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Next-generation wireless networks for V2X

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***Abstract*— EU-China 5G collaboration trials will be conducted addressing two specific scenarios: (1) enhanced Mobile Broadband (eMBB) on the 3.5GHz band; and (2) Internet of Vehicles (IoV) based on LTE-V2X using the 5.9 GHz band for Vehicle-to-Vehicle (V2V) and the 3.5 GHz band for Vehicle-to-Network (V2N). This paper discussed scenario 2, and presents the use cases based on next generation communication technologies in the domain of Cooperative Intelligent Transport Systems (C-ITS) for cooperative and automated road transport. In addition, it describes for each use case the developed physical architecture. Finally, it provides an overview of the joint V2X trials to be conducted in the EU and China, in the context of the 5G-DRIVE project.**

I. INTRODUCTION

The European Union and China are cooperating on 5G (the fifth generation of mobile communications technology) in the context of the EU-funded project 5G-DRIVE (Harmonise*D* Research and Tr*I*als for ser*V*ice *E*volution between the EU and China) under Horizon2020 [1]. One of the key activities in this research project is the realisation of joint trials in the two regions. These trials will address two specific scenarios: (1) enhanced Mobile Broadband (eMBB) on the 3.5GHz band; and (2) Internet of Vehicles (IoV) based on Long Term Evolution Vehicle-to-Everything (LTE-V2X) using the 5.9 GHz band for Vehicle-to-Vehicle (V2V) and the 3.5 GHz band for Vehicle-to-Network (V2N). In this context, one of the key challenges is to develop joint trials aimed at demonstrating technologies and system interoperability for a number of core applications of interest in the EU and China, as well as to validate the interoperability between the EU and Chinese 5G networks.

To create momentum for early 5G adoption, the trials have the following objectives:

1) To test and demonstrate the latest key 5G technologies in the eMBB and V2X scenarios in pre-commercial 5G networks. This activity will be conducted through extensive twinned trials in Europe and China for evaluating synergies and interoperability issues, as well as for providing recommendations for technology and spectrum harmonisation.

2) To conduct research on key innovations in network slicing, network virtualisation, 5G transport network, edge computing and 5G-New-Radio (5G NR) features, and to fill the gap between standards and real-world deployments.

3) To stimulate EU-China 5G collaboration at all levels through active involvement of mobile operators and industry, including a prominent car manufacturer, SMEs and academia. One of the main goals of 5G-DRIVE is to trigger the roll-out of 5G networks and V2X innovative solutions driving new business opportunities.

4) To investigate the robustness of the technology in view of future scenarios like automated vehicles. These scenarios will require much higher bandwidth, better access to the communication channel and lower latency.

The paper discusses scenario 2. The development of Cooperative Intelligent Transport Systems (C-ITS), also referred to as connected vehicles, started around 15 years ago [2-6]. The competing access technologies, i.e. WLAN-based and cellular-based communication, are very different in their philosophies. Short-range communication [7] would provide connectivity between neighbouring vehicles to vehicle position and velocity, and other information from vehicle sensors, e.g. concerning obstacles on the road or road surface conditions. The idea was that this would enable a whole range of new safety and driver comfort applications. Also other road users, especially vulnerable road users such as pedestrians and cyclists, could participate in such connectivity, now that smartphones have become widespread [8].

The paper is structured as follows: Section 2 describes the V2X use cases in the domain of C-ITS. Section 3 presents the physical architecture for each one of the V2X use cases. Section 4 proposes the plan for the joint trials. Section 5 outlines some preliminary results. Section 6 provides a discussion on 5G for V2X applications. Finally conclusions are drawn in Section 7.

II. V2X USE CASES AND KEY PERFORMANCE INDICATORS

A. Green Light Optimal Speed Advisory (GLOSA)

GLOSA provides drivers an optimal speed advice when they approach a signalized intersection. This advice may involve recommendations to maintain the actual speed, to slow down, or to adopt a specific speed different from actual. If a green traffic light cannot be reached in time, GLOSA may also provide time-to-green information when the vehicle is waiting at the stop line. The GLOSA application processes real-time traffic sensing and infrastructure information, and communicates the result to a vehicle with the aim to reduce fuel consumption and emissions. [9-10].

