Enhancing Vulnerable Road User Awareness of Intelligent Transport Systems Through Relay and Aggregation of Collective Perception Messages with Road Side Units

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Abstract: The Collective Perception Service (CPS) allows connected vehicles to gain a more comprehensive picture of their environment by sharing information about the dynamic state of objects with other vehicles and infrastructure. Objects detected by on-board sensors are shared through Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I) communication. However, the range of V2V communication is limited, and Road Side Units (RSUs) can be deployed to enhance the range and attenuate the negative effects of V2V signal propagation. We enhance the vehicular network by RSUs to aggregate and forward Collective Perception Messages (CPMs) received from neighboring vehicles, thus improving the overall environmental perception and the perception of Vulnerable Road Users (VRUs) in particular. Our simulation results, based on the ETSI ITS-G5 standard, demonstrate the effectiveness of the CPS in an urban intersection scenario, showing the positive impact of additional V2I communication and the deployment of RSUs on vehicular perception of VRUs. The addition of RSUs results in a significant improvement in VRU perception, while packet loss on the network channel increases moderately.

1 INTRODUCTION

Recent advancements in Advanced driver-assistance systems (ADAS) and autonomous driving have led to the development of a variety of services for Intelligent Transportation System Stations (ITS-Ss), including collision detection, emergency braking, lane-keeping assistance, and many others. These services require accurate and reliable information from ITS-Ss, which must provide high-precision local sensor data and a comprehensive Local Environment Model (LEM). The LEM of each vehicle is updated by the on-board sensor detections, as modern ITS-Ss are equipped with Lidar, radar or camera sensors. Vehicle-to-Everything (V2X) communication provides services to enhance the LEM by receiving messages from other stations about the position and dynamics of one vehicle (Cooperative Awareness Message, CAM) and by sharing the LEM with other ITS-Ss. This is provided by the Collective Perception Service (CPS) proposed by the European Telecommunications Standards Institute (ETSI).

The Collective Perception Service does not need to rely on Vehicle-to-Vehicle (V2V) links exclusively. The V2V communication can be assisted by Vehicle-to-Infrastructure communication, which enables message exchange between Road Side Units (RSUs) and connected vehicles. The CPS has lots of potential to decrease the risk of collisions, as it provides ITS-S with data about other traffic participants, objects and obstacles in its surrounding. Especially Vulnerable Road Users (VRUs), i.e. pedestrians and cyclists, are more prone to critical accidents with high fatality rate (den Berghe, 2021). VRUs are not equipped with sensors and have no communication capabilities, making them all the more reliant on the V2X communication, in particular Collective Perception. The ETSI CPS (ETSI, 2019b) tackles this communication gap and provides the ITS-S with information about current VRU dynamics and position which is gathered by the on-board sensors of each station. In current research the CPS is mostly investigated in terms of its capabilities to improve the environmental awareness ratio (EAR) of vehicles and safety related metrics (Schiegg et al., 2021). While Collective Perception has been shown to improve vehicle detec-

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tion and increase safety by reducing blind spots, related work often overlooks the perception of VRUs. In this work the focus is on enhancing the perception of VRUs, which is crucial for ensuring road traffic safety. As VRU safety is most critical in urban environments, a scenario for an urban intersection is created. In addition, the impact of RSUs is examined by placing an RSU at the intersection center. The RSU helps to compensate urban-specific communication challenges such as multi-path signal propagation, diffraction and shadowing due to building and other obstacles. Maintaining a reliable communication link even with Non-Line-Of-Sight (NLOS) communication has big impact on the CPS: Research found that NLOS links significantly reduce communication range and signal strength not only implementing 802.11p on physical layer, but also for the upcoming 802.11bd and 5G NR-V2X. (Anwar et al., 2019).

In this study, we simulate the Cooperative Perception System (CPS) using the ETSI ITS-G5 (ETSI, 2020) and CPM (ETSI, 2019b) standards in an urban setting. The simulated scenario incorporates typical signal propagation characteristics at intersections and varying densities of vehicles and VRUs. The service performance is examined by the vehicular environmental awareness of VRUs and network related metrics.

