Average Speed Based Broadcast Algorithm for Vehicular Ad Hoc Networks (Workshop)

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Abstract. In order to solve the problem of broadcast storm and broadcast unreliability in Vehicular Ad Hoc Networks (VANET) on highways, an improved algorithm based on Speed Adaptive Probabilistic Flooding (SAPF) [1], which is referred to as Average Speed Based Broadcast (ASBB), is proposed. Since the average speed of vehicles in the vicinity reflects the network congestion around the current node more accurately, ASBB dynamically calculates the forwarding probability according to the average speed of the current node and the corresponding neighbor nodes. To obtain the speed of neighbor nodes, each node encapsulates its speed into the header of packets it transmits, instead of employing new types of packet for exchanging speed. This approach alleviates the network load and reduces the complexity of implementation. Meanwhile, only the nodes located behind the current node may participate in the forwarding of the broadcast packet, which reduces the number of nodes participating in the forwarding and further mitigates the broadcast storm and improves the broadcast reliability. The simulation results show that ASBB performs well in terms of suppressing broadcast storms, increasing the reachability and reducing the end-to-end delay.

Keywords: Vehicular Ad Hoc Networks · Broadcast storm · Broadcast reliability · Probability based broadcast algorithms · Average speed based broadcast algorithms

1 Introduction

On highway, many accidents are usually caused by slow detection of rear vehicles to the accidents in front of them [2]. Vehicular Ad Hoc Networks (VANETs) [3] are a type of network in which self-organizing technology is applied to the inter-vehicle communication. It can rapidly and automatically form a network providing communication between vehicles. Hazard warning applications in VANETs can extend the vision of drivers, allowing drivers to know the accidents in advance and take steps to avoid traffic accidents. The problem faced by VANETs in this scenario is how to quickly and reliably transmit emergency warning messages to other vehicles.

Broadcasting is the technique by which a source node transmits a broadcast packet to all other nodes in a network. After receiving a broadcast packet, a node may forward

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it to the nodes within its coverage. Therefore, a message is disseminated throughout the network quickly.

Flooding is the simplest broadcast algorithm in VANETs [4]. By flooding, each node forwards the packet received after receiving it for the first time. When the node distribution is sparse, it achieves high broadcast coverage and low latency. However, when the node distribution is dense, it is easy to cause serious broadcast storm due to a large number of redundant transmissions. Redundant transmission may also result in unreliable broadcast and longer end-to-end delay which seriously deteriorate the performance of emergency information transmission. In addition, since the topology of VANETs changes rapidly, traditional broadcast algorithms are not able to be applied to VANETs directly. Therefore, it is desirable to design efficient, reliable broadcast algorithms which are suitable to VANETs.

To address the broadcast storm problem of VANETs, many algorithms have been proposed. Basically, they can be categorized into single-hop broadcast algorithms and multi-hop broadcast algorithms [5–8]. The single-hop broadcast is referred to as the approach by which the source nodes only transmit the broadcast packets to the nodes within its one-hop coverage, and the broadcast packet cannot be transmitted throughout the entire network. In contrast, by the multi-hop broadcast, the broadcast packets are forwarded throughout the entire network. Since the coverage of the multi-hop broadcast is larger, it is more suitable for the highway scenario. The multi-hop broadcast algorithm in VANETs can be further divided into probability based broadcast algorithms, delay based broadcast algorithms, location based broadcast algorithms, cluster based broadcast algorithms and hybrid broadcast algorithms.

By the probability based broadcast algorithms, the node that receives a certain broadcast packet for the first time calculates the forwarding probability according to a predetermined rule, then the node forwards the broadcast packet according to the forwarding probability. The forwarding probability is calculated based on local or global parameters, such as distance, density, speed, and so on. Such algorithms have the advantages of its simplicity to be implemented. The SAPF [1] algorithm is one of representative algorithms by which each node calculates its forwarding probability according to the speed of the vehicle. The higher the speed, the larger the forwarding probability. However, when calculating the forwarding probability, only its own speed of the current node is considered. By observing the fact that the speed of only one node cannot well reflect the node density in its vicinity, the calculation of its forwarding probability in SAPF is not reasonable enough.

