A Novel Position-based Multi-hop Broadcast Protocol for Vehicular Ad Hoc Networks

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***Abstract*—Vehicular Ad Hoc Networks (VANETs) are considered as a promising scheme to actively guarantee vehicle safety, and broadcast is a key technology for warning message dissemination in VANETs. This paper proposes a novel Position-based Multi-hop Broadcast (PMB) protocol for VANETs in view of some shortcomings of existing broadcast protocols for VANETs, such as ignoring the differences of transmission range among different nodes (vehicles), and disseminating warning messages only with the help of nodes in the one-way lane, PMB calculates waiting time to select the rebroadcast nodes based on additional coverage area of adjacent nodes considering the transmission ranges of nodes together with the inter-vehicle spacing, to guarantee less nodes used to rebroadcast warning packets. Besides, it guarantees the reliability of warning message dissemination by adopting the alternative answering mechanism named implicit ACK and explicit ACK adaptively and rebroadcast packets based on nodes in the two-way lane. The simulation results show that PMB outperforms existing broadcast protocols for warning message dissemination in VANETs in terms of suppression of broadcast redundancy, real-time performance and reliability even if all nodes have different transmission ranges.**

***Index Terms*—Broadcast Protocol, Position-based Scheme, Transmission Range, Vehicular Ad Hoc Networks, Warning Message Dissemination**

I. INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) dedicated to Wireless vehicle communications are considered as an off-shoot of Mobile Ad hoc Networks (MANETs) [1]. VANETs have two kinds of communication methods， namely Inter-Vehicle Communications (IVC) and Roadside-to-Vehicle Communications (RVC). IVC provide direct exchange of information between nodes (vehicles), and are mainly used to achieve warning message dissemination for vehicle collision accident, cooperative driving and real-time traffic information dissemination. RVC can access other networks (e.g. Internet) for more information sharing via the pre-existing roadside infrastructure resulting in providing comfortable travel for passengers. Unlike other traditional passive safety protection technology such as the use of air bags, seat belts, automatic braking system and brake lamps, VANETs can provide active vehicle collision warning via IVC to make drivers have enough reaction time for braking in advance to eliminate safety hazards, and as a result VANETs can significantly prevent or reduce traffic accidents, IVC are considered as the most effective communication methods for vehicle collision warning on behalf of VANET safety applications.

Broadcast is the most widely used technology for warning message dissemination in vehicle collision avoidance applications. Whether VANETs can effectively avoid or reduce vehicle collision directly depends on the ability to quickly and reliably broadcast warning packets to the rear vehicles for proactive warning, therefore, the design of broadcast protocols supporting VANET safety applications is crucial for warning message dissemination. However, Compared to MANETs, VANETs have some unique features, such as node mobility restricted by the road, fast-changing network topology due to high-speed moving of nodes [2], as a result directly applying traditional broadcast protocols for Ad Hoc networks to VANETs would make protocol performances degraded or cannot even work correctly. Designing efficient broadcast protocols specifically for VANETs is very essential.

II. RELATED WORK

Researchers have been proposed various broadcast protocols for message dissemination as yet. The existing broadcast protocols were classified into categories as follow:

Flooding-based scheme: A source node broadcasts a packet and all of its neighbors will rebroadcast the packet as soon as they receive it. This scheme is relatively simple and not subject to network topology, especially suitable for the scenarios of high-speed mobile nodes where the network topology changes frequently. However, because each node in the rear of the source

doi:10.4304/jnw.6.1.112-120

node will rebroadcast packets, as the network node density increases, it will bring well-known "broadcast storms" problem [3]. NB [4] and OZF [5] are typical of flooding-based broadcast protocols. I-BIA protocol [6] makes improvements to NB, it reduces redundant packet rebroadcasting by means of the implicit ACK mechanism, but its rebroadcast nodes are randomly selected, if two-hop adjacent rebroadcast nodes are close to each other, real-time message dissemination will not be guaranteed.

Probability-based scheme: Compared with the flooding-based scheme, probability-based scheme enables rebroadcast nodes to broadcast received packets with probability p, where p is usually calculated by current receiving nodes based on the ratio of the distance from them to the previous-hop rebroadcast node and their transmission range. In such scheme, the receiving node farthest away from the previous-hop rebroadcast node within one-hop range is most likely to become a rebroadcast node. Typical representatives of such scheme include Wp-PB [5], FDPD [7], p-IVG [8], NPPB [9] etc., they are essentially of no difference, but differ from each other only in some details, such as the calculation of probability p. However, probability-based mechanisms have an inherent shortcoming that it is still possible for nodes with the litter and the greater probability to rebroadcast packets simultaneously, resulting in high redundancy of packet broadcasting.

