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A Driver Safety Information Broadcast Protocol for VANET

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Abstract: Due to the highly mobile nature of VANET, especially on highways, a reliable and fast penetration of emergency messages is required so that in-time decisions can be performed. A broadcast routing protocol can perform flooding in sparse network but it will suffer from high control overhead, higher delay and lower packet delivery ratio in dense environment. Since, a significant number of VANET messages including neighbour discovery, safety, destination discovery, location and service advertisements is broadcast, therefore, the area of broadcast routing is important and needs careful design considerations. In this article, we propose ZoomOut Broadcast Routing Protocol for driver safety information dissemination in VANET. In ZBRP, 1-hop neighbour discovery messages are used in an intelligent way based on the speed and inter-vehicle distance of 1-hop neighbours to select a front and a behind vehicle. A neighbour from the front area is called front relative while the neighbour from behind area is called behind relative. During the processing of multi-hop safety messages, only a front or a behind relative rebroadcasts a safety message whereas non-relatives drop it. ZBRP is compared with G-AODV, PGB and DV-CAST through ns-2 simulations. The results show that ZBRP performs better than the stated protocols in terms of network penetration time, packet delivery and broadcast suppression.

Keywords: Information dissemination; CAM; DENM; Intelligent beaconing; Intelligent transportation system; Broadcast suppression.

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1 Introduction

Vehicular Ad hoc Network (VANET) is a highly mobile network that spans in cities and on highways. The wireless communication standard used by vehicles in VANET is the IEEE 802.11p or Dedicated Short Range Communication (DSRC). A vehicle equipped with DSRC can send message to other vehicles in the range of 300 m to 1000 m with 6-27 mbps data rate and with line of sight directionality. Vehicles on the roads move in an organized manner and follow traffic regulations like signals, signs and road separator lines. VANET nodes normally operate in two modes: Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) [1]. For the end-to-end (E2E) communication between two vehicles that are separated by a long distance, any of the V2V or V2I communication model can be used.

VANET has special characteristics like: dynamic topology due to high speed; frequent obstructions like buildings, trees, mountains; variable traffic density; and limited mobility variation subject to roads. MANET protocols are not suitable for VANET [2] because: they perform flooding that limits them to scale for VANET where road density can be very high; do not use position and speed information due to which they produce poor performance; and presume E2E connectivity that cannot be guaranteed in high speed vehicular environment where connections are short lived. Since frequent disconnections and change in topology are inherent property of the vehicular network, therefore topology-based routing strategy that requires establishing an end-to-end path is not suitable for VANET [3,4,5,6,7,8,9]. Since position-based or geographic routing does not maintain E2E path and is performed based on the up-to-date destination position, so it is best suited for VANET where

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network size is scalable [4], [8], [10]. In geographic routing, a vehicle obtains its neighbour information using periodic 1-hop HELLO messages while that of destination is obtained through the use of location service [9].

VANET applications can be categorized as Safety, Traffic efficiency and Infotainment [11]. Similarly the Intelligent Transportation System (ITS) uses periodic or aperiodic message sending strategy depending on the application in use. If neighbour discovery is required then a periodic broadcast message is sent to inform relatives about the availability of neighbour vehicles. Similarly, if an accident, a road obstruction or an ambulance event is detected, then an aperiodic message is sent which needs to be delivered instantly towards the vehicles that are moving towards the scene of emergency. In order to facilitate such situations, IEEE 802.11p WAVE [12] and ETSI have defined an intermediate layer called message sub layer and facilities layer respectively. In the facilities layer two messages called Cooperative Awareness Message (CAM) [13] and Decentralized Environmental Notification Message (DENM) [14] are defined which are aperiodic and periodic respectively [11]. CAM is meant for 1-hop communication whereas DENM is meant for multi-hop communication, with IEEE 802.11p in both message exchanges.

CAM messages contain vehicle position, speed, direction and other related parameters and are periodically emitted by each vehicle after an interval between 100ms to 1000ms. The receiving vehicles add an entry in their neighbour table and update that entry when next CAM message is received. Such an entry is deleted when CAM is not received within the threshold interval. A neighbour entry shows the presence of neighbour. DENM messages are always triggered by an event which can be driver oriented or traffic oriented. The possible events can be roadwork, adverse weather condition, road accident, road obstruction, traffic jam, an approaching ambulance etc. All these conditions are notified by the Road Hazard Signaling (RHS) application [15] of the originating vehicle that broadcasts a DENM message for other vehicles.

In the DENM standard [14], a high level view to process emergency messages is specified whereas in RHS application standard [15] ten important use cases have been documented that explain the detection of emergency situation and the sending of DENM message in the air. However, none of the standard explains the coordination of stations while transmitting or rebroadcasting DENM. The RHS application standard states that the first DENM message shall be emitted immediately while the subsequent DENM messages shall be transmitted periodically based on the priority of the traffic situation. For the critical safety situation, the priority is 0 or 1 and the period is less than or equal to 100ms. On the other hand, for the non-critical safety situation, the priority is 2 and the period is between 100ms and 1000ms. The RHS and DENM standards do not state how vehicles would coordinate while sending DENM. As a result, there could be broadcast storm on the Control Channel 178 (CCH 178) in IEEE allocated spectrum or, on the 5 GHz Service Channel 2 (G5SC2) in ETSI allocated spectrum. This broadcast storm can affect other vehicles that might also want to report some critical or non-critical road condition. Both CCH178 and G5SC2 operate at 5.890 GHz frequency.

The proposed ZoomOut Broadcast Routing Protocol (ZBRP) is an information dissemination protocol with high degree of broadcast suppression, high probability of successful message delivery and fast network penetration. ZBRP has two components ZoomOut HELLO (ZOH) [16] and ZoomOut Emergency Message (ZEM), where ZOH is a network layer message while ZEM is an application layer message. ZEM works on top of ZOH functionality. During ZOH, intelligent 1-hop beaconing (improvement of CAM) is performed to not only build 1-hop neighbourhood view but to also identify few 1-hop neighbours as relatives. These relatives are later used as relays for the dissemination of all type of messages including ZEM (our view of DENM) and to also suppress broadcast traffic on CCH 178 or G5SC2. The rest of the paper is organized as follows. Section (2) explains the related work in the context of broadcast suppression techniques to mitigate broadcast storm problem as explained above, section (3) states motivation of the proposed work, section (4) explains the detailed design of the proposed ZBRP, section (5) is analytical evaluation of the proposed protocol, section (6) is simulation setup and results while the last section is conclusion.

2 Related Work

In VANET, majority of the times a protocol performs broadcast suppression as there are vehicles on the roads almost all times of the day. During opening and closing hours of offices and schools; on weekends; and on national holidays, there is heavy traffic or even traffic jams. In this case, every vehicle is surrounded by a large number of vehicles. During other times of the day when traffic is normal, still many vehicles are present in 1km vicinity as sensed by DSRC based IEEE 802.11p transceiver. If an accident on road occurs, the traffic tends to slow down and starts queuing up. In these circumstances vehicles approaching from behind need to be informed about the traffic jam or rush and also about accident or road obstruction so that an alternate path can be chosen and sudden strikes can be avoided. The broadcast suppression comes into play at such times. However, when the network is disconnected, store-carry-and-forward scheme is used.

Broadcast routing protocols share road conditions, urgent situations with vehicles, advertisements and announcements [17]. These protocols start from flooding and become complex by putting intelligence as to suppress redundant packet broadcast and move towards limited broadcast. Flooding guarantees the arrival of the message to all destinations but incurs heavy control traffic and delay in data transmission. If flooding is done in dense traffic environment, then collisions occurs and overall network performance degrades.

Reliable message dissemination over 802.11p networks is hindered by a number of problems including the most important broadcast storm that creates congestion for data flows currently taking place. A number of channel access mechanisms and congestion control schemes have been proposed to ensure that a driver safety message will be delivered with the best possible achievable service guarantees. Since VANET uses IEEE 802.11p- whose broadcast range is 1km, therefore multi-hop forwarding is required. This paper considers broadcast schemes as emergency messages are normally meant for the whole traffic coming towards the point of emergency e.g. accident/traffic jam or an approaching ambulance. We therefore only discuss VANET broadcast protocols. In Smart Broadcast [18] authors present distance based forwarding technique that elects the farther vehicle in communication range as the rebroadcasting vehicle called relay on black-burst. The technique presented in Urban multi-hop broadcast protocol [19] exchanges message among nodes to calculate inter vehicle distance and then select the rebroadcasting vehicle which is farthest from the sending vehicle. The Multi-hop vehicular broadcast scheme [20] adjusts beacon frequency based on the number of 1-hop neighbours. As a result, network congestion is controlled.