2 RELATED WORK

2.1 ETSI Collective Perception

The ETSI standardizes CPM and proposes generation rules which define which objects and with which frequency these objects will be added to a CPM. The dynamic-based generation follow these rules:

1. The Object is detected for the first time
2. Object has moved more than 4 meters since last inclusion
3. Object velocity changed more than 0.5m/s since last inclusion
4. Object heading angle has changed more than 4 degrees since last inclusion
5. Object is a VRU and was not included in a message in the last 500ms

After the generation rules are applied, redundancy mitigation techniques can be deployed to filter redundant objects. There are frequency-based, entropy-based, dynamic-based and confidence-based rules defined, which combine object information of local detection and received V2X-detection to determine the priority to send one object (ETSI, 2019b). Redundancy mitigation rules were studied by (Delooz et al., 2022) in terms of environmental awareness, channel load and information redundancy. They found that no single redundancy mitigation technique reaches all requirements and propose a filtering algorithm to combine different mitigation techniques.

2.2 Infrastructure-Assisted CPM

To enhance object detection reliability and range, RSUs can be integrated in an VANet to assist the V2V links. (Yu et al., 2022) provide an overview of related studies on infrastructure-assisted vehicular services. They focus on object perception and detection using different type of on-board sensors (camera, Lidar and a fused system).

There are two different operating options of RSUs related to the CPS: RSUs can either detect objects with local sensors and create CPMs from local detections or they relay received CPMs by other ITS-Ss.

The impact of RSUs on Collective Perception has been studied in several forms: (Chtourou et al., 2021) studied a RSU implementation with 802.11p in the VEINS simulator. They conclude that RSU-assisted CPS provides higher efficiency compared to CPS based on V2V communication. (Pacella et al., 2021) used a pure Road Side Unit Scenario, where the RSU is equipped with sensors to broadcast CPMs. Their focus is on latency measurements, where they estimate an end-to-end delay of less than 250ms. (Garlichs et al., 2020) implemented a relay mechanism to aggregate CAMs received by vehicles and broadcast the aggregated information in CPMs. They studied that the driver reaction time can be improved while the additional network load remains moderate.

2.3 Vulnerable Road User Safety

The safety of Vulnerable Road Users (VRUs), such as pedestrians and cyclists, plays a critical role in the concept of Collective Perception within transportation systems. As these individuals are typically not equipped with Vehicle-to-Everything (V2X) communication modules, they must rely on vehicular safety systems for protection. One approach to address this issue is to integrate VRUs into a Vehicular Ad-hoc Network (VANet) by allowing them to broadcast their own messages regarding their location and movements. The European Telecommunications Standards Institute (ETSI) has standardized the Vulnerable Road User Awareness Message (VAM) to facilitate communication between VRUs and vehicles (ETSI, 2019a). However, it is important to note that the widespread

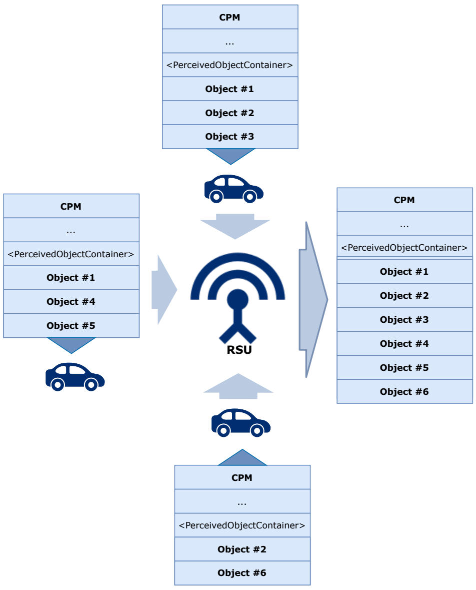

Figure 1: Aggregation of CPMs in the RSU.

adoption of this technology cannot be guaranteed, and the accuracy and reliability of VRU communication devices, such as smartphones, must be established before they can be effectively utilized.