Fig. 1. An LTE-V2X GLOSA demonstration by China Mobile, Huawei and ASTRI (5G-DRIVE EU-China joint kick-off, Wuxi (China), November 2018).

Relevant KPIs (Key Performance Indicators) for this use case are: 1) Packet Error Rate (PER): ratio of unsuccessfully received packets in the on-board unit (OBU) vs. total number of packets sent by the roadside unit (RSU) (as a percentage). 2) Latency: the radio access network contribution to the total elapsed time, measured from the moment when the RSU sends a packet to the moment when the OBU receives it (in ms).

B. *Intelligent intersection*

This use case deals with road safety on intersections, focusing on infrastructure detection of situations that are difficult to perceive by vehicles themselves. A good example is the situation where a vehicle intends to make a right turn, while parallel VRUs (Venerable Road Users) also have a green phase and right of way (permissive green for motorized traffic). The situation is depicted in Fig. 2.

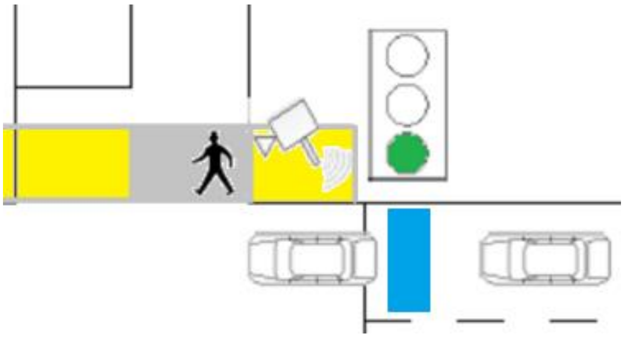

Fig. 2. Perception areas of the intelligent intersection.

When a pedestrian is detected in the grey area, a Decentralized Environmental Notification Message (DENM) shall be broadcast by the RSU, while the backoffice shall geocast this to all vehicles in the vicinity. This is to warn vehicles further upstream that a potential conflict may occur downstream and to prevent hard braking as a consequence of this. Other DENMs can also be tested, as the message supports various warnings. Depending on the complexity of the warning, the message can have a different length, which can result in different results with regards to communication performance. It should be noted that the focus of the use case is not on the Human Machine Interface (HMI), but on the V2X performance and that situations on the test tracks will be mostly emulated, in order not to put real pedestrians at risk, and to ease requirements on timing the approach of the vehicle.

The GLOSA and the intersection scenario were adopted as the main use cases for the 5G-DRIVE project. The main motivation is that these use cases have already been adopted by the ETSI standardisation body when formulating message formats for 5,9 GHz ITS channels. Since there are already benchmarking results available in the ITS-G5 environment, the benefits C-V2X can be compared to benchmarking level of the existing DSRC capabilities. Even if bandwidth requirements are not high, latencies are critical for the intersection use case, since speed is typically more 40 km/h and cars and pedestrians have crossing trajectories.

The KPIs for this use case are: 1) Packet Error Rate (PER): ratio of unsuccessfully received packets in the OBU vs. total number of packets sent by the RSU (as a percentage). 2) Latency: the radio access network contribution to the total elapsed time, measured from the moment when the RSU sends a packet to the moment when the OBU receives it (in ms). 3) Number of active stations: This KPI tracks how many other stations were active at the same time while in communication range of the test subject. 4) Total channel load in MB/s: The total load of the channel is an important contextual variable to determine how much interference can be expected. 5) Number of messages per second on the channel: One other client using a load of 1MB/s has much less chance of packet collisions than a hundred clients transmitting at 10 KB/s.

