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# Influence of infrastructure antenna location and positioning system availability to open-road C-V2X supported Automated Driving


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***Abstract*— Automated driving has attracted enthusiasm worldwide with its potential to transform mobility and realize transport, economical and societal benefits. Gaining perspectives from previous V2X trials in 5G-Drive project, this paper is motivated to focus on two challenges encountered with LTE-V2X enabled automated driving: the impact of infrastructure antenna height in C-V2X supported automated driving and the influence of C-V2X in vehicle positioning, especially when satellite signals is unavailable. Two trials have been designed and performed in Finland, as an attempt to continue and examine the two LTE-V2X enabled automated driving use cases in previous V2X trials. The outcome shows C-V2X latency is affected when antenna height is low. Optimizing and configuring the antenna height is crucial in C-V2X enabled automated driving tests. Important lessons on RTK, Inertial and C-V2X enabled automated vehicle positioning are drawn from the trials, where the enhancement of C-V2X could be augmented by testing and strengthening the GNSS signals.**



***Keywords*— *Automated Driving, C-V2X, LTE-V2X, latency, antenna height, GNSS, signal, positioning***


## I. Introduction and Motivation

In the past twenty years, automated driving has risen fast due to the rapid growth of technologies and microprocessor capacity, such as cooperative perception system and the vehicle on-board sensors, which utilize such related technologies like RADAR, LiDAR, camera, GNSS and telecommunications. Although current research is inconclusive due to low penetration rate of Automated Driving (AD) and the biased ideal AD test conditions, early studies have shown that automated driving' lower crash rate comparing to conventional driving cannot be ruled out [1]. Automated vehicles typically rely on on-board sensing systems, which is limited in practice to less than 120 m surrounding of the vehicle and insufficient for driving on motorway [2]. With low latency and high-reliability, C-V2X (cellular Vehicle-to-Everything) is the state-of-the-art solution to extend the coverage and improve perception range of automated driving. The evolution of C-V2X coincides with 5G New Radio (5G NR) because C-V2X uses 3GPP (The 3rd Generation Partnership Project) 4G (The fourth generation) LTE (Long-Term Evolution) or 5G (The fifth generation) NR connectivity to transmit and receive signals. Two transmission modes: direct communication and cellular network communication of C-V2X can enable vehicles to transmit and receive information about its surrounding traffic conditions with other vehicles, pedestrian, infrastructure, and network. These C-V2X benefits motivate 5G-Drive (Horizon 2020 project) to study and trial V2X experiments with 3GPP Rel-14 conformed LTE-V2X devices (On-Board-Unit (OBU) and Roadside-Unit (RSU) for direct communication mode) on open-roads automated driving in Finland, as an attempt to examine the potential of low latency and influence on positioning system of LTE-V2X communication in terms of road safety benefits to automated driving.

## II. System Architecture of LTE-V2X Enabled Automated Driving

Originated from two use cases (Intersection safety and GLOSA: Green Light Optimal Speed Advisory) in 5G-Drive V2X trials, this paper presents C-V2X performance in C-V2X supported AD on open-road, and its impact on AD navigation and positioning system. The latter sets up AD navigation and positioning trials in densely built area with underground parking hall to test vehicle positioning error correction and C-V2X impact on various positioning methods. The former one was initiated with two use cases in previous trials. Figure 1 is the system architecture of both use cases [3]. The key components in this architecture are: Connected and Automated Vehicle (equipped with LTE-V2X OBU), a pedestrian (the Vulnerable Road User), a traffic camera (overviewing intersection and the zebra line), Traffic Light Controller (installed on Mobile Edge Computing system and equipped with LTE-V2X RSU), Backoffice server, and related software tools.

The Intersection safety use case starts with the traffic camera detecting and tracking the pedestrian. Such information is processed in the Backoffice. The RSU that is connected to Backoffice, transmits Decentralized environmental notification message (DENM) messages to the surroundings, such as to the approaching and turning vehicle with risk of blind spots. CAM Messages are being transmitted from the LTE-V2X OBU (integrated in the test vehicle) to

RSU. This use case is intended to trial out enhanced safety of AD by integrating C-V2X and measure the latency of LTE-V2X sidelink communication (Mode 4) between RSU and OBU via the PC5 interface.

The GLOSA use case is straight-forward. When the test vehicle is approaching the intersection from a designed route, the LTE-V2X RSU (connected with the traffic light controller) transmits Signal Phase and Timing (SPaT) messages to indicate time-to-green. Speed advice to pass the intersection during green light can be calculated based on the ego vehicle position. The GLOSA use case intends to prevent higher cognitive load than manual driving by preventing stopping of test vehicle, so that the traffic safety, traffic efficiency and AD comfort level can be increased.

