Enabling Efficient Coexistence of DSRC and C-V2X in Vehicular Networks

Ghafoor, Kayhan; Guizani, Mohsen ; Kong, Linghe ; Maghdid, Halgurd S.

Published in:
IEEE Wireless Communications

DOI:
10.1109/MWC.001.1900219

Publication date:
2019

Document Version
Peer reviewed version

Citation for published version (APA):
Ghafoor, K., Guizani, M., Kong, L., & Maghdid, H. S. (2019). Enabling Efficient Coexistence of DSRC and C-V2X in Vehicular Networks. *IEEE Wireless Communications*, *27*(2), 134-140. https://doi.org/10.1109/MWC.001.1900219

Author Accepted Manuscript version of Ghafoor, Kayhan ; Guizani, Mohsen ; Kong, Linghe ; Maghdid, Halgurd S. . / Enabling Efficient Coexistence of DSRC and C-V2X in Vehicular Networks. In: IEEE Wireless Communications. 2019.

Enabling Efficient Coexistence of DSRC and C-V2X in Vehicular Networks

Kayhan Zrar Ghafoor, Mohsen Guizani, Linghe Kong, Halgurd S. Maghdid

***Abstract*—Radio access technologies, such as Cellular vehicle-to-everything (C-V2X) and dedicated short range communications (DSRC), have been used to support robust communication in connected vehicles' scenarios. However, existing studies mostly dealt with homogenous vehicular networks, where coexistence of different radio access technologies in vehicles are not considered. More precisely, such multi radio interface environments burden communications among vehicles. In this paper, we first review DSRC and C-V2X radio access technologies and existing packet relaying mechanisms that are specifically designed for homogenous or heterogeneous vehicular environments. We then present quality of service aware relaying algorithm (QR) that incorporates multi metric to prioritize dual interface vehicles (DVs) and provide robust communications among vehicles that are equipped with different radio access technologies. The simulation results confirm the superiority of the proposed QR in terms of message reception and relaying count as compared to the standard protocols.**

***Index Terms*—Vehicular communications, C-V2X, DSRC, Dual interface vehicles, Relaying.**

I. INTRODUCTION

Vehicular networks are significant for efficient communications among vehicles and between a vehicle and a roadside unit. This communication environment works as an umbrella for next generation smart transportation and then provides several applications such as road traffic safety and infotainment related services. At present, several types of sensors, e.g., automotive radar and visual camera, are embedded in vehicles to meet the requirements of the aforementioned applications. However, these sensors, on one hand have limited awareness capability, and on the other hand are more affected by weather, such as snow, fog and heavy rain, as well as non-line-of-sight (NLOS) conditions. For instance, in snow falling weather conditions V2V cooperative communication is more feasible than sensing vehicle's surrounding conditions using embedded sensors. For this reason, car manufacturing companies and government sectors are promoting V2V cooperative awareness for efficient and safe traffic management systems. With cooperative awareness, vehicles use beacon messages to exchange their status with other cars in the vicinity. IEEE named such messages as basic service set (BSS) [1] while in Europe it is called Cooperative Awareness Message (CAM) [2].

Car auto-makers are actively experimenting on the existing Radio Access Technologies (RAT) in order to assure their performance in safety and comfort-related applications. In US, General motors have embedded 3G and LTE wireless technologies to provide internet access. The two competing technologies for connected vehicles are Dedicated Short Range Communication (DSRC) and Cellular Vehicle-to-Everything (C-V2X). In the near future, both radio access technologies will coexist to empower efficient communication for automated and connected vehicles. DSRC is supported by IEEE 802.11p and Wireless Access in Vehicular Environments (WAVE) protocol stack. IEEE 802.11p is based on the amendment of IEEE 802.11a for V2V and V2I communication [1]. Later in September 2016, 3GPP improved LTE D2D communication of release 12 in order to support vehicular communication and named C-V2X in release 14 [3].

Two leading radio access technologies named IEEE 802.11p and C-V2X are in competition to support efficient connected vehicles and hence dominate the market. From a popularity point of view, the DSRC access technology is unique and widely deployed to provide V2X communication. Although C-V2X is recently developed and not a mature access technology, it has gained attention of researchers in academia and car manufacture companies. Particularly, C-V2X in the 3GPP release 14 could tackle communication issues due to high mobility and vehicular density scenarios. For example, they could address Doppler shift due to high mobility, random channel allocation in dense scenarios, and lack of synchronization in ad hoc mode of communication [3]. As a result, C-V2X can promote the effectiveness of promising V2X traffic safety, environmental and infotainment applications.

It is important to take advantage of both access technologies. This can be done by integrating both DSRC and C-V2X radio frequency in vehicles. At present, coexistence of both technologies are not significant as C-V2X is not mature while DSRC has issues like small coverage and low throughout [3]. Despite the superiority of C-V2X over the long run, the existence of DSRC is necessary till C-V2X will be mature in experimentation and deployment. In many countries, car manufactures in cooperation with communication and technology companies are performing test-bed trials on DSRC and LTE (LTE and C-V2X are used interchangeably). After 3GPP's release 14, China successfully implemented C-V2X

Manuscript received Day Month Year.

Kayhan Zrar Ghafoor is with Department of Computing, School of Science and Engineering, University of Dundee, Queen Mother Building, Balfour St, Dundee DD1 4HN, UK; Department of Software Engineering, Salahaddin University-Erbil, Iraq. kayhan@ieee.org.