Counter-based scheme: it implies that the more duplicated packets a node receives in Random Assessment Delay (RAD) which is randomly chosen between 0 and a maximum delay value, the less chances the node has to become a rebroadcast node, but the counter threshold of this scheme is usually fixed and cannot be dynamically adjusted to adapt to changes of node density. DBCG [9] is a typical example of this scheme, where RAD is inversely proportional to inter-node distance.

Distance-based scheme: nodes always obtain the position information of vehicle with the help of GPS device, and they make decisions for packet rebroadcasting based on inter-node distance. Within a RAD, if a node receives packets from at least one node in a place to which the distance is less than distance threshold from the previous hop node, it will give up rebroadcasting packets after a random waiting time [11][12]. Similarly to Counter-based scheme, it is very difficult to determinate the distance threshold, and cannot be dynamically adjusted to adapt to changes of local node density.

Neighbor knowledge scheme: It needs nodes to maintain and update the neighbor node information with the help of periodic broadcasting of “Hello” packets (which include neighbor node information and itself). Nodes determine whether to broadcast packets based on these neighbor knowledge maintained by themselves. Flooding with Self Pruning [13], Dominant Pruning [13], AHBP [14], CDS-Based Broadcast [15], LENWB [16], INK [17] and GPCR [18] are typical examples of this scheme. Such scheme has better performance in the static or other networks with slow-changing network topologies, but it is not suitable for VANETs whose topologies are fast changing. Because nodes in VANETs need to exchange neighbor information more frequently, more packet collisions are brought out deteriorating the network performance.

Cluster-based scheme: the nodes in one network are divided into several clusters and each cluster has one head node. Only cluster heads will broadcast packets to their neighbors within cluster, and gateway nodes are responsible for inter-cluster packet broadcasting, while other number nodes only need to receive packets [18]. Wei Lou et al. [19] proposed two cluster-based backbone infrastructures respectively based on Source-Independent and Source-Dependent Connected Dominating Sets (SI-CDS and SD-CDS) for broadcasting. These backbones infrastructures only require few cluster heads and gateway nodes to rebroadcast packets reducing broadcast redundancy. Fan P [20] proposed a cluster-based broadcasting scheme that provides an efficient and stable hierarchical network backbone，and make cluster heads and some selected gateway nodes rebroadcast packets to reduce the redundant retransmissions. it decreases the overhead required to maintain network topology due to high mobility based on Lowest-ID algorithm by incorporating moving direction information and leadership duration. But the cluster-based scheme can lead to reduced performance level if there are increasing control message exchanges between the nodes for the formation and maintenance of cluster.

Position-based scheme: Similarly to distance-based scheme, it does not need to rely on the network topology information, and especially suitable for VANETs whose topologies are fast-changing. This scheme is based on additional coverage of two-hop adjacent nodes, within one-hop range; the neighbor node farthest from the previous-hop broadcast node has the largest additional coverage, and will become a rebroadcast node. The rebroadcast node for each hop is selected determinately and uniquely, differing from other broadcast schemes such as flooding-based, probability-based, and counter-based distance-based schemes which may cause multiple nodes broadcasting at the same time, therefore, the position-based scheme has lower broadcast redundancy relatively. At present, most of VANET broadcast protocols are usually position-based protocols, e.g. S1-PB [5], PAB [21], ODAM [22], SNB [23], EDB [24] and RBRS [25] etc..

All the schemes above assume that all nodes in a network have the same transmission range, but it is not always true in the real world. Different vendors or different types of vehicles may be equipped with wireless communication devices with different transmission ranges, and different transmission ranges will lead to the unidirectional link, thereby resulting in a lot of unnecessary packet retransmissions. Besides, various existing broadcast protocols simply use rebroadcast nodes in one-way lane to rebroadcast packets, while packet rebroadcasting based on two-way lane can overcome the problem of connectivity gaps which always appear in the sparse traffic scenarios [15]. In view of these shortcomings, in this paper, we propose a novel Position-based Multi-hop Broadcast (PMB) protocol deriving from the position-based scheme considering the fact that nodes in a network have different transmission ranges for VANETs. The simulation results show that even in the case of different transmission ranges for different nodes, PMB can significantly bring lower broadcast redundancy so as to improve broadcast efficiency, and guarantees better real-time performance and reliability of warning message dissemination.

The rest of the paper is organized as follow: in section

III the proposed protocol called PMB is described in detail. In section IV we evaluate the performance of PMB together with other protocols using Network simulator Version 2 (NS2). Finally, we conclude in section V.

III. Proposed Protocol

In designing PMB, we make the following assumptions: (1) Each node is aware of its geographical position by means of GPS device; (2) All nodes have the same receiving sensitivity, but they have different transmission power, therefore, there will have different transmission ranges; (3) Nodes are equipped with omni-directional antennas.

