

## Research Article

# A Local Information Sensing-Based Broadcast Scheme for Disseminating Emergency Safety Messages in IoV

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Internet of Vehicle (IoV) is playing an increasingly important role in constructing an Intelligent Transport System (ITS) of safety, efficiency, and green. Safety applications such as emergency warning and collision avoidance require high reliability and timeliness for data transmission. In order to address the problems of *slow response* and *local broadcast storm* commonly existing among waiting-based relay schemes of emergency messages, a local topology information sensing technology-based broadcast (LISCast) protocol is proposed in this paper, making use of the advantage of probability-based forwarding scheme in redundancy inhibition. According to the beacon broadcasted periodically between vehicles, LISCast collects information about number and distribution of neighbor, from which the *characteristic information* such as effective candidate number, maximum forwarding distance, and global traffic density are extracted. Through embedding the characteristic information into the head of broadcast packets by the message sender for assisting in making relay decision, the alternative receivers uniformly schedule forwarding priorities in a distributed and adaptive way. LISCast works without the help of a roadside unit and generates a little more overhead. The simulation results show that LISCast improves the ability to adapt to dynamic topology by optimizing the performance of delay, redundancy, and broadcast efficiency upon the condition of satisfying the high level of transmission reliability.

## 1. Introduction

IoV is the most typical applications for the Internet of Things (IoT) technology [1] in the field of transportation. The communication networks of IoV mainly include vehicle to vehicle (V2V), vehicle to infrastructure (V2I), vehicle to pedestrian (V2P), vehicle to network (V2N), and so on [2]. Vehicles can communicate to each other and share data through the onboard devices, which are of great importance in reducing traffic accidents and improving road efficiency [3]. IoV is one of the most significant technologies to realize ITS, which attracts the increasing attentions from the industry and academia. Nowadays, there are two main standards [4] about IoV. One is the developed DSRC (dedicated short range communications) [5], which is proposed and carried out by American and Japan, in the way of ad hoc to

generate network using 802.11p as the communication protocol. The other is C-V2X (cellular vehicle-to-everything), which is suggested at most by Europe and China, making use of developing and widely distributed cellular network to satisfy the low delay and high reliability of vehicular environment [6].

Emergency messages always contain information about life, which should be notified to the vehicles located behind in the range of several kilometers driving towards the accident place, for the purpose of avoiding the serial collision and improving driving safety [7, 8]. Because the communication range of vehicle devices is about 300 meters only, multihop forwarding will be used to spread the emergency messages to the risk of zone (RoZ). As is known the core of multihop routing protocols is how to select the relay nodes. According to the way of relay selection, the existing

broadcast strategies mainly include two kinds [9]: the sender-based forwarding scheme and receiver-based forwarding scheme.

The sender-based schemes specify relay nodes by the sender based on the neighbor information. The specified forwarder forwards packets as soon as possible once it receives emergency messages. This scheme can spread messages rapidly. Besides, no matter how to change for the density of traffic, the level of useless duplicates remains steady. It is an effective method to avoid broadcast storm, which is a common problem for designing broadcast protocols. However, these schemes depend on real time and precise neighbor information. As a matter of fact, it is a challenge for beacon to collect the accurate neighbor information because of the highly dynamic topology of IoV. The chosen relay node is not always the optimal candidate in geography, which means that covering the whole RoZ will experience more hops of forwarding. Actually, each time one hop increases in the process of multihop forwarding, more redundancy is produced and the probability for the broadcast to be interrupted increases as well. Furthermore, the reliability of sender-based schemes falls sharply when encountering channel fading and interference in the quickly changing topology of networks.

Receiver-based schemes do well in utilizing the sharing features of wireless channel to disseminate emergency messages. The candidate receivers cooperate with each other to forward packets in a distributed way according to certain rules. For example, the most popular broadcast protocols are farthest-first schemes, which are based on the position of vehicles. The priorities of candidates are directly proportional to the distance between the sender and receivers. The farthest node will forward packets preferentially. On the one hand, the nearer candidates will be suppressed to compete for forwarding, so that less redundancy will be produced. On the other hand, the farthest-first rule can ensure the most extensive coverage per hop, so that fewer hops will be needed to warn all the vehicles locating in the RoZ. Because the forwarding decision is made after receiving packets, the broadcasting continuity can be ensured to some extent, which is why receiver-based schemes attract so much attention from researchers. However, there exist problems of *slow response* and *local broadcast storm* [10] because of the receivers' lack of enough knowledge about the sender's topology, which will be discussed in detail in Section 3.

Based on the analysis of the requirements for disseminating emergency safety messages, this paper focuses on the receiver-based broadcasting scheme, which is one of the most promising protocols in IoV. The main contributions of this paper are two-fold:

- (i) First, we highlight and indicate the problems of *slow response* and *local broadcast storm*, which commonly exist in the farthest-first waiting-based broadcasting protocols but are ignored.
- (ii) Second, a fast and low overhead broadcasting scheme, called LISCast, is proposed based on the sensing of local topology information as a solution to the problems we analyzed.

The study is organized as following. Section 2 reviews the related works. Section 3 introduces the problems and challenges existing in the farthest-first broadcasting schemes. Section 4 describes in details the design of proposed broadcast protocol LISCast, including the technology of local information sensing, forwarding scheme, and retransmission strategy. Finally, simulation and results analysis are shown in Section 5, which is followed by conclusions in Section 6.

## 2. Related Works

In order to disseminate emergency messages quickly and reliably, many excellent broadcasting protocols have been proposed in the past years, among which waiting-based, contention-based, and probability-based schemes are the most popular ones.

The waiting-based broadcasting scheme was first introduced to IoV in [11]. All candidates configure their forwarding priorities by assigning different waiting times according to the distance from themselves to the previous forwarder. The famous priority schedule rule is seen in the following formula, which is shown as formula (2) in [11]:

$$D_{\text{wait}}^j = D_{\text{max}} \cdot \left(1 - \frac{d_{ij}}{R}\right), \quad (1)$$

where  $d_{ij}$  is the distance between the receiver  $j$  and last forwarder  $i$ ,  $R$  is the communication range, and  $D_{\text{max}}$  is the maximum waiting time. We can see from formula (1) that the larger distance from the receiver to sender, the less waiting time can be scheduled, suppressing the nearer receivers to rebroadcast. In this way, the geography progress of messages in each forwarding hop can be maximized. As a result, fewer hops will be needed to cover the whole RoZ.

