Reliable Groupcast For NR V2X

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ABSTRACT With the development of autonomous vehicles, the high reliability and low latency vehicular communication technologies have become more critical. The Third Generation Partnership Project (3GPP) specifies the sidelink (SL) transmission based on New Radio (NR), aiming to meet stringent vehicle-to-everything (V2X) requirements. Compared with Long Term Evolution (LTE) V2X, which only supports broadcast use cases, NR V2X also supports unicast and groupcast. The groupcast operation allows the transmitter to communicate with multiple receivers in the same group at once. In general, the group size for vehicles is limited due to the high-reliability requirement. In this paper, we present reliable blind retransmission for NR V2X groupcast. We improve the groupcast transmission reliability by assigning the proper retransmission user equipment (UE). This paper proposes a retransmission UE assignment. We formulate a retransmission UE selection problem to maximize the group packet reception ratio (GPRR) for NR V2X distributed groupcast. The simulation results show that the proposed retransmission method improves the V2X groupcast in terms of GPRR, packet inter-reception time (PIR), and the available group size.

INDEX TERMS V2X, New Radio, Resource Allocation, Groupcast

I. INTRODUCTION

The Third Generation Partnership Project (3GPP) specified the support of Long Term Evolution (LTE) vehicle-to-everything (V2X) for various vehicular use cases since release 14. The main application of LTE V2X is for the connected vehicles to exchange cooperative awareness message (CAM) and decentralized environmental notification message (DENM), which improve driving safety. Since these two messages are disseminated to nearby vehicles periodically, LTE V2X supports the periodic and broadcast scenario to meet these requirements.

With the development of autonomous vehicular technologies, studies have paid more attention to some advanced vehicular use cases [1]. 3GPP classifies the advanced vehicular use cases into four classes: vehicle platooning, extended sensors, advanced driving, and remote driving. These advanced V2X use cases require high reliability and low latency communications. To meet the stringent service requirements, 3GPP specified New Radio (NR) V2X since release 15 as the compliment of LTE V2X [2]. Unlike LTE V2X, which only supports broadcast scenarios to disseminate CAM and DENM, NR V2X also supports unicast and groupcast scenarios. Unicast allows the transmitter to communicate with a specific receiver, whereas the groupcast allows the transmitter to communicate with a vehicle group [3]. Since some use cases are nature to be groupcast such as vehicle platooning, this scenario is an essential component of NR V2X.

In LTE and NR V2X, resource management includes two modes: centralized and distributed. In centralized resource allocation, transmission resources are configured by the base station. Since this centralized mode involves the base station, it only supports the in-coverage scenario. On the other hand, transmission resources are configured by each transmitter in the distributed resource allocation. The distributed mode allows vehicles to schedule the transmission resources without the base station autonomously. Since the base station controls the centralized resource allocation, this mode has higher reliability than the distributed. In contrast, because centralized resource allocation requires requesting the base station’s resources, the initial transmission latency is higher.

In order to improve reliability, V2X supports two types of retransmission: blind retransmission and feedback-based retransmission. For the blind retransmission, the transmitter transmits several duplicated packet. For the feedback-based retransmission, the transmitter retransmits when the receiver sends Negative-Acknowledgment (NACK). In general, blind retransmission consumes more resources than feedback-based retransmission because it sends duplicated
packet no matter the initial transmission success. When the latency requirement is not strict for V2X services, feedback-based retransmission is a resource-efficient operation to ensure transmission reliability. When the latency requirement is strict, the time gap between initial transmission and retransmission may exceed the time constraint. In this case, although consuming more resources, blind retransmission is an efficient way to maintain high reliability and low latency simultaneously. However, the effectiveness of retransmission is limited when the channel status between transmitter and receiver is bad. To solve this problem, we propose the retransmission UE to help the transmitter to retransmit. This paper focuses on the blind retransmission for the groupcast scenario, which is the vital technology to support advanced V2X use cases with high reliability and low latency requirement.

A. RELATED WORK

Several recent works discussed the enhancement of various V2X services. Some research focuses on resource allocation improvement on the system performances. An implicit autonomous resource selection for Device-to-Device Communications (D2D) is provided to achieve low data collision ratio and high throughput [4]. A cluster-based resource allocation management scheme is proposed to maintain throughput, packet reception ratio, and latency [5]. The cluster head selection algorithm is applied to improve the sum rate of cellular users. Consider the scenario of Mobile Edge Computing (MEC) assisted cellular V2X networks, the transmission resource allocation and task offloading are formulated as a non-cooperative game, aiming to maximize throughput [6]. By adding the payment on interference, transmission power control is distributedly performed. Another resource allocation research discusses the group-based V2X communications with different Quality of Service (QoS) requirements [7]. With the slowly varying large-scale channel parameters, the cloud-based SL resource management can solve the QoS requirement-aware optimization problem. A reliable D2D framework is proposed for two-hop unmanned aerial vehicles [8]. Different feedback mechanisms for two-hop UAV communications are compared to enhance the performance of resource allocation.

Since the high reliable requirement of V2X services, some research aims to meet the reliability demand. In order to provide better reliability for broad range V2X communications, a multi-radio-access technology is applied [9]. This paper proposed that packets are transmitted on both Sidelink and traditional Uplink and then Downlink path. A novel group retransmission scheme is proposed to minimize the retransmitted data [10]. By only transmitting parity code blocks generated by the outer code and using shared resources for HARQ feedback, the amount of retransmission resources reduces. Considering the scenario of downlink ultra-reliable low-latency communication (URLLC) V2X data may be blocked, data dissemination can be improved with the user cooperation [11]. When the receivers fail to receive a packet, it requests retransmission from the neighbor user equipment (UE) in the same group. An important issue for moving vehicle communications is handover. A group-based SL communications for seamless handover is proposed to decrease the handover failure ratio. V2X service continuity can be increased by assigning the main leader and sub-leader in the sidelink group [12].

