Prioritization for Latency Reduction in 5G MEC-Based VRU Protection Systems

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***Abstract*—Protecting Vulnerable Road Users (VRU) is and important challenge in the field of connected mobility. The dissemination of VRU-related information plays a key role for the development of technical solutions for VRU protection. The current 5G standard for cellular networking promises a lower latency and increased reliability in comparison to previous technologies. While most efforts are focused towards the development of decentralized systems, Multi-Access Edge Computing (MEC) could be used to build centralized systems that could be a valuable addition to the proposed decentralized systems and increase efficiency and reliability. A potential problem of MEC-based VRU protection systems is a high demand for network resources as data has to be transmitted to a large number of nodes. This paper describes the optimization of such MEC-based systems by introducing filtering- and prioritization strategies to lower the network load. The proposed strategy is then tested and evaluated using coupled network- and mobility simulations. The results indicate that the prioritization strategy can reduce the network load in certain scenarios. This also prevents network congestion and ensures a reliable dissemination of high-priority VRU beacons.**

***Index Terms*—MEC, V2X, VRU, 5G, Simulation**

I. Introduction

Vulnerable road users (VRUs, for example pedestrians and cyclists) are especially at risk in road traffic. Therefore, technical solutions that help protecting VRUs are currently being developed and evaluated. A key aspect of such systems is the communication between road users. For the exchange of the required information, there already exist standards like the CAM format for V2X (vehicle-to-everything) [1]. An adaption of this format that was specifically developed for information exchange by VRUs is the VAM format [2]. Both message standards, among other information, contain the position of the vehicle / VRU which allows to map the traffic environment and detect dangerous situations.

An often proposed technology for exchanging those messages between traffic participants is cellular radio. The benefits of using this technology is the long communication range and high coverage. The recent 5G standard provides support for V2X communication. [3]

We thank the research office (FORWIN) of the Munich University of Applied Sciences for supporting the research collaboration. The authors also acknowledge the financial support by the Federal Ministry of Education and Research of Germany in the framework of roVer (project number 13FH669IX6).

While current research mostly covers decentralized approaches for V2X and VRU communication, using a centralized system could be beneficial in some situations. Offloading the collision detection algorithms, for example, could reduce the battery drain on mobile devices [4]. The MEC (Multi-access Edge Computing) standard [5] provides a way of performing computation directly at the network edge and thus allows for low-latency communication between the centralized components and traffic participants.

A downside of MEC-based VRU protection systems is the fact that the MEC component has to share mobility information of all nodes (vehicles, VRUs) with all other nodes which can result in a high network load in crowded environments. This was also discovered by Coll-Perales et. al. [6] which led them to the conclusion that a high amount of resources is required to build such a system. The increased network load also leads to a higher latency if not enough network resources are available which can be fatal for safety-critical systems.

The goal of this paper is to demonstrate that the network load on the downlink side can be significantly reduced by running filtering and prioritization strategies on the MEC application. Therefore, in Section III, we describe the architecture of the MEC-based VRU protection system and outline a simple strategy that prioritizes mobility beacons based on their distance to the receiving node. To prove that our optimizations are capable of reducing network load and thus latency, we modeled and simulated different scenarios with coupled network- and mobility simulations using OMNeT++ and Sumo. The simulation model as well as the parameters are described in Section IV. In Section V we evaluate, describe and discuss the results. There we analyze the impact of our optimization on network load as well as on beacon latency. Section VI concludes our paper by summarizing the results as well as giving advice on possible future optimizations of the approach.

A. Contributions

The main contributions of this paper are:

- The proposal of a simple prioritization strategy for MEC-based VRU systems that lowers the network load and therefore decreases the latency of VRU beacons.

- An evaluation of the proposed strategy based on measurements conducted using coupled network- and mobility simulations.

II. Related Work

We are currently not aware of any published work that proposes a message prioritization strategy to lower the latency in MEC-based VRU systems.

However, the optimization of decentralized V2X systems has been researched in different publications. A possible strategy is the adaption of message rate and sizes based on network conditions or vehicle density [7].

Bischoff et al. published an article [8] that describes the optimization of decentralized V2X systems by prioritizing relevant messages. Using this approach, the availability of relevant messages can be increased. The approach, however, is tailored towards decentralized V2X systems and does not consider the special requirements of centralized MEC-based VRU systems.

The use of MEC in VRU and V2X systems has been proposed and evaluated multiple times:

Most publications conclude that MEC-based approaches for VRU communication are capable of achieving the required low latency and even outperform traditional approaches in some scenarios [9], [10].