Akkhara et. al. propose efficient alarm messaging [21] that uses waiting time approach. In this strategy vehicles having least timer value rebroadcast. The preference is given to the vehicle that is farthest in the communication range. The same concept of waiting time is proposed by Preferred group broadcast (PGB) [22] where each vehicle classifies itself with respect to received signal strength of sender and classifies itself into IN group, preferred group (PG) and OUT group. If the receiving node lies in the preferred group (PG), it can rebroadcast. Before, rebroadcast, the node in PG group has to wait for a hold off time interval to confirm that another vehicle belonging to PG has not broadcasted the emergency packet. A node in the PG after receiving two rebroadcasts during the hold off time will drop the emergency packet. The concept of hold off timer adds further delay in the delivery of emergency packet. The main issue here is that when the hold off time expires and the node decides to retransmit, the channel may be busy. The node has to wait for channel access. During the time, this node is waiting for random channel access; two other nodes rebroadcast. Now this node is unaware of it, so it will rebroadcast the emergency packet. Secondly, each PG that rebroadcasts adds additional information in the emergency field of the routing protocol, which means a routing protocol on top of PGB, has to reserve extra fields so that it can function correctly.

In Reliable Opportunistic Broadcast in VANETs (R-OB-VAN) [23], an acknowledgement scheme called active signaling phase takes place among 1-hop neighbours. Predecessor selects a vehicle and the rebroadcast is done by that vehicle. According to the procedure, all neighbours enter into random listening and produce an acknowledgement that is basically the sequence of send and receive intervals. A send is represented by 1 and receive is represented by 0. The best progressive vehicle is selected by the predecessor who then rebroadcasts. Among neighbours, if a vehicle listens an ACK from another vehicle, it infers that another better vehicle is available to rebroadcast, so it does not send its signal. The active signaling phase adds a delay of t which is the sum of inter frame spacing and ACK.

There are few protocols that use link disconnections along with velocity and select the rebroadcasting vehicle. Example of such scheme is GVGrid [24]. The work presented by Torrent-Moreno et. al., in [25] changes the transmission power to guarantee channel access among neighbours. However, 1-hop neighbours and network density are exchanged via control messages causing further congestion in the network. Unfortunately, the timer based approach and the exchange of extra information incurs delay and congestion respectively, which cannot be an ideal choice while broadcasting driver safety information.

The Distributed Vehicular Broadcast (DV-CAST) [26] uses states associated with vehicles and considers broadcast suppression in dense VANET environment and store-carry-forward in disconnected VANET environment. DV-CAST uses Message Direction Connectivity (MDC), Opposite Direction Connectivity (ODC) and Destination Flag (DFlg) variables on each vehicle. The algorithm uses these three flags to decide whether it has to perform broadcast suppression or carry forward. If a vehicle has next hop connectivity in the direction of message then its MDC flag is set to 1 otherwise it is 0. If a vehicle has next hop connectivity opposite to message forwarding direction, its ODC flag 1 otherwise its 0. Finally, if a vehicle is approaching towards the direction of accident, its DFlg is 1 because it is the intended recipient of the message. DV-CAST suggests that slotted 1-perseistence be used for broadcast suppression and the waiting time be set based on the value of relative distance of rebroadcasting vehicle from the sending vehicle. A vehicle farthest in the communication range gets benefit out of it and rebroadcasts early than the vehicle near to the sending vehicle.

Authors in Position-based adaptive broadcast [27] guarantee message delivery by taking help from the global map which is constructed using the velocity and position of vehicles. Like other map based techniques, it also suffers from delay which is the main parameter while evaluating broadcast message of driver safety. The scheme presented in Dynamic time-stable geocast routing [28] suffers from control message overhead as they frequently exchange control messages to form clusters.

The information in the table entries in cluster-based approach is stale as the vehicles move with high velocity and when the update of their position reaches the end of intended vehicle, the sending vehicle has already changed its position. The exchange and handling of cluster formation messages itself creates congestion and delay. Same is the problem with Reliable geographical multicast routing [29] technique.

3 Motivation

The schemes presented in the previous section suffer from control message overhead and wait time delay to suppress broadcast messages. In the above techniques, HELLO is used to discover neighbours whereas emergency broadcast message works independently to carry the safety message towards the end of VANET fleet. The above techniques suffer from one or more of the following high control overhead, high information dissemination time and low message delivery probability.

Our view is slightly different. We argue that, if neighbour discovery is performed carefully in an intelligent way (local view of network) then few 1-hop neighbours can be discovered such that a broadcast routing protocol can use them at the time of rebroadcast. This is divide-and-conquer strategy because the selection process is performed by neighbour discovery while rebroadcasting is performed by the routing protocol. In the proposed model, there is no group decision making for the rebroadcasting vehicle and therefore there is no additional delay. The packet smoothly travels and reaches at the end of VANET fleet informing all non-relative vehicles in the way. This VANET model may ultimately prove to be more reliable and faster to disseminate information with high packet delivery and reduced rebroadcast overhead.

4 The Proposed ZoomOut Broadcast Protocol

The proposed ZoomOut Broadcast Routing Protocol (ZBRP) is a network-cum-application layer protocol with two components ZOH [16] (layer 3) and ZEM (layer 7), where the later works on top of ZOH. During ZOH, reference pointers are maintained at the sender and receiver of ZOH. ZBRP takes benefit of these soft states while disseminating ZEM. Table 1 defines ZOH and ZEM messages that are exchanged between zoomOut vehicles. For reporting position and speed, zoomOut vehicles use HELLO; for informing relative ZOH is used; and for disseminating safety or non-safety messages, ZEM is used. ZBRP can also work in the disconnected VANET environment which is a specific situation that arises when an emergency message (EM) needs to be delivered to the vehicles approaching towards the scene of emergency but there are no vehicles in between. So, the last vehicle travelling in the direction of EM stores the packet and carries it forward until a vehicle approaching towards emergency location is found or another vehicle in the same direction is detected in front of it.

4.1 Working of ZoomOut HELLO (ZOH)

In this section, we present enhanced functionality of ZOH [16]. If CAM support is not available in the On-Board Unit (OBU) of vehicle Z, it would be sent as an independent ZOH message. However, if CAM support is available, the proposed ZOH message would be encapsulated inside the Low Frequency (LF) Option of CAM [13] and would then be termed as ZoomOut HELLO Container. After every nb_interval=100ms, a HELLO is broadcasted perpetually while, a ZOH is sent after zor_interval. The minimum size of ZOH would be CAM+16bytes (sum of mandatory fields and IP address of one relative) whereas its maximum size would be CAM+24bytes (sum of mandatory fields and IP address of two relatives).

Both HELLO and ZOH are meant to update neighbours about the position and speed of sender. However, ZOH additionally informs those neighbours that have been chosen as relatives of sender. The relatives on front side of vehicle Z are called Front relative (FR) while the relatives on the behind side are called Behind relative (BR) as shown in Fig 1. The senders and receivers of ZOH maintain reference pointers towards sender which is explained in the next sub-section. A vehicle Z discovers its relatives at periodic interval given by:

$$zor_{interval} = \alpha \times nb_{interval} \tag{1}$$

where, $\alpha \in [15,25]$.

On high speed roads, vehicles move between 80km/h to 130km/h as suggested by World Health Organization [30]. A vehicle with this speed covers a distance between 34m to 90m when zor_interval times out and find_relatives() functionality is invoked to update relatives.

4.1.1 Calculating reference points x_1,x_2,x_3 and x_4

If P_Z and R are the current position and the broadcast range of vehicle Z in meters respectively, then points x_1,x_2,x_3 and x_4 as given as:

$$\delta = S_z \times T \tag{2}$$

$$x_1 = P_z + \delta \tag{3}$$

$$x_2 = P_z + (R - \delta) \tag{4}$$

Table 1: ZBRP MESSAGES

Type	**Name**	**Detail of ZoomOut Messages**
Periodic	HELLO/CAM	Traditional HELLO

	ZoomOut
	HELLO (ZOH)
		struct VehicleInfo
		{
		int vehicleID; // 10.11.20.30
		double latitude; // 4.3856557^{o}
		double longitude; //100.979269^{o}
		short speed; // 110 km/h
		short direction;
		};

	(extended
	HELLO/CAM)
		struct ZOH
		{
		int BR; // 10.11.21.75
		int,FR; // 10.11.22.101
		VehicleInfo selfInfo;
		};

Aperiodic	ZoomOut
	Emergency
	Message (ZEM)
	
	(our view of DENM)
		struct ZEM
		{
		int em_type; // 1, 3, 5
		char em_message[35]; // (”road accident ”, ”traffic jam”,etc.)
		int em_hop_count;
		int em_bcast_id; // 1, 2, 3, ,
		nsaddr_t em_src; // 10.11.23.125
		nsaddr_t,em_dst; // 10.51.17.200
		double em_timestamp;
		int em_direction; // Behind=1,
		double em_xAxis; // Position
		double em_yAxis;
		};

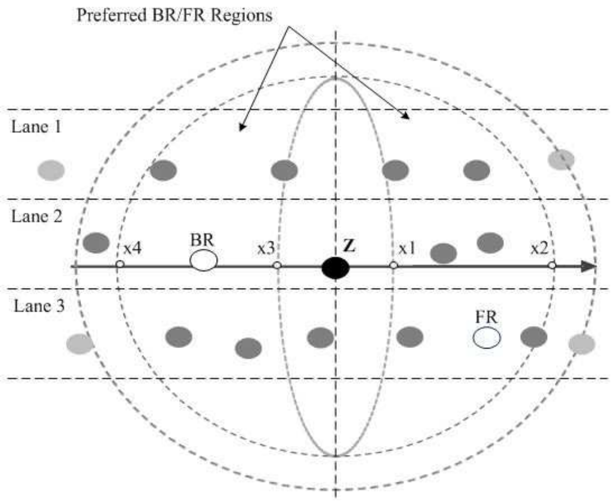


Fig. 1: Broadcast region of vehicle Z is shown by outer dotted circle. Vehicles inside the range are neighbours. Among neighbours, one vehicle is Behind Relative (BR) while other is Front Relative (FR).

$$x_3 = P_z - \delta \tag{5}$$

$$x_4 = P_z - (R - \delta) \tag{6}$$

where, δ is the distance in meters and $T = 4.5$ seconds is a fixed interval. From Eq. 1 and Eq. 2 we observe that $T > zor_{interval} > nb_{interval}$. Hence, vehicle Z would get a preparation time of T seconds to compute its new relatives. In can be observed in Fig. 1 that FR is chosen between points x_1 and x_2 while BR is chosen between points x_3 and x_4.

