Emergency Optimized Low Latency MAC Protocol for VANETs based on VeMAC

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***Abstract*—Latency is an important metric for time-critical safety applications in vehicular ad-hoc networks (VANETs). Medium access control (MAC) protocol can be greatly exploited to achieve low latency. In this paper, we modify the existing VeMAC protocol frame structure to enhance its latency aspects for time-critical applications. We introduce additional emergency slots for transmission of emergency messages so that vehicles with time-critical emergency messages do not have to wait for their turn for the transmission of such messages. Our modified low latency version of the existing VeMAC protocol shows great improvements in latency for transmission of emergency messages. We analyze the VeMAC protocol and the proposed protocol through simulation and show that the proposed MAC achieves low latency under different scenarios.**

Keywords—Vehicular ad-hoc network (VANET); Medium Access Control (MAC); Vehicle-to-Vehicle (V2V); VeMAC.

I. INTRODUCTION

A vehicular ad-hoc network (VANET) is a network of moving vehicles, where the vehicles, equipped with sufficient sensing, computation, and communication capabilities, dynamically form an ad-hoc network without any mandatory infrastructure. VANETs are a special class of mobile ad-hoc networks (MANETs), but having unique characteristics such as high mobility of nodes, dynamic network topology, varying communication environment, varying number of nodes, varying node distribution, etc. VANETs are designed for the purpose to exchange traffic or accidental information between vehicle-to-vehicle (V2V) and vehicle-to-road side unit (V2RSU) networks. VANETs have received tremendous attention due to plethora of applications they support such as *intelligent transportation system* (ITS), traffic information dissemination, infotainment, and the Internet connectivity on the go [1] [2]. Among these, the potential application of VANET is ITS, where the core objective is to control accidents, reduce traffic congestion, and improve driving safety in urban areas.

Owing to importance of VANETs and the multitude of applications supported by the technology, several efforts were taken to standardize it, FCC allocated 75 MHz spectrum in the 5.9 GHz band for Dedicated Short-Range Communication (DSRC) [3] solely for the purpose of V2V and V2RSU communication. DSRC is widely recognized as the IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) and is considered the *de facto* standard for VANETs [4], it is based on IEEE 802.11 MAC and IEEE 802.11a PHY layer [5].

The prime goal of VANETs is to disseminate safety and emergency messages, the timely transmission of such messages is critical to smooth operation of safety applications. As latency is an important performance metric for safety/emergency applications and can be controlled through the medium access control (MAC) layer so this requires for efficient medium sharing. Thus, an efficient MAC protocol should ensure high reliability, low end-to-end latency, and high throughput. Therefore, we analyze and exploit the MAC layer in reducing the latency for safety/emergency messages in the context of V2V communication.

In this paper, we propose the emergency enhanced MAC protocol which is a variant of the VeMAC [6] protocol. VeMAC is a multichannel TDMA MAC protocol which is based on ADHOC MAC [7]. The proposed protocol uses emergency slots to transmit time critical emergency messages in case of road accidens or collisions among vehicles in VANETs. Our proposed protocol achieves low latency for emergency messages under different scenarios and is evaluated through simulation.

The remainder of the paper is organized as follows. In Section II, we discuss VeMAC, its working principle, frame structure and highlight its drawbacks for low latency aspects. Subsequently, Section III gives overview of the desired changes in VeMAC to achieve low latency. In Section IV, we describe the evaluation details of our proposed MAC protocol through simulation. We also discuss different real life scenarios for which the protocol is evaluated. Section V discusses results of the simulation and shows latency improvements through box plots. Finally, Section VI concludes the paper.

II. RELATED WORK

In this section, we review the related work, especially we focus on VeMAC. We thoroughly explain VeMAC and its frame structure.

