Awareness Information Dissemination using Aggregation into Collective Perception Messages for Connected Vehicles

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ABSTRACT
In the last few years, two critical situations have arisen in the ecosystem of Intelligent Transportation Systems (ITS) related to the Vehicle-to-Everything (V2X) radio technologies, that are delaying their commercial development. One is the unclear standard to use for this radio access layer, and the other is the limited coverage range of the used frequencies in the presence of obstacles, like buildings in an urban scenario. In this paper we present an infrastructure architecture, which utilizes edge computing that receives V2X messages in varying radio technologies and optimally forwards awareness information, using CPM messages, to all vehicles regardless of their radio technology, increasing at the same time the area where these messages are received.
Keywords: C-ITS, V2X, CAM, CPM, MEC, LDM.

1. INTRODUCTION

The ecosystem of Cooperative Connected and Automated Mobility (CCAM) is built on the foundation of vehicles connected to everything (V2X) and enables the emergence of new and innovative cooperative traffic safety and traffic efficiency applications. These applications are based on the real-time exchange of status updates between vehicles, which are typically broadcasted periodically.

The European Telecommunications Standards Institute (ETSI) has standardized various types of messages for use in Intelligent Transport Systems (ITS) applications. The Cooperative Awareness Message (CAM) [1] contains basic information such as vehicle position, direction, and speed. The Decentralized Environmental Notification Message (DENM) is used to alert road users of detected events, such as traffic jams, slippery roads, or stationary vehicles, etc. Additionally, ETSI has released a Technical Report [2] outlining the Collective Perception Service (CPS), which allows for the communication of detected objects, such as pedestrians and obstacles, via on-board sensors. This information is conveyed through the use of Collective Perception Messages (CPM).

On the other hand, the communications protocol architecture for ITS applications includes an Access Technologies layer at the base, which is responsible for the Radio Access Technology (RAT) used to transmit messages between vehicles (V2V) and between vehicles and infrastructure (V2I). One of the main challenges in this field is that various stakeholders are supporting different RATs, which results in scenarios where multiple radio systems must be used and integrated to enable interoperation between vehicles using different RATs. Currently, there are two main competing technologies to support direct V2X communications in the 5,9 GHz ITS band: IEEE 802.11p and 3GPP's LTE-PC5. Additionally, the current situation in the field of ITS is that car manufacturers are slow to integrate V2X communication devices, called On-Board Units (OBUs), into their vehicles. Instead, they are more prone to integrate cellular communication capabilities to enable features such as emergency calls, real-time traffic updates, and infotainment for their users. To facilitate the implementation of ITS services, it would be greatly beneficial to have the ability to transmit V2X messages over the cellular networks of mobile network operators.

Another important consideration is that direct V2V communication in Non Line-of-Sight (NLoS) situations using the ITS 5.9 GHz band is generally poor, requiring Line-of-Sight (LoS) for effective transmission. However, direct communication between vehicles is crucial in intersections, where vehicles need to be aware of each other's presence to avoid collisions. CAM messages are important in identifying critical situations such as when vehicles from perpendicular streets converge at an intersection, but due to the NLoS conditions between these streets, vehicles cannot detect each other. One potential solution is to use a fixed infrastructure to forward messages generated in one street to other perpendicular streets. This approach can mitigate the NLoS limitations and enhance V2V communication reliability in intelligent intersections.

This paper presents an architecture to address the two aforementioned problems. Our solution integrates Multi-access Edge Computing (MEC) with Road Side Units (RSUs) that support different RATs, and cellular networks connected via the Internet. Within this MEC, we have developed a forwarding algorithm that forwards messages between different RATs and regions, including between perpendicular streets. To increase efficiency, we aggregate several CAM messages into a single CPM message. However, this approach raises challenges, such as determining which information should be included in a CPM and how frequently new CPMs should be generated to ensure fresh information about the positions of neighboring vehicles, trying to avoid overloading the communication channel and diminishing the packet delivery ratio. As a preliminary result, we present a simulation analysis of our approach for forwarding information, aggregated into CPMs, in intersection scenarios using IEEE 802.11p.

