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Abstract. The rapid development of 5G provides opportunities for growth for a great variety of services, also including cooperative Intelligent Transport Services (C-ITS). In this framework, of high importance are Vehicle-to-Everything (V2X) applications that can contribute towards improving driving safety, efficiency and comfort, together with the inclusion of automation processes. Based on the broader context for promoting innovative features and by assessing various opportunities appearing for the benefit of the market sector, our work specifically focuses on the scope of the 5G-DRIVE project, supporting cellular V2X trials between the EU and China. In particular, we explain the benefits for the two selected cases of use about Green Light Optimised Speed Advisory and Intelligent Intersection. Both can be examined in a joint form of architectural implementation, as in our approach. These use cases support the realization of an enhanced traffic management in urban areas, contribute to road safety and reduce fuel consumption.

Keywords: 5G, autonomous driving, cellular V2X (C-V2X), Connected and Automated Mobility (CAM), Cooperative ITS (C-ITS), GLOSA, Intelligent Transportation Systems (ITS), latency, reliability, road safety, Vehicle-to-Network (V2N) communications, Vehicle-to-Vehicle (V2V) communications.

1 Introduction

Advances in wireless communications and, in particular vehicular communications, have led to the advent of cooperative Intelligent Transportation Systems (ITS) [1]. These systems are a global phenomenon and have been among the priorities for many “actors” of the market sectors such as the automotive industry, network and service operators and policy makers. ITS imply for the effective inclusion of ICT and electronics so that to deal with a series of actual critical challenges affecting modern societies, such as traffic congestion, transport efficiency, environmental conservation and enhanced security. In fact, ITS’ main objective is to provide an improved system by informing users about traffic situations and by making transportation safer, more efficient and more environmentally sustainable.

In recent years, ITS have been widely applied along with the development of IT technologies such as robotics, signal and image processing, computing, sensing, and communications. ITS vary in the technologies they apply, from basic management systems such as car navigation, traffic signal control systems, container management systems, variable message signs, enforcement systems for monitoring applications (security closed circuit TV systems), through to more advanced applications that integrate live data and incorporate feedback from other sources, such as parking guidance and information systems or weather information. Furthermore, ITS can apply to the vast transportation infrastructure of highways and streets as well as to a growing number of vehicles and can also apply to all transport modes thus facilitate their interlinking or multimodality. Regarding the European framework, the ITS Directive 2010/40/EU [2] adopted since August 2010 and its subsequent already adopted Delegated Regulations, for instance on road safety, real-time-traffic and multimodal travel information, provides the necessary legal and technical framework to steer and ensure the interoperability of deployed ITS services [3-4].

A typical example of an anticipated evolution strategy towards the beneficial use and inclusion of the fifth generation of mobile communications (5G) is the case of the “connected vehicles” application. In Europe, Basic System Profiles (BSPs) have been developed by the Car-to-Car Communication Consortium (C2C-CC) [5] and the EU funded C-Roads Platform project [6], assuming ITS-G5 with IEEE specifications as radio access technology for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. However, during the latest years, research in the area of intelligent vehicles has been focused upon Cooperative ITS (C-ITS) which is a case of vehicle communications vehicles with each other and/or with the underlying infrastructure [7]. C-ITS offer benefits such as improvement of the quality and the reliability of information that is exchanged between vehicles, traffic signals, road environment as well as with other road users [8]. They also improve existing services and support the offering of new ones which, in turn, results to social and economic benefits; this also leads to greater efficiency of the road transport and increases safety with various sorts of alerts generated from the increased information available.

Modern vehicles are becoming safer, cleaner and more intelligent, mainly due to the fact that they can incorporate a variety of sensors together with assistant systems, enabling them to better monitoring their surrounding environments. Exchanging of information between vehicles and/or the roadside infrastructure allows vehicles to be conceived from autonomous systems to cooperative systems. The development of C-ITS is primarily driven by applications for active road safety and traffic efficiency, which help drivers to be aware of other vehicles, disseminate warnings about road hazards, and provide real-time information about traffic conditions for speed management and navigation. Such applications rely on always-on connectivity among the vehicles in the vicinity – including the roadside infrastructure – and frequent data exchange. Additionally, Internet access and location-based services, such as for point-of-interest notification, road access control, improve the driving convenience.

Our work is organised as follows: Section 1 serves as an introduction, explaining current trends and challenges rising from modern C-ITS. Section 2 briefly focuses on the specific context of V2X communications, especially within the 5G framework of reference. Section 3 discusses the V2X approach proposed in the 5G-DRIVE framework, which promotes corporative research and joint trials for 5G deployment and testing between the EU and China. Section 4 discusses the concept of the two selected use cases being about GLOSA and intelligent intersection. Our work summarises with an overview of our approach.

2 V2X Communications in the 5G Era

In order to reduce the number of road accidents and improve road safety, vehicles should be able to detect what is happening around them, predict what will happen next and take protective actions, *accordingly.* The case of "V2X" ("Vehicle-to-Everything", where "X" stands for "Vehicle" (V2V), "Network" (V2N), "Infrastructure" (V2I), "Cloud" (V2C), "Pedestrian" (V2P), "Road Side Unit (RSU)" (V2R) and "Sensors"(V2S)) is a sort of solution which can be assessed as a wireless sensor system allowing vehicles to share information (between them or with other (network) entities) via a dedicated communication channel [9]. Compared with standard sensors (such as radar, light detection and ranging (LIDAR), lasers, ultrasonic detectors, etc.) the use of a V2X communication system can allow reception of information out of sight and test of hidden threats, thus increasing driver's perception. Consequently, this improves driving safety, efficiency and comfort and results to an enhanced driving automation process [10]. This also contributes to the minimization of pollutant emissions and, in a more generalised concept, serves several "key" objectives of the EU transport policy. Automation, in the above framework, is assessed as "automated and autonomous driving applications" actively interacting with the intelligent surrounding environment.