VeMAC frame structure: VeMAC [6] is a multi-channel TDMA protocol for VANETs, which utilizes two radios. One of the radios is always tuned to the control channel c_0, while the other radio can be tuned to one of the service channels. Each node should acquire exactly one slot on the control channel. The node holds onto this slot until it does not need it anymore or until a merging collision occurs. The collisions occur if two nodes, with the same slot, enter the same two-hop-neighborhood due to their Monument. To reduce the number of collisions, the slots are divided into disjunct sets L, R, and F as shown in Figure 1. The frame structure is split in two disjunct sets based on the general direction of movement of the vehicles. If a node travels in general eastern direction, so $0 - 180^\circ$ degrees of a compass, it would be in the R-subset, the rest in the L-subset as shown in Figure 2. F is an optional set for RSUs which has no direction of movement. That way, vehicles driving in opposing directions are not competing for the same slot and it reduces the relative speed of nodes competing for the same slots and thereby increases the network topology persistence within these sets.

The directions are provided by the GPS unit that each vehicle is mandatory to be equipped with. With the GPS unit it is possible to synchronize the frames through the pulse per second (PPS) signal provided by each GPS receiver. A frame should start at the beginning of each GPS second.

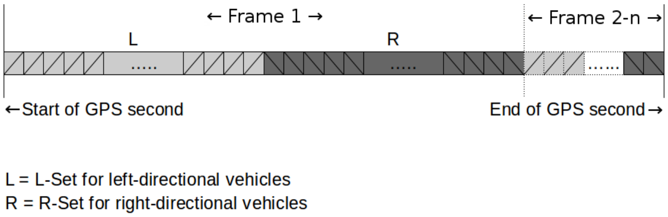


Figure 1. Frame structure of VeMAC [6].

The VeMAC protocol proposes a time division in a periodical frame structure of fixed duration. One frame consists of 100 slots, where the length of one slot is of 1 ms duration, hence a frame length of 100 ms. Each node should transmit periodically one message per frame in its allocated slot. The message consists of a header field, two fields to organize the allocation of slots on the service channels as well as one field for exchange of information for high-priority short applications.

Each node should have a unique random ID to identify the node. The header of the message of node x includes, amongst others, the set $N(x)$ which is the set of IDs of the one-hop neighbors of node x on channel c_0, from which node x has received packets on channel c_0 [6] in the previous 100 slots. With the sets $N(y)$ of each one-hop neighbor y, the node is able to determine which slots are used by its two-hop neighborhood. These slots, that the node must not use in the next 100 time slots, are denoted by $T_0(x)$. With this information, the node builds the set of available slots $A(x) = \overline{T_0(x)}$ respectively with regard to the directional division, e.g., $A(x) = \overline{T_0(x)} \cap R$ for vehicles driving in eastern direction. With the provided information the node is able to solve the hidden-terminal problem.

Node x also determines whether or not all of its one-hop neighbors received its last broadcast by looking for its ID in the right slot in all $N(y)$. It thereby constitutes a reliable broadcast mechanism. Due to the regular transmitting, there exists an upper bound for transmission of messages of 100 ms. However 100 ms is a long time in high mobility scenarios.

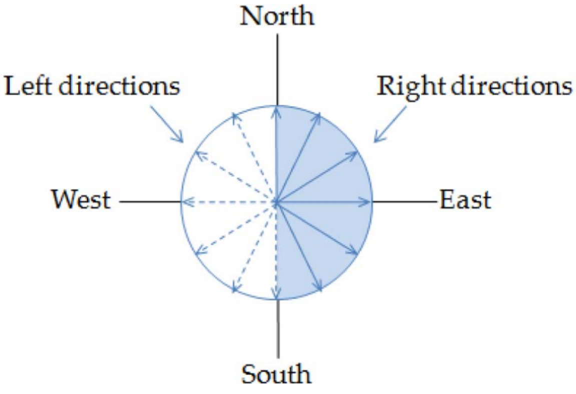


Figure 2. Division of node per direction [6] showing the distinction for the L set and R set.