Other work focuses on the offloading of collision detection calculations from the UE (User Equipment) to the MEC system to save energy on battery-powered devices. The results show that the MEC-based approach is superior to a local processing of the data if the data arrives at a low-enough frequency [4]. This work differs from ours as it targets the collision avoidance calculation instead of data dissemination.

A research published by Coll-Perales et. al. [6] analyzed the network capabilities and processing power required for running MEC-based V2X systems. It showed that, unless downlink broadcasting is available, MEC-based V2X systems generate high traffic load as all beacons have to be sent to all nodes individually. While this paper outlines the potential performance issues with MEC-based V2X systems, it does not propose optimizations to mitigate the problems for MEC-based systems without downlink broadcasting. Our research also points out the problem with high network load, however, our main contribution is providing and evaluating a possible solution to this problem.

III. System Description

The system under consideration uses MEC to disseminate VRU beacons between vehicles and pedestrians (here referred to as *nodes*). Nodes send beacons to the MEC system at a regular interval r_{up}. Beacons at minimum contain the node's position, type (vehicle, pedestrian, ...) and an unique id. Once a node joins the VRU system, a MEC application is started on the MEC host. It acts as the endpoint of all communication between the node and the MEC system. As the MEC application handles all processing for the specific node, the system is expected to scale well with an increasing number of nodes.

A centralized MEC service acts as a repository for all mobility information of the area for which the system is responsible.

Once the MEC application receives beacons from the coupled node, it converts and stores it in the MEC service. The MEC application then queries this repository regularly and sends the mobility information of all other nodes back to the corresponding node in one aggregated message. Nodes can then use these mobility information to detect and mitigate possible traffic safety hazards. See Fig. 1 for a simplified representation of the system.

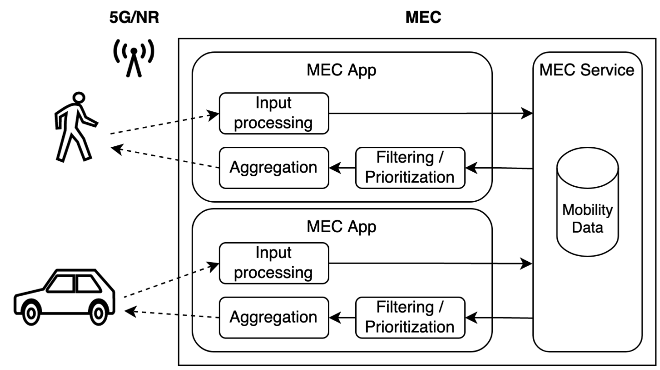


Fig. 1: MEC-based VRU protection system

A. Optimization

A significant disadvantage of MEC-based VRU systems is that each node communicates with the MEC system individually. Therefore, the current position of all nodes has to be sent to every node regularly. This can cause network overload and therefore drastically increase the beacon latency, which could be fatal for safety critical VRU systems. Limiting the number of beacons that are transmitted from the MEC system to the nodes is consequently important for stable low-latency communication. Our approach consists of two steps: Filtering and Prioritization. Both run as a part of the MEC application right before the aggregation and transmission to the corresponding node.

1) Filtering: In a first step, we filter nodes by the node type. Beacons generated by vehicle nodes are only sent to pedestrian nodes, beacons generated by pedestrian nodes are only sent to vehicle nodes. This already lowers the number of beacons that have to be disseminated. Depending on the goal of the system, this step can be adjusted or omitted. Allowing beacon exchange between two vehicle nodes, for example, might be important for a system that is also responsible for car crash prevention.

2) Prioritization: While filtering can already reduce the latency, it is necessary in many cases to further reduce the number of beacons. We choose to use a prioritization approach to adapt the rate dependent on the priority of beacons. See Fig 2 for a visualization of the prioritization approach. The prioritization strategy is based on the assumption that mobility information of near nodes are more important for road-safety than mobility information of distant nodes. Some situations might require prioritization based on different criteria, for example speed or location in dangerous areas.