C. *Collaborative perception and manoeuvre coordination*

This includes two use cases that target cooperative and automated vehicles directly. The first imposes requirements on bandwidth for sharing sensory information via a Collaborative Perception Message (CPM) [11]. The sensors on automated vehicles may substantially extend the capabilities of infrastructure sensors alone, potentially resulting in many object detections from many different angles.. The message does not only contain detected objects, but also data about the sensor capabilities. This enables receivers to evaluate the quality of the detections and draw conclusions about areas where no objects were detected. All this information will lead to large messages being broadcast to assist all V2X nodes with getting a complete image of their surroundings even in case of sensor obstruction by another object. In this research, this use case will be applied to the intersection scenario of a right-turning vehicle with parallel VRUs, as described in Section II B (and as depicted in Figure 2), but this time, sharing of object detection enables anticipating action. A DENM is intended for warnings, so a pedestrian that is on the sidewalk (yellow areas in Figure 2) would not warrant a warning, even if a crossing manoeuvre were imminent. Infrastructure and other vehicles shall send out Collaborative Perception Messages (CPM) with this detection instead.

The other use case focusses on channel access with the Manoeuvre Coordination Message (MCM) [12]. This supports negotiation of right of way and yielding, and can result in large numbers of smaller messages being sent, which is a different kind of challenge for a communication network. It can also be used for very detailed instructions from the infrastructure to the vehicles, such as for a lane change advice.

The KPIs for these use cases are the same as for the previous: PER, latency, number of active stations, bandwidth and number of messages per second on the channel. The challenge of the CPM is with the bandwidth, while the challenges for the MCM are with the number of active stations and the message rate.

III. ARCHITECTURES

A. *Architecture for GLOSA trial*

The physical architecture of the GLOSA (Green Light Optimal Speed Advisory) use case is depicted in Fig. 3.

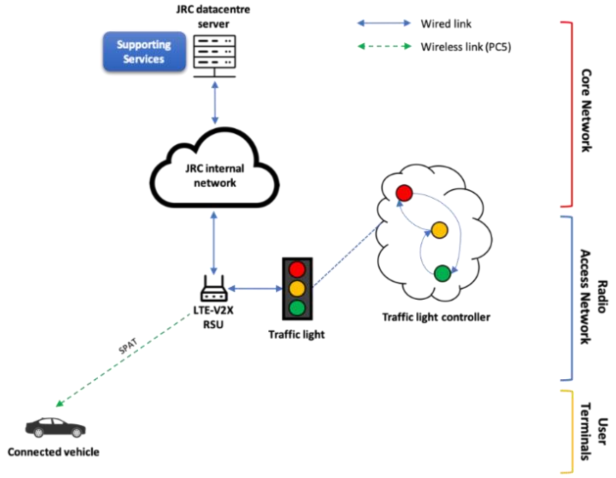

Fig. 3. The GLOSA physical architecture at the JRC Ispra site.

As shown in the above figure, the key architecture elements of this use case are the following:

1) A physical or virtual traffic light and its associated controller to orchestrate the transitions between the "red", "amber" and "green" states. For the purpose of experimentally evaluating this use case, the traffic light can be either physical (i.e., a commercial, end-user product) or virtual (a software running on or communicating with the LTE-V2X RSU and implementing the transitions described in the controller).

2) An LTE-V2X RSU co-located with the traffic light (if physical) or running/communicating with the FSM implementation (if virtual). The RSU will periodically broadcast Signal Phase and Timing (SPaT) messages (e.g., every 100 ms) to all neighbouring vehicles. Amongst other, SPaT messages will include the traffic light's current state and FSM timing information.

3) LTE-V2X OBUs deployed in the test vehicles. The OBUs will receive and process the SPaT messages locally to compute the relevant GLOSA information in various forms (e.g., remaining time until next traffic light state transition, optimal speed to reach traffic light in green state). Once computed, the GLOSA information will be relayed to an on-board laptop (or UI device), where it will be displayed both visually and audibly to the driver.

4) The JRC internal communication network will provide connectivity between the LTE-V2X RSU and various supporting services running in the JRC data centre (e.g., experiment management console, traffic light controller, log server)

5) Physical/virtual servers at the JRC data centre running the above supporting services. For the purpose of implementing and experimentally evaluating this use case, these servers can be either physical or virtual (Virtual Machines (VMs)).