Similarly, the authors in [12] allowed the candidates to wait some time before forwarding according to the farthest-first rule. But they did not give exact equations to calculate the waiting time. UMB [13] was first proposed to configure nodes' priorities in the MAC layer. RTS/CTS (Response To Send/Clear To Send), which was first used in unicast, was introduced into broadcast protocol to alleviate the impact of hidden terminal and to enhance broadcast continuity. However, frequent handoff caused by break link would increase extra control delay, preventing messages disseminating quickly. Besides, apart from distance, the speed of candidates was considered to schedule the forwarding priorities in [14]. Although in [15] the farthest-first forwarding scheme was extended to implement in multichannel operation. In the past few years, many other protocols have been proposed with the similar forwarding rule to optimize broadcast performance in certain scenarios such as OppCast [16], UV-CAST [17], ROFF [18], and so on.

Different from waiting-based forwarding schemes, contention-based forwarding schemes assign candidates' priorities using the size of Contention Window ( $CW_{\text{min}}$ ) rather than the waiting time. In [19], different values of  $CW_{\text{min}}$  are set to vehicles according to their distance from the sender. The longer distance between the receiver and

sender, the smaller  $CW_{\min}$  value could be configured. In order to reduce redundancy furthermore, in [20] only vehicles falling in some narrow segments could join to compete channel access. Other similar contention-based broadcasting schemes could be seen in [21, 22]. Although the extra waiting delay was eliminated in contention-based schemes, the broadcast efficiency would decrease because the optimal candidates in geography may fail to access the contention channel. Furthermore, since the size of  $CW_{\min}$  is limited, the number of candidates joining the program of channel competition is certain, leading to serious collision in the dense network, and expanding the size of  $CW_{\min}$  would increase the delay of channel access.

The orobability-based scheme was firstly proposed on the basis of the farthest-first forwarding scheme by Wisitpongphan et al. [23]. It was an effective method to control redundancy. The well-known representatives are Weighted- $p$  and Slotted $P$ . The forwarding probability is directly proportional to the distance between the receivers and senders in Weighted- $p$ , so that the farthest vehicles had higher probabilities to rebroadcast. To avoid erroneous forwarding judgment, vehicles in Slotted $P$  firstly wait for some time according to formula (1) and then rebroadcast messages in a certain probability  $P$ . To improve the adaptive capacity of routing, many schemes were proposed. For example, in [24] dynamic density was estimated, while in [25] the usage of channel was monitored to adjust forwarding probability. Besides, in [26, 27], real-time vehicle density and distance between vehicles and other factors were combined to schedule rebroadcasting probability. The fewer the vehicles, or the longer the one hop distance, the higher the probability can be set. Although probability-based scheme can reduce packets collision caused by rebroadcasting of neighbors at the same time slot, it is at the cost of reducing broadcast efficiency, because the most optimal candidates do not always win the channel contention for they are forwarding data in some probability.

### 3. Problems and Challenges

As the popularization of positioning module and the continuous improvement of positioning accuracy, GPS (global positioning system) turns to be the standard configuration of automobile gradually. Position-based protocols have made a great progress in the past few years for disseminating emergency safety messages, among which waiting-based schemes were the most popular ones because they made fully use of the sharing feature of wireless channel and were easy to be realized in engineering. As is shown in formula (1), the priority was set in terms of a timer, by which the farthest candidates were configured the least waiting time to forward packets, so that the single hop progress was maximized and the nearer candidates were restrained to relay, resulting in less redundancy, less contention and fewer hops. However, the difference of waiting time between adjacent candidates was so small that they may forward simultaneously, leading to drastic collision and larger latency of channel access. The situation may be more serious especially in the dense networks. Take the Slotted-1 persistence scheme [23] as an

example, without loss of generality, to discuss the problems that waiting-based schemes face.

As is shown in Figure 1, Slotted-1 divides communication range into  $N_s$  segments. Vehicles in the same segment have the same priority, and the priority is directly proportional to the distance from the center of segment to the last forwarder. So that vehicles in the farthest segment have the highest priorities in terms of waiting time to rebroadcast. Upon receiving a packet, a node checks the packet ID at the end of assigned time slot  $D_{\text{wait}}$  if it receives the packet for the first time and has not received any duplicates during  $D_{\text{wait}}$ ; otherwise, it discards the packet. To avoid erroneous forwarding judgment when receiving duplicates from multisources, vehicles firstly wait for a regular duration  $WAIT\_TIME$  before rebroadcasting, and the waiting time of candidate  $j$  is calculated by the following formula, which is shown as formula (2) in [23]:

$$D_{\text{wait}}^j = S_{ij} \cdot \sigma, \quad (2)$$

where  $\sigma$  is the one hop time slot and  $S_{ij}$  is the configured time slot number between candidate  $j$  and the previous forwarder  $i$ , which is cited from formula (3) of [23] as following:

$$S_{ij} = N_s \left( 1 - \left\lfloor \frac{\min(d_{ij}, R)}{R} \right\rfloor \right). \quad (3)$$

Note that if node  $j$  receives duplicates from multiple forwarders within the duration of  $WAIT\_TIME$ , it selects the largest  $D_{\text{wait}}^j$  value as its waiting time. In other words, each candidate should use the relative distance to the nearest forwarder to assign waiting time in order to ensure that the farthest receivers rebroadcast firstly. So that the nearer candidates are suppressed to relay. We can see from Figure 1 that vehicles E and F falling in the farthest segment are assigned the highest priority, and vehicle E will be chosen to calculate the waiting time of receiver of next hop so as to reduce the delay of single hop.

