The testing framework for Vehicular Edge Computing and Communications on the Smart Highway

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***Abstract*—Vehicular Edge Computing (VEC) brings cloud infrastructure to the vehicular edge, resulting in better performances and avoiding network congestions. In this work-in-progress paper, the benefits of edge computing over cloud computing are discussed in a vehicular environment context, and they are leveraged by creating a Cooperative, Connected and Automated Mobility (CCAM) performance measurement framework. This measurement tool can follow vehicles by moving across different devices, enabling measurements on Key Performance Indicators (KPIs) using edge computing. We already used this tool to evaluate latencies of both a stationary and driving vehicle, moving over the Smart Highway testbed in Antwerp, Belgium. When driving, smart-edge-following algorithms can be deployed to choose the nearest Road Side Unit (RSU) using broadcasted Cooperative Awareness Messages (CAMs) of the vehicle. While driving on the Smart Highway, the application monitors important performance metrics such as throughput, latency, packet loss, packet delivery rate and more. We compare short-range vehicular communications technologies on the Smart Highway (ITS-G5 and LTE-V2X PC5) against the cellular. Our preliminary results demonstrate the benefits in terms of latency by using short-range communications technologies in VEC applications. These results validate that moving applications to the edge is truly beneficial, since our results confirmed up to 90% lower latency using ITS-G5, up to 50% using LTE-V2X PC5. Future deployments of 5G in the Smart Highway are planned, which would further improve the performance edge computing technologies.**

***Index Terms*—Measurement tooling, V2X , ITS-G5, LTE-V2X PC5, 5G, LTE-V2X Uu, Vehicular Networks, Edge computing, MEC, VEC**

I. INTRODUCTION

In vehicular networks, low latencies and high reliabilities are the key performance indicators (KPIs) of Advanced Driver-Assistance Systems (ADAS), later to be continued into autonomous driving functions [1] [2]. In order to fulfill these strict requirements, computational units can be placed more close to the end user. Vehicular Edge Computing (VEC) guarantees better performances and avoids network congestions, by using near infrastructure instead of centralized cloud computing units. VEC offers computing power and improved performances for a wide range of use cases, such as ADAS applications to in-vehicle entertainment. Next to serving computing power, it can also help in dealing with the current chip shortage we are facing and expanding the lifetime of (older) vehicles with limited resources on board [3] [4].

In this work, we introduce edge computing in vehicular environments and its opportunities and challenges. The paper is organized as follows. In Section II, we evaluate current state-of-the art and related work in the context of edge computing technologies being applied to vehicular environments. Further, in Section III, the current supported V2X technologies on the Smart Highway are discussed, followed by the explanation of our current measurement approach and discussion of the possibilities of the framework. In Section IV we discuss the results on the non-moving and driving along the Smart Highway testbed. Finally, the paper is concluded in Section V. Future work of this research is discussed in Section VI.

II. RELATED WORK

Current edge computing research has been generally focused on MEC architectures and 5G use cases. In a recent survey, Bréhon-Grataloup et al. summarised mobile edge computing for V2X architectures and applications [5]. They shared their view on this emerging topic, but they also mentioned a lack of research from a V2X standpoint [5]. In their conclusion, the benefits and opportunities that real life testbeds (such as the Smart Highway) could offer is recognized, thereby confirming the contributions of edge computing in vehicular environments [5]. Wang et al. proposed the offloading of tasks on mobile devices to nearby vehicles cloudlets [4]. This is

