Network-assisted Two-hop Vehicle-to-Everything Communication on Highway

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***Abstract*—Recently, both the industry and academy societies are trying to develop the next generation of cellular network (5G) to support vehicle-to-everything (V2X) communication. V2X communication can be used for information exchange among traffic participants and enable a cooperative driving to avoid accidents and also improve traffic efficiency. Compared with the services offered by the fourth generation (4G) cellular network, V2X communication is a new emerging service for 5G and it faces certain technical challenges. For instance, the fast movement of vehicles in highway scenarios requires a large V2X communication range which can not be guaranteed by a single-hop direct V2X communication. In this work, we propose a two-hop direct V2X communication scheme to improve packet transmission range and therefore enhance service reliability. In this scheme, a V2X packet will be broadcasted by its generator directly to all nearby users (UEs) over sidelink. Among these receivers that locate in the proximity of the transmitter, some receivers will be selected and act as relays to retransmit its received packet. In this way, receivers which locate inside the targeted communication range but far away from the transmitter have a possibility to receive the packet from two different transmission hops and therefore the packet reception ratio can be increased. In order to select the proper receivers as relays, it is proposed for the network to collect and exploit certain context information. In addition, an optimization problem is constructed to optimally adapt the resource allocation among different hops according to the real-time system conditions. Last but not least, a system-level simulation is implemented to evaluate the proposed two-hop direct V2X communication with different resource allocation options.**

I. Introduction

In recent decades, certain issues emerge with the development of transportation systems, such as traffic congestion, energy consumption, air pollution, and highway-related fatalities and injuries due to crashes [1]. Meanwhile, the development of Cooperative Intelligent Transport Systems(C-ITS) has the potential to facilitate cooperative driving applications, such as platooning (i.e., road-trains) and highly-automated driving. These cooperative driving applications can efficiently reduce travel time, fuel consumption, CO_2 emissions, and also improve road safety [2]. Since the C-ITS systems rely on timely and reliable exchange of information among traffic participants, governments and organizations over the world have recognized the needs to design the next generation cellular network (5G) to enable V2X communication.

In order to support V2X communication, 5G should be designed to offer a solution with a high degree of reliability and availability, in terms of latency, packet reception ratio (PRR) or other quality of service (QoS) parameters [2] [3]. A lot of work in the literature focus on the exploitation of direct V2X communication [4] [5] [6] where data packets are directly transmitted from a transmitter (Tx) to the receiver (Rx) without going through network infrastructure. For instance, the 3rd Generation Partnership Project (3GPP) proposes to use the PC5 air interface to facilitate the direct communication between the two ends of a V2X communication link [7] and this wireless link is usually referred to as sidelink. Since network infrastructure is not involved in the user-plane data transmission with direct V2X communication, packet transmission latency can be efficiently reduced. Moreover, European Telecommunication Standards Institute (ETSI) Intelligent Transport Systems (ITS) propose to apply IEEE 802.11p protocol as the air interface for the direct V2X communication [8]. In IEEE 802.11p protocol, there is no central entity (e.g., a base station (BS)) to coordinate the transmissions among different traffic participants and therefore a packet collision problem can not be avoided [9].

In the literature, the performance of V2X communication under cellular network control is restricted by using a single-hop direct V2X communication. It is worth noticing that the ultra-high reliability requirement of V2X communication in certain scenarios can not be fulfilled by a single-hop direct V2X communication [10]. For instance, in order to obtain a good perception of the environment and avoid accidents, a V2X communication range up to 1000 meters should be achieved in a highway scenario [10]. However, targeting at such a large V2X communication range, packets transmitted over a single-hop direct V2X communication will reach the Rxs far away from the Tx statistically with a bad signal quality. Due to the bad receiving signal quality, the Rxs have a high probability to not successfully receive the packets and thus the V2X communication reliability is decreased. To increase packet transmission range and increase V2X communication reliability, we propose a two-hop direct V2X communication over sidelink in this work. The packet transmission range is defined in this work as the range over which a packet can be successfully received.

