Use Cases and Standardisation Activities for eMBB and V2X Scenarios

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***Abstract*—The H2020 project 5G-DRIVE (5G HarmoniseD Research and TrIals for serVice Evolution between EU and China) [1] cooperates with the Chinese twin project to trial and validate key functions of 5G networks operating at 3.5 GHz bands for enhanced Mobile Broadband (eMBB) and 3.5 GHz & 5.9 GHz bands for V2X scenarios. This paper describes the ongoing standardisation efforts for eMBB and V2X scenarios. Furthermore, it introduces the use cases considered by the 5G-DRIVE project.**

Keywords—5G, standardisation, enhanced mobile broadband (eMBB), vehicle-to-vehicle (V2V), EU-China collaboration.

I. INTRODUCTION

The socio-technical evolution in the last few decades has been significantly driven by the evolution of mobile communications and has contributed to the economic and social development of both developed and developing countries. Mobile communications have become closely integrated in the daily life of the society as a whole [2]. It is expected that the socio-technical trends and the evolution of mobile communications systems will remain tightly coupled together and will form a foundation for society in 2020 and beyond [3]. In the future, however, it is foreseen that new demands, such as more traffic volume, many more devices with diverse service requirements, better quality of (user) experience (QoE) and better affordability by further reducing costs, will require an increasing number of innovative solutions.

A connected society in the years beyond 2020 will imply to accommodate a comparable user experience for end-users on the move and when they are static (e.g. at home or in the office). To offer the "best experience" to highly mobile users and communicating machine devices, robust and reliable connectivity solutions are needed as well as the ability to efficiently maintain service quality with mobility. Maintaining high quality at high mobility will enable successful deployment of applications on user equipment located within a moving platform such as cars or high-speed trains. Connectivity on mobile platforms may be provided via International Mobile Telecommunications (IMT), Radio Local Area Network (RLAN) or another network on that platform using suitable backhaul.

In this context, 5G communications can facilitate connectivity, network access and service security of different vertical sectors and be instrumental to the management and automation of business assets and processes.

The 5G-DRIVE project is part of the H2020 ICT-22-2018 Call ("EU China 5G Collaboration"), aiming at performing a close collaboration between EU and China to synchronise 5G technologies and spectrum issues before the final roll-out of 5G. The main scope is to conduct 5G trials addressing two specific scenarios:

Enhanced Mobile Broadband (eMBB) on the 3.5 GHz band, which is a priority band in the two regions for early introduction of very high data rate services. The applications used to test and validate the use of eMBB in the 3.5 GHz band are typical mobile broadband services as well as Virtual and Augmented Reality (VR, AR).

Internet of Vehicles (IoV) based on LTE-V2X using the 5.9 GHz band for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) services, as well as the 3.5 GHz band for Vehicle-to-Network (V2N) communications. More specifically, the optimisation of the band usage in multiple scenarios with different coverage is a key target, so as the validation of the geographic interoperability of the 3.5 and 5.9 GHz bands for these use cases.

Each scenario will be illustrated by use cases describing particular applications of the technologies and solutions defined in 5G-DRIVE to real-life situations. Subsequently, some of these use cases will be demonstrated through project trials – i.e., tangible implementations of the use cases, each featuring its own architecture comprising software/hardware components, services and network infrastructure.

The paper is organized as follows: Sections II and III discuss the fundamental standards for eMBB and V2X correspondingly, that can affect the progress of 5G in their respective areas. Section IV outlines the main 5G-DRIVE use cases. We conclude our remarks in Section V.

II. eMBB STANDARDS

eMBB is one of three primary 5G New Radio use cases [4] defined by 3GPP as part of its SMARTER ("Study on New Services and Markets Technology Enablers") project [5], [6],[7]. 3GPP qualifies ultra-fast mobile broadband as mobile systems capable of delivering speeds of 20 gigabits per second, at least unidirectionally, and without specific latency

978-1-7281-7440-2/20/$31.00 ©2020 IEEE

requirements [8]. eMBB will initially be an extension to existing 4G services and will be among the first 5G services, which could be commercially available before the end of 2019. The objective behind SMARTER [9] was to develop high level use cases and identify what features and functionality 5G would need to deliver to enable them. This section describes the ongoing standardisation efforts in 3GPP for eMBB services.