Note that the broadcast performance is easy to be affected by the fixed parameters such as  $WAIT\_TIME$  and  $N_s$ . The larger the value of  $WAIT\_TIME$ , the lesser the redundancy can be produced, and the higher broadcast reliability is achieved, but the longer extra end-to-end delay could be postponed. In addition, the larger  $N_s$ , the greater difference of waiting time between adjacent candidates will be set, hence the less collision will occur, but the longer waiting delay will be assigned for the low priority candidates. Moreover, the waiting-based schemes are weak to adapt to the rapid changing topology, which will be illustrated by the following two examples.

**3.1. Slow Response Problem.** As is shown in Figure 2, few vehicles locate on the road nonuniformly, which often happens on the highway or during the leisure time in urban scenarios such as morning or night. There are always many empty segments in the coverage of vehicle communications. The *farthest candidates* (e.g., yellow vehicles), even which are actually the optimal candidates in this situation, have to wait certain time to forward packets because it is the *farthest*

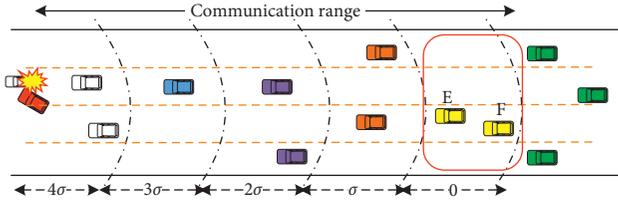


FIGURE 1: Priority schedule of Slotted-1.

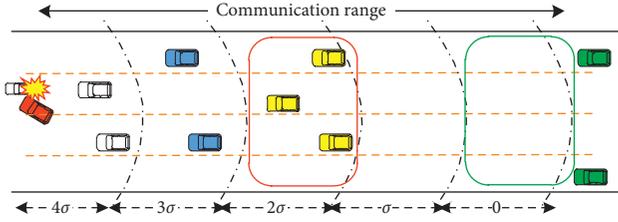


FIGURE 2: Slow response of Slotted-1.

segment (e.g., green box) that is set the highest priority according to formula (2). The reason is that candidate receivers' lack of enough knowledge about the topology of previous forwarder such as the number of candidates, their distribution and the real-time density, and so on to make more intelligent relay decision. This schedule scheme postpones packets disseminating quickly, and this phenomenon is called *slow response*.

**3.2. Local Broadcast Storm.** Meanwhile, as is shown in Figure 3, there are so many vehicles running here and there in the dense network such as rush hours in the urban or near toll station on the highway. Many vehicles locating in the same segment (e.g., yellow cars in red box) have the same priority to forward packets, according to the waiting time schedule rule, formula (2), for instance. The time difference of them is so little that they relay packets almost at the same time slots simultaneously, leading to more useless duplicates, higher probability of collision, longer channel access delay, and lower reliability, and this phenomenon is called *local broadcast storm*.

Different from mobile ad hoc network, vehicles in IoV move in high speed, resulting in highly dynamic topology, channel fading, and interference, which are serious challenges for data transmission. Besides, slow response and local broadcast storm problems of waiting-based forwarding schemes lead to obvious performance deterioration, which should be optimized so as to adapt to the dynamic characteristic of IoV.

## 4. Design of LISCcast

Since the typical waiting-based forwarding scheme lacks of enough knowledge about the topology characteristic of candidates, it is hard to adapt to the dynamic topology, leading to the problems of *slow response* and *local broadcast storm*. A local information sensing broadcast protocol is

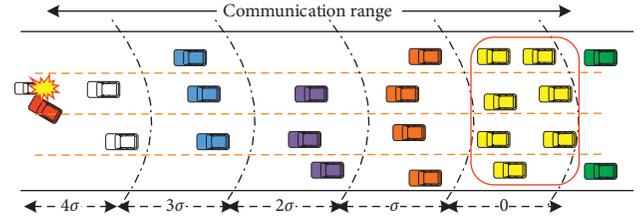


FIGURE 3: Local broadcast storm of Slotted-1.

proposed in this section to optimize the broadcast performance.

**4.1. Overview of LISCcast.** The packet flow of LISCcast can be seen in Figure 4. The flow of emergency packets works under two models. One model is the sender (called source for the first hop) sensing local topology information based on BSM, while the other model is the receivers completing forwarding packets. When receiving emergency packets on the network layer from upper layer, the sender calculates its characteristic information of topology using the local information sensing technology, which will be described in detail in the next Section 4.2. Together with other normal information about broadcast messages, the important characteristic information are embedded into the head of emergency packets before broadcasting around. Upon receiving emergency packets, the candidates assign the waiting time and forwarding probability according to the uniform characteristic information of the previous forwarder and separate distance from themselves to the sender. Only the candidates that pass the probability test can take part in the progress of waiting. If candidates do not receive any duplicate or ACK during the period of waiting time, they will relay packets; otherwise, the waiting progress will be canceled, which means other candidates have already rebroadcasted. The retransmission progress will be started at the end of the max waiting time if the sender (last forwarder) does not receive any ACK or duplicates. The packet will be disseminated hop by hop in this way, unless it covers the whole RoZ.

**4.2. The Local Information-Sensing Technology.** The wildly existed beacon (called BSM, Basic Safety Message in [5]) in IoV is used to sense the local topology information for relay decision. The local information sensing technology faces two aspects of challenges at least as follows:

**Challenge 1: Low Overhead and Fully Distributed.** As we know, it is better for safety messages to operate in a distributed way in the highly dynamic environment for satisfying the requirements of extremely low timeliness. It is difficult, if not infeasible, to design a centralized controller for safety data dissemination due to rapid mobility of vehicles. Frequent control information exchange will introduce heavy overhead and postpone emergency messages disseminating quickly. We need to design a fully distributed and lightweight protocol so that safety data can be efficiently spread to vehicles.