At the beginning of this work, we illustrate the system model to facilitate V2X communication among different traffic participants by a two-hop direct V2X communication in Sect. II. Following that, an optimization problem is constructed in Sect. III to maximize packet transmission range by adapting resource allocation between the first hop and the second hop direct V2X transmissions. Afterwards, we introduce how to use context information to efficiently select relay UEs in Sect. IV and the procedures to collect the corresponding context information are also described. To evaluate the proposed technology, a system-level simulator is implemented and the corresponding assumptions are described in Sect. V. Based on these assumptions, numerical results are given and analyzed in Sect. VI to validate the proposed two-hop direct V2X communication. Finally, we draw the conclusion of our work in Sect. VII.

II. System Model of Applying Two-hop Direct V2X Communication

To improve traffic safety and efficiency, each vehicle on road needs to broadcast its information (e.g., geometrical location, mobility pattern and its sensed environment information) to other traffic participants within a certain radius. This radius is often referred to as the V2X communication range and its value is related to detailed service requirements. For instance, different vehicles can exchange their sensed environment information to obtain a collective perception of environment (CPE) and therefore efficiently avoid accidents [10]. In 3GPP, a direct V2X communication over sidelink can be used to facilitate this information exchange procedure [7]. In order to achieve the CPE and enable the fully automated driving in highway, a communication range of 1000 meters is required. However, the signal propagation loss can be quite high with such a large transmission distance. In addition, as the direct V2X communication over sidelink corresponds to a point-to-multi-point (M2MP) multicast transmission [7], the Tx of a single-hop direct V2X communication can not be aware of the channel conditions to all Rxs. Therefore, it can not be guaranteed that the transmission signal arrives at all Rxs with a good quality for successful packet decoding. To overcome this problem, Fig. 1 illustrates the proposed two-hop direct V2X communication over sidelink. This technology is used in this work to increase packet transmission range and therefore enhance the V2X service reliability. As can be seen from this figure, data packets are generated at a vehicle Tx and it broadcast the data packets to other vehicles over sidelink. However, due to a large V2X communication range requirement, packets directly transmitted by the Tx can not be successfully received by the Rxs far away from the Tx. This problem has a direct impact on the PRR which is calculated as the ratio of the number of successfully received packets to the number of packets which should be received. In addition, the direct transmission link between the packet generator and a Rx is referred to as the first hop in this work. After transmission over the first hop, a vehicle Rx which successfully receives the packets from the first hop can be triggered as a relay and broadcast the received packets to other Rxs. In this way, the Rxs who did not successfully receive the packets from the first hop can try to receive the packets broadcasted by the relay vehicle. The transmission link between the relay vehicle and its Rx is called as the second hop in this work. In order to receive a packet, a Rx needs to successfully receive this packet from at least one of the two hops.

To enable the proposed two-hop direct V2X communication scheme, there are some questions to be answered, as stated below.

- How many vehicles should act as relays for a packet transmission? - The number of relay vehicles for each packet transmission needs to be reasonable. A large number of relay vehicles will introduce either additional interference or request more dedicate spectrum resource, depending on whether the different relay vehicles will simultaneously use the same resource to transmit their packets.
- Which vehicle should act as a relay? - The relay vehicles for each packet transmission should be carefully chosen. If a relay vehicle is too closed to the Tx, the coverage extension by applying the two-hop direct V2X communication over sidelink can be limited. In the other case, if a relay vehicle is too far away from the Tx, there is a high probability that it will not be able to successfully receive the packet from the first hop. As the PC5 interface for direct V2X communication is connection-less, there will be no feedback message from a Rx to the Tx. Therefore, the Tx is not aware whether a packet is received by a relay vehicle successfully or not.
- How to allocate radio resource among diffe[illegible] mission hops? - Since radio resource is requ[illegible] second hop direct V2X communication, th[illegible] allocation among different hops plays a criti[illegible] system performance.