Some studies pay attention to the multicast/groupcast scenario for V2X services. For the V2X services based on LTE Multimedia Broadcast/Multicast Service (MBMS), the high end-to-end setup latency fails to meet the latency requirement of V2X services. A preconfigured multicast group based on geographical position is proposed to solve the high End-to-End (E2E) setup latency problem [13]. Utilizing the beamforming technologies, 5G Communication Automotive Research (5GCARe) shares the concept to improve broadcast and multicast V2X services [14]. In this paper, adaptive and robust beam management is proposed to guarantee the fast transmission of localized data traffic, local data V2X radio path is configured over the Uu interface. Another research combines the V2X broadcast/multicast services with the non-orthogonal multiple access (NOMA) technologies to optimize the transmission between the roadside unit (RSU) and vehicles. A power allocation optimization problem for two-phase transmission is formulated to achieve high data rate [15]. In this scenario, the first phase is the broadcast scenario between the base station and RSU, and the second phase is the multicast scenario between RSU and vehicles. Two new algorithms are proposed for cluster-based multicast vehicular networks to share the safety message among the edge nodes [16]. Combining the inter and intracluster safety packet distribution and the cluster-based multicast power adaptation, low transmission delay, and high packet delivery ratio are achieved. Under the HARQ-based retransmission operation, a study presents the groupcast scheme to minimize the time consumption and maximize the groupcast success ratio [17]. The paper introduces the retransmission UE concept to enhance the vehicle platooning use case to improve the performance. The authors provide a Markov decision process to solve the time resource allocation and retransmission UE selection problem. Unlike the above-related works, we focus on the blind retransmission for NR V2X groupcast scenario in this paper. For some low latency use cases, the time gap between initial transmission and retransmission may not meet this requirement. As a result, distributed blind retransmission is suitable for this scenario. Our contributions can be summarized in next subsection.

B. CONTRIBUTION AND ORGANIZATION

We provide an introduction about the distributed resource allocation for NR V2X, which is an essential feature of 5G. The component of sidelink mode 2 includes the channel multiplexing, resource selection procedure, resource reservation, and its related control information. In the latest 3GPP release 16, NR V2X also supports the blind retransmission to meet the requirements. Unlike the LTE V2X, which only supports...
broadcast, the NR V2X supports unicast and groupcast. This paper provides our design about the reliable blind retransmission for NR V2X groupcast and a solution for high reliability and low latency requirements. Our main idea is that in a groupcast group, a transmitter can start an initial transmission of a TB and assign a retransmission UE from its receiver. If the retransmission UE successfully receives the TB, it can perform the retransmission. Our simulation shows that the proposed reliable blind retransmission scheme outperforms the NR V2X. As far as we know, this is the first paper that discusses the design of reliable blind retransmission for NR V2X groupcast.

In the NR V2X groupcast scenario, one target evaluation performance is groupcast packet ratio reception (GPRR). In this paper, we formulate the retransmission assignment problem, which aims to increase GPRR performance. We compare two different objective functions and other retransmission schemes. We conduct a simulation to show that our proposed retransmission scheme increases the GPRR.

II. NR V2X MODE 2 STRUCTURE AND PROCEDURE
A. SIDELINK PHYSICAL LAYER STRUCTURE
There are three physical channels NR V2X: physical sidelink control channel (PSCCH), physical sidelink shared channel (PSSCH), and physical feedback sidelink channel (PSFCH). Fig. 1 shows the multiplexing between PSCCH, PSSCH, PSFCH. The PSCCH is used to transmit sidelink control information (SCI), including reserved resources, reference signal patterns, and other essential information for decoding. The PSSCH is used to transmit data payload and partial signal patterns, and other essential information for decoding. The PSFCH is the feedback channel utilized to transmit Acknowledgment (ACK) or NACK message. When the receiver successfully decodes the packet, it transmits an ACK message to the transmitter on the PSFCH. The candidate resources for PSFCH are associated with the first subchannel of PSSCH.

![FIGURE 1: Sidelink Physical Layer Structure](image)

B. MODE 2 RESOURCE ALLOCATION PROCEDURE
NR V2X mode 2 is a distributed resource allocation and allows UEs to select transmission resources autonomously. The vehicles are assumed to keep on sensing and blind decoding on all sub-channels. For the vehicle initializes a sidelink transmission, the operation of NR V2X mode 2 includes two steps:

- Step 1: When the transmitter has the packet to send but no resource to use, it excludes resources based on the sensing result in a sensing window.
- Step 2: The vehicle reports the remaining resources to the MAC layer. The MAC layer will select the transmission resources randomly from these candidate resources.