4.1.2 Maintaining reference pointers

In Fig. 2, we present sequence diagram of ZOH messages that are exchanged between neighbours to shows how soft states are maintained on sender and receiver of ZOH. As an example, vehicles E, A, D, W and P are shown to exchange ZOH message. The soft states are the variables that are maintained at the vehicles that send and receive ZOH message. The reference pointer at the ZOH sender is the set of variables Behind Relative (BR) and Front Relative (FR) whereas the reference pointer at both receiving ZOH vehicles (relatives) is the set of variables Behind Neighbour (BN) and Front

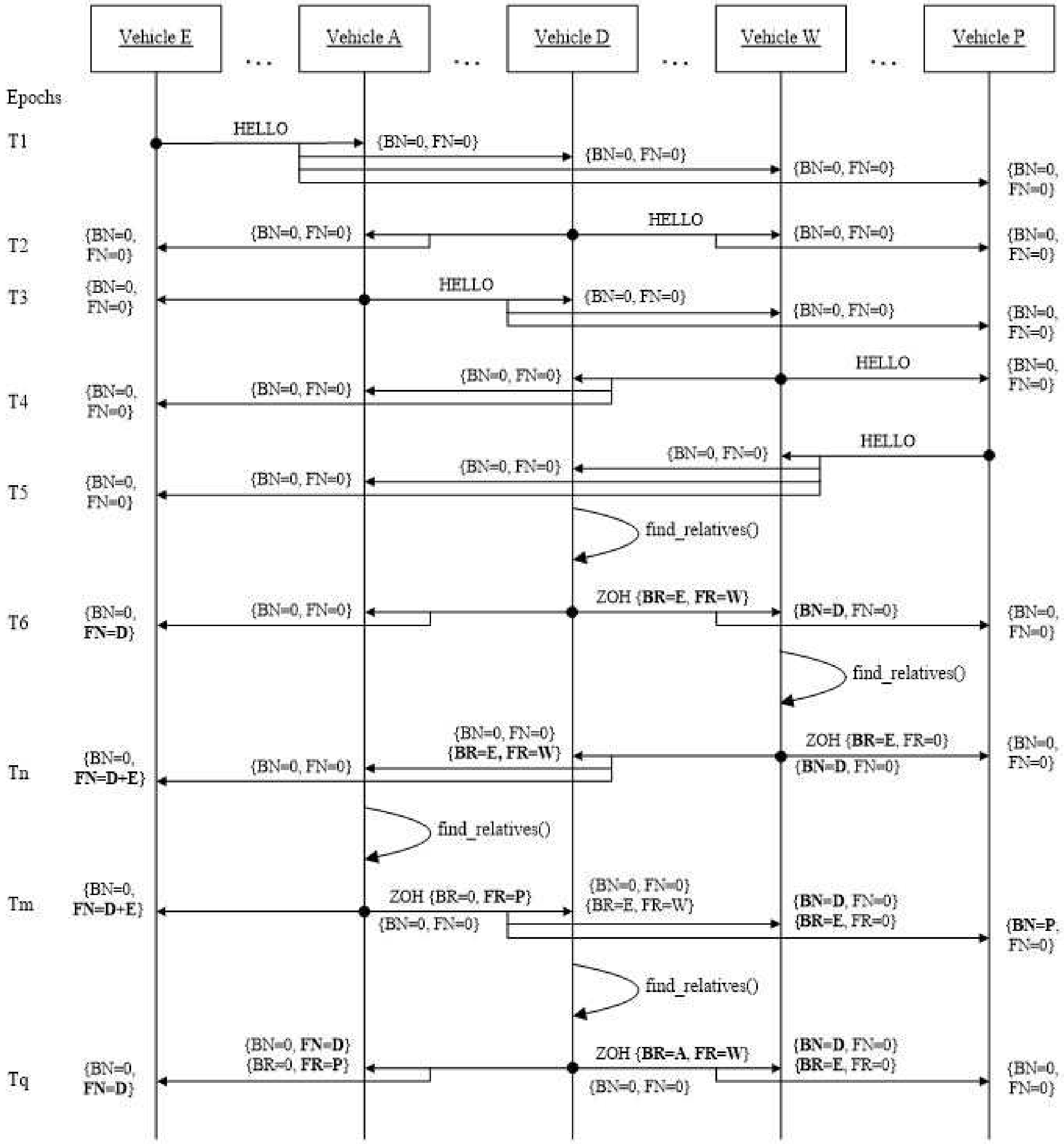


Fig. 2: Sequence Diagram of ZOH message. Each message has a time stamp associated with it (e.g. T6, Tn, Tq, etc.)

Neighbour (FN). Initially, each vehicle sends HELLO message to build its neighbourhood. This is basically the phase when each vehicle informs its neighbours about its presence. Then, the aperiodic $find\_relatives()$ procedure of vehicle D is invoked that discovers E and W, as its behind and front relatives respectively. The IDs of vehicles E and W are stored in the variables BR and FR respectively. This information is then sent by vehicle D in ZOH message as represented at the timestamp $T6$ in Fig. 2. All vehicles receive this message and update the position and speed of vehicle D in their neighbour table whereas vehicles E and W store the ID of vehicle D in the FN and BN variable respectively. Doing this, a reference pointer is said to be maintained on the relatives as well.

As shown in Fig. 2, the aperiodic function $find\_relatives()$ runs next at time T_n on vehicle W. Based on the relative speed and distance, vehicle E becomes BR. This information is communicated to vehicle E via

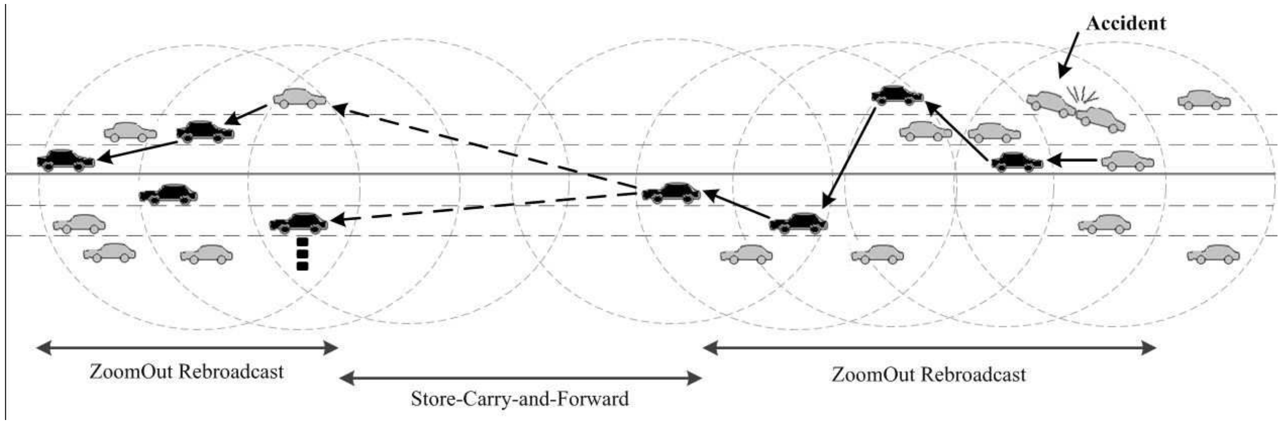


Fig. 3: Procedure of ZBRP

ZOH message. Only vehicle E updates its reference pointer. The same concept is repeated by vehicle A at time T_m. It can be observed in Fig. 2 that a HELLO message is not shown between ZOH messages but, in reality a HELLO is sent after every $nb\_interval$. If a vehicle changes it FR or BR vehicles (connectivity) due to change of IVD with neighbours, the updated information is passed by sending a ZOH message. At time T_q, the same can be observed. Vehicle D detects that its new BR is vehicle A, so it sends this ID in ZOH and the reference pointers are updated at relatives E and A.