Limitation of VeMAC for emergency messages: In 100 ms, a car traveling on the highway with the recommended speed of 130 km/h already covers a distance of 3.6 meter and many cars drive considerably faster on the highway in Germany. While the 100 ms limit should be sufficient in normal use, it might be too long for emergency situations where fast responses are crucial.

III. PROPOSED LOW-LATENCY OPTIMIZED MAC

To reduce the latency in emergency situations, in this paper, we propose emergency enhanced VeMAC (EEVeMac), which is variant of the VeMAC protocol, by introducing emergency slots at the beginning of the L set in slot 0 and R set in slot 50 as shown in Figure 3. They are evenly distributed across the frame structure to reduce the average distance to any other slot. The slots are based on the principle of CSMA for the transmission of time-critical emergency data. In case of an emergency, a vehicle wants to send time-critical data to notify other vehicles of its situation. In this way, instead of waiting for its next allocated slot, the vehicle can use these additional emergency slots to quickly transmit the messages and avoid catastrophic situations. With additional slots, vehicles have three possible slots instead of one to transmit their data during emergency situations, effectively bringing down the upper bound latency to 50 ms. While the upper bound latency is 50 ms, the median average is further reduced since a slot is able to choose from three possible slots for emergency transmission instead of one.

While the original VeMAC protocol does not define the exact nature of $N(x)$ for node x, we implemented them in both VeMAC and EEVeMAC as pair of ID and slot number to preserve the reliable broadcast mechanism in EEVeMAC. Through this modification, an ID can be twice in a set. A receiving node then thereby acknowledges the reception of an emergency message by including the ID of the sending node in the emergency slot number in which it received the emergency message. This implementation decision will extend the length

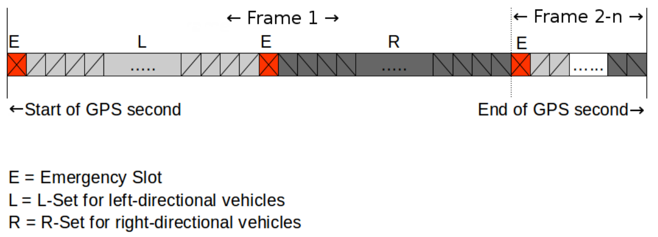


Figure 3. Frame structure of VeMAC with emergency slots. The emergency slots are set at the beginning of the L set respectively the R set.

of the regular message by a maximum of 100 bytes (88 bits total, 7 bits for representation of numbers up to 128, rounded up to 8, multiplied by 100 slots).

IV. PERFORMANCE EVALUATION

We evaluate the proposed protocol in OMNeT++ [8] simulation environment together with Veins [9] and SUMO [10]. Veins is an open source simulation framework for vehicular network simulation. It bi-directionally couples two softwares: OMNeT++ is utilized for network simulation and the open source traffic suite SUMO of the German Aerospace Center provides the traffic simulation data. SUMO has several car-following-models and lane-changing-models to reproduce realistic traffic behavior. Veins integrates MiXiM [11] for modeling physical layer effects and provides realistic interference models. For our simulation we use the two-ray-interference model provided by Veins [12].

Scenario: The highway interchange Münster south, Germany was created in SUMO as shown in Figure 4 and provided with traffic statistic of the state office for road construction NRW [13] to achieve a realistic traffic scenario.

Two scenarios "straight" and "interchange" with reduced road traffic and normal road traffic were tested to examine the influence of node numbers on collisions. In the straight scenario, only traffic from northern and southern directions was present; in the interchange scenario vehicles started from each direction. In each scenario, 20% of cars were presumed to change from one highway to the other highway with 10% in each direction of the highway. The road traffic was implemented with the traffic flow functionality of SUMO which regularly introduces vehicles based on the number of vehicles per hour. The scenario consists of a car that drives on the highway in northern direction and wants to change the highway in western direction on the interchange. It breaks down on the clover interchange lane and sends an emergency message. The car drove in north-west direction and hence it has a regular slot in the first half of the frame structure. In each scenario, the emergency was set to three different slots. To slot 1, directly after an emergency slot, to slot 25, in the middle between two emergency slots, and to slot 49, right before an emergency slot. Each configuration was run with 50 repetitions to achieve a good confidence interval. In combination with the other parameters as summarized in TABLE I, this resulted in 600 simulation runs.