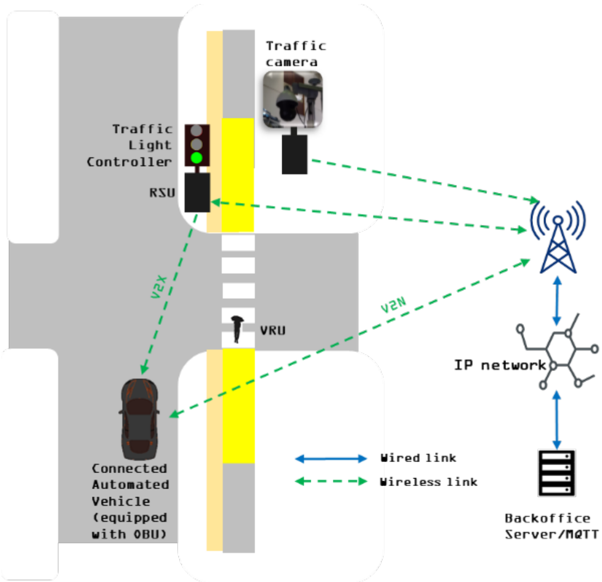


Fig. 1. Architecture of Inteligent Intersection and GLOSA use cases.

## III. PROBLEM DEFINITION OF LTE-V2X ENABLED AUTOMATED DRIVING

When considering the cellular network and its coverage availability in major European cities, an average latency of 50ms, which means 0.7 meter is reachable (e.g., urban area with vehicle speed 50 km/hr). However, in some cases, the latency may jump to 150-350 ms which means about 3 meters longitudinal movement before error correction is available via cellular network connection. With the acceptable level of 0.2 meter to ensure proper safety margin, this is of course far from acceptable level.

3GPP set the latency and reliability requirements of specific services for LTE-V2X to 20ms for latency sensitive use cases such as V2V application (e.g., pre-crash sensing) and to 100ms for most V2V/P/I applications [4]. For a high level of automation, 3GPP requires messages to be exchanged between vehicles with less than 10ms latency and 25ms for a low level of automation. The stringent latency requirements for AD are due to stricter safety margin and high positioning accuracy prerequisite of AD.

In 5G-Drive V2X trials (April 2019-Dec 2020), the two use cases in section II were performed and the average end-to-end latency are measured. The results showed the average latencies in both use cases were between 25ms to 32ms when there were ten emulated stations transmitting messages (message size 250 byte). This paper focuses on two challenges that are encountered during the V2X trials.

### *A. LTE-V2X enabled automated driving - Antenna location challenge*

To ensure the performance of a V2X system, certain KPI requirements must be met. Being the most used to evaluate the quality of a network the packet-error-rate (PER), the latency and the jitter were measured throughout the trials. Previous studies clearly showed the degradation of a radio link. Therefore, the PER of a system within line-of-sight is used in some regions to determine the minimum range of a C-V2X system (e.g. [5]).

Being a wireless communication system, the V2X system performance is heavily influenced by the position of its antennae. Such performance could be simulated via radio propagation models but, as discussed in [6], the use of models such as the free-space and the two-ray ground model cannot properly do it. That is due to the distances constrain (short range communication) where C-V2X operates and its extreme complex scenarios with different surfaces, reflection on other vehicles moving in different directions, scattering in vegetation, etc. The above reasons emphasize that testing in real-life conditions is extremely valuable to evaluate the quality of the network.

### *B. Automated vehicle positioning issue - Error correction challenge*

Vehicle positioning via GNSS is the most prevalent and lack of GNSS satellite signals visibility in some areas are quite common. In underground parking halls where total satellite signals are blocked; road tunnels and building areas where signals are partially blocked, signals multipath propagates, causing lower positioning accuracy or even the lack of the location information.

Out of GNSS signal, the Inertial Measurement Unit (IMU) in combination with RTK (real time kinematics) creates temporary relief, based on 5G-Drive project test results in 2020. Figure 2 shows the automated vehicle driving route in Otaniemi area, Espoo. GNSS signal in the underground parking is unavailable (red). In this situation, GNSS positioning with open view suffering from scattering and reflections (green). The red line has no GNSS signal (underground), but thanks to IMU's support, position is still tracked to assist the automated vehicle positioning. C-V2X communication could bring more help to supporting inertial navigation system when IMU's accumulative errors in positioning increase over time and the position accuracy is weakened.


