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Abstract:

Vehicles equipped with V2X communication technology are expected to be launched within a year. These vehicles will be shipped with a basic set of applications attributed to Cooperative Awareness (CA) and Decentralized Environmental Notification (DEN) services. Yet, research and standardization of advanced services is under way, e. g., to realize a Collective Perception of vehicles: With local perception sensors such as radar sensors continuously capturing the surroundings, previous research has shown the significant benefit of sharing such detected objects with other V2X-capable vehicles. In this paper, we present the current advancements compared to previous research as well as open research questions regarding the standardization process of a Collective Perception service in the European Telecommunications Standards Institute as well as its evaluation in the established simulation framework Artery.

Realizing Collective Perception in the Artery Simulation Framework

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***Abstract*—Vehicles equipped with V2X communication technology are expected to be launched within a year. These vehicles will be shipped with a basic set of applications attributed to Cooperative Awareness (CA) and Decentralized Environmental Notification (DEN) services. Yet, research and standardization of advanced services is under way, e. g., to realize a Collective Perception of vehicles: With local perception sensors such as radar sensors continuously capturing the surroundings, previous research has shown the significant benefit of sharing such detected objects with other V2X-capable vehicles. In this paper, we present the current advancements compared to previous research as well as open research questions regarding the standardization process of a Collective Perception service in the European Telecommunications Standards Institute as well as its evaluation in the established simulation framework *Artery*.**

I. INTRODUCTION

The advent of vehicular communication is peeking over the horizon as first car manufacturers announced to introduce V2X technology in their cars, starting in 2019 [1], [2]. In Europe, those vehicles will be transmitting Cooperative Awareness Messages (CAMs) as standardized by the ETSI [3]. The aim is to inform vehicles in vicinity about the own type (e. g., bus, truck, car), location, heading, speed, etc. That information increases the awareness of the surrounding Intelligent Transport System Stations (ITS-Ss) and enables their Advanced Driver Assistance Systems (ADASs) to incorporate the knowledge about the presence of the sending ITS-S into their local environment models even if their own sensors are yet unable to detect them. This can be very beneficial e.g. for safety systems now being able to break for a slow truck behind a corner and so far impossible to be seen.

However, from the CAM, an ITS-S can only learn about the presence and state of other communication-enabled vehicles. Unequipped vehicles – which will still be the majority for a long while due to vehicles' average life span – will not be able to announce themselves. Modern, communication-enabled vehicles on the other hand are equipped with a plethora of sensors that can sense those vehicles. Hence, it seems natural to broadcast not only the own position, but also information about sensed objects. This has the additional benefit of being able to also announce objects that might never be able to communicate, like pedestrians, cyclists and even obstacles, such as fallen trees. This is called Collective Perception. The potential of an according message has already been shown, e.g., by Günther et al. [4]. As a result, a corresponding new message, called Collective Perception Message (CPM), is currently being standardized by the ETSI.

To help the process of standardization as well as the development of applications leveraging this new CPM, extensive simulations will be necessary. These simulations require realistic traffic- and network behavior modeling in order to acquire meaningful results. The main contribution we want to display in this paper is the Collective Perception Service (CP Service) we are currently in the process of adding to the V2X simulation framework Artery [5]. Furthermore, we will also provide some insights to the status quo of standardization.

The remainder of this paper will be organized as follows: In Section II, the Vehicular Ad Hoc Network (VANET) simulator Artery and other related work will be introduced. Then the current status of standardization will be briefly outlined in Section III. Afterwards, the current status of a reference simulation study for the CPM standardization will be outlined in Section IV. Finally, the implementation of the CP Service in Artery is explained in Section V before we will conclude the paper in Section VI.

II. RELATED WORK

Günther et al. [6] painted a picture of how to generally realize a CP Service in a single vehicle and analyzed the required components, etc. Their results were the basis of the ongoing standardization process at the ETSI. However, for standardization, a holistic view on aspects only coming into play when the service is used in large VANETs like, e.g., generation rules, message fragmentation/segmentation or access layer properties is required.

For a large-scale evaluation of vehicles communicating via ITS-G5 services, we chose to extend the holistic VANET simulation environment *Artery* [5]. It is based on the renowned simulator Vehicles in Network Simulation (Veins) [7].