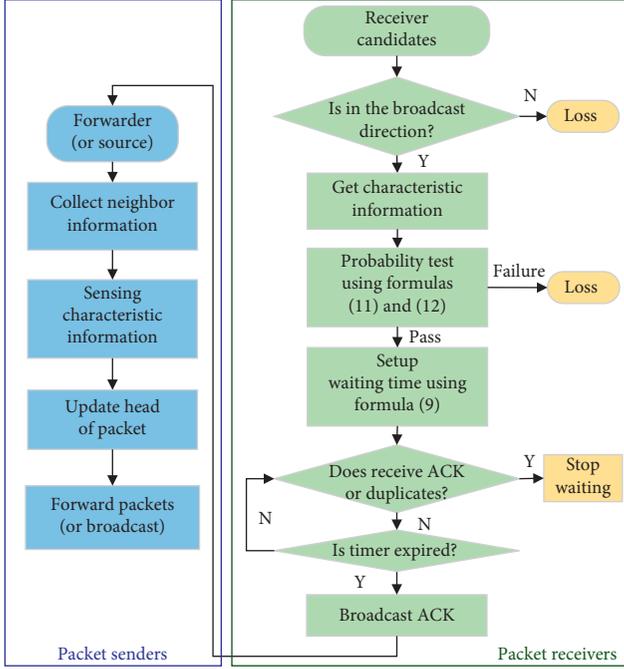


FIGURE 4: The packet flow of LISCast.

**Challenge 2: Uniform Forwarding Rule.** The characteristic information which is used by candidates to cooperate to assign priorities should be uniform. Because of the highly changing topology and packet loss, the characteristic information that each vehicle senses according to periodic beacons may be different from each other. If assigning priorities using vehicles' respective characteristic information, several candidates could be scheduled the same waiting time to forward packets simultaneously, intensifying packets collision and increasing channel accessing delay. Therefore, uniform characteristic information is beneficial to distinguish the forwarding priorities of candidates.

The following parts of this section discuss the design of local information sensing technology in detail.

Vehicles in the network periodically broadcast beacons to notify neighbors its basic status information such as ID, location, velocity, direction, and time stamp and so on. Through sensing the number and distribution of neighbors, vehicles can construct a local topology graph. According to the enough information about topology graph, it is easy for candidates to select the optimal relay nodes. However, sharing the topology graph costs heavy overhead, which is also easy to cause network congestion. In order to reduce the overhead, a tradeoff scheme can be available. Only a list of IDs ordered by descending priority in advance is embedded into the head of packets for relay decision. Although the size of IDs list is much smaller than that of topology graph, it still occupies several bytes which cannot be ignored, especially in the dense network where hundreds of neighbors running around. Broadcasting such large packet immensely increases the probability of channel congestion. To address the Challenge 1, a low overhead scheme is proposed in this section. Based on the neighbor information, only the characteristic information of local topology such as the

effective candidate number, the effective communication distance, and traffic density are extracted and embedded into the head of packets. No matter how density of traffic is changed, the size of characteristic information remains unchanged. Therefore, the increased overhead is low and keeps stable when emergency events happen. Besides, the local information sensing technology operates only on the basis of beaconing messages, without any help of centralized controller, satisfying the distributed feature of IoV for disseminating safety messages.

The definitions of variables are given below.

**Definition 1.** Effective candidate number (ECN): the number of candidates located in the broadcast direction considering the distribution of vehicles.

ECN is used to adjust the number of segments that the communication range is divided into, taking the changing distribution of vehicles into consideration. In fact, we mainly care about the number of vehicles locating in the farthest segment. Thus, positive distance weighting coefficient [28] is used to calculate the value of ECN, which is shown in the following equation:

$$N_{\text{ECN}} = \sum_{k=1}^{N_s} \lambda_k \cdot N_k, \quad (4)$$

where  $N_k$  is the number of vehicles in the  $k_{\text{th}}$  segment and  $\lambda_k$  is the weighting coefficient of the  $k_{\text{th}}$  segment, which is expressed as

$$\lambda_k = \frac{d_{kS}^q}{R}, \quad (5)$$

where  $d_{kS}$  is the distance from the  $k_{\text{th}}$  segment to the sender, and  $q$  is a positive integer.

We can see from formula (4) that the more vehicles far away from the sender, the larger ECN can be set. For example, in the situation of dense traffic, more segments will be beneficial to differentiate the priorities of adjacent candidates, mitigating the *local broadcast storm* caused by simultaneous rebroadcasting. On the contrary, the less vehicles locate in the farther segments, in the sparse network for instance, the smaller ECN can be configured, and the fewer empty segments turns up where with no vehicles locating. So that at least one vehicle can be assigned into the optimal segment, avoiding unnecessary waiting time before forwarding.

**Definition 2.** Effective communication distance (ECD): the distance from the farthest neighbor to the sender.

The relative distance from candidates to previous forwarder is the key to calculate the priorities of candidates. Using ECD to substitute the fixed parameter  $R$  for assigning the waiting time for each candidate can improve the adaptability of routing protocol against the dynamic of topology.

ECN represents the changing number of candidates, while ECD reflects the dynamic distribution of candidates. With the help of ECN and ECD in LISCast, there are always

candidates locating in the dynamic farthest segment and they can rapidly relay packets without any delay, no matter the density of topology how to change. Thus, the *slow response* problem can be solved mostly.

*Definition 3.* Effective traffic density (ETD): the estimated density with the consideration of vehicle distribution.

Due to the high mobility of vehicles, it is hard to collect the precise neighbor information for designing the exact values of ECD and ECN. Hence, there may be no less than one candidate locating at the farthest segment for competing channel access, which still leads to collision. ETD is proposed in this section to provide the changing topology information for supporting prediction of ECN and ECD and assignment of forwarding probability.

The speed-density liner model [29] is used in this section to estimate the real time traffic density  $\bar{\rho}$ , which is expressed as

$$\bar{V} = V_f \left( 1 - \frac{\rho}{\rho_0} \right), \quad (6)$$

where  $V_f$  is the limited velocity when vehicle drives freely,  $\rho_0$  is the maximum density that the road can support, and  $\bar{V}$  is the average velocity of target vehicle, which can be estimated by the neighbor information.

