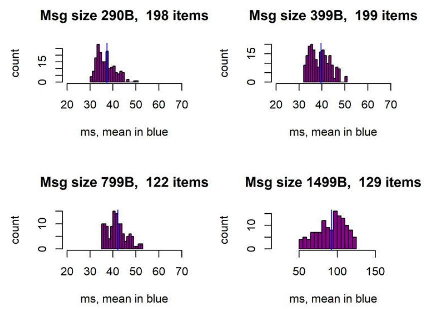

Fig. 2. LTE-V2X latencies for GLOSA message

Fig. 3. shows same results for in the 5G cellular network connection in the same location where LTE-V2X measurements have been conducted. Deviation of cellular network latencies is higher and worst cases latencies can be more 100 ms whereas max latency of LTE-V2X remained less than 55 ms when message size is less than 800 Bytes.

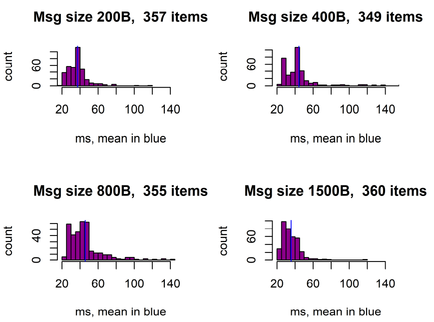

Fig. 3. LTE/5G message latencies for GLOSA message

Table 1 shows summary of the results for trial done with driving fixed speed 30km/h and message transmission interval was 100 ms. Therefore, the measured mean latencies are lower compared to the graphs in Fig. 2 and Fig. 3.

TABLE 1. LTE-V2X AND LTE/5G COMMUNICATION PERFORMANCE IN AUTOMATED INTERSECTION DRIVING

	LTE-V2X				LTE/5G			
Packet size [Byte]	250	500	750	1000	250	500	750	1000
Mean latency [ms]	15	15	13	13	43	58	61	50
Jitter [ms]	5	9	6	6	20	23	26	14
Number of messages	662	596	550	623	665	847	512	829
Max communication distance [m]	294	284	299	285	282	328	268	299
Packet error rate [%]	0	0	2	6	0	0	0	0

The test located behind the small hill where altitude variance is about 2 meters. Antenna height was adjusted which mainly influenced the availability of line-of-sight. The additional tests indicate that maximum latencies decreased from 55 ms to 50 ms by raising the antenna of RSU 1,4 meters higher.

B. China experiments

In China trial sites, the C-V2X experiments in Shanghai can be divided into three categories: interoperability tests between different vendors, V2I/V2V (C-V2X technology) coverage tests, and finally, LTE-V2X (PC5) performance tests. The interoperability tests between different terminal (RSUs and OBUs in this case) vendors are performed under the GLOSA use case which confirms the interoperability. Under non-line-of-sight condition, the coverage tests showed that the RSU's coverage could be around 800 meters. The packet loss rate (PLR) significantly increased when two OBU devices were 450 meters apart, which indicates the communication range in this case is around 400 meters. The LTE-V2X performance showed the average end-to-end latency was within 25 ms and the PLRs of all receivers are less than 10%, which confirms the performance reliability of the LTE-V2X and devices. The scaled-up performance tests with twenty RSU/OBU stations showed that the average latency was less than 38 ms and the PLR was less than 10%.

II. USER ASPECTS FOR AUTOMATED DRIVING FUNCTIONS

An extensive and detailed amount of use cases (UC) have been already defined for the connected vehicle (e.g. [4], [5]). They try to cover and analyze most possible situations a connected vehicle might face when in operation. A classification was done to differentiate the UC regarding which aspects they cover. It includes important future needs such as safety, traffic efficiency and autonomous driving.

When defining the UC, the focus lay in the improvement of the user's experience, the safety of the system and its compatibility with actual and future systems. It shall be defined disconnected from any specific technology to ensure its applicability is not affected when evolved or just different systems are developed in the future. In the UCs, not only the User Story is detailed, but the Service Level Requirements (SLR). They ensure that the use case performance is as intended when such experience was developed. They also guarantee users' best experience and uncompromised safety.

Since the topic is connected vehicle, some are vehicle related (position, velocity, density of vehicles) and others are related to the communications (range, latency, bandwidth, service reliability). The focus of the tests presented in this paper were the SLR position (vehicle related requirement) and latency (communication requirement), since both are some of the most common requirements in all UC and they can severely impact the performance of any system.

III. CONCLUDING REMARKS

Although the C-V2X experiments were performed in Europe and in China, the 5G-Drive and 5G Large-scale twinning project jointly designed C-V2X use cases, defined KPI and carried out experiments under the same framework. The following key findings were found: When the trial configuration parameters and road test environment are similar, the chosen KPI metrics (mean end-to-end latency and the PLR) share few similarities in C-V2X tests, despite some initial differences, such as differences in the message type, equipment, and terminal providers. The latencies at both the Finnish and Shanghai sites experienced degradation when the user stations (emulated or physical) increased from a single to multiple stations. The message size and antenna height were also proven to be of impact to the latencies.

IV. ACKNOWLEDGMENT

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