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Research Article

A Reliable and Efficient Highway Multihop Vehicular Broadcast Model

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A reliable and efficient highway broadcast model based on gain prediction is proposed to solve excessive information retransmission and channel conflict that often happen to flooding broadcast in vehicular ad hoc network. We take accountof the relative speeds, the intervehicle distance, and the coverage difference of the neighboring vehicles into predicting the gain of every neighbor, and further select the neighbor with the maximum gain as the next hop on the every direction of road. Simulations show that the proposed model is clearly superior to the original flooding model and a recent variant based on mobility prediction in packet arrival rate, average delay, forwarding count, and throughput.

1. Introduction

Vehicular ad hoc network (VANET) is a temporary autonomous system composed by a group of vehicles equipped with transceivers and global positioning system (GPS). VANET is specifically designed to communicate among vehicles so that drivers can acquire the information about other vehicles (e.g., speed, direction, and location) as well as real-time traffic information beyond visual range. The current main goal of VANET is providing safety and comfort for passengers [1]. With this stream of research, highway safety has attracted more attentions, such as active accident warning, icy patch alarm, and others. Whether a successive collision can be effectively avoided is mainly dependent on transmitting warning information reliably and efficiently on multipaths. Due to limited transmission range of nodes, each mobile vehicle in VANET acts as router, for transmitting information to destination. Broadcast is a common means to disseminate messages. Among various broadcast approaches, flooding is the first one. Each node rebroadcasts the received message exactly once, which results in broadcast storm problems [2]. Although [2] proposes mechanisms to improve flooding, they are not effective for all range of node density and packet loads in VANET [3]. Therefore, multihop broadcast in VANET is faced with many challenges [4].

This work proposes a *reliable broadcast routing based on gain prediction* (RB-GP) in which the relative speeds and coverage differences of the neighboring vehicles are calculated, and the intervehicle distance is also considered, and thus the neighbor under consideration with gain and reliability is selected as the next hop on the every direction. Moreover, RB-GP switches to the storage and forwarding when there are not proper next hop temporarily, weakening the negative impacts caused by the serious topological segmentation in VANET [5].

The remainder of this paper is organized as follows. Section 2 introduces the background, including some standards and related work. The RB-GP model is explained in details in Section 3. The simulations are provided in Section 4. Finally, in Section 5, some conclusions are drawn, and suggestions for future work are made.

2. Background

2.1. IEEE 802.11p/IEEE 1609 Standards. IEEE 802.11a/b/g/ has been extensively used in the wireless network but is not adaptive to vehicular networks because this standard is designed only for little mobility. Recently, IEEE 802.11-based solutions for vehicular networks are also investigated by IEEE 802.11p. IEEE 802.11p wireless access in the vehicular environment (WAVE) defines amendments to IEEE 802.11 to support intelligent transportation system (ITS) applications in the area of traffic safety and efficiency, as, for instance, *green-light optimal speed advisory* or *traffic jam ahead warning*. Its protocol stack is shown in Figure 1. The IEEE 1609 family of standards for WAVE consists of four trail use standards [7]: (1) *resource manager* (IEEE 1609.1) describes the data and management services offered within the WAVE architecture, defines command message formats and the appropriate responses to those messages, data storage formats that must be used by applications to communicate between architecture components, and status and request message formats; (2) *security services for applications and management messages* (IEEE 1609.2) defines the circumstances for using secure message exchanges and how those messages should be processed based upon the purpose of the exchange; (3) *networking services* (IEEE 1609.3) defines network and transport layer services, including addressing and routing, in support of secure WAVE data exchange; (4) *multi-channel operations* (IEEE 1609.4) provides enhancements to the IEEE 802.11 media access control (MAC) to support WAVE operations. As a whole, the IEEE 1609 family of standards defines the architecture, communications model, management structure, security mechanisms, and physical access for high-speed (up to 27 Mb/s) short-range (up to 1000 m) low-latency wireless communications in the vehicular environment. We employ IEEE 802.11p as the lower layers' (PHY and MAC) communication protocol in order to simulate more real scene.