B. *Architecture for intelligent intersection trial*

The physical architecture for the intelligent intersection is similar to the GLOSA architecture, with the exception of not using an internal network, but likely a VPN to connect the back office to the RSU, and the Traffic light not present. A functional view of the architecture is shown in Fig. 4. The red dashed lines are eMBB wireless communication lines, while the green dashed lines concern V2X local communication.

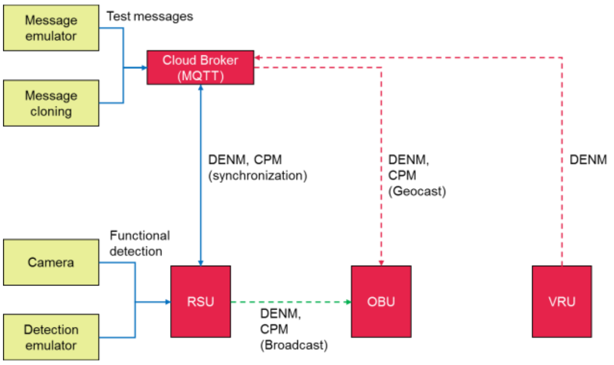

Fig. 4. Functional architecture of the intelligent intersection use case.

IV. JOINT TRIALS

The trials are divided between joint EU-China trials and EU trials. The first focus on interoperability and potential differences in performance, while the latter examine capabilities in more detail. The EU trials are listed in Table 1.

The environment will be increasingly more difficult with each trial in order to see under which conditions the KPI target can still be achieved. In the case of the CPM and MCM, the main KPI is actually directly influenced by the environment. Increasing the number of stations directly increases the bandwidth. At the same time, the PER and latency targets are treated as constraints. Depending on the results, the environment settings can still be adjusted for those tests in order to find the precise threshold value of the KPIs.

Table 1: European trails

Trial	*Environment*	*KPI targets*
DENM V2I	5/10/15/20 DENM stations 50/100/150/200 CAM stations	PER < 1% Latency < 10 ms
GLOSA V2N	100/200/300/400/500 CAM stations	PER < 10% Latency: MAP < 5s, SPaT < 2s
CPM V2X	80/100/120/140 CAM and CPM station	PER < 10% Latency < 100ms Bandwidth > 1.6 Mbyte/s
MCM V2X	100/200/300/400/500 active CAM and MCM stations	PER < 10% Latency < 100ms Active stations >=300

Note:
CAM - Cooperative Awareness Message
CPM - Collective Perception Message
DENM - Decentralized Environmental Notification Message
MCM - Manoeuvre Coordination Message
PER - Packet Error Rate
SPaT - Signal Phase and Timing

The table only shows a summary of the planned trialling activities. Sub-scenarios are also defined for different V2N architectures, and there are also V2V variants of the V2X scenarios. In general, the infrastructure has a better antenna with a better placement, which can lead to different effects. A whole set of security and coexistence trials have also been defined. These coexistence tests focus on simultaneous use of 802.11p, tolling systems and LTE-V2X systems. The security looks into privacy and channel jamming attacks.

For the Joint EU-China trials, there are a few challenges. The first one is the use of the message sets, which is the CSAE instead of the SAE. This means that for instance Basic Safety Messages (BSM) are used instead of CAM and MAP, while instead of SPaT and DENM also different messages are used inside the CSAE framework. A message converter will be made by 5G-DRIVE to cope with this issue. The lower layers of the OSI (Open Systems Interconnection) model should of course be the same, but settings should be agreed upon to ensure using the same channels..

V. PRELIMINARY RESULTS

The preliminary results have been acquired from the specific LTE test network located in Tampere, Finland. The network is LTE based, operating in BAND 38 (2575 - 2615 MHz). The site is also equipped with ITS-G5 devices for capturing reference performance indicators. The Reference Signals Received Power (RSRP) measurements are illustrated in Fig. 5.

One of the KPIs is to understand coverage and availability of the 5G networks which in the twinning project led by China Mobile is 2.6 GHz band, thus the same as the Tampere-network frequency. It is obvious that the signal coverage drops quickly away from the base-station. When the signal level has dropped to -90 dB, the network becomes basically useless for transport and automated driving needs, for which coverage and low latencies are critical to guarantee safe and remotely supervised real-time driving.