Given a velocity set of target vehicle at the moment  $t$ ,  $\{V_{h0}, V_{h1}, V_{h2}, V_{h3}, \dots, V_{hm}\}$ , where  $h$  is the  $h$ th broadcasting period,  $V_{h0}$  is the velocity of target vehicle,  $V_{hl}$  is the velocity of neighbor  $l$ , and  $m$  is the number of neighbors. Then, the average velocity of target vehicle at this moment considering vehicles' distribution can be expressed as

$$\bar{V}_h = \sum_{k=1}^m \lambda_k V_{hk}, \quad (7)$$

where  $\lambda_k$  is the weighting coefficient of the  $k$ th neighbor, which can be calculated by formula (5) similarly. After broadcasting beacons for  $T$  times, a set of average velocity can be produced, and the average velocity of target vehicle during period  $T$  can be expressed as

$$\bar{V} = \frac{\sum_{h=1}^T \bar{V}_h}{T}. \quad (8)$$

Gathering formulas (6)–(8) can calculate the estimated density, as the indicator of real-time traffic flow.

In addition, because of the channel fading and dynamic topology, the characteristic information that single vehicle senses is different from each other. The priorities of some candidates scheduled by the single characteristic information of themselves may turn to be the same, which will lead to packet collision and interrupt broadcast progress. Therefore, to solve the Challenge 2, LISCast assigns the priorities of all candidates using the same characteristic information, which represents the main topology information of previous forwarder and is embedded into the head of packet itself. Scheduling the waiting time according to the uniform information and the same rule, the candidates will compete to forward packets orderly.

After sensing the local topology information based on the neighbor information collecting from beacons, the data frame in LISCast is designed in Figure 5.

The head of LISCast packet includes three parts. The first part is main information about emergency events such as the type of message, the time and location of emergency events, the time stamp and position of last forwarder, broadcast direction, and so on. The second part is characteristic information of candidate topology, which is used for forwarding cooperation including the effective communication distance, the effective candidate number, and the effective traffic density. The last is the extension field.

In LISCast, the precise of neighbor information collecting from periodic beacon is the key. Many schemes were proposed to ensure the reliability of beacons [30]. The most popular method is repeating broadcasting several times during the period of beacon, and the packet reception ratio could reach more than 90% through test [31].

*4.3. Relay Strategy.* LISCast is improved from the typical formula (2) of waiting-based forwarding scheme, for the purpose of optimizing the performance of delay and redundancy and enhancing the adaptability of routing protocol against the dynamic topology. The priority schedule rule is shown as follows:

$$T_{\text{wait}}^j = N_S^j \cdot \sigma, \quad (9)$$

where  $T_{\text{wait}}^j$  is the waiting time of candidate  $j$ , and  $N_S^j$  is the number of segment that candidate  $j$  belongs to in the communication range of previous forwarder, which is expressed as

$$N_S^j = \left\lceil N_{\text{ECN}} \cdot \frac{\max(0, d_{\text{ECD}} - d_{ij})}{d_{\text{ECD}}} \right\rceil, \quad (10)$$

where  $d_{\text{ECD}}$  is the ECD of previous forwarder  $i$ ,  $d_{ij}$  is distance between candidate  $j$  and  $i$ , and  $N_{\text{ECN}}$  is the ECN of  $i$ .

When receiving emergency messages carrying the characteristic information of last forwarder, all the receivers calculate their waiting time using formula (9). Both of the characteristic information  $d_{\text{ECD}}$  and  $N_{\text{ECN}}$  are used by LISCast to make sure that one candidate at least but not so much candidates are falling in the farthest segment ready to forwarding messages with the least waiting delay, which is always set as zero.

Furthermore, in order to restraint the useless redundancy, a probability-based scheme is introduced to suppress the nearer candidates to compete to rebroadcast. The probability is directly proportional to the distance between the receivers and senders, which is shown in formula (11).

$$P_j = \min \left( 1, \frac{d_{ij}}{d_{\text{ECD}}} \right), \quad (11)$$

where  $P_j$  is the forwarding probability of candidate  $j$ . In order to balance the waiting delay and redundancy, the value of  $N_{\text{ECN}}$  is always not larger enough in LISCast to differentiate all the candidates. As a matter of fact, there are still

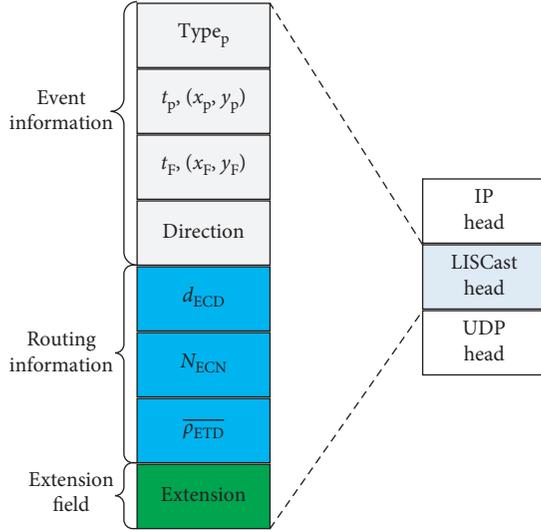


FIGURE 5: Data frame of LISCast.

many candidates with the same priorities colliding to each other when rebroadcasting packets simultaneously in the extremely dense network. Therefore, the estimated density indicator ETD is used by LISCast to mitigate collision through suppressing some candidates relaying together with distance-based probability  $P_j$ , which is shown as formula (12).

$$P_d = \begin{cases} P_{d1}, \overline{\rho_{ETD}} \in \{\text{sparse traffic}\}, \\ P_{d2}, \overline{\rho_{ETD}} \in \{\text{medium traffic}\}, \\ P_{d3}, \overline{\rho_{ETD}} \in \{\text{dense traffic}\}, \end{cases} \quad (12)$$

where  $1 \geq P_{d1} \geq P_{d2} \geq P_{d3} \geq 0$  is the forwarding probability assigned through the estimated density indicator  $\overline{\rho_{ETD}}$ , which is used here to schedule forwarding probability roughly.  $\overline{\rho_{ETD}}$  can be used to adjust the dynamic  $N_{ECN}$  more precisely in the future.