ch6 resource allocation

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III. Transmission Range Maximization for Two-hop direct V2X communication

As mentioned before, the two-hop direct V2X communication over sidelink can be applied to extend packet transmission range. In order to maximize the overall packet transmission range, the amount of resource allocated to different hops should be adapted by the network in an efficient way. Thus, we can construct a packet transmission range maximization problem, as:

$$\begin{aligned}
&\textbf{maximize}_{(BW_1, BW_2)} && D(BW_1) + D(BW_2), && (1)\\
&\textbf{subject to} && BW_1 + BW_2 \leq BW, && (2)\\
& && BW_1 \geq 0, && (3)\\
& && BW_2 \geq 0. && (4)
\end{aligned}$$

Eq. (1) represents the optimization problem on how to maximize the transmission range by allocating bandwidth resource (i.e., BW_1 and BW_2) to different hops. The function $D(BW)$ is referred here as the transmission range function and it is used to calculate the packet transmission range if a bandwidth of BW is assigned to a direct V2X communication hop. Thus, $D(BW_1)$ and $D(BW_2)$ stand for the packet transmission ranges for the first hop and the second hop, respectively. In addition, BW_1 and BW_2 correspond to the bandwidth resources allocated to the first hop and the second hop. In Eq. (2)-(4), constraint functions are presented to show that the summation of the bandwidth resources of the two different hops should not exceed the overall available bandwidth, given that the sets of resources allocated to two different hops are orthogonal to each other.

In order to derive the transmission range function $D(BW)$, we use a general formula to calculate pathloss value, as:

$$PL = A \cdot d^{\gamma}. \quad (5)$$

A is a constant number and γ is the pathloss exponent whose value is related with the concrete communication environment. In addition, d represents the signal propagation distance between a Tx and its Rx. Thus, for a packet transmitted by the j-th Tx, we can further calculate the received signal power at the i-th Rx, as:

$$P_{Rx}(i,j) = \frac{P_{Tx}}{A \cdot d(i,j)^{\gamma}}. \quad (6)$$

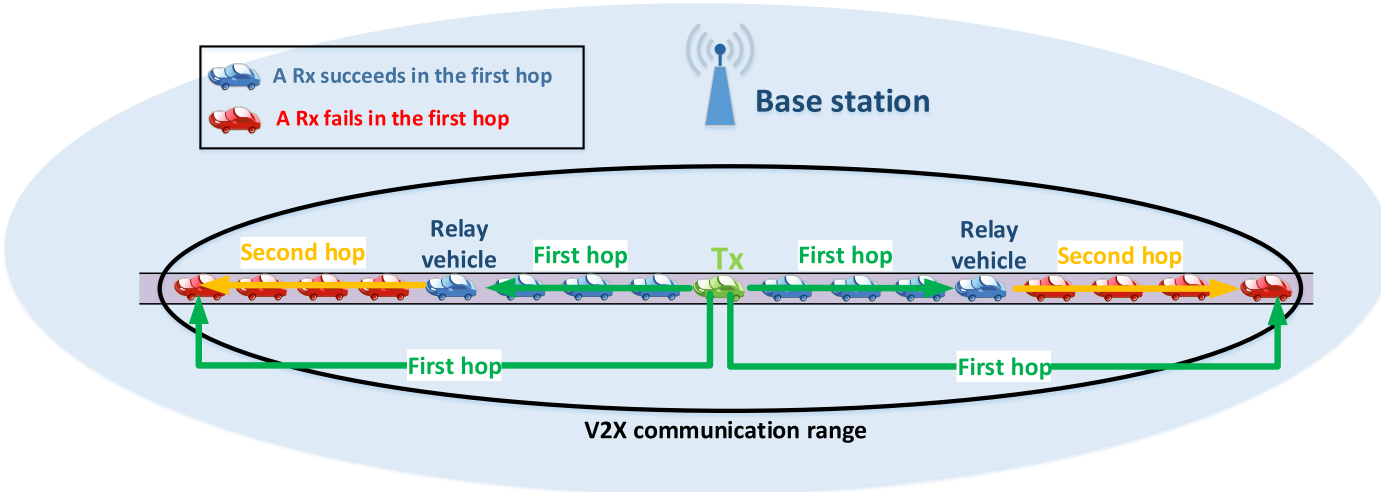

Fig. 1: Example of applying the two-hop direct V2X communication to enable local information exchange among traffic participants on highway

