Latency-aware C-ITS application for improving the road safety with CAM messages on the Smart Highway testbed

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***Abstract*—The Cooperative Intelligent Transportation System (C-ITS) testbed or simplified called the Smart Highway (Antwerp, Belgium) is designed to facilitate research in the area of distributed/edge computing and vehicular communications. The Smart Highway testbed deploys the Cooperative Awareness Basic Service to exchange Cooperative Awareness Messages (CAMs) between road C-ITS entities, e.g., C-ITS vehicles and Road-Side Units (RSUs). CAMs support vehicular safety and traffic efficiency applications by providing them with the continuous status information of relevant C-ITS entities. Therefore, it is important that those messages are delivered with low latency, especially the CAMs that originate from special vehicles, e.g., emergency vehicles, police cars, and fire trucks. In this paper, we research the impact of CAM messages configuration on the communication latency among vehicles. Moreover, we have performed the practical experimentation to evaluate the aforementioned impact, using ITS-G5 and LTE-V2X system under realistic vehicular conditions, on the Smart Highway testbed located in Antwerp.**

***Index Terms*—autonomous driving, C-ITS, CAM, ITS-G5, LTE-V2X, vehicular communications, V2X, smart mobility.**

I. Introduction

Cooperative Intelligent Transportation Systems (C-ITS) are improving safety, efficiency, and driving comfort on the roads by reducing or completely eliminating the road accidents, since they support wireless connectivity, and enable awareness between road and user applications [1]. One way to implement this awareness between road users is through Vehicle-to-Everything (V2X) communication. V2X communication enhances the driver's awareness regarding potential hazards as it connects wirelessly, vehicles with other vehicles (V2V), with the roadside infrastructure (V2I), with the network (V2N), with pedestrians (V2P), with everything (V2X) [2].

In order to provide wireless connectivity in C-ITS environments, communication technologies for vehicular networks (VN) are necessary, and some of the promising examples are Visible Light Communication (VLC), ITS-G5 (IEEE 802.11p), Wi-Fi, and LTE-V2X (3GPP). Vehicular networks rely on Cooperative Awareness Messages (CAMs), specified by the European Telecommunication Standard Instituted (ETSI), to provide the awareness in the C-ITS environment by periodically sending the status data to neighboring nodes (e.g., position and speed) [3]. A CAM message is constructed out of two mandatory containers and two optional containers, where the optional containers are mostly used by special vehicles, e.g., police cars, thereby requiring the delivery of a CAM message with low latency.

To communicate these CAM messages in a C-ITS environment, there are two main wireless technologies supporting the first generation V2X communication [4]. One of them is a cellular based technology that is defined by the Third Generation Partnership Project (3GPP) in Release 14 and 15, named as Long-Term Evolution-V2X (LTE-V2X) [4]. The cellular-based technologies can also be referred as Cellular-V2X (C-V2X). This technology is based on the PC5 or sidelink LTE radio interface [4]. 3GPP is currently working on 5G-V2X communication platforms to overcome the shortcomings in LTE-V2X [4]. The other technology is IEEE 802.11p, which is also the basis for ITS-G5 standardized by ETSI and Dedicated Short-Range Communications (DSRC) standards [4,5]. The IEEE 802.11p is extensively tested and analyzed globally considering V2X communications [5]. Both IEEE 802.11p and C-V2X are not compatible with each other, which implies that vehicles are not able to interconnect with each other if they are equipped with communication units from different technologies [4,5]. This present issue in VNs opened a new area of research and debate focused on how these technologies can be used together, and which technology should be used at the specific moment [4,5]. This includes the spectrum allocation at the 5.9 GHz band, and the capability to develop and offer compatibility with the implemented first generation V2X system [4,5].

Several studies have compared IEEE 802.11p and LTE-V2X. For instance, the study conducted by Hu et al. [6] introduces a link level evaluation of the main technologies (IEEE 802.11p, LTE-V2X), and 5G. The IEEE 802.11p technology usually offers good throughput with limited mobility. Furthermore, the research presented by Chung et al. [7] concluded that, with few competing nodes using the IEEE 802.11p, the delay in channel access gets high in worst-case scenarios, thereby directly increasing overall latency. One of the IEEE 802.11p limitations is its limited coverage, which can be improved with LTE-V2X and 5G communications.