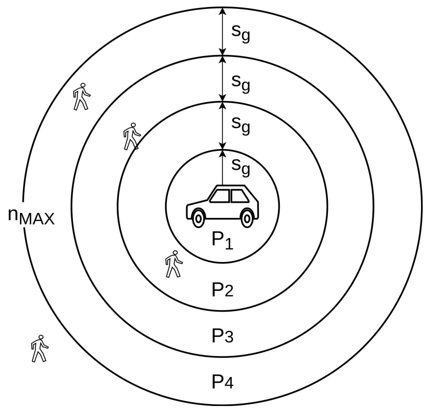


Fig. 2: Visualization of the proposed prioritization approach

The rate r (in Hz) at which position beacons from node Φ_s are sent to node Φ_r is calculated following:

1) The distance $d(\Phi_s, \Phi_r)$ between Φ_s and Φ_r is calculated.
2) Φ_s is then assigned to a priority group P_n based on the previously calculated distance. The parameter s_g defines the base-radius of priority groups in meters:
Be $n \in \mathbf{N}^{+}$:

$$\Phi_s \in P_n \Leftrightarrow d(\Phi_s, \Phi_r) > (n-1) \cdot s_g \wedge$$
$$d(\Phi_s, \Phi_r) \leq n \cdot s_g$$

The size of priority groups s_g could be chosen according to the current network load or be a constant value. P_1 is the priority group with highest priority.
3) The rate r_n for beacons in priority group P_n can now be calculated. The rate decreases with a decreasing priority. Empty groups do not generate messages:

$$r_n = \begin{cases} \frac{1}{n} \cdot r_{base} & \text{if } |P_n| > 0 \\ 0 & \text{if } |P_n| = 0 \end{cases}$$

The parameter r_{base} controls the base message rate. The beacon-rate adaption of $\frac{1}{n}$ is a very simple approach. Other methods like lookup-tables could be used according to the system's requirements.
4) Beacons beyond a certain distance might not be relevant to Φ_r. Therefore we define that Φ_s is only sent to Φ_r if

$$\Phi_s \in P_n : n \leq n_{max}$$

Using this prioritization approach results in a high beacon rate for near nodes and a lower beacon rate for nodes that are further away. While this is generally a desirable behavior, the actual values of the parameters s_g, r_{base} and n_{max} must be carefully chosen to ensure the system works well in a given situation. In general, r_{base} should also be adapted to the observed network load. However, for the sake of simplicity, we consider this adaption process to be out-of-scope for this paper.

IV. Simulation

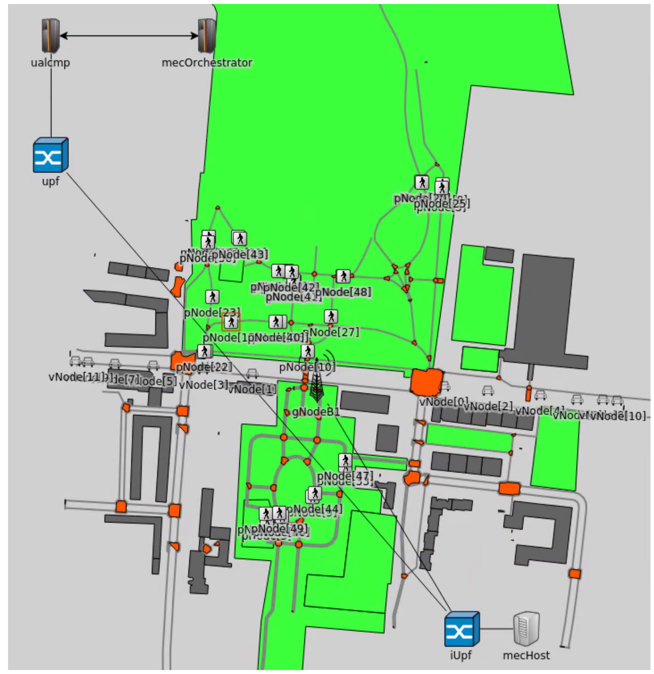


Fig. 3: Simulation environment

The following section describes the simulation that was used to evaluate the proposed optimizations of the MEC system. The code of the simulation including all parameterized scenarios can be found on GitHub[1].

A. Simulation Model

To evaluate our proposed system in a realistic scenario, we use a combined approach that uses OMNeT++ with the INET Framework[2] for network simulation and SUMO for simulating vehicle and pedestrian mobility. The CrowNet framework[3] was used for coupling both simulations. The simulated environment replicated a park in Munich that is divided by a busy road (see Fig. 3). The Simu5G [11] framework is used for simulating the behavior of a real 5G network. The setup of the MEC system was adopted from the proposed MEC setup of Simu5G [12]. Each node (vehicle and pedestrian) runs a DeviceApp that interacts with the MEC system to launch a MEC application and the UEMECApp that sends beacons to the MEC application at a regular interval.

B. Simulation Parameters

The scenario that was built to evaluate the proposed system consists of 50 pedestrians walking in the park and 50 vehicles driving along the street. The simulated 5G network was limited to 15 resource blocks which could be a realistic number if

[1]https://github.com/roVer-HM/crownet/tree/en4ppdr_wimob22
[2]https://inet.omnetpp.org/
[3]https://crownet.org/

the network is already under load from different applications. Beacon size is set to 400B to match the size of a typical CAM message. In simulations where no prioritization was used, beacons were disseminated at a constant rate of r_{base}.