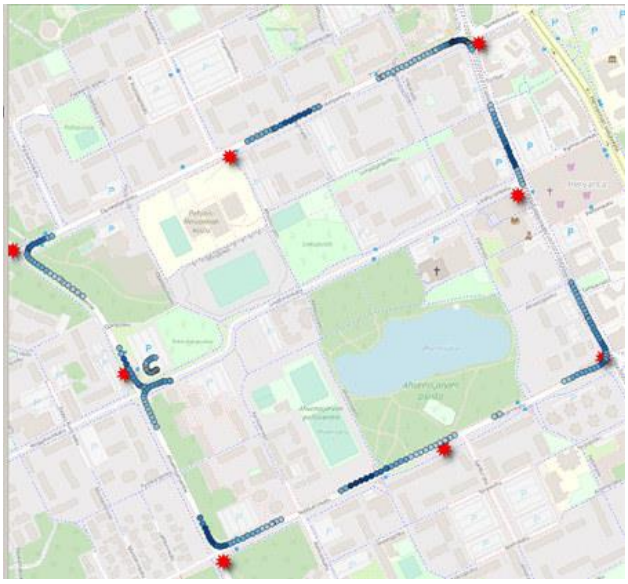

Fig. 5. LTE 2.6 GHz network signal coverage measurements

In the context of the China - Europe collaboration, the research comprises two parts: 1) LTE/5G Uu - Ue communication using the 2.6 GHz band; and 2) PC5-based direct C-V2X communication using the 5.9 GHz band.

MIIT (the Ministry of Industry and Information Technology of China) has allocated 2.515-2.675GHz, 3.4-3.6GHz, 4.8-4.9GHz to different operators for 5G testing [13]. The China-Mobile band of 2.6 GHz is aligned with the LTE band in Tampere, Europe. Therefore, network speed and latency tests can be carried out even if handshaking in the China-5G network is different compared to the European LTE network. Another issue is that the SPaT messages are transmitted in a different format (as mentioned above). China uses BSM (Basic Safety Message) whereas Europe uses DEMN.

MIIT has allocated the 5.905GHz-5.925GHz band for PC5-based communication for On-Board Units (OBU) and Road-Side Units (RSU). Europe has adopted to use the 5.875-5.905 GHz band, which is a different band and therefore requires different radios. Some of the existing devices are overlapping between these bands which enables parallel testing with similar devices to be conducted.

VI. DISCUSSION

The fifth generation of wireless networks (5G) is not just an evolutionary upgrade of the previous generations of cellular communications, but rather a revolutionary technology envisioned to meet the access, bandwidth, performance, and latency requirements associated with various vertical industries [14-15]. As the 5G-based V2X is currently under standardization by the 3GPP (The 3rd Generation Partnership Project), the current research mainly tests use cases based on LTE-V2X technologies. However, since cooperative and automated driving is one of the test cases in this study, the research will closely monitor the progress of 5G-V2X development in 3GPP Release 16, and test the performance of 5G V2N through gNBs deployed at the trial site. In the following, we briefly introduce why we need 5G-V2X and what extensions we expect from LTE-V2X.

LTE-V2X is mainly designed for automotive safety. It has the inherent limitations on bandwidth, latency and reliability to support new features, particularly autonomous driving, in V2X applications. The coordination and information sharing in automated driving will easily require a data rate up to 1 Gbps, a latency of 3-10ms in communication. To overcome the limitation of LTE-V2X, in the 3GPP Release 15, the PC5 interface of LTE-V2X, which is used for the sidelink in V2I and V2N, has been extended with carrier aggregation, higher modulation scheme, latency reduction and transmission diversity.

The fully-featured 5G-V2X will be introduced from 3GPP Release 16. 5G-V2X will utilize the 5G new radio (NR) to support autonomous driving. While the frequency band for PC5 remains at 5.9GHz, 5G-V2X will use several key features of 5G NR, which include, inter alia, an OFDMA-based air interface, a smaller and self-contained slot structure, advanced channel coding, and advanced MIMO, all intended to realise a high data rate, low latency, and high-reliability communication. The advanced use cases supported by 5G-V2X will include high-throughput sensor sharing, coordinated driving, remote driving, planned-trajectory sharing, and dynamic--map sharing. Since in the automotive field the compatibility is an important consideration, 5G-V2X will coexist with and complement LTE-V2X. Based on 5G V2N, further study plans to test the remote driving, and LDM-sharing (Local Dynamic Map) use cases.