In this paper, we conduct a comparative study and investigate what impact different sizes of CAM messages have on latency performance, comparing scenarios when we send a regular CAM (two containers), and a CAM that is constructed out of all its four CAM containers. In this realistic experimentation on the real-life Smart Highway testbed, we make use of two communication technologies, i.e., ITS-G5 (IEEE 802.11p) and LTE-V2X (3GPP), thus, enabling communication between an Onboard Unit (OBU) and a Road-Side Unit (RSU) or eNBs, which have the role of base stations. The real data measurements collected on the testbed are incorporated as a prominent feature to obtain preliminary results of the behavior of the CAM messages, and its capabilities to be used for optimising the vehicular network. We define here the latency as the amount of time that it takes to construct a CAM message, encode it, transmit it, and then decode it back at the receiver side such that it is available on the application layer for C-ITS applications.

The main contribution of this study is to bring insights and awareness of the latency performance in V2X systems by studying the size of a CAM messages, and communication technology (i.e., ITS-G5 or LTE-V2X, in short range communication) that best fits the selected CAM. Since the future of transportation systems is going towards autonomous and assisted driving, aiming to reach full automation, it is important that (semi-)autonomous vehicles do not only rely on their embedded sensors but also communicate with each other to know what is happening in their Non-line-of-sight (NLOS). Therefore, it is important that the awareness messages have an as low as possible latency.

The remainder of this paper is divided as follows: Section 2 is an in depth overview of the current two main leading technologies that support the first generation V2X communication. We discuss in depth CAM messages in Section 3. Furthermore, we present our experiment, the developed application, as well as technologies that we make use of in order to conduct our experiment in Section 4. The experiment results, discussions, and comparisons between the two main vehicular technologies are presented in Section 5. Conclusions and future work are summarized in Section 6.

II. Wireless technologies for vehicular communication

A. IEEE 802.11p

In 2010, IEEE introduced the IEEE 802.11p standard. In Europe, it is used as basis for the ITS-G5 standard which has been standardized by ETSI. It is an improved version of the IEEE 802.11a standard for vehicle networking. The IEEE 802.11 standard introduces a new PHY feature called Orthogonal Frequency Division Multiplexing (OFDM), which has a channel bandwidth of 10 MHz and aids in the development of IEEE 802.11p [4,5]. IEEE 802.11p can sync faster than 802.11, which is a critical feature for vehicle communication [4].

IEEE 802.11p has control channels (CCH) and service channels (SCH). Control channels (CCH) and service channels (SC) are two types of channels in IEEE 802.11p (SCH).

The IEEE 802.11p standard uses the same coding and modulation schemes as the IEEE 802.11a standard. IEEE 802.11p uses several coding schemes, such as binary phase shift keying, convolutional coding, quadrature phase shift keying, 16 quadrature amplitude modulation, or 64-quadrature amplitude modulation, to support data rates ranging from 3 to 27 Mbps [4]. The Carrier Sense Multiple-Access with Collision-Avoidance (CSMA/CA) is the IEEE 802.11p access technique that uses the distributed coordination function (DCF). Before transmitting a packet in CSMA/CA, a node must sense the radio channel. If another node is using the channel, the node will not transmit. If the node detects that the channel is idle, it can start its transmission. If the channel is sensed as busy, the node defers its transmission until the end of the current transmission. When the vehicle detects a signal with a received power strength higher than the Clear Channel Assessment (CCA) threshold, the radio channel is considered busy. The receiver its sensitivity level must be higher than the CCA threshold (or sensing power threshold). The node waits for a backoff time at the end of the channel busy period to avoid collisions during contention between multiple nodes that have also deferred their transmission. The random backoff time the node randomly waits is calculated by the multiplication of the slot time with a random number between zero and the Contention Window (CW), for transmitting in 10MHz channels at minimum CW is 15 with a slot time of 13µs [4]. This is also referred to the Enhanced Distributed Channel Access (EDCA) mechanism, which support QoS thorough traffic classes with high (e.g., voice) and low priority (i.e., best effort) were thus, the traffic classes differ in their average channel access delay.