$d(i,j)$ represents the distance between the j-th Tx and the i-th Rx. And P_{Tx} is the transmission power. Since we do not inspect on an adaptive power control scheme in this work, we assume that all Txs use same transmission power per resource block. Further, the signal-to-interference-plus-noise-ratio (SINR) experienced at the i-th Rx can be written as:

$$\mathrm{SINR}(i,j) = \frac{P_{Tx}/[A \cdot d(i,j)^{\gamma}]}{\sum_{m \neq j}\{P_{Tx}/[A \cdot d(i,m)^{\gamma}]\} + \sigma^2}, \quad (7)$$

where $m \neq j$ represents the interfering Txs that transmit their packets over the same resource as the j-th Tx and σ^2 is the noise power. For simplification, $I(i,j)$ is used to present the interference power, if the i-th Rx is trying to receive a packet from the j-th Tx, as

$$I(i,j) = \sum_{m \neq j}\{P_{Tx}/[A \cdot d(i,m)^{\gamma}]\}. \quad (8)$$

Thus, Eq. (7) can be simplified as

$$\mathrm{SINR}(i,j) = \frac{P_{Tx}/[A \cdot d(i,j)^{\gamma}]}{I(i,j) + \sigma^2} \quad (9)$$

In order to successfully receive a packet from the j-th Tx, the SINR value experienced by the i-th receiver should be better than a threshold value. Theoretically, the SINR threshold value can be calculated from the famous Shannon's capacity limit equation, as

$$C = BW \cdot log_2(1 + \mathrm{SINR}). \quad (10)$$

Eq. (10) provides us a theoretical limit on the capacity C over a bandwidth of BW. Thus, the SINR threshold for successfully receiving a packet can be calculated as:

$$\mathrm{SINR}(i,j) \geq 2^{(C/BW)} - 1. \quad (11)$$

By using Eq. (7) to represent the left hand side of Eq. (11), the maximal distance at which a packet can be successfully received (i.e., packet transmission range over a single hop) can be derived as

$$D(BW) = \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{[I(i,j) + \sigma^2] \cdot (2^{C/BW} - 1)}}. \quad (12)$$

As can be seen from Eq. (12), the transmission range of a single-hop direct V2X communication over sidelink is not only related with the allocated resource BW, but also related with the interference power $I(i,j)$. The concrete interference power is impacted by the radio resource management scheme executed at the network side and further details will be given in Sect. IV-B. In addition, please note that the value of system capacity (i.e., C in Eq. (12)) should be derived from a real-time V2X communication scenario. For instance, if N vehicles in total are in coverage of a BS and each vehicle tries to broadcast a packet with a size of S bits periodically with a frequency of R packets per second, then the system capacity can be calculated as

$$C = S \times R \times N \text{ bits/s}. \quad (13)$$

With the help of Eq. (12), the objective function given by Eq. (1) can be re-written as

$$D(BW_1) + D(BW_2) = \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{[I(i,j) + \sigma^2] \cdot (2^{C/BW_1} - 1)}} + \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{[I(n,i) + \sigma^2] \cdot (2^{C/BW_2} - 1)}}. \quad (14)$$

Eq. (14) represents the maximal transmission range of the proposed two-hop direct V2X communication. And it refers to the case that the i-th Rx acts as a relay to forward packets from the j-th Tx to the n-th Rx.

IV. Context-aware radio resource management

As mentioned in the last part of Sect. II, there are certain aspects to be considered when applying the two-hop direct V2X communication over sidelink. In this section, we will provide more insights in these aspects.