PMB uses timer-based method to select rebroadcast nodes and its waiting time is inversely proportional to Additional Coverage Area (ACA). A node with the largest ACA has the shortest waiting time, so it will become a rebroadcast node in the competition with other nodes, and other nodes will stop timer to give up packet rebroadcasting when they receive a duplicated packet from the rebroadcast node, therefore fewer nodes are selected as rebroadcast nodes to be responsible for packet broadcasting of the rear warning zone, thereby reducing broadcast redundancy and end-to-end delay. In addition, according to the relationship between the transmission range of current receiving node and the distance from the current receiving node to the previous rebroadcast node, PMB adopts the implicit and the explicit ACK answering mechanisms adaptively, and rebroadcasts packets with the help of nodes in two-way lane so as to guarantee the reliability of warning message dissemination. In message dissemination, PMB also restricts both the coverage of message dissemination and the remaining valid times of nodes reasonably to bring high efficiency of message dissemination.

A. *Selection of the Rebroadcast Node*

Suppose node j denotes the current receiving node in a lane, and node i denotes the previous-hop broadcast node. The ACA of node j is denoted as ACA_{ij}, and it is defined by the expression $ACA_{ij} = S_j - S_{i\cap j}$, where S_j is the signal coverage area of node j, and $S_{i\cap j}$ is the overlapping coverage area of node i and j. Considering the transmission range of node is usually far greater than the width of lane, as for the signal coverage area, only the covered part over the lane is considered, and the ACA is illustrated in Fig. 1.

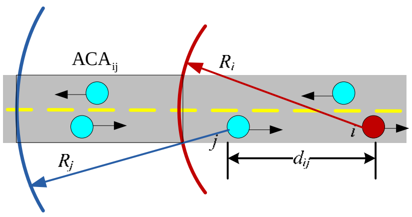


Figure 1 The ACA of node *j*

Thus, (1) will be simplified as follows:

$$ACA_{ij} = S_j - S_{i\cap j} = R_j \cdot W_{road} - (R_i - d_{ij}) \cdot W_{road} = (R_j - R_i + d_{ij}) \cdot W_{road} \quad (1)$$

Where R_i and R_j denote the transmission ranges of node i and j respectively, d_{ij} denotes the distance between node i and j, and W_{road} denotes the width of the two-way lane. The preset waiting time of rebroadcast node is defined as follows:

$$T_{defer} = \left| T_{\max} \cdot \left(1 - \frac{ACA_{ij}}{ACA_{max}}\right) \cdot \alpha + T_{rand} \right| \quad (2)$$

Where T_{max} is the (assumed) maximum waiting time defined by PMB (for PMB, T_{max}=100ms), and $ACA_{\max}$ is the upper limit of ACA achieved only when node j has the largest transmission range at the edge of coverage area of node i. In order to make the node that would most likely become a rebroadcast node further reduce the waiting time, multiplier factor α is used and defined as follows:

$$\alpha = 1 - \exp\left(-\lambda \cdot \left(1 - \frac{ACA_{ij}}{ACA_{max}}\right)\right) \quad (3)$$

Where $\lambda>0$ (λ is a constant), and evolutions show the best performance of PMB occurs when λ=15. In addition, in order to prevent nodes with the same ACA rebroadcasting packets simultaneously to bring more packet collisions, a random short delay T_{rand} , which is randomly chosen from the uniform distribution over the interval [-C/2, C/2], is added to T_{deffer}, where C is the number of lanes. Noting the equation $ACA_{\max}=R_{max} \cdot W_{road}$, the following expression is inferred from (1) and (2):

$$T_{defer} = \left| T_{\max} \cdot \left(1 - \frac{R_j - R_i + d_{ij}}{R_{\max}}\right) \cdot \alpha + T_{rand} \right| \quad (4)$$

Where we have

$$\alpha = 1 - \exp\left(-\lambda \cdot \left(1 - \frac{R_j - R_i + d_{ij}}{R_{\max}}\right)\right) \quad (5)$$

From (4), we can conclude that for all neighbor nodes of node i within one-hop, a neighbor node with larger transmission range and farther from node i is more likely to become a rebroadcast node, thereby usually resulting in only one neighbor node selected as a rebroadcast node within one-hop to be responsible for packet rebroadcasting. Therefore, in other words, the least hops are required to broadcast packets throughout the rear warning area, thereby reducing the delay of message dissemination.

B. *Reliability of the Proposed Protocol*

As for satety applications of VANETs, it is as important as the real-time performance to guarantee the reliability of warning message dissemination. In the paper, the following two answering mechanisms for broadcasting are used, for convenience, we assume CRN is the current rebroadcast node selected in competition, PRN is the previous rebroadcast node, the transmission ranges of PRN and CRN are denoted by R_p and R_c respectively, and d is the distance between PRN and CRN.