So, the CSMA/CA enhances the performance of IEEE 802.11p and it is implemented on a wide range of vehicular applications [5]. This carrier avoidance method makes a robust effect on VANET by resolving the problem of hidden terminal [5]. It is also advantageous to improve the likelihood of receiving safety signals over short distances [5]. The transmission link between roadside infrastructure and vehicles are primarily for a short period of time, and this indicates that there is not sufficient time for authentication processes [5]. The 802.11p deals with that issue by defining a technique that allows transferring messages between vehicles and roadside infrastructure by not creating a Basic Service-Set (BSS) [4,5].

B. LTE-V2X

The standardization of the Cellular Vehicle-to-Everything (LTE-V2X or C-V2X) technology has been finalized by 3GPP in 2017. This communication standard operates with the channels at 10 or 20 MHz. LTE V2X uses a structure for resources in frequency and time similar to that of LTE [4,5]. The 14 OFDM frames are embedded in a 1 ms sub-frame, with time and bandwidth allocated to each channel and 180 kHz resource blocks shared (RBs) [4,5]. Every individual RB is made up of 12 OFDM sub-carriers separated by 15 kHz [5]. Each RB-containing sub-frame is organized into sub-channels. Various modulation and coding systems (MCSs) are used in LTE V2X, including 16 QAM, turbo coding, and QPSK [4,5]. Side-link Control Information (SCI) and Transport Block (TB) are used to compress the control and data information of the LTE V2X network, respectively. The Physical Side-link Control Channel (PSCCH) is used by SCI, whereas the Physical Side-link Shared Channel is used by TB (PSSCH) [4,5]. A TB contains a full packet and can occupy multiple sub-channels, which is determined by the total number of RBs per sub-channel as well as the MCS [4,5]. Every SCI is linked to a TB which takes 2 RBs [4]. An SCI needs to be correctly decoded at the receiving side to be able to correct decode the TB since, each SCI contains important information to decode a TB [4]. LTE-V2X works under two modes, respectively Mode 3 and Mode 4. In Mode 3, the cellular base station (or eNB) determines and manages the sub-channels for direct vehicle communication [4]. In mode 4, vehicles determine their sub-channels on their own in an autonomous way [4].

III. Cooperative Awareness Messages

In order to enable vehicles to be aware of their environment, all vehicles that make use of C-ITS broadcast CAMs. Therefore, each vehicle that uses C-ITS will generate new CAM messages depending on its current position, speed and direction [8]. The vehicle will compare its current kinematic measurements with the ones from the last generated message, and if the difference between them is above pre-defined thresholds, the vehicle triggers a next CAM message to be generated and sent [8]. The specific process to generate a CAM message is as followed; a C-ITS vehicle generates a new CAM when its position changed more than 4 m, its speed changed more than 0.5 m/s or its heading changed more than 4° [3,4]; the speed and heading variations are both computed as absolute values. A CAM is also generated if the time elapsed since the last generated CAM is equal to or higher than 1 second [4]. Current CAM generation rules establish that CAM messages are not necessarily periodic, except when the vehicle is stopped then a CAM is generated every one second. The maximum frequency of a CAM message is set to 10 Hz.

A. Message Containers

When a CAM needs to be generated, the cooperative basic service will construct the mandatory containers specified in the ETSI EN 302 637-2 [3], in this paper we will only discuss the vehicle containers as shown in Figure 1. The standard, indeed, states that, "the mandatory containers include the high dynamic information of the originating ITS-Station presented in the basic vehicle container and high frequency vehicle container" [3]. The standard also states that, "Optionally, a CAM may include optional data" [3]. The optional data includes status of the originating ITS station which is less dynamic that is presented in the low frequency vehicle container [3]. Specific information is included for some types of originating ITS-Station, such as the special vehicle container specified in the ETSI EN 302 637-2 standard [3]. Figure 1 shows the ITS Protocol Data Unit (PDU) header and multiple containers of a CAM message. The ITS protocol data unit header comprises the protocol version, the message type and the ITS station ID of the originating ITS station according to ETSI EN 302 637-2 [3]. The protocol version is used to select the appropriate protocol decoder at the receiving ITS station [3]. Specified by the ETSI standard, "the message type and the message ID should be harmonized with other ETSI message identifier definitions" [3]. For CAM, the message ID is set to 2 [3]. For vehicle ITS stations, a CAM is comprised of one basic vehicle container and one high frequency vehicle container, and may also include one low frequency vehicle container and one or more other special vehicle containers [3].