A. *Context-aware selection of relays*

From the efficiency perspective, relay selection procedure should be executed and adapted w.r.t. the concrete application scenario. Thus, some context information (e.g., geometrical location of nearby traffic participants, estimation of PRR, and environment information) can be used to optimize system performance. Therefore, a relay selection procedure taking account of context information contains two technical components, as

- selection of relay UE(s);
- collection of the useful context information.

Before a packet is transmitted over the first hop direct V2X communication, the Tx needs to locally select the Rxs which should act as relays. The target of this relay selection procedure is to serve the most Rxs which face difficulty to successfully receive packets from the first hop. Meanwhile, the number of relays can not be arbitrarily large, in order to control the mutual interference and reduce the consumed radio resource. However, if the number of relays is too low, certain Rxs will not be in the proximity of any relay and therefore they can not successfully receive the packet. In this work, since we inspect on the two-hop direct V2X communication in a highway scenario and potential Rxs for traffic-related packets are either in the front side or in the back side of the Tx, two relay vehicles will be selected to perform the second hop transmission for each packet, as shown in Fig. 1. The following steps take place in a Tx to select relays in this work.

1) The Tx searches for all Rxs which have an estimated PRR higher than a pre-defined threshold value $\mathrm{Prob}^{\mathrm{threshold}}$;
2) Among these Rxs, the Rx with the largest distance to the Tx at each side (i.e., eith front side or back side) will be assigned as a relay.

In this work, a value of 99% is set for $\mathrm{Prob}^{\mathrm{threshold}}$. As inputs for the relay selection procedure, some context information should be collected and presented at each V2X Tx. For instance, in each V2X data packet, the real-time location and mobility pattern of its generator are embedded. Thus, a V2X UE can receive and cache the information of the nearby traffic participants to predict their geometrical location in future. In addition, a mapping table from the packet transmission distances to the estimated PRRs is required, in order to check which Rxs have a high probability to receive a packet from the first hop and therefore can act as relays. The transmission of cooperative awareness messages (CAMs) can contribute to obtain this information. Since the CAM messages are periodically transmitted, a V2X UE can record the status of the receptions (i.e., successful reception or not) of the CAM messages from a specific Tx. As location information of the Tx is embedded in the CAM message, the V2X UE can calculate distance from the Tx to itself. Based on these information, the mapping table between transmission distances and estimated PRRs can be created. It is also worth noticing that modulation and coding schemes (MCSs) with different spectral efficiency are applied in LTE and each MCS provides different robustness. Thus, the mapping table should be created w.r.t. different MCSs. For example, if there are totally 15 optional MCSs and the estimated PRRs should be collected within a communication range of 1000 meters and with a resolution of 5 meters, then the mapping table should have dimensions of 15×200.

B. Radio resource allocation between two different hops

As mentioned previously, the resource allocation between the first hop and the second hop transmissions should be adapted to increase the packet transmission range. In Sect. (III), the objective function is constructed in Eq. (14) and the constraint functions are given in Eq. (2) - Eq. (4). In Eq. (14), it is reflected that the maximal transmission range is related with the sum of the interference power and the noise power. However, the interference power is not a constant number and it is related with the positions of the Txs which transmit on the same radio resource. Currently, there are two approaches (i.e., V2X sidelink transmission mode 3 and V2X sidelink transmission mode 4) in LTE release 14 [11] to allocate radio resource to a V2X Tx. In sidelink transmission mode 3, the transmission resource is scheduled by network and therefore network can allocate the same radio resource to different Txs if the minimal distance between any two of them is larger than certain threshold. In mode 4, a V2X Tx autonomously selects a resource from a resource pool which is either configured by network or pre-configured in the user device. In addition, network can divide the whole area into different zones and assign a resource pool to each specific zone. The mapping information between a geometrical zone and its resource pool will be broadcasted in the system information block (SIB) 21 [12]. Thus, network can assign the same resource pool to different zones if they are separated with a distance larger than a threshold. The distance threshold value for both modes should be determined in a way that the mutual interference power is low enough. To obtain an estimation on interference power, network needs to be aware of the pathloss model. As reference signals are embedded in packets transmitted over PC5 for channel estimation at a Rx, the Rx can estimate the pathloss values from different Txs. Since location information of these Txs are also carried by thees transmitted packets, the Rx can also calculate the transmission distances from the Txs and therefore obtain the pathloss model. Afterwards, each V2X UE can report its formulated pathloss model to the network. At network side, it can utilize this information to calculate the distance threshold value so that mutual interference is under control.

