Information Technology Journal, 2010
ISSN 1812-5638

NPPB: A Broadcast Scheme in Dense VANETs

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Abstract: The Nth-Powered P-persistent Broadcast protocol (NPPB) is a probabilistic broadcasting scheme, which is designed to alleviate broadcast storms and support effective emergency message disseminations in dense VANETs. In this protocol, a probability p is calculated by the receiver to decide whether it should rebroadcast or not. This method reduces the rebroadcast probabilities more efficiently, which can alleviate the serious competitions and collisions. Comparative analyses have been done in two aspects to compare the new NPPB with traditional schemes. And a saturated traffic jam scenario is established to evaluate the NPPB scheme. Simulations results show that if the value of n is selected appropriately, NPPB can achieve higher performance such as less delay, fewer hops, lower load and higher throughput, at the same time the reliability can be guaranteed.

Key words: Inter-vehicle communication, ad hoc networks, broadcast, VANET, dense network

INTRODUCTION

VANETs (Vehicular Ad-hoc NETworks) are emerging as a new type of ad hoc networks, in which vehicles play the role of wireless network nodes. As in common ad hoc networks, broadcasting is an elementary operation to support many applications in VANETs (Tseng *et al*., 2003). Big automobile manufactures and research institutions are paying more and more attention to the techniques of broadcasting in VANETs. Today, so many vehicles are running on roads that serious traffic problems including traffic accidents and traffic jams are raised. In the United States, about six million accidents, tens of thousands of deaths and millions of injuries occurred every year (Biswas *et al*., 2006). In 2007, 327, 209 traffic accidents occurred in China, which caused 81, 649 deaths and 380, 422 injuries. Investigations show that most traffic accidents are collisions, however, 60% of crashes would be avoided by 0.5 sec earlier warning (Yang *et al*., 2004). An attempt should be made to distribute the safety messages to the vehicles with possibility of accidents. On the other hand, the traffic conditions of big cities become terrible, which result in time wasting, gasoline exhausting and serious air pollution. Some works should be done to make drivers know which ways can be selected to avoid traffic jams. So, at present, two main research objects on urban traffic are enhancing safety and increasing efficiency. Broadcasting in VANETs can disseminate assistant traffic condition messages to all vehicles within a certain geographical area to make drivers or vehicle control models pre-act to avoid accidents and pre-select ways to avoid traffic jams. In this condition, VANETs rely heavily on broadcast to transmit emergency messages efficiently in modern road traffic environment (Wisitpongphan *et al*., 2007).

The VANETs are considered as a specific case of MANETs (Mobile Ad hoc NETworks), therefore they have MANETs' characteristics, such as multi-hopped, decentralized and self-organized etc. By VANETs, vehicles running on the road can constitute decentralized, burst and temporary networks. The shape of network can be described and the aim broadcast region can be determined. For example, the Vehicle Infrastructure Integration (VII) initiative in the United States proposes that the information about an accident should be communicated through VANET within half a second to all equipped vehicles in a 500 m range (Menouar *et al*., 2006). Because of the shared wireless medium, a simple broadcast scheme which is called flooding may lead to frequent contention and collisions in transmission among neighbors (Wisitpongphan *et al*., 2007). The inherent problem of the blend flooding technique is the huge amount of superfluous retransmissions that consume the limited network resources (Eichler *et al*., 2006). These may lead lower reliability and more latency (Tseng *et al*., 2003). At an extreme condition, the channels may be blocked and broadcasts may fail, this phenomenon is called broadcast storm. In reality, traffic jams often occur in big cities, e.g., at the traffic peaks of big cities, more than 1 km long saturated traffic jams are common. The investigation shows that the traffic become saturated when the density reach 133 vehicles/km/lane (Ni *et al*., 1999). Figure 1 shows a usual scene happened in Beijing. The flooding scheme is infeasible in dense VANETs, because it brings

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Fig. 1: A common traffic jam in Beijing

us serious contentions, redundancies and collisions. To reduce these problems, an effective VANET broadcast protocol is necessary in dense traffic schemes.

In this study, the broadcast problem in a dense VANET environment is studied; a weighted p-persistent scheme is investigated and a new nth-powered p-persistent broadcast scheme is proposed finally.

