

Towards realistic simulation of MEC-based Collective Perception: an initial edge service design for the Artery/Simu5G framework

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Abstract—Day 2 V2X applications are the next step in vehicular communications, as they aim to extend the scope of shared information. In addition to status data, traffic participants are also aware of each other's sensory capabilities and the data deriving from those sensors. Collective Perception (CP), one of the flagship Day 2 services, enables vehicles and infrastructural elements, like roadside units or smart intersection controllers, to provide information about detected objects, significantly increasing the level of cooperative awareness V2X can grant for the communicating entities. However, with the escalation in the amount of data to be sent over the vehicular or mobile networks and the need for more processing power to enable real-time safety applications based on CP, some form of infrastructural aid is needed. The traditional central cloud-based approach might fall short of meeting the latency requirements. To keep latency within an acceptable range and solve the computational tasks locally, leveraging the capabilities of 5G Multi-access Edge Computing (MEC) could be a potential solution, thus ensuring a minimum impact on the core network. The architectural design and the modular approach of service implementation in the MEC specification by ETSI enable quick service deployment. This paper focuses on advanced Collective Perception-based V2X applications and the potential positive impact on their performance when operating with the support of edge computing. We also present the description – including the design considerations – of an initial, Artery/Simu5G-based edge service model working as a network-side intelligence extending the functionality of applications hosted on the vehicles.

Keywords—V2X; Collective Perception; MEC; Artery/Simu5G

I. INTRODUCTION

The idea of V2X services based on sharing sensory data has been around for a few years and has motivated industrial organizations and academic parties alike [1]–[3]. Collective Perception, one of the Day 2 applications, builds on top of the ideas set in the Day 1 application Cooperative Awareness and increases the potential of creating even safer traffic environments very shortly while also making possible the evolution toward fully automated vehicles [4]–[6]. Although the exact specifications of the message format to be used, namely the Collective Perception Message (CPM), were submitted for

approval only in Dec. 2022 [7], the potential use cases for a cooperatively sensed environment have occupied many researchers. A stable connection capable of delivering high throughput with very low latency is crucial for safety applications working with real-time object data. Hence, the applicability of such low-latency services is not independent of the access technology being used for communication. The exact performance of 802.11p and C-V2X, or 802.11bd and NR-V2X, their enhanced versions, respectively, can be effectively tested in various scenarios using sophisticated simulation models [8]–[10]. Although the competition between the two major trends (i.e., Wi-Fi vs. cellular) is complex, and the most plausible solution soon seems to be a hybrid-RAT-based approach, many greatest opportunities come with the 5G ecosystem, like the architectural support of the core network and the many functions that can be implemented using technologies like network slicing or NFV [11]. However, as the amount of data to be processed increases exponentially with the sharing of sensory information, the technology that could be of the most assistance is edge computing, which is, not surprisingly, being standardized to be a great asset in V2X scenarios, with the cooperation of telecommunication and automotive organizations [12]–[16]. These systems' complexity and dynamic nature make them challenging to evaluate and optimize through traditional testing methods. Therefore, simulations have become essential for researching and developing advanced V2X technologies in 5G and beyond architectures.

One of the most used V2X simulators is Artery, which is built upon the OMNeT++ engine [17]. This framework is a powerful tool for testing V2X services and applications. However, 5G network elements and technologies are not yet available with Artery. In our previous article [18], we introduced an integrated framework where the existing Artery simulator was extended with a standalone 5G simulation library Simu5G [19] which is also based on the same OMNeT++ platform. The resulting framework is not only capable of simulating the mechanisms of the NR-Uu interface (unfortunately, PC5 is not yet implemented in this library), but powerful core functionalities, like 5G MEC (Multi-access Edge Computing), are also available. Moreover, this integrated model collection can be enhanced with applications being instantiated in the edge

cloud. This way, the factor of easing computation for vehicles or the effectiveness of edge services based on Collective Perception can be easily verified or rejected with highly configurable, complex, and precise simulations. The next step towards implementing this goal is to design a Collective Perception Service that conforms to ETSI standards and is hosted by the MEC service registry. This service will be added to existing applications and enable the use of CPMs in the edge cloud. This service is supposed to collect and process all the messages from various road users, serving as a central databank of object information. Later developments could include extensions of sensor data fusion, like incorporating safety notifications of other ITS Facilities protocols for vehicles in danger with CPM data, either as an extension of this service or adding this functionality as an additional component.

The remainder of this paper is as follows. In Section II, a brief collection of CP-based V2X use cases can be found, with an emphasis on use cases potentially aided by MEC infrastructures. Section III lists some important related works that inspired the MEC service model under development, whereas Section IV demonstrates the main components of the model and the most important design considerations. The potential improvements and the possibilities regarding future research are discussed in Section V. Section VI concludes the paper.