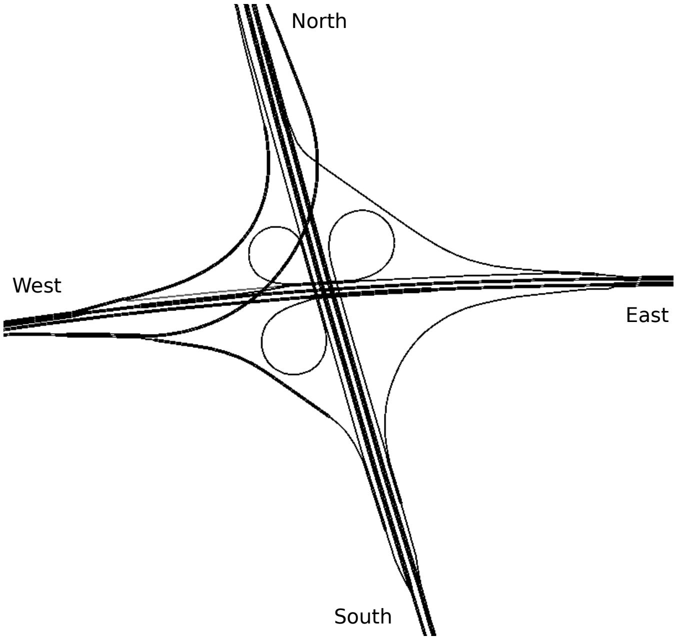


Figure 4. Interchange Münster south, the car with the emergency tries to travel from south direction to west direction and breaks down in the clover interchange line.

TABLE I
OVERVIEW OF SIMULATION PARAMETERS IN THE TWO SCENARIOS.

Parameters	Value	
Scenario	Straight	Interchange
Traffic flow from direction	North/South	North/East/South/West
vehsPerHour (total value)	4645	9476
Use of Emergencyslots	False/True	False/True
Emergency in Slot	1/25/49	1/25/49
Replications	50	50
Simulation duration	80 sec.	80 sec.

In addition to the aforementioned scenarios, we conducted a scenario "dense traffic" with additional cars to simulate extremely dense traffic as it would be expected in urban traffic. We conducted it with the same parameters as the "Interchange" scenario, but increased the numbers of vehicles to 13600 vehicles per hour.

V. RESULTS

For the evaluation of EEVeMAC protocol, we measured two values. The latency from the moment the emergency occurred to the moment the one-hop neighbors receiving the emergency message. The second evaluation value consists of the occurrence of collisions, which were calculated to the arithmetic average per node. The results showed an overall improvement of the latency as further explained below.

A. Latency in straight scenario

In the straight scenario, there were 21 nodes in transmitting range of the emergency vehicle at the moment of the emergency situation. The emergency message took a median