The sensing information includes blind PSCCH decoding and RSRP measurement. If the transmitter decodes the SCI in PSCCH, it acknowledges the reserved resources corresponding to this PSCCH. These reserved resources are excluded in resource allocation step 1. For blind retransmission, resource reservation indication is as shown in Fig. 2. The selection of resources for retransmission are randomly selected from the candidate resource sets, which is the same as the resource allocation mode 2 procedure. The retransmission resources should meet the packet latency requirements. Note that the transmission and its future reservation shown in Fig. 2 represent periodic message transmission. There is no future periodic reservation for aperiodic traffic. There is one period of time difference between the next resources used and the current resources. The SCI in PSCCH carries the period value, and it provides information on reserved resources for future transmission. When the vehicle decodes an SCIs in the sensing window subframe $t$, it can speculate the $(t+n\cdot Period)$ subframe within the same subchannel are occupied by the SCI transmitting UE. For each TB transmission, the initial transmission can reserve at most other two resources for retransmission. These reserved resources for retransmission and future retransmission are also indicated in the SCI. Resources for retransmission are also excluded in the resource allocation step 1. Since the reserved resource information is the same in initial transmission and retransmission, the other sensing UE can exclude these resources as long as one of these SCI is decoded.

It is worth noting that NR V2X mode 2 is similar to LTE V2X mode 4. Both LTE V2X mode 4 and NR V2X mode 2 support broadcast transmission, which allows the transmission to all possible neighboring UE. The main difference between LTE V2X mode 4 and NR V2X mode 2 is that NR V2X additionally supports groupcast and unicast. Groupcast allows the transmission to multiple interesting receivers, whereas unicast allows the transmission to one receiver. On the other hand, the new introduced feedback channel also allows the receivers to transmit ACK/NACK messages. The HARQ feedback-based retransmission is also available in NR V2X mode 2.

C. RESOURCE POOL ORGANIZATION AND RESOURCE RESERVATION
The resource pool and resource allocation parameters can be described in Fig. 2. The total bandwidth can be divided into several subchannels, which is the minimal resource allocation.
unit. In our study, we set bandwidth to be 20MHz. According to the agreement made in 3GPP RAN1 98 bis meeting [18], one subchannel consists of 10 resource blocks and each RB is 180KHz. For a 20MHz bandwidth, there would be 11 subchannels. We suppose that each transmission reserves ten subchannels, and hence the total bandwidth can be divided into 11 resource candidates. The timing \( n \) presents the time for triggering resource selection or reselection. Since vehicles are assumed to keep on sensing, the resource selection window. The resource selection window is defined from the timing \( n + T_0 \) to \( n \), which is defined as the sensing window. 

The resources in the resource selection window are candidate resources for the transmitter to select. Based on the period and reserved resources indicated in SCI decoded in the sensing window, the transmitter can speculate occupied resources. The physical layer excluded these occupied resources and report the candidate resources to the MAC layer. Afterward, the MAC layer selects transmission resources from these candidate resources. In MAC layer, a reservation integer number \( N \) is randomly generated from the range \( N_{min} \) to \( N_{max} \). Each periodic resource reservation can be used \( N \) times, and then the transmitter reselects new periodic resources.

### III. SIMULATION SETTING AND ASSUMPTIONS

Each UE in our system transmits groupcast packets if it belongs to a group. Packet traffic distribution follows the specification [1]. For a grouped UE transmitter, the target receivers are all UE in the same group beside the transmitter itself. Only intragroup transmission is considered in this work. Group management is also a fundamental property of groupcast and is provided by the application layer. Under different scenarios, a particular application may be applied. For example, platooning is used for the highway scenario.

#### A. UE DROPPING AND GROUP MANAGEMENT

The V2V scenario can be described with UE dropping and group management. In this paper, the UE dropping and groupcast scenario follows system level simulation defined in 3GPP TR 37885 [1]. UE dropping indicates locations and movement of UEs, while group management defines how UEs form groups. We evaluate the proposed method in the following two scenarios.

- **Highway:** There are three lanes in each direction (6 lanes in total) in the highway scenario. Lane width is 4m, and length is 2000m. A group consists of several vehicle UEs located in the same lane and has the same direction and speed. In our paper, we first randomly decide whether the next generation node is a group or a single vehicle. If a single vehicle is generated, it does not belong to any group. If a group is next generated, then vehicles with the number of group size are consecutively yielded in the same lane. Their distance depends on the average speed. A fixed distance separates two adjacent UEs belonging to the same group, and no other UEs can be located between them. The distance between two adjacent vehicles is:

\[
\text{max}\{2, \text{Exp}(\lambda)\} 
\]

where \( \lambda = \text{average speed} \times 2 \text{ sec} \). Short inter-vehicle distance results in a higher intragroup density. Intragroup density can affect the performance and is shown in the discussion section. Fig. 3 plots the UEs’ distribution in the highway scenario.

- **2D random:**

Another realistic two-dimensional scenario is also provided [19]. Device locations in the 2D random scenario are modeled by a Poisson Cluster Process (PCP). In PCP, a parent point modeled by a Poisson Point Process (PPP) firstly generates, and an offspring process runs accordingly. Offspring points distribute based on symmetric normal distribution around a parent center point with variance \( \sigma^2 \). The union of generated offspring points forms the PCP. According to a symmetric normal distribution, we drop \( K \) parent points on a plain square uniformly and generate a fixed number of \( N \) of group members. The total number of UE is \( N \times K \) all the time in simulations. In the 2D random scenario, the intragroup density can be expressed in terms of group size \( N \) divided by the area of a group. As \( \sigma \) is related to distance from a group center to its member UEs, we use \( \sigma^2 \) to represent the group area. We adjust the intragroup density by changing \( N/\sigma^2 \). The impact of intragroup density is also shown in the discussion section. Fig. 4 plots the locations of UEs in the 2D random scenario that proximate devices form a group (cluster) and a spatial correlation exists in the content demand. Devices may share the same interest for some files in the same group, and each of them can act as a transmitter to deliver files locally. Although the 2D random scenario seems to be irrelevant for V2X networks, it is related to the D2D network. D2D communication is also a use case for sidelink transmission. However, 3GPP release-12 D2D communication supports only broadcast scenarios. In this paper, we also verify the feasibility of applying the retransmission UE selection scheme to the
clustering D2D use case.