1) *The implicit ACK and the explicit ACK:* When the front node detects the emergency such as vehicle collision accident, it will immediately generate and broadcast warning messages to its rear zone per 1 second. Each node in the rear of the emergency source node adds its own position and velocity vector information to the packet header before rebroadcasting. In packet broadcasting, packets permanently contain some

important information, namely the indentifier, position, and velocity vector of emergency source node, they can uniquely identify where the current emergency occurs, When CRN receives a broadcast packet from PRN, it will determine whether PRN is in its own transmission range based on the position information of PRN in the packet header, and determine whether PRN is moving in the same direction as itself based on the angle between the velocity vector of PRN and that of itself.

If PRN is in the transmission range of CRN as shown in Fig. 2 (where $d \le R_c$), PRN and CRN can communicate with each other, the implicit ACK mechanism is adapted by PMB at the moment, that is, CRN retransmits the just received packet to PRN. As for PRN, successful reception of packet indicates that the packet from PRN has already been received and rebroadcasted by some rear nodes, and PRN will stop the rebroadcast timer so as not to rebroadcast this packet. Otherwise, CRN cannot communicate with the PRN directly as shown in Fig. 3 (where $d > R_c$). Even if CRN rebroadcasts ACK packet, PRN cannot be informed, so ACK packet has to be retransmitted to PRN with the help of the intermediate nodes between CRN and PRN. This process is the so-called explicit ACK mechanism.

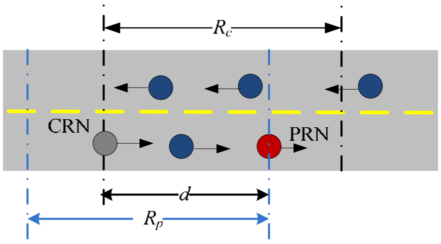


Figure 2 Implicit ACK mechanism

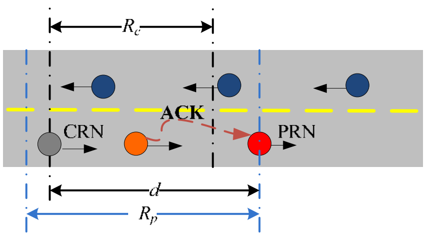


Figure 3. Explicit ACK mechanism

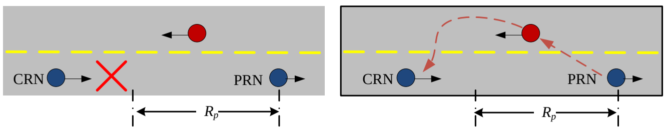
If $d > R_c$, CRN will add the ACK transmission flag into packet header before packet rebroadcasting. The moment that the intermediate node receives the warning message packet from CRN, its will immediately stop its waiting timer, and consequently determine whether to transmit ACK packet to PRN according to the ACK transmission flag in packet header. If desired, and PRN is within the scope of its radiation, the intermediate node will wait for a period of time randomly chosen from a limited time interval to compete with other intermediate nodes for transmitting the ACK packet, the implementation process is described in detail as follows:

Firstly, the (assumed) maximum waiting time T_{Ack_max} for ACK packet transmission is equally divided into $N_{TimeSlice}$ slots, and the length of each slot is defined as the expression $L_{TimeSlice}=T_{Ack\_max}/N_{TimeSlice}$, consequently, the *idx*-th slot time will be randomly chosen from a uniform distribution over the interval [0, $N_{TimeSlice}$-1], and then an offset denoted by T_{offset} within the interval [0, $L_{TimeSilce}$] will be randomly determined from a uniform distribution. Finally, we have the waiting time T_{Ack} calculated as follows:

$$T_{Ack} = idx \cdot L_{TimeSlice} + T_{offset} \qquad (6)$$

After the two random choices, the waiting time of the intermediate node that competes for ACK packet transmission is greatly discretized, thereby preventing multiple nodes transmitting ACK packets at the same time effectively. The intermediate node with the shortest waiting time will be chosen to generate and transmit ACK packet to PRN immediately. ACK packet includes the identifier of emergency source node and the sequence number of the warning packet which uniquely identify the warning message. In addition, two identifiers of PRN and CRN are also included in ACK packet, where the identifier of PRN is used for ACK packet transmission as a destination address. PRN will stop rebroadcast timer as soon as receiving this explicit ACK packet, and give up packet broadcasting.