In the delay based broadcast algorithms, each node in the network sets a different waiting delay before forwarding the broadcast packet. Generally, the delay is set according to the distance between the transceiver nodes. The farther the distance, the shorter the delay. The node whose delay count down to zero first forwards the broadcast packet first. If the other nodes that is still deferring receive the broadcast packet again, they stop the delay and no longer participate in the forwarding process. This type of algorithms achieves low broadcast packet redundancy. However, when the node density is heavy, the nodes whose distances to the upstream node are close have almost identical delay.

Hence, their delay timers expire and then those nodes start to transmit almost simultaneously which result in more redundant broadcast packets [9]. Moreover, according to [10], the optimal forwarding node may suffer from the longest waiting delay.

In location based broadcast algorithms, the forwarding nodes are selected according to the location and the direction of the nodes. Generally, the node that is the farthest from the source node is selected as the forwarding node. In this way, the number of nodes participating in forwarding is reduced. The main drawback of this category of broadcast algorithms is that GPS or other positioning devices are generally required to obtain the position. There are some representative algorithms such as BPAB (Binary-Partition-Assisted Broadcast) [11], improved BPAB, UVMBP (Urban VANET Multi-hop Broadcast Protocol), UMBP (Urban Multi-hop Broadcast Protocol) [10], and 3P3B (Trinary Partitioned Black-burst-based Broadcast) [12]. The core idea behind these algorithms is to use the dichotomy or the trichotomy to select the farthest effective area. Then, the nodes in the farthest effective area compete to forward broadcast packets. These algorithms can select the optimal forwarding node faster, with low delay. However, the complexity of selecting the forwarding node is high.

In the cluster based broadcast algorithms, each cluster is composed of cluster head nodes, gateway nodes, and member nodes. The cluster head is responsible for transmitting the message to the member nodes in the cluster, and the gateway node is responsible for realizing communication between the clusters. This type of algorithms reduces the redundancy of transmission. However, because the topology of VANETs changes rapidly, the cluster based broadcast algorithms have large maintenance overhead. Also, they have longer delay.

The aforementioned types of broadcast algorithms are able to suppress the broadcast storm and provide the broadcast reliability to some extent. However, they suffer from one problem or another. Therefore, some hybrid broadcast algorithms are proposed with the aim to perform better. However, hybrid broadcast algorithms still have many problems, e.g. high redundant broadcast packets and low reliability. They may not meet the requirements for low delay [13, 14] and high reliability [15] under highway scenario.

From the above discussion, the following conclusions can be drawn for the highway scenario. Firstly, the fewer nodes participating in the broadcast, the more favorable to mitigate the broadcast storm. Secondly, the fewer the number of packets forwarded, the better the suppression effect on the broadcast storm. Thirdly, the broadcast algorithm must accurately reflect the situation of surrounding nodes, thereby improving the reliability of the algorithm. An improved algorithm based on SAPF, Average Speed Based Broadcast algorithm (ASBB), is proposed.

In ASBB, each relay node calculates the forwarding probability based on the average speed of the current node and the neighbor nodes, and then forwards the broadcast packet according to the probability. First of all, the algorithm is a probability based broadcast algorithm, which is simple and easy to be implemented and can effectively suppress broadcast storm. Secondly, the average speed of the current node and the neighbor nodes is used as a parameter for dynamically calculating the forwarding probability, which can accurately reflect the network congestion in the vicinity of the current node. In addition, the speed and location of the neighbors are carried by the broadcast packet header, so it is not required to periodically exchange additional new type of packets to acquire the speed of the neighbor nodes. Consequently, the network load is reduced, possible congestion is alleviated and the broadcast storm is mitigated. As a result, the broadcast reliability is not deteriorated. Furthermore, only the nodes located behind the immediate upstream nodes may be selected as the forwarding nodes, which further reduce the number of forwarding nodes and suppress the broadcast storm.