![Figure 3: UE dropping in highway scenario.](image)

Because a transport block (TB) may transmit more than once, the definition of PIR is the time gap between the first success reception. The intended set of receivers is the UEs in the same group besides the transmitter itself. The performance metrics are abbreviated to PRR, Group PRR (GPRR), and PIR to make notation simpler.

![Figure 5: An example of calculating PIR.](image)

**C. ASSUMPTIONS**

In this section, we list the assumptions used in the system model. In the same group, the UE has the location information of all member UEs. Each vehicle knows the distance between member vehicles due to the CAM message exchange. In our simulator, UE location and channel status are updated every 100 ms according to [1], which can influence retransmission performance as will be discussed in the discussion section. Note that UE locations exchange between UEs through CAM with periods ranges from 100ms to 1000ms. Tx UE occupies only one subchannel for each transmission. The threshold of receiver sensitivity is set as -90 dB. Rx UEs can decode the packets transmitted from Tx UEs if Rx antenna gain minus path loss is above -90 dB. The traffic of packets is periodic, and the period is the same for all UEs.

**IV. RETRANSMISSION UE SELECTION PROBLEM FORMULATION FOR DISTRIBUTED SCHEDULING MODE**

**A. PROBLEM DESCRIPTION**

Generally, Tx UEs contend for the resource and use it to transmit packets consecutively. Each generated packet only has one chance to be transmitted when retransmission is not applied. Not all intended receivers in the same group are in Tx’s one-hop coverage due to channel status variation. Retransmission is a mechanism that has been widely used to increase channel status diversity and achieve higher reliability constraints. However, the effectiveness of retransmission is limited when the channel status between transmitter and receiver is bad. To solve this problem, we propose the retransmission UE to help the transmitter to retransmit. Fig. 6 shows the retransmission procedure and message flow of twice retransmission. Tx UE firstly senses and reserves resources for transmission and retransmission by indicating in PSCCH. Tx does initial transmission with the reserved resources and assigns them to retransmission UEs, as shown in the lower part of the figure. Retransmission UEs will use these resources to perform retransmission. Finding an appropriate retransmission UE is the key problem we want to solve in this paper.
B. CHANNEL MODEL AND PACKET RECEPTION BEYOND RSRP THRESHOLD ESTIMATION

NR Vehicle-to-Vehicle (V2V) channel model includes three states: line-of-sight (LOS), non-line-of-sight (NLOS), and non-line-of-sight vehicle (NLOSv). For the scenarios we used, a link between two vehicles is either in LOS or NLOSv state. The probability of channel states is calculated as follows:

- **LOS state:**
  
  \[
  P(\text{LOS}) = \min\{1, a \cdot d^2 + b \cdot d + c\} \quad (2)
  \]
  
  if \( d \leq 475 \text{m} \),
  
  \[
  P(\text{LOS}) = \max\{0, 0.54 - 0.001 \cdot (d - 475)\} \quad (3)
  \]

- **NLOSv state:**
  
  \[
  P(\text{NLOSv}) = 1 - P(\text{LOS}) \quad (4)
  \]

where \( a = 2.1013 \times 10^{-6} \), \( b = -0.002 \), \( c = 1.0193 \) and \( d \) denotes the the distances between transmitter and receiver.

In addition, pathloss model is also provided as follows:

- **LOS, NLOSv:**
  
  \[
  PL(d) = 32.4 + 20\log_{10}(d) + 20\log_{10}(f_c) \quad (5)
  \]

where \( f_c \) denotes the center frequency in GHz.

When in the NLOSv state, additional blockage loss is added to the pathloss model.

\[
\max\{0, \text{Lognormal}(\mu, \sigma^2)\} \quad (6)
\]

where \( \mu = 9 + \max\{0, 15 \cdot \log_{10}(d) - 41\} \) dB, \( \sigma = 4.5 \) dB.

First of all, we provide a model to evaluate the transmission performance based on different retransmission UEs and formulate it into an optimization problem. Recall that the channel state and path loss model are functions of the distance obtained from CAM exchange. Hence, we derive the expression of the probability of packet reception under RSRP threshold. Note that in the real scenarios, the success packet reception depends on packet collision, reception energy and half duplex problem. However, the packet collision is hard to evaluate for a distributed communication system. As for the half duplex problem, it only depends on the transmission period, and irrelevant to the transmission distance. On the other hand, the simulation shows the success packet reception ratio has a similar decreasing tendency as the probability derived from the pathloss model. Our simulation shows that although there is an estimation deviation of success packet reception ratio, it still provides a good estimation with the derivation from the pathloss model. Hence, we derive the expression of the probability of packet reception beyond RSRP threshold as follows:

\[
P(\text{LOS}) \cdot P(G - pl_{\text{LOS}} \geq R) + P(\text{NLOSv}) \cdot P(G - pl_{\text{NLOSv}} \geq R) \quad (7)
\]