2.2. Related Work. Much of the literature [8, 9] on inter-vehicle communications (IVCs) is navigation safety related. At the network layer, the most common way to broadcast safety messages is via reliable, robust flooding. However, the efficiency of flooding quickly decreases with the number of nodes. For scalable delivery, researchers have proposed georouting and further have focused on exploiting innate characteristics of vehicular networks such as high speed, but restricted, mobility. Recently, there have been many literatures for alleviating broadcast storms [10, 11]. For example, urban multihop broadcast (UMB) [12] features a form of redundant flood suppression scheme where the furthest node in the broadcast direction from a sender is selected to forward and acknowledge the packet. The scheme alleviates broadcast storm and hidden terminal problems. However, according to the contention resolution scheme, the potential relay nodes wait the longest time before retransmission. UMB may lead to a large delay, especially in high-mobility scenarios. Segment-oriented data abstraction and dissemination (SODAD) [13] collects only the information relative to a given locality (i.e., a road segment) to create a scalable decentralized information system. But SODAD is specially designed for the provision of comfort applications. Movement prediction-based routing (MOPR) [14] predicts future positions of vehicles and estimates the time needed for the transmission of data to decide whether a route is likely to be broken or not during the transmission time. The performance of the scheme largely depends on the prediction accuracy and the estimate of the transmission time that depends, in turn, on several factors such as network congestion status, driver's behavior, and the used transmission protocols. Distributed movement-based routing algorithm (MORA) [15] exploits the position and direction of movement of vehicles. The metric used in this protocol is a linear combination of the number of hops and a target functional, which can be independently calculated by each node. This function depends on the distance of the forwarding car from the line connecting the source and destination and on the vehicle's movement direction. Each vehicle needs to be able to implement this in a distributed manner. Preferred group broadcasting (PGB) [16] aims to reduce control messages overhead by eliminating redundant transmissions and to obtain stable routes with the ability to autocorrect. PGB classifies each node that receives a broadcast packet (e.g., route request) into one of the three groups based on the sensed signal level: preferred group, IN group, and OUT group. PGB enhancements are bound to ad hoc on-demand distance vector (AODV), however. Vector-based tracking detection (V-TRADE) and history-enhanced V-TRADE (HV-TRADE) [17] classify the neighbors into different forwarding groups each of which only selects a small subset of vehicles with high speed to rebroadcast the message. But they still select the fastest nodes which is not suitable for the highly dynamic vehicular topology. Recently, reliable broadcast routing scheme based on mobility prediction (RB-MP) [18] selects the node with the maximum speed on the every direction as the next hop according to the prediction holding time provided by position and relative velocity, which can effectively avoid the problems in the earlier discussed work. But the coverage of the node with the maximum speed may be very small in the next rebroadcasting because the maximum speed is affected by the relative speed and the intervehicle distance. One consideration in selecting a proper rebroadcast node is that the node with a short distance may increase transmission hops, but the node with a long away trip often causes connection instability. Therefore, for a suitable tradeoff between reliability and efficiency, the work in this paper is partially motivated from the aforementioned work and aims to a reliable and efficient broadcasting scheme for highway scenario.

3. RB-GP Model

3.1. Definitions. We list necessary definitions as follows for clear presentation.

Neighbor nodes set $N(i)$ is composed of node i's of all neighbors. $|(N_i)|$ is the total number of members in $N(i)$.

Two-hop node communicates with node i only by one forwarder.