Mohsen Guizani is with Department of of Computer Science and Engineering, Qatar University, Qatar. mguizani@ieee.org

Linghe Kong is with Department of Computer Science and Engineering, Shanghai Jiao Tong University, Shanghai, China. linghe.kong@sjtu.edu.cn.

Halgurd S. Maghdid is with Department of Software Engineering, Faculty of Engineering, Koya University, University Park, Kurdistan Region-F.R., Iraq; Department of Computer Science, Faculty of Science, Cihan University-Erbil, Erbil, Iraq. Halgurd.maghded@koyauniversity.org.

This work is partly supported by National Natural Science Foundation of China grants 61972253, 61672349.

and DSRC trials in many cities [4]. For instance, Shanghai Anting project used LTE V2X and DSRC to experiment vehicular communication that involved 10,000 vehicles travelling 300 Km. Moreover, a single technology can not satisfy the needs of efficient traffic safety and efficiency. Thus, it is feasible that C-V2X with DSRC can coexist in intelligent vehicles (refereed to Dual interface Vehicle (DV)). In such heterogeneous vehicular environment, efficient alert message forwarding regarding traffic accidents and unusual situations is demanded to vehicles in the vicinity. In the existing literature, many research challenges not addressed when developing short message forwarding in V2V heterogeneous scenarios. In particular, multi-score function is not considered to favor best candidate neighbor DV to relay the CAM among C-V2V, DV and DSRC vehicles, and deriving multi-score forwarding function for different radio interfaces (DSRC and C-V2V) is a daunting task.

In this paper we first review the efforts that have been made on message relaying in vehicular networks and in coexistence of C-V2X and DSRC. Then, we present an efficient CAM forwarding mechanism, named quality of service aware relaying algorithm (QR), that selects a neighbor DV with a more reliable link and neither very far nor too close to the source. More precisely, the best candidate relay DV should have good Signal to Interference and Noise Ratio (SINR) and have mid-distance to the CAM source. To this end, we formulated the multi-score function for relaying CAM from the DSRC and the C-V2V vehicles. The QR algorithm has been modeled and simulated using LTE-V2V [5] simulator for performance evaluation. Moreover, the proposed QR algorithm can mitigate channel congestion by reducing unnecessary CAM relaying by DVs. The proposed algorithm is useful for traffic safety applications in heterogeneous vehicular networks. From a technical standpoint, we summarize the most important contributions of this paper as follows:

1) In heterogeneous V2V network, inefficient short message relaying might happen in case of considering only distance for message dissemination. QR is proposed to use a multi-metric relaying algorithm that favors reliable and giving higher priority to the relay DVs that are neither outermost DV nor has very close distance to the source. For this purpose, a mathematical model is formulated based on SINR and distance to the source.
2) We derive a multi-score function for CAM relaying from DSRC and LTE-V2V at the DV.
3) The proposed QR could tackle the communication disruption of single radio interface vehicles (either DSRC or LTE-V2V) by forwarding their CAM using DV.

The rest of the paper is organized as follows: we will provide the literature review on recent advances of message relaying in homogenous and heterogeneous vehicular scenarios (Section II and III). Section IV gives an overview of the proposed protocol and also discusses the details of the QR algorithm. This is followed by a performance validation and evaluation in section V, where we highlight the feasibility of our protocol by considering an urban vehicular scenario and realistic wireless channels. Finally, section VI concludes the paper.

II. BACKGROUND

This section presents the state-of-the-art on message forwarding in vehicular networks. The issue of massage relaying has been broadly studied in several aspects for connected vehicles, where vehicles are equipped with a single radio interface. Vehicular networks mainly utilize broadcast mechanism to share traffic information with vehicles in the vicinity. Hence, large number of vehicles probably should receive the safety related packet. Such a wireless environment is shared among vehicles, blind flooding lead to severe channel congestion. This wireless network situation is called broadcast storm problem [6].

Variants of message relaying are proposed in the literature for broadcast traffic mitigation. In [7], (PVCast) a lightweight packet-value-based safety data traffic dissemination is developed to make packet relaying decision based on the packet value and dissemination additional coverage. The PVCast protocol could tackle data preferences of nearby vehicles. Further, in [8] a novel technique is developed LTE-V2V to increase message reception rate of non-line-of-sight (NLOS) communication channel. They proposed a technique,called relay assisted enhanced V2V (RA-eV2V), that uses Road Side Unit (RSU) for relaying messages.

Previous studies focused on efficient relaying in homogeneous vehicular environment [6], [9]. But, they can not be applied in heterogeneous vehicular scenarios, where both multi-radio interface of DSRC and C-V2X can coexist. Besides, most of exiting work favor the farthest vehicle to increase the effective dissemination coverage whereas others give priority to vehicles close to the packet source as the message is significant to the vehicles in the vicinity. Neither favoring the farthest vehicle nor the vehicles close to the source are efficient. More precisely, favoring the farthest node as the next relay vehicle is efficient for fast message dissemination. However, the larger number of vehicles close to the packet source are more important than increasing effective radio communication by giving priority to the farthest node. On the other hand, transmitting messages by vehicles that have short distance to the source might lead to more interferences and that could be less innovative to nearby vehicles [6]. As a result, the radio access of vehicles are severely affected by the channel impairment and interference. In the state of the arts, coexistence of multi-interface solutions in vehicular networks are addressed in [5], [10], [11]. FCC is allowed that nodes embedded with IEEE 802.11ac devices to operate in the 5350—5470 MHz and 5850—5925 MHz bands. In this case (5850—5925 MHz band), IEEE 802.11p users act as primary users, and the 802.11ac users shall be unlicensed secondary users. However, the IEEE 802.11ac devices could have significant interference to DSRC vehicles. In [10], Real-time Channelization Algorithm (RCA) to increase the throughput of IEEE 802.11ac operating in a shared spectrum. Following the trend, in [5] the performance of C-V2X and IEEE 802.11p is deeply evaluated in order to show their advantages and drawbacks. In [11], the proposed relaying mechanism, called