2. V2X AWARENESS AND PERCEPTION

The first and primary ITS application is the Cooperative Awareness (CA) basic service, which uses the transmission of CAM messages between ITS stations (ITS-S) to establish and maintain awareness of the presence, location, and status of other ITS-S. CAM messages contain both mandatory and optional information about the disseminating ITS-S as: station identifier, timestamp of the generated information, station type (pedestrian, cyclist, motorcycle, passenger car, bus, light truck, RSU ...), position in latitude and longitude, heading, speed, drive direction, vehicle dimensions, acceleration, lane position, vehicle role (public transport, special transport, dangerous goods, emergency vehicle, ...), exterior lights turned on, path history, and some other specific information for special vehicles [1].

The current ETSI CAM generation rules establish that the CAM generation interval shall be within 0.1 s ≤ *T_GenCam* ≤ 1 s depending on the transmitter change of position or speed as well as the Decentralized Congestion Control (DCC), which tries to prevent radio channel saturation. Upon receiving a CAM, the CA basic service makes the content of the CAM available to ITS applications within the receiving station, by storing this information into the Local Dynamic Map (LDM), the data base with all relevant information for a vehicle or for the managing system in the road infrastructure side.

On the other hand, the CPS is used to share information about detected objects by the disseminating ITS-S. The message consists of information about the disseminating ITS-S, its sensory capabilities and its detected objects. The CPM is transmitted cyclically with adaptive message generation rates to decrease the resulting channel load while focusing on reporting changes in the dynamic road environment. The CPM generation rules establish that the CPM generation interval shall be within 0.1 s ≤ *T_GenCpm* ≤ 1 s. Additionally, this CPM should include the known objects if the objects comply to any of the following conditions: i) the object has just been known and has not been reported before, ii) the object has moved 4 m from its last reported position, iii) its absolute speed has changed by more than 0.5 m/s since it was last reported, and iv) the last time the object was reported exceeds 1s.

The CPM message contains: i) the mandatory ITS Protocol Data Unit header with the type of message, version and station identifier; ii) the mandatory Management Container providing the type of station (vehicle, truck, RSU, ...), reference position and CPM segmentation information; iii) the optional Station Data Container provides additional information about the disseminating ITS-S as speed or heading for vehicles, or two parameters to reference information in MAP messages for RSUs; iv) the optional Sensor Information Containers provide information and capabilities of up to 128 sensors of the disseminating ITS-S (sensor type or detection area); v) the optional Perceived Object Containers report information about up to 128 detected objects (distances to the reference point, dimensions, speed, acceleration, ...); and vi) the optional Free Space Addendum Container which is used to provide different confidence levels for certain areas within the detection area of a particular sensor.

The size of the CPM plus lower protocols should not exceed the Maximum Transmission Unit (MTU) of the access layer technology. In case that all the information to be send does not fit in the available space, the transmitter shall use the CP segmentation procedure. This mechanism uses several CPM segments, that can be decoded independently, and objects are inserted in a descending order of the product of the object's confidence and speed.

3. SYSTEM ARCHITECTURE

The objective of the system presented is to effectively disseminate awareness information, which is generated through CAM messages transmitted by vehicles. After being converted to CPMs in the MEC, the information is retransmitted using all the available RATs in particular regions of interest, as perpendicular streets converging to an intersection. In order to do so, we require a hardware architecture and communication protocol architecture adaptation, for the case of cellular networks.

3.1 Hardware architecture

The proposed road infrastructure (Fig. 1) comprises a MEC that runs all necessary software and it is connected to Internet, as well as two types of RSUs, one for IEEE 802.11p and another for LTE-PC5. We assume that the road is within the coverage area of one or several cellular networks that provide Internet connectivity to vehicles with cellular network interfaces.

The RSUs transmit and receive V2X messages in a transparent manner, without performing any operation with them. V2X messages are handled by the V2XCom module which implements the network, transport, management, security and facilities layers of the ETSI ITS G5 protocol stack. Each RSU deployed in the operation area is controlled by its own V2XCom module, having a single V2XCom devoted to all V2X messages transmitted over cellular networks. On reception of a V2X message, a V2XCom module decodes its information and, by means of a MQTT broker, sends the application-level information to the "V2X Intercommunication enabler" (V2XIE) module which stores this information in the LDM. Additionally, the V2XIE, following the rules of CPM generation, retrieves information from the LDM and builds customized CPMs for different groups of vehicles. These CPMs are then forwarded to the V2XCom modules, that attach the required low-level headers, encode, sign and transmit them to the RSUs or to the cellular network, to be finally transmitted to vehicles.

