On-demand Quality-of-Service for Crucial Vehicle-to-Pedestrian Communication

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***Abstract*—Vehicle-to-Pedestrian safety communication extends the capabilities of vehicle's on-board driver-assistance systems by establishing cooperative safety communication among vehicles and pedestrians. Such safety communication may involve periodic broadcast of safety messages to the surrounding nodes and also, the peer-to-peer communication between a vehicle and pedestrian on the verge of collision. However, in the presence of a large number of pedestrians, the network can become congested and the safety communication may suffer from degradation in Quality-of-Service. This paper aims to improve the reliability of the peer-to-peer crucial safety communication between the pair of vehicle and pedestrian on the verge of collision. This work proposes a Dedicated Short Range Communication system-based mechanism that informs the surrounding nodes about the ongoing crucial communication and requests them to lower the priority of their safety messages for the subsequent transmissions. The lower priority of the surrounding nodes results in the improvement of channel access for the involved vehicle and pedestrian nodes. We evaluate the proposed mechanism under different configurations of number of pedestrians, different safety message periodicity, and varying duration for lower-priority safety message transmissions. The simulation results show improvement in the packet delivery ratio under the proposed mechanism and also provides basis for the effective implementation of on-demand Quality-of-Service mechanism for crucial communication.**

***Index Terms*—V2X, V2P, 802.11p, QoS, VRU.**

I. Introduction

Vehicle-to-Everything (V2X) communication system have been designed to supplement the capabilities of existing vehicular driver assistance systems. V2X provides a cooperative safety mechanism by establishing communication among the participating entities such as, vehicles in the vicinity and infrastructure. European Telecommunications Standards Institute (ETSI) has also undertaken efforts to incorporate Vulnerable Road Users (VRUs) in such cooperative communication [1].

The Vehicle-to-VRU (V2P) communication systems may be built upon the existing V2X systems such as Cooperative Intelligent Transportation (C-ITS) and Dedicated Short Range Communication (DSRC) system, that were designed to operate in Europe and USA respectively. Even if each of these systems has its own protocol suite, they use a common Medium Access Control (MAC) and Physical layer based on IEEE 802.11p. They both operate in the spectrum 5.850 - 5.925 GHz. Both the systems use the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism to support the channel access. Also, they leverage the Enhanced Distributed Channel Access (EDCA) mechanism provided by IEEE 802.11 for different levels of Quality-of-Service (QoS) provisioning. The V2P communication requires the vehicles and VRUs to transmit the safety messages with periodicity up to 10 Hz. The safety messages include status information, such as location, speed and direction of movement of the sender. The safety messages are always transmitted with the highest EDCA priority, i.e. AC_VO, for the V2X safety applications.

Sewalkar et. al. in [2] describe a V2P cooperative crash prevention system where vehicles and VRUs participate in exchanging the safety messages. The *tracking and prediction* phase of this system involves the vehicles and VRUs to track all of their surrounding nodes using the information from received safety messages and predict the probability of crash based on the trajectories. As the number of vehicles and VRUs grow, the high number of safety messages can congest the network quickly [2], [3]. This affects the delivery ratio of the safety messages at the network level and also, the communication between a vehicle-pedestrian pair that may have predicted a high possibility of crash [2]. The crucial communication between the crash-prone vehicle-pedestrian pair requires the highest reliability among all other V2X communication. However, as all of the safety messages are being transmitted with the highest EDCA priority i.e. AC_VO, higher QoS provisioning for such crucial communication currently cannot be supported under existing schemes. There have been multiple efforts to ease the overall network congestion by improving the channel access and channel capacity [4], [5], [6], [7]. However, these efforts do not distinguish between the crucial communication and the rest V2X safety communication. Also, the surrounding nodes are not aware of the high crash probability of the vehicle-VRU pair. Although the V2X safety communication is cooperative in nature, such awareness of the crucial communication is currently not supported.