II. COLLECTIVE PERCEPTION USE CASES

With CP-based applications generally available and widely used in vehicles in many situations – be it urban/rural, fully/partially automated, or entirely human-driven – traffic safety could be significantly improved. The exchanged object data could be displayed for the driver to notify of potentially dangerous objects or situations that would otherwise remain completely unseen, further increasing the impact of ADAS (Advanced Driver-Assistance Systems) implementations. Examples mentioned in [3] include cooperative overtaking and cooperative merging. Both rely on a shared environmental model building upon the sensory data shared in CPMs (Collective Perception Message), which in the end can be used to pop up some notification for the driver to assist the maneuver to be performed (e.g., lane free/not free). Automated vehicles could even share vehicle intentions and trajectory calculations to provide finer input for the algorithms controlling the vehicles.

Enhancing the safety of Vulnerable Road Users (VRUs) is another benefit of using CP. Systems implementing passive protection, e.g., at a pedestrian crossing, could broadcast information about all pedestrians being obscured by any big object and not visible to some vehicles approaching the area. In this sense, "passive" refers to pedestrians, as they do not participate in the scenario from a communication perspective. On the other hand, active protection could involve mobile phones or devices held by pedestrians or embedded into bicycles/motorbikes working as active nodes, warning other vehicles about the VRU presence [20]. Hybrid scenarios, where V2X-capable and legacy plain vehicles coexist, use cases like Emergency Electronic Brake Light (EEBL), Left Turn Assist (LTA), Intersection Movement Assist (IMA), and Blind Spot Warning (BSW) might also be imagined [21], further improving

some already familiar ADAS applications with the involvement of CPMs.

A. MEC-assisted use cases

The effective functioning of a CP-based application could be significantly boosted if the CP service can use a local database of the perceived objects. With the advantages of an edge-based cloud setup taken into consideration, many researchers think that MEC could be a powerful asset in the realization of sophisticated services like Sensor and State Map (SSM) Sharing [22], which is an advanced implementation of a dynamically formed local database of objects, or could even help to render V2X-integrated real-time multi-layered HD maps of the environment [23].

3GPP has also defined a set of use case groups for cooperative autonomous applications, two of which may be effectively backed up by MEC soon [24]. The Extended sensors use case group includes heterogeneous scenarios in terms of connectivity. This means that plain vehicles coexist with V2X capable ones, the latter of which can be further divided into two groups depending on how sophisticated the outer sensory equipment is. Different types of vehicles, roadside equipment, street cameras, and even pedestrians' mobile devices can then share sensory data via V2X protocols to notify or alert each other. This data could also be uploaded to nearby MEC servers hosting SSMS or HD map rendering applications. Another example from this group is Video data sharing for automated Driving (VaD), where the edge computing hardware could help in traffic control, and processing live on-demand video feed sourced from vehicles [22].

The other group, Advanced driving, focuses more on higher-level applications building upon the basic features of CP [21], with use cases mainly connected to automated/autonomous vehicles. In addition to sensory data, the maneuver intentions and pre-calculated trajectories can also be shared using the usual V2X messages (or maybe some future standards made for this purpose), e.g., in Cooperative Collision Avoidance (CoCA). Edge assist might also boost the general information flow in partially/fully automated scenarios, handling traffic control tasks, hosting complex safety algorithms for emergency applications, e.g., Emergency Trajectory Alignment (EtrA), or controlling the data transmission to a remote site in case human intervention is needed through the network (remote driving). In *Intersection Safety Information Provisioning for Urban Driving*, the MEC servers could take the classic role of a central entity and handle the information flow among vehicles, warning the right vehicles about possible dangers. Cooperative lane change (CLC) features the same principles of sharing sensory and trajectory data as CoCA, set in a highway scenario, reducing the risk of colliding with vehicles in blind spots. Another extremely computationally heavy use case is the 3D video composition of a V2X scenario, where an application server renders a to-scale and accurate 3D video model of a region based on video streams collected from vehicles.