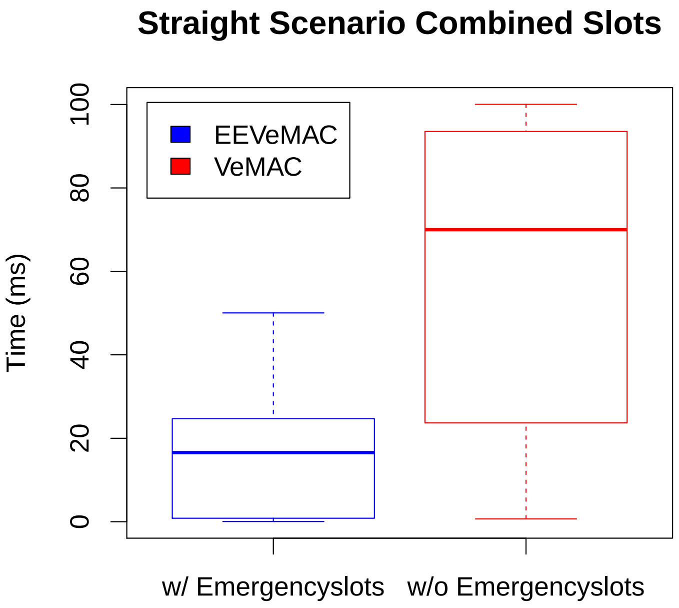


Figure 5. Evaluation results of straight scenario: On the left the latency results of EEVeMAC, on the right the latency results of original VeMAC.

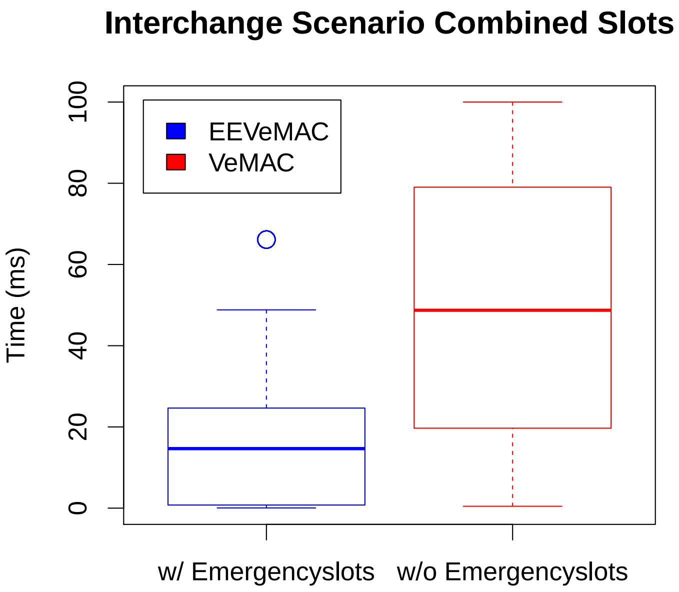


Figure 6. Evaluation results of interchange scenario: On the left the latency results of the EEVeMAC, on the right the latency results of original VeMAC.

time of 69.99 ms to reach the one-hop neighbors of the emergency vehicle in the original VeMAC. With EEVeMAC, with the addition of emergency slots, this value was reduced to 16.57 ms as shown in Figure 5. If the emergency occurred in the first slot after an emergency slot, the median latency was closest to the original protocol with 34.58 ms (VeMAC) vs. 25.01 ms (EEVeMAC) since there is a good chance that the regular slot of the emergency vehicle is between the slot in which the emergency occurs and the next emergency slot. If there is a regular slot in between the emergency and an emergency slot, there is no difference between both protocols as they would both transmit the emergency message in the regular slot. The improvement occurs in the cases where the emergency slot is used. The biggest improvement could be measured with the emergency in slot 49, directly in front of an emergency slot with 73.79 ms (VeMAC) vs. 0.61 ms (EEVeMAC) as shown in Figure 8 (a). Without the emergency slots, the emergency vehicle has to wait at least 50 ms if it does not have slot 49 as its regular slot. It can not transmit in the slot numbers 50-99 since the emergency vehicle is driving in north western direction and hence prefers a slot in the L-set in slot numbers 0-49 of the frame. With the emergency right between two emergency slots, the median latency was improved by 57.61 ms from 81.730 ms in the original VeMAC to 24.120 ms in EEVeMAC with emergency slots.