Artery couples the network simulator OMNeT++ with the microscopic traffic simulator Simulation of Urban MObility (SUMO) and specifically focuses on providing an architecture with a middleware and facilities according to the ITS-G5 protocol stack specification provided by the European Telecommunications Standards Institute (ETSI) for European V2X communication [8] as well as implementations for CA and DEN services. With the bundled *Vanetza* library, a reference implementation of ETSI ITS-G5 network and transport protocols is provided. Furthermore, Artery supports the simulation of radar sensors which populate a local environment model on each vehicle with objects perceived in the vicinity of each vehicle [9].

Thereby, Artery enables the holistic, simultaneous evaluation of multiple VANET applications, their network effects and possible interference. This is achieved as follows: The coupled SUMO itself is able to realistically simulate the movement of vehicles according to a driver model with respect to a given road network with defined traffic flows [10]. Traffic flows are carefully derived from real-world traffic flow measurements and demands (cf., e. g., [11], [12]). Via SUMO's Traffic Command Interface (TraCI) protocol, for each vehicle a node is instantiated in the network simulator OMNeT++ and its movement is synchronized with the vehicles in SUMO. Each node in OMNeT++ simulates Artery's middleware, the desired VANET applications as well as a complete ITS-G5 network stack, including MAC and PHY layers with signal propagation models.

Thus, Artery provides a combination of a full, compliant ETSI ITS-G5 protocol stack and realistic signal propagation models, multiple VANET applications as well as local perception sensors and an environment model which makes it uniquely suited for simulation of a Collective Perception Service, especially when compared to other simulation environments such as ITETRIS [13] or VSimRTI [14].

III. STATUS OF CP SERVICE STANDARDIZATION

The ETSI is currently standardizing the Collective Perception Service and the message format of the corresponding CPM in the Work Item TR 103 562. All details shown in this section are preliminary and subject to change. They are presented as coarse outline of what to expect.

A. Message Format

The most progressed aspect right now is the message format of the CPM. It has mostly been agreed upon and is defined in a ASN.1 format, accessible to ETSI members, like other ITS G5 service messages. A CPM's basic structure is depicted in Figure 1. A CPM generally consists of the following parts: A header is followed by the actual body, the Collective Perception Message. The Station Data and the CPM Management Container provide information about the sending ITS-S. The Sensor Information Container provides details about type and specifications of the equipped sensors. Finally, the Perceived Object Container includes type and measured dimensions, status, etc. of relevant objects sensed by the sender's local perception sensors.

B. Multi-Channel Operation (MCO)

As ITS-G5 service for road safety, the CP Service will operate either on the Control Channel (CCH) or on one of the dedicated Service Channels (SCHs), i. e., G5-CCH, G5-SCH1 or G5-SCH2 [15]. All channels are eventually shared by multiple services and subject to the Decentralized Congestion Control (DCC) [16]. Previous research on collective perception suggests that the CCH of will be saturated with respect to the restrictions imposed by the employed DCC mechanism [17]. The presented study suggests a severe interference for any service employed on the CCH along the Cooperative Awareness Service (CA Service). Therefore, a thorough evaluation of MCO for the CP Service has to be conducted to achieve the best possible leverage from the CP Service as well as freshness of objects sent with a CPM.

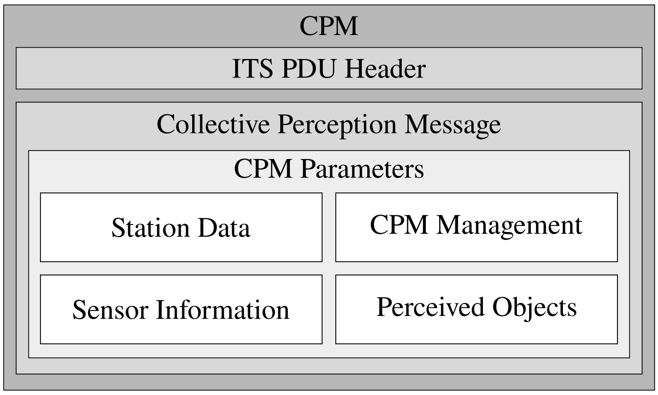

Fig. 1. Preliminary message structure of a CPM

C. Generation Rules

Another central aspect of the service are the message generation rules, i.e., the triggers leading to the generation of a CPM and what information to include. Those rules need to consider the trade-off between minimizing the age of the information about perceived objects at a receiver and minimizing the induced load on the network at the same time. To mitigate this, only relevant perceived objects should be included.