5G-based Connected and Automated Mobility services along roads implicates for a wide variety of digital services in and around vehicles, including safety-related, transport efficiency-related and other commercial services offered, to become available or supported by 5G multi-service networks [11]. The growth of the next generation of mobile technologies (5G) is expected to become a critical "game changer" for most of the applications offered, as it allows for an extended range of connectivity performances including gigabit speeds and mission critical reliability, *among others*. The immense opportunities provided to all involved market actors, also including the so-called "vertical industries", further widen all potential options for innovation and economic growth, via the offering of new services/applications able to revolutionize our every-day experiences [12-13].

The V2X technology becomes the next "big feature" to evolve further the automotive and transportation industry [14]. In particular, the V2X concept uses the latest generation of information and communication technology to realize omnidirectional V2V, V2I, V2P and V2N/V2C network connection [15] and, consequently, the above types of V2X applications can use "co-operative awareness" to provide more intelligent services for the involved end-users. This means that entities, such as vehicles, roadside infrastructure, application server and pedestrians, can collect knowledge of their local environment (e.g., information received from other vehicles or sensor equipment in proximity) to process and share that knowledge in order to provide more intelligent services, such as cooperative collision warning or autonomous driving [9]. The basic categories of V2X services have originally been described in [16] and can be grouped into the following main categories based on ITS definition of basic set of services: (i) Road Safety Requirements (e.g., queue warning use case related requirements); (ii) Mutual Vehicle Awareness – Information only (e.g. forward collision warning requirements), and; (iii) Vehicle Related Application Requirements (e.g. automated parking system requirement). The related service requirements can be categorised as follows:

- *Latency/Reliability Requirements:* This implicates for the maximum tolerable elapsed time from the instant a data packet is generated at the source application to the instant it is received by the destination application. Low Latency values are provided to support services in the case of mutual awareness of vehicle or to send warning messages as defined in some use cases in [16].
- *Reliability:* This implicates for the maximum tolerable packet loss rate at the application layer; a packet is considered lost if it is not received by the destination application within the maximum tolerable end-to-end latency for that application.
- *Message Size Requirements:* Messages sizes are important when multicast or broadcast messages are being sent to vehicles within range to either warn them for collision prevention or when an event occurs to inform other vehicle about an accident.
- *Frequency Requirements:* This implicates for the minimum required bit rate for the application, to function correctly. The sending rates, that is the frequency of messages, is a relatively important context, especially for critical vehicular safety application.
- *Range Requirements*: This is the maximum distance between source and destination(s) of a radio transmission, within which the application should achieve the specified reliability
- *Speed Requirements:* It is the maximum relative and absolute speed under which the specified reliability should be achieved.

It is predicted that by 2022, there will be more than 125 million vehicles connected by various V2X technologies [17] potential to offer unprecedented safety, novel transportation services as well as other novelties [18].

3 5G-DRIVE Implementation of V2X Communications

The consideration of V2X communications in various potential scenarios, implicates for a variety of concerns to be taken into account, as these strongly affect the applicability of modern solutions such as intelligent transportation and automated driving [19]. Each one among the potential solutions sets different requests about latency, reliability, throughput, user density, and safety of the corresponding V2X framework [16]. In recent years, different regions in the world have conducted intensively V2X trials. There are two V2X technical paths followed by the global automotive industry. One is the ETSI ITS-G5 [20], being an extension of the original IEEE 802.11p standard, modified and optimized for operation in a dynamic automotive environment; this sort of technology includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). The other is the 3GPP LTE-V2X rooted from the 3GPP standards [21-22]. The LTE-V2X is a wireless communication technology for V2X with high data rate and controlled QoS [23] which is based on the evolution of LTE mobile communication technology defined by 3GPP, including two kinds of working modes of cellular communication (Uu) and direct communication (PC5) [24]. The Uu mode uses the existing LTE cellular network to implement V2V communication by forwarding and the PC5 mode is similar to the dedicated short range communications (DSRC), enabling direct communication between vehicles [18]. Additionally, the PC5 interface has been enhanced in many aspects to accommodate exchanges of rapidly changing dynamic information (position, speed, driving direction, etc.) and future advanced V2X services (automatic driving, vehicle platooning, sensor sharing, etc.) [25]. 3GPP Releases 15 and 16 [26-27] have defined both a traditional Base Station-User Equipment (BS-UE) Uu interface and a peer-to-peer PC5 interface for V2X communication. Those 5G systems are designed to support 10 ms end-to-end (E2E) latency, 1 ms physical (PHY) layer latency and 99.999% reliability.