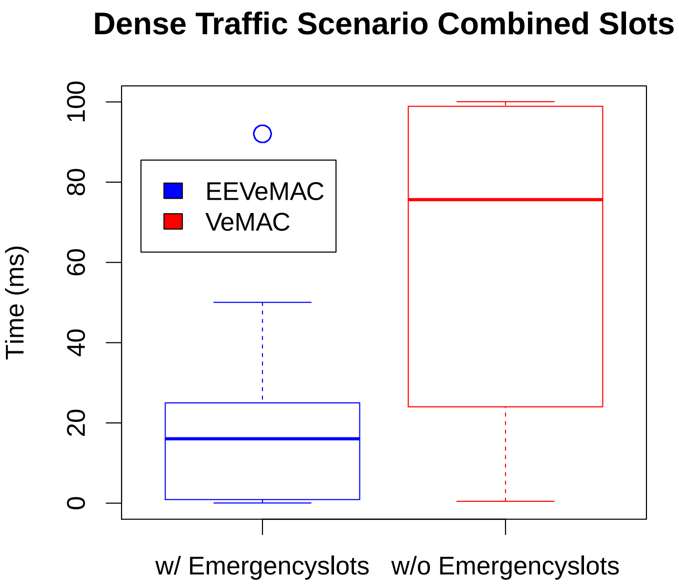
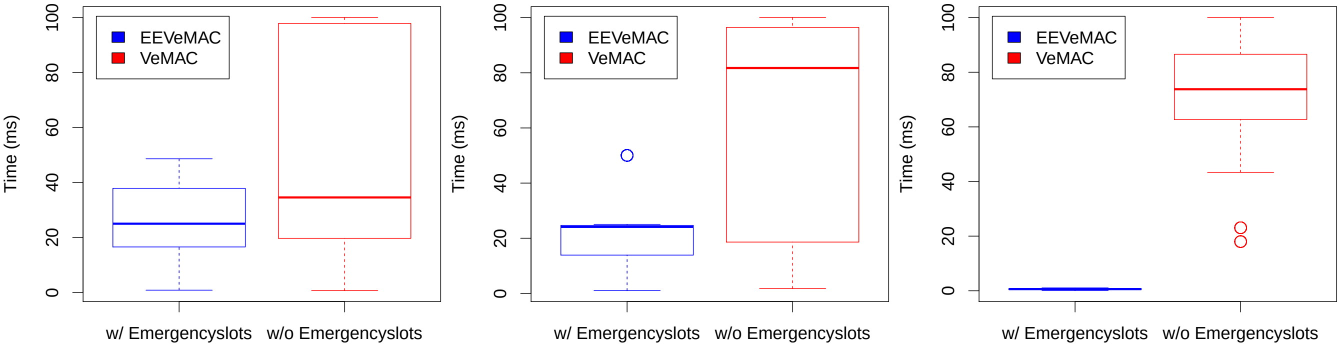


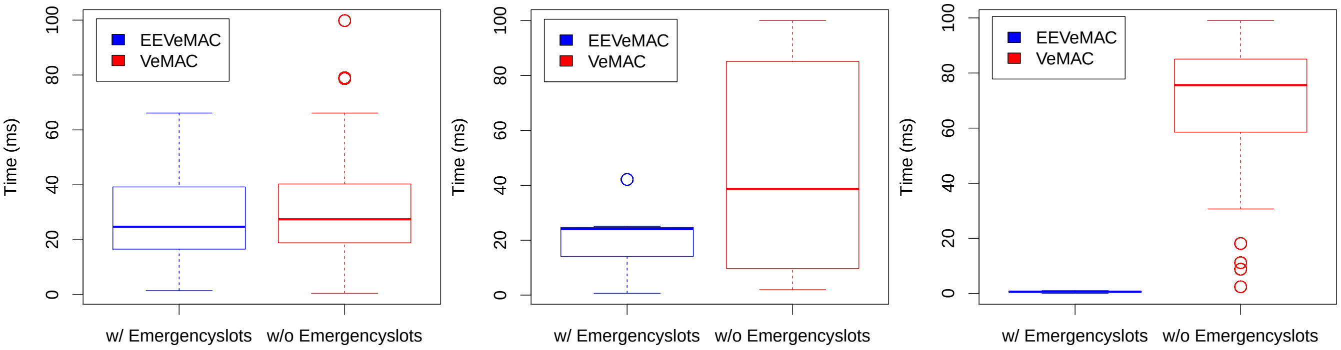
Figure 7. Evaluation results of dense traffic scenario: On the left the latency results of the EEVeMAC, on the right the latency results of original VeMAC.