This could be achieved by regularly checking all objects in the vehicle's Local Environment Model (LEM) that have not been deducted from received CPMs, i.e., all objects perceived by this vehicle's own sensors. If the their dynamic state (i.e., speed, heading, etc.) has changed by the specified difference that would trigger the generation of a CAM according to the rules of the CA Service [3], the objects will be included in the next CPM. The downside would be to completely filter out slow or static objects. Since they are of interest too, they also should be included – but with a much lower frequency.

The optimal frequency of the CPM generation itself as well as the timeout after which a perceived object is included independent of it's dynamic state however have to be determined by the upcoming simulations.

D. Fragmentation/Segmentation

If there are numerous objects in the vicinity, it might not be possible to fit all of them into a single CPM due to restrictions by lower layer Maximum Transferable Units (MTUs). Since the ITS-G5 Access Layer will discard frames exceeding the MTU in ITS G5-A and -B frequency bands (cf. Section

6.3.2.4 in [18]), the CP Service must consider this. Byte-level fragmentation in arbitrary places, with respect to the CPM format, is infeasible since the receivers of that message cannot start processing the message until it is completely received. Given the volatility of VANETs some fragments of a message might never actually be received, rendering even successfully received fragments useless. Hence, a better approach is to provide means of segmentation within the CP Service. The CP Service can sort the perceived objects by descending relevance and disseminate standalone CPMs as large as the underlying MTU allows for. Consequently, suitable segmentation rules have to be defined and evaluated as part of the following simulation study as well.

IV. DESIGN OF THE REFERENCE SIMULATION STUDY

As a first use-case of the CP Service in Artery, this section will give a brief introduction to the simulation study planned in the ETSI Working Group in order to test and verify the mechanisms introduced in Section III.

For those types of simulations, it is crucial to use realistic scenarios in order to acquire meaningful results. One of the most commonly used scenarios in that case is Luxembourg SUMO Traffic (LuST) [11]. This is planned to be used as the main simulation scenario for the CP Service. Highly dense and congested scenarios which are likely to happen in (future) mega-cities however, are not covered in the LuST scenario. Therefore, artificial scenarios covering extreme situations will be used to assess the limitations of the new service in worst-case scenarios. One of those scenarios could be a street network consisting of many concentric circles – similar to the web of a spider. If all those lanes are saturated with cars, so should be the radio spectrum for ITS-S on the inner circles.

The main questions for the study will be the evaluation of the aforementioned mechanisms for message generation, MCO, message fragmentation/segmentation and, related to the latter, prioritization of containers. In order to judge the effectiveness of the measures taken, several metrics need to be recorded during the simulation runs.

Important evaluation criteria are the Channel Busy Ratio (CBR) of the respective channel, i.e. its utilization, in conjunction with the resulting DCC state of all used channels. Albeit the general importance, this is especially relevant if the CP Service shares the channel with other services because bad design decisions might negatively affect those services, too.

In addition to these technical considerations, high-level assertions have to be considered as well. One example is the communication induced object age, i.e., the overall age at the receiver of a transmitted perceived object w. r. t. its last measurement at the sender, which will be heavily dependent by the message generation rules.

All these research questions need to be thoroughly investigated prior to final design decisions. That in turn requires a solid simulation framework, the implementation of which will be described in the following section.

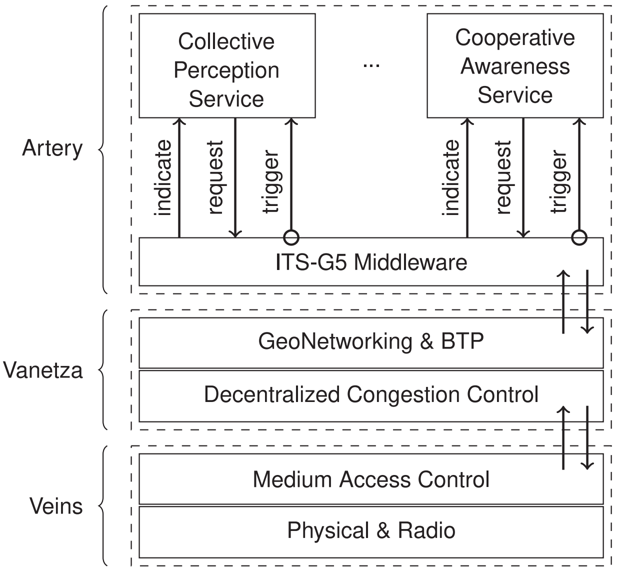

Fig. 2. Integration of the CP Service in Artery (cf. [5])