BROADCASTING SCHEMES IN VANETS

In VANETs, TDMA, FDMA, or CDMA are difficult to implement due the need to dynamically allocate slots, codes, or channels without centralized control (Xu *et al*., 2004). Federal Communications Commission (1999) allocated 75 MHz spectrum at 5.9 GHz to Dedicated Short-Range Communications (DSRC). The DSRC uses a variant of the IEEE 802.11a technology to support safety critical communications (Xu *et al*., 2004). An IEEE working group is investigating a new PHY/MAC amendment of the 802.11 standard designed for VANETs: the Wireless Access in Vehicular Environments (WAVE), which is referred as IEEE 802.11p (Menouar *et al*., 2006). The IEEE 802.11 protocol employs CSMA/CA (Carrier Sense Multi Access with Collision Avoidance) strategy to deal with the media access problem. However, in a dense environment, the performance of networks is decreased and network jam even will occur when CSMA/CA strategy is used in flooding because frequent collisions cause a large amount of packets to be discarded. In VANETs, the characteristics of safety messages which are disseminated through the networks make multi-hop broadcasting the uppermost way for messages exchanging (Yousefi *et al*., 2006). To avoid the collisions, traditional techniques mainly focus on reducing retransmission times to control the formation of redundant information. Many exiting solutions alleviate the broadcast storms in the usual MANET environment, but only a few have been proposed to resolve this issue in the VANET context (Wisitpongphan *et al*., 2007). Ni *et al*. (1999) summarized some broadcast methods of MANET and they considered the broadcast problem has two characteristics: spontaneousness and unreliableness. Our scheme is based on these preliminaries, too. The existing methods were classified into categories as follow:

Simple flooding: A source node broadcasts a packet to its neighbors and all of them will rebroadcast the packet as soon as they receive it. As it is difficult to implement in dense MANETs, simple flooding can’t be used in dense VANETs either.

Counter-based scheme: When a broadcast begins, several nodes will rebroadcast the same packet, so one node will receive the same packet several times. Each node will count the number of times that a packet is received during a random period, then nodes will compare the numbers with predetermined thresholds to decide whether rebroadcast the packet or just drop. The advantage of this scheme is that nodes don’t need to know the structure of the network and don’t need to exchange neighbors’ knowledge, which suits VANETs’ temporary environment. But if counter-based scheme is used in VANETs, every node should wait a period and the delay will be increased; On the other hand, the threshold relates to the density of the network and it is difficult to select a suitable threshold value. The counter-based scheme alone cannot effectively prevent packet collisions which frequently occur in dense VANETs (Oh *et al*., 2006).

Distance-based scheme: In this kind of schemes, nodes use the relative distance to make the decision. The longer the distance between receiving node and sending node is, the larger the additional coverage is. So the nodes whose distances to the senders are bigger than the threshold will rebroadcast the received packets.

Location-based scheme: Nodes evaluate additional coverage area based on their location, if the additional area is less than a threshold, node will not rebroadcast the packet and vice versa.

The distance-based and location-based methods are feasible in VANETs because vehicles are the nodes of VANETs and by equipping GPS, it is easy to get vehicles’ geography information. However, the determination of threshold is difficult too. If the value is too small, the effect is not obvious; if the value is too big, the reliability can’t be guaranteed.

Cluster-based schemes: Cluster-based methods can enhance the performance of dense MANET (Lou and Wu, 2003). In this scheme, the nodes in one network are divided into several clusters and each has a cluster head node. When broadcast is implementing, only cluster heads will rebroadcast the messages, which minimizes broadcast flooding by using only head nodes to rebroadcast. The schemes use statistical and geometric characteristics divide the network into clusters. The cluster-based methods are common in MANET and they are usable in VANET too. This kind of methods is more suitable to the scenario in which vehicles distribute to clusters spontaneously and the clusters can maintain for a period of time. In despite of in a traffic jam the vehicles obtain a normal distribution, we only take the core traffic jam region into account and in this core region, the vehicle often obtain uniform distribution approximately. So, in our scenario, the density is saturated and vehicles obtain a uniform distribution. There are few available location characteristics and information, so it is difficult to divide network effectively by using statistical and geometric characteristics.

Neighbor knowledge scheme: Williams and Camp (2002) compared several kinds of MANET broadcast protocols, they classify probabilistic scheme and counter-based scheme into probability based methods, distance-based scheme and location-based scheme into area based methods. They also proposed neighbor knowledge methods, which are implemented by broadcasting the nodes' information and storing neighbor nodes' information locally and then they determine whether rebroadcast or not by that information. This kind of methods include flooding with self pruning (Lim and Kim, 2000), dominant pruning (Lim and Kim, 2000), scalable broadcast algorithm (SBA) (Peng and Lu, 2001), CDS-based broadcast algorithm (Peng and Lu, 2001), multipoint relaying (Qayyum *et al*., 2002), ad hoc broadcast protocol (AHBP) (Peng and Lu, 2000) and LENWB (Lightweight and Efficient Network-Wide Broadcast protocol) (Sucec and Marsic, 2000).

This kind of methods is infeasible in VANETs broadcasting. In VANETs, the safety applications need to disseminate the emergency information rapidly and effectively, yet the VANETs are temporary and burst and it is useless for vehicles to exchange neighbors' information frequently. At the same time, frequently information exchanging and storing will consume the limited bandwidth and local storage resources.