- Basic vehicle container:

The basic vehicle container provides basic information of the originating ITS station [3]. This is mandatory for every CAM [3]. It is composed by a station ID, which identifies the ITS station. The ID changes over time, it is a pseudonym, this implies that the ID is always anonymous, for more information we refer to the following ETSI standard that is specially devoted on pseudonym IDs: ETSI TR 103 415 [9]. It also includes the generation delta time to generate the reference position [3]. The reference position is given by longitude, latitude, and altitude of the vehicle [3].

- High frequency vehicle container:

The high frequency container is mandatory within every CAM, it contains all fast changing status information of the vehicle ITS station [3]. For example, the heading of the vehicle, e.g, north, the speed of the vehicle, the driving direction in the lane front/rear, the vehicle length, the vehicle width, the steering wheel angle, the performance class, the longitudinal acceleration, lateral acceleration, vertical acceleration, curvature, and yaw.

- Low frequency vehicle container:

The low frequency vehicle container is an optional container that contains static or slow changing vehicle data [3]. The vehicle role is specified in here. For example, default public transport, military, taxi, emergency, etc. The exterior lights are also specified here, for example, the main beams, turning lights, rear lights, fog lights, etc.

- Special vehicle container:

The special vehicle container is an optional container that is only used in vehicle ITS stations which have a specific role in road traffic [3]. For example, emergency vehicles like the police. They include this container to inform other ITS stations [3].

IV. Experiment and setup

A. Experiment

In this research experiment, we showcase the impact on the latency, when sending a regular (small) CAM message i.e., a CAM message that is constructed out of its two mandatory containers, compared to a CAM message that is constructed out

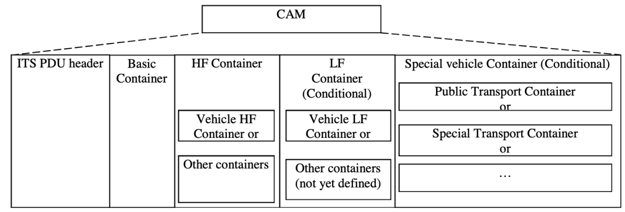

Fig. 1: CAM message containers [3].

the four CAM containers (Full-CAM) i.e., the two mandatory and two optional containers, over ITS-G5 (IEEE 802.11p) and LTE-V2X (3GPP). We used both for ITS-5G and LTE-V2X 180 channels, with a channel bandwidth of 10MHz, TX power of 23 dBm with a data rate of 6 Mbps. In particular, since the future of transportation systems is going toward autonomous and assisted driving, latency is crucial so that the messages are received on time. The two optional CAM containers respectively the low frequency vehicle container and the special vehicle container are used when, for example, a police car is going to an emergency situation. With our experiment we make a conclusion for both technologies assuming the vehicles are standing still. We created a CAM message generator that takes a timestamp (called timestamp A) for every CAM that will be created. On the receiving side we decode the CAM message and when it is available for the application (so fully decoded) we take a timestamp called timestamp B. Therefore, the latency can be calculated by measuring the difference between these two timestamps, this calculation is performed by our developed latency calculator. A visualisation of our setup and all components interacting with each other is shown in Figure 5. Since the receiver and transmitter are both running on different physical CPUs, we use a NTP Stratum 0 server such that the clocks are not out off sync. Furthermore, all the OBUs and RSUs on the Smart Highway are configured to use their local gpsd daemon as a time source thus, all clocks in the Smart Highway are synchronized to the most accurate time source available. The following sections describes the setup and technologies we used for our experiment and describe in more depth our developed tools for this experiment.