Set out on a mission to cooperate with different members of the automotive industry, the Automotive Edge Computing Consortium (AECC) covers some additional edge-assisted use cases in its publications. One of the main ideas (already touched on before) is maintaining HD maps to digitize the physical

environment [25] as precisely as possible. The way AECC imagines the service is a multi-layered map that, in the first of the two operation modes, is not distributing real-time data, therefore not stressing the edge infrastructure or the network. However, it can use the frequently collected vehicle and sensor data to process and distribute highly-dynamic information available in an area. This kind of flexible operation seems more scalable since, e.g., in the case of traffic congestion, the network and computational load on the edge server also increases, with lots of similar dynamically sent messages reporting very similar data. In such a scenario, the static layer could serve as a stable fail-safe layer reporting the most essential, non-dynamic information (e.g., the exact place/magnitude of the traffic jam), while the functions responsible for the upper, more dynamic layers optimize the handling of incoming redundant data. Another case involving edge cloud support is Intelligent Driving, where driver performance is constantly monitored through the evaluation of mobility/behavior information and collected sensor data of the physical condition [25]. The information gained could result in wholly revised insurance models for vehicle drivers, as the insurance companies could personalize their plans in a way never seen before, benefiting competent drivers [16].

III. RELATED WORKS

Several studies have been published that cover the evaluation of edge-assisted implementations of some of the above use cases and provide inspirational ideas for our research. One of the examples tested using real-world equipment as part of project 5G-CARMEN was an implementation of an edge service called Server Local Dynamic Map (S-LDM) [26]. S-LDM is a centralized local dynamic map that stores up-to-date information about connected vehicles and non-connected traffic participants observed with onboard sensors. In addition to effectively processing the incoming data and creating a complex environmental model, the system can also detect patterns that trigger safety instructions for vehicles approaching dangerous situations. In [27], the design issues concerning the task migration and task scheduling processes and the problems with data communication flow (focusing on the level the data should be handled) are discussed, followed by a performance evaluation of F-Cooper, a project introducing a feature-level data fusion technique for creating cooperative environmental models in real-time [28].

Another testbed implementation experimented with a Cooperative Collision Avoidance use case in which the edge application collected data from DENM (Decentralized Environmental Notification Message) and CAM (Cooperative Awareness Message) messages and could notify vehicles approaching road hazards or other vehicles [29]. Systems like those listed above incorporate different sensor fusion techniques to mediate data from different types of sensors to create a unified environment model. However, this is a challenging task when the data to be processed can become outdated quickly. Despite being an older study, the examination of timing parameters in [30] could still be helpful in future work.

The experiment to which our approach may be the closest in terms of architectural design is also an edge-based extended virtual sensing (EVS) service collecting object data and

providing safety information to vehicles [31]. Although the vehicle mobility information used for the creation of CAM messages was simulated in SUMO [32] (the traffic simulation tool used in Artery as well), the authors created their ETSI-compliant MEC implementation to be used with OpenAirInterface, which is an LTE RAN and EPC implementation. The description of the implemented MEC service was of much use during the design of our Collective Perception Service. It is important to note some key differences, though. The first difference is the general structure of the simulation engine. Unlike OpenAirInterface, our choices, namely Artery and Simu5G, are building upon the discrete event simulator OMNeT++, making it able to carry out full-stack simulations. The second concerns the V2X message format used for the simulations. Our Artery model has recently been updated with the newest ASN.1 model of CPM available in the final draft submitted for the approval of the CPM specification [7]. This message structure differs from older models in terms of a slightly different sub-container structure of the message (e.g. sensor data and detected object containers) and a new fixation of the maximum length of the CPM message itself. Using this format the transmission data of detected objects is more accurate and realistic, where messages include information sourced from a wide range of sensors, a necessary detail for future implementations of sensor fusion (see the expansion of the environment model in Section V).

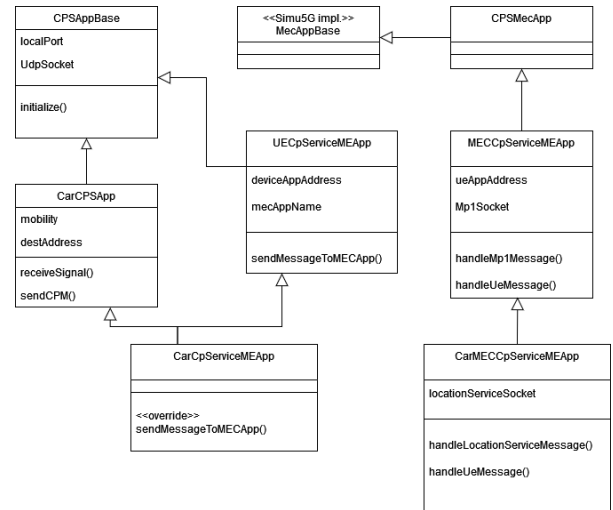


Fig. 1. Simplified UML class diagram of the existing MEC application based on [18]