In this paper, we aim to improve reliability of the crucial communication between the vehicle-VRU pair by informing the surrounding nodes about the high crash probability. We propose an DSRC-based on-demand QoS mechanism which involves a *Priority Request Message* to be transmitted by the vehicle-pedestrian pair. Upon reception of this message, surrounding nodes become aware of the potential crash and may decide to "yield" by lowering the priority of their subsequent safety messages thereby improving the channel access of the pair. As the results show, the improved channel access results in improved reliability of the crucial communication.

This paper is organized as follows: Section II describes the concepts and related work. Section III provides the system model, and its implementation and evaluation is given in section IV. Sections V and VI provide discussion and conclusion, respectively.

II. Background

A. WAVE Service Advertisement

The IEEE 1609 family of standards define the Wireless Access in Vehicular Networking (WAVE) architecture for operations of DSRC-based systems. At the networking layer, the WAVE Short Message Protocol (WSMP) provides services to the higher layers which include the application layer and the so-called WAVE Management Entity (WME) [8]. The application layer can be an ITS application, such as V2P collision warning app. WME is an intermediate entity between the application layer and WSMP and performs specific management tasks. It uses WAVE Service Advertisements (WSA), a management plane message, to provide advertising services for the application layer. WSMP encapsulates WSA in the WAVE Short Messages (WSM) packet as part of the WSM data. The packet structure of the WSA has four segments: *WSA Header*, *Service Info Segment*, *Channel Info Segment* and *WAVE Routing Advertisement Segment*. All of these segments within WSA have a field named *WAVE Information Element Extension*, which allows the V2P system developers to define additional functionality and services which are not described within the standard.

B. Quality of Service Provision

The WAVE architecture leverages the QoS provisions supported by IEEE 802.11p into its functionality. The application layer can set the *User Priority* on per message basis and forwards it to the WSMP layer. WSMP sets the *priority* of the WSM packet accordingly which is then used by the MAC layer to set the appropriate EDCA priority for transmission.

C. Related work

The majority of the approaches to further enhance the QoS provided by EDCA, or guarantee it, are based on modifications of EDCA, adaptation of TDMA (Time Division Multiple Access), or a hybrid approach. In this section, several proposed solutions to improve QoS for V2X protocols are presented.

Ouni et. al. [5] propose Real-Time Enhanced Distributed Channel Access (RT-EDCA). It is a modification of EDCA with the aim of resolving channel access collisions in a deterministic manner, compared to the probabilistic one used in the EDCA standard. A prevention zone is defined where vehicles with transmission collisions are identified. Then, a tree collision resolution procedure is used to resolve the collisions.

Nasrallah et. al. [6] propose two algorithms to modify the assignment of Arbitration Inter-Frame Spacing (AIFS) in EDCA. The first is the Strict Priority Algorithm (SPA), where higher priority Access Categories (ACs) are guaranteed strict priority despite the value of the Contention Window (CW). The second is the Adaptive AIFS Algorithm, which adaptively adjusts the value of AIFS according to the current density of the channel.

Gopinath et. al. [4] propose Dynamic EDCA (D-EDCA). In this scheme, EDCA processes such as AC queue allocation and choosing of the contention window, are performed dynamically based on real-time values of network density. Also, the frequency of broadcasted safety messages is incremented based on the density of nodes.

QoS-aware Centralized Hybrid MAC (QCH-MAC) was proposed by Boulila et. al. [9]. It is a MAC protocol that combines the capabilities of TDMA and EDCA mechanisms to improve the QoS. It divides the access time period into two phases: Transmission Period (TP) and Reservation Period (RP). TP is divided in several time slots with respect to the TDMA mechanism. RP is used for new nodes to reserve a time slot in TP. This is done using the EDCA mechanism with two categories. However, Road Side Units (RSU) are needed to manage the time slot allocation for nodes.

In [10] Hirari et. al. propose a cluster-based method to improve the QoS for crash warning communication. Cluster heads will broadcast only the estimated status data of the cluster members. In case an unacceptable estimation error is detected by the cluster member, it will correct it by broadcasting the real data. The goal is to lower the intracluster communication to free bandwidth and reduce congestion for intercluster communication.