B. Setup and technologies

1) Smart Highway: The setup we use to conduct the experiment is the Smart Highway testbed located in Antwerp, Belgium more specifically its permanent setup [10] as shown in Figure 3. CAM messages are sent from the Onboard Unit (OBU) to the Roadside Unit (RSU) over ITS-G5 and LTE-V2X. Since here the OBU is not mobile the CAMs are sent every one second in time to fulfill the standard. We mimic if the vehicle is standing completely still. In future research we will use the Smart Highway strip of 4 km equipped with seven RSUs as shown in Figure 2, to increase the distance between the OBU and RSU and also to make the wireless channels more crowded, if we transmit from multiple RSUs CAMs. We will then also use the Smart Highway test vehicle, a BMW X5 xDrive25d LO enhanced with an OBU as shown in Figure 4. This OBU is the same OBU that we use on the permanent setup. All RSUs and OBUs of the Smart Highway are equipped with a Cohda MK5 and MK6c for communication over ITS-G5 and LTE-V2X.

C. Technologies

The following sections discusses the already existing technologies we use to conduct our experiment on the Smart Highway testbed.

1) CAMINO: The vehicular communication management framework or simplified called CAMINO framework is a flexible hybrid V2X connectivity platform for the Cooperative, Connected and Automated Mobility (CCAM) services [11]. CAMINO is designed to be dynamic, it is a framework for managing multiple vehicular communication technologies and the services running on top of them [11]. The framework provides integration with existing and future short- and long-range V2X technologies such as ITS-G5, C-V2X PC5 and C-V2X Uu (5G/4G) [11]. In addition, it allows integration with vehicle or infrastructure sensors, vehicle actuators, HMIs and third-party service providers [11]. CAMINO can support several standardized, future or custom C-ITS services that can be triggered dynamically [11]. The corresponding generated messages can be transmitted in a flexible way by one or multiple V2X technologies increasing the transmission capacity or enhancing the transmission reliability [11]. Furthermore, the CAMINO framework is ITS device agnostic, meaning that it can run on top of any type of station such as OBU, RSU, UE, servers, etc [11]. The CAMINO framework is developed by the IDLab research group part of IMEC. We use this framework to transmit our CAM messages from the OBU to the RSU at the permanent setup and at the Smart Highway as shown in Figure 3.

2) DUST: The Distributed Uniform STreaming (DUST) [12] framework is a publish/subscribe communication middleware for distributed applications, enabling transport-agnostic applications to communicate. It provides a software interface to create software modules dynamically placed over heterogeneous networks from the cloud to edge devices. Its orchestration functionality takes the available resources into considerations to determine where to place each module in the network [12]. The DUST framework is developed by the IDLab research group part of IMEC. CAMINO makes use of DUST since it can listen to a CAM DUST channel, when it receives on that channel a CAM messages it distributes the message over the C-ITS network of the Smart Highway.

D. Developed tools

This section describes the components that we developed as shown in Figure 5, to perform our experiment on the Smart Highway.

1) CAM generator: To generate each CAM message, we developed a custom CAM message generator as shown in Figure 5. We use the Onboard Unit (OBU) along the permanent setup of the Smart Highway [13] as shown in Figure 3. This CAM message generator can transmit a regular CAM message with the basic vehicle container, and the high frequency container. We made the content inside that CAM messages as small as possible. We also made a version of a CAM message that is constructed out of all the mandatory containers and optional containers. With the CAM message generator we can choose to transmit the regular CAM or the largest possible CAM. From the moment a CAM message will be created a timestamp is logged, this timestamp we call timestamp A. Then these CAM messages are sent over a DUST channel to the CAMINO framework. CAMINO sends the CAMs to the C-ITS network. In our case, since we use the permanent setup at the Smart Highway, this CAM message generator software block is running in the transmitting OBU. This OBU sends these CAMs to his local CAMINO core running in the OBU such that the CAM messages are received on the receiving RSU via the CAMINO core that is running in the RSU as shown in Figure 5.