Different regions show their own preference on the technologies. For example, China selects C-V2X (LTE-V2X) as the national standard while in Europe the debate is ongoing on how to adopt these technologies. The Cellular in association with V2X (C-V2X) is a communicating base that offers enhanced road safety and autonomous driving [28]. It uses a transmission mode called direct C-V2X, which provides longer communication range and higher reliability to connect “vehicles”, “things” and “human”. The 5G Automotive Association (5GAA), the international association with the mission to promote C-V2X technologies, expects that the first commercial deployments of V2X will occur in China and Europe, while deployments in the US and other parts of Asia will follow closely. Considering the life cycle of road infrastructure is normally 30 years, and the life cycle of a car is 10-15 years, the selection the V2X technology will be critical for the future evolution of technologies. For compatibility reasons, it is crucial that the various regions cooperate to ensure harmonization of technologies. Under this consideration, Europe and China have established a way of cooperation on C-V2X technology validation through joint research and trials.

The 5G-DRIVE EU-funded project [29] is one of the projects that work on C-V2X trials with China. One of the two fundamental aims of the project is to compare the performance in selected V2X use cases and identify any potential interoperability problems, for the synchronisation of the effective use of 5G technologies and for handling challenging spectrum issues before the expected wide roll-out of 5G. Towards this direction, the 5G-DRIVE context focuses upon LTE-V2X communications using the 5.9 GHz band for Vehicle-to-Vehicle and the 3.5 GHz band for Vehicle-to-Network applications, by realising demonstrations in real-life setups. The 5G-DRIVE scope supports collaborative actions between solid research competence, commercial grade test-beds and some of the stakeholders (who will eventually become major customers of the 5G systems and the proposed applications).

As previously mentioned, in Europe the V2X deployment is underpinned by the European Commission's C-ITS Framework Directive [2]. The related EU standardization efforts are driven by: (i) the European Car-2-Car Communication Consortium [5], an industry consortium of automobile manufacturers, suppliers and research organizations; (ii) ERTICO, a European organization of stakeholders with public and private partners, and; (iii) the ETSI's Centre for Testing and Interoperability (CTI). The C-ITS standards follow a general architecture, specified in [30] and [31], with the ITS station as the core element, representing vehicle, personal (mobile personal devices), roadside (infrastructure), and central (backend systems and traffic management centres) subsystems. For C-ITS, the ISO OSI reference model was adapted to cover horizontal layers for access technologies, networking and transport, facilities and applications, and vertical entities for management and security. In November 2016, the European Commission approved the C-ITS strategy for the EU, providing a legal framework to facilitate the convergence of investments and regulatory frameworks across the EU. In the EU, C-ITS services are implemented in phases, based on their priority [32]. There are two priority groups called *Day 1* and *Day 1.5* services [33]. The former have been deployed, starting from 2019; these services are used for hazardous location notifications and signage and include road works warning, weather conditions, emergency break light, etc. The later include in-vehicle signage, green light optimal speed advisory (GLOSA), traffic signal priority request, etc.; these services include vulnerable road user (VRU) protection, on/off street parking information, traffic information, etc.

In China, the V2X development is regulated by the Ministry of Industry and Information Technology (MIIT), Ministry of Public Security (MPS) and Ministry of Transport (MOT). The MIIT specifies the spectrum for V2V and V2I operation, and coordinates the C-V2X trial activities in China. The MPS takes charge of the standard revision on traffic light and regulations on traffic information access. The MOT is responsible for regulating the road infrastructure for V2X services. Three ministries have defined the V2X test specification. So far, the LTE-V2X trials have been done in Wuxi, Shanghai, and other pilot areas. The V2X services defined match the Day-1 C-ITS services defined by Europe. However, in China some Day-1.5 services, like VRU protection have also been tested. C-V2X has initially been standardized by 3GPP in Release 14. Both Europe and China have adopted 5.9 GHz spectrum for the V2V, V2I, and V2P services. In addition, Qualcomm, Huawei, and Datang have released LTE-V2X chipsets and modules. The C-V2X standard continued in 3GPP release 15 for performance improvement. The 5G V2X, known as NR-V2X has been within the scope of 3GPP Release 16 and introduces the 5G New Radio features and low latency services into C-V2X.

A primary goal of C-ITS is to ensure users of the same service can interoperate with each other, to maximize the safety effect [34]. However, automotive and transport ecosystems involve different stakeholders such as car original equipment manufacturers (OEMs), regional roads and transport authorities as well as third-party service providers, who may adopt different implementation solutions when offering the same services. This makes interoperability of C-ITS services a real challenge.

Even both Europe and China have considered C-V2X technologies, when comparing the different flavours of V2X standards, there are differences in terms of both message types and available functional capabilities. For example, while China uses Basic Safety Message (BSM) for both status information and event notifications, Europe has split these into Cooperative Awareness Message (CAM) and Decentralised Environmental Notification Message (DENM) [35]. The CAM protocol conveys critical vehicle state information in support of safety and traffic efficiency application, with which receiving vehicles can track other vehicles positions and movement. The DENM protocol disseminates event-driven safety information in a geographical region. EU-China collaborative projects such as the case of 5G-DRIVE, investigate these inter-operability problems.