4.1.3 Selecting Relatives of vehicle Z

The implementation of $find\_relatives()$ is based on Eq. 7 - 10. Let S_Z,S_i,P_Z and P_i are the speeds and positions of vehicle Z and 1-hop neighbour n respectively. If m and n are total vehicles in the front and behind region respectively, we can explain four cases.

Vehicle Z is faster than front neighbour

The relation to find a front relative that gives longest connectivity among 1-hop front neighbours is given as:

$$FR_{S_Z > S_i}^{(x1,\ x2)} = \max_{V_i=1}^{m} \left\{ \frac{P_Z - P_i^{(x1,\ x2)}}{S_Z - S_i^{(x1,\ x2)}} \right\} \tag{7}$$

Vehicle Z is faster than behind neighbour

The relation to find a behind relative that gives longest connectivity among 1-hop behind neighbours is given as:

$$BR_{S_Z > S_i}^{(x3,\ x4)} = \max_{V_i=1}^{n} \left\{ \frac{P_i^{(x3,\ x4)} - P_Z}{S_Z - S_i^{(x3,\ x4)}} \right\} \tag{8}$$

Vehicle Z is slower than front neighbour

The relation to find a front relative that gives longest connectivity among 1-hop front neighbours is given as:

$$FR_{S_Z < S_i}^{(x1,\ x2)} = \max_{V_i=1}^{m} \left\{ \frac{P_Z - P_i^{(x1,\ x2)}}{S_i^{(x1,\ x2)} - S_Z} \right\} \tag{9}$$

Vehicle Z is slower than behind neighbour

The relation to find a behind relative that gives longest connectivity among 1-hop behind neighbours is given as:

$$BR_{S_Z < S_i}^{(x3,\ x4)} = \max_{V_i=1}^{n} \left\{ \frac{P_i^{(x3,\ x4)} - P_Z}{S_i^{(x3,\ x4)} - S_Z} \right\} \tag{10}$$

4.2 Working of ZoomOut Emergency Message (ZEM)

To highlight the functionality of ZEM, an accident is shown in Fig. 3 whose alarm is generated by a nearby vehicle through the method as explained in RHS [15]. The vehicles in black colour are either BR or FR depending upon the direction of motion. It can be observed that the emergency message is dropped at the end of store-carry-forward region by the vehicle moving in the direction of packet. It is because a vehicle in the opposite lane is sensed and therefore ZEM is passed to it. For any emergency condition, for example accident, the vehicles nearby shall send an alarm indicating the presence of emergency. An alarm can be rebroadcasted on the CCH 178 or G5SC2 only by the *relatives* of a vehicle that emits an emergency message.

Due to the exchange of periodic ZOH messages and the presence of reference pointers, a vehicle knows its role at the time of rebroadcasting a specific Emergency Message (EM). Since, a road event is normally meant for the vehicles approaching to the scene of emergency,

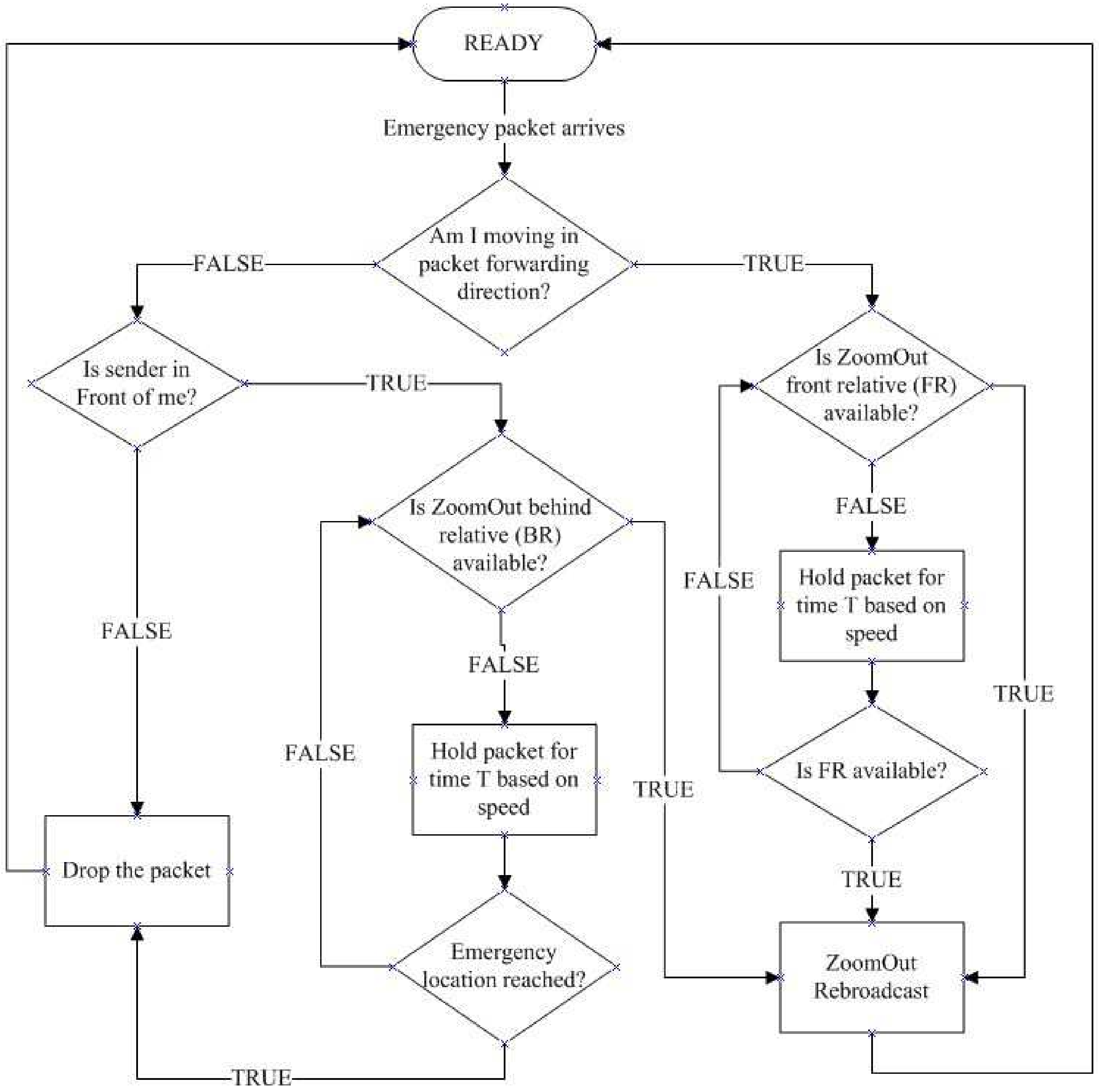


Fig. 4: Procedure of ZBRP

therefore when ZEM is generated by an event-detecting source all 1-hop vehicles in the direction of EM check their local soft states. If FN contains the ID of predecessor, the receiving vehicle considers itself to be the relative of predecessor and then checks its BR connectivity. If BR connectivity is not null, ZEM packet is immediately rebroadcast by the receiving vehicle. This process is iterative and therefore only a chain of BRs of the originating vehicle would rebroadcast as shown in Fig. 3.

If the BR connectivity of a vehicle is null, but there is an opposite lane connectivity (OLC), the packet would still be rebroadcast. Since opposite lane vehicle is moving in the direction of EM therefore it would check its FR connectivity and the packet would immediately be rebroadcasted if FR connectivity is not null. However, if FR connectivity of vehicle moving in the opposite lane is null, the packet will be stored and carried forward until it is handed over to a vehicle that is coming towards the emergency location. Lastly, if BR connectivity of the vehicle moving in the direction of emergency is not null, EM would be dropped by the vehicle if it crosses the scene of emergency. The detailed handling of ZEM packet is given in Fig. 4 and implemented in NS2.33.

5 Analytical Evaluation of ZBRP

In this section, we present analytical study of ZBRP based on four metrics that are: (1) hop count, (2) network penetration time over N-km area, (3) broadcast suppression of ZEM, and (4) the probability of successful message delivery of ZEM. We need to first understand the channel access mechanism of IEEE 802.11p. Since ZBRP is a Network layer protocol, therefore this section considers MAC and Network layer delays.

5.1 Channel Access Delay

In IEEE 802.11p WAVE, queue scheduling mechanism is FIFO which is inherited from IEEE 802.11e EDCA, and the channel access mechanism is CSMS/CA with Distributed Coordination Function (DCF) because RTS/CTS scheme incurs control overhead [31]. In reality a packet at a non- head position in the queue actually waits for the successful transmission of the packets in front of it in the queue. A queue head packet is actually dependent on the medium access and the propagation delays. In IEEE 802.11p, transmission delay $(T_t ransmission)$ is ¡ $4s$ while the channel access unit Slot time $(T_s lot)$, is $16s$ [31]. In the analytical system, each vehicle has a queue with N slots and FIFO scheduling. Let us represent a frame by pkt_z where, z is packet type within the flow.