The rest of this paper is organized as follows. The introduction is given in Sect. 1. Section 2 describes ASBB in detail. The simulation scenario and simulation results are given in Sect. 3. Conclusions are drawn in Sect. 4.

2 Description of ASBB

Firstly, density of nodes distribution is relevant to the velocity of nodes [1]. However, we argue that the average speed nodes can better reflect the nearby density of nodes. Thus, the forwarding probability of each relay node is determined according to the average speed of the current node and the neighbor nodes.

The following strategies are adopted in ASBB. (1) Each node in the network obtains the speed and location of its neighbors by extracting from the headers of the packets received and calculates the average speed of the current node and its neighbors. (2) Calculate the forwarding probability according to the average speed of the current node and the neighboring nodes and forward the broadcast packet according to the forwarding probability. (3) The speed and location information of the neighbor nodes are carried in the broadcast packet headers. (4) Nodes located behind the immediate upstream node may be selected as the forwarding nodes.

2.1 Table Maintaining

In ASBB, each node in a network needs to maintain a neighbor information table (NIT) and a table recording the broadcast packets received (TRBPR).

A node establishes or updates the corresponding entry in NIT which is consisted of upon receiving a broadcast packet. The NIT includes the IP address of the current node j and entries of neighbor nodes. The entry of the qth neighbor node of node j is consisted of the IP address of the qth neighbor node of node j, the speed v_{jq} of the qth neighbor node of node j, and overtime value T_1 of the corresponding entry. So after running for a period of time, each node has the speed values of its neighbor nodes. If the overtime of an entry is expired, this entry should be canceled since the entry has not been updated by the corresponding nodes.

2.2 Calculate the Forwarding Probability

The basic idea behind ASBB is that a node forwards a packet received according to the forwarding probability of the node which varies with the average speed of the node and its own neighbor nodes. The higher the average speed, the higher the broadcast probability, and vice versa. Therefore, calculating the broadcast forwarding probability is the key step of ASBB. Before that, it is required to determine the average speed of a node.

The average speed $\bar{v}_j$ of the node j and its surrounding area is calculated as the Eq. (1):

$$\bar{v}_j = \frac{1}{n+1}\left(v_j + \sum_{q=1}^{n} v_{jq}\right) \tag{1}$$

Where n is the number of neighbor nodes of node j recorded in NIT of node j, v_j denotes the speed of the current node j, and v_{jq} denotes the speed of the qth neighbor node of node j.

The forwarding probability P_j of node j is calculated as in Eq. (2):

$$P_j = \begin{cases} 0.08 & \bar{v}_j < 15\,\text{km/h} \\ \frac{2}{\pi} sin^{-1}\frac{\bar{v}_j}{120} & 15\,\text{km/h} \le \bar{v}_j \le 110\,\text{km/h} \\ 0.738 & \bar{v}_j > 110\,\text{km/h} \end{cases} \tag{2}$$

When $\bar{v}_j < 15$ km/h, the traffic on the road is close to saturation, which means the network reaches a very high density. So, the forwarding probability of node j is set as $P_j = \frac{2}{\pi} sin^{-1}\frac{15}{120} \approx 0.08$. When 15 km/h $\le \bar{v}_j \le$ 110 km/h, calculate the forwarding probability of node j according to $P_j = \frac{2}{\pi} sin^{-1}\frac{\bar{v}_j}{120}$. When $\bar{v}_j > 110$ km/h, the network density is sparse. In order to improve the broadcast coverage, the forwarding probability is set as $P_j = \frac{2}{\pi} sin^{-1}\frac{110}{120} \approx 0.738$, which is a relatively high probability. It can be seen from Eq. (2) that P_j is monotonically increased with $\bar{v}_j$. Apparently, $P_j \in [0.08, 0.738]$.

2.3 Source Node Sends a Broadcast Packet

Assuming that node i is a source node in the Vehicular Ad Hoc Network, the steps for the source node i to send a broadcast packet are as in Algorithm 1.