where \( G \) denotes antenna gain, \( pl_{\text{LOS}} \) denotes path loss in LOS state, \( pl_{\text{NLOSv}} \) denotes path loss in NLOSv state, and \( R \) set as -90 dBm denotes the receiver sensitivity. \( P(\text{LOS}) \) and \( P(\text{NLOSv}) \) can be derived from (2), (3) and (4). Based on (5),

\[
P(G - pl_{\text{LOS}} \geq -90) = P(pl_{\text{LOS}} \leq 90 + G)
\]

\[
= P(32.4 + 20\log_{10}(d) + 20\log_{10}(f_c) \leq 90 + G)
\]

\[
= P(20\log_{10}(f_c)d \leq G + 57.6)
\]

\[
= \begin{cases} 
1 & \text{if } d \leq \frac{10^{G+57.6}}{f_c} \\
0 & \text{if } d > \frac{10^{G+57.6}}{f_c} 
\end{cases}
\]

As regards \( P(G - pl_{\text{NLOSv}} \geq -90) \), we should consider...
additional vehicle blockage loss $\eta$.

$$P(G - p_{\text{NLOS}} \geq -90) = P(p_{\text{NLOS}} \leq 90 + G) = P(32.4 + 20\log_{10}(d) + 20\log_{10}(f_r) + \eta \leq 90 + G) = P(\eta \leq G + 57.6 - 20\log_{10}(f_r)d)$$

Given that the CDF of $\eta$ is $\frac{1}{2} + \frac{1}{2}e^{f(\ln x - \mu)}$, $P(\eta \leq G + 57.6 - 20\log_{10}(f_r)d) = \frac{1}{2} + \frac{1}{2}e^{f(\ln(G + 57.6 - 20\log_{10}(f_r)d) - \mu)}$. (10)

Fig. 7 plots the probability of successful transmission in terms of the distance between Tx UE and Rx UE.

Based on (7), for a Tx UE and its receivers Rx UEs in a group, the probability of successful transmission can be calculated from the distance of each Tx-Rx pair. As we mention in subsection IV-A, the problem can be divided into the following two main cases: one-time retransmission and two-times retransmission. We exclude larger retransmission times for the poor performance caused by the channel congestion, as will be discussed later in the simulation part.

**C. ONE-TIME RETRANSMISSION**

In the one-time retransmission case, a Tx UE only performs retransmission once after initial transmission. It can use either itself or other UE in the same group to perform retransmission. The overall transmission procedure can be shown as Fig. 8. Each arrow in Fig. 8 represents part of the transmission. Let $P_{a-b}$ be the probability of transmission failure from UE $a$ to UE $b$ and $RT$ denotes the retransmission UE, the probability of successful transmission can be shown as

$$1 - P_{Tx-Rx}(P_{Tx-RT} + (1 - P_{Tx-RT}) \cdot P_{RT-Rx}) \quad (11)$$

where $P_{Tx-Rx}$ is the failure probability of initial transmission and $P_{Tx-RT} + (1 - P_{Tx-RT}) \cdot P_{RT-Rx}$ is the failure probability of transmission retransmitted by retransmission UE. Assuming that there is a group of UE expressed as set $\omega$ and a Tx UE $t \in \omega$, we can derive the mean of GPRR for certain retransmission UE $i$:

$$GPRR_i = \frac{1}{|\omega - t|} \sum_{r \in \omega - t} 1 - P_{t-r}(P_{t-i} + (1 - P_{t-i}) \cdot P_{t-r})$$

To obtain the highest probability of success transmission based on our model (7), we can select UE $i$ from $\max_{i \in \omega} GPRR_i = \max_{i \in \omega} \frac{1}{|\omega - t|} \sum_{r \in \omega - t} 1 - P_{t-r}(P_{t-i} + (1 - P_{t-i}) \cdot P_{t-r})$. (13)

**D. TWO-TIME RETRANSMISSION**

In the two-time retransmission case, a Tx UE performs retransmission twice after initial transmission. Like the one-time retransmission scheme, retransmission UEs are UEs in the same group, including the initial transmission UE. The overall transmission procedure can be shown as Fig. 9. Let $P_{a-b}$ be the probability of transmission failure from UE $a$ to UE $b$ and $RT$ denotes the retransmission UE, the probability of successful transmission can be shown as:

$$1 - P_{\text{init. transmission fail}} \cdot P_{\text{retransmission with RUE1 fail}} \cdot P_{\text{retransmission with RUE2 fail}}$$

(14)
where $P_{Tx-RT2}$ is the failure probability of direct transmission from Tx to retransmission UE 2 and $P_{Tx-RT1} + (1 - P_{Tx-RT1}) \cdot P_{RT1-RT2}$ is the failure probability of transmission from Tx to retransmission UE 2 by means of retransmission UE 1. Now, we can express (14) as:

$$1 - P_{Tx-Rx}(P_{Tx-RT1} + (1 - P_{Tx-RT1}) \cdot P_{RT1-Rx}) \cdot (P_{Tx-RT2} + (1 - P_{Tx-RT2}) \cdot P_{RT2-Rx})$$

(16)

where $P_{Tx-Rx}$ is the failure probability of initial transmission, $P_{Tx-RT1} + (1 - P_{Tx-RT1}) \cdot P_{RT1-Rx}$ is the failure probability of transmission retransmitted by retransmission UE1 and $P_{Tx-RT2} + (1 - P_{Tx-RT2}) \cdot P_{RT2-Rx}$ is the failure probability of transmission retransmitted by retransmission UE2. Assuming that there is a group of UE expressed as set $\omega$ and a Tx UE $t \in \omega$, we can derive the mean of GPRR for arbitrary two retransmission UEs $i, j$:

$$GPRR_{ij} = \frac{1}{|\omega - t|} \sum_{r \in \omega - t} 1 - P_{t-r}(P_{t-i} + (1 - P_{t-i}) \cdot P_{t-r})$$

$$\cdot (P_{t-j} + (1 - P_{t-j}) \cdot P_{j-r})$$

(17)