We consider a VANET fleet with v vehicles stretched over a highway of D-km. Let there are $M(<v)$ vehicles in a broadcast range. If the channel is idle then channel access time to successfully transmit a frame at queue head is T_1 whereas if channel is busy then channel access time to successfully transmit a frame at queue head is T_2. These are given as:

$$ACK = SIFS\ (32\mu s) + T_{slot}(16\mu s) + T_{transmission}(<4\mu s) \tag{11}$$

$$T_1 = DIFS\ (64\mu s) + pkt_z + SIFS + ACK \tag{12}$$

$$T_2 = \left(\sum_{r=1}^{rand[0,\ Max_{ret}]} CW_r \right) + T1 \tag{13}$$

For the first channel grabbing vehicle, the medium could be either idle or busy. By considering both cases, we represent the random channel access delay, $d_c hannel$, at the turn m of vehicle v and represent it as:

$$d_{channel} = \sum_{k=1}^{m-1} T_2^k \tag{14}$$

If frame pkt_z is at position p in queue, its delay is the sum of delays of all frames in front of it. The delay equation will become:

$$d_{pkt_Z}^v = \sum_{j=1}^{p-1} \left(d_{channel}^j \right) = \sum_{j=1}^{p-1} \sum_{k=1}^{m-1} T_2^{jk} \tag{15}$$

5.2 Number of Relatives over D-km Area (hop count)

The number of relatives, L_N over D-km area, also called hop count, is the sum of relatives needed to propagate a message over N-km area and can be given by the following relation:

$$L_N = [N,\ 2N] \tag{16}$$

5.3 Network Penetration Time of ZEM

Network penetration time, also called ETE delay, is the time which starts when a ZEM packet is transmitted by and event-detecting source and ends when the same packet reaches at the end of VANET fleet over D-km area. Network penetration time of ZEM is the sum of delays incurred on relatives plus the wait time during retry (in milliseconds) represented by $T_{ret-ZEM}$. Network penetration time can therefore be computed using Eq. 15 and 16 as given below:

$$D_{pkt_{ZLU}}^{ETE} = \sum_{i=1}^{L_{behind}} \left(T_{ret\_ZEM} + d_{pkt_Z}^v \right)$$

$$+ \sum_{i=1}^{L_{front}} \left(T_{ret\_ZEM} + d_{pkt_Z}^v \right) \tag{17}$$

$$= \sum_{i=1}^{L_{behind}} \left(T_{ret\_ZEM} + \sum_{j=1}^{p-1} \sum_{k=1}^{m-1} T_2^{jk} \right)$$
$$+ \sum_{i=1}^{L_{front}} \left(T_{ret\_ZEM} + \sum_{j=1}^{p-1} \sum_{k=1}^{m-1} T_2^{jk} \right)$$

where, $T_{(ea_Z EM)} = 3ms$ and is explained in section E.

5.4 Control Message Overhead of ZEM

The control overhead of a ZEM packet is the sum of broadcasts by the ZEM originating vehicles and by all relatives. According to Fig. 3, ZEM message propagates in one direction which is opposite to the direction of motion of vehicles moving towards the scene of emergency. Therefore, the number of control messages is equal to the number of relatives behind plus the number of retries performed at each relative which is maximum two. The control message overhead of ZEM over D-km can be computed from the following relation:

$$CO_{ZEM} = \sum_{i=1}^{L_{behind}} \left(i + \sum_{j=1}^{[1,\,2]} ret_j \right) \qquad (18)$$

where, $ret_j \in 1,2$ is the number of retries by a relative

5.5 Probability of Successful Message Delivery of ZEM

The probability of successful ZEM message delivery can be modelled by understanding the retry operation of ZEM as shown in Fig. 5. When vehicle Z originates a ZEM message, it also waits for T_{ret_ZEM} time to hear the retry from its relative. Since rebroadcasting relative is only one, therefore, single point of failure can occur and ZEM packet may be dropped. Due to this reason, every time a ZEM packet is broadcasted, the broadcasting vehicle performs maximum 2 retries to attempt to hear the rebroadcast of the same packet. If during the three attempts (one rebroadcast and two retries), it does not hear rebroadcast, the ZEM packet is considered to have been be dropped. A ZEM packet is rebroadcasted after an interval of 2 seconds by a vehicle that is within 1km vicinity. It means if the speed of a vehicle is in the range 80km/h to 130km/h, it will receive next ZEM after travelling a distance in the range 44m to 72m.

It is also important to note that the criticality of ZEM is highest for vehicles within 1km range. It then decreases subsequently for every farther vehicle. In Fig. 5, the first rebroadcast failure is transitioned into first fair chance and second rebroadcast failure is transitioned into second and final fair chance. After which if ZEM rebroadcast is unsuccessful, it is considered as dropped. It means the successful rebroadcast probabilities over the sample space success,failure in 1-km region, represented by R_1, can be given as:

$$P^{R_1}_{ZEM}\left(Rebroadcast\right) = 1 - q3 \qquad (19)$$

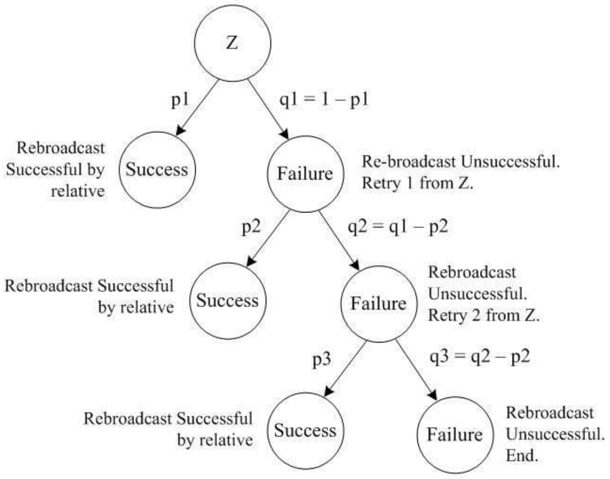


Fig. 5: Probability of ZEM rebroadcast

The successful rebroadcast probability over the sample space success,failure in the *Dth*-km area, given as $P^{R_N}_{ZEM}(Rebroadcast)$ is independent from the successful rebroadcast probability over the sample space success,failure in the *(D-1)th* km area, given as $P^{R_{N-1}}_{ZEM}(Rebroadcast)$. In other words, the retry algorithm running in the *Dth* region runs independently but its invocation is dependent on the successful broadcast of the retry algorithm running in the *(D-1)th* region. Same procedure applies to $P^{R_2}_{ZEM}(Rebroadcast)$ to $P^{R_1}_{ZEM}(Rebroadcast)$. Since finding success probabilities for retries from region 1 to N is the set of independent compound events, therefore, using Eq. 19, we compute the probability $P^{R_N}_{ZEM}(Success)$ of successful delivery of packet P_{ZEM} via N relatives and is given as:

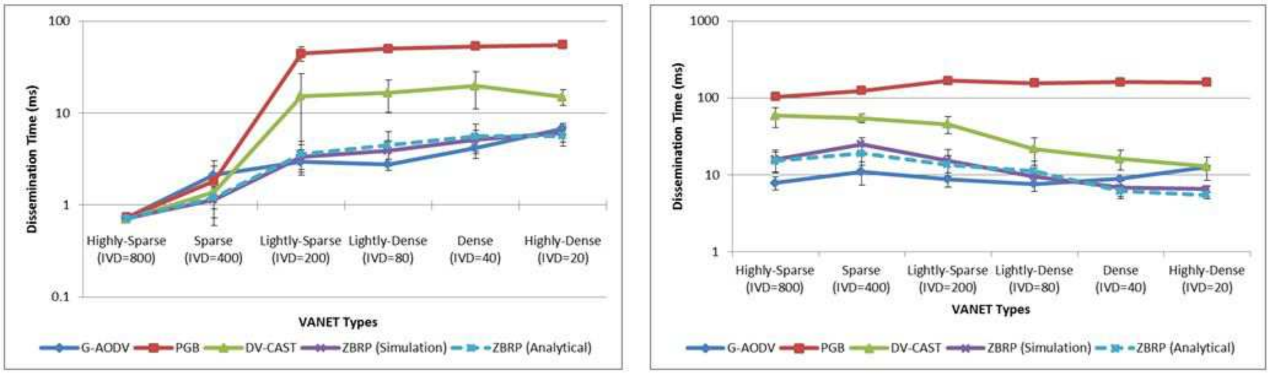
$$P^{R_N}_{ZEM}(Success) = \prod_{i=1}^{L_N} P^{i}_{ZEM}(Rebroadcast) \qquad (20)$$

6 Simulation Setup and Results

We performed simulations in NS2.33 with IEEE 802.11p MAC using 3-lane highway scenario. For mobility, we used MOVE which in turn uses SUMO (Simulator of Urban Mobility). Our mobility simulations use SUMO 0.13.1. We have compared the proposed ZBRP with PGB [22] and DV-CAST [26] protocols which are the most prominent broadcast mechanisms in VANET. We also include geographic version of AODV [32] because its broadcast mechanism is widely used and is different from PGB and DV-CAST. The implementation of these protocols is done by authors and is available in NS2.33. Each graph represents simulation and analytical evaluation of ZBRP.