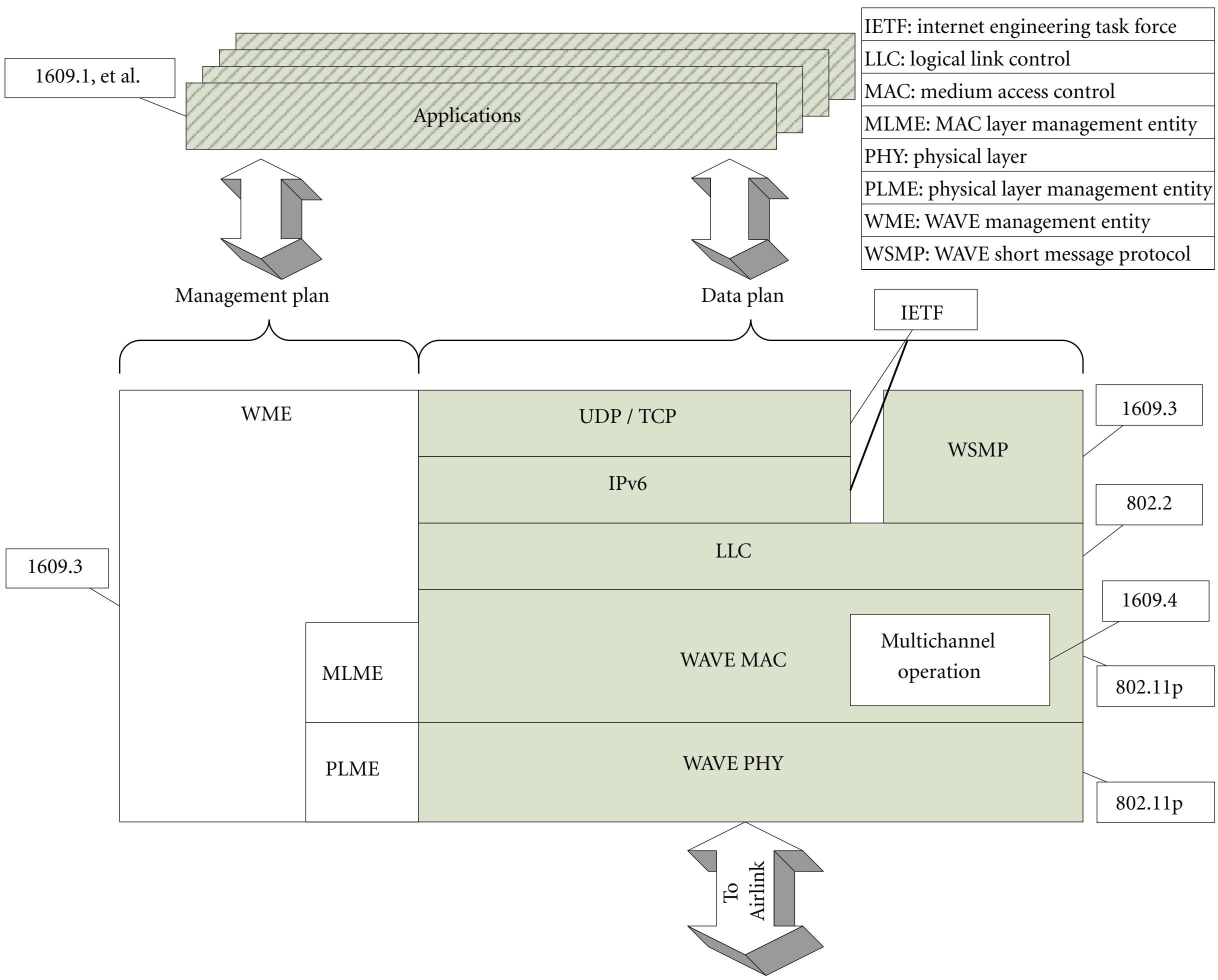


Figure 1: Protocol stack [6].

Two-hop node set $T(i)$ is composed of node i's all two-hop nodes. $|T(i)|$ denotes the total number of members in $T(i)$. $T(i)$ is defined as

$$T(i) = \bigcup_{j \in N(i)} T^j(i), \tag{1}$$

where $T^j(i)$ is the two-hop set connected by the neighbor j; that is, $T^j(i) = N(j)$.

Forwarding nodes set $R(i)$ is composed of the nodes; node i supposes which will forward the packets from it.

Neighbor information table records neighbor information, such as location, speed, and direction.

Position updating period μ is regular periodic interval by which the node's location is evaluated.