To obtain the highest probability of success transmission based on our model (7), we can select UE $i, j$ from $\max_{i,j \in \omega} GPRR_{ij} = $:

$$\max_{i,j \in \omega} \frac{1}{|\omega - t|} \sum_{r \in \omega - t} 1 - P_{t-r}(P_{t-i} + (1 - P_{t-i}) \cdot P_{t-r})$$

$$\cdot (P_{t-j} + (1 - P_{t-j}) \cdot P_{j-r})$$

(18)

V. PERFORMANCE EVALUATION

A. SIMULATOR AND CONFIGURATION

Our simulator is written in Python based on NR sidelink mode 2. In this mode, each UE autonomously selects its resources, similar to C-V2X sidelink mode 4. The basic frame structure for 5G/NR and sensing-based Semi-Persistent Scheduling (SPS) is implemented. Communication types in the simulator support broadcast mode and groupcast mode. Vehicular traffic, channel model, and UE dropping scenarios we use are mentioned in the above section III. The term broadcast ratio refers to the ratio of UEs that transmit packets using broadcast mode. Simulation under different broadcast ratio helps us analyze the interference between groupcast UEs and broadcast UEs. The simulation parameters are set as listed by TABLE 1.

B. BENCHMARKS

We design several schemes to compare with the proposed scheme maxmean GPRR once/twice. Without retransmission and retransmission by init. Tx once/twice are schemes that use initial transmission Tx. Retransmission by middle Tx and maxmin GPRR once/twice are schemes that use other UEs to help retransmit. Retransmission by middle Tx selects the middle UE in the highway scenario or the UE closest to the group center in the 2D random scenario to perform retransmission, which creates bigger one-hop coverage in a group despite the channel status. There is another benchmark scheme called maxmin GPRR. In the proposed scheme, we first derive the mean of GPRR given arbitrary retransmission UE and pick the highest one. While in maxmin GPRR scheme, we first derive the minimum of GPRR given arbitrary retransmission UE and pick the highest one. Vehicle UEs’ speed is 140 km/h in the highway scenario, and group standard deviation is 100 in the 2D random scenario.

C. SIMULATION RESULTS AND DISCUSSION

1) Improvement with the proposed retransmission UE selection:

Firstly, we show the PRR and collect the packets that fail to be transmitted in each scheme as Fig. 10 and 11. The failed transmission packets are divided into two classes: out of coverage and collision packets. We define the out of coverage packets as the packets that cannot be received by intended Rx UEs due to low received signal power; while the collision packets are remaining packets that are not successfully transmitted nor out of coverage. A comparison of the two results between Fig. 10a and Fig. 10b examines the impact of the distance between Tx UE and Rx UE. As the distance increases, PRR gradually falls, and the ratio of out of coverage packets rises. Retransmission by the UEs selected by the proposed scheme increases PRR and reduces the ratio of out of coverage packets (extends the coverage). Increasing the number of retransmission also improves PRR. Fig. 12, Fig. 13, Fig. 14 and Fig. 15 show the results of using different schemes in both scenarios. Our proposed Maxmean GPRR scheme has higher GPRR, especially with two-time retransmission. However, retransmission by other UEs increases the ratio of collision packets. The main reason for increasing collision is the mechanism of sensing-based SPS. The sensing results would make the proximate Tx UEs tend to choose different resources to avoid collisions. However, these mechanisms failed to avoid some collisions when the resources are selected by initial Tx UE but are transmitted by other UE. The interference coverage for the retransmission UE is different from the initial Tx, especially when retransmission UE is far from the initial Tx UE.
retransmission schemes in the highway scenario.

![Figure 10](image-url)

**FIGURE 10:** Ratio of different types of packets versus distance in highway scenario

![Figure 11](image-url)

**FIGURE 11:** Ratio of different types of packets versus distance in 2D random scenario

![Figure 12](image-url)

**FIGURE 12:** GPRR versus group size with one-time retransmission schemes in the highway scenario.

![Figure 13](image-url)

**FIGURE 13:** GPRR versus group size with two-time retransmission schemes in the highway scenario.

further UEs to retransmit with initial Tx UE’s resources could increase the collision rate, as shown in Fig. 10c and Fig. 11c. Despite the higher collision probability, the extended coverage provides more chance for farther groupcast members to receive data packets. Some UE with poor channel quality to the transmitter benefits from the retransmissions from another UE. Nevertheless, the gain in PRR of using selected retransmission UEs is still higher. In summary, these results show that overall performance improves with our proposed retransmission scheme.