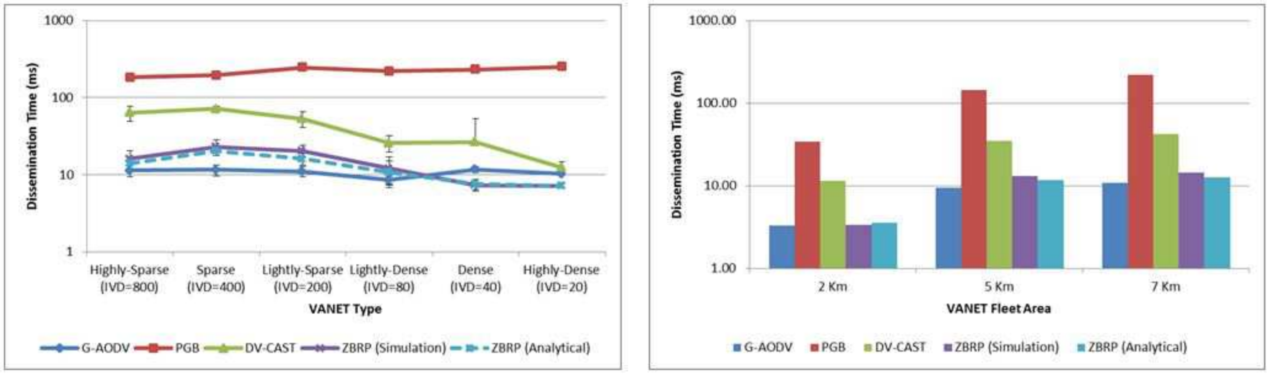
In our mapping, the IVDs 800m, 400m, 200m, 80m, 40m and 20m correspond to highly sparse, sparse, *lightly sparse*, *lightly dense*, *dense* and *highly dense* VANET types respectively. Considering an area fix (e.g. 2km), we performed 10 experiments for each VANET type. Since EM frequency is 2s as given in Table II therefore, a mean of 10 simulations is actually a mean of 500 emergency messages. All the results are drawn using 95% Confidence Interval (CI).

It is also important to mention here that a smaller CI value represents consistency of the protocol behaviour in a particular simulation environment. A larger CI value means that the confidence from mean value is low. As stated, it is due to the non-uniform behaviour of the protocol. In order to test EMs close to real environment,



(a) 2km, 3 lanes

(b) 5km, 3 lanes



(c) 7km, 3 lanes

(d) ZoomOut view of the dissemination times (each bar is average of mean values presented in Fig. 6–a,b,c)

Fig. 6: Network Penetration Time. (a), (b) and (c) represent the comparison of network penetration time between ZoomOut and non-ZoomOut (G-AODV, PGB and DV-CAST) techniques on the logrithmic scale with 95% Confidence Interval.

data traffic was initiated between vehicles moving at two ends of the VANET fleet. For PGB, DVCAST, G-ADOV and ZBRP, the simulation environment was kept same. In NS2, at the start of each simulation, we assigned random speeds to vehicles between 80km/h to 120km/h inclusive.

Table 2: SIMULATION PARAMETERS

Name	Description
BeaconInterval_ (CAM)	100 ms
Vehicle Speeds	80km/h 120km/h
Propagation Model	TwoRayGround
No. of Lanes	3
Vehicle Size	5 m
VANET Fleet Area	2 km, 5 km, 7 km
Inter vehicle distance (IVD)	{800, 400, 200, 80, 40, 20} m
CWMin_, CWMax_	15, 1023
Simulation time	100 s
Data traffic (Start,End)	(5s, 98s)
EM Frequency	Every 2 s

6.1 Network Penetration Time

Fig. 6 gives a detailed comparison of the emergency messages over VANET fleet area of 2km, 5km and 7km. Since an emergency message is meant for every vehicle moving towards the scene of emergency, therefore we calculate network penetration time when an emergency message reaches at the end of VANET fleet. In other words, we observe that how much time is taken to cover a distance of 2km, 5km and 7km when a particular EM dissemination technique is applied. The values shown below use logarithmic scale with CI=95% and are mean of 10 experiments as explained above.

Fig. 6(a, b, c) shows that in PGB, when VANET is *sparse* and *highly sparse*, the number of vehicles is few in one broadcast range therefore, packet drop is negligible. In 2km area, VANET fleet is quite small so time taken by EM to reach the other end of VANET is smallest whereas, this value is quite high for 5km and 7km areas. When the network gets dense form *lightly sparse* to *highly dense*, packet drop starts to increase. Although nodes in the PG group rebroadcast but EM is often dropped. Therefore, backup vehicles in the OUT group after wait interval, as mentioned above, rebroadcast. PGB trend in Fig. 6 (a, b, c) shows that when there are few vehicles and the area is also small, the delay to penetrate EM in the network is also small but, when number of vehicles and VANET area increases and packet drop starts to occur, the delay starts to increase as vehicles in the OUT group do not hear enough rebroadcasts and therefore, they go into wait increasing delay in per broadcast region.

In DV-CAST, 1-persistance broadcast suppression is used where a vehicle farthest from the sender has the least timer value to rebroadcast. If one vehicle broadcasts, other vehicles in range simply drop the packet on hearing that rebroadcast. The results of 2km are different in trend from 5km and 7km. As explained for PGB, when VANET is *sparse* and *highly sparse* in 2km area, the delay is quite small because, EM reaches at the end of VANET after first rebroadcast and collision is also very low but when distances increases to 5km and 7km area, dissemination of EM takes longer time. When number of vehicles increase, collision also increases as there may be more than one vehicle in DV-CAST having same longest distance from sender so re-broadcast timer would be same. When VANET gets dense from *lightly sparse* to *highly dense*, vehicles move closer to each other thereby setting timer values close to each other. DV-CAST trend shows that dissemination delay stabilizes around 10ms value as shown in Fig. 6 (a, b, c).

In G-AODV, every vehicle rebroadcasts exactly once (like AODV) therefore, the penetration time of EM is better than PGB and DV-CAST. The behaviour of G-AODV in 2km, 5km and 7km is similar to other protocols as shown in Fig. 6 (a, b, c). Here we would like to remark that any technique which would restrict nodes from rebroadcasting, may give higher delay as the suppression mechanism takes time in deciding. Due to this fact, ZBRP operates in a divide-and-conquer manner so that least time is taken while performing suppression.

In ZBRP, after the broadcast of an event-detecting source, only a BR of predecessor can rebroadcast. If a predecessor does not hear rebroadcast from its BR within 5ms, it makes a rebroadcast attempt. An EM packet is dropped after 2 rebroadcast attempts by a predecessor. The analytical results of ZBRP tend to be close to the simulation results. Fig. 6 (a, b, c) shows that an emergency message sent by ZBRP is faster to penetrate in the network than PGB and DV-CAST. Since every vehicle in G-AODV rebroadcasts an EM at least once, its rebroadcast is therefore better than ZBRP.

In Fig. 6 (d), we give a zoomOut view of dissemination times of all protocols. The values shown are average of the mean values presented in Fig. 6 (a, b, c). The results of ZBRP presented in Fig. 6 (a, b and c) are quite promising with respect to G-AODV, PGB and DV-CAST. It shows that ZBRP gives better results than PGB and DV-CAST whereas its results can be compared to G-AODV which does not employ any broadcast suppression technique. In G-AODV, every vehicle *re-broadcasts* exactly once and therefore it provides high network penetration but at the cost of high control traffic. The results of ZBRP (Analytical) are close to ZBRP (Simulation).

6.2 Broadcast Suppression

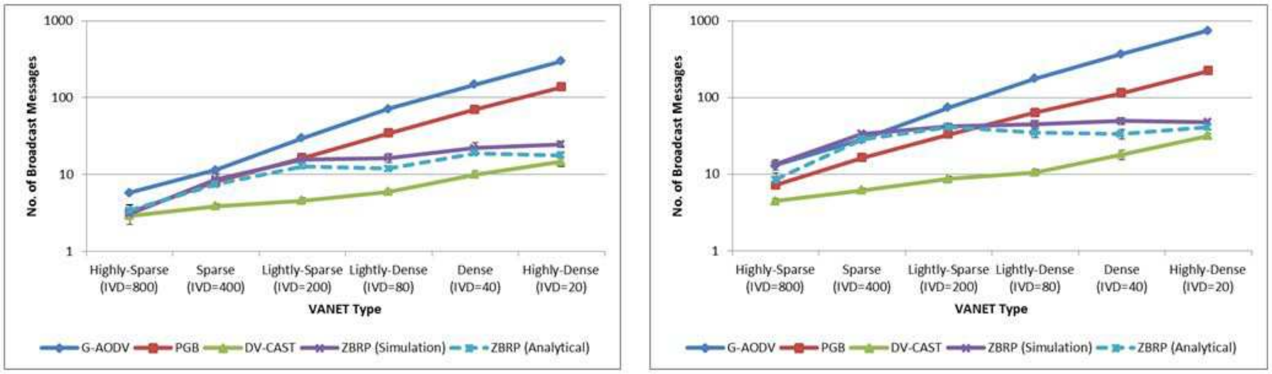
Fig. 7(a, b, c) represent graphs using logarithmic scale with CI=95%. It shows that the emergency message rebroadcast is highest when there is absence of suppression technique. Rebroadcast is lowest when suppression technique employs retries or there are no backup nodes to rebroadcast in case of packet drop.