A. 3GPP Release 15

In order to support the initial rollout of eMBB services, since March 2017 the 3GPP's RAN (Radio Access Network) Group committed to finalise the Non-Standalone (NSA) 5G NR variant by March 2018. In fact, the standard was approved in December 2017 [10]. The NSA mode considers the current 4G network, as supplemented by 5G NR carriers to boost data rates and decrease latency. The NSA 5G NR will utilize the existing LTE (Long Term Evolution) radio and core network as an anchor for mobility management and coverage, while adding a new 5G carrier.

This is the configuration that will be the target of early 2019 deployments (in 3GPP terminology, this is NSA 5G NR deployment scenario option 3). The Standalone (SA) variant was to be completed by September 2018 but was also finished early, in June 2018. The SA 5G NR implies full user and control plane capability for 5G NR, utilizing the 5G next-generation core network architecture (5G NGC) also being done in 3GPP. SA 5G NR technical specifications have been completed in June 2018 as part of 3GPP Release 15. Thus, eMBB can be assessed as the first phase of 5G, which will be encompassed in the 3GPP Release 15 standard [11]. 5G Phase 2 will go beyond the eMBB services to more transformational Ultra-Reliable Low Latency Communications (URLLC) and Massive Machine-Type Communications (mMTC) applications and will be included in Release 16, which is due to be completed at the end of 2019. By considering the case of connected cars as a characteristic example, the first phase of eMBB services will include enhanced in-vehicle infotainment, like real-time traffic alerts, high-speed internet access, streaming real-time video or playing games involving 3D 4K video. The second phase would involve autonomous vehicles on a mass scale capable of connecting to and interacting with other vehicles and/or with the nearby road infrastructure [12].

3GPP has defined both a new radio access network, NG-RAN, with a new radio interface protocol architecture called New Radio (NR), as well as a new 5G core network [13] (5GC). The NG-RAN is composed of two types of NG-RAN nodes: gNBs, providing NR protocol terminations towards the UE, and ng-eNBs, providing E-UTRA protocol terminations towards the UE. The NG-RAN nodes can be interconnected with each other via Xn interfaces and with the 5GC via NG interfaces. In contrast to the 4G traditional evolved packet core (EPC), the 5GC does no longer consider network elements but network functions, which can be virtualized and hosted in a cloud environment. As a result, the physical deployment of well-known EPC network elements such as the Mobility Management Entity (MME), Serving Gateway (SGW) and Packet Data Network Gateway (PGW) are now replaced by virtualization and software, thus increasing core network flexibility to meet the 5G requirements [14].

With 5G it is possible to integrate elements of different generations in different configurations, namely Standalone using only one radio access technology, and Non-Standalone combining multiple radio access technologies.

In a standalone scenario, the 5G NR or the evolved LTE radio cells and the core network are operated alone. This means that the NR or evolved LTE radio cells are used for both control plane and user plane. The standalone option is a simple solution for operators to manage and may be deployed as an independent network using normal inter-generation handover between 4G and 5G for service continuity. Three variations of SA are being defined in 3GPP:

- *Option 1* using EPC and LTE eNB access (i.e. as per current 4G LTE networks);
- *Option 2* using 5GC and NR gNB access;
- *Option 5* using 5GC and LTE ng-eNB access.