IV. DESIGN CONSIDERATIONS

As shown in the previous section, the topic of an edge-assisted CP-based service can be approached from various directions depending on the software and hardware available for testing. The Artery/OMNeT++ ecosystem components rely on the INET-based 802.11p [33] as a radio access technology and the Vanetta-based ITS-G5 stack for the networking and facilities layer models [34]. The extended model integrated with Simu5G [18] only implements the NR-Uu interface, omitting PC5 used for direct device-to-device communication. Therefore, the scope of the concept service is the first thing to consider. Even though side-channel communication could be much more

suitable for ultra-low latency use cases, connecting vehicles to the MEC architecture, even with the Uu interface, could prove the usability of the edge servers. Furthermore, as the used simulators evolve, adding new radio access features should not be difficult if the architecture is already hosting services based on CP. It is also essential to clarify the motive of the project. At present, the goal is to explore the simulator's capabilities extended with the Simu5G library, which could later be used as a stepping stone for implementing more complex services and algorithms, realizing some of the functionalities listed above that comply with the ETSI standards of the MEC architecture.

A. Edge application based on Simu5G examples

The working versions of the user and edge side applications (see Figure 1 for the class hierarchy) at present are the proof-of-concept implementations that we developed to test the integrated framework [18]. In this model, the CPMs generated in the C-ITS stack implemented by Vanetza [34] are directly sent to the user application instance using the OMNeT++ signaling feature. Of course, in a real-world application, the messages would be sent from one module to another using the CAN bus or some Ethernet interface, but modeling this part of the message stack is out of the scope of the work. However, omitting this part makes little difference to the result, as we had not experienced any extra latency when the Vanetza module was connected to the application via the gate mechanism of OMNeT++. The user application, upon the reception of a CPM, wraps the CPM in a UDP packet and sends it to the MEC app instance bound to the user app. The binding is achieved with the instantiation request during the startup sequence of the user application. This way, the required object data is effectively transferred to the MEC architecture using the 5G connectivity of the vehicles. Figure 2 illustrates the general structure of the model under discussion with a brief depiction of the data flow from the user-side application to the MEC instance.

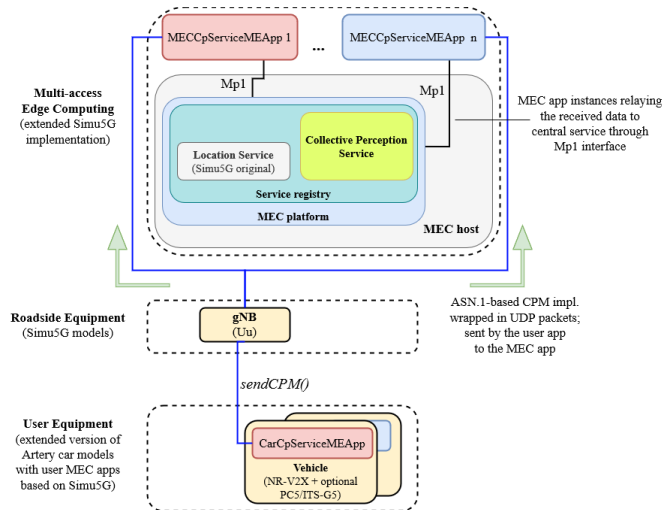


Fig. 2. MEC+CPS in the integrated Artery/Simu5G simulation architecture

Although the extension of the Simu5G library with our MEC application shows that the integration was successful, this is not nearly enough for an effective safety service. The CPMs are only present in the MEC app instances, each instance containing the

messages originating from their respective user counterparts. Without collecting and processing the CPMs of different vehicles, none of the use cases described in Section II can be successfully realized. Therefore, the extension of the model with a design of a Collective Perception Service (see Figure 2) residing in the MEC Service registry is necessary.

B. Advanced edge service design for Collective Perception

Simu5G provides an example Location Service and a base service class implementation for the rapid development of various MEC services. The services can be interacted with using a RESTful API, as specified by ETSI. Therefore, the first task is to implement the correct API endpoints for the derived CollectivePerceptionService class so that edge application instances can send requests to the CP service. Figure 3 introduces a simplified diagram of the classes' relations with a preview of the necessary modifications in the current codebase. With the subscription mechanism and HTTP message handling done, the MEC-side app instances should be extended with methods to effectively store the object data from the incoming CPMs in JSON objects. The JSON descriptions can then be sent to the service using the preserved HTTP socket, much like in [31].

Upon receiving the incoming data, the service must process the incoming JSON files by extracting relevant information about the sender vehicle and the detected objects. This data can be used to create a dynamic map of the local environment, enabling a simple implementation resembling the services discussed among the different use cases and related works. Of course, as data is constantly being sent to the service, the model of the environment has to keep up with the real-world motion of the vehicles. Therefore, some form of object tracking, e.g., using Kalman filters, has to be implemented [35].