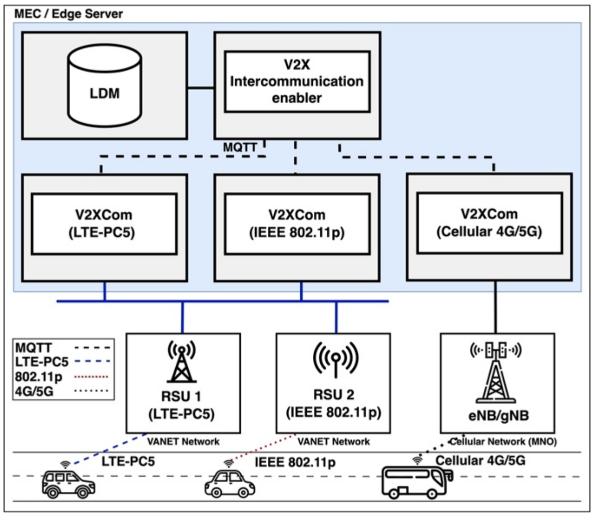

Figure 1. General architecture of the secure ITS system.

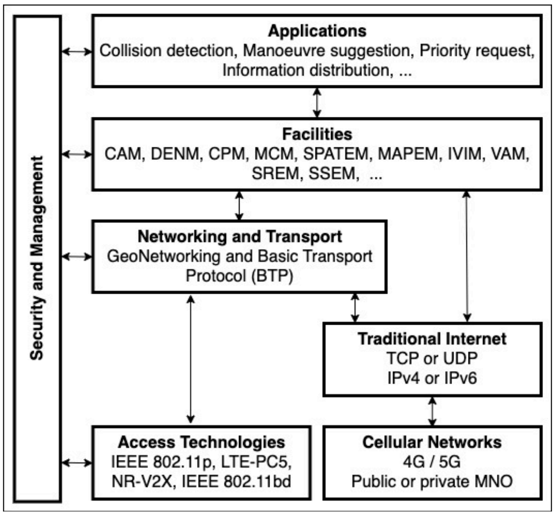

Figure 2. ITS communication protocols architecture.

3.2 Communications protocol stack

In recent years, numerous V2X related projects and testbeds have been funded by organizations such as the European Commission, with CARAMEL [3] being one example, that use the protocols specifically designed by ETSI for vehicular applications. These protocols, GeoNetworking (GN) at the network layer and Basic Transport Protocol (BTP) at the transport layer, are transmitted directly through V2X RATs (802.11p or LTE-PC5) (Fig. 2). One advantage of 802.11p and LTE-PC5 is that they offer the possibility to transmit unicast or broadcast frames, with broadcast being particularly useful for disseminating messages as CAM, DENM or CPM.

In the case of transmitting facilities layer messages over a cellular network, there is the need to use standard Internet protocols, that is TCP or UDP in the transport layer and IPv4 or IPv6 in the network layer. The payload can consist of the facilities message alone, or it can include the facilities message, along with the BTP header and the GN header. Among all these different possible configurations we have to consider different aspects due to the fact that current public cellular networks have several limitations: i) IPv4 must be used because they don't have IPv6 activated yet, ii) although 5G networks permit groupcast or multicast transmissions, mobile operators do not provide this facility, so every broadcast message has to be sent individually, using unicast addressing, to all vehicles connected through cellular network, iii) User Equipment (UE) nodes are assigned a private IP address and datagrams have to go through a Network Address Translator (NAT).

Considering the described restrictions, our proposal for V2X message transmission via cellular networks utilizes an OBU software that establishes a persistent TCP/IPv4 connection with the V2XCom on the MEC to bypass NAT restrictions. Additionally, messages are encapsulated using whole stack (Cellular Network - IPv4 - TCP - GN - BTP - Facilities) to fully leverage the ETSI ITS-G5 protocol stack's functionalities, including message signatures.

4. SYSTEM EVALUATION

The testbed to provide interoperability between vehicles connected through 802.11p and 4G cellular networks has been tested in the finished European project CARAMEL [3], and between LTE-PC5 and 5G cellular networks is currently been deployed in European project PODIUM [4]. However, due to limitations in these testbeds, it is not feasible to stress the system with a large number of vehicles transmitting and receiving V2X messages. Therefore, the performance of dissemination of awareness information using CPMs is analysed through simulation.