Probabilistic scheme: The probabilistic scheme predetermines a probability for every node and nodes will rebroadcast the received packet with their predetermined probabilities (Ni *et al*., 1999). When the probability is 100%, the scheme is equivalent to simple flooding.

Probabilistic schemes are simple methods for dense environments broadcasting to mitigate broadcast storms. A basic probabilistic scheme is p-persistence scheme, each node retransmits the packet with a predetermined probability p and this approach is sometimes referred to probabilistic flooding (Haas *et al*., 2006). The selection of p is the main problem in this kind of schemes. With the help of assistant location information, Wisitpongphan *et al*. (2007) propose weighted p-persistence broadcasting which is abbreviated to WPB in this study. The WPB is a classic probabilistic scheme. The assistance of location information makes WPB rational. They calculate the probability by using distance between receiving node and transmitting node to divide the average transmission range.

The basic rule of WPB is: upon receiving a packet from node j, node i checks the packet ID and rebroadcasts it with probability P_i if it receives that packet for the first time; otherwise, the node discards the packet (Wisitpongphan *et al*., 2007).

$$P_i = \left(L_{ij} / R \right) \times 100\% \qquad (1)$$

Equation 1 is used to calculate the probability P_i. Denoting the relative distance between nodes i and j by L_{ij} and the average transmission range by R. The forwarding probability of node i is denoted by P_i. Equation 1 is used to calculate the probability P_i in WPB. P_i increase with the distances L_{ij} increasing, that is the nodes which are closer to the transmission coverage border have more chance to retransmit the data. However, investigations show that the effect of this scheme is not up to much in saturated VANETs. The probability P_i increase with the distance linearly, as is shown with the solid line in Fig. 2. We note that the probability is more than 50% when the distance is more than half radius. That

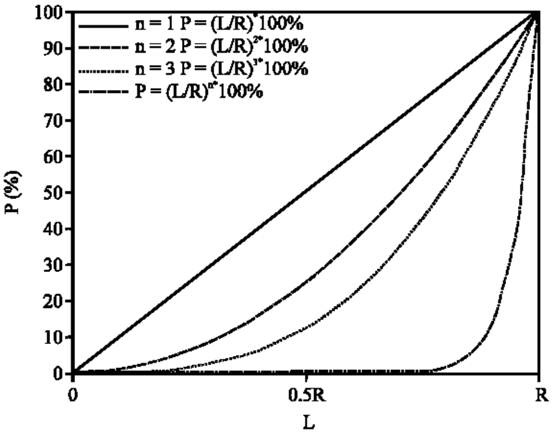

Fig. 2: Variation of probability P in the different schemes

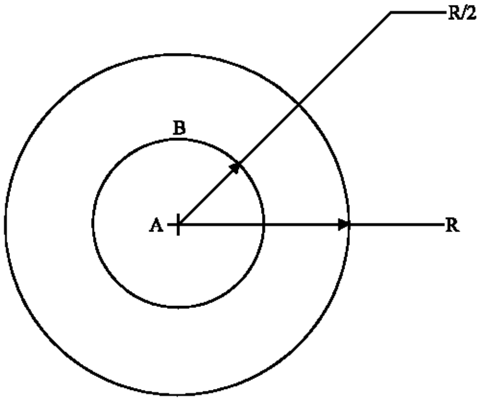

Fig. 3: Comparison of coverage areas of different radius

is all the nodes in the area B of Fig. 3 have the retransmission probabilities more than 50%. It can be calculated that the coverage area of B is three times as big as that of A. So a conclusion can be drawn that there are 3/4 neighbors have the more than 50% probabilities to retransmit. As a result, in a dense environment, the effect of WPB in saturated VANETs is not evident enough. So, a new effective scheme should be proposed to minimize the broadcast storm in dense VANETs, which can disseminate the information to enough far nodes rapidly.

NTH-POWERED P-PERSISTENT BROADCAST PROTOCOL

As analyzed in upper section, in spite of the WPB scheme makes the nodes closing to the transmission border have bigger probabilities the probability of collision is still big in dense VANET. Therefore, we try to make less nodes closing to border have the probability to rebroadcast, then a new nth-powered p-persistent broadcast (NPPB) scheme is proposed. The variation of the probability to the distance is show with the dotted curves in Fig. 2.

$$P_i = \left({}^{L_{ij}}\!/_{R} \right)^n \times 100\% \qquad (2)$$

The basic rule of NPPB is same to WPB. Denoting the relative distance between nodes i and j by L_{ij} and the average transmission range by R. The forwarding probability of node i is denoted by P_i. Equation 2 is designed to calculate new probability in our nth-powered p-persistent scheme. When n = 0, the scheme is a one-time flooding (OTF). That is every node will rebroadcast the packet as soon as they receive it first time. If n = 1 in the expression, the scheme is equal to WPB. When n>1 in NPPB scheme, P_i increases exponentially, it makes retransmit nodes concentrate toward the border of source nodes' coverage area, which results in the increasing of the additional coverage area of next hop and less rebroadcasts. The concentration increases with n value. The lager n is selected, the more concentration of retransmission nodes to the border is. Different n values can be selected according to the various densities of different VANETs.