In non-standalone (NSA) scenario, the NR radio cells are combined with LTE radio cells using dual connectivity to provide radio access and the core network may be either EPC or 5GC depending on the choice of operator. This scenario may be chosen by operators that wish to leverage existing 4G deployments, combining LTE and NR radio resources with existing EPC and/or that wish new 5GC to deliver 5G mobile services. This solution will require tight interworking with the LTE RAN. The end-user experience will be dependent on the radio access technology(-ies) used. Three variations of NSA are defined in 3GPP:

- *Option 3* using EPC and an LTE eNB acting as master and NR en-gNB acting as secondary;
- *Option 4* using 5GC and an NR gNB acting as master and LTE ng-eNB acting as secondary;
- *Option 7* using 5GC and an LTE ng-eNB acting as master and an NR gNB acting as secondary.

Two deployment options have been defined for 5G:

The ***Non-Stand Alone (NSA) architecture***, where the 5G Radio Access Network (AN), also called New Radio (NR) is used in conjunction with the existing LTE and EPC infrastructure Core Network (respectively 4G Radio and 4G Core), thus making the new 5G-based radio technology available without network replacement. In this configuration, only the 4G services are supported, but enjoying the capacities offered by the 5G Radio (lower latency, etc.). The NSA is also known as E-UTRA-NR Dual Connectivity (EN-DC) or Architecture Option 3.

The ***Stand-Alone (SA) architecture***, where the NR is connected to the 5G Core Network (CN). In this configuration, the full set of 5G Phase 1 services are supported, as specified in TS 22.261.

In the NSA architecture, as described in section 4.1.2 of TS 37.340 [15], the NR base station (logical node en-gNB) connects to the LTE base station (logical node eNB) via the X2 interface. Although the X2 interface has been used so far to connect eNBs, Release 15 extends the interface to also support connecting an eNB and en-gNB in case of NSA operation. In addition, E-UTRAN for NSA architecture connects to the EPC network using an S1 interface. Dual connectivity between eNB (as master node) and en-gNB (as secondary node) is called EN-DC.

In the SA architecture, the NR base station (logical node gNB) connects each other via the Xn interface [16]. The NG-RAN for SA architecture connects to the 5GC network using the NG interface.

5G deployment options are being defined in 3GPP using either the existing EPC (Evolved Packet Core, specified in 3GPP TS 23.401 [17]) or the 5GC (5G Core network, specified in 3GPP TS 23.501 [18]). The two architectures follow a very different set of design principles.

While EPC could be considered an evolution of previous generation packet core networks, the 5GC has been designed from its inception to be cloud native, that is inheriting many of the technology solutions used in cloud computing and with virtualisation at its core. 5GC also offers superior network slicing and QoS features. Another important characteristic is the separation of the control plane and user plane that besides adding flexibility in connecting the users also allows an easier way to support a multitude of access technologies, better support for network slicing and edge computing.

III. V2X Standards

Vehicle-to-Everything (V2X) communications refer to the exchange of information from a vehicle to an external entity that may affect the vehicle, and vice versa. It is a vehicular communication system that incorporates other more specific types of communication as V2I (Vehicle-to-Infrastructure), V2N (Vehicle-to-Network), V2V (Vehicle-to-Vehicle), V2P (Vehicle-to-Pedestrian), V2D (Vehicle-to-Device) and V2G (Vehicle-to-Grid).

By employing cooperative awareness, the above types of V2X applications can be jointly used for smarter services for end-users. For example, vehicles, pedestrians, application servers, and road infrastructure can obtain local environmental information by receiving messages from sensors in proximity or other vehicles, to enable more intelligent services such as autonomous driving, vehicle warning, and enhanced traffic management.

The fundamental motivations for V2X applications are road safety, traffic efficiency and energy savings. There are two types of V2X communication technology depending on the underlying technology being used, that is, WLAN-based (ITS-G5) and cellular-based (C-V2X). The following subsections describe these two technologies in more detail.

A. ETSI ITS-G5

IEEE 802.11p is an amendment to the IEEE 802.11 standard aimed at adding wireless access in vehicular environments (WAVE), a vehicular communication system. It defines enhancements to 802.11 (which is the basis of products marketed as Wi-Fi) required to support ITS applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure, so called as V2X communication, in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). IEEE 1609 [19] is a higher layer standard based on the IEEE 802.11p. It is also the basis of a European standard for vehicular communication known as ETSI ITS-G5 (described by the ETSI EN 302 663 [20]).