2) *Packet rebroadcasting based on the two-way lane:* When the distance between PRN and its rear nodes is greater than the transmission range of PRN, packet delivery will be interrupted, which is well-known connectivity gap problem [26] as illustrated in Fig. 4(a). PRN will rebroadcast packets until at least one rear vehicle node drives into its scope of radiation or the packet is expired. If packet broadcasting is realized only based on the vehicle nodes in one-way lane, the speed difference between vehicles is too little to eliminate the connectivity gaps in a short time, while PMB uses the two-way lane mode as shown in Fig. 4(b), it can eliminate the connectivity gaps rapidly with the help of packet rebroadcasting of intermediate nodes located in the opposite lane, resulting in successful packet reception for the rear nodes.



(a) Emergence of connectivity gap (b) Elimination of connectivity gap

Figure 4 Connectivity gap problem in the lane

In PMB, if the intermediate nodes find that the remaining valid times of the just received packets are still greater than the one-hop propagation delay, they will resume packet rebroadcasting to disseminate warning messages to the rear zone, thus guaranteeing the reliability and real-time performance of the message dissemination. Even in the dense traffic scenarios of VANETs, a rear vehicle node in the same lane is more likely to become a CRN due to long distance from PRN, and the intermediate node located in the opposite lane between PRN and CRN will give up packet broadcasting as soon as it receives the duplicated packet from CRN, so it will not bring too much packet collisions.

C. *Restrictions of Message Dissemination*

Noting that the emergency warning process by means of warning messages has the inherent properties of region and time in the real world, PMB considers the restrictions of region and time integratedly instead of using the traditional method of ceasing packet transmissions only based on Time To Live (TTL), thus reducing some unnecessary packet transmissions and improving the efficiency of message dissemination.

1) *The regional restriction:* PMB protocol has defined two zones, namely warning zone and rebroadcast zone as shown in Fig. 5. Warning zone only contains the nodes in the same lane as the emergency source node, the nodes located in the warning zone decelerates as soon as receiving warning message, and is responsible for processing and rebroadcasting warning messages. Besides the warning zone, the rebroadcast zone also contains the nodes that are in the corresponding opposite lane, and the nodes located in the opposite lane are only responsible for rebroadcasting packets, all nodes outside of the rebroadcast zone will ignore warning messages.

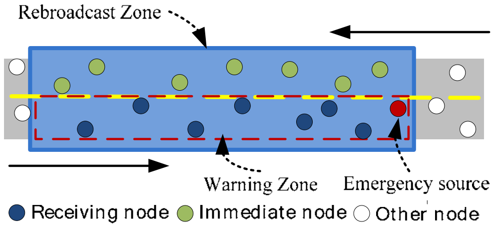


Figure 5. Definition of the warning zone and rebroadcast zone

2) *The time restriction:* Besides the spatial restriction, the time restriction is also imposed on warning message dissemination. Vehicle nodes in both the warning zone and the rebroadcast zone will check the received warning messages. The warning messages received in the warning zone will be processed and rebroadcast only when it has not expired, while the nodes in the rebroadcast zone will drop the warning messages which has expired or whose remaining valid time has already been shorter than one-hop propagation delay.

IV. SIMULATION AND ANALYSIS OF PROTOCOLS

In the paper, we design a mobility model, and make simulation experiments on NB, I-BIA, Wp-PB, ODAM and PMB protocols with Network Simulator version 2 (NS-2) [27]. In different traffic scenarios, PMB is compared with four other existing broadcast protocols in terms of Saved ReBroadcast (SRB), REachability (RE), MAC-layer Packet Collision (MPC), and Average End-to-end Delay (AED), and they are all the averages of 20 simulation results

A. Establishment of Simulation Scenarios

In order to simulate the behavior of moving vehicles in different traffic scenarios, a vehicle node mobility model is designed and the relevant parameter settings are tabulated in Table I. Table II shows six traffic scenarios in descending order of vehicle density, which are calculated by changing parameters such as the maximum Inter-Vehicle Spacing (IVS_{max}), the minimum IVS (IVS_{min}), the average velocity (V_{avg}) and a small positive parameter ε which is defined as a velocity offset, where ID is the identifier of the emergency source node, and it is also the source address of warning message. The selection of emergency source node is arbitrary in principle, but in our simulation experiments, the total length of lane is set to be limited (we select 3000m here.). In order to guarantee the emergency source node has enough rear area to accommodate the warning zone, we select the emergency source node according to the positions of vehicle nodes in the lane. Vehicle density is denoted by ρ and calculated from IVS_{max} as shown in the expression $\rho = 1000/ IVS_{max}$.