Authors in [11] propose a channel access scheme, named Earliest Deadline First based Carrier Sense Multiple Access (EDF-CSMA). Vehicles are organized in clusters called WAVE Service Groups (WSG) where a vehicle is chosen as Group Head (GH). Other vehicles, called Group Members (GM), send QoS transmission requests to GH, which in turn is responsible to coordinate channel access for GMs.

All of these efforts aim to improve the overall channel access and channel capacity of the network which result in the overall improvement in reliability. However, none of these efforts distinguish between the crucial communication and the rest V2X safety communication. Thus, they do not consider reliability specifically for the crucial communication. We propose a mechanism based on our previous work [12], [13] that forms the basis of improvement in reliability of the crucial communication and increases awareness of the crucial communication among surrounding nodes.

III. System Model

As discussed in Section II, the WAVE architecture supports the EDCA-based QoS mechanism for different types of V2X messages. The safety messages are transmitted with the highest EDCA priority i.e. AC_VO. Nevertheless, a higher priority is required for the crucial communication between a vehicle and a pedestrian on a collision course. Considering that the WAVE architecture does not allow a higher priority than AC_VO, the higher priority for the vehicle-pedestrian crucial communication may be provided by temporarily reducing the priority of safety messages by the surrounding nodes.

The proposed on-demand QoS mechanism focuses on improving the channel access for the crucial pair. It involves the transmission of a *Priority Request Message* (PRM) by the crucial vehicle-pedestrian pair to the surrounding nodes. The PRM serves two purposes: a) it provides an indication to the surrounding nodes about the ongoing crucial communication, and b) it also signals the surrounding nodes to lower the priority of their safety messages. Consequently, the surrounding nodes may choose to lower the priority of their safety massages. This results in better channel access for the crucial pair which in turn improves the QoS of the crucial communication. The mechanism transmits the PRM on the same MAC channel as that of the safety messages to ensure its broadcast to a maximum number of nodes. PRM leverages the WSA message format and is backward-compatible with the existing WSA message definition. Also, as defined by the standard [8], if a node cannot recognize the WSA, it may simply discard it.

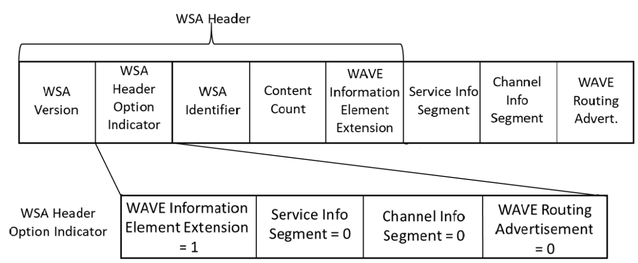

Fig. 1. WSA Header Option Indicator

It is assumed that lowering the priority of the safety messages by surrounding nodes is discretionary and not all surrounding nodes may comply with the request. This is due to the possibility of more than one crucial communication in progress in the given geographical area. Besides, all surrounding nodes may not be equipped with the on-demand QoS mechanism and hence, may discard the PRM WSA due to its unknown nature.

A. Priority Request Message Design

The proposed structure of PRM is based on the WSA message packet format. As PRM is a safety-critical message it is imperative to keep it as small as possible in size. For this purpose, only the WSA header segment is kept in WSA. The other three segments are optional in WSA and can be removed. This is achieved by indicating their absence in the *WSA Header Option Indicator* field. *WSA Header Option Indicator* structure is shown in figure 1. Also, the presence of the *WAVE Information Element Extension* field is indicated by setting its value to 1. The structure of the *WAVE Information Element Extension* field is shown in figure 2. It allows for 255 *WAVE Information Elements* indicated by the *No. of WAVE Information Elements* field. For the case of PRM, it is set to 1 to indicate the presence of only one *WAVE Information Element*. This *WAVE Information Element* is 10 byte long and has four fields: *WAVE Element ID*, *Length*, *Latitude* and *Longitude*. The *WAVE Element ID* identifies elements in WSA. The first 23 *IDs* are already allocated [8], so value 24 is chosen to identify WSA as PRM. Fields *Latitude* and *Longitude* indicate the location of the PRM WSA transmitter node.