ETSI ITS-G5 is an extension of IEEE 802.11p, modified and optimized for operation in a dynamic automotive environment. ETSI ITS-G5 was originally defined in 2004 and has undergone a thorough standardisation process. This included extensive field testing (starting in 2008 with the German SIM [21] field tests with 400 vehicles) and multi-vendor interoperability testing (ETSI plug tests since 2011). Automotive-grade implementations have been available for a number of years to allow Original Equipment Manufacturers (OEMs) and Tier-1 suppliers to perform extensive tests and validation, which is absolutely of “key” importance for a safety-related product.

The EN 302 663 standard has outlined the two lowest layers - physical layer and data link layer - in the protocol stack for supporting V2V communications in an ad hoc network to be used at the 5.9 GHz frequency band allocated in Europe. The two lowest layers are termed as access layer and data link layer of the OSI model. The technology specified for the access layer is collectively called as ITS-G5. During its validation, the ITS-G5 standard has used already existing standards for communications.

The data link layer is divided into two sublayers – Medium Access Control (MAC) and Logical Link Control (LLC). The physical layer and the medium access control layer are covered in IEEE 802.11 [22]. The logical link control is based on the ANSI/IEEE Std 802.2 [23]. The ITS-G5 standard also adds features for decentralized congestion control (DCC) methods [24] to control the network load and avoid unstable behaviour.

The EN 302 663 standard has assessed the communications architecture as proposed in ETSI EN 302 665 [25].

ITS-G5 technology is tailor-made for road safety applications. The ETSI EN 302 663 standard offered the low latencies that are essential for vehicles travelling at high speed. Since it is a wireless technology, it can communicate beyond the LoS (e.g. around corners) and complements in-vehicle sensors. Since it is a broadcast technology, it can also communicate with many vehicles and other relevant recipients at once. Its properties made it suitable for numerous road safety applications, such as reduction of fatalities by vulnerable road users, electronic emergency brake light, distance-keeping in platoons of trucks and for future higher levels of more automated driving. It has been designed to operate at short-range.

ITS-G5 and WAVE technologies do not require any network coverage or roadside units to exchange messages. Communication takes place whenever vehicles or C-ITS stations are within range of each other, as they can form ad-hoc networks. Whilst not requiring any network coverage, road operators may opt to equip critical spots on their road infrastructure, such as traffic lights or intersections, to improve road safety. This may make sense, particularly in the beginning, when the penetration rate of the vehicle fleet is still growing.

ITS-G5 technology is designed to be operated on the 5.9 GHz frequency band and fulfils the requirements set out by

ETSI EN 302 571 [26] and the ITS Directive 2010/40/EU [27]. ITS-G5 and WAVE technologies [28] are tried and tested in many European and US projects: the simplicity and efficiency with which it uses radio spectrum also makes it a very robust V2X short-range communication technology.

ITS-G5 protocol technology also meets all requirements to operate under the European Commission's Security Policy [29] and Security Certification Policy [30] which assure the trustworthiness of messages sent using C-ITS. As several ITS-G5 systems have been developed by automotive suppliers, functional safety like compliance with the Automotive Safety Integrity Level (ASIL) according to ISO 26262 [31] is already taken into account.

B. 3GPP LTE-V2X (Release 14)

3GPP started standardisation work of cellular V2X (C-V2X) in Release 14 [32] in 2014. It is based on LTE as the underlying technology. Specifications were published in 2016. Because these C-V2X functionalities are based on LTE, it is often referred to as LTE-V2X. The scope of functionalities supported by C-V2X includes both direct communication (V2V, V2I) as well as wide area cellular network communication (V2N).