B. Latency in interchange scenario

The results of the interchange scenario with traffic flow from each direction showed similar improvements as shown in Figure 6. In this scenario, 35 nodes were in transmitting range present during the emergency situation. The median latency was improved by factor 3 from 48.73 ms (VeMAC) to 14.66 ms (EEVeMAC). The biggest improvement could be once again measured if the emergency occurred in the slot right before an emergency slot 75.61 ms in the original VeMAC vs. 0.61 ms in the EEVeMAC, the smallest improvement with the emergency right behind an emergency slot 27.45 ms vs. 24.7 ms. When the emergency occurred in the middle between two emergency slots, the median latency still shows an improvement of 14.6 ms with 38.67 ms measured in the VeMAC and 24.07 ms in the EEVeMAC as shown in Figure 8 (b).



(a) Straight scenario - Emergency in slot 1 (b) Straight scenario - Emergency in slot 25 (c) Straight scenario - Emergency in slot 49



(d) Interchange scenario - Emergency in slot 1 (e) Interchange scenario - Emergency in slot 25 (f) Interchange scenario - Emergency in slot 49

Figure 8. Overview of evaluation of latency results for the straight scenario and the interchange scenario with the emergency in slots 1, 25, and 49.

C. Latency in dense traffic scenario

In this scenario with additional traffic, 50 nodes were in range of the emergency vehicle. The results showed overall similar results as in the normal interchange scenario. The median latency was measured slightly higher with 16.05 ms (EEVeMAC) vs. 75.65 ms (VeMAC) as shown in Figure 7.

D. Collisions

The reservation of two slots for transmission of emergency messages results in a higher expectation of collisions. Instead of 100 slots for transmission of their regular message, the nodes only have a maximum of 98 slots to choose from. Therefore, we also measured the number of collisions. As a measurement, we took the average number of collisions per node. The number of collisions increases in the straight scenario from 0.04575 average collisions per node in the original VeMAC to 0.04747 average collisions per node in the EEVeMAC. The results of the second scenario show that the effect is negligible compared to the effect the numbers of nodes have. The VeMAC had 0.29483 collisions per node whereas the EEVeMAC had 0.29096 collisions per node on average. The average number of collisions increases further with additional traffic in the dense traffic scenario. In the simulation runs with VeMAC, 0.52835 collisions occured whereas EEVeMAC measured 0.66370 collisions.

VI. CONCLUSION

The introduction of emergency slots in VeMAC shows great improvements for the transmission of high-priority emergency messages. Instead of median latencies of up to 80+ ms we achieved in our test configurations a maximum of median latencies smaller than 25 ms. The latencies were reduced by factor of 3-4. The median and average latencies were improved in each study configuration. The reduction of available slots for regular transmission through the reservation of emergency slots had negligible effects on the rate of collisions.

Further, in situations where several vehicles try to send out an emergency message at the same time, competition emerges and latency increases as the vehicles fail to acquire the emergency slot. The vehicles can still use their normal slots to transmit the emergency message which means that the average latency converges to the maximum latency of VeMAC, e.g. 100 ms. The performance of EEVeMAC in emergency situations with two or more involved vehicles remains to be evaluated. Moreover further research is to be conducted in regards to the optimal number of emergency slots and their effect on collision rates.

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