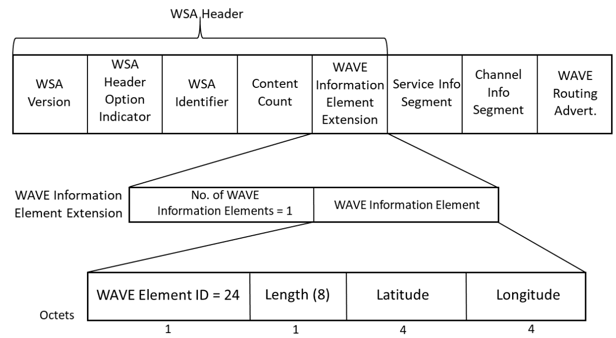

Fig. 2. WAVE Information Element

B. Processing of the Priority Request Message

This section describes the processing mechanism of PRM within the existing WAVE architecture. The procedure leverages the processing mechanism for the WSA.

1) PRM on the Transmitter Side: PRM is generated in the same way as WSA. To generate a PRM, the application layer (the transmitter V2P collision warning app) sends a *Provider service request* to the WME. Further, WME creates the PRM WSA and sends a *WSM.request* to the data plane at the WSMP entity, which encapsulates the PRM WSA into an WSM message.

2) PRM on the Receiver Side: When a node receives a PRM WSA, it forwards it to WME entity which verifies its validity before forwarding it to the application layer (the receiver V2P collision warning app). Further, as the compliance to the request is discretionary, the application layer decides whether to lower the priority of its subsequent safety messages for a certain duration. Not all surrounding nodes may decide to lower the priority. Also, as the priority may be lowered over a certain duration, it may improve the channel access for the crucial vehicle-pedestrian pair during this duration. The receiver node may discard the PRM WSA in case it does not have knowledge of the new *WAVE Element ID*.

IV. Performance Evaluation

This section describes the implementation and evaluation details of the proposed on-demand QoS mechanism. We use OMNeT++ [14], Veins [15], and Simulation of Urban Mobility [16] for implementation and evaluation of the mechanism.

A. Scenario

The proposed on-demand QoS mechanism is implemented on top of the Dedicated Short Range Communication (DSRC)/WAVE protocol stack. The new PRM WSA message and its processing mechanism are implemented as described in the system model.

We consider a busy urban intersection scenario with vehicle and pedestrian traffic. Vehicles travel in two bidirectional perpendicular roads of 500 m length. They are inserted periodically at each end of the roads. Vehicles travel straight until the end of the road where they exit the simulation. They travel with 13.89 m/s (50 km/h), which is a typical speed for urban traffic. Also, four footpaths of 200 m length are created for pedestrian traffic. For each footpath there are three insertion points for pedestrians to create a more even dispersion of pedestrian traffic. Pedestrians travel with 1.3 m/s towards the intersection where they exit upon arrival. One particular vehicle-pedestrian pair that are on a collision course is considered. For simulation purpose, we assume that the collision of this pair has already been predicted. Buildings and traffic lights are included to simulate a more realistic urban environment. The intersection scenario is shown in Fig. 3.

Vehicles and pedestrians broadcast their safety messages over the control channel. Vehicles transmit safety messages with 10 Hz periodicity. Pedestrians transmit the safety messages with 2 Hz, 5 Hz, and 10 Hz periodicity under different configurations of simulation. This helps evaluate the impact of pedestrian-generated safety messages under different network load conditions. The vehicle-pedestrian pair broadcasts their safety messages with 10 Hz periodicity.