In particular, the mechanism of LISCast depends on the precise of neighbor information collecting from periodic beacon, which is near real time. So it is normal that the distance between the candidates and sender is larger than  $d_{ECD}$ . In this situation, the waiting time is set zero and the forwarding probability only relays on the  $P_d$ , which reflects the global traffic density in the perspective of the previous forwarder. So that LISCast can adapt to the dynamic topology to some extent. Besides, the farthest-first forwarding rule in LISCast can also maximize the coverage of each hop, realizing rapid dissemination of emergency messages.

**4.4. Retransmission Mechanism.** As we know, there is no handoff or retransmission mechanism like unicast adopted in broadcast scheme of 802.11p MAC layer, so the broadcast reliability may not be ensured. The simplest method to improve reliability is repeating broadcasting emergency messages many times. It will produce heavy redundancy and exhaust the limited spectrum. A retransmission mechanism is proposed by LISCast to ensure the continuance of broadcast. The last forwarder (including the source node)

will start the retransmission progress only in the case of monitoring none duplicates or ACK at the end of the maximum waiting time.

## 5. Simulation and Results Analysis

The popular network simulator NS2 and transportation simulator SUMO [32] are introduced in this section to illustrate and analyze the performance of LISCast.

**5.1. Simulation Scenario.** Take a bidirectional highway with six lanes and 3 km long as an example of scenario. The width of the single lane is ignored comparing to the communication range of 300 meters. 20~100 vehicles enter the highway randomly and drive at the speed of 30~100 km/h using SUMO. Vehicles generate one emergency packet per one second at the probability of 0.5. The other main parameters are summarized in Table 1.

**5.2. Performance Metrics.** To illustrate the effectiveness and feasibility of the proposed broadcast scheme, the following typical protocols are studied comparatively.

**5.2.1. Mflood.** The most original receiver-based protocol is implemented into VANET. Upon receiving a packet, vehicles only in the direction of broadcast in this paper forward it immediately if the packet is new. Broadcast storm in the scenario of dense network needs to be optimized.

**5.2.2. FARTHEST.** The farthest-first scheme is first proposed in [11] for VANET. The vehicles that are farther to the sender are assigned higher priority to access the channel in terms of less waiting time, optimizing hop progress and forwarding latency. That is why farthest is suggested as the basic idea of many protocols.

**5.2.3. Slotted-1.** This is one of the most representative waiting-based schemes in IoV. Slotted-1 firstly waits for the period time  $WAIT\_TIME$  for receiving packets from multi forwarders and then configures waiting time using farthest-first rule for the candidates locating in the divided narrow segments.

**5.2.4. SlottedP.** This is one of the typical probability-based schemes. Similar to Slotted-1, SlottedP assigns priorities of candidates through relative distance between the receivers and forwarders, but forwards packets with a probability (e.g., 50%).

**5.2.5. Mflood, FARTHEST, Slotted-1, and SlottedP.** Represent the most familiar design principles of safety messages dissemination schemes in IoV and have served as benchmarks for quite a few researches, e.g., [9, 16–18]. In LISCast, we configure the forwarding probability  $P_d$  as {0.95, 0.85, 0.75} according to the estimated traffic density, for the purpose of mitigating collision roughly in dense network. As

TABLE 1: Parameters of simulation.

Parameter	Value
Car following model	Krauss
PHY model	TwoRayGround
MAC model	802.11 DCF
Size of CBR	512 bytes
Maximum waiting time	25, 100 ms
Number of segments	5
Forwarding probability, $P_d$	{0.95, 0.85, 0.75}
Simulation time	200 seconds

a matter of fact, this probability-based scheme that LISCast uses in this paper is only an ordinary advice for reducing redundancy, which should be meticulously designed together with the developed density estimation method in the future.

The following performance metrics are evaluated for comprehensively understanding the benefits of LISCast.

**5.2.6. Packet Delivery Ratio (PDR).** It is the percentage of packets covering the whole RoZ among the total packets the sources generate.

**5.2.7. End-to-End Delay (E2ED).** It is the time difference between generating time and receiving time when the messages reach the end of RoZ.

**5.2.8. Broadcast Redundancy (BR).** It is the number of duplicates generating per packet.

**5.2.9. Forwarding Efficiency (FE).** FE is the contribution yields to PDR each hop.

**5.3. Results Analysis.** First of all, this section configures the maximum waiting time as 25 ms and runs the simulation 10 times with different initialization and gets the average values in NS2.

As is shown in Figure 6 that as the increase of vehicle number, the PDR of all the protocols increase as well, because the connectivity of network becomes better, and more vehicles are available to rebroadcast messages. When the number reaches 80 vehicles/3 km, the PDR of most protocols begins to decline, because more frequent collision causes high packet loss due to simultaneous forwarding. Probability scheme are introduced by SlottedP and LISCast to mitigate collision and reduce redundancy, so their PDRs keep increasing even in dense network. Because candidates in SlottedP forward messages in the fixed probability, the PDR is lower than other protocols in the sparse network. On the contrary, LISCast adjusts the forwarding probability according to the estimated real time density and the dynamic distribution of candidates, thus its PDR keeps at the high level. However, the PDR of LISCast is still inferior to that of Slotted-1 when the number is less than 80 per 3 km. That is because the candidates with lower priorities fail to hear the rebroadcasting due to channel fading and interference. And

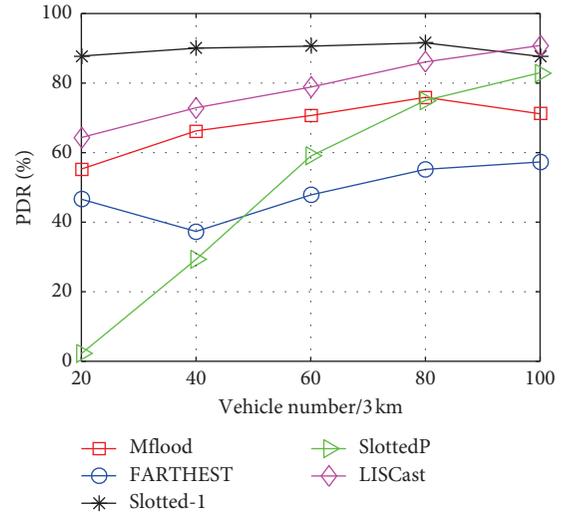


FIGURE 6: Packet delivery ratio vs vehicle number.

they still take part in forwarding, leading to more collision and packet loss. Furthermore, Slotted-1 improves PDR through mitigating erroneous forwarding judgment in the way of waiting for a period of  $WAIT\_TIME$  for receiving message from multisources. Hence, the PDR of Slotted-1 plays best among the chosen protocols. Nevertheless, none measure is adopted by FARTHEST to reduce collision and erroneous judgment, thus its PDR is the worst of all in the most density scenarios.