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beneficial to save battery life, support computational-intensive tasks on older vehicles or vehicles that are not equipped with computational units [4]. In [6], Feng et al. created an Autonomous Vehicular Edge computing scheduling framework algorithm based on ant colony optimization. They simulated 802.11p DSRC communication using the Omnet++ simulator, in combination with Veins. It showcased once again potential benefits of the communication technology, primarily in highway conditions compared to urban environments. In [7], the authors implemented a mobility-aware smart placement algorithm in order to place content in central zones to ensure higher availability to the end-users. In [8], the impact of AI on smart orchestration and management are researched and tested on the Smart Highway. In [9], broadcasted CAM messages of emergency vehicles are used to calculate an estimated time of arrival to ITS enabled vehicles. Slamnik-Kriještorac et al. already suggested the potential deployment of cameras or usage of CAM messages to assist in the deployment of applications in the edge, but does not discuss the latency performance of vehicular technologies and its possible speedups against cloud computing [10]. The edge computing setup provides distributed control over the host using a centralized orchestrator (main MEC application orchestrator) [10]. To the best of our knowledge, a real-life measurement tool/application to test out the impact of vehicular edge computing is still lacking. Most of the conducted research is purely simulation based, where different algorithms on smart edge orchestration need to be tested and confirmed leveraging on real-life testbeds. A thorough characterization of KPIs is a crucial step in understanding which applications could benefit from running in the edge.

III. PROPOSED SOLUTION

In this paper, we make use of the Smart Highway infrastructure. It is an Intelligent Transportation System (ITS) and Cellular Vehicle to Everything (LTE-V2X) based testbed, located at the E313/E34 highway in Antwerp, Belgium [11]. Supported vehicular communication technologies are ITS-G5 (also known as Dedicated Short-Range Communications in the United States), and LTE-V2X. LTE-V2X has two different operating modes, it can use its interfaces PC5 or Uu. By using LTE-V2X PC5, it will be another short range technology. The Uu interface is used to connect to the widely deployed 4G net.

We are developing two applications in order to run our experiments on edge computing. The first one is a monitoring web application, which is ran on the On Board Unit (OBU) of a BMW X5. In this application, all the received messages are visualized on a web page. The monitoring web application is used to send out tasks to the nearest or a specific Road Side Unit (RSU). Example tasks to be carried out by the RSUs are send a CAM, Decentralized Environmental Notification Message (DENM) or Infrastructure to Vehicle Information Message (IVIM) over the desired technology (ITS-G5, LTE-V2X PC5 or LTE-V2X Uu). The query is encoded and sent to the second application, which is the Decentralized Edge CCAM Generator (DECA). This application listens on a topic to queries and generates the appropriate messages, the amount of them and the timeout as being set in the query. In the metrics section of the web application, performance measurements about the technologies and messages can been found on the fly (Figure 3). The application uses the vehicular communication management framework (CAMINO) to forward generated messages over vehicular communication technologies [12]. By using an edge-following algorithm using CAM messages of the vehicles, the DECA generator can forward those queries to other generators, in order to continue the state of the application (Figure 1).

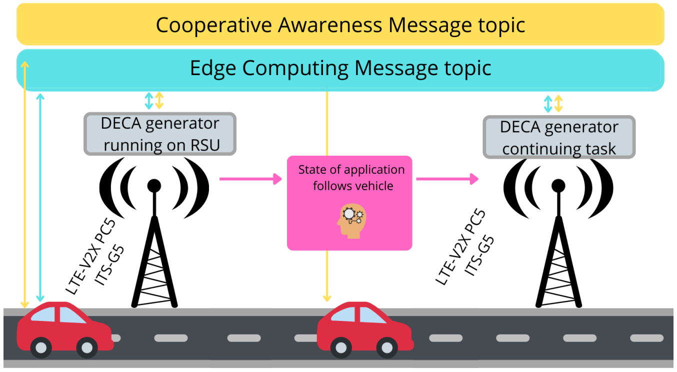


Fig. 1. Experimental results performances.

IV. EXPERIMENTAL RESULTS

A. *Single RSU non-moving results*

The first results are extracted from the permanent setup at Campus Groenenborger, Wilrijk. The permanent setup consists of an OBU and RSU close to each other. Our first test consists of sending different message types (CAM, DENM and IVI) over the different technologies (ITS-G5, LTE-V2X PC5 and LTE-V2X Uu) to get to know the latency and reliability performances of each technology. Especially understanding the latency of those short-range technologies is important for this research, since we intend to investigate the possible speedup compared to the long-range LTE-V2X Uu approach.