(Willecke et al., 2021) simulate ETSI Collective Perception using the Artery framework and show that the CPS can significantly improve vehicular awareness of VRUs while maintaining a stable network load. Also alternative parameterizations for CPS are analyzed to indicate different tracking accuracies for person objects. (Lobo et al., 2022) study VAM and a combination of CPM and VAM, which outperforms implementing one standalone service.

3 CONTRIBUTION

Although urban scenarios have already been studied in regards to CPM, there is a lack in research of the combination of VRUs and RSUs in characteristic urban environments. As current research of RSUs suggest a placement at intersections centers (Wang et al., 2017), it is worth to study the impact of RSUs on VRU awareness. As stated in 2.2 related work found that the relay mechanism can be beneficial implementing the aggregation of Cooperative Awareness (CA) messages, which indicates that the relay and aggregation of CPMs can be a next step to be deployed.

Our goal is to demonstrate the impact of a relay and aggregation system on the perception ratio of VRUs. Most related work focuses on general object perception and seldom takes into account the unique safety concerns of VRUs. Compared to ITS-equipped vehicles, VRUs lack the ability to broadcast their location and current movement via the CA service, which makes them more dependent on the CPS.

We also investigate the impact of the additional RSU message dissemination on the overall network channel load, as the CPS bandwidth is limited and competes with other V2X technologies. In addition, different vehicle densities and market penetration rates are tested to analyze the impact of increasing channel congestion. The simulation is conducted using the ETSI ITS-G5 communication model and ETSI CPM generation rules according to 2.1, providing a realistic communication environment and ensuring comparability with other studies.

This simulation study examines the combination of V2I and V2V links in order to fully evaluate the impact of Road Side Units (RSUs) on the perception of the environment. To provide a comprehensive analysis, we compare the results of the implementation with both V2I and V2V links enabled to those obtained using pure V2V communication without RSUs.

4 IMPLEMENTATION

The proposed implementation utilizes an RSU relay and aggregation mechanism, which is described in the following section. The urban scenario poses significant challenges for signal propagation, hence the GemV2 model (Boban et al., 2014), which supports different types of signal links, is used. Additionally, the characteristics of the chosen road scenario and traffic simulation will be discussed.

4.1 CPM Aggregation and Relay

Each car generates its own CPMs based on dynamic ETSI rules described in 2.1, which are broadcasted to ITS-Ss in communication range. When the CPMs are received by the RSU, they are aggregated to build newly generated CPMs, ideally containing a greater number of objects in the $PerceivedObjectContainer$. The RSU relays the messages with a fixed frequency of 100ms. Figure 1 shows an example of the aggregation, where the RSU receives CPMs by 3 cars and aggregates the including objects to one new CPM. The LEM of the RSU is created out of the LEMs of the vehicles in the VaNET according to equation 1.

$$LEM_{RSU} = \sum_{i=1}^{n} LEM_{Vehicle(i)} \tag{1}$$

In our RSU service implementation, VRUs are given the highest priority when generating and aggregating CPMs. After the type of object, the next priority is the age of the information. This ensures that the most recent sensor measurements are prioritized when generating and aggregating CPMs. The information shared among connected vehicles is as up-to-date as possible.

The use of Road Side Units (RSUs) in this implementation allows for enhanced range and improved signal propagation of the CPMs, which can improve the overall perception and safety of connected vehicles in urban environments.

4.2 Signal Propagation Modelling

Simulating V2X communication requires a signal propagation model to implement realistic communication characteristics. For the simulation we choose the GemV2 geometry-based model for simulating Vehicle-To-Everything (V2X) communication. It considers three types of links: line-of-sight (LOS) links, non-line-of-sight (NLOS) links due to vehicles, and NLOS links due to static objects.

In GemV2, the LOS links are modeled using a two-ray propagation model. This model considers the direct path between the transmitter and receiver, as well as a reflected path off of a reflecting object, such as a building or vehicle. The reflected path can affect the signal strength and the performance of the V2V communication system.