Prediction holding time of the connection λ_{ij} is the time that node i may stay in the transmission range of node j [18]. Without loss of generality, it is assumed that node i and node j are on a straight road, so λ_{ij} can be calculated by

$$\lambda_{ij} = \begin{cases} \left| \dfrac{\max\{0,\ \Delta D_{ij}\} \times R - D_{ij}}{\Delta v_{ij}} \right|, & \Delta v_{ij} \neq 0, \\ 2 \times \mu, & \Delta v_{ij} = 0, \end{cases} \tag{2}$$

$$D_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}, \tag{3}$$

$$\Delta D_{ij} = \begin{cases} \operatorname{sign}(D - D_0), & \text{if } D_0 \text{ exists}, \\ 0, & \text{otherwise}, \end{cases} \tag{4}$$

$$\Delta v_{ij} = v_i^2 + v_j^2 - 2 \times v_i \times v_i \times \cos\left(\theta_i - \theta_j\right), \tag{5}$$

$$\theta_i = \begin{cases} \left(2\pi + \arctan \dfrac{y_i - y_{i0}}{x_i - x_{i0}}\right) \% 2\pi, & x_i > x_{i0}, \\ \pi + \arctan \dfrac{y_i - y_{i0}}{x_i - x_{i0}}, & x_i < x_{i0}, \\ \dfrac{\pi}{2} \times \max\{0, \operatorname{sign}(y_i - y_{i0})\}, & \\ \qquad - \dfrac{3\pi}{2} \times \min\{0,\ \operatorname{sign}(y_i - y_{i0})\}, & x_i = x_{i0}, \end{cases} \tag{6}$$

where i and j are the ID of the receiver and the sender, respectively. (x_{i0}, y_{i0}) and (x_{j0}, y_{j0}) are the previous position while (x_i, y_i) and (x_j, y_j) are the current. When the distance between node i and node j increases, the function sign() returns +1, otherwise returns −1.

Direct gain $E(i, j)$ is the ratio of the coverage difference of the neighboring nodes i, j to node i's two-hop node set $T(i)$. The precondition for calculating $E(i, j)$ is ensuring that the neighbor node j can receive the packets from node i successfully; that is, $\lambda_{ij} > \mu$. $E(i, j)$ is calculated by

$$E(i,j) = \frac{|N(j)| - |N(i)|}{|T(i)|}. \tag{7}$$

Indirect gain $I(i, j)$ is the benefit possibly brought by the assumption that node i selects node j as the next hop, and also its precondition is that node j can receive node i's packets. In detail, if $\lambda_{ij} > \mu$ and λ_{ij} is close to μ, it means that node j will leave the transmission range of node i in short time, and some changes may happen to its local topology. $I(i, j)$ is calculated by

$$I(i, j) = \frac{\mu}{\lambda_{ij}}. \tag{8}$$

Gain function $G(i, j)$. node i uses this function to calculate the gain value of neighbor j as follows:

$$G(i, j) = \alpha E(i, j) + (1 - \alpha) I(i, j), \tag{9}$$

where $\alpha \in [0, 1]$, as $E(i, j) \in [0, 1]$ and $I(i, j) \in (0, 1)$; so the range of $G(i, j)$ is $[0, 1]$.

3.2. Specific Process. In RB-GP model, node information is assumed to be available for each node which can be acquired through beacon or periodical short message exchanging, including ID (node identity), position (x, y is the GPS coordinate), speed (the average relative speed Δv_{ij}), and direction (direction of the relative speed ΔD_{ij} defined by an angle with x-axis). Each node establishes its own neighbor information table through exchanging node information with each other. The neighbor information table is exchanged only between one-hop neighbors and is not forwarded to other far away nodes.

The design goal of RB-GP model is to maximize the range of every rebroadcasting and to minimize transmission delay through selecting the proper next hop on every direction and meanwhile ensures the neighbor node can receive the packets from the upstream node. In detail, RB-GP model tries to find the neighbor node with the biggest gain on the every direction. We take Figure 2, for example, to explain the working process of RB-GP model. The current forwarding node records the identities of the next hops on all directions into packet header in order that the next hop can decide whether or not it needs to rebroadcast the received packets. Node A's working process is as follows when receiving a broadcasting packet p.

Step 1. Node A judges whether it has received p before. If so, it will drop p directly and exit.

Step 2. Node A judges whether it is indeed the forwarding node selected by the upstream node through analyzing the packet header. If not, it exits; otherwise node A continues the next step or stores p temporarily when the network is not connected.

Table 1: Simulation parameters.