Fig. 2. Good GNSS positioning accuracy and IMU's support in underground parking area with weak signal (green >2m and red <0.5m).

However, the C-V2X enabled RSU and OBU transmit and receive CAM messages with information such as current location, speed etc., which is a potential solution to overcome the above challenge and provide a mean for error correction. The field trial findings indicate that GNSS satellite signals are utilized to ensure the C-V2X stack starting correctly. GNSS-based location information (longitude and latitude) is part of GeoNetworking protocol-based messages routing. Although GNSS-based location can be overruled with a fixed location, missing GNSS satellite signals generating issues with C-V2X stack and limiting possibilities to manage devices. Since GNSS signals does not exist underground and all radio connectivity will be a challenge inside, C-V2X positioning support by utilizing RSU would have limitations in practice.

## IV. Approach and Test Arrangements

Targeting the two challenges, this section provides the test arrangements for both experimental trials.

### *A. Test site and Equipment - LTE-V2X enabled automated driving*

The tests in Finland were carried out in a specific public area that is dedicated for the development and validation of automated driving sub-systems. The test route is about 350 meter long, including a hill, pedestrian crossings, and a four-way intersection (see Figure 3).

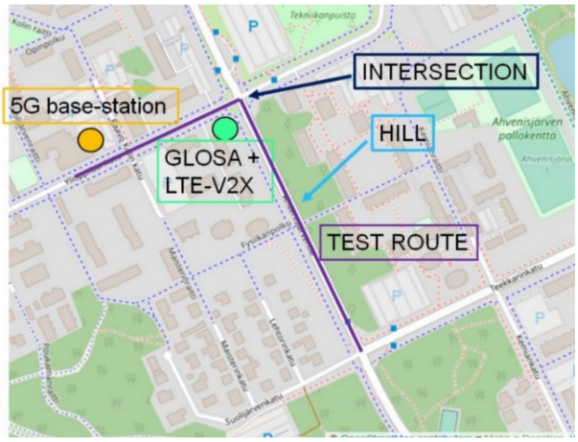


Fig. 3. The test intersection for C-V2X supported automed driving in Tampere, Finland.

The C-V2X equipments used in Tampere site were the 5.9 GHz Qualcomm® Cellular Vehicle-to-Everything (C-V2X) Development Platform. The used antenna in this setup were NMO4E5350 from PulseLarsen Antennas. The measurements conducted with three different antenna height installations on trailer: 1.4 meter, 2.8 meter and 3.8 meter. Such heights were chosen to represent the most common positions where a C-V2X antenna could be installed, being the average height of a vehicle, a roadside traffic light height and an over-the-road traffic light gantries height respectively. Test vehicle 'Martti' had a fixed height for all measurements, 1.8 meter. Both the test vehicle 'Martti' and the trailer 'Marsu' were equipped with the same hardware.


Fig. 4. Variable antenna height installations in C-V2X trials. Roadside installations (left); roof rack installations on test vehicle 'Martti' (right).

### *B. Test site and Equipment - Automated vehicle positioning issue*

For these tests Otaniemi area in city of Espoo was used. The test site was selected with the availability of a building area, small forests, and big and underground parking hall, tens of meter underground inside bedrock. Interesting to note that there were no high-rise buildings in place, although ground-level differences create difficulties for ground-based radio signaling.

Vediafi's test lab vehicle was used for tests. The RTK device and LTE-V2X OBU were integrated to the vehicle, while the LTE-V2X RSUs were installed at stationary position inside the parking hall and at the entry of parking hall.

## V. Experimental Results and Discussion

### *A. Results from variating antenna height*

Table 1 presents the measured values with different RSU antenna heights with constant driving speed and 100 ms message interval. During the trial, the test vehicle was approaching the RSU at constant speed 30 km/h and was sending UDP messages with constant 100 ms message interval. Total number of sent messages per measurement drive was around 400. Latency values are below 30 ms with antenna height 3.8 meter. Jitter is calculated using 5-samples moving median window and almost all values are slightly below 10ms. When the antenna height was low (1.4-meter height), the test arrangement became non-line-of-sight due to the intersection topology. Heavy scattering due to trees on both sides of the road and climatic conditions such as rain fade also affected the latency and packet loss rate. However, packet loss values are remarkably low when the used antenna height was 3.8 meter. In conclusion, higher antenna installations show better performance results, specifically in this environmental test setup, where RSU was on top of a small hill and line-of-sight was achieved with the antenna height 3.8 meter. The maximum distance for 750B message is consistently (around 21%) shorter comparing to 250B. Since distance is a major contributor to the error in the transmission and data analysis shows that most of errors are located in the farther parts of the test route, which is a possible reason for the lower PLR in 750B cases.