The purpose of the V2X trial collaboration between EU and China is to evaluate similar use cases and identify potential interoperability problems. 5G-DRIVE [29] is an EU H2020 project working under EU-China collaboration agreement and cooperates with a *5G Large-scale Trial project* led by China Mobile. One of its main objectives is to develop "key" 5G technologies at pre-commercial test-beds, test V2X services and then demonstrate IoV (Internet of Vehicles) services by using V2I and V2V communications. The project develops two dedicated use cases, that is the GLOSA (Green Light Optimised Speed Advisory) and intelligent intersection, while special attention is paid for automated driving challenges. Thus, 5G-DRIVE's framework promotes research and innovation cooperation on 5G and V2X through joint trials and dedicated research activities [36-37]. The project incorporates 17 partners from 10 European countries and works on trials in V2N, V2V and V2I scenarios. The V2N scenario tests the performance of cellular network to support V2N services, in which DENM, In-Vehicle Information (IVI), Signal Phase and Timing (SPAT) and MAP messages [38] are evaluated. The multi-access edge computing (MEC) server is deployed in the 5G network to process vehicle sensing data. The V2V and V2I scenarios are realised by using LTE-V2X modules.

5G-DRIVE has two V2X trial sites in Espoo and in Ispra. The Espoo trial site is located in Karaportti area at Espoo, Finland, which is equipped with 3.5 GHz base-stations, LTE-V2X equipment and mobile traffic light. The length of the roads available in site is about 2.6 km including intersections and parking areas. The trial use cases in the Espoo trial site include GLOSA and intersection safety. The JRC site at Ispra, Italy, features 36 km of internal roads under real-life driving conditions and 9 vehicle emissions laboratories for calibration and electromagnetic compatibility and interference testing, *among others*. The JRC Ispra site also evaluates GLOSA and tests the co-existence of LTE-V2X and ITS-G5 in the 5.9 GHz band.

4 GLOSA and Intelligent Intersection V2X Use Cases

Since vehicles usually spend most of their time moving at high speed, it may have serious consequences when an accident happens and even threaten the safety of the driver and passengers. Safety always has the highest priority, so how to ensure vehicle safety has always been a serious topic.

A method to reduce extreme stop-and-go driving on urban streets is to optimize signal timings. Historically, signal timing optimization tools were developed to reduce delays and stops experienced by urban drivers. More recently, new methods in traffic signal optimization have incorporated changes in drivers' behaviour to achieve optimum performance at signalised intersections. In this framework, traffic lights control – as one of the traffic management methods – becomes an important and effective way to improve urban road capacity, ease traffic congestion and reduce vehicle delay time [39]. A method to reduce extreme stop-and-go driving on urban streets is to optimize signal timings. Traffic light forecast is a service that improves safety and convenience for drivers by assisting them at intersections. This includes services like Time-To-Green (TTG), which provides real time information about the traffic light cycles and Green Light Optimised Speed Advisory (GLOSA), which calculates the optimum approach speed to get a green light at the upcoming intersection [40]. These services that act as "cooperative" green light functions, implicate for several benefits as they: save fuel and reduce pollution; "bring" comfort to drivers; increase throughput, and; enhance safety as relaxed drivers can behave in a more secure way [41].

The GLOSA systems are an interesting "first-step" in advanced driver-assistance systems (ADAS) systems based on V2X communication with infrastructure, before the use of information by autonomous vehicles to handle intersections. A GLOSA-based business model aims to provide car drivers an optimized driving experience through real-time optimized speed advice; in this scope, a participating service provider will offer a software application (or an on-board unit) to the car drivers, thus enabling them to track their speed and location. Through integrating user/traffic data, the service provider will offer real-time advice with regards to the (expected) state of upcoming traffic lights, allowing the car drivers to alter their speed, accordingly.

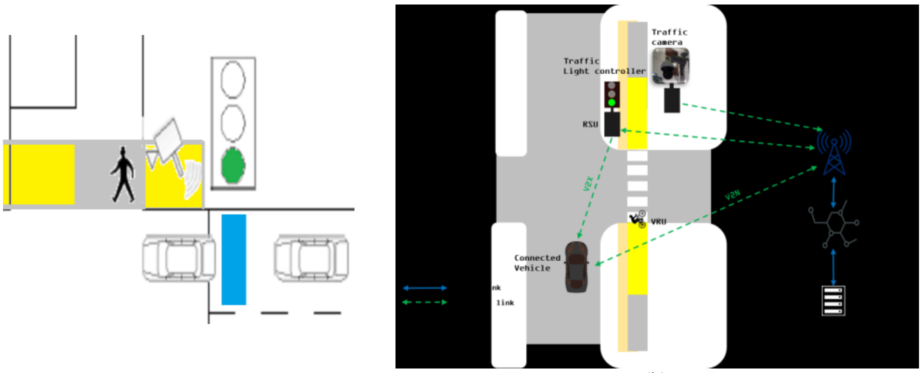
A GLOSA system uses timely and accurate information about traffic signal timing and traffic signal locations to guide drivers (through infrastructure-to-vehicle communication) with speed advice for a more uniform commute with less stopping time through traffic signals [42]. A potential implementation can be evaluated for two types of traffic signal timing: predictable fixed-time signal timing and unpredictable actuated-coordinated signal timing. The objective of GLOSA systems is to provide to the driver the optimal speed to cross the next intersection with a green phase [43-44]. GLOSA systems improve traffic efficiency by: (i) reducing stop times; (ii) bettering the fluidity of the traffic; (iii) giving anticipating data which improve the safety; and (iv) reducing CO_2 emissions, fuel consumption and reducing waiting time and travel time. This system can ensure a continuous flow of vehicles if several traffic lights are coordinated; moreover it is also useful for emergency vehicles to request a right of way if traffic lights are able to communicate. GLOSA systems have been shown to reduce both CO_2 emissions and fuel consumption by giving drivers speed recommendations when approaching a traffic light [45-46].