Nearest-first, assigns the highest priority to the DV which is close to the original packet source. The simulation results show that the performance of Nearest-first is better than existing relaying approaches. However, relaying CAM packets by DVs that have short distances to the packet source might lead to more interferences and that could be less innovative to nearby vehicles [6].

III. BACKGROUND OF IEEE 802.11P AND C-V2X TECHNOLOGIES

Presently, a popular radio access technology for vehicular environments is IEEE 802.11p. This technology uses DSRC spectrum and Wireless Access in Vehicular Environments (WAVE) protocol stack [1]. In 2010, IEEE 802.11p was developed based on amendments of IEEE 802.11a and modified in 2012 to support vehicular communications. At the PHY layer level, IEEE 802.11p uses half channel bandwidth (10 MHz) data rate (27 Mbps). The detail of changes of IEEE 802.11p is illustrated in Table I.

IEEE 802.11p uses the principle of Enhanced Distributed Channel Access (EDCA) of IEEE 802.11e to support Quality of Service (QoS). The traffic prioritization is achieved through four Access Categories (ACs). The AC0 is used for background traffic, AC1 is used for Best Effort data traffic, AC2 is used for Video data transmission and AC3 for voice traffic. In a vehicular environment, priority of safety messages is very crucial and it can be matched to different ACs. Then, data traffic uses specified ACs that have different Arbitration Inter-Frame Space Number (AIFSN) and Contention Window (CW) values (CWmin, and CWmax) for service and control channels. Moreover, IEEE 802.11p uses AIFS to assign priority for message transmission. The lower value of AIFS for a specific AC, results in higher priority of accessing the wireless medium. This radio technology is currently used in USA and Europe a standard for vehicular communication.

TABLE I
COMPARISON OF IEEE 802.11P AND IEEE 802.11A PHY LAYER COMPARISON

Parameter	**IEEE 802.11a**	**IEEE 802.11p**	**Modification**
Channel bandwidth	20 MHz	10 MHz	Half
Data rate	12,18,24,36, 48,54	5,6,9,12,18,24,27	Half
Modulation mode	BPSK, QPSK,16QAM, 64QAM	BPSK, QPSK,16QAM, 64QAM	Non
Number of sub-carriers	52	52	Non
Symbol duration	4 Micros	8 Micros	Double
Guard time	0.8 Micros	1.6 Micros	Double
Subcarrier spacing	0.3125 MHz	0.15625 MHz	Half

Cellular V2V standard is an improved version of LTE based D2D communication that first was developed in release 12 of 3GPP. Then, this C-V2X standard is officially released by 3GPP in 2016. At the beginning, the standard considered V2V communication and improved to support safety and comfort related applications. Further, 3GPP developed a new interface in release 14 with modification in link and system level in order to address the main challenges of vehicular communications: high mobility of vehicles and high dense scenarios.

IV. OVERVIEW OF THE PROPOSED QR ALGORITHM

This section presents the proposed relaying mechanism. In the proposed mechanism, a DV allocate a specific wireless channel (10 MHz bandwidth) for each of IEEE 802.11p and C-V2X. A guard band is used to separate both channels. Particularly, a DV is embedded with two radio access interface for short range (IEEE 802.11p) and wide range (C-V2X) communication. Thus, simultaneous communication of each radio wireless access is possible for DVs.

The QR algorithm uses a periodic beacon broadcast message for packet relaying service. Positional information, such as position, direction, ID and speed of the vehicle, is embedded in the beacon message. An event-driven message is another type of packet broadcast in vehicular networks. This type is utilized in emergency situations such as traffic accidents and vehicles in collision situations. In this work, we assume that there is no critical emergency situation rather periodic (every 100 ms) broadcast message is regularly transmitted and relayed by DVs. For the beacon message, the standard communication range is about 150 meters. Further, in C-V2X a set of Resource Blocks (RB) are required for one beacon message transmission.

A. *QR Design*

The purpose of the packet relaying in homogenous vehicular networks is to disseminate packets for a large number of vehicles in a specific area. In realistic heterogeneous vehicular networks, DVs and single interface (IEEE 802.11p or C-V2X) may coexist. Besides, buildings are acting as obstacles that obstruct radio signals. Thus, only favoring farthest distance vehicle lead to suboptimal packet relaying. In this case, many vehicles in the target range of a source do not receive the data packet as the outermost vehicle that performs relaying. Thus, it is necessary to favor relay DVs that have good quality channel with source on one hand and giving higher priority to the relay DVs that are neither outermost DV nor has very close distance to the source. For this purpose, a multi-objective function is needed to combine multi-metrics for relay selection.