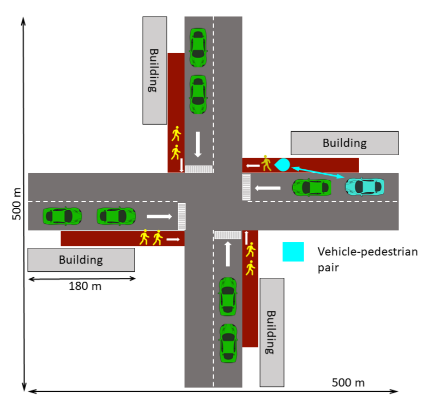

Fig. 3. Scenario

As stated in the system model, not all the surrounding nodes that receive the PRM WSA message will lower their EDCA priority. This assumption has been considered in the implementation as well. Configurations where 25%, 50% and 75% of the surrounding nodes agree to lower the priority of their safety messages are considered. This provides the opportunity to test the performance of the proposed mechanism under three different levels of agreement by the surrounding nodes.

Finally, the system model expects that the surrounding nodes will lower their EDCA priority for an extended amount of time. To study the effects of different time lengths on the crucial communication between the vehicle-pedestrian pair, three window sizes of 1 s, 3 s, and 5 s are considered.

B. Simulation

As stated above, a scenario with high traffic density is considered. The number of vehicles is set to 150. For pedestrians, two levels of densities are used, 150 and 300 pedestrians. This allows to investigate the performance of PRM WSA under different pedestrian densities. The communication range for all nodes is around 400 m. *TwoRayInterferenceModel* and *SimpleObstacleShadowing* channel models are utilized to simulate realistic channel characteristics of V2X communication.

The simulation has a warm-up period of 30 s to get the network into typical intersection conditions. When the simulation warm-up period is over, the pedestrian from the pair sends the PRM WSA message. Then, depending on the window size used, there are 1 s, 3 s, and 5 s of simulation time where performance data are collected. So, the overall simulation time is 31 s, 33 s, or 35 s, respectively. Also, the same simulation is run without the PRM WSA to provide precise comparative results. Every configuration is repeated three times using different seeds. Detailed simulation parameters are given in table I.

Simulation Parameters	**Value**
Road length	500 m
Road layout	Two-way, two-lanes
No. of vehicles	150 + 1
Max. vehicle speed	13.89 m/s = 50 km/h
No. of pedestrians	150, 300
Max. pedestrian speed	1.3 m/s
Vehicle Tx Power	20 mW
Pedestrian Tx Power (BSM)	20 mW
Pedestrian Tx Power (PRM WSA)	20 mW
Vehicles beacon periodicity	10 Hz
Pedestrian beacon periodicity	2, 5, 10 Hz
Nodes in agreement	25%, 50%, 75%
Window size	1s, 3s, 5s

TABLE I
SIMULATION PARAMETERS

C. Evaluation

1) Beacon Delivery Ratio: To measure the performance of the on-demand QoS mechanism, its impact on the communication between crucial vehicle-pedestrian pair needs to be evaluated. We use crucial Beacon Delivery Ratio (B_cDR) between the particular vehicle-pedestrian pair in order to evaluate this impact. We compare the B_cDR results of the configurations with and without on-demand QoS as denoted by *With WSA* and *Without WSA* on the graphs, respectively. B_cDR at the vehicle and pedestrian side are calculated using equations 1 and 2 respectively [2].

$$B_cDR_{(\mathrm{V})} = \frac{num_{\mathrm{received}}(Vehicle)}{num_{\mathrm{sent}}(Pedestrian)} \tag{1}$$

where:
$num_{\mathrm{received}}(Vehicle)$ = the number of beacons received by the

vehicle
$num_{\text{sent}}(Pedestrian)$ = the number of beacons sent by the pedestrian.

$$B_cDR_{(\text{P})} = \frac{num_{\text{received}}(Pedestrian)}{num_{\text{sent}}(Vehicle)} \tag{2}$$

where:
$num_{\text{received}}(Pedestrian)$ = the number of beacons received by the pedestrian
$num_{\text{sent}}(Vehicle)$ = the number of beacons sent by the vehicle.