Description	Value
Simulated area	1200 m × 600 m
Simulated scenarios	Six crossed roads with two ways and two lanes
MAC protocol	802.11 p
Data rate	1 Mbps
Transmitting range	250 m
Packet size	1024 Bytes
Simulation time	100 s
Beacon interval	1 s
Position updating period μ	1 s
Vehicle number	100
Speed range	40 km/h∼80 km/h

Step 3. Node A classifies the neighbors into three groups according to node A's neighbor information table.

(i) The nodes locate in the same road as node A and are in the front of A, as node F in Figure 2.

(ii) The nodes locate in the same road as A and are in the back of A, as node B.

(iii) The nodes locate in the different road from A, as nodes C, D, and G.

Step 4. Node A calculates the gain value G of every neighbor node using (9) and, further, selects the node with the maximum gain in each group as the next hop, records its ID into the header of p, and finally sends packet p.

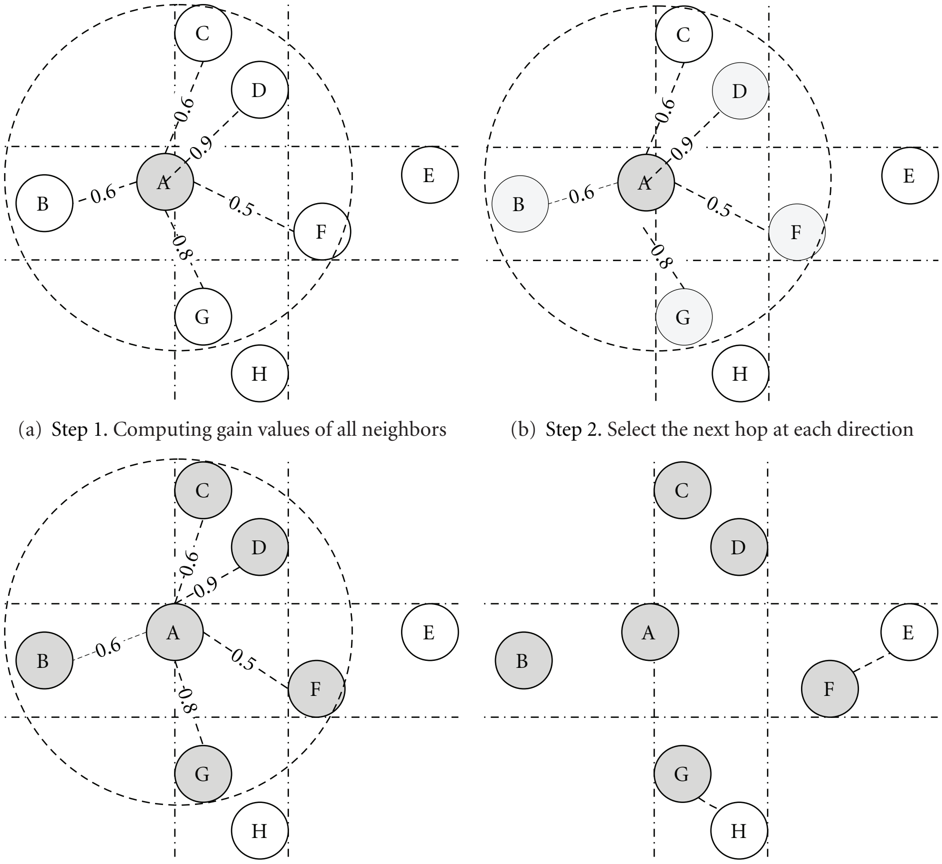
Node A will start the store-and-forward mechanism [19] when it does not find any proper node in Step 3. Node A stores the broadcasting packet in memory temporarily and then continues forwarding to other appropriate nodes within its communication range at some time.

4. Simulations

We adopt NS2.34 [20] to evaluate the RB-GP, the RB-MP, and the flooding models and use VanetMobiSim [21] to create highway scenario.

4.1. Settings. Table 1 lists the simulation parameters, and Figure 3 shows the simulated scenario we used in this work. We mainly focus on highway scenario, so traffic lights and roadblocks are neglected. Vehicles randomly decide to keep going ahead, to turn left, or