In G-AODV, every vehicle has to rebroadcast exactly once, therefore, in each VANET type and for every area, the number of EM broadcasts is highest. Next highest broadcast is from PGB as shown in Fig. 7(a, b, c). This is due to the fact that in PGB, when vehicles in the PG node rebroadcast and there is collision, then nodes in the OUT group work as backup nodes which if could not broadcast, then nodes in the IN group rebroadcast. Since a small group of vehicles in the broadcast range is rebroadcasting instead of all vehicles, therefore, number of broadcast packets are still high in number.

In DV-CAST, a vehicle farthest from sender rebroadcasts. All neighbours go into broadcast suppression mode which is wait state. As soon as a rebroadcast is heard the EM is discarded otherwise EM is rebroadcast by the vehicle whose timer expires next. Since PGB forces to hear at least 3 rebroadcasts before discarding an EM and DV-CAST just relies on the single rebroadcast, therefore number of rebroadcast in DV-CAST are lower than PGB. The other characteristic of DV-CAST is that all vehicles from boundary to sender are waiting one after the other to rebroadcast, so if one misses the other rebroadcasts. In this way like AODV and PGB there is no single point of failure with respect to rebroadcasting vehicle. The trend of G-AODV, PGB and DV-CAST is almost exponential on the logarithmic scale.

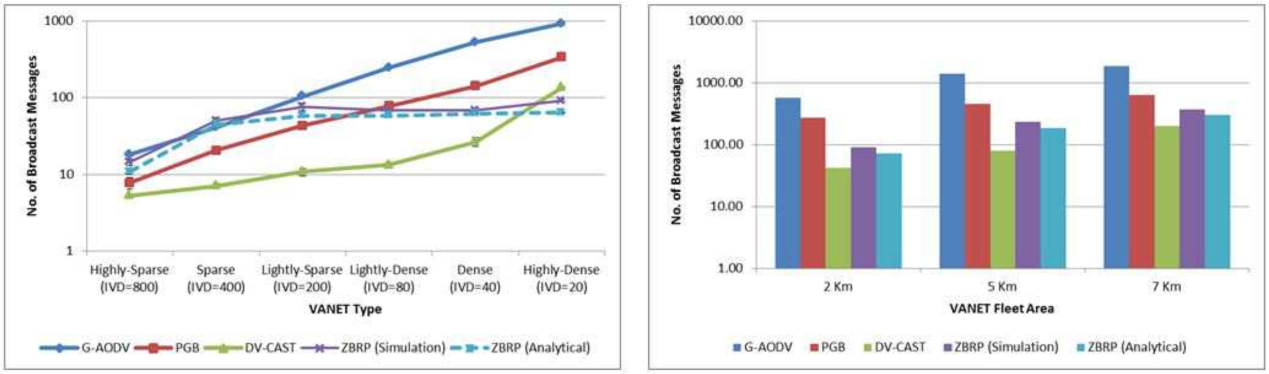
The broadcast suppression of ZBRP uses two retries by the BR. A vehicle waits 5ms for retry which is rebroadcast of the same EM by its BR. In ZBRP, the rebroadcasting vehicle is only the BR therefore it may become single point of failure and in case of collision, rebroadcasts increase. We observe in Fig. 7(a, b, c) that ZBRP performs better than G-AODV and PGB when in *lightly sparse* to *highly dense* modes, and its performance is better than DV-CAST in *dense* and *highly dense* modes. The ZBRP trend is neither exponential nor straight line rather it remain confined between the values 3 to 91 inclusively starting from *highly sparse* to *high dense* over 2km, 5km and 7km areas. The ZBRP (Analytical) model results are close to ZBRP (Simulation).

In Fig. 7 (d), we give a zoomOut view of the broadcast suppressions of all protocols. The graphs show that, the number of rebroadcasts produced by ZBRP are



(a) 2km, 3 lanes

(b) 5km, 3 lanes



(c) 7km, 3 lanes

(d) ZoomOut view of the sum of broadcast suppressions from the values presented in Fig. 7–a,b,c

Fig. 7: Broadcast Suppression. (a), (b) and (c) give comparison of average emergency message re-broadcasts between ZoomOut and non-ZoomOut (G-AODV, PGB and DV-CAST) techniques on the logrithmic scale with 95% Confidence Interval.

slightly higher than DV-CAST but amply lower than PGB and G-AODV.

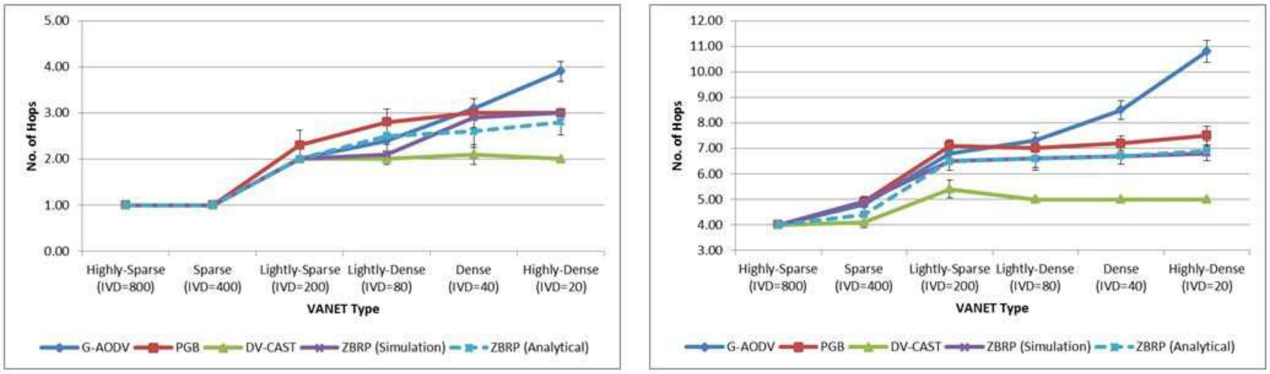
6.3 Hop Count

The hop count parameter is important to evaluate the protocol. It is of interest to see that how many vehicles are selected over N-hop area by a specific protocol to forward an EM because unnecessarily selecting more hops may add delay. It therefore explores the internal functionality of the protocol.

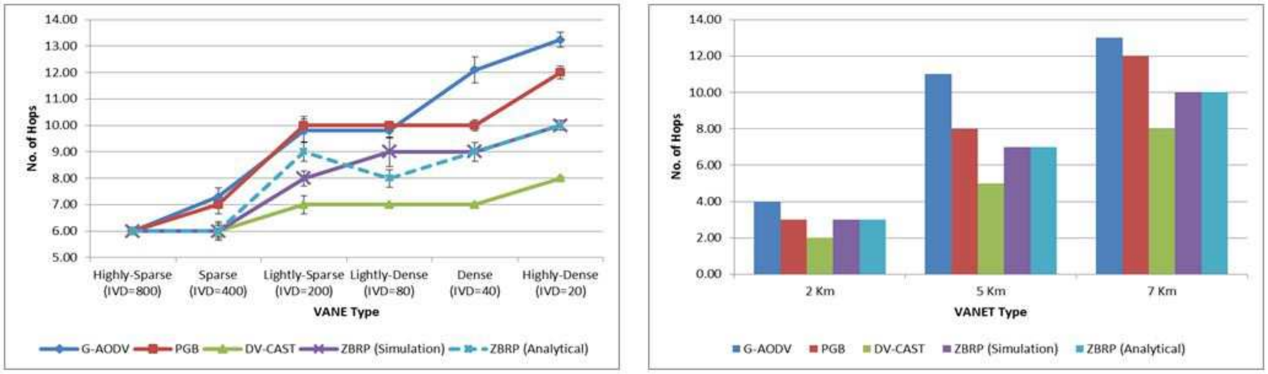
In 2km area, when VANET is sparse of *highly sparse* hop count for all protocols is one. But as VANET changes from *lightly sparse* to *highly dense*, protocols start exhibiting their behaviour. In case of AODV, it is normally assumed that it gives the shortest hop count, but the RFC 3561 [32] states that a fresh route from source to destination may also be chosen other than the shortest path. So when there is packet drop and new RREQ is initiated, then a longer fresh route is chosen by G-AODV than an old shorter route. This behaviour is evident from Fig. 8(a, b, c). When network gets dense, G-AODV starts to select more forwarding vehicles and therefore its hop count constantly increases over the same area as the network gets dense.

In case of PGB, the group formation mechanism based on received signal strength is such that vehicles in the PG group, which is in the middle of broadcast range, have highest preference to relay the information. When network gets dense, only PG nodes rebroadcast due to their random timer values within an upper and lower bound value and therefore, hop count also increases. Secondly, if multiple vehicles have the same timer value then there is a collision and therefore the backup vehicles rebroadcast. These backup vehicles may be nearer to the sender and therefore may effect hop count negatively. This can be seen from Fig. 8(a, b, c).