The DSRC 1 vehicle in Fig. 2 can not communicate with C-V2X 1 as vehicles are embedded with different radio technologies. Based on the proposed QR mechanism and in the same scenario, when a DSRC 2 wants to broadcast a CAM packet, it gives a higher priority to DV 3 among DV 1, DV 3 and DV 4 as our proposed QR algorithm favors a vehicle with good channel quality and neither the outermost nor the one that has a close distance to the source. Particularly, as

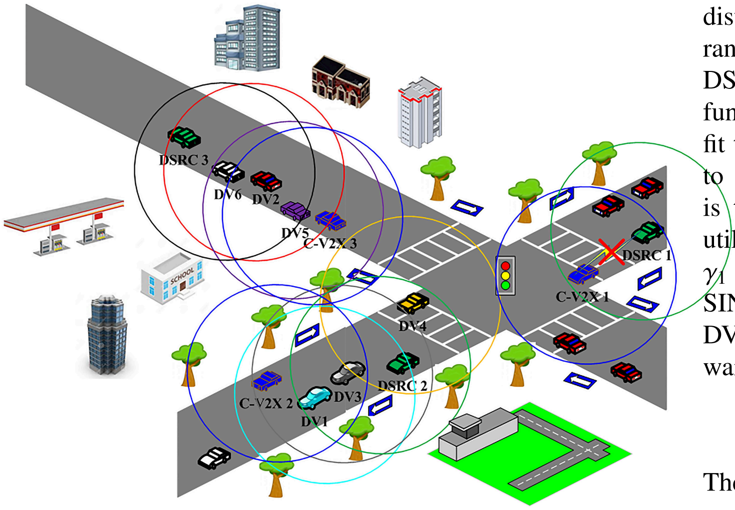

Fig. 1. Coexistence of dual interface vehicles and vehicles embedded with IEEE 802.11p or C-V2X. dual interface vehicles are used to relay packets from vehicles equipped with different radio access technologies

it is illustrated in equation 1 for packet relaying to DSRC vehicle, the preferable dual interface vehicle is the one that has the best SINR with respect to the source and neither the farthest nor the one that has the short distance to the source. Similarly, according to equation 3 for packet relaying to the C-V2X vehicle, ranking of RBs is varied according to the distance between DVs and quality of the signal SINR of RBs that are used by the source to broadcast the packet. In this case, C-V2X 3 also favors DV2 to relay CAM packet toward vehicles in the vicinity. It is noteworthy that the proposed QR algorithm achieves remarkable low complexity because of using simple equations 1 and 3 to find the waiting time during packet forwarding from C-V2X to DSRC vehicle and compute the ranking of resource blocks among the DVs in packet forwarding from DSRC to C-V2X vehicle, respectively. But, in high dense traffic scenarios, the QR algorithm incurs additional delay due to multi-metric based DVs selection and scheduling of radio interface type by the packet source. The next sections detail out the mechanism of packet relaying by a dual interface vehicle.

1) Packet Forwarding from C-V2X to DSRC Vehicle: Dual interface vehicle relays CAM packets from C-V2X to DSRC vehicles in the vicinity. Fig. 2 shows the CSMA/CA channel allocation mechanism by DV. When the DV fetches CAM packets from C-V2X, it utilizes the CSMA/CA algorithm to sense and access the wireless channel after distributed inter frame space (DIFS) time and the duration that takes a decreasing backoff counter.

Favoring only a single metric for packet relaying in a heterogeneous vehicular environment will lead to suboptimal solution. For instance, considering only the distance will not be efficient as in realistic wireless network scenarios quality of the channel is also significant. The quality of the wireless link between vehicles depends on the SINR, which defines the ratio of incoming CAM packet power to the interference power of other vehicles in the vicinity plus the noise power. Moreover, distance is also another important metric to be considered to rank the neighboring DVs by a source either equipped with DSRC or C-V2X. For this purpose, we adapt a multi-metric function proposed in our previous work [12] and modify it to fit two metrics based packet relaying. This function is utilized to combine the SINR and distance parameters. Consider γ_i is the i_{th} relaying parameters as $\gamma = \{\gamma_1, \gamma_2, \gamma_3, ..., \gamma_i\}$ and utilized in the maximized multi-score formula. For example, γ_1 is defined as a measured distance and γ_2 represents the SINR of the wireless channel between the packet source to DVs. Dual interface vehicles use formula 1 to compute the waiting time in the range $[0, T_{max}]$:

$$F(SINR, d) = z \times SINR^{\alpha_1} \times d^{\alpha_2} + T_{\max}, \qquad (1)$$

The maximum value of $F(SINR, d)$ is shown below:

$$z = \frac{-T_{\max}}{SINR_{\max}^{\alpha_1} \times d_{\max}^{\alpha_2}}. \qquad (2)$$

where z is the weight to balance the value of function. Particularly, variable z forces the function value $F(\gamma_1, \gamma_2, ..., \gamma_k)$ to be $<= T_{max}$. Further, α_k is the weight for the relaying metrics $\gamma_1 and \gamma_2$. The greater the value of α_k, the more impact the relaying metric has on priority of DVs. T_{max} depends upon DIFS time, CAM message time duration, slot time and Contention Window (CW_{min}).

The mechanism of CAM packet relaying is illustrated in Fig. 2. Particularly, when DVs receive the CAM packet from the DSRC Vehicle, they compute the waiting time by utilizing formula 1. Then, if the channel remains idle for DIFS and backoff time intervals, the DVs will relay the packet to DSRC vehicle. After successful relaying, a DV performs DIFS and a random backoff even if there is no pending CAM packet for relaying. This DIFS and backoff time interval is named post backoff as this procedure is called after relaying the CAM packet.