In case the distance threshold value is set large enough, the mutual interference power can be much lower than the noise power. Thus, the objective function in Eq. (14) can be simplified to:

$$D(BW_1) + D(BW_2) \approx \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{\sigma^2 \cdot (2^{C/BW_1} - 1)}} + \frac{\sqrt[\gamma]{P_{Tx}/A}}{\sqrt[\gamma]{\sigma^2 \cdot (2^{C/BW_2} - 1)}}. \quad (15)$$

With the constraint functions in Eq. (2) - Eq. (4), the objective function in Eq. (15) will achieve the maximal value if $BW_1 = BW_2$.

V. Simulation Assumptions

In order to evaluate the proposed two-hop direct V2X communication over sidelink, a system-level simulator is implemented in this work. In this section, we highlight the detailed simulation assumptions with a focus on V2X application. Other system parameters (e.g., noise power) are aligned with the ITU-R simulation guideline document in [13].

A. Environment model

A two-directional highway with a length of 20 kilometers is considered. In each direction, there are three lanes.

B. Deployment model

BSs are deployed with an inter-site-distance (ISD) of 6 kilometers alongside the highway to provide control-plane connections to V2X UEs. The V2X sidelink transmission mode 3 is used and it operates on a carrier frequency of 2 GHz. Thus, transmission resource for direct V2X communication is scheduled by network. In addition, we use two options for inter-vehicle-distance (IVD) (i.e., 10 meters and 15 meters) and each vehicle has a length of 5 meters. On top of each vehicle, an antenna is installed at a height of 1.5 meters with a constant transmission power density of -46 dBm/Hz (i.e., corresponding to a transmission power of 24 dBm within a 10 MHz bandwidth). Moreover, 1×2 antennas configuration (i.e., receiver diversity) is exploited for the direct V2V communication over sidelink.

C. Channel model

Hata model is used to calculate the pathloss values for direct V2X communication.

D. Traffic model

Packets with a size of 212 bytes are generated with 10 Hz periodicity for each UE [14] and packets should be delivered to all traffic participants located within a radius of 1000 meters [10].

E. Modulation and coding schemes

Since there are different MCSs used in LTE network, the network needs to configure the appropriate MCSs for both the first and the second hops. And an appropriate MCS should meet the system capacity requirement and provide a good robustness. Thus,

$$SE \geq \frac{C}{BW}, \tag{16}$$

where SE, C, and BW represent the spectral efficiency of a MCS, the system capacity calculated in Eq. (13), and the allocated bandwidth, respectively. Additionally, since a MCS with a higher spectral efficiency provides a worse robustness, the network should apply the MCS which has the lowest spectral efficiency while fulfills the condition shown in Eq. (16).