Cellular V2X was developed within the 3GPP to replace the US promoted DSRC and the Europe-originated Cooperative Intelligent Transport Systems (C-ITS) as such standards are decisive steps towards the target of autonomous driving and clues to market influence. C-V2X technology is designed to connect vehicles to each other, to roadside infrastructure, to other road-users and to cloud-based services.

C-V2X technology has been designed to operate in two modes:

- **Device-to-device:** this is Vehicle-to-Vehicle (V2V), Vehicle-to-(Roadway) Infrastructure (V2I) and Vehicle-to-Pedestrian (V2P) direct communication without necessarily relying on network involvement for scheduling.
- **Device-to-network:** this is Vehicle-to-Network (V2N) communication which uses the traditional cellular links to enable cloud services to be part of the end-to-end solution by means of network slicing architecture for vertical industries.

LTE-V2X was standardised by the 3GPP in 2016 under the umbrella of LTE Release 14 and encompasses two interfaces: (i) *a wide area network LTE interface (Uu) that connects end-user devices and vehicles to mobile network base stations and mobile core networks, for provision of Internet and vehicle to network (V2N) services*, and; (ii) *a direct communications interface (PC5) that connects vehicles to vehicles (V2V), to roadside infrastructure (V2I) and to pedestrians and other vulnerable road users (V2P), for provision of low-latency and high-reliability vehicular services*. The LTE-V2X (PC5) interface does not necessarily require assistance from a mobile network.

The above two modes of operation fulfil different use cases and scenarios and can also be used in combination. The PC5 interface was specified during the work on Proximity Services [33] (ProSe), which provided public safety UEs the option to communicate directly. However, commercial equipment was excluded mostly due to the lack of operator control with respect to charging and legal interception. The ProSe feature offers with the PC5 interface additional functionality like discovery of other UEs [34], which is not utilized for V2X communications. LTE-V2X mode 3 is a subscription service in 3GPP, i.e. a UE must have a subscription in the Home Subscriber Server (HSS) with relevant information, which allows a UE to be authorized in order to perform LTE-V2X communication over the PC5 reference point and its PC5-AMBR. Further, the subscription information contains the list of the Public Land Mobile Networks (PLMNs) where the UE is authorized to perform LTE-V2X communication over the PC5 reference point. By contrast, mode 4 of LTE-V2X does not require connectivity to a cellular network.

In principle, LTE-V2X has some advantages over ITS-G5, including its ability to also provide (via its Uu interface) longer-range vehicle-to-network (V2N) communications, leveraging use of the commercial mobile telecommunications network spectrum to enable connections to cloud-based infrastructure and back-office systems, and utilising the existence of extensive mobile infrastructure along the EU road networks. Furthermore, its scalability and ability to evolve as mobile communications develop (e.g. the transition from 4G to 5G) are seen as significant benefits of LTE-V2X. At the same time, LTE-V2X (via its PC5 interface) is also able to provide direct V2V communications between devices, with no subscription or network intervention required. On the other hand, ITS-G5 is a mature and tested technology, and its market deployment at the time of writing is well ahead of that of LTE-V2X.

C. 3GPP 5G-V2X (Release 15 and beyond)

In Release 15, 3GPP continued its C-V2X standardisation to be based on 5G. Specifications have been published in 2018. To emphasise the underlying technology, the term 5G-V2X is often used in contrast to LTE-based V2X (LTE-V2X). In both cases, C-V2X is the generic terminology that refers to the V2X technology using the cellular technology irrespective of the specific generation of technology.

Release 16 of the 3GPP Technical Specifications further enhances the C-V2X functionality. Standardisation work is currently in progress. This way, C-V2X is inherently future-proof by supporting migration path to 5G.

The target of Release 14's work to support V2X service has been mostly to provide data transport service for basic road safety service such as CAM, DENM, BSM and relevant applications. In addition to the work done in Release 14 to support V2X services based on LTE, the Release 15 work eV2X [35] (enhanced Vehicle-to-Everything) further specifies service requirements to enhance 3GPP support for V2X scenarios.