2) Discussion on the impact of broadcast ratio and group size:

In order to find the impact of the proposed solution for both intra-group groupcast UE and normal broadcast UE, we simulate the scenario that both groupcast and broadcast
UEs share the same resource pool. We simulate the different ratio of broadcast UE to find the impact on the GPRR performance. The first scenario is 0% of broadcast UE, which means that all UE in this scenario belong to one group and transmit with groupcast packet. The second scenario is 20% of broadcast UE, which is the case that there are some individual UEs that may cause interference to the groupcast UEs. The third scenario is 50% of broadcast UE, which is the case that there are more individual UE transmit on its own. Fig. 16 and 17 provide the results obtained from simulations under three scenarios with different broadcast ratio. The total number of UEs is 300, and different group sizes are ranged from 10 to 30 in each simulation. From these figures, we can see that the GPRR declines steadily as the group size increases, given the same intragroup density. The simulation results show that the group size should be limited to meet specific reliability constraints. For example, if we want to achieve a 90% reliability, the without retransmission scheme should cut down the group size to under 10, whereas using our proposed schemes can further increase the available group size to 20 in both scenarios. As regards the broadcast ratio, the GPRR rises when the broadcast ratio increases. The lower broadcast ratio, which means a smaller number of UEs using groupcast, can lead to less inter-group interference. These findings may help us to set proper configurations according to the broadcast ratio in the realistic scenario.

3) Discussion on the vehicle intragroup density
In the highway scenario, we define the intragroup density as the reciprocal of the average interval distance between UEs in one lane. There are more UEs in a lane with higher density, and the average interval distance is short. Fig. 18 shows that higher density gets better performance (smaller PIR) in highway scenario. This observation is because of higher density (shorter interval distance) results in an increased number of UEs under Tx UEs’ coverage. However, when using other UEs to help retransmission, especially our proposed scheme, due to the limited resources and increased collision failure, the performance also decreases at higher density.

In the 2D random scenario with a fixed amount of UEs, PIR decreases as the density increases. The parameter group standard deviation controls how dense a group is in the scenario. For the denser group, the average distance between UEs in the same group is short, and PIR is small. Overall, our proposed retransmission UE selection scheme can improve the performance comparing using initial transmission UE to retransmit or without retransmission.

4) Discussion on the impact of channel status update period:
As Fig. 16a and 17a show, retransmission improves overall performance, particularly with our proposed scheme. Interestingly, retransmission with the initial transmission UE cannot improve the performance compared with without retransmission scheme. We examine this phenomenon by doing the simulation with a shorter channel status update period of 50 ms. As can be seen from Fig. 20, 21, 22 and 23, the GPRR of retransmission by init. Tx once or twice further increase. The observed decline in the GPRR in the 100 ms channel update period scenario could be attributed to the channel state’s correlation between each transmission. If a link is in NLOSv, using the initial transmission Tx to retransmit remains the same state with high probability. Shortening the update period or selecting other UEs to retransmit leads to more chance of channel state changing or diversity of Tx UE’s coverage. The correlation of channel status in time reduces the advantage of blind-retransmission.

5) Discussion on the difference between the highway and 2D random scenario:
With different UE dropping and group management configurations, UEs are arranged as a line in the highway scenario and distributed in 2D in the 2D random scenario. In the highway scenario, the interval distance could be much longer because UEs need to keep a safe distance while forming a line platoon in one lane. Also, choosing one or two retransmission UEs can cover most member UEs in the highway scenario.
In the 2D random scenario, it is challenging to select only two retransmission UEs to cover two-hop topology since the member UEs are distributed in 2D.

6) Discussion on congestion
We have limited channel capacity in our scenarios. Reserving more than one resource for a TB transmission can lead to congestion in channels. To evaluate the influence, we vary the time interval between two periodic transmissions to control the traffic. The results are shown in terms of channel busy ratio (CBR) and GPRR. Heavier traffic load results in higher CBR, as shown in Fig. 24 and 26. In Fig. 25 and 27, with the most massive traffic load such as 10 ms time interval, the GPRR in each retransmission scheme is lower than without...
the retransmission scheme. Reserving additional resources to retransmit further aggravates the problem of channel congestion. The phenomenon also reveals that a larger number of times for retransmission causes severer channel congestion, as the maxmean three times scheme shows in figures. With these observations, we only consider the one-time and two-time retransmission schemes. When we set the time interval as 30ms in the highway scenario and 40 ms in the 2D random scenario, all retransmission schemes except maxmean three times scheme start to perform better than without retransmission scheme. When the interval is longer than 50 ms in the highway scenario and 80 ms in the 2D random scenario, our proposed two-time retransmission scheme has the highest GPRR. Using the packet traffic configurations {10, 30, 50} ms in highway scenario and {10, 40, 80} ms in 2D random scenario, we plot the result in Fig. 29 and Fig. 30. The results also show that two-time retransmission has the best performance in light and medium traffic. For the heavier 10 ms traffic, retransmission is not able to improve overall performance.

7) Simulations of different transmission period combination

In our simulation, we simplify the packet transmission period to be the same. In order to show that our proposed retransmission UE selection also works on the scenario with different periods, we simulate the scenario which assigns different periods to each UE. We simulate two different combinations of transmission periods. The first scenario is that 50\% of UEs transmit with period 50ms, and another 50\% of UEs transmit with period 100ms. The second scenario is that UEs transmit with periods 60ms, 70ms, 80ms, 90ms, and 100ms. Each period accounts for 20\% of UEs. As shown in Fig. 28, the proposed Tx selection method provides improvement when different combinations of transmission periods.
VI. CONCLUSIONS

In this paper, we present reliable blind retransmission for NR V2X groupcast mode 2. Our simulation shows that when the channel state is NLOS, the initial transmitter’s retransmission has a limited gain on GPRR. To fully utilize the benefit of retransmission and meet the stringent reliability requirement of V2X services, we propose retransmission by the member UE in the same group. When the transmitter initializes a transmission, it reserves the retransmission resources and assigns the UEs in the same group to retransmit the TB. We also formulate the retransmission UE selection problem, which aims to maximize the GPRR. We compare the GPRR optimized retransmission UE selection with other UE selection schemes, including selecting middle UE and Max-Min PRR scheme. Simulations show that the proposed retransmission UE selection scheme outperforms other methods in terms of GPRR, PIR, and available group size. To further discuss the system performance under various scenarios, we simulate different broadcast UE ratio and UE density and find their impact on GPRR and PIR. Simulation results show that the higher broadcast UE ratio results in severe interference and lower GPRR. We also find that higher vehicle density leads to lower PIR when the channel is not congested.