Then, the average $\text{B}_\text{c}\text{DR}$ for the pair is calculated using equation 3.

$$B_cDR_{(\text{Avg})} = \frac{B_cDR_{(\text{V})} + B_cDR_{(\text{P})}}{2} \tag{3}$$

Figures 4, 5, and 6 show $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ results for 25%, 50%, and 75% node agreement configurations, respectively. For each configuration, results with PRM WSA are compared against those without WSA. It can be observed in all of the 3 figures that $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ decreases with the increase of beacon periodicity. This result is expected since the increase of pedestrian beacon periodicity increases the network load.

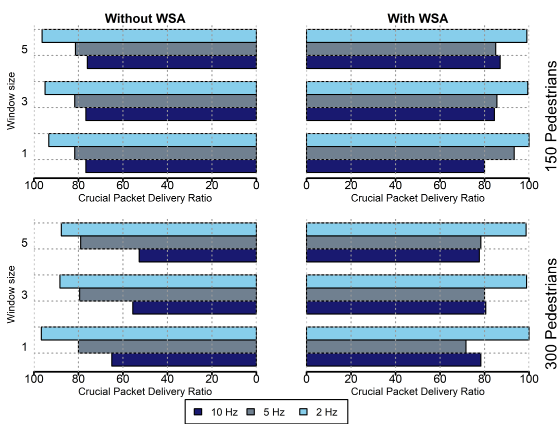

Fig. 4. Crucial Beacon Delivery Ratio for 25% node agreement

Figure 4 shows $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ results for 25% node agreement. For 150 pedestrians $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ shows improvement in all configurations. For 300 pedestrians, $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ shows improvement for 2 Hz and 10 Hz periodicities, for all window sizes. However, for 5 Hz periodicity $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ decreases for window size 1 s, and slightly for window size 5 s. To further analyze this outlier configuration, simulations were run with only the crucial vehicle-pedestrian pair and without any surrounding nodes. In this case, the $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ was 100%. For this particular configuration, the crucial pair may be suffering the hidden node problem. The hidden node problem is known to exist in the systems using CSMA/CA for channel access.

Figure 5 shows the results for 50% node agreement. It is shown that $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ is improved for all configurations except for 150 pedestrians with 2 Hz periodicity configuration where the results are nearly equal.

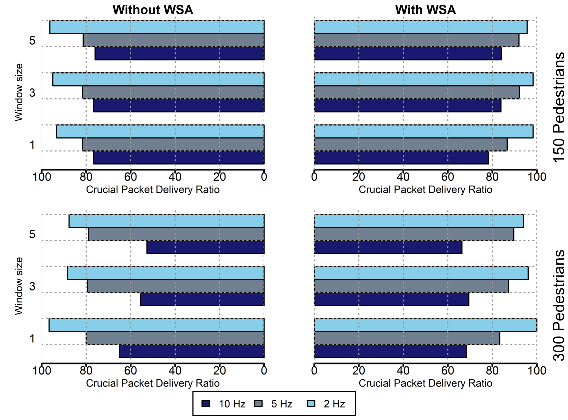

Fig. 5. Crucial Beacon Delivery Ratio for 50% node agreement

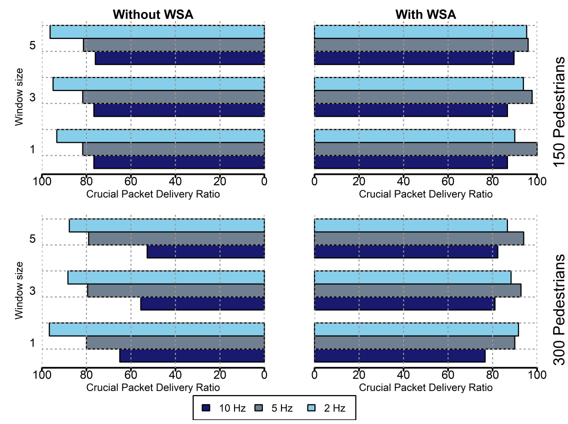

Fig. 6. Crucial Beacon Delivery Ratio for 75% node agreement

Figure 6 presents the results for 75% node agreement. It can be seen that $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ is improved for 5 Hz and 10 Hz periodicities, for all variations of window sizes and number of pedestrians. However, for 2 Hz periodicity with window sizes 3 s and 5 s, $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ is nearly equal. Also, it decreases for window size 1 s. This configuration too may have hidden node issues as the $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ was 100% when we ran similar analysis for this configuration.