Furthermore GemV2 considers NLOS links due to vehicles and static objects. In these cases, the signal must pass through or around the obstructing objects, which can cause attenuation, delay, and other impairments. GemV2 takes into account the geometry of the environment and the objects within it to accurately model the NLOS links and their effects on the V2V communication system. (Boban et al., 2014)

Equation 1 defines the well-known two-ray ground reflection model, which models the V2X signal propagation. (Sommer and Dressler, 2011)

$$\begin{aligned} |E_{TOT}| &= \frac{E_0 d_0}{d_{LOS}} \cos(\omega_e(t - \frac{d_{LOS}}{c})) \\ &+ R_{ground} \frac{E_0 d_0}{d_{ground}} \cos(\omega_c(t - \frac{d_{ground}}{c})) \end{aligned} \tag{1}$$

For the pass loss PL, the following equation applies:

$$PL(d) = PL(d_0) + 10\gamma \log_{10}(\frac{d}{d_0}) \tag{2}$$

The factor γ is set differently for LOS, NLOSb (building) and NLOSv (vehicle) links to model the signal propagation according to different types of obstacles. GemV2 has the ability to efficiently scale to high-density scenarios, where there are many vehicles and obstacles that can affect the V2V communication. GemV2 uses geometric calculations and approximations to quickly and accurately simulate V2V communication in these scenarios.

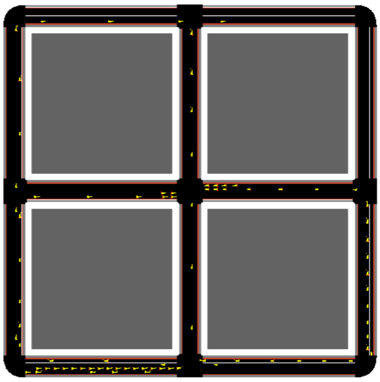

Figure 2: SUMO scenario of the simulation.

5 SIMULATION

The simulation is built to evaluate the performance of a vehicle-to-everything (V2X) communication system in accordance with the ETSI ITS-G5 (ETSI, 2020) standard. The simulation environment is constructed using the open-source framework Artery (Riebl et al., 2015). The traffic simulation is implemented in a scenario created using the Simulation of Urban Mobility (SUMO) (Krajzewicz et al., 2002). A two-lane road in each direction is simulated, with an intersection arm length of 150 meters. Two different density modes are evaluated, one with a den-

Table 1: Simulation parameters.

Parameter	**Value**
Enabled services	ETSI CA, ETSI CPS
Physical layer	IEEE 802.11p
Bit rate	6Mbit/s
Carrier frequency	5.9GHz
Bandwidth	10MHz
Channel	G5-CCH
Transmission power	200 mW
Signal threshold	-85 dBm
Noise threshold	-65 dBm
V2X propagation model	GEMV2
Penetration rate	100%
DCC	Disabled
RSU max antenna gain	10dB
RSU antenna type	Constant gain antenna
Vehicle sensor set	85m 360°camera