CONCLUSION

Communication requirements will be substantially more challenging with the advent of automated driving. The paper focuses on the scenario Internet of Vehicles (IoV) based on LTE-V2X using the 5.9 GHz band for Vehicle-to-Vehicle (V2V) and the 3.5 GHz band for Vehicle-to-Network (V2N) communication. C-ITS use cases are proposed. Physical architectures for two V2X use cases are developed: GLOSA (Green Light Optimal Speed Advisory) and intelligent intersection. The key architectural elements are analysed. Within the context of EU-China collaboration, LTE/5G Uu - Ue communication using the 2.6 GHz band and PC5-based direct C-V2X communication in the 5.9 GHz band are targeted. An outline of the planned EU-China joint trials is provided, and some preliminary results from the specific LTE test network in Tampere, Finland are presented. In addition, future 5G-based V2X applications are discussed in detail. For additional research, interoperability issues need to be further identified.

ACKNOWLEDGMENTS

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REFERENCES

[1] 5G-DRIVE Consortium, "Description of Actions", 5G-DRIVE (HarmoniseD Research and TrIals for serVice Evolution between EU and China). 5G-DRIVE Consortium, Brussels, 2018. (restricted)

[2] SAFESPOT Consortium, "Annex I - Description of Work", SAFESPOT Consortium, Brussels, 2005. (restricted)

[3] CVIS Consortium, "Annex I - Description of Work", CVIS Consortium, Brussels, 2005. (restricted)

[4] COOPERS Consortium, "Annex I - Description of Work", COOPERS Consortium, Brussels, 2005. (restricted)

[5] PRE-DRIVE Consortium, "Annex I - Description of Work, PRE-DRIVE C2X (Preparation for driving implementation and evaluation of C2X communication technology)", PRE-DRIVE Consortium, Brussels, 2008. (restricted)

[6] DRIVE C2X consortium, "Annex I - Description of Work", DRIVE C2X Consortium, Brussels, 2011. (restricted)

[7] SAE International, Dedicated Short Range Communications (DSRC) Message Set Dictionary, SAE J2735, 2016.

[8] Lu, M. (Ed.) 2019. *Cooperative Intelligent Transport Systems: Towards High-Level Automated Driving*. IET (Institution of Engineering and Technology), London. DOI: 10.1049/PBTR025E

[9] C-ITS Platform, 2016. Platform for the Deployment of Cooperative Intelligent Transport Systems in the EU (E03188) (C-ITS Platform) Final report, DG MOVE - DG Mobility and Transport, Brussels, January 2016.

[10] C-MobILE Consortium, Deliverable D2.2 "Analysis and Determination of Use Cases". C-MobILE (Accelerating C-ITS Mobility Innovation and deployment in Europe) Consortium, Brussels, 2018.

[11] MAVEN Consortium, Deliverable D5.1 "V2X Communications for Infrastructure Assisted Automated Driving". MAVEN (Managing Automated Vehicles Enhances Network), Brussels, 2018.

[12] TransAID Consortium, Deliverable D7.2 "System Prototype Demonstration". TransAID (Transition Areas for Infrastructure-Assisted Driving), Brussels, 2019.

[13] Kutila, M. Pyykönen, P. Huang, Q. Lei, W. Pollakis, E. 2019.. C-V2X Supported Automated Driving. Proc. IEEE ICC 2019 Workshop on 5G-Trials, Shanghai, China, May 2019.

[14] Thomas, B. 2019. 5G: More Capability. More Complexity. IEEE Future Networks Webinar. IEEE Future Networks Initiative - Enabling 5G and beyond.

[15] IEEE Future Networks Initiative - Enabling 5G and beyond. 2018. Perspectives on 5G Applications and Services. IEEE Future Networks Technology Roadmap Working Group.