As being shown in Figure 2, primarily ITS-G5 is a good fit to compare its performances against the cellular approach. Charpentier et al. concluded similar results for the performance of CAM messages for his experimental evaluation between the technologies ITS-G5 and LTE-V2X PC5 [13]. With the average latency performance results of a single RSU and single OBU standing still next to each other in hand, we will move to a more realistic experimental setup using a moving vehicle over the Smart Highway. In order to have the results of the nearest node, a basic smart placement algorithm is developed to choose the nearest RSU using broadcasted CAM messages of the vehicle.

B. *Highway results*

The highway results are extracted on the Smart Highway, using a moving vehicle. The vehicle is equipped with an

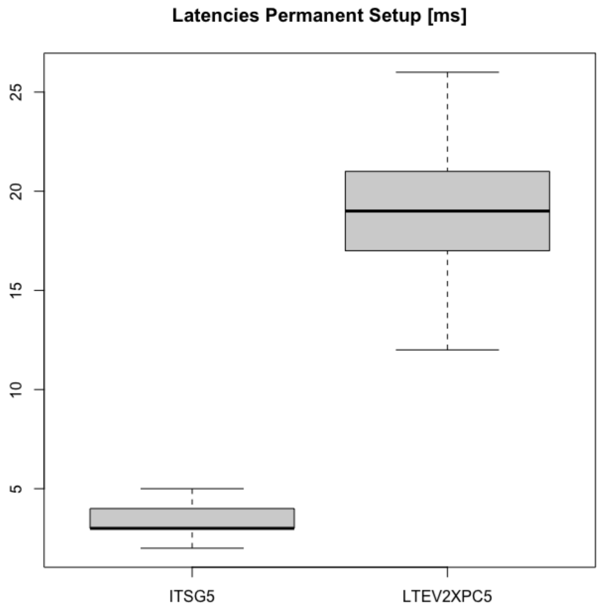
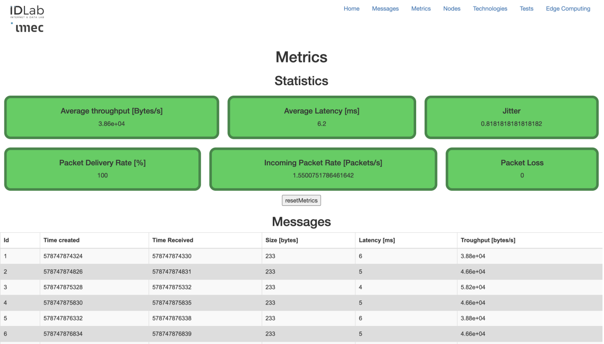


Fig. 2. Experimental results performances.



Metrics

Statistics

Average throughput [Bytes/s]: 3.86e+04

Average Latency [ms]: 6.2

Jitter: 0.8181818181818182

Packet Delivery Rate [%]: 100

Incoming Packet Rate [Packets/s]: 1.5500751786461642

Packet Loss: 0

Messages

Id	Time created	Time Received	Size [bytes]	Latency [ms]	Troughput [bytes/s]
1	578747874324	578747874330	233	6	3.88e+04
2	578747874826	578747874831	233	5	4.66e+04
3	578747875328	578747875332	233	4	5.82e+04
4	578747875830	578747875835	233	5	4.66e+04
5	578747876332	578747876338	233	6	3.88e+04
6	578747876834	578747876839	233	5	4.66e+04

Fig. 3. Experimental results: performance metrics (viewed in web application).

Smart Highway RSUs

OBU

Fig. 4. Smart Highway RSU, next to BMW X5 equipped with ITS-G5 and LTE-V2X module

Onboard Unit (OBU), ITS-G5, LTE-V2X and a 4G module, as been shown in Figure 4.

In general, the most important aspect is to compare these characteristics with its LTE-V2X Uu performance to conclude about possible speedups by using edge computing instead of cloud computing units. We are sending out messages over Message Queuing Telemetry Transport (MQTT) to test out the LTE-V2X Uu latency performance over the highway. In our MQTT experiments, a public, online broker is used (HiveMQ). We use HiveMQ because it is hosted using Amazon Web Services (AWS) [14] [15]. AWS is a web service platform which is widely used to run applications in the cloud [15]. An important parameter is Quality Of Service (QOS). It can be set on three different levels, being at most once(0), at least once(1) and exactly once(2) [16]. The higher the reliability of the message delivery, the higher the latency is [16]. As it is necessary to guarantee message arrival, we evaluated its performance using Quality Of Service (QOS) level 2. The short range technologies differ in latency performance due to their different protocols.