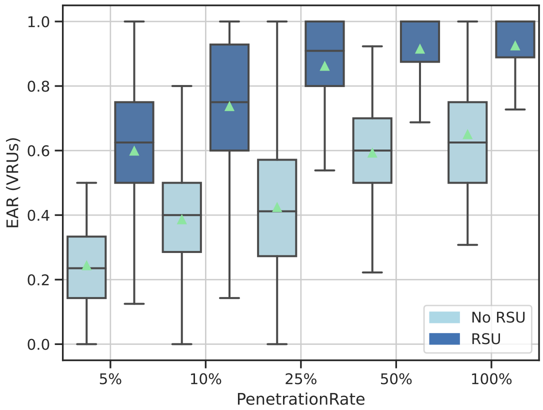

Figure 3: EAR of VRUs for low density scenario

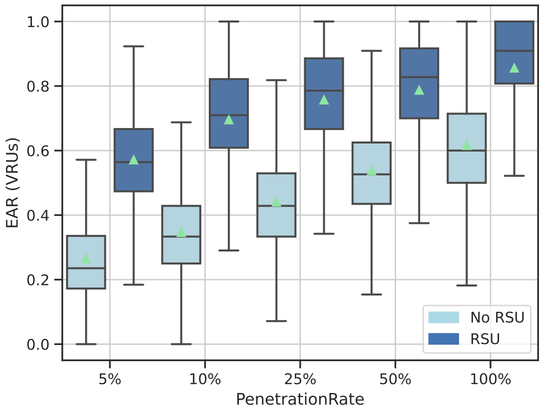

Figure 4: EAR of VRUs for high density scenario.

sity of 75 vehicles per kilometer and the other with a density of 150 vehicles per kilometer. The number of VRUs is set proportional to the vehicular density. The VRUs consist of cyclists and pedestrians, that share the sidewalk. The scenario implemented in SUMO is illustrated in Figure 2. Obstacles (grey areas) are placed on each intersection arm to simulate the impact of buildings at intersections. The evaluation is conducted at the intersection center, and the impact of network load and sensor detections by the outer junctions is mitigated by filtering the data to only consider vehicles in the area of interest. The RSU is placed at the intersection center.

Simulation parameters are set according to table 1. The physical layer of the system is based on the IEEE 802.11p standard, which specifies the use of the 5.9 GHz frequency band for wireless communication in intelligent transportation systems. The channel used in the simulation has a bandwidth of 10MHz. The transmission power is set to 200 mW. The signal and noise thresholds are -85 dBm and -65 dBm, respectively, which represent the reconstruction thresholds of the signal from noise. The V2X propagation model used in this simulation is GemV2, described in 4.2. The penetration rate, which is the proportion of vehicles equipped with V2X technology, is set to a range of values: 5%, 10%, 25%, 50%, and 100%. The Decentralized Congestion Control (DCC) is disabled, which means that the system does not control the flow of data on Facilities or Access layer. The type of antenna used is a constant gain antenna (omnidirectional), thus the gain of the antenna does not vary with frequency or direction. In the simulation vehicles are equipped with 360-degree camera sensors with a range of 85m as on-board sensors, while the RSU does not have any environmental sensors.

As ITS-Ss can be equipped with multiple services, besides the CPS the CA service is enabled.

6 RESULTS

For the evaluation of our simulation, perception and network related metrics are investigated. We adapt the Environmental Awareness Ratio (EAR) metric from (Schiegg et al., 2019), which was originally introduced for objects of any type. Figure 3 and 4 shows the EAR of the vehicles in respect to VRUs according to equation 3. It is defined as the ration between the sum of detected VRUs within a specific range and the total number of VRUs in the range. The range of interest is set to 200m in the simulation. The tracking age of information is set to a maximum of 1 second. Tracks with older updates are not considered.

$$EAR(VRUs) = \frac{\sum_{i=1}^{n} VRU_{Detected,i}}{\sum_{i=1}^{n} VRU_{Range,i}} \tag{3}$$

Figure 3 and 4 shows the EAR for low- and high-density scenarios, respectively. In both cases, it is clearly demonstrated that the EAR increases as the penetration rate of equipped vehicles increases. This outcome is expected as the number of vehicles capable of sharing locally-sensed objects increases. The impact of the RSU on the EAR is significant. For example, with no RSU and a 5% penetration rate, the mean EAR jumps from 0.26 to 0.62. This trend is consistent for higher penetration rates, though the relative increase becomes smaller. In the low-density scenario, a median of 100% EAR is achieved at a penetration rate of 50%. In contrast, for the high-density scenario, the median is only reached at a penetration rate of 100% with the RSU enabled. Another important observation is that when the RSU is turned on, the lower quartile value is significantly improved, providing a higher minimum coverage of detected objects. It is also noteworthy that the overall EAR is lower for the high-density scenario. This could be due to the fact that while one vehicle may detect more VRUs