TABLE I.
PARAMETER SETTINGS OF DIFFERENT TRAFFIC SCENARIOS

Scenario	IVS (m)		V (m/s)		Emergency source node (ID)	Vehicle density ρ (vehicles/lane/km)
	IVS_{min}	IVS_{max}	V_{avg}	ε		
1	10	30	5	1	509	33.3
2	20	50	8	2	256	20.0
3	45	100	12	3	100	10.0
4	85	140	15	4	68	6.7
5	120	200	25	5	65	5.0
6	180	350	30	3	27	2.9

TABLE II.
PARAMETER SETTINGS OF MOBILITY MODEL

Parameter	Value
Length of the lane (L_{road})	3000 m
Length of warning zone	1000 m
Number of lane (C)	Six two-way lanes
Inter-vehicle distance (IVS)	uniform distribution on [IVS_{min}, IVS_{max}]
Vehicle speed (V)	uniform distribution on [V_{avg} -ε, V_{avg} +ε]
Acceleration of brake (a)	-8 m/s^2
Number of vehicle (N)	L_{road} /IVS_{max}·C

Parameter settings of simulation with NS-2 are tabulated in Table III, and in the simulation experiments, the transmission ranges of vehicle nodes are chosen randomly from a uniform distribution over the interval [100, 300] so as to simulate different vehicles are of different transmission ranges

TABLE III.
PARAMETER SETTINGS OF SIMULATION WITH NS-2

Parameter	Value
Simulation scope	3000× 100 m^2
Simulation duration	30 s
Generation time of warning message	1st s、3rd s、5th s、7th s、9th s
Packet length	512 Bytes
Application layer protocol	PBC
Network layer protocol	NB, I-BIA, Wp-PB, ODAM,PMB
MAC protocol	IEEE 802.11 DCF
Transmission range (m)	Selected randomly from [100, 300]
Transmission rate	1 Mbps
Channel transmission model	Two-Ray Ground
Antenna type	OmniAntenna

B. Analysis of Simulation Results

In order to evaluate the performance of message dissemination, four following evaluation metrics are adopted:

a) SRB that is used to measure suppression of broadcast redundancy is defined by the expression $SRB=NF_r\text{-}NF_f$, where NF_r is the number of nodes in the rebroadcast zone that have received packets, and NF_f is the number of rebroadcasting nodes in the rebroadcast zone.

b) RE that is used to investigate the reliability of broadcast is defined by the expression $RE=NR_r\ /NR$, where NR is the number of nodes having received packets in the warning zone, and *NR* is the total number of nodes in the warning zone.

c) MPC demonstrates the performance of MAC channel access, and reflects the broadcast redundancy indirectly.

d) AED is used to investigate the time properties of protocol, and is composed of network-layer waiting delay, MAC-layer channel access delay and propagation delay.

The simulation results in Fig. 6 shows that PMB outperforms I-BIA, Wp-PB, and ODAM in different traffic scenarios as for SRB (NB is not considered because of no broadcast redundancy suppression.). Because PMB considers both IVS and the transmission range, and it determines the optimum rebroadcast nodes based on ACA, as for a neighbor node with larger transmission range within one-hop range, the farther it is from PRN, the more likely it is to become a rebroadcast node, thereby resulting in more broadcast hops and redundancy of packet broadcasting. The situation that nodes with shorter transmission ranges rebroadcast packets could hardly happen. Moreover, PMB can make PRN be convinced quickly that packets have been delivered successfully by using the implicit ACK and the explicit ACK adaptively via packet rebroadcasting in two-way lane, resulting in lower rebroadcast redundancy. While ODAM only uses implicit ACK mechanism and only considers IVS without considering the transmission range. Thus, in the case of unidirectional link from PRN to CRN, PRN will rebroadcast packets constantly due to not receiving packets from CRN, moreover, the CRN farthest from the PRN is not guaranteed to have the maximum transmission range, resulting in needing more rebroadcast nodes for packet rebroadcasting, so the SRB of ODAM is unsatisfactory. I-BIA considers neither the position information of nodes nor the transmission range, so the unidirectional link would occur like ODAM, in addition, the selection of rebroadcast nodes from the nodes behind PRN is so uncertain as to increase the broadcast redundancy. Wp-PB calculates the random rebroadcasting probability based on the distance between two-hop adjacent nodes, every node behind PRN calculates its rebroadcasting probability respectively, and even if the nodes have smaller probability, they may still rebroadcast packets in parallel with the nodes of larger probability, thus causing higher broadcast redundancy. In conclusion, PMB has the optimum SRB comparing with four other broadcast protocols.

As shown in Fig. 7, the RE of PMB, I-BIA and ODAM can reach 100%, because they all have reliability guarantee mechanisms adjusted to the different scenarios. NB has no reliability guarantee mechanism, rear nodes rebroadcasts packets as soon as receiving them at the first time regardless of whether the packets have been successfully received, while Wp-PB has a limited guarantee mechanism that a duplicated packet is transmitted by a node for at most two times, so both NB and Wp-PB have the poor reliability of packet rebroadcasting when the connectivity gaps occur in the sparse traffic scenarios.

Fig. 8 shows that the simulation results of MPC, where Fig. 8(b) is the local amplification of Fig. 8(a) in the interval [2, 10] as for vehicle density. As illustrated in Fig. 8, PMB has the least number of MPC in different traffic scenarios. With the growth of the vehicle density, as for NB, the number of MPC increases sharply, because all neighbor nodes within one-hop will rebroadcast packets almost simultaneously. While I-BIA, Wp-PB, and ODAM have less number of MPC relatively, but they are all higher than PMB, the reason is similar to the analysis on SRB.

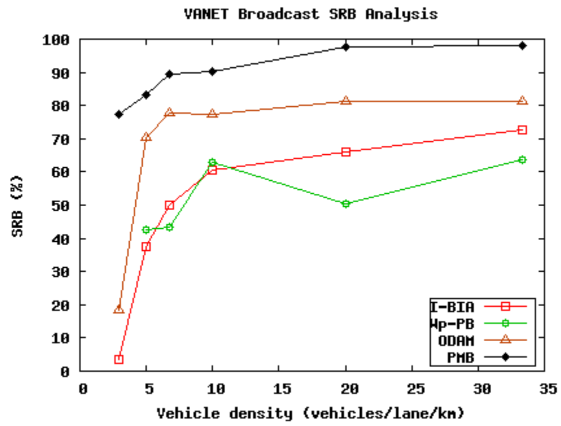


Figure 6. Vehicle density versus SRB

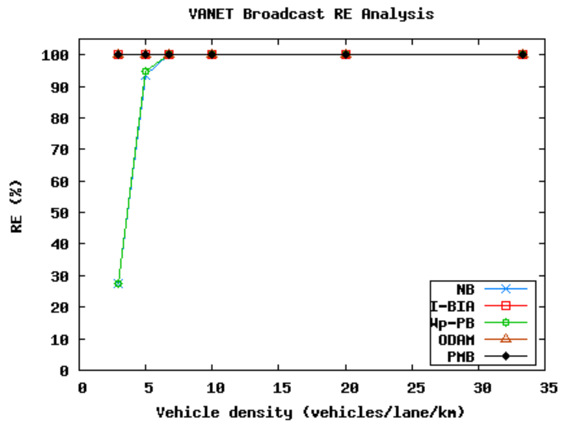
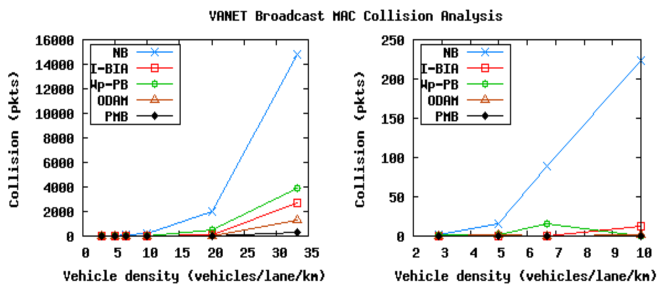


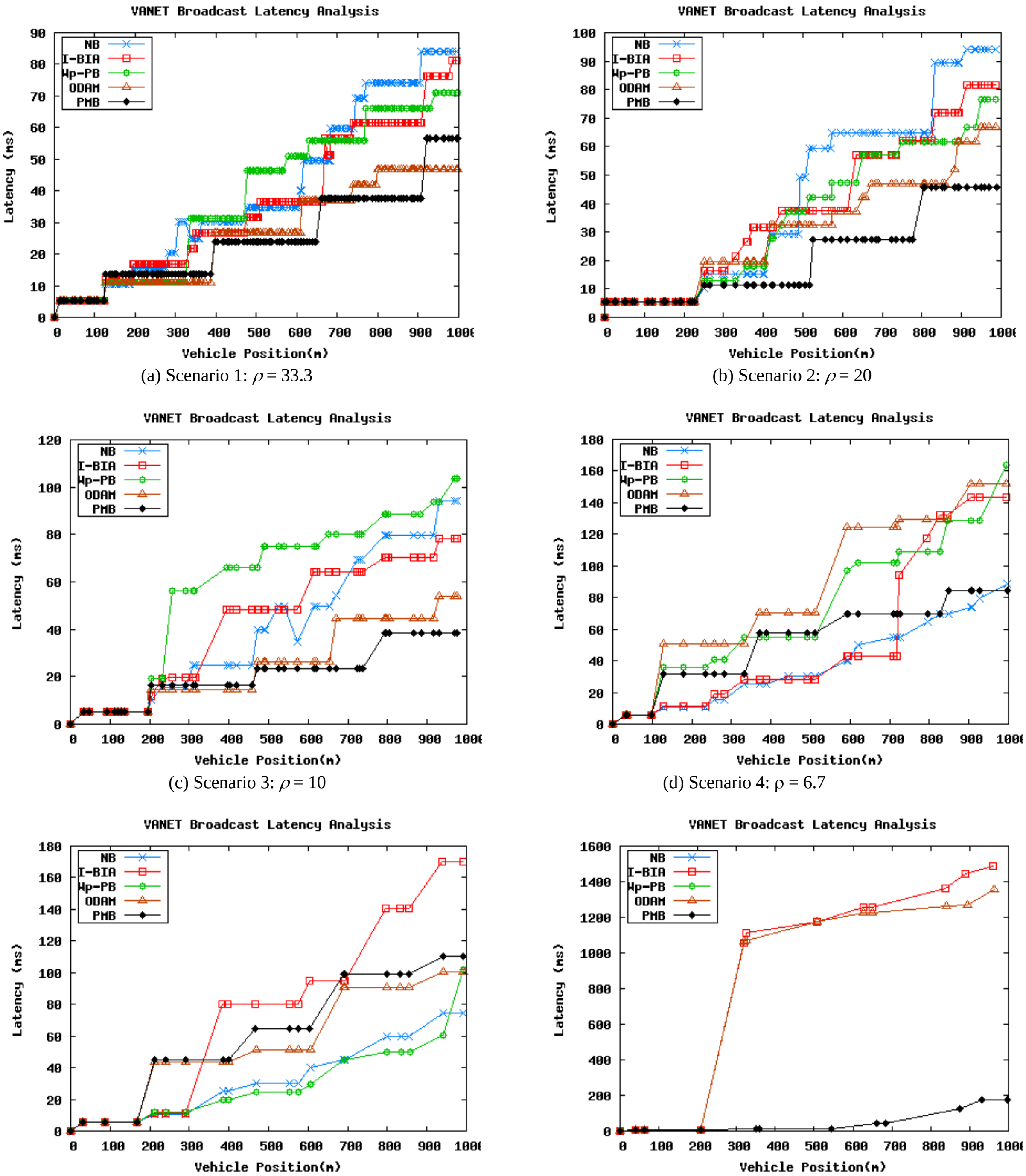
Figure 7. Vehicle density versus RE



(a) $\rho \in [0, 35]$ (b) $\rho \in [2, 10]$

Figure 8. Vehicle density versus the number of MPC

Fig. 9 shows the simulation of AED, where horizontal axis marks the distances between vehicles having receiving packets and the emergency source node. As shown in Fig. 9(a), (b) and (c), in dense traffic scenarios, PMB selects the optimum rebroadcast nodes, thus bringing the least broadcast hops and the least packet collisions relatively, so it has the minimum AED. Fig. 9(d) shows the sparse traffic scenario where VANETs have more connectivity gaps. Because the unreliability of packet broadcasting can cause incomplete message coverage of the warning zone, NB and Wp-PB have longer AED. ODAM and I-BIA rebroadcast packets only based on the one-way lane, which leads to longer AED in the case of connectivity gap due to slower recovery rate. PMB rebroadcasts packets with the help of nodes in the two-way lane so as to have rapider recovery rate of connectivity gap, so the AED of PMB decreases sharply.



(a) Scenario 1: $\rho = 33.3$

(b) Scenario 2: $\rho = 20$

(c) Scenario 3: $\rho = 10$

(d) Scenario 4: $\rho = 6.7$

(e) Scenario 5: $\rho = 5.0$

(f) Scenario 6: $\rho = 2.9$

Figure 9. Vehicle position versus AED in different scenarios

V. CONCLUSIONS

Existing broadcast protocols for VANETs usually do not consider the fact that different vehicle nodes always have different transmission ranges, and rebroadcast packets only with the help of vehicle nodes in one-way lane. In order to achieve better performance of warning message dissemination, a novel position-based multi-hop broadcast protocol is proposed in this paper. The proposed protocol selects the optimum rebroadcast nodes by calculating waiting time before packet rebroadcasting base on the additional coverage area of two adjacent nodes, and eliminates the connectivity gaps rapidly with the help of packet rebroadcasting in the opposite lane, thereby achieving better real-time performance of VANETs. In addition, it adopts the implicit and the explicit ACK answering mechanism adaptively, and controls the warning message dissemination by means of an integrated method based on regional restriction and time restriction, thereby improving the reliability and efficiency of warning message dissemination in VANETs. In this paper, four existing broadcast protocols and the proposed protocol have been simulated with NS-2 in different traffic scenarios, and the simulation results show that the proposed protocol outperforms the four other existing broadcast protocols, and is more suitable for the safety applications of VANETs such as vehicle collision avoidance.

ACKNOWLEDGMENT

This paper was supported by the National High Technology Research and Development Program of China (863 Program) (No.2007AA11Z227)

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