Fig. 2: Location of the RSUs along the Smart highway testbed [11]

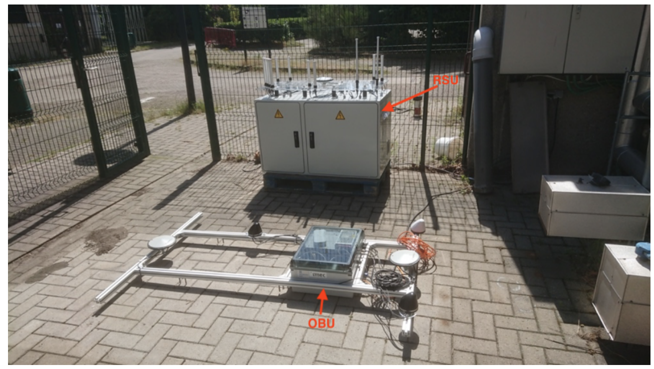

Fig. 3: Secondary test-site of the Smart Highway testbed at Campus Groenenborger of the University of Antwerp

2) CAM decoder: The developed CAM message decoder as shown in Figure 5, is in charge of decoding CAMs. This software block runs in the RSU of the permanent setup of the Smart Highway, as shown in Figure 3. It receives the CAMs over a DUST channel from the CAMINO core that is running in the RSU. When a CAM message is decoded, a timestamp, that we call timestamp B, is logged as shown in Figure 5. In our setup this CAM decoder is running in the receiving RSU at the permanent setup as shown in figure 5.

3) Latency Calculator: The developed latency calculator as shown in Figure 5, calculates the average latency by subtracting the timestamps of the CAM decoder, i.e., timestamp B, with the timestamps of the CAM generator, i.e., timestamp A. This software block runs in the RSU of the permanent setup of the Smart Highway as shown in Figure 5.

V. Results

The result of our experiment shows that the average latency for regular CAM messages, i.e., a CAM that is constructed out of its two mandatory containers, over ITS-G5 (IEEE 802.11p) is 4,05 milliseconds, as shown in Figure 6. When we compare this with the average latency of a CAM message that is constructed

Fig. 4: Smart Highway testbed test vehicle [11]