VI. Numerical Results

In this section, system performances of different V2X communication schemes are provided w.r.t. PRRs. In Tab. I, the IVD is set to be 10 meters and the PRRs of different resource allocation schemes are given. BW_1 and BW_2 are the amount of resources allocated to the first hop and the second hop. Please note that, there are two relay vehicles for the second hop transmission of each packet and the two relay vehicles simultaneously use the same resource for their second hop transmission. In case no resource is allocated to the second hop, then only the single-hop direct V2X communication is used. From this table, we can see that the single-hop direct V2X communication have low PRRs, since the communication range requirement of 1000 meters can not be fulfilled. An efficient approach to increase the transmission range of single-hop communication is to increase the system bandwidth. As shown in Eq. (16), a larger system bandwidth can reduce the required spectral efficiency of the transmission technology. Thus, a MCS with a better robustness can be applied in this case and the packet transmission range can be improved. Alternatively, the proposed two-hop direct V2X communication can utilize the spectral resource in an efficient manner. For instance, a single-hop direct V2X communication with a 10 MHz system bandwidth can achieve a PRR of 56%. However, if we apply the two-hop direct V2X communication with the same amount of bandwidth, the transmission range can be efficiently improved. In this approach, the 10 MHz bandwidth is divided into two subsets and they are not overlapped in frequency domain. As we can see, an equal resource allocation between the two different hops (i.e., 5 MHz for the first hop and another 5 MHz for the second hop) provides us the best performance and it can increase the PRR from 56% in the single hop case to 77.72%. This is due to the fact that the interference power in the considered scenario is much lower than the noise power. And this observation validates our mathematical analysis provided in Sect. IV-B. Please also note that the PRR (i.e., 77.72%) in the two-hop transmission scheme with equal resource allocation between different hops (i.e., 5 MHz for the first hop and another 5 MHz for the second hop) are slightly lower than two times of the PRR (i.e., 39.67%) in the single-hop transmission scheme with 5 MHz bandwidth. The reason is that the strongest interference for the second-hop transmission is from the other relay vehicle which transmits the same packet. The distance between two relay vehicles transmitting the same packet has a value lower than two times of the communication range (i.e., 2000 meters in the considered scenario). However, the interference for the single-hop transmission is from a Tx which is served by another BS and the distance between two neary Txs using the same resource for the first hop has statistically an average value the same as the ISD (i.e., 6000 meters in the considered scenario). Therefore, a higher interference power density for the second hop can be experienced at a Rx than the first hop and the transmission range of the second hop is slightly lower than that of the first hop, though the same amount of resources are allocated to the two different hops.

In Tab. II, we increase the IVD from 10 meters to 15 meters and therefore less vehicles will be deployed on the highway, compared with the previous case. Since a lower number of vehicles introduces a lower system capacity, a MCS with better robustness can be applied. This is the reason why the PRRs in Tab. II are higher than those in Tab. I. In addition, the PRR of using singel-hop direct V2X communication with 10 MHz bandwidth is 71.28% and it can be increased to 100% by the two-hop direct V2X communication scheme with equal resource allocation to different hops (i.e., 5 MHz for the first hop and another 5 MHz for the second hop). As a compromise, the packets successfully received from the second hop will experience a higher end-to-end (E2E) latency than the packets received from the first hop. However, since the Rxs that fail in the receptions from the first hop are statistically located far away from the Tx, certain E2E latency increase is tolerable.

In Tab. III, different resource allocation schemes for the second hop are inspected. The total bandwidth is 20 MHz and 10 MHz from that is allocated to the first hop. In the first scheme,

TABLE I: System performances of different resource allocation schemes (inter-vehicle-distance is 10 meters)

BW_1	BW_2	PRR (IVD = 10 meters)
5 MHz	0 MHz	39.67%
6 MHz	0 MHz	45.74%
8 MHz	0 MHz	54.26%
10 MHz	0 MHz	56%
5 MHz	5 MHz	77.72%
6 MHz	4 MHz	77.31%
8 MHz	2 MHz	70.90%

TABLE II: System performances of different resource allocation schemes (inter-vehicle-distance is 15 meters)

BW_1	BW_2	PRR (IVD = 15 meters)
5 MHz	0 MHz	54.26%
6 MHz	0 MHz	57.54%
8 MHz	0 MHz	67.02%
10 MHz	0 MHz	71.28%
5 MHz	5 MHz	100%
6 MHz	4 MHz	99.82%
8 MHz	2 MHz	84.93%

10 MHz bandwidth is allocated to the second hop and the two relays transmit the same packet over the same resource. Therefore, the strongest mutual interference for the second hop is introduced by the other relay which transmits the same packet. In the second scheme, the 10 MHz bandwidth is also allocated to the second hop but the two relays transmitting the same packet will use different sub-bands (i.e., 5 MHz for one relay and another 5 MHz for the other one). Thus, there is no mutual interference between the two relays transmitting the same packet. Compared with the first scheme, though the interference power of the second hop is now lower, there is less resource allocated to the second hop transmission and a MCS with a worse robustness needs to be used. Thus, the PRR in the second scheme has a lower value than the first resource allocation scheme.