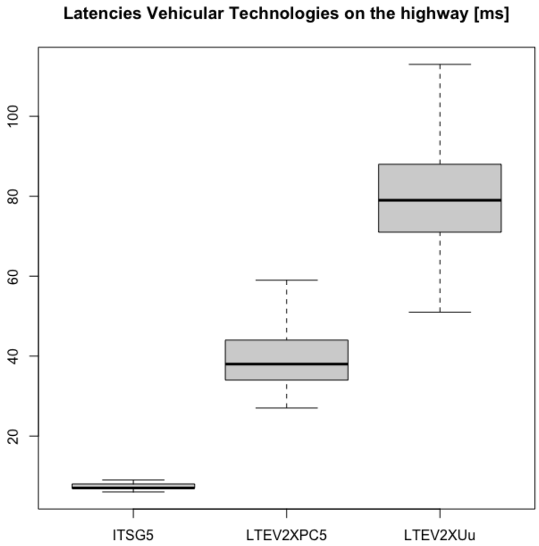


Fig. 5. Vehicular technologies latency performances over the Smart Highway.

ITS-G5 has no advanced resource scheduling mechanism, while LTE-V2X PC5 does [17]. LTE-V2X PC5 has a Semipersistent Scheduler (SPS), this technology can reserve resources and predict the usage, in order to avoid collisions [17]. The resource access duration has the largest influence on latency for LTE-V2X compared to ITS-G5 [17]. Despite the higher latency, LTE-V2X will be more useful in dense traffic environments [17]. In general, there is a potential to run applications in the edge instead of outsourcing applications to more centralized, cloud computing units using cellular technologies.

V. CONCLUSION

In this work-in-progress paper, we discussed the supported vehicular technologies on the Smart Highway and explained which KPIs we calculate in our application. We discussed related work and our solution is presented and explained, including the work in progress. We discussed experimental results on a real testbed, first for a vehicle standing still, later for a moving vehicle on the Smart Highway using vehicular communication technologies. The potential speedup of edge computing over centralized clusters is explained and provided using our field testing data. To end, we presented future work and use cases for this research.

VI. FUTURE WORK

Currently, 5G is a well-researched topic and the technology is planned be deployed soon on the Smart Highway testbed. A real-life comparison in between the vehicular communication technologies, 4G and 5G performances in terms of KPIs can truly enable further edge computing research and deployments. Next to the performances of the vehicular communication technologies, smart edge orchestration is another important research topic. In this work-in-progress framework, a general edge placement algorithm is developed and used to generate the first edge computing results on the Smart Highway. A second smart-edge placement algorithm, using predications is currently ready to be tested. The ultimate goal of this framework is to compare the algorithms against each other and see which algorithm performs the best in which vehicular infrastructures or conditions. Next to the deployed edge following algorithm, which could range from a simple algorithm to smart edge orchestration algorithms using artificial intelligence, the representation of the vehicular infrastructure is another key challenge to be researched using this framework. In order to enable these researches and comparisons, the tool will be easy to set up and deploy in any ITS enabled testbed. Another interesting addition is a balancing mechanism for task offloading to optimize overall efficiency [18]. Rather than outsourcing all the tasks to the edge, it could be beneficial to calculate certain tasks on board, depending on the computational needs and available resources. In this research, we are purely evaluating CCAM performance. In deployments, it would be interesting adapt the current messages to sensor data such as serialized video or lidar streams, in order to run computational expensive calculations in the edge while driving. A great example is running intelligent applications like CAMAF [19]. The CAMAF core (CAM message processor) can be ran in the edge, while the results to be shown on the display to the user are being sent over ITS-G5, LTE-V2X PC5 or 5G.

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