In case of DV-CAST, the hop count is smallest because vehicles farthest from sender have the highest preference to acquire channel due to smallest wait timer value. It is also visible that when VANET is *highly sparse*, then hop count is 5 but when it gets dense, EM



(a) 2km, 3 lanes (b) 5km, 3 lanes



(c) 7km, 3 lanes (d) ZoomOut view of max hop counts of G-AODV, PGB, DV-CAST and ZBRP from the values presented in Fig. 8–a,b,c

Fig. 8: Hop Count. (a), (b) and (c) give comparison of average hop counts between ZoomOut and non-ZoomOut techniques on the non-logrithmic scale with 95% Confidence Interval.

from the farthest vehicles my sometimes collide due to same wait timer value because of same distance from sender. Hence, the hop count slightly increases and reaches to value 8. However, whether the VANET is *highly sparse* or *highly dense* hop count is smaller than other protocols and can be observed from Fig. 8(a, b, c).

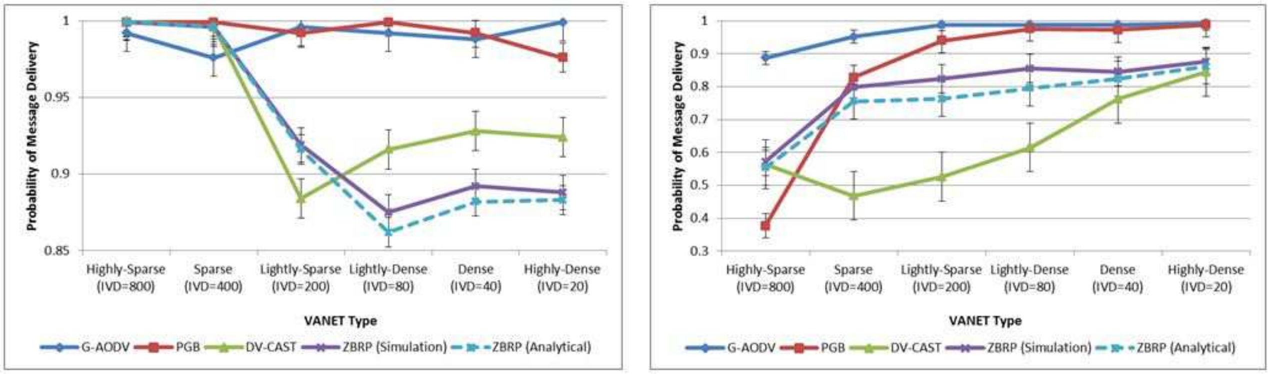
For ZBRP, we refer to Fig. 1 where the position of BR is anywhere between point x3 and x4. A vehicle at any position between x3 and x4 can be selected and therefore hop count of ZBRP is slightly higher than DV-CAST but better than G-AODV and PGB as shown by Fig. 8(a, b, c).

In Fig. 8 (d), we give a zoomOut view of max hop count by all protocols. The graph shows that ZBRP (Simulation and Analytical) produces greater hop count value than DV-CAST and lower hop count value than G-AODV and PGB.

6.4 Packet Delivery Function

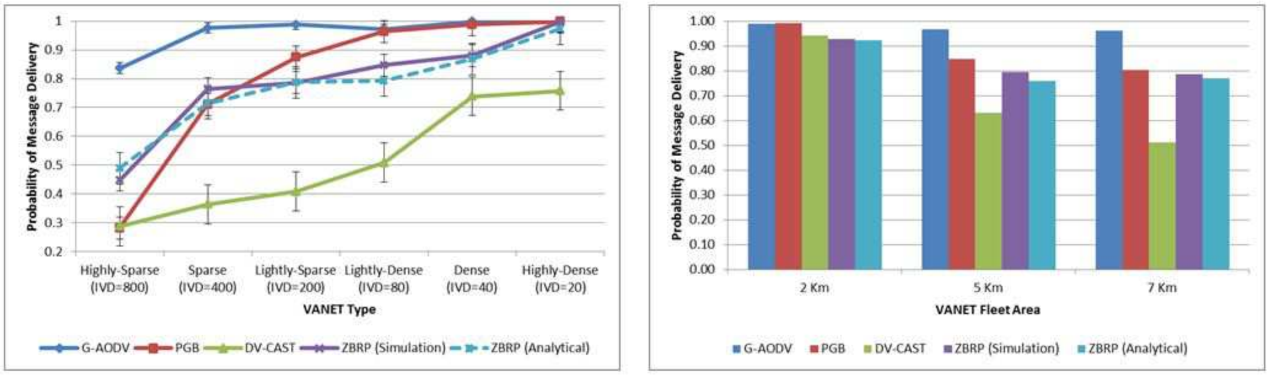
Packet delivery function (PDF) is an important parameter to evaluate that how many packets will reach at the desired area/destination out of the total transmitted. Our simulations reveal that protocols in which all or multiple nodes rebroadcast have higher PDF value than the protocols which employ timer based wait approach and have proper retries mechanism or have backup vehicles to rebroadcast. In other words, if a protocol has one rebroadcasting vehicle, the PDF value would be lower than the protocols having multiple or all re-broadcasting vehicles. This behaviour is visible in Fig. 9(a, b, c) and is explained below. It is also important to remark here that if VANET spans over a large area and vehicle are also sparse; there will be disconnection points due to the varying speeds of vehicles. This disconnection affects only those protocols which exhibit the behaviour of most forward within range. Therefore, PDF will also be lower if a protocol does not focus on the longevity of hop-to-hop connectivity.

G-AODV has the highest PDF value as every vehicle is rebroadcasting so EM will definitely reach at the end of connected VANET fleet. In PGB, the retries mechanism is stronger than DV-CAST and the proposed ZBRP; therefore PDF of PGB is higher than both of these



(a) 2km, 3 lanes

(b) 5km, 3 lanes



(c) 7km, 3 lanes

(d) ZoomOut view of EM delivery of G-AODV, PGB, DV-CAST and ZBRP from the values presented in Fig. 9–a,b,c

Fig. 9: Packet Delivery Function. (a), (b) and (c) give comparison of average EM delivery probability between ZoomOut and non-ZoomOut (G-AODV, PGB and DV-CAST) techniques on the non-logrithmic scale with 95% Confidence Interval.

protocols. A sending vehicle in PGB waits to hear at least two rebroadcasts before dropping EM. Therefore it guarantees that multiple copies of the message are in air and least one will reach the desired destination area.

In DV-CAST, PDF is lowest over long distances of 5km and 7km but it is better over short distance of 2km. The reason is that DV-CAST operates based on MFR approach and therefore the destination is reached after 1 rebroadcast when the area is 2km. As explained, in wireless medium, if a protocol of broadcast nature does not employ proper retry mechanism or if a single vehicle is rebroadcasting or if multiple vehicles due to same timer value rebroadcast simultaneously, the PDF will decrease. Similarly, when the number of vehicle increase and data transmission is also taking place between multiple vehicles, then drop at the queue is a factor as well. Out of the above reasons, the reasons of lower PDF in DV-CAST are collision due to same timer value in multiple vehicles; single rebroadcasting vehicle and lack of rebroadcast mechanism after collision.

In ZBRP, only BRs remain in the broadcast range for the longest period of time with respect to speed and position of other 1-hop neighbours. In 2km area, the PDF value drops but then stabilizes around 90%. In 5km and 7km VANET the effect of connectivity (longevity of hop-to-hop connection) in terms of better results, can be observed in *sparse* and *highly sparse* networks with respect to PGB and DV-CAST.

In Fig. 9 (d), we give a zoomOut view of PDF by all protocols. The graph shows that G-AODV gives highest PDF because all vehicles rebroadcast at least once. Similarly, in PGB multiple PG vehicles rebroadcast to increase the probability of successful delivery. In ZBRP, only one BR is rebroadcasting and there are maximum two retries. The performance of DV-CAST is poorer than all over long distance. The performance of ZBRP is almost similar to G-AODV and PGB when VANET is *dense* and *highly dense*.

7 Conclusion

In this work we have shown that, based on the concept of intelligent 1-hop beaconing, not only neighbourhood view can be established but safety messages can also be disseminated effectively. The proposed ZBRP is overall a better choice in providing high network penetration, probability of successful message delivery, high broadcast suppression and hop count, against the compared protocols which give better performance for one metric but poor for the other. From the results presented above, we state that ZBRP gives faster network penetration than PGB and DV-CAST; better broadcast suppression than G-AODV and PGB in all VANET types and better suppression than DV-CAST in dense VANET; lower hop count than G-AODV and PGB in all VANET types while higher hop count than DV-CAST; and finally higher probability of successful message delivery than DV-CAST over longer VANET area but lower than PGB and G-AODV in *sparse* or *lightly dense* VANET. It can be concluded that the proposed broadcast protocol, in which local view of 1-hop relatives is zoomed out to global view of chains of relatives, is a better choice than the non-chained broadcast protocols liked G-AODV, PGB and DV-CAST. Other unicast, broadcast or location service protocols can work on top of ZOH to achieve better network QoS.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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