We can see from Figure 7 that the E2ED of all protocols keeps increasing as the increase of vehicle number. That is because more vehicles compete to forward messages, leading to longer access delay of wireless channel. In particular, the E2ED of FARTHEST, Slotted-1, and SlottedP, which belong to waiting-based forwarding schemes, in the extremely sparse network such as 20 vehicles per 3 km is much larger than that in other density scenarios, 40–60 vehicles per 3 km, for instance. That is because the lower priorities candidates have to wait for the extra time before forwarding, while the higher priorities positions locating none candidates due to nonuniform distribution, which phenomenon is slow response we have discussed in detail in Section 3. Therefore, LISCast uses characteristic information such as effective candidate number and the maximum forwarding distance to assist to assign waiting time for receivers in a distributed way, ensuring the optimal candidates forwarding messages without any extra delay even in the situation of sparse network. Besides, in order to avoid erroneous judgment, Slotted-1 and SlottedP introduce  $WAIT\_TIME$  before forwarding, thus their E2ED is much larger than the three other protocols in which candidates do not have to wait for the extra time. Indeed, the PDR is improved in this way, but is at the cost of increasing delay. On the contrary, LISCast innovatively makes use of effective candidate number to mitigate collision and designs effective forwarding distance to ensure the optimal candidates forwarding without any latency. Hence, its E2ED is much less than other protocols. At the point of 20 vehicles per 3 km, the E2ED of LISCast is 3 times less than that of Slotted-1. The problem of *slow*

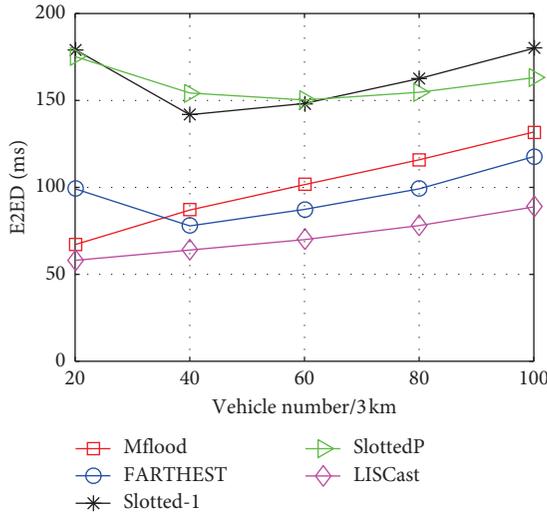


FIGURE 7: End-to-end delay vs vehicle number.

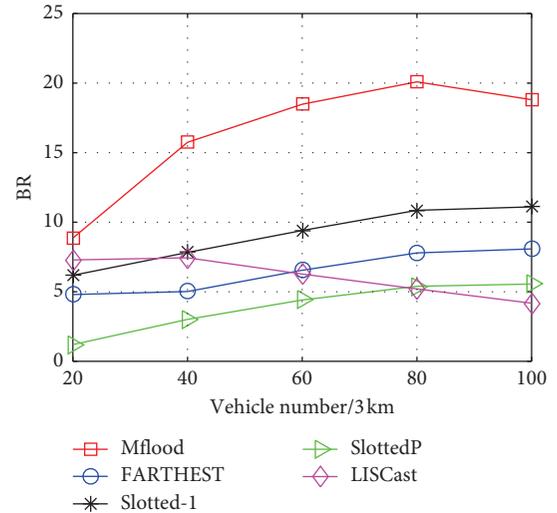


FIGURE 8: Broadcast redundancy vs vehicle number.

response discussed in Section 3 is addressed in LISCast reasonably.

Figures 8 and 9 show the broadcast redundancy and forwarding efficiency vs the number of vehicles. We can see that as the increase of density of vehicles, the connectivity of network gets better, and more vehicles joins to forward packets. Thus, the increasing rebroadcasting aggravates channel contention and packets collision, leading to more redundancy and bringing down the increasing speed of PDR. As a result, all the existed protocols' BR (Figure 8) increase and the FE (Figure 9) decrease inversely, and the descending speed increases with the number of vehicles. This is the problem of *local broadcast storm*. FARTHEST schedules priorities based on the distance between the sender and receivers to restrain near candidates forwarding, so its BR and FE outperform Mflood. Moreover, Slotted-1 divides communication range into some segments to differentiate candidates' priorities so as to reduce redundancy, so its BR and FE are superior to that of FARTHEST, but worse than SlottedP, in which probability forwarding scheme is proposed to alleviate collision in dense network. However, the configuration of fixed probability in SlottedP losses the PDR, especially in the situation of sparse network. Correspondingly, LISCast makes use of characteristic information about dynamic topology such as the maximum forwarding distance, and candidate number and distribution to adjust the number of segments at which candidates locating, and to assign forwarding probability according to sensing traffic density and distribution. As a result, the performance of BR and FE are improved tremendously compared to the other schemes. In this way, the problem of *local broadcast storm* we have analyzed in Section 3 is solved in LISCast with low overhead and in a fully distributed way. Nevertheless, in the sparse network, the performance of LISCast does not very well. That is because the precise of neighbor information, based on which the sensing technology collects characteristic information for forwarding decision, gets worse due to quick mobility of vehicles. So that the adaptive beacon broadcasting scheme is necessary for LISCast to grantee accurate services.