REFERENCES

[1] 3GPP TR 37.885, “Study on evaluation methodology of new Vehicle-to-Everything (V2X) use cases for LTE and NR,” 3rd Generation Partnership Project (3GPP), Technical Report (TR), 06 2019, version 15.3.0.
[2] 3GPP RP-191723, “Revised WID on 5G V2X with NR sidelink,” 3rd Generation Partnership Project (3GPP), Work Item Description RP-191723, 09 2019.
[3] 3GPP TR 38.885, “Study on NR Vehicle-to-Everything (V2X) (Release 16),” 3rd Generation Partnership Project (3GPP), Technical Report (TR), 03 2019, version 16.0.0.
[4] M.-J. Shih, H.-H. Liu, W.-D. Shen, and H.-Y. Wei, “Ue autonomous resource selection for d2d communications: Explicit vs. implicit ap-
proaches," in 2016 IEEE Conference on Standards for Communications and Networking (CSCN). IEEE, 2016, pp. 1–6.
[5] F. Abbas, G. Liu, P. Fan, and Z. Khan, “An efficient cluster based resource management scheme and its performance analysis for v2x networks,” IEEE Access, vol. 8, pp. 87 071–87 082, 2020.
[6] L. Feng, W. Li, Y. Lin, L. Zhu, S. Gao, and Z. Zhen, “Joint computation offloading and urllc resource allocation for collaborative mec assisted cellular-v2x networks,” IEEE Access, vol. 8, pp. 24 914–24 926, 2020.
[7] P. Keshavamurthy, E. Pateromichelakis, D. Dahlhaus, and C. Zhou, “Resource scheduling for v2v communications in co-operative automated driving,” in 2020 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2020, pp. 1–6.
[8] Y.-T. Kuo, H.-Y. Wei et al., “Reliable two-hop device-to-device communications for uavs,” in 2019 IEEE VTS Asia Pacific Wireless Communications Symposium (APWCS). IEEE, 2019, pp. 1–5.
[9] J. Lianghai, A. Weinand, B. Han, and H. D. Schotten, “Applying multiradio access technologies for reliability enhancement in vehicle-to-everything communication,” IEEE Access, vol. 6, pp. 23 079–23 094, 2018.
[10] J. Yeo, H. Ji, J. Bang, Y. Kim, and J. Lee, “A novel group retransmission scheme for industrial iot over 5g,” in 2019 IEEE Globecom Workshops (GC Wkshps). IEEE, 2019, pp. 1–5.
[11] M. Schellmann and T. Soni, “Ultra-reliable v2x communication: On the value of user cooperation in the sidelink,” in 2019 European Conference on Networks and Communications (EuCNC). IEEE, 2019, pp. 570–574.
[12] Y.-H. Chang, H.-H. Liu, and H.-Y. Wei, “Group-based sidelink communication for seamless vehicular handover,” IEEE Access, vol. 7, pp. 56 431–56 442, 2019.
[13] S. Roger, D. Martín-Sacristán, D. García-Roger, J. F. Monserrat, P. Spapis, A. Koussidas, S. Ayaz, and A. Kaloxylos, “Low-latency layer-2-based multicast scheme for localized v2x communications,” IEEE Transactions on Intelligent Transportation Systems, vol. 20, no. 8, pp. 2962–2975, 2018.
[14] M. Fallgren, T. Abbas, S. Allio, J. Alonso-Zarate, G. Fodor, L. Gallo, A. Koussidas, Y. Li, Z. Li, Z. Li et al., “Multicast and broadcast enablers for high-performing cellular v2x systems,” IEEE Transactions on Broadcasting, vol. 65, no. 2, pp. 454–463, 2019.
[15] Z. Wang, J. Hu, G. Liu, and Z. Ma, “Optimal power allocations for relay-assisted noma-based 5g v2x broadcast/multicast communications,” in 2018 IEEE/CIC International Conference on Communications in China (ICCC). IEEE, 2018, pp. 688–693.
[16] S. K. Gupta, J. Y. Khan, and D. T. Ngo, “A d2d multicast network architecture for vehicular communications,” in 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring). IEEE, 2019, pp. 1–6.
[17] J. Kim, Y. Han, and I. Kim, “Efficient groupcast schemes for vehicle platooning in v2v network,” IEEE Access, vol. 7, pp. 171 333–171 345,
2019.

[18] 3GPP R1-1913275, “Final Report of 3GPP TSG RAN WG1 98bis v2.0.0,” 3rd Generation Partnership Project (3GPP), Work Item Description R1-1913275, 11 2019.

[19] M. Afshang, H. S. Dhillon, and P. H. J. Chong, “Modeling and performance analysis of clustered device-to-device networks,” IEEE Transactions on Wireless Communications, vol. 15, no. 7, pp. 4957–4972, 2016.

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