2) Packet Forwarding from DSRC to C-V2X Vehicle: In C-V2X, a standard channel bandwidth either is 10 or 20 MHZ. The channel consists of a set of subchannels in the frequency domain and subframes in the time domain. Subchannels is further divided to RBs. The proposed QR algorithm in a distributive manner searches for most suitable Resource Elements (RE), as defined an intersection of specific subframe and sub frequency band in a resource pool, and assign to the DVs for the packet relaying purpose. On this basis, a resource pool in C-V2X is partitioned to several sub-resource pools based on the number DVs within the radio coverage of the source. For instance in Fig 2, three vehicles of DV1, DV3 and DV5 are within the coverage of DSRC 2, thus each vehicle divides the RBs by $j+1$, where j is the number of neighbor vehicles of a DV. More precisely, vehicle DV1 in the same scenario divides RBs by 3 as $j = 2$.

After receiving the resource pool partition information, the DVs perform the mapping of sub resource pools among themselves. The source's SINR of the resource blocks and distance between each of the DVs to the source are used to rank the DVs to relay packets from the DSRC to the C-V2X vehicle. The source uses resource blocks to transmit a

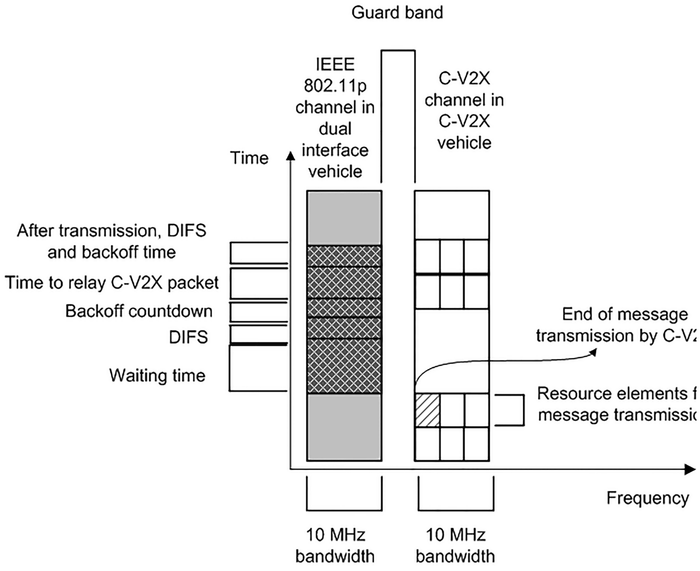

Fig. 2. Dual interface vehicle computes waiting time to access the channel and relay packets from vehicles embedded with C-V2X to DSRC ones

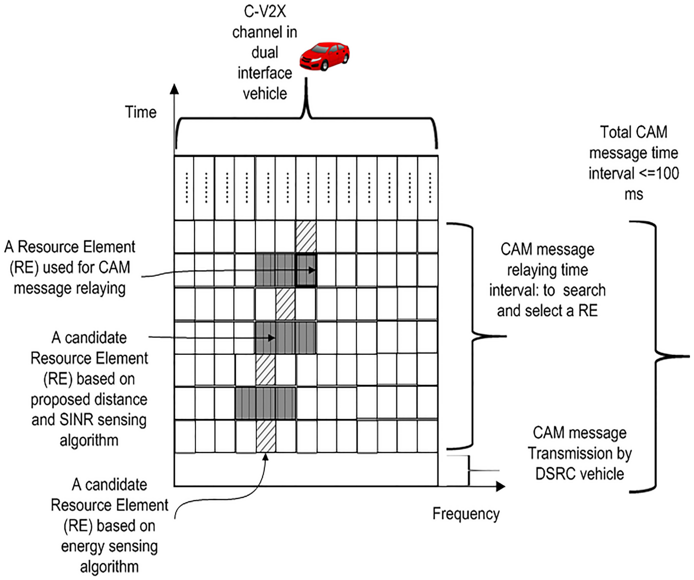

Fig. 3. Dual interface vehicle search and select a specific RE to relay CAM packets from vehicles embedded with DSRC to C-V2X ones

packet to neighbor vehicles and we estimate the value of the SINR of those resource blocks. For the distance measurement, as vehicles are embedded with navigation system, DVs find the distance to the source. Afterwards, the QR algorithm distributively uses formula 3 to compute the ranking of resource blocks among the DVs:

$$RB_{rank} = \lambda_1 \times \frac{d}{R} + \lambda_2 \times \frac{SINR - SINR_{th}}{SINR_{th}} \tag{3}$$

where RB_{rank} is the ranking function that varies with the distance d between the dual interface relay and the source vehicle as well as the quality of the signal $SINR$ of RBs that are used by the source to broadcast the packet. The $SINR_{th}$ is a threshold of signal quality. λ_1 and λ_2 are weights that show the effectiveness of the relaying parameters.