VII. Conclusion

In this work, we have proposed a two-hop direct V2X communication over sidelink to increase the packet transmission range of traffic-related data packets. As some V2X communication applications require a large communication range which a single-hop direct V2X communication can not achieve, an increased packet transmission range by the proposed two-hop transmission technology can contribute to a higher packet reception ratio than the single-hop transmission scheme. To exploit the two-hop direct V2X communication in an efficient manner, we have provided detailed analysis of the resource allocation scheme. In addition, context information have been collected and taken into account to select proper relays. In order to evaluate the proposed technology, we have also implemented a system-level simulator to inspect on the performance of different V2X communication schemes in a highway scenario. The simulation results have shown the performance improvement by applying the two-hop direct V2X communication over sidelink with the same amount of spectral resource as for single-hop direct V2X communication. In addition, the results have also shown that the performance of the two-hop direct V2X communication can be optimized by adapting the resource allocation for different hops.

TABLE III: System performance comparison of different resource allocation schemes for the second hop transmission (inter-vehicle-distance is 10 meters)

BW_1	BW_2	PRR (IVD = 15 meters)
10 MHz	10 MHz	99.98%
10 MHz	5 MHz + 5 MHz	95.90%

VIII. Acknowledgment

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References

[1] Harding, John, et al. *Vehicle-to-vehicle communications: Readiness of V2V technology for application*, No. DOT HS 812 014. 2014.

[2] ICT-317669 METIS, Deliverable 1.1 Version 1, *Scenarios, requirements and KPIs for 5G mobile and wireless system*, April 2013.

[3] A. Osseiran et al., *The Foundation of the Mobile and Wireless Communications System for 2020 and Beyond: Challenges, Enablers and Technology Solutions*, 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), Dresden, 2013, pp. 1-5.

[4] Vinel, A. *3GPP LTE Versus IEEE 802.11p/WAVE: Which Technology is Able to Support Cooperative Vehicular Safety Applications* Wireless Communications Letters, IEEE , vol.1, no.2, pp.125,128, April 2012.

[5] Araniti, G.; Campolo, C.; Condoluci, M.; Iera, A.; Molinaro, A. *LTE for vehicular networking: a survey* Communications Magazine, IEEE , vol.51, no.5, pp.148,157, May 2013.

[6] Ji Lianghai et al., *Direct vehicle-to-vehicle communication with infrastructure assistance in 5G network*, 2017 16th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net), Budva, 2017.

[7] 3GPP document, TS 23.303, *Proximity-based services (ProSe); Stage 2*, June 2017.

[8] IEEE document, 802.11p, *Amendment 6: Wireless Access in Vehicular Environments*, July 2010.

[9] Vinel, Alexey, *3GPP LTE versus IEEE 802.11 p/WAVE: Which technology is able to support cooperative vehicular safety applications?*, IEEE Wireless Communications Letters 1.2 (2012): 125-128.

[10] 3GPP document, TR 22.886, *Study on enhancement of 3GPP support for 5G V2X services*, March 2017.

[11] 3GPP document, TS 36.213, *Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures*, September 2017.

[12] 3GPP document, TS 36.300, *Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2*, September 2017.

[13] Itu, R, *ITU-R M. 2135: Guidelines for evaluation of radio interface technologies for IMT-Advanced*, 2008.

[14] 3GPP document, R1-155411, *TP for TR 36.885 evaluation assumption*, RAN1, RAN1#82-BIS, Malm, Sweden, 5th-9th October 2015.