Algorism 1 Source node sends a broadcast packet.	
1	the source node i generates a broadcast packet with sequence number z; establishes the broadcast packet entry in TRBPR; sets an overtime value T_2; records that the broadcast packet has been received;
2	node i obtains the speed v_i of the current node;
3	encapsulates the IP address of the source node i, the broadcast packet sequence number, the IP address of the current node i, the broadcast destination IP address, the speed and location information of the node i into the broadcast packet header;
4	transmits the broadcast packet;
5	end;

2.4 Relay Node Receives and Forwards Broadcast Packets

All nodes in the network can act as relay nodes. Assume that node j is a relay node in the Vehicular Ad Hoc Network. Node j receives a broadcast packet with sequence number z from its previous hop neighbor nodes h. The steps are shown as in Algorithm 2.

Algorism 2 Relay node receives and forwards a broadcast packet.

node j receiving a broadcast packet with sequence number z from its previous hop neighbor node h;
if node j receives the broadcast packet from node h for the first time **then**
  establish a new entry for node h in NIT; record the speed v_{jq} of the node h; set the overtime value T_1;
else
  update the speed v_{jq} in the corresponding entry of the node h in NIT; update the overtime value T_1;
if there is an entry of the broadcast packet in TRBPR of node j **then**
  directly discards the broadcast packet (the node j does not receive the broadcast packet for the first time);
  end;
obtain the position (x_h, y_h) of the last hop neighbor node h in the broadcast packet header; obtain the position (x_h, y_h) of the current node j, and compare the values of x_j and x_h;
if $x_j > x_h$ **then**
  directly discarding the broadcast packet (it is indicated that node j is located in front of the previous hop node h);
  end;
establish a new entry of the broadcast packet in TRBPR of node j; set the overtime value T_2; add the record that the broadcast packet has been received;
Obtain the speed v_j of the current node j; calculate the average speed $\overline{v_j}$ of the current node j and its neighbors according to $\overline{v_j} = \frac{1}{n+1}\left(v_j + \sum_{q=1}^{n} v_{jq}\right)$;
calculate the forwarding probability P_j of the node j according to the equation (2); generate a random number σ which is uniformly distributed over [0-1];
if $\sigma > P_j$ **then**
  directly discarded the broadcast packet;
else
  node j encapsulates the broadcast packet received in the format of the broadcast packet; forwards the broadcast packet;
end;

3 Simulation

To evaluate the performance of ASBB, we conducted a series of simulations over a diverse range of network conditions. To compare the performance, Flooding and SAPF are taken as references. In the simulation, a highway whose size is 1.0 km * 9.0 km has three lanes in each direction. Initially, nodes in a network are randomly and uniformly distributed on the road according to the node density set before the simulation. The initial velocity of vehicles is uniformly distributed over [60, 120] km/h. Each node adaptively adjusts the speed according to its distance from the front node. According to the 80th entry of the Enforcement Regulations of the People's Republic of China Road Traffic Safety Law, a vehicle should maintain a distance of more than 100 m from the immediate front vehicle of the same lane when the vehicle speed exceeds 100 km/h. The distance can be shortened appropriately, but the shortest distance is 50 m when the vehicle speed is lower than 100 km/h. In this case, the speed of the vehicle should be maintained constant. When the distance between the two closest nodes on the same lane is less than 50 m, the deceleration starts at an acceleration speed of $-5\,\text{m/s}^2$. The acceleration starts at $5\,\text{m/s}^2$ when the distance is greater than 100 m. The maximum speed is no more than 120 km/h. Each node remains in the same lane when moving forward and will not change lanes during driving. All vehicles use an omni-directional antenna and moves in the same direction. A source node in the network transmits at Constant Bit Rate (CBR). Detailed parameter setting is shown in Table 1.