After assigning the RBs to the dual interface vehicles within the coverage of packet source, they need specific Resource Element (RE) for collision avoidance. For this purpose, we adapt the standard MAC layer collision avoidance mechanism of LTE-V2V named sensing based semi persistent scheduling (SPS) to monitor channel occupancy. Sensing-based SPS uses both semi-persistent transmission, which pre-allocate the same resource for a certain time period, and relative energy-based selection. The sensing-based SPS technique makes the optimal resource selection based on sensing and forecasting congestion for choosing the best resource without excessive contention overhead. Since most of vehicular network applications rely on the CAM packet periodic transmission, the Sensing-based SPS technique is suitable for V2X scenarios. By using this technique, every dual interface vehicle computes the energy level of REs before using it for transmission. Thereafter, relaying vehicles select 20 % lowest energy RE as a candidate for transmission. These lowest energy REs are shown in Fig. 3. The proposed QR algorithm uses modified SPS for allocating RE to the DVs. To be more specific, a DV randomly selects a RE based on the intersection of candidate REs determined by the SPS algorithm and the one is determined based on equation 3.

V. Performance Evaluation

A. Simulation Setup

The experiments were conducted using LTEV2Vsim 3.5 [5] with IEEE 802.11p and LTE-V2V MAC as MAC layers for DSRC and C-V2X respectively with 10 MHz bandwidth for both radio access technologies. An area 9200.63 $m \times 5717.06$ m of Montreal downtown is used to simulate connected vehicles in urban scenarios. The mobility traces of vehicle's movement are generated using SUMO - Simulation of Urban MObility [13]. SUMO has a feature of macro and micro-mobility for road traffic flow that produce realistic vehicle's movement. Moreover, SUMO has an efficient vehicle following model, precise location service and real-time traffic controller. In this scenario, vehicles travel with an average speed of 50.15 Km/hour and the average number of vehicles is 350. The number of vehicles embedded with both DSRC and LTE-V2V is 175, while the number of vehicles equipped with only DSRC 90 and 85 vehicles embedded with LTE-V2V.

At the physical layer, we set the transmission power radiated by vehicles on 23 dBm, transmitter and receiver antenna gain on 3 dB. We use WINNER+ as path loss model of the wireless channel among vehicles. This propagation model is suitable for short and long range communication [14]. DSRC vehicles use quadrature phase-shift keying (QPSK) with a coding rate of 3/4 and 48 bit per symbol. Further, LTE-V2V use QPSK 3/5 with channel coding rate of 0.5878 and number of RBs is 50. At the MAC layer of IEEE 802.11p, we configure the slot time, DIFS, CW_{min} 13 μs, 58 μs and 15, respectively. The post backoff procedure is implemented based on the IEEE standard for MAC and physical layer specifications because the transmission-completing vehicle performs the same DIFS and standard mechanism of random backoff even there is no outstanding frame in the interface queue. In other words, the post backoff is exactly similar to the backoff mechanism that is done before the CAM packet transmission. In LTEV2Vsim 3.5 simulator, the same backoff procedure, which is done before the CAM packet transmission is called for post backoff. Moreover, the beacon size is set on default value of 300 bytes and we empirically set the value of the $SINR_{th}$ on 7 dB.

We compare the performance of the proposed QR algorithm with the standard relaying scheme [15]. In relaying from the DSRC to the C-V2X of standard scheme, a dual interface vehicle selects a RU in a resource block that receives 20 % lower energy in the past 1000 ms. On the other hand, for relaying packets from C-V2X to DSRC vehicle, a dual interface vehicle uses contention based CSMA/CA to access the wireless channel. Particularly, after DIFS and backoff counter time intervals, a DV starts relaying CAM packets to nearby DSRC vehicles. The simulation results represent an average of 10 simulation runs. The simulation time of each run is 150 s.

B. Simulation Results

Packet Reception Rate (PRR) is an important metric for message relaying as it is a ratio of successful receptions of beacons to the number of neighbor vehicles. This successful packet delivery leads to prompt reactions in vehicular safety applications. Fig. 4 shows PRR with respect to the number of vehicles within the coverage of either dual or single interface vehicle named Awareness Range (AR). A superficial notice indicates that the standard protocol is always lagging behind our proposed QR algorithm. The performance hit of the standard protocol is due to high congestion on the control channel among vehicles. More particularly, the standard protocol does not give priority to a specific vehicle rather once vehicles within the awareness range rebroadcast the received packets. In such a way, the high control channel congestion leads to a high rate of collision. In contrast, taking benefit from prioritization of neighboring vehicles, QR achieves a high average PRR, which is 87 %. QR assigns priority of neighboring vehicles based on multi-metric function of the SINR of the channel or RBs, and distance between the packet source and vehicles within the awareness range. This result illustrates that th proposed QR can reduce the load on the wireless channel and lead to less packet collisions.

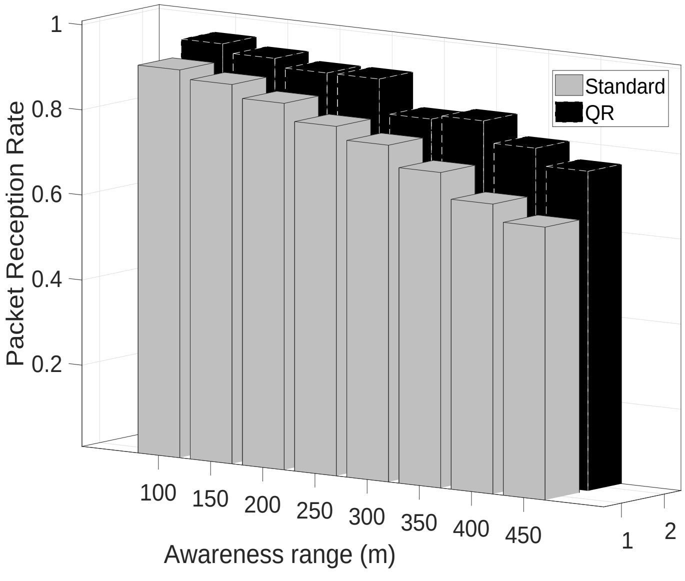

Fig. 4. Reception rate of dual interface vehicle according to the awareness range of proposed QR and standard relaying protocol