4.1 Simulation environment

We simulated a network of vehicles to implement our awareness dissemination messaging model. In our simulation, we assumed a typical urban traffic environment with streets and intersections. This is to capture several practical driving scenarios such as changing lanes, increasing speed, manoeuvres, and observing traffic lights. In our design, we leveraged the SUMO traffic simulation tool to create realistic car trajectories. We used the network event simulation tool, OMNeT++, which provides functionalities for transmitting CAM messages over GeoNetworking, BTP and IEEE 802.11p, and we upgraded it with the required extensions for transmitting CPMs and for maintaining a LDM in every vehicle of the simulation, which is updated when receiving new CAMs and CPMs. We also added nodes representing RSUs, one in the centre of each street defined by two intersections, which transmit CPM messages generated by the simulated MEC in the infrastructure.

As a measurement of the system's performance, we use the Neighborhood Awareness Ratio (NAR(r)), which describes the portion of cars registered in a given vehicle's LDM from all the cars that are present at a given radius *r* from that vehicle, and the average Position Error (PE(r)) which computes the average error between the real position of one vehicle and the position of this vehicle stored in the LDMs of the rest of vehicles at a given radius *r* from that vehicle.

4.2 Results and Analysis

In this section, we present the simulated results of applying our method in cases a) awareness information is not forwarded, and b) awareness information is forwarded from the infrastructure using CPM messages.

The simulated scenario is a Manhattan layout, with streets of 124 m between intersection centres, with four lanes of 4 m width each. The forwarding is done in such a manner that the RSU deployed in each street only forwards the awareness information obtained in its adjacent streets. We use a scenario with a vehicle density average of approximately 12,1 vehicles between two intersections of streets. This is not too low to enable to have some radio interference in the V2X radio channel, and not too high, where vehicles would be stooped most part of the time.

Figure 3 depicts the NAR perceived by vehicles. The graph reveals that when no forwarding is employed, there is a 100% NAR up to approximately 60 meters distance, which represents half the distance between street intersections. However, beyond this point, the perception rate declines dramatically due to the presence of vehicles on perpendicular streets that cannot be detected. In contrast, the implementation of awareness forwarding in the form of CPM messages results in a significant improvement in perception. With CPM messages, the NAR remains above 90% even at distances of up to 280 meters.

Figure 4 displays the PE using boxes that extend from the Q1 to Q3 quartile and the median line (Q2). The whiskers display the data range but not exceeding 1.5 * IQR (IQR = Q3 – Q1) from the box edges, in this last case outliers are represented by separate dots. We observe that there is no much difference between forwarding or not forwarding awareness due to the fact that non perceived vehicles do not compute as samples for PE statistic, and the known vehicles are equally well localized on the scenario in both cases.

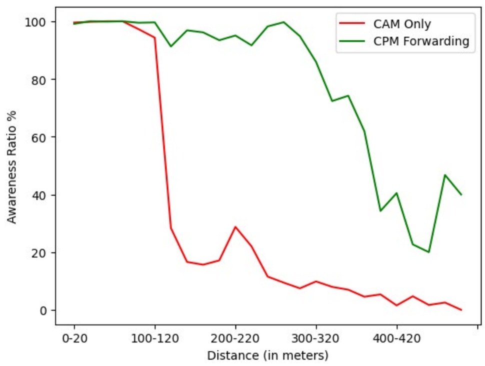

Figure 3. NAR of the different scenarios.

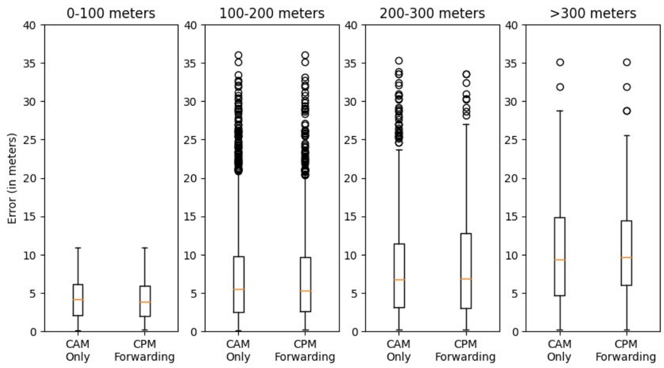

Figure 4. PE of the different scenarios.

5. CONCLUSIONS

This paper has presented an infrastructure architecture that utilizes edge computing, which receives V2X messages in different radio technologies and optimally forwards awareness information using CPM messages to all vehicles, regardless of their radio technology, extending the radio coverage of the awareness perception and reducing the error position perceived in neighbour vehicles. This architecture addresses two critical situations of current ITS, the unclear standard to be adopted for the radio access layer and its limited coverage range in NLoS situations.

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