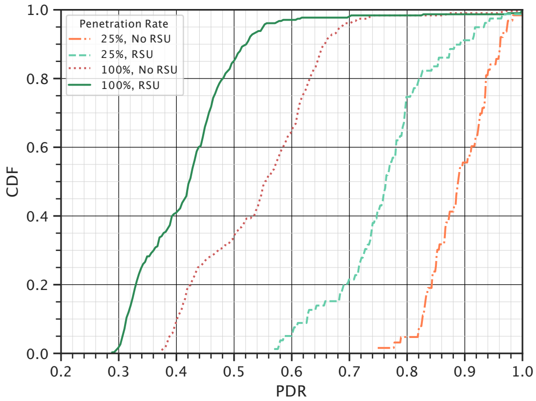

Figure 5: Cumulative Distribution Function of PDR for low and high penetration rate, RSU turned on and off.

in the high-density case, the total number of VRUs is also increased. Another possible reason is that with an increasing number of objects, the obstruction of the field of view sensor increases. Other reasons could be network-related and warrant further investigation.

It is observed that the VRU awareness does not reach 100% without the RSU enabled. At first glance this is not a result to be expected as previous studies found that the EAR enhanced by the CPS covers 100% of detected objects even with penetration rates of 25% and beyond (Schiegg et al., 2021). However this work focus on the perception of VRUs. Compared to other type of traffic participants, they are often hidden by the vehicular on-board sensors due to their small surface. Furthermore, no difference has been made between VRUs on the sidewalk or VRUs crossing the street. Therefore a number of undetected VRUs could be on the sidewalk. However it is worth to consider all VRUs in the EAR: Pedestrians or cyclists could intend to cross the street or behave unexpectedly. Another aspect that decreases the EAR is the inclusion of obstacles in the simulation by placing buildings at all intersection arms: The on-board 360 degree sensor can be blocked and the communication range is attenuated due to the NLOS signal propagation. The evaluation of network-related parameters is illustrated in figure 5, which shows the Packet Delivery Ratio (PDR) for a low (25%) and high (100%) penetration rate, represented as a Cumulative Distribution Function (CDF). In the graph, the vehicle density is fixed at the low density scenario to simplify the analysis by reducing the number of parameters. This type of graph allows for a clear visualization of the distribution of PDR and the minimum PDR ($CDF(x) \rightarrow 0$). The graph compares the PDR with and without the enabled RSU. It can be observed that, for the same penetration rate, there is a significant increase in network load with the RSU enabled, resulting in a lower PDR: The minimum PDR decreases from 0.75 to 0.39 (25% penetration rate) and from 0.57 to 0.29 (100% penetration rate), respectively. The 50th percentile drops from 0.89 (25% penetration rate) to 0.56 and from 0.76 to 0.42 (100% penetration rate), respectively. Additionally, it is evident that the variance of the distribution increases as the PDR decreases, indicating a less reliable system overall. The observations of PDR also provide insight into another potential reason for the decreased EAR in the high-density scenario. As the PDR decreases, the communication channel becomes increasingly saturated, resulting in a greater number of packet losses. In an over-congested channel, not all information will be shared between the ITS-Ss, leading to a reduction in the EAR.

7 CONCLUSION

The results of the simulation according to ETSI standards show that an RSU at urban intersections can improve the vehicular perception of VRUs by enabling the aggregation and dissemination of CPMs to ITS-Ss. However, it should be noted that this implementation also incurs a cost in the form of increased network congestion, leading to a decrease in the Packet Delivery Ratio (PDR) on the communication channel. Despite this decrease in PDR, the results indicate that the overall improvement in Environmental Awareness Ratio (EAR) when the RSU is activated outweighs the decrease in PDR, resulting in a net benefit from the utilization of the RSU. It is also revealed that improvement of VRU awareness is a challenging task in highly-congested urban scenarios: High CPS penetration rates are needed to achieve proper EAR. As the results are promising, in future work additional scenarios can be investigated. Special RSU CPM generation rules could be introduced to enhance the net benefit of an RSU at urban intersections, leading to a more controlled dissemination strategy by the RSU. This could result in an decrease of network channel load while maintaining a high EAR.

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