Table 1. Simulation parameters

Parameters	Value	
Wireless interface rate (Mb/s)	11	
MAC layer protocol	IEEE802.11DCF	
Antenna	Omni-directional antenna	
Node wireless coverage radius (m)	300	
Road length (km)	9.0	
Number of lanes (lane)	3	
Lane width (m)	3.75	
Broadcast packet size (bytes)	1024	
Simulation time (s)	200	
Change parameters		
Node density (vehicles/km/lane)	10/15/20/25/30	20
CBR (Packets/s)	1	0.5/1/1.5/2

The node density and CBR are set as follows.

Scenario 1: The node density in the network is set to 10, 15, 20, 25, 30 vehicles/km/lane, while CBR of a source node is 1 Packet/s.

Scenario 2: The node density in the network is set to 20 vehicles/km/lane while a source node varies CBR from 0.5, 1, 1.5, to 2 Packets/s.

The performance of Flooding, SAPF and ASBB are compared in terms of ratio of forwarding nodes, reachability and average end-to-end delay.

Ratio of forwarding nodes is the result of the number of forwarding nodes over the number of all nodes in a network. Figure 1 shows the ratio of forwarding nodes versus the node densities. Figure 2 shows the ratio of forwarding nodes versus the CBR rates. It can be seen that, in most cases, the ASBB algorithm has the lowest ratio of forwarding nodes,

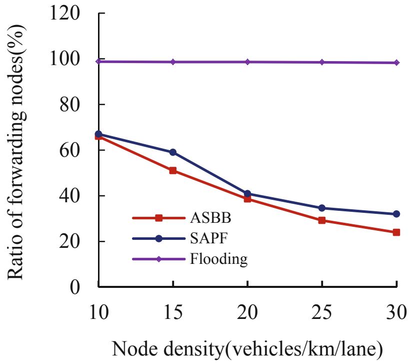

Fig. 1. The ratio of forwarding nodes versus different node densities

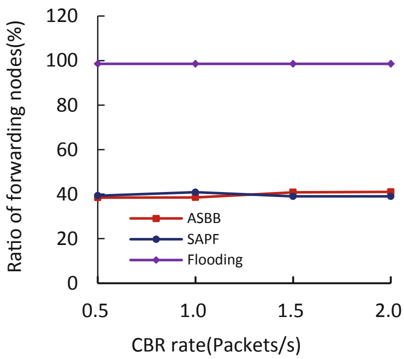

Fig. 2. The ratio of forwarding nodes versus CBR rates

followed by SAPF, Flooding, respectively. The reasons are given as follows. According to Eq. (2), the forwarding probability is calculated based on the average speed of the current node and the neighbor nodes in ASBB. The average speed of the current node and the neighbor nodes can better reflect the network congestion around the current node. While in SAPF, the forwarding probability is calculated only according to the speed of the current node which cannot accurately reflect the traffic situation around the current node. Thus, the selected forwarding node may not be reasonable. For example, when the nodes on the same lane are densely distributed on a highway, there may be several nodes moving fast, which leads to a higher forwarding probability and then more nodes are involved in forwarding. However, if the ASBB algorithm is adopted the forwarding probability that is calculated according to the average speed of the current node and its neighbor nodes is lower than that of SAPF. So less nodes are involved in forwarding, which directly leads to the lower ratio of forwarding nodes. For Flooding, all nodes participate in the forwarding of broadcast packets, so the ratio of forwarding nodes is the highest.

The lower the ratio of forwarding nodes, the better the broadcast storm suppression effect. Therefore, the ASBB algorithm suppresses broadcast storm best among the above three broadcast algorithms.

Reachability is the number of packets received in the entire network over the number of packets should be received. Figure 3 shows the reachability versus the node densities and Fig. 4 shows the reachability versus CBR rates. We can observe that Flooding has the best performance in terms of reachability, followed by ASBB, and SAPF respectively. This can be explained as follows. In Flooding, all the nodes participate in the forwarding of broadcast packets. Intuitively, the reachability flooding is the highest. In SAPF, sometimes the case that one node is of low speed which leads to low forwarding probability while its neighbors are of high speed exists. The node with low forwarding probability may not participate in the forwarding of broadcast packets, which may lead to network fragmentation. In this case, the broadcast packet will not be received by all nodes. As a result, the reachability decreases. If the ASBB algorithm is adopted however, the forwarding probability that is calculated according to the average speed