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 SPAT messages. Neighbouring vehicles can receive these messages and process them locally along with their own positioning, speed and direction data. 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. The dynamic information is disseminated using the SPaT V2X I2V message and contains the traffic lights' time to change and speed advice information that apply to group of ingressing lanes [47]. The MAP and SPaT messages are already standardized and profiled [48]. However, the interpretation of their content at the receiving side (cooperative vehicles) and the relation between this content and the actual current status of the traffic light controller can still lead to confusion. Knowing how to interpret the SPaT content at the receiving side is particularly critical in the case of Connected Automated Vehicles (CAVs) [49].

For the purpose of conducting the GLOSA trial, the JRC has deployed a commercial C-ITS roadside unit covering a section of its internal road infrastructure. The RSU sits at the junction of two suburban-type roads of 420m and 220m, respectively, at a height of approximately 10 m. In addition, the RSU is connected to the internal JRC network infrastructure to allow remote configuration, management and traffic monitoring. The commercial RSU runs an Automotive Grade Linux operating system, thus allowing the execution of custom user space applications (such as a virtual traffic light for the GLOSA service).

Intersections are hazardous places. The intersection plays an important role in the traffic network, but it is also one of the main causes of traffic accidents. Based on statistical data, more than 50% of the combined total of fatal and injury crashes in the U.S. in 2018 occurred at or near intersections [50]. Crashes near intersections might also lead to serious traffic jams on multiple roads, which apparently waste time and money of drivers and also cause unnecessary air pollution. It is also reported that about 94% of the intersection-related crashes had critical reasons attributed to drivers, such as inadequate surveillance, false assumption of other's action and turned with obstructed view [51]. Usual relevant threats arise from interactions among pedestrians, bicycles and vehicles, more complicated vehicle trajectories in the absence of lane markings, phases that prevent knowing who has the right of way, invisible vehicle approaches, vehicle obstructions and also illegal movements. Accidents can also occur because drivers, bicyclists and pedestrians do not have the information they need to avoid wrong decisions [52]. In these cases, the missing information can be calculated and communicated by an intelligent intersection [53-54] so that to significantly enhance security [55]. A proper set of information may be about providing the current full signal phase, an estimate of the time when the phase will change, the occupancy of the blind spots of the driver or autonomous vehicle, and detection of red-light violators, *among others*. Following to the above concerns, the intersection management becomes one of the most challenging problems within the transport system for keeping traffic safety and smoothing traffic flow [56-57]. Traffic light-based methods have been efficient but are not able to deal with the growing mobility and social challenges. On the other hand, the advancements of automation and communications have enabled cooperative intersection management [58-59], where road users, infrastructure, and traffic control centres are able to communicate and coordinate the traffic safely and efficiently. Examples of intelligent management systems include machine learning methods, fuzzy systems, and multi agents, as well as enhancing V2I connectivity as in GLOSA systems. In all cases the objective is to ensure that the intersection operates well and serves the public [60].

By using V2V, V2I, and I2V communication and Autonomous Vehicle (AV) technologies, a sort of autonomous intersection management can improve the efficiency of existing intersections [61]. An intelligent intersection can broadcast two crucial information messages. A SPAT I2V message that the SAE has standardized [48], gives the full signal phase (not just the partial view of the signal that a user or AV has) and an estimate of the time when the signal phase will change. Together with what road users and AV sensors can see, SPaT eliminates most possible conflicts. The second message informs an AV [59] what its blind spots are and which of them (if any) is occupied by another user. Computation of the SPaT message requires real time access to the intersection phase. Calculation of blind spot occupancy requires real time sensing of well-defined regions of the intersection. These two messages can resolve all conflicts within the intersection. Active monitoring of intersections provides the driver and/or intelligent vehicle system a very important time advantage to take action, even before a problem would have otherwise become visible. This means the technology potentially allows drivers to take preventative action and avoid critical situations. The 5G-DRIVE intelligent intersection use case deals with safety on intersections, by focusing on infrastructure detection 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), as depicted in Fig.1(a).



(a) (b)

Fig. 1. (a) Intelligent intersection; (b) proposed joint architecture for both uses cases.

When a pedestrian is detected on the crosswalk (as in the grey area of Fig.1(a)) a Decentralised Environmental Notification Message (DENM) should be broadcasted by the RSU. (A DENM is structured as a code for a specific warning event together with a small map of the relevance area and the approach towards it and the approach is similar to the principle of the MAP, so that vehicles should check whether they are close to the approach and driving in the same direction). When the DENM message is transmitted, the back-office should geocast this to all vehicles in the vicinity. This is to warn vehicles further upstream that a potential conflict may occur in the future and to prevent future hard braking. In the yellow areas of Fig.1(a), given a movement direction of the pedestrian towards the intersection, the infrastructure should send out Collective Perception Messages (CPM) [62]. This is to warn vehicles further upstream that a potential conflict may occur in the future and to prevent future hard braking. This use case deals with safety on intersections, focusing on infrastructure detection of situations that are difficult to perceive by vehicles themselves. The example of the collision avoidance is shown in Fig.1(a). In this example, 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). 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 are mostly emulated not to put real pedestrians at risk and ease requirements on timing the approach of the vehicle.

The intelligent intersection use case development has been done in parallel with the GLOSA use case. GLOSA is dedicated for sending CAM messages but intelligent intersection is dedicated for using SPAT messages to improve vehicle situation awareness. Currently, the vehicle and interfaces exist in the software level and first implementation exists but with ITS G5. Now the communication devices are changed to C-V2X but this should not influence to messages minimally. A joint set-up supporting both use cases has been proposed in the trials taking place at the site in Finland. For this purpose, a dedicated architecture has been as shown in Fig.1(b).