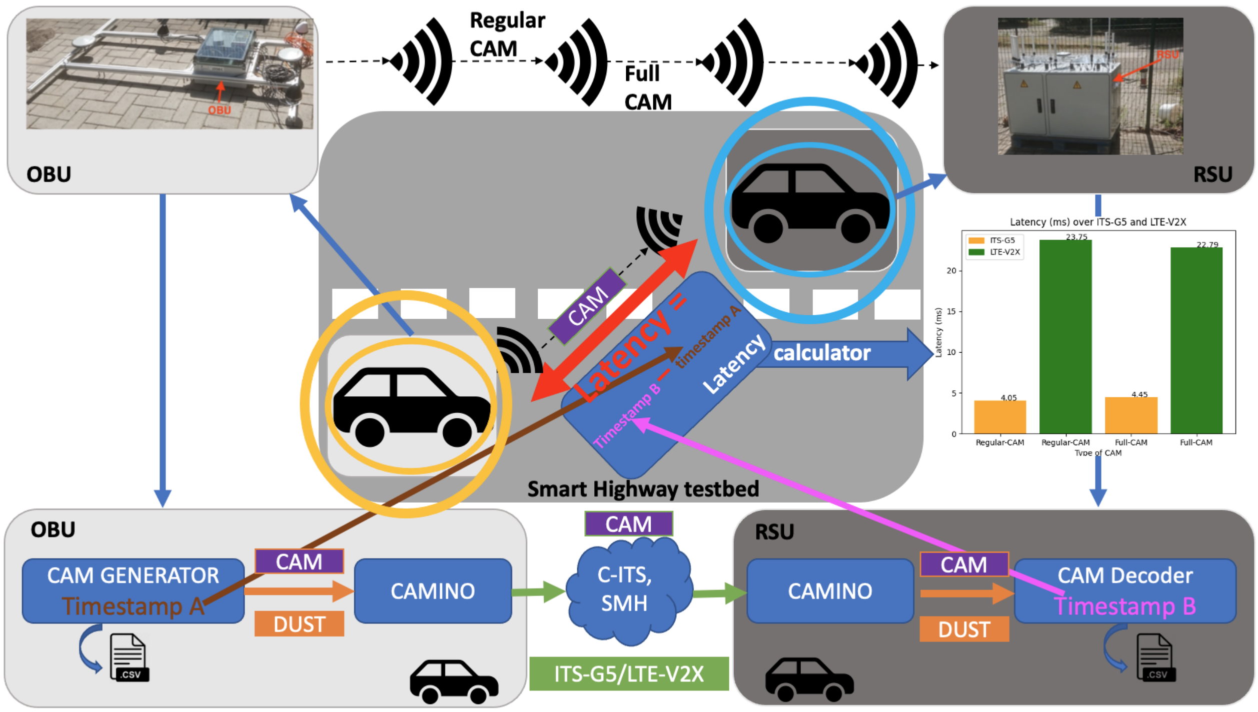

Fig. 5: Visualisation of the developed tools and used technologies

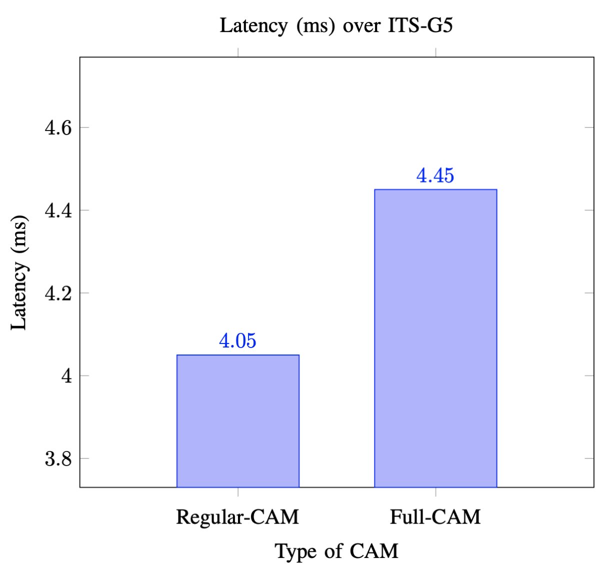

Fig. 6: Latency over ITS-G5

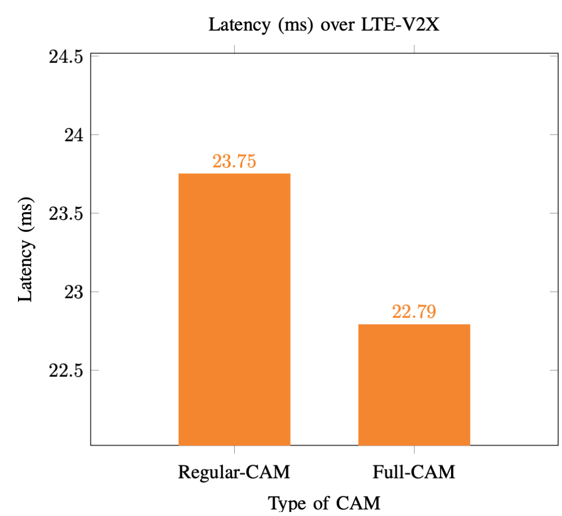

Fig. 7: Latency over LTE-V2X

out of four containers, i.e., the two mandatory containers and the two optional containers (full-CAM), we see that the average latency is 4,45 milliseconds as shown in Figure 6. On average it takes 0,40 milliseconds more to transmit the CAM message constructed out of four containers then the regular CAM. Our results for transmitting a regular CAM over LTE-V2X show that on average its latency is 23,75 milliseconds, as shown in Figure 7. When we compare this with the average latency of a CAM that is constructed out of its four containers its average latency is 22,79 ms as shown in Figure 7. So, on average its a difference of 0,96 milliseconds which means that a regular CAM message has on average 0,96 milliseconds more latency then a Full CAM, that is constructed out of its four containers over LTE-V2X. Which is the opposite of ITS-G5 since there a regular CAM message has less latency then the Full CAM message. When we now compare the latency of ITS-G5 with the latency of LTE-V2X for a vehicle that is standing still and is less then 3 meters away from each other, we see that LTE-V2X on average has more then 5 times more latency compared to ITS-G5. Since for a regular CAM message the latency for LTE-V2X is 23,75 milliseconds and over ITS-G5 it is 4,05 milliseconds which is a difference of 19,70 milliseconds. In other words, there latency is 5.86 times larger in LTE-V2X compared to ITS-G5 for transmitting a regular CAM message. When we compare the latency for transmitting a full CAM message over LTE-V2X with ITS-G5, we see that it takes for LTE-V2X 22,79 milliseconds and for ITS-G5 4,45 milliseconds. Which is a difference of 18,34 milliseconds or in other words, LTE-V2X has 5,12 times more latency then ITS-G5, which is a smaller difference then when a regular CAM was transmitted. So, for very short range communication between a vehicle and another vehicle or the road side infrastructure, for the lowest possible latency ITS-G5 is recommended. Since e.g., emergency vehicles use typically the two optional CAM containers and for C-ITS safety applications it is critical that those messages are received as soon as possible, especially when CAM messages will be used on autonomous vehicles.

This difference in latency appears partially due to the fact that ITS-G5 (802.11p) uses CSMA/CA . As discussed in depth in section II, with ITS-G5 before transmitting a packet in CSMA/CA, a node must sense the radio channel. If the node detects that the channel is idle, it can start its transmission. If another node is using the channel, the node will not transmit. In our experiment the channel was almost the entire time idle since there was only one CSMA/CA node competing to obtain access to the medium. As discussed