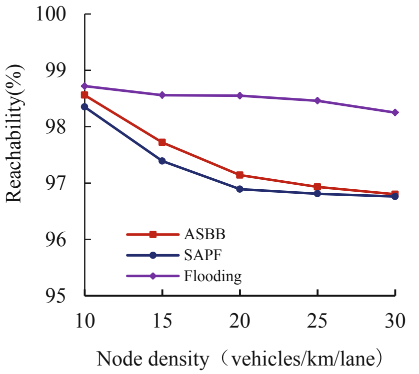

Fig. 3. The reachability versus node densities

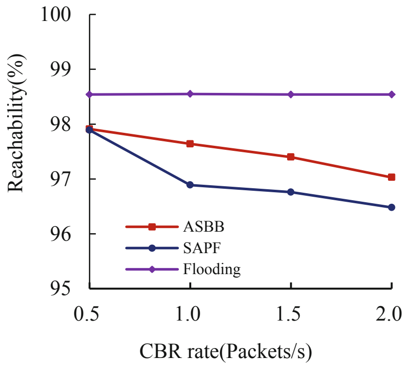

Fig. 4. The reachability versus CBR rates

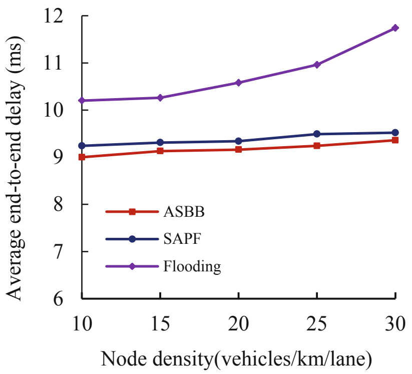

Fig. 5. The average end-to-end delay versus node densities

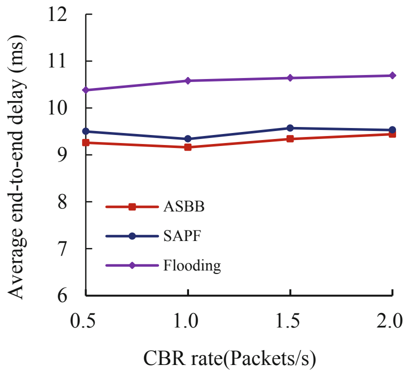

Fig. 6. The average end-to-end delay versus CBR rates

of the current node and its neighbor nodes is higher than that of SAPF. More nodes are involved in forwarding, which directly increases the reachability.

The higher the reachability of the broadcast packet, the higher the reliability of the broadcast algorithm. In summary, ASBB is more reliable than SAPF.

Average end-to-end delay is defined as the averaged time duration from the time when a packet is sent from a source to the time when the packet reaches a destination. Figure 5 shows the average end-to-end delay versus the node densities. Figure 6 shows the average end-to-end delay versus the CBR rates. It is evident that ASBB maintains the lowest average end-to-end delay, followed by SAPF and Flooding respectively. While the fewer the number of forwarding nodes, the smaller the probability of the channel contending, the smaller the collision probability between broadcast packets. Thus, the simulation results can be explained as follows. In ASBB, the forwarding probability is adaptively adjusted according to the average speed of the current node and its neighbor nodes which is more reasonable than SPAF. As a result, fewer forwarding nodes are involved in forwarding in ASBB than that in SPAF. Intuitively, the forwarding nodes involved in Flooding are the most, which lead to the highest end-to-end delay.

4 Conclusions

In this paper, to mitigate the broadcast storm and to provide reliability, an average speed based broadcast algorithm ASBB is proposed. The simulation results show that the performance of ASBB algorithm is better than that of SAPF in terms of ratio of forwarding node, reachability and average end-to-end delay. Therefore, ASBB algorithm can effectively suppress broadcast storm, providing higher reliability and short end-to-end delay at the same time. It can be well applied to VANETs on highway.

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