Figure 7 shows the improvement of crucial Beacon Delivery Ratio $\text{B}_\text{c}\text{DR}_{(\text{Avg})}$ in percentage. Here, the improvements and anomalies can be seen more clearly. It is shown that configurations with 10 Hz periodicity (highest network density) have the highest improvement. This proves that the higher the density of the network is, the higher is the impact of the on-demand QoS mechanism on the crucial communication.

2) Processing Delay: The processing Delay metric indicates the delay caused by extra processing needed for the PRM WSA. In our simulations, we did not observe any significant delays caused by the processing of PRM WSA as compared to the regular safety message. This is because the proposed PRM WSA size is smaller than the regular safety message size.

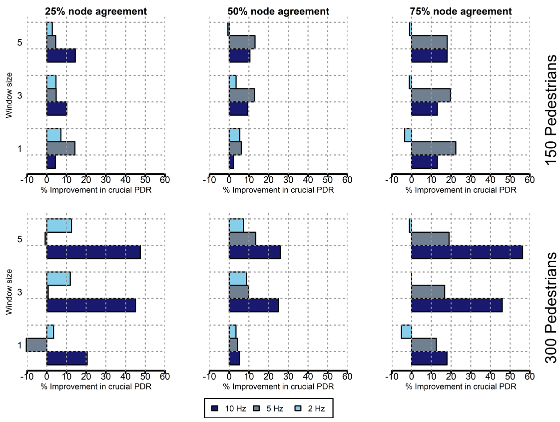

Fig. 7. Improvement in crucial Beacon Delivery Ratio

V. Discussion

This paper presents a novel concept of cooperative on-demand QoS mechanism in the broadcast-based V2X networks. It shows that the reliability of communication between the crucial vehicle-pedestrian pair can be improved by making such a distinction. The proposed mechanism makes such a distinction by informing the surrounding nodes about the crucial communication and requesting them to lower the priority of their safety-critical communication. Yet, it is imperative to recognize that not all the vehicles will comply with the request because they might have other critical communication in progress or because they do not have the PRM mechanism implemented. This has been studied in this work by testing three different percentages of node agreement. Also, this work assumes that all vehicles and pedestrians will comply with the request with the same window size. However, this might not be the case in reality, where different nodes choose to comply with different window sizes. Such a scenario needs to be further investigated.

There are other crucial communication scenarios in V2X where the idea of on-demand QoS could be utilized. For example, when a vehicle wants to make a left turn in front of oncoming vehicle. This may be qualified as crucial communication and the on-demand QoS may be used. Other potential scenarios may be identified, which requires more investigation. Another approach is to request to lower the periodicity and not the priority of safety messages. This also needs to be studied further.

The concept of on-demand QoS can also be ported to other V2P technologies, such as C-ITS and 5G/Cellular-V2X. C-ITS too may use lowered EDCA priorities. A special request message, which maintains backward compatibility with the C-ITS protocol suite may be implemented to provide the on-demand QoS improvement. Cellular-V2X uses network assigned and autonomous resource allocation algorithm to coordinate the channel access. When a special request message is transmitted by the crucial vehicle-pedestrian pair, the resource allocation algorithm could adapt to the required QoS for the crucial communication.

VI. Conclusion and Future Work

In this paper, we have proposed an on-demand QoS mechanism to improve the reliability of crucial communication between a vehicle and a pedestrian on a collision course. It includes creating a new message that informs the surrounding nodes to lower the priority of their safety messages. Simulation results show a significant improvement of the beacon delivery ratio for the crucial communication when using the proposed mechanism.