Another performance measure is the number of relaying events by vehicles. We compared the performance of standard relaying protocol with that of the proposed QR algorithm in Fig. 5. In this experiment, we simulated an error-prone wireless channel by setting the Standard Deviation (σ) of the Gaussian distributed random variable X to the range of 5 and 8. Note that, more error-prone wireless channel caused by a larger value of Standard Deviation (σ). When the error increases, the QR maintains the average number of relaying below 4 during 100 ms, but the standard protocol based on DSRC increases. At (σ)=8, the QR algorithm remains at 3 of the relaying event, while the Standard protocol's number of relaying event increases to 10. This is due to the fact the QR considers multi-metric for relay candidate selection and supports coexistence of both DSRC and C-V2X protocols. Note that, the higher the value of (σ)=8 leads to less relaying events. The reason is that a higher erroneousness wireless channel leads to more packet drops and these packets are not counted as relaying events. Thus, the QR algorithm significantly reduces the number of packet relaying. The high successful packet delivery and low relaying events, as compared to the standard relaying algorithm, makes proposed the QR algorithm feasible in heterogeneous vehicular scenarios. Furthermore, advances in Integrated Circuit (IC) manufacturing technology (for both DSRC and C-V2X) have made it feasible to embed the QR algorithm in hardware ICs. Thus, the practical implementation of the proposed QR algorithm from software and hardware perspectives promises to be feasible.

VI. CONCLUSION

In this paper, we review the DSRC and C-V2X radio access technologies and message relaying mechanisms that are specifically designed for homogenous or heterogeneous vehicular environments. Then, we illustrate the communication inability of vehicles embedded with different radio access technologies (DSRC or C-V2X) in heterogeneous vehicular networks. Further, existing relaying mechanisms fail to consider multi-metric for packet relaying and integration of radio technologies in a single vehicle. To overcome this limitation, we propose a QR algorithm, a quality aware packet relaying algorithm that exploits a combination of distance and SINR metrics in order to prioritize dual interface vehicles for next packet forwarder service. The QR algorithm defines a mechanism to support the coexistence of both radio access technologies in a dual interface vehicle. Hence, we expect that the new QR algorithm can tackle the communication inability among vehicles that are equipped with different radio access technologies. Extensive

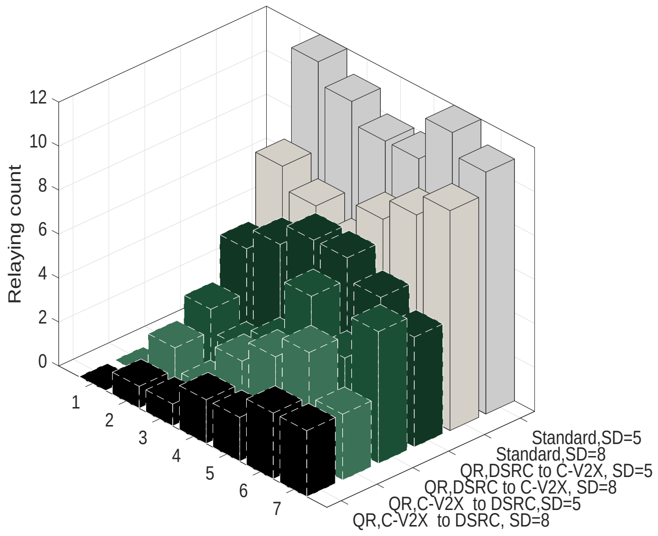

Fig. 5. Number of message relaying in one CAM lifetime of proposed QR and standard relaying protocol when Standard Deviation (SD) (σ) are 8 and 5

simulation results show that the performance gains obtained from the QR algorithm is an error-prone wireless channel.

REFERENCES

[1] IEEE-802.11-2010. Ieee standard for information technology telecommunications and information exchange between systemslocal and metropolitan area networksspecic requirementspart 11: Wireless lan medium access control (mac) and physical layer (phy) specications amendment 6: Wireless access in vehicular environments, ieee std 802 (11). (2019, January).

[2] E. ITS. vehicular communications; basic set of applications; part 2: Specification of cooperative awareness basic service.

[3] D. Flore, "Initial cellular v2x standard completed," *3GPP News, September*, 2016.

[4] G. W. paper. White paper on its spectrum utilization in the asia pacic region, www.5gaa.org, january,2018.

[5] G. Cecchini, A. Bazzi, B. M. Masini, and A. Zanella, "Ltev2vsim: An lte-v2v simulator for the investigation of resource allocation for cooperative awareness," in *Models and Technologies for Intelligent Transportation Systems (MT-ITS), 2017 5th IEEE International Conference on*. IEEE, 2017, pp. 80–85.

[6] M. Li, K. Zeng, and W. Lou, "Opportunistic broadcast of event-driven warning messages in vehicular ad hoc networks with lossy links," *Computer Networks*, vol. 55, no. 10, pp. 2443–2464, 2011.

[7] Q. Xiang, X. Chen, L. Kong, L. Rao, and X. Liu, "Data preference matters: A new perspective of safety data dissemination in vehicular ad hoc networks." in *INFOCOM*, 2015, pp. 1149–1157.