ANALYSIS OF NPPB

Here, we analyzed and compared OTF, WPB and NPPB scheme in two aspects to prove that the new scheme is more effective.

Redundant coverage area: As shown in Fig. 4, A is the broadcast region. S is the area of aim area A. There are k node's in A, and the average transmit radius is R. It can be calculated that every node's coverage area is $S_i = \pi R^2$ ($i \in [1, k]$). We suppose that a message is going to broadcast to all the K nodes in area A. When the OTF scheme is used, all nodes will rebroadcast the packets once, the total area of all the nodes is:

$$S_{all}' = \sum_{i=1}^{k} S_i$$

then

$$S_{all}' = \sum_{i=1}^{k} \pi R^2 = k\pi R^2$$

As shown with shadowed area in Fig. 4, coverage area is seriously overlapped because the network is dense and the nodes locate closely. The overlapped area is redundant coverage area. The total redundant area is:

$$S_r' = S_{all}' - S = k\pi R^2 - S$$

The basic rule of our scheme is same to that of WPB scheme. It can be considered that:

$$S_i = P_i \pi R^2 (i \in [1,k])$$

It is because that every node rebroadcasts the broadcast message with probability P_i. Then the total area can be calculated as:

$$S_{all}'' = \sum_{i=1}^{k} S_i = \sum_{i=1}^{k} P_i \pi R^2$$

Replace P_i with Eq. 1, then we get:

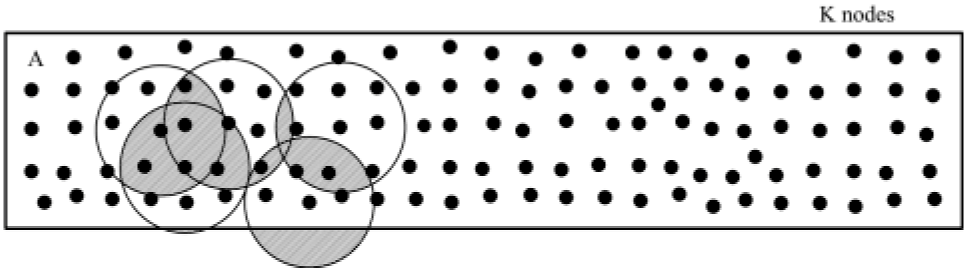

Fig. 4: Overlapped coverage of density area

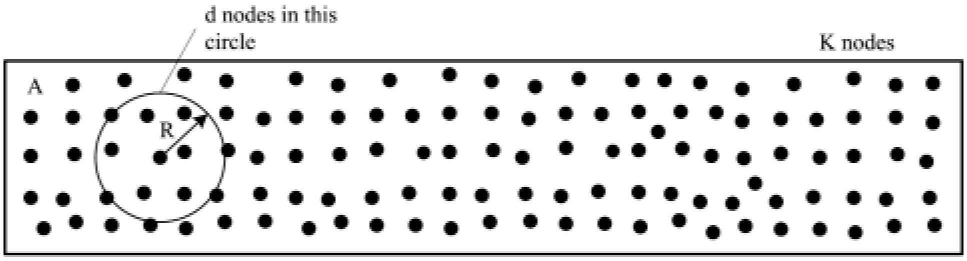

Fig. 5: Node's broadcast degree

$$S_{all}' = \sum_{i=1}^{k}\left(\frac{L_{ij}}{R}\right)\pi R^2$$

So, S_{all}'' calculated as follows:

$$S_{all}' = \sum_{i=1}^{k}\pi L_{ij} R$$

At last, the total redundant area can be calculated as:

$$S_r'' = S_{all}'' - S = \sum_{i=1}^{k}\pi L_{ij} R - S$$

Note that L_{ij} is smaller than R because L_{ij} is the distance between the receiving node i and the sending node j. The distance between two connected nodes will not exceed the transmission radius. So we can draw a conclusion that:

$$k\pi R^2 > \sum_{i=1}^{k}\pi L_{ij} R$$

that is $S_r' > S_r''$. This means that the total redundant area of WPB is smaller than that of OTF. Therefore, the WPB scheme is more efficient than OTF.