Table I summarizes the most important simulation parameters.

Parameter	Symbol	Value
Basic simulation parameters		
Time limit		200s
Area size		$1100m \times 800m$
Number of pedestrians		50
Number of vehicles		50
Mobility simulation		
Max. pedestrian speed		1.39 m/s
Max. vehicle speed		14 m/s
App parameters		
Beacon uplink rate	r_{up}	5 Hz
Beacon size		400B
Prioritization		
Base rate of beacon downlink	r_{base}	3.3 Hz
Parameter	s_g	20m
Parameter	n_{max}	4
Cellular network		
UE transmit power		28 dBm
gNodeB transmit power		30 dBm
Number of resource blocks		15
Channel model		NRChannelModel [11]
CQI report interval		40ms

TABLE I: Simulation parameters.

The simulation was repeated with prioritization- and filtering strategies enabled and disabled. The comparison between the results of these configurations allows to measure the impact of the chosen strategy on beacon latency.

V. Results

In the following, we present the results of our simulations. This section compares the results of three different configurations of the MEC app:

- *Aggregation*: No filtering or prioritization strategy was used. The MEC system was only used for the aggregation into a single message containing multiple beacons.
- *Node-type*: Node-type based filtering of beacons was used (see III-A1).
- *Prioritization*: Both the filtering- as well as the prioritization strategy were used.

A. Network Load Analysis

To see the influence of the filtering- and prioritization strategy on the network load, we measured the number of utilized downlink resource blocks (DL RBs). Fig. 4 shows a histogram of utilized DL RBs during the simulation.

It can clearly be seen that the simulations that use only aggregation and filtering utilize a high number of DL RBs (14-15 out of 15 available) most of the time. This indicates an overload situation as the network uses almost all available resources most of the time. In contrast, when the prioritization strategy is used, the network uses zero DL RBs in over 70% of time. This indicates that the network can easily handle the data-bursts and doesn't get into an overloaded condition.

While this measurement alone does not indicate a bad performance of the aggregation- and filtering strategies, it clearly shows that the prioritization strategy requires much less network resources and probably works better in high-load scenarios.

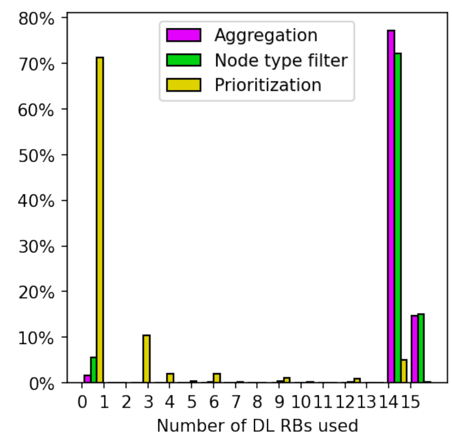


Fig. 4: Downlink resource block usage histogram by strategy

B. Position Error

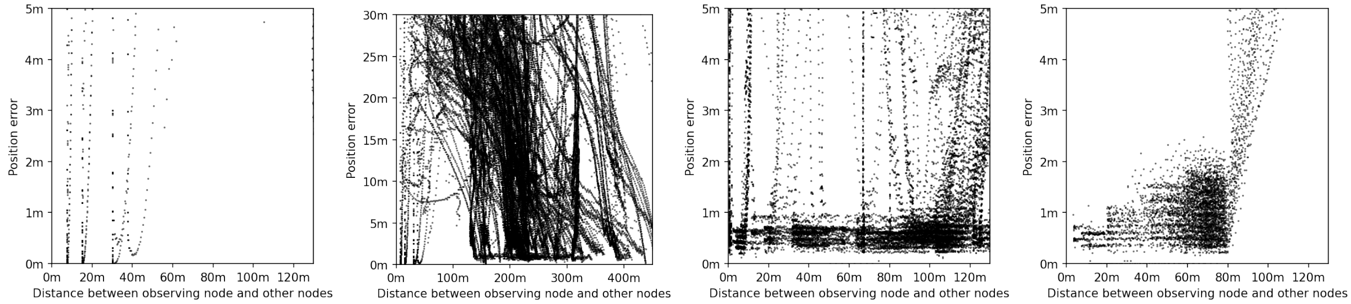
While the network load measurements already show that the prioritization-based scenario put the lowest load on the network which suggests that this scenario also provides the best results in terms of latency, we conduct additional measurements to prove this assumption.