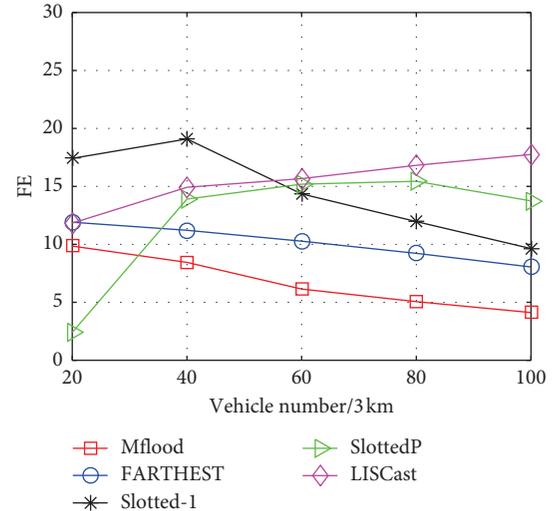


FIGURE 9: Forwarding efficiency vs vehicle number.

Furthermore, we configure the maximum waiting time as 100 ms in the simulation to explore the performance of the proposed scheme, compared with the Slotted-1 in the case of 25 ms.

Figures 10–12 show the delay, broadcast redundancy, and forwarding efficiency of LISCast and Slotted-1 in the case of 25 ms and 100 ms, respectively. We can see from these figures that in the situation of 100 ms, the performance of BR and FE of Slotted-1 is much better than that in the case of 25 ms, but the E2ED is larger. That is because the larger maximum waiting time is beneficial to differentiate the priorities of forwarding, reducing collision caused by simultaneous rebroadcasting, but is at the cost of longer E2ED. Accordingly, in order to balance the broadcast reliability, timeliness and efficiency, LISCast makes use of characteristic information to adjust the waiting delay and probability dynamically according to the local topology sensing technology. As is shown in Figures 10–12 that

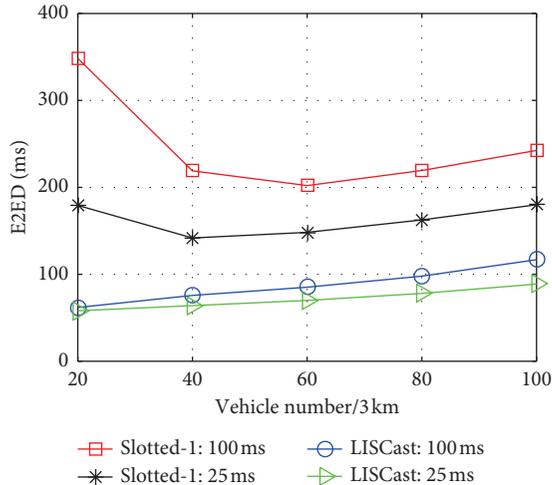


FIGURE 10: End-to-end delay in 100/25 ms vs vehicle number.

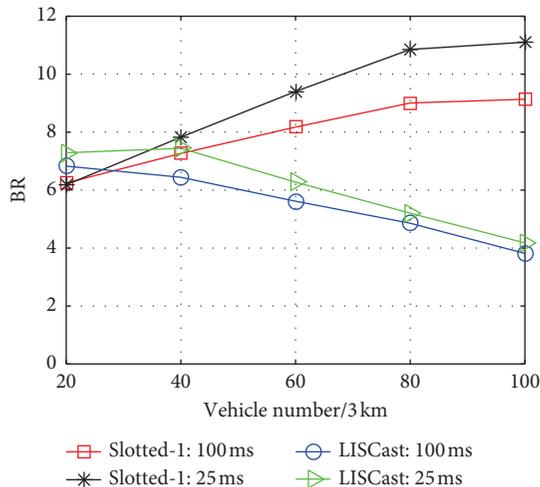


FIGURE 11: Broadcast redundancy in 100/25 ms vs vehicle number.

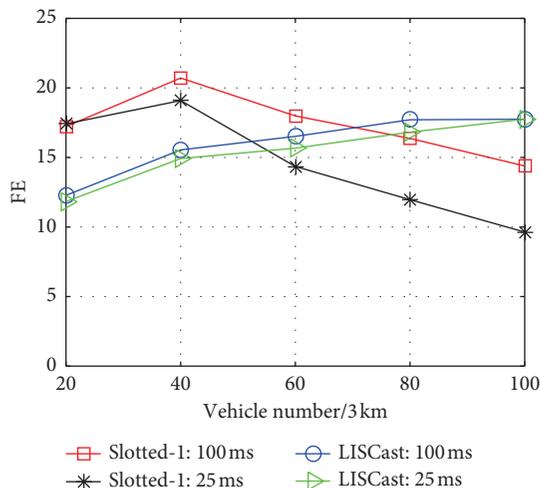


FIGURE 12: Forwarding efficiency in 100/25 ms vs vehicle number.

LISCast perform well both in the two waiting time configurations and is not sensitive to the changing topology. In the case of 100 ms, the E2ED of LISCast is 7 times better than that of Slotted-1 in the sparse network, while in the situation of 25 ms, the BR of LISCast is 3 times better than that of Slotted-1 in the dense network. This observation can show that it is beneficial and feasible for LISCast to optimize the performance using local information sensing technology.

## 6. Conclusions

A local topology information sensing technology based broadcast scheme is proposed in this paper to address the slow response and local broadcast storm problems existing in the typical protocols. LISCast makes use of periodic beacon to collect neighbor information, through which the characteristic information of topology are extracted such as effective candidate number, effective forwarding distance, and effective traffic density. The original information of emergency messages and uniform characteristic topology information of the sender are gathered together for the purpose of assisting receivers to rebroadcast messages in a fully distributed way. The simulation results show that the proposed scheme is effective and feasible on improving the broadcast performance with little overhead. Compared with the typical waiting-based and probability based protocols, LISCast plays the best on end-to-end delay in most kinds of density scenarios and outperforms on broadcast redundancy and forwarding efficiency in the dense networks. However, LISCast does not always work the best, in the sparse networks, for instance, because the characteristic information that BSM provides is not so precise. Therefore, beacon adaptive technology is necessary in the future for the proposed scheme to support more precise services and to improve the availability to adapt to the highly dynamic topology.

## Data Availability

Readers can access the data underlying the findings of the study by sending email to the author Wenjie Wang at isa\_guet@163.com or the corresponding author Tao Luo at tluo@bupt.edu.cn.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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