[8] S. Park, B. Kim, H. Yoon, and S. Choi, "Ra-ev2v: Relaying systems for lte-v2v communications," *Journal of Communications and Networks*, vol. 20, no. 4, pp. 396–405, 2018.

[9] K. Liu and K. Niu, "A hybrid relay node selection strategy for vanet routing," in *Communications in China (ICCC), 2017 IEEE/CIC International Conference on*. IEEE, 2017, pp. 1–6.

[10] G. Naik, J. Liu, and J.-M. J. Park, "Coexistence of dedicated short range communications (dsrc) and wi-fi: Implications to wi-fi performance," in *INFOCOM 2017-IEEE Conference on Computer Communications, IEEE*. IEEE, 2017, pp. 1–9.

[11] B. Kim, S. Kim, H. Yoon, S. Hwang, M. X. Punithan, B. R. Jo, and S. Choi, "Nearest-first: Efficient relaying scheme in heterogeneous v2v communication environments," *IEEE Access*, vol. 7, pp. 23 615–23 627, 2019.

[12] K. Z. Ghafoor, L. Kong, A. S. Sadiq, Z. Doukha, and F. M. Shareef, "Trust-aware routing protocol for mobile crowdsensing environments," in *IEEE INFOCOM 2018-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*. IEEE, 2018, pp. 82–87.

[13] M. Behrisch, L. Bieker, J. Erdmann, M. Knocke, D. Krajzewicz, and P. Wagner, "Evolution of sumos simulation model," *Traffic and Transportation Simulation*, vol. 64, 2014.

[14] T. Jämsä, J. Meinilä, P. Kyösti, D. Baum, H. E. Sallabi, T. Rautiainen, C. Schneider, M. Milojević, and P. Zetterberg, "Overview of winner channel modelling activities," in *15th WWRF meeting, Paris-France*, vol. 96, 2005.

[15] T. ETSI, "Intelligent transport systems (its); vehicular communications; basic set of applications; part 2: Specification of cooperative awareness basic service," *Draft ETSI TS*, vol. 20, pp. 448–451, 2011.

Kayhan Zrar Ghafoor (S'10-M'15-SM'19) is currently working as postdoctoral fellow at Shanghai Jiao Tong University. Before that, he was visiting researcher at University Technology Malaysia. He received the BSc degree in Electrical Engineering from Salahaddin University, the MSc degree in Remote Weather Monitoring from Koya University and the PhD degree in Wireless Networks from University Technology Malaysia in 2003, 2006, and 2011, respectively. He has published over 45 scientific/research papers in ISI/Scopus indexed international journals and conferences. Dr Kayhan authored two books named Cognitive Networks: Applications and Deployments and "Privacy and Cybersecurity in Smartcities". He is the receipt of the UTM Chancellor Award at 48th UTM convocation in 2012.

Mohsen Guizani (S'85-M'89-SM'99-F'09) received the bachelor's (with distinction) and master's degrees in electrical engineering, the master's and doctorate degrees in computer engineering from Syracuse University, Syracuse, NY, USA, in 1984, 1986, 1987 and 1990, respectively. He is currently a professor and the ECE Department chair at the University of Idaho. Previously, he served as the associate vice president of Graduate Studies, Qatar University, chair of the Computer Science Department, Western Michigan University, chair of the Computer Science Department, University of West Florida. He also served in academic positions at the University of Missouri-Kansas City, University of Colorado-Boulder, Syracuse University and Kuwait University. His research interests include wireless communications and mobile computing, computer networks, mobile cloud computing, security and smart grid. He currently serves on the editorial boards of several international technical journals and the founder and the editor-in-chief of Wireless Communications and Mobile Computing journal (Wiley). He is the author of nine books and more than 400 publications in refereed journals and conferences. He guest edited a number of special issues in IEEE journals and magazines. He also served as a member, chair and the general chair of a number of international conferences. He was selected as the Best Teaching Assistant for two consecutive years at Syracuse University. He received the Best Research Award from three institutions. He was the chair of the IEEE Communications Society Wireless Technical Committee and the chair of the TAOS Technical Committee. He served as the IEEE Computer Society Distinguished Speaker from 2003 to 2005.

Linghe Kong (S'09-M'13-SM'18) is currently a research professor in Shanghai Jiao Tong University. Before that, he was a postdoctoral fellow at Columbia University and McGill University. He received his PhD degree in Shanghai Jiao Tong University 2012, Master degree in TELECOM SudParis 2007, B. E. degree in Xidian University 2005. His research interests include wireless communications, sensor networks and mobile computing.

Halgurd S. Maghdid received the B.Sc. degree in software engineering from Salahaddin University, Erbil, Iraq, in 2004, the M.Sc. degree in computer science from Koya University, Koya-Erbil, Iraq, in 2006, and the Ph.D. degree in applied computing from the University of Buckingham, U.K., in 2016. He is currently serving as an Instructor in Koya University and part-time lecturer in Cihan University-Erbil. He has attended several IEEE, ACM, and Springer Conferences, and has publications in different journals, including the ACM Computing and Telecommunication Systems. His research focuses on mining technologies and techniques, smart algorithms in web applications, hybrid GNSS with other wireless/sensor technologies, including WiFi, Bluetooth, and inertial sensors to offer seamless outdoor-indoor smartphone localization.