The Connected Vehicle 1 (CV1) is warned about the VRU (i.e., the cyclist) with intelligent intersection service (DENM message). Note that the messages for GLOSA are not shown in the above figure and that two possible locations of the RSU are shown (with the MEC/back-office server or attached to the traffic light). The key architectural elements of this use case are as follows:

- A *physical/virtual traffic light* in static control mode to implement 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, but without loop detectors) or virtual (a software running on/communicating with the RSU). Another variable is the communication channel. Data can be retrieved locally if interfaces are available on-site, or it can be originated from a traffic management centre and distributed to communicate with agents in the field. The traffic light is only required for the GLOSA use case and the content of the SPaT message has to be retrieved from it.
- An *LTE-V2X RSU* as well as a *ITS-G5 RSU,* both co-located with the traffic light (if physical) or running/communicating with the traffic light implementation (if virtual). When a VRU is detected in the zebra crossing of Fig.1(b), a DENM should be broadcasted by the RSU, while the back-office should geocast this to all vehicles in the vicinity. In the yellow areas, given a movement direction of the VRU towards the intersection, the infrastructure should send out CPM. For GLOSA it should broadcast both MAP and SPaT messages.
- At least *two (on-board units) OBUs* (one ITS-G5, one LTE-V2X) deployed in the test vehicles. The OBUs receive and process the MAP, SPaT, DENM and CPM messages locally to show GLOSA information or compute the potential conflicts with the VRUs on the zebra crossing and also warn vehicles further upstream that a potential conflict may occur in the future and to prevent future hard braking.
- An *automated vehicle with sensors* to fill CPM messages with real sensor data in

V2V scenarios.

- A *traffic camera* detecting and tracking vulnerable road users (VRUs).
- A *traffic camera server* can provide connectivity between the RSUs and various supporting services/servers running in the respective testing data centre. When a pedestrian is detected in the zebra crossing, a DENM should be broadcasted by the RSU, while the RSU back-office server should geocast this to all vehicles in the vicinity (Connected vehicle 1, Connected vehicle 2). In the yellow areas, given a movement direction of the VRU towards the intersection, the infrastructure should send out CPM. The length of the yellow area is the same as the length of the zebra area. For more controlled testing it should also be possible to generate messages based on emulated VRU movements.
- *RSU back-office server* in the data centre running all needed supporting services.

4 Concluding Remarks

In the scope of the present work we have discussed the important role of V2X communications for the promotion of modern 5G features, especially within the area of C-ITS and automated driving, towards enhancing traffic management in urban environments and also enhancing road safety. The way of realising any possible solution, also implicates for different demands as of latency, reliability, throughput, user density and safety. More specifically, our approach has been around the scope of the innovative research performed by the 5G-DRIVE project, which is a synergetic collaborative effort between EU and China that promotes testing LTE-V2X communications using the 5.9 GHz band for V2V applications and the 3.5 GHz band for V2N applications. Our main focus has been about the discussion of the two 5G-DRIVE selected uses cases, that is GLOSA and intelligent intersection. Both can offer a multiplicity of advantages for the participating users at various domains ranging from enhanced road safety and comfort to the reduction of fuel consumption and emissions.

For the 5G-DRIVE project, GLOSA is an attractive V2X use case to improve the traffic flow. It provides drivers an optimal speed advice when they approach to a signalised intersection and they are instructed to maintain actual speed, slow down, or adapt a specific speed. On the other hand, intelligent intersections have been assessed as “indispensable” parts of modern road infrastructures, especially with the aim or proving the necessary information preventing from accidents and allowing for better security of both drivers and VRUs, while on-the-move. Both use cases have been discussed and assessed as of their respective technological background, especially via the use of dedicated, per case, messages serving informative purposes. In addition, on the basis of the 5G-DRIVE trials, we have proposed a sort of joint architectural approach able to serve both use cases. Future trials will provide more detailed results on the potential applicability and the novelties provided by our approach.