Requirements for the following areas have been covered in this work and are specifically described within the framework of the 3GPP TS 22.186. In brief, these are as follows:

Vehicle Platooning: Vehicles platooning enables the vehicles to "dynamically form" a group travelling together. All the vehicles in the platoon receive periodic data from the leading vehicle, in order to carry on platoon operations. This sort of information allows the distance between vehicles to become extremely small; that is the gap distance translated to time can be very low (practically at the order of magnitude of sub-second). Platooning applications may allow the vehicles following the one leading the group to be autonomously driven. The requirement on the communication latency is directly related to the assumed inter-vehicle gap (distance between successive vehicles and equivalent to vehicle density), which can be specified in meter or seconds.

Advanced Driving: Advanced Driving practically enables the case of semi-automated or fully-automated driving. In this case, longer inter-vehicle distance is assumed. Each vehicle and/or road side unit shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or manoeuvres. In addition, each vehicle shares its driving intention with vehicles being in its proximity. The benefits of this use case group include safer travelling, collision avoidance as well as improved traffic efficiency.

Extended Sensors: Extended Sensors enables the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, devices of pedestrians and other V2X application servers. The vehicles can enhance the perception of their environment beyond what their own sensors can detect and, consequently, have a more holistic view of the local situation. Here, high data rate is one of the key characteristics.

Remote Driving: Remote Driving enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments. For a case where variation is limited and routes are predictable (such as public transportation) driving based on cloud computing can be used. In addition, access to cloud-based back-end service platform can be considered. High reliability and short low latency are the main requirements.

Vehicle quality of service support: This enables a V2X application to be notified of change of quality of service before actual change occurs and to enable the 3GPP System to modify the quality of service in line with V2X application's quality of service needs. Based on the quality of service information, the V2X application can adapt behaviour to 3GPP System's conditions. The benefits of this use case group are smoother user experience of service and increased safety

In Release 15, the WI "V2X phase 2 based on LTE" was approved (as in the WID in RP-171740 [36]). This WI enhances the Cellular-based V2X services (V2V, V2I/N, and V2P) to support advanced V2X services as identified in TR 22.886 [37] in a holistic and complementary manner to Release 14 V2X. This work item specifies 3GPP V2X Phase 2 to support advanced V2X services as identified in SA1 TR 22.886 in a fully backward compatible manner with Release 14 V2X.

IV. 5G-DRIVE USE CASES

This section describes the eMBB and V2X use cases considered in 5G-DRIVE. These use cases will be demonstrated through experimental tests in some of the 5G-DRIVE trial sites.

A. eMBB Use Cases

1) Cloud-Assisted AR/VR

Cloud-assisted 3D Augmented Reality (AR) is a 5G-DRIVE use case in the eMBB scenario. As opposed to conventional gaming consoles or personal computers (which are highly dependent on the signal processing capabilities of the GPU), cloud-assisted AR enables users to stream video games or virtual contents from cloud servers like other streaming media. This new type of services offers an opportunity for more varied and interactive contents and makes user devices lighter and cheaper.

While some new technologies, such as eye tracking and foveated rendering are essential ingredients for high-resolution head-mounted displays (HMDs), bandwidth and latency requirements have pushed the expectations for 5G networks. As it is known, display resolutions and high immersive content play a key role to push users to seek out more robust data service and plans. FOV could range from 1080x1200 per eye to retina AR display (6600x600) per sys and require data rates at the low end (30 fps) between 100 Mbps to 9.4 Gbps at the high end (120 fps). eMBB is required to reach tens of Gbps to support the speed requirement of AR application, providing a more uniform experience for users of AR given the ultra-high data volume requirements that can be handled more effectively.

2) Indoor Positioning

Indoor position information obviously supports navigating within building premises. However, this location information is also a valuable asset for providing and maintaining high quality eMBB services to end user devices. Positioning offers means to utilize location information to improve network communication reliability, to reduce latency, and to balance data loads.