in section II, LTE-V2X uses a Semi-Persistent Scheduler (SPS), with SPS each station needs to schedules its own resource blocks for transmissions in time. Furthermore, LTE-V2X schedules its resources more spread in time, to prevent possible collisions with other transmissions during the same moment and at the same sub-carriers. Due to this fact that LTE-V2X schedules its resources more spread in time, it results in a higher latency compared to ITS-G5. However, in highly congested wireless environments, where multiple ITS-G5 stations compete for access to the same medium, ITS-G5 latency could potentially increase, this is something we plan to research more, in future work.

In the research performed by Lee et al. [14], they constructed a table with the minimum latency criteria for C-ITS use cases which are given a minimum latency requirement respectively from 100ms, 50ms, 20ms, and 10ms. In our experiment ITS-G5 fulfills all these latency requirements since it is below 10ms. On the other hand, if we match it with the latency values we obtained for LTE-V2X, we can say that LTE-V2X cannot be used for the following use cases, Pre-crash sensing warning (minimum latency is 20ms), Automated overtake (minimum latency is 10ms), and High density platooning (minimum latency is 10ms) since LTE-V2X does not meet the minimum latency requirements since it is higher than 20ms for both the Regular-CAM and Full-CAM messages.

VI. Conclusion and Future Work

In this paper, we presented an in-depth overview of the two leading communication technologies that support the first generation V2X communication. We introduce the need for CAMs in the C-ITS environment, and thoroughly discuss the concept of a CAM message. Furthermore, we presented our experimentation with the realistic vehicular setup that is built on top of the Smart Highway testbed. We presented our results, where the main finding is that the latency of a CAM message in very short range is significantly better for ITS-G5 compared to LTE-V2X. Thus, it means that LTE-V2X cannot be used in the C-ITS use cases, such as Pre-crash sensing warning, Automated overtake, and High density platooning, since it does not meet the latency requirements.

As future work we intend to research what the effect is on latency if we increase the distance between the CAM transmitter and the CAM receiver. We will also extend the experimentation to more crowded wireless environments when multiple ITS-G5/LTE-V2X stations compete to access the medium, researching how the ITS-G5 latency changes. We will again compare a regular CAM message, i.e., a CAM message that is constructed out of the two mandatory containers, with a full CAM, i.e., a CAM message that is constructed out of its four maximum containers. We will also research how much latency is consumed in each different level of the system (CAM generator/decoder, CAMINO, DUST, channel access, and packet duration).

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