The necessary interfaces for the inclusion of a compound sensor fusion logic are also sensible. Even though the current environment model of Artery does not support multiple types of sensors, since the used CPM implementation can contain information from any sensor typically used in modern cars, future extensions would undoubtedly rely on this feature. With the unified object data stored in a dynamic map, it would also ease the data analysis of simulations if the collected data could be visualized. Rendering images or even a simple video about the detected objects as time progresses, either coming from one specific vehicle source or the result of the data fusion procedure could enable much more thorough analysis methods. A possible design choice could be to define the interfaces needed first-hand to access these functionalities and leave room for implementations using the strategy design pattern so that later the underlying realization could be seamlessly switched to make simulation tests more smooth.

V. FUTURE WORK

As mentioned at the end of the introduction, the functionality of the CP Service extension of Simu5G could be extended, e.g., with a collision detection and warning system, similar to [29]. Another possible feature would be to implement API endpoints for interworking other edge services with the CPS so that collision avoidance or other services depending on the dynamic

model can easily access real-time environmental information. This could be an excellent example for others working with any kind of MEC service simulation using Simu5G, generally boosting the usability of the simulation environment.

Although it was beneficial to choose Simu5G for the integrated framework to handle 5G network elements, mainly because of the detailed MEC realization, it does not implement the PC5 interface. The evaluation of existing libraries and frameworks for modeling C-V2X communications is necessary to assess how direct links between the vehicles and/or infrastructure nodes could be handled using 5G [36]. One of the possible options is migrating the device-to-device features of SimuLTE [37] while updating the features and channel modes according to NR-V2X enhancements compared to C-V2X [38]. Another option would be to further increase the number of standalone projects packed together and integrate some parts or the whole of the OpenCV2X. Still, extensive work on the updates according to NR specifications could not be omitted, as OpenCV2X is an implementation of 3GPP Rel. 14 sidelink mode 4, specifically.

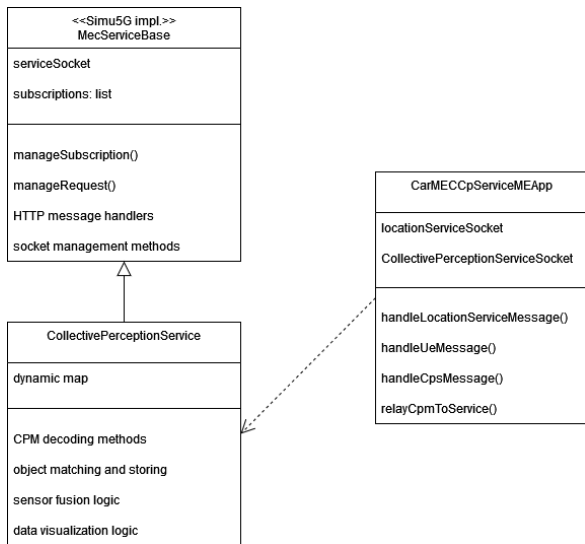


Fig. 3. Simplified UML diagram of the proposed edge service

Another grand upgrade would be the integration of CARLA into the Artery framework [39], replacing Artery’s simple sensor suit and environment model and extending SUMO as the traffic simulator. Although SUMO can run in parallel to the OMNeT++-based network simulation quite effectively thanks to a well-defined control interface [40], its environment model is overly simplistic. The available radars have very few configurable parameters, and 3D support is inadequate. In comparison, CARLA is a 3D simulator based on Unreal Engine 4, providing a diverse set of sensor options, including cameras, LIDARs, or depth sensors. With this leap in the availability of environmental detail and the granularity of sensor models, the simulations can become significantly more realistic. The expansion could make the experiments on the network and resource toll of real-time MEC-based sensor fusion possible. Testing algorithms for autonomous driving and other services requiring an environmental model as realistic as possible would also be more effective with such a sophisticated tool.

VI. CONCLUSION

The topic of MEC-assisted V2X applications is popular among researchers and automotive industry members alike. The platform offers the necessary background for applications requiring computational power while keeping the low latency crucial for safe operation. One segment of V2X applications that may be the driver behind the development and fine-tuning of MEC for automotive use cases is the group of services relying on the collective perception of the environment, most probably based on CPMs. Since the quickest way of implementing and evaluating different algorithms or testing different parameters is to use some sort of simulations, the necessary tools capable of such functionalities must be available to the community. Therefore, we also plan to release a public repository of the integrated framework soon after the proposed, CP-aware MEC service is implemented.

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