We plan to develop our work further by devising a mathematical model for the proposed concept. We also plan to design a receiver-side algorithm that would help make the decision regarding the reduced priority for the safety messages.

References

[1] ETSI, "ETSI TS 103 300-2 V2.1.1 Vulnerable Road Users (VRU) awareness; Part 2: Functional Architecture and Requirements definition," 2020.

[2] P. Sewalkar, S. Krug, and J. Seitz, "Towards 802.11p-based Vehicle-to-Pedestrian Communication for Crash Prevention Systems," in *9th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*. IEEE, 2017.

[3] X. Wu, R. Miucic, S. Yang, S. Al-Stouhi, J. Misener, S. Bai, and W. hoi Chan, "Cars Talk to Phones: A DSRC Based Vehicle-Pedestrian Safety System," in *80th Vehicular Technology Conference (VTC)*. IEEE, 2014.

[4] A. J. Gopinath and B. Nithya, "Enhancement of ieee802. 11p-based channel access scheme for internet of vehicle (iov)," in *2019 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*. IEEE, 2019, pp. 1–6.

[5] S. Ouni, N. Boulila, and B. A. Zafar, "Enhanced EDCA with Deterministic Transmission Collision Resolution for Real Time Communication in Vehicular Ad Hoc Networks," *Wireless Personal Communications*, vol. 98, no. 1, pp. 311–335, 2017.

[6] Y. Y. Nasrallah, I. AlAnbagi, and H. T. Mouftah, "Enhanced Algorithms for the IEEE 802.11p Deployment in Vehicular Ad Hoc Networks," in *IEEE 86th Vehicular Technology Conference (VTC Fall)*. IEEE, 2017.

[7] J.-W. Kim, J.-W. Kim, and D.-K. Jeon, "A Cooperative Communication Protocol for QoS Provisioning in IEEE 802.11p/Wave Vehicular Networks," *Sensors*, vol. 18, no. 11, p. 3622, 2018.

[8] IEEE, "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services:Std 1609.3^{TM}-2016," 2016.

[9] N. Boulila, M. Hadded, A. Laouiti, and L. A. Saidane, "QCH MAC: A Qos-Aware Centralized Hybrid MAC Protocol for Vehicular Ad Hoc NETworks," in *IEEE 32nd International Conference on Advanced Information Networking and Applications AINA*. IEEE, 2018.

[10] T. Hirai and T. Murase, "Node clustering communication method with member data estimation to improve qos of v2x communications for driving assistance with crash warning," *IEEE Access*, vol. 7, pp. 37 691–37 707, 2019.

[11] C.-Y. Chang, H.-C. Yen, and D.-J. Deng, "V2V QoS Guaranteed Channel Access in IEEE 802.11p VANETs," *IEEE Transactions on Dependable and Secure Computing*, vol. 13, no. 1, pp. 5–17, 2016.

[12] M. Shala, "On-demand QoS for Crucial Vehicle-to-Pedestrian Communication," Master's thesis, Technische Universität Ilmenau, 2019.

[13] P. Sewalkar and J. Seitz, "Vehicle-to-Pedestrian Communication for Vulnerable Road Users: Survey, Design Considerations, and Challenges," *MDPI Sensors: Enhances in V2X Communications for Connected Autonomous Vehicles*, vol. 19, p. 358, 2019.

[14] OMNeT++ Network Simulation Framework. [Online]. Available: http://www.omnetpp.org/

[15] C. Sommer, R. German, and F. Dressler, "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," *IEEE Transactions on Mobile Computing*, vol. 10, pp. 3–15, 2011.

[16] D. Krajzewicz, J. Erdmann, M. Behrisch, and L. Bieker, "Recent development and applications of SUMO - Simulation of Urban MObility," *International Journal On Advances in Systems and Measurements*, vol. 5, no. 3&4, pp. 128–138, 2012.