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References

1. European Telecommunications Standards Institute (ETSI): TR 102 638 V1.1.1 (2009-06): "Intelligent Transport Systems; Vehicular Communications; Basic set of Applications; Definitions" (2009)
2. European Parliament and Council: Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. Official Journal (OJ) L207, 06.08.2010, pp.1-13. (2010)
3. European Commission: Communication on "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility", [COM(2016) 766 final]. (2016)
4. European Telecommunications Standards Institute (ETSI): ETSI TS 103 723 V1.2.1: "Intelligent Transport Systems (ITS); Profile for LTE-V2X Direct Communication" (2020)
5. Car-to-Car Communication Consortium: Basic System Profile, Release 1.5.0. (2020)
6. C-Roads Platform, https://www.c-roads.eu
7. Festag, A.: Cooperative Intelligent Transport Systems in Europe. IEEE Communications Magazine **53**(12), 64--70 (2015)
8. Lu, M., and Blokpoel, R.J.: A Sophisticated Intelligent Urban Road-Transport Network and Cooperative Systems Infrastructure for Highly Automated Vehicles. In: Proceedings of the 2016 World Congress on Intelligent Transport Systems, pp.1-8. (2016)
9. Storck, C.R., and Duarte-Figueiredo, F.: A Survey of 5G Technology Evolution, Standards, and Infrastructure Associated With Vehicle-to-Everything Communications by Internet of Vehicles. IEEE Access **8**, 11759--117614 (2020)
10. Next Generation Mobile Networks (NGMN) Alliance Ltd.: V2X White Paper – V1.0 (2018). https://www.ngmn.org/wp-content/uploads/V2X_white_paper_v1_0-1.pdf
11. 5G Public Private Partnership (5G-PPP):2020): 5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe (2020)
12. Andrews, J.G., Buzzi, S., Choi, W., et *al*.: What Will 5G Be? IEEE JSAC, Special issue on 5G Wireless Communications Systems **32**(6), 1065--1082 (2014)
13. Malandrino, F., and Chiasserini, C.F.: Present-day verticals and where to find them: A data-driven study on the transition to 5G. In: Proceedings of the 2018 14th Annual Conference on Wireless On-demand Network Systems and Services (WONS), pp.1-5. (2018)
14. Global System for Mobile Communications Association (GSMA): Connecting Vehicles – Today and In the 5G Era with C-V2X – White Paper (2019)
15. 5G Americas: Cellular V2X Communications Towards 5G – White Paper (2018, March)
16. The 3rd Generation Partnership Project (3GPP): 3GPP TR 22.885 V14.0.0: Study on LTE Support for Vehicle to Everything (V2X) Services Architecture Enhancements for V2X Services (Release 14)" (2015, December)
17. Counterpoint: Global Connected Car Tracker 2018, Market Research Report (2018)
18. Chen, S., Hu, J., et *al.*: Vehicle-to-Everything (V2X) Services Supported by LTE-Based Systems and 5G. IEEE Communications Standards Magazine **1**(2), 70--76 (2017, July)
19. Rebbeck, T., Steward, J., Lacour, H.A., Killeen, A., et *al.*: Final Report for 5GAA Socio-Economic Benefits of Cellular V2X. 5G Automotive Association (5GAA) (2017)
20. Eckhoff, D., Sofra, N., and German, R.: A performance study of cooperative awareness in ETSI ITS G5 and IEEE WAVE. In: Proceedings of the 2013 10th Annual Conference on Wireless On-demand Network Systems and Services (WONS), pp.1-5. (2013)
21. Roux, P., Sesia, S., Mannoni, V., and Perraud, E.: System Level Analysis for ITS-G5 and LTE-V2X Performance Comparison. In: Proceedings of the 2019 IEEE 16th International Conference on Mobile Ad Hoc and Sensor Systems (MASS-2019), pp.1-9. IEEE, (2019)

22. Molina-Masegosa, R., Gozalvez, J., and Sepulcre, M.: Comparison of IEEE 802.11p and LTE-V2X: An Evaluation With Periodic and Aperiodic Messages of Constant and Variable Size. IEEE Access **8**, 121526--121548 (2020)
23. Araniti, G., Campolo, C., Condoluci, M., Iera, A., and Molinaro, A.: LTE for vehicular networking: A survey. IEEE Communications Magazine **51**(5), 148--157 (2013)
24. The 3rd Generation Partnership Project (3GPP): 3GPP TS 23.285 V14.9.0: "Architecture Enhancements for V2X Services (Release 14)" (2019, December)
25. 5G Automotive Association (5GAA): An Assessment of LTE-V2X (PC5) and 802.11p Direct Communications Technologies for Improved Road Safety in the EU (2017)
26. The Third Generation Partnership Project (3GPP): TR 21.915 V15.0.0: "Release 15 Description; Summary of Rel-15 Work Items (Release 15)" (2019, September)
27. The Third Generation Partnership Project (3GPP): TR 21.916 V1.0.0: "Release 16 description; Summary of Rel-16 Work Items (Release 16)" (2020, December)
28. Kutila, M., Pyykonen, P., Huang, O., Deng, W., Lei, W., and Pollakis, E.: C-V2X supported automated driving. In: Proceedings of the IEEE 2019 International Conference on Communications, Workshops (ICC Workshops 2019), pp.1-5. IEEE (2019)
29. 5G-DRIVE Project (Grant Agreement No.814956), https://5g-drive.eu/
30. European Telecommunications Standards Institute (ETSI): EN 302 665 V1.1.1: "Intelligent Transport Systems (ITS); Communication Architecture" (2010, September)
31. International Organization for Standardization (ISO): "ISO 21217:2014 (Intelligent transport systems - Communications access for land mobiles (CALM) – Architecture" (2014, April)
32. European Commission: C-ITS Platform, Technical Report (2016, January)
33. Mellegård, N., and Reichenberg, F.: The Day 1 C-ITS Application Green Light Optimised Speed Advisory - A Mapping Study. Elsevier Transportation Research Procedia **49**, 170--82 (2020)
34. Lu, M., Türetken, O., Adali, O.E., Castells, J., Blokpoel, R., and Grefen, P.: C-ITS (Cooperative Intelligent Transport Systems) deployment in Europe - challenges and key findings. In: Proceedings of the 25th ITS World Congress, pp.1-10. (2018, September)
35. European Telecommunications Standards Institute (ETSI): ETSI EN 302 637-3 V1.2.2: "ITS Vehicular Communications: Basic Set of Applications; Part 3: Specification of Decentralized Environmental Notification Basic Service" (2014, November)
36. Kostopoulos, A., Chochliouros, I.P., et *al.*: 5G trial cooperation between EU and China. In: Proceedings of the IEEE 2019 International Conference on Communications, Workshops (ICC Workshops 2019), pp.1-6. IEEE (2019)
37. Chochliouros, I.P., Spiliopoulou, A.S., Kostopoulos, A. et *al.*: Testbeds for the Implementation of 5G in the European Union: The Innovative Case of the 5G-DRIVE Project. In: Proceedings of the AIAI-2019 International Conference, IFIP Advances in Information and Communication Technology (AICT) 560, pp.78-92. Springer (2019)
38. Amelink, M.: Signal phase and time (SPAT) and map data (MAP). Amsterdam Group (2015, September)
39. Yang, K., Guler, S.I., & Menendez, M.: Isolated intersection control for various levels of vehicle technology: Conventional, connected, and automated vehicles. Transportation Research Part C: Emerging Technologies **72**, 109--129 (2016)
40. Stevanovic, A., Stevanovic, J., and Kergaye, C.: Green Light Optimized Speed Advisory Systems: Impact of Signal Phasing Information Accuracy. Journal of the Transportation Research Board, **2390**(1), 53--59 (2013)
41. Radivojevic, D., Stevanovic, J., and Stevanovic, A.: Impact of green light optimized speed advisory on unsignalized side-street traffic. Journal of the Transportation Research Board **2557**(1), 24--32 (2016)
42. Katsaros, K., Kernchen, R., Dianati, M., and Rieck, D.: Performance study of a green light optimized speed advisory (GLOSA) application using an integrated cooperative ITS