V. IMPLEMENTATION OF THE CP SERVICE IN ARTERY

In order to conduct the above reference simulation study, a working implementation of a CP Service for Artery was required. Artery provides an application layer to the user to implement ITS G5-services such as the bundled implementation of the CA Service. Hence, the CP Service was implemented analogously (cf. Figure 2).

The CP Service gets triggered with a frequency equivalent to the maximum CPM transmission frequency which is yet to be defined. Now, the generation rules as they have been outlined in Section III will be applied and the generation of a CPM including relevant perceived objects will be initiated, if indicated accordingly.

In order to create a CPM, its structure needs to be adopted in Artery's programming language C++. Although Artery already utilizes the open source ASN.1 compiler asn1c, it was decided to incorporate the yet proprietary "OSS® ASN.1 Tools for C++" into the CP Service, being the de-facto standard among ETSI members in general as well as those participating in the standardization of the CP Service. OSS's ASN.1/C++ compiles a given ASN.1 definition of a message into C++ classes with the according interfaces. Those are then used to assemble all required containers that comprise the CPM. First of all these are the CPM Management Container and the Station Data, i.e., Originating Vehicle Container. They include state information about the sending ITS-S which is mainly queried from Artery's Vehicle Data Provider.

The Sensor Information Container is constructed next with information about sensor types and their field of views. Currently, Artery provides an implementation of radar sensors for local perception as a first prominent sensor type and can be easily extended for other sensor types as well.

Afterwards, the actual payload of the CPM, the Perceived Object Containers (POCs), are generated by iterating over all locally perceived objects in the LEM and generating a POC for each of them. All required information (e.g., an object's current location, speed, possibly heading, etc.) is directly provided by the LEM.

Once the CPM has been completely assembled, its C++ class representation is encoded into the appropriate ASN.1 using the ASN1/C++ tools. After the encoding step, the message is emitted via the ITS-G5 middleware in Artery. Note that during the whole process described above, all relevant metrics are logged. This is done by leveraging OMNeT++'s result recording facilities to enable a comprehensive assessment of core performance metrics of the CP Service.

Whenever the ITS-G5 middleware of a vehicle receives a CPM, the CP Service gets notified by a call to its *indicate()* function (cf. Figure 2) which processes the message. First, it is decoded from the binary ASN.1 encoding into a C++ class structure. Again, core performance metrics such as the packet error rate are logged upon this reception, yet no further processing follows. For future work however, information about perceived objects needs to be assessed and registered with the vehicle's LEM, for eventual access by other, dependent ITS-G5 services (cf. Section I).

For Multi-Channel Operation, Artery had to be extended with the ability to simulate multiple ITS-G5 services operating on different channels, such as G5-CCH, G5-SCH1 or G5-SCH2, respectively (cf. Section III-B). To this end, we implemented full Multi-Channel Operation support in *Artery* for single-hop messages like the CAM and CPM. At the time of writing, the changes are proposed for inclusion in Artery[1].

With these changes, vehicles in Artery can be equipped with multiple ITS-G5 radios each of which is tuned to another channel of ITS-G5. Services can be configured which channel to use via their Application Identifier (AID) [15], and the middleware is able to dynamically decide which of the equipped radios is to be used for transmission of a message depending on this AID.

VI. CONCLUSION

In order to increase the awareness of evolving smart vehicles about their environment it is helpful to share information among these vehicles. Some services are already standardized and will be deployed in the near future, e.g., the Cooperative Awareness Service. In addition to these services, standardization is underway for the Collective Perception Service. While certain core aspects such as the message format have already matured, other mechanisms such as the generation and segmentation rules still have to be developed. To support that work, a reference Collective Perception Service was implemented in Artery, enabling its simulation to find well working mechanisms and parameterize these. Once the ETSI publicly releases the first draft of the CP Service, the presented reference implementation will be made publicly available. The CP Service is envisioned to enable a plethora of new ADASs and with the release of the CP Service specification their development will eventually commence.

VII. ACKNOWLEDGMENTS

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