TABLE 1 THE MEASURED VALUES FOR THE C-V2X CONNECTION WHEN RANGE IS BELOW 400M, DRIVING SPEED 30 KM/H AND MESSAGE INTERVAL 100MS

| Antenna height in RSU [m] | Message size [bytes] | Latency mean [ms] | Jitter [ms] | Maxdist [m] | Packet Loss Rate [%] |
|---|---|---|---|---|---|
| 1,4 | 250 | 35 | 9 | 385 | 32 |
| 1,4 | 750 | 33 | 12 | 311 | 12 |
| 2,8 | 250 | 30 | 9 | 368 | 19 |
| 2,8 | 750 | 32 | 9 | 288 | 11 |
| 3,8 | 250 | 26 | 8 | 373 | 9 |
| 3,8 | 750 | 27 | 7 | 305 | 7 |

### B. *Results from enhanced accurate positioning of C-V2X automated driving*

#### *1) Baseline results*

RTK is losing positioning immediately when GNSS signals are not existing, with Inertial input direct driving keeps positioning relatively accurate until first turns. As time propagates and vehicle performs more turning manoeuvres, inertial (Dead Reckoning) losing position accuracy.

#### *2) Enhancement results*

##### *a) C-V2X*

RSU and OBU communication is extremely limited without GNSS coverage. Normal GPS positioning accuracy is not enough for lane level especially inside densely built areas, indoors and normal parking halls. Underground parking areas without any visibility to satellite signals position accuracy does not exist at all and inertial (Dead Reckoning) accuracy is fading with distance and turns.

Table 2 is the results overview of C-V2X improvement regarding each GNSS method and fix. In densely built areas, the results show that C-V2X positioning improvement is limited, when a single C-V2X-RSU and a moving vehicle equipped with RTK float accurate positioning and C-V2X OBU were used in the trials. Table 2 shows the complete list of trial combinations between C-V2X and each GNSS method. The rightmost column shows the C-V2X improvement (in meter) for each GNSS/Inertial method.

TABLE 2 THE MEASURED VALUES (ELLIPSE CONFIDENCE AND C-V2X IMPROVEMENT) FOR DIFFERENT GNSS METHODS

| GNSS method and fix in built areas | Position ellipse confidence (Major) (meter) | Position ellipse confidence (Minor) (meter) | C-V2X accuracy improvement (meter) |
|---|---|---|---|
| RTK fix | 0.5 | 0.3 | none |
| RTK float | 10.21 | 7.27 | Limited |
| GPS | 27.62 | 5.36 | Limited |
| Dead Reckoning (Inertial), after last known position fading | Large / n.a. | Large / n.a. | 20-50 (position circle within narrow parking area driving lane) |
| No satellites signals, no base position | No position/n.a. | No position/n.a. | 20-50 (position circle within narrow parking area driving lane ) |

##### *b) GNSS Repeater*

With GNSS repeater possibility to get satellites signal underground (GNSS repeater would be ideal and validation still to be done). Underground 5G network coverage still needs to be tested for the "synchronization" of RSU and OBU to keep communication working. With multiple RSUs, the possibility to chain GNSS information from not covered area and the possibility to calculate moving vehicle OBU location should theoretically increase the positioning accuracy by multiple connection points (triangulation of a signal). Lack of multiple RSU leading this to be more theoretical approach.

## VI. CONCLUSIONS

This article indicates that antenna height has significant influence of availability of C-V2X devices. The trees, buildings and geography of the roads create more influence when antenna height is low. High frequencies (5,9 GHz) are very sensitive when light-of-sight (LoS) is not available and therefore packet error rate may increase from 7 % up to 32 % in real world scenarios when operating in the areas having hills and trees blocking LoS to the base station. The enhanced accurate positioning showed limitation when GNSS signals are unavailable or unstable. The problem is that additional latency of having error correction for positioning signal, gets higher and more inaccurate, which eventually preventing any automated driving functions to be running properly.

As an outlook for the future trials and studies, 3GPP Rel-16 [7] also shows that lower latency values (<1ms) can be achieved using higher numerologies, even when using a 14-symbol slot. This is instrumental for automated driving, especially with the 5G NR development in the foreseeable future when C-V2X's full potential is realized.

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