simulation platform. In: Proceedings of the 7th International Wireless Communications and Mobile Computing Conference (IWCMC), pp. 918-923. (2011)

43. Lebre, M.A., Le Mouël, F., Ménard, E., Garnault, A., et *al.*: Real scenario and simulations on GLOSA traffic light system for reduced CO_2 emissions, waiting time and travel time. In: Proceedings of the 22nd ITS World Congress, pp.1-12. (2015)
44. Wan, N., Luckow, A., and Vahidi, A.: Optimal speed advisory for connected vehicles in arterial roads and the impact on mixed traffic. Transportation Research Part C: Emerging Technologies **69**, 548--563 (2016)
45. Bradaï, B., Garnault, A., Picron, V., and Gougeon, P.: A green light optimal speed advisor for reduced CO_2 emissions. Springer International Publishing (2014)
46. Bodenheimer, R., et *al.*: Enabling GLOSA for Adaptive Traffic Lights. In: Proceedings of the IEEE 2014 Vehicular Networking Conference (VNC), pp.167-174. IEEE, (2014)
47. MAVEN Project: Deliverable 4.1 “Cooperative adaptive traffic light with automated vehicles (Initial version)” (2018, January)
48. Society of Automotive Engineers (SAE): SAE J2735_201603, Dedicated Short Range Communications (DSRC) Message Set Dictionary (2016, March)
49. Englund, C., Chen, L., Ploeg, J., et *al.*: The grand cooperative driving challenge 2016: Boosting the introduction of cooperative automated vehicles. IEEE Wireless Communications **23**(4), 146--152 (2016, August)
50. U.S. Department of Transporation, Federal Highway Administration: Safety Evaluation of Multiple Strategies at Signalized Intersections (Publication No.FHWA-HRT-17-062), (2018, May). https://www.fhwa.dot.gov/publications/research/safety/17062/17062.pdf
51. General Motors. GM self-driving safety report (2018)
52. Ahn, H., and Del Vecchio, D.: Safety verification and control for collision avoidance at road intersections. IEEE Transactions on Automatic Control Systems **63**(3), 630--642 (2018)
53. Grembek, O., Kurzhanskiy, A., et *al.*: Making intersections safer with I2V communication. Transportation research Part C: Emerging Techmologies **102**, 396--410(2019, May)
54. Guler, S.I., et *al.*: Using connected vehicle technology to improve the efficiency of intersections. Transportation Research Part C: Emerging Technologies **46**, 121--131 (2014)
55. Kurzhanskiy, A., and Varaiya, P.: Safety and Sustainability with Intelligent Intersections. University of California, Berkeley, US (2019)
56. Chen, L., and Englund, C. (2016): Cooperative intersection management: A survey. IEEE Transactions on Intelligent Transportation Systems **17**(2), 570-586 (2016).
57. Rios-Torres, J., and Malikopoulos, A.A.: A survey on the coordination of connected and automated vehiclesat intersections and merging at highway on-ramps.IEEE Transactions on Intelligent TransportationSystems **18**(5), 1066--1077 (2016)
58. Chouhan, A.P., and Banda, G.: Autonomous intersection management: A heuristic approach. IEEE Access **6**, 53287--53295 (2018)
59. Namazi, F., et *al.*: Intelligent Intersection Management Systems Considering Autonomous Vehicles: A Systematic Literature Review. IEEE Access **7**, 91946--91965 (2019)
60. Muralidharan, A., Coogan, et *al.*: Management of intersections with multi-modal high-resolution data. *Transportation Research, Part C* **68**, 101--112 (2016)
61. Wuthishuwong, C., and Traechtler, A.: Consensus-based local information coordination for the networked control of the autonomous intersection management. Complex Intelligent Systems **3**(1), 17--32 (2017, March)
62. European Telecommunications Standards Institute (ETSI): ETSI TR 103 562 V0.0.15: “Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective -Perception Service (CPS)” (2019, October)