We choose the position error as our metric. This is defined as the distance in meters between the real position of the nodes (extracted from the mobility simulation) and the mobility data received from the MEC system. This metric is calculated every 100ms by every node in the simulation.

For the following visualizations, we combine the position errors received by six randomly chosen vehicle nodes to get a better understanding of the general system performance. Fig. 5 shows the position error in relation to the distance between sending- and receiving node.

Fig.5a and 5b show the diagrams for a aggregation-based scenario without filtering and prioritization. The traces of single nodes with increasing position errors can be clearly seen. This indicates an overload situation where almost no recent beacons are received which increases the error over time. This already shows that this approach cannot guarantee the low latency required for a safety-critical system.

Fig. 5c shows the position error in the scenario where only node-type filtering was used. Compared to the aggregation-based scenario, it already indicates a better result as it shows



(a) Aggregation (b) Aggregation (zoomed out) (c) Node-type filtering (d) Prioritization

Fig. 5: Position errors

more position errors that are smaller than 1 m. However, it also shows traces of nodes with an increasing position error due to network overload. This makes this approach also not suited for a safety-critical system.

The results of the scenario using the prioritization strategy are shown in Fig. 5d. Here, all beacons whose distance to the receiving node is smaller than $n_{max} \cdot s_g = 80m$ are received with a much smaller position error. The four priority groups with an increasing position error are clearly visible. The receiving node intentionally does not receive beacons from nodes which are further than $n_{max} \cdot s_g$ away, therefore their position error increases over time which can be seen in the chart at 80m.

C. Statistical Evaluation

The graphical evaluation above already suggests that the prioritization based scenario allows the lowest latency for beacons of near nodes. To reinforce that claim, a statistical analysis was conducted. The goal was to evaluate the position errors of different priority beacons from nodes with different distances to the receiving node. Those distances were chosen to match the different priority groups of the prioritization strategy of the simulation. Table II shows the mean and maximum position error of those nodes as well as the standard deviation.

The results confirm that the aggregation and filtering approaches are not suited for a safety-critical system in the simulated scenario, as their mean and especially maximum position error are way to large for near high-priority nodes. The prioritization based approach, on the other hand, with a low mean and maximum position error for near high-priority nodes proves to be well suited for such systems. As expected, the mean and maximum position error increases in lower-priority groups. Once beacons are further away than $s_g \cdot n_{max}$, the position error increases drastically as beacons from those nodes are considered too low priority and are therefore not disseminated to the receiving node.

$d(\Phi_s, \Phi_r)$	**Strategy**	**Mean**	**Max**	**STDEV**
0...20m P_1	Aggregation	83.26m	342.79m	95.72m
	Node-type	7.89m	52.06m	10.24m
	Prioritization	0.45m	1.13m	0.22m
20...40m P_2	Aggregation	107.29m	346.8m	89.84m
	Node-type	11.30m	60.03m	13.99m
	Prioritization	0.70m	2.17m	0.36m
40...60m P_3	Aggregation	96.65m	393.5m	92.01m
	Node-type	13.61m	228.68m	20.95m
	Prioritization	0.94m	2.43m	0.42m
60...80m P_4	Aggregation	101.14m	429.34m	100.39m
	Node-type	10.26m	259.22m	17.83m
	Prioritization	1.05m	7.45m	0.58m
80...100m	Aggregation	76.11m	386.57m	78.14m
	Node-type	8.25m	284.09m	18.0m
	Prioritization	5.8m	20.3m	4.31m

TABLE II: Position error of nodes with different distances

VI. Conclusion and Future Research

The results show that prioritization strategies can be used to improve the latency in MEC-based VRU systems. This is especially needed in scenarios with high network load due to limited resources or a high number of nodes. The proposed strategy works well in the simulated scenario and was able to reduce the network load drastically which resulted in an overall lower position error in the simulated VRU protection system.

The reduced network load could also simplify the process of integrating a VRU protection system into an existing 5G network without obstructing other services running within this network.

The results indicate that prioritization and filtering are well suited methods for reducing the latency and position error as well as reducing the network load. The parameters of the prioritization strategy, however, must be chosen for each scenario individually to obtain the best results. A more generic approach would be an adaptive prioritization strategy, which dynamically adapts its parameters to the current network load or number of nodes. The development and evaluation of such an adaptive system will be done as future research work.

We also suspect that similar filtering and prioritization on the uplink-side could further reduce the network- and processing load and therefore help to further improve latency and stability. This will also be evaluated in future research.

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