Since most of the network control components are fixed at specific locations, eMBB services to mobile end user devices require also support for mobility. First the mobile terminal receives the eMBB service signal from one base station and then gradually moves to the coverage area of another base station, so a handover in the indoor network is executed.

Mobility comes at a cost in terms of extra signalling messages, processing resources and delay in setup and data message transactions. Due to the nature of network control and monitoring, additional signalling overhead gets created from sending infrequently small packets. From the mobile network side, this requires re-allocation and scheduling of radio resources with increased latency. Location information can be used by the network and devices to optimise communication and to save energy by reducing signalling. Combining location information with other forthcoming functionalities, it may be possible to dynamically adjust data loads and routing and to control the latency and its deviation. The shared location information is therefore a valuable asset for both mobile end users and eMBB service providers to maintain and operate their devices.

B. V2X Use Cases

1) Green Light Optimal Speed Advisory (GLOSA)

GLOSA (Green Light Optimal Speed Advisory) is a day-1 signage C-ITS service aimed at informing end users about the speed that needs to be sustained (within legal limits) to reach an upcoming traffic light in green status. GLOSA provides end users with short-term information on upcoming traffic light status to optimise traffic flows, help prevent speed limits violations, improve fuel efficiency and reduce pollution.

In a GLOSA use case, an RSU co-located with a traffic light (and having access to its internal finite state machine), broadcasts timing information about the traffic light's "red", "amber" and "green" status via Signal Phase and Timing messages (SPAT). Neighbouring vehicles can receive these messages and process them locally along with their own positioning, speed and direction data (amongst others). By doing so, on-board V2X modules can notify drivers about the optimal speed to reach an upcoming traffic light in green status or, alternatively, to be aware that the traffic light will nevertheless transition to red imminently.

2) Intelligent Intersection

This use case deals with 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 wants to make a right turn while parallel VRUs also have a green phase and right of way (permissive green for motorized traffic).

When a pedestrian is detected, a Decentralized Environmental Notification Message (DENM) should be broadcasted by the RSU, while the backoffice should geocast this to all vehicles in the vicinity. Given a movement direction of the pedestrian towards the intersection, the infrastructure should send out Collaborative Perception Messages (CPM). This is to warn vehicles further upstream that a potential conflict may occur in the future and to prevent future hard braking.

Other DENMs can also be tested within 5G-DRIVE, 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, but on the V2X performance and that situations on the test tracks will be mostly emulated not to put real pedestrians at risk and ease requirements on timing the approach of the vehicle.

Since this use case is about safety, latency of V2X communications is very critical. Latency on older 3G networks was found to have outliers up to 25 seconds in [38], which is unacceptable for these applications. Instead, 100 ms is the absolute maximum for the intersection safety DENM and 1000 ms for the CPM as it is more of a preventive message.

V. Discussion

The H2020 project 5G-DRIVE cooperates with the Chinese twin project to trial and validate key functions of 5G networks operating at 3.5 GHz bands for enhanced Mobile Broadband (eMBB) and 3.5 GHz & 5.9 GHz bands for V2X scenarios.

This paper describes the ongoing standardisation efforts for eMBB and V2X scenarios. Furthermore, it introduces the use cases considered by the 5G-DRIVE project. Use cases aim at illustrating real-life situations where the technology and solutions developed in 5G-DRIVE can be applied to the two project scenarios. Use cases will be demonstrated through experimental trials in the different 5G-DRIVE trial sites. To do so, each trial features a specific architecture that encompasses all software, hardware, network infrastructure and services needed to implement the use case in a real-life setup.

5G-DRIVE intends to instill significant impact on the validation of standards and trigger the roll-out of real 5G networks and V2X innovative solutions driving new business opportunities and creating thereby new jobs and brand new business models.

Acknowledgment

The paper has been based on the context of the "5G-DRIVE" ("*5G HarmoniseD Research and TrIals for serVice Evolution between EU and China*") Project (GA No. 814956), funded by the EC. EC has no responsibility for the content of this paper.

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