When the probability P_i is determined as Eq. 2 in NPPB scheme, the total area can be calculated as:

$$S_{all}'' = \sum_{i=1}^{k}\left(\frac{L_{ij}}{R}\right)^n \pi R^2, (n > 1)$$

it can be deduced that:

$$S_{all}'' = \sum_{i=1}^{k}\pi L_{ij}^n / R^{n-1}, (n > 1)$$

As is derived that:

$$S_{all}' = \sum_{i=1}^{k}\pi L_{ij} R$$

let:

$$S_{all}' = \sum_{i=1}^{k}\pi\left(\frac{L_{ij}}{R}\right)^{n-1}\left(\frac{L_{ij}^n}{R^{n-1}}\right), (n > 1)$$

then replace the equation with S_{all}''', we get:

$$S_{all}' = \sum_{i=1}^{k}\left(\frac{R}{L_{ij}}\right)^{n-1} \bullet S_{all}'', (n > 1)$$

As described before, L_{ij} is smaller than R and n>1, so:

$$\left(\frac{R}{L_{ij}}\right)^{n-1} > 1$$

then, $S_{all}'' > S_{all}'''$ and $S_r'' > S_r'''$. can be deduced. As a result, the redundant area of NPPB scheme is smaller than that of the WPB scheme, and the NPPB scheme is more efficient.

Redundant broadcast degree

Definition 1: Broadcast degree: The degree of a node i, denoted as D_i, is the number of neighbors of node i.

As shown in Fig. 5, there are k nodes in the broadcast region A. The region is in dense condition, and the density of nodes is saturated. R is the average transmit radius, in each node's coverage area, there are d nodes that can communicate with the node in one hop. That is the node has d neighbors. According to definition 1, D_i is used to denote the broadcast degree of node i, and $D_i = d$, ($i \in [1, k]$). In an ideal condition, there is an integer m, which is the smallest integer of retransmission times in which a message can be broadcast to the whole network. So the smallest summation of broadcast degrees of all nodes that participate in rebroadcasting is $D_{all} = md$. When OTF is used, all nodes in area A rebroadcast packets they received, the summation of broadcast degree is $D_{all}' = kd$. In the WPB scheme, every node rebroadcast the broadcast message with probability P_i, and the total broadcast degree is:

$$D_{all}'' = \sum_{i=1}^{k} P_i D_i$$

Replace P_i with Eq. 1, we get:

$$D_{all}'' = \sum_{i=1}^{k} {}^{L_{ij}}\!/_{R}\, D_i$$

then, it can be deducted that:

$$D_{all}'' = d\sum_{i=1}^{k} {}^{L_{ij}}\!/_{R}$$

where, L_{ij} is certainly less than R because L_{ij} is the distance between receiver and sender, so:

$$\sum_{i=1}^{k} {}^{L_{ij}}\!/_{R} < k$$

the result can be derived that:

$$d\sum_{i=1}^{k} {}^{L_{ij}}\!/_{R} < kd$$

so $D_{all}''' < D_{all}'$.

In NPPB, the total nodes' broadcast degree is:

$$D_{all}''' = \sum_{i=1}^{k} P_i D_i$$

the probability P_i is determined as Eq. 2, then we get:

$$D_{all}''' = \sum_{i=1}^{k} \left({}^{L_{ij}}\!/_{R}\right)^{n} d, (n > 1)$$

it can be derived that:

$$D_{all}''' = d\sum_{i=1}^{k} {}^{L_{ij}}\!/_{R} \bullet \left({}^{L_{ij}}\!/_{R}\right)^{n-1}, (n > 1)$$

$(L_{ij}/R)^{n-1}$ follows from $L_{ij} < R$ and $n > 1$, So $L_{ij}/R \bullet (L_{ij}/R)^{n-1} < L_{ij}/R$, at last, a conclusion can be drawn that $D_{all}''' < D_{all}''$. The total broadcast degree of the nodes that participate in rebroadcasting figures out the total times of wireless communications founded. The smaller the value is the fewer collisions will occur. Finally, a conclusion is drawn that the total broadcast degree of NPPB is smaller than that of the WPB, and the NPPB scheme is more efficient in a saturated VANET.

PERFORMANCE SIMULATIONS

To evaluate the NPPB scheme, the commercial simulator OPNET is used to simulate different scenarios includes OTF, WPB and NPPB with different integral exponent n to compare the effects of different schemes. Note, when n = 0, the scheme is the OTF scheme, when value 1 is selected, the WPB scheme is simulated, the other n values are selected to simulated the NPPB scheme.

The aim of our studies is to disseminate emergency information to enough nodes in time in a traffic jam condition. Our studies are on the assumption that all the vehicles equip GPS receiver. The scenario is a long straight road with a saturated traffic condition, on which the vehicles go slowly. The length of the area is 1000 m and the width is 50 m. The road has 8 lanes bidirectional, but just a single direction with 4 lanes is taken into account. We consider that the average distance between two vehicles is 1.3 m and the average length of vehicles is 5 m, so the average distance between two nodes is about 6.3 m. On this 4-laned road, there should be about 636 vehicles. In these scenarios, the vehicles obtain a uniform distribution, the relative location of vehicles will not change and the relative speed of different vehicles is 0 approximately. This is because all the vehicles go slowly and there is no place for overtaking in a saturated environment.

The scenario is shown in Table 1. IEEE 802.11 standard is referenced as the MAC layer protocol to simulate CSMA/CA strategy. The fixed parameters in our simulations are transmission rage (300 m), the

Table 1: Simulation parameters

Scenario length	100 m
Scenario width	50 m
No. of lane	4 lane
Nodes No.	636 nodes
MAC protocol	IEEE 8.2.11 with CSMA/CA
Transmission range	300 m
Packet size	1024 bytes
Bandwidth	1 M bps
Packet generation speed	1 packet sec^{-1}

broadcast packet size (1024 bytes), the transmission rate (1 M bits sec^{-1}) as suggested in IEEE 802.11. The simulation lasts 100 sec and each of the first 5 nodes generates 1 packet sec^{-1}. The following metrics are considered in evaluating the performances of different schemes:

- **Broadcast Coverage Ratio (BCR):** The percentage of the nodes in a VANET that received a broadcast packet over the nodes which should receive that packet in the broadcast region. This performance parameter indicates the coverage ratio of a broadcast protocol, which can reflect the reliability of VANETs, the higher the value is, the more reliable the VANET is
- **Reachability (RE):** The percentage of the packets received by one of the farthest node over the sending packets. This metric can reflect the reliability in another aspect
- **Broadcast Delay (BD):** The latency from the time on which packet is generated to that on which the packet is received by the farthest node that should receive that message in a VANET. As other indicators about latency, the smaller value is more appealing
- **Rebroadcast Ratio (RR):** The percentage of VANET nodes which participate in rebroadcasting. The smaller this ratio is, the more effective the scheme is
- **Average Number of Hops (ANH):** The average number of hops in which a broadcast message is transmitted from the original node to all the destinations. As the upper metric, a smaller value is expected
- **Load:** The average flow of data in a time unit all over the VANET. The lower load means the network is more efficient
- **Throughput:** The average rate of successful message delivery over the whole target region in the VANET. A bigger throughput is expected

Figure 6 shows the broadcast coverage ratios of different n values. Almost all values of the curves reached 100%, except that some points in the curves were less than 90%. That is, in a saturated scenario, all the schemes could guarantee the reliability basically.

Figure 7 shows the reachability of the farthest node. The curve of n = 3, n = 7 and n = 12 were higher than 90%. The reachabilities of OTF and WPB were lower than and close to 90%. Obviously, when n value was bigger than 30, the reachability dropped rapidly. As designed, our scheme used nth-power to reduce rebroadcast probability in a dense VANET and this made the scheme obtain better performance when n went up. But, when n value was big enough, the rebroadcast probability was too low to guarantee the retransmissions. So, the reachability went down.

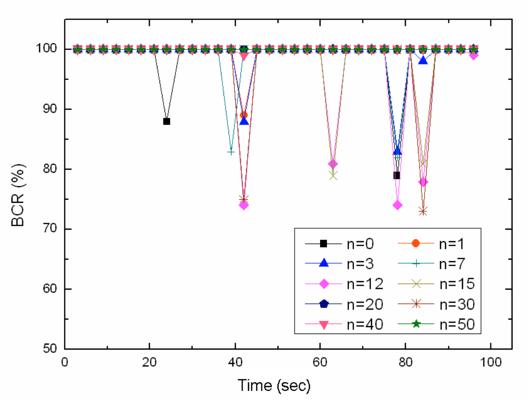

Fig. 6: Broadcast coverage ratio of different n values

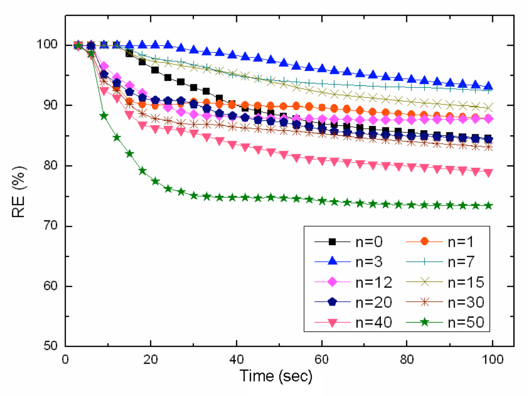

Fig. 7: Reachability of the farthest node

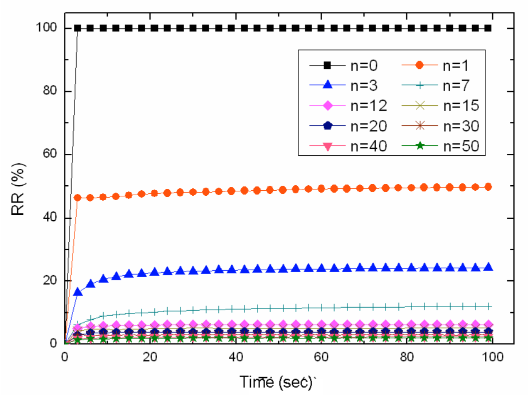

Fig. 8: Rebroadcast ratio

Rebroadcast ratio, as shown in Fig. 8, is the different percentages of network nodes who participate in rebroadcasting when n is chosen different values. It

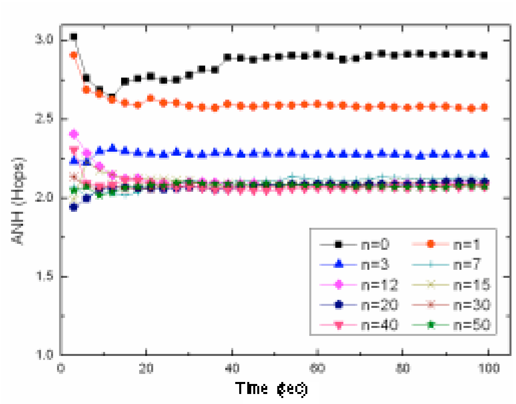

Fig. 9: Average number of hops

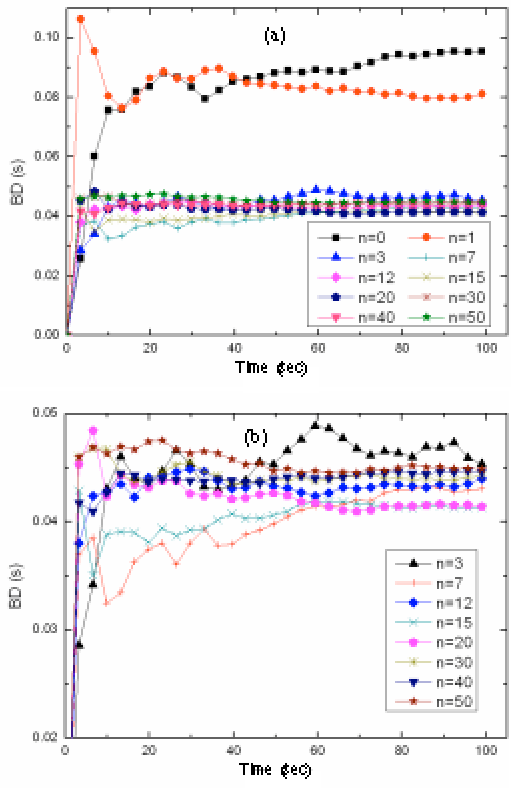

Fig. 10: Average broadcast delay

can be noted in the figure that the curve of n = 0 was a line at 100%. This is OTF, every node in this scheme will rebroadcast the packets. When n = 1, the percentage was close to 50 and other curves were described as a set of parallel lines. The bigger n was selected, the lower the line was drawn. The curve was lower than 2% when n = 50. It is detected that the rebroadcast ratio can reflect probabilities p of different n values in p-persistent schemes and this phenomenon is rational.

Figure 9 is the average number of hops of the whole VANET with different n values. Fewer hops were needed when the exponent n was bigger. The number of average hops was the biggest when n = 0, the curve of n = 1 was higher than that of other n>1 values. With the growth of exponent, fewer retransmissions were needed, that is to say fewer nodes participated in the rebroadcasts and the chances of collisions were lower.

Figure 10 shows the average broadcast latency of different schemes, in which a packet can be transmitted across the target region in dense VANETs. Figure 10a depicts that the average delay went down from more than 0.09 sec to about 0.04 sec. Because when n = 0, the scheme brought out so many competitions and collisions, OTF have the largest delay. In p-persistent schemes, the delays decreased with n's increasing. The decreasing was inconspicuous when the value of n was bigger than 3. But Fig. 10b shows that if the value of n was selected from 7 to 20, the latency was low. When n was bigger than 30, the latency increased due to the lower rebroadcast probability that brought more retransmission attempting.

Figure 11 compares the average loads of the network in different scenarios. It is shown that the load of OTF was the biggest. The bigger the n value was selected the smaller the load was. As shown in Fig. 11b, when n = 3, the curve was lower than n = 1 evidently, but the trend of being lower was more and more inconspicuous. It is because that the schemes with smaller n, especially the OTF and WPB schemes, had more retransmission nodes, then they had more chance of collisions in dense VANETs, the longer waiting time and the more retransmissions made the loads bigger.

Throughput is the average rate of successful message delivery over a communication channel, which can reflect the performance of VANETs. The bigger the throughput was, the higher the network efficiency was. The square curve in Fig. 12 shows that when n = 0, the throughput of OTF was the smallest. All the throughputs of p-persistent schemes were bigger than that of OTF obviously, because in OTF scheme, every node rebroadcast the packets, which brought out too many redundant transmissions and collisions to broadcast the messages effectively. The curves go higher with the growth of n. When n is selected from 12 to 30, the network obtained high throughputs. But when n = 50, the curve went down to the level of n = 3 and n = 1. Too big n is selected, which made the rebroadcast probability became so low that too many retransmissions attempting occurred, so the rate of successful message delivery can't be guaranteed.

In conclusion, the results show that the metrics of rebroadcast ratio, number of hops and average load

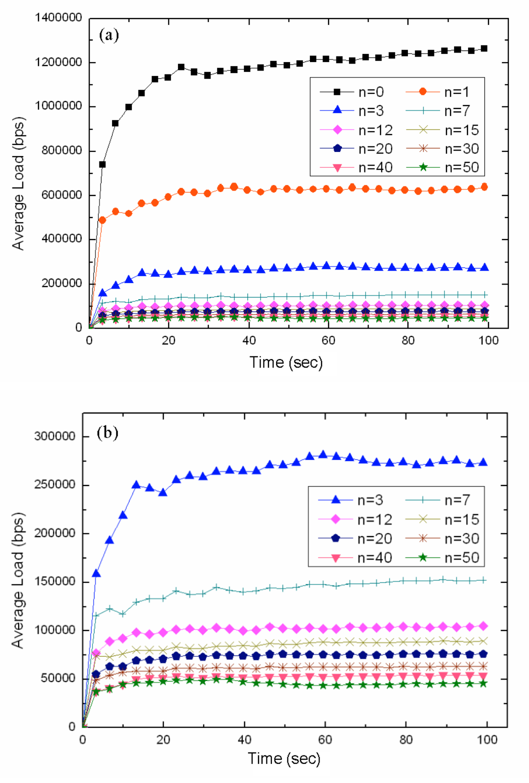

Fig. 11: Average loads of the network

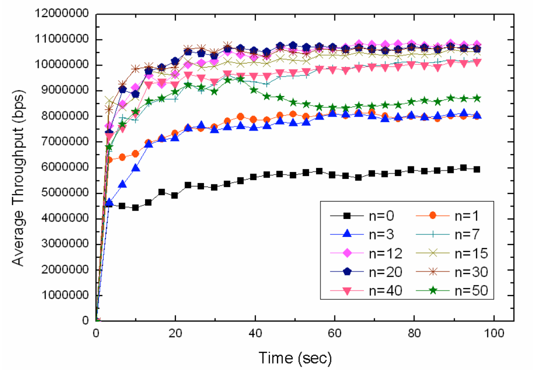

Fig. 12: Average throughputs of the network

obtain monotonic variations with n's growth; but inflection points can be found in the indicators of reachability, broadcast delay and throughput of the VANET. It is because that, when value of n is small, the rebroadcast probabilities are not low enough for alleviating collisions effectively in a saturated VANET. The performances were improved and higher efficiency was obtained when n's value went up. But when the value of n was selected too high, the probabilities of retransmissions were too low to rebroadcast messages successfully, so the degradation of performance occurred.

Investigations show that the values from 7 to 12 are good selections in out saturated VANET scenario. At the same time, when n = 7 and n = 12, the reachability and coverage ratio indicate that the NPPB scheme can guarantee the reliability of the dense VANET.

CONCLUSIONS

Multi-hop broadcasting in a traffic jam is familiar in VANETs, however, serious redundancy, contention and collision are caused by the frequent communication in this condition. All methods devote to reducing rebroadcasts to relieve above problems, among which p-persistent is an effective one. However, the efficiency of traditional p-persistent schemes is unsatisfactory. A new nth-powered p-persistent scheme is proposed in this study. Analyses and simulations show that if the value of n is selected appropriately, NPPB can achieve higher performance such as less delay, fewer hops, lower load and higher throughput, at the same time the reliability can be guaranteed. This is attributable to the less collisions brought by the NPPB scheme in dense VANETs. In NPPB, the selection of integral exponent n is pivotal. By simulations, we find that the larger n is selected the better the performances of network are. But when the value goes too big, some performances degrade, because the retransmission nodes is so little that effective coverage can not be ensured. On the other hand, the values of n should be selected according to the density of network. In our saturated VANET scenario, the values from 7 to 12 are good selections.

In the later researches, the relation of density to the exponent will be studied and an adaptive way to make the exponent vary with the density will be investigated.

ACKNOWLEDGMENTS

This study is supported by 863 Hi-tech Research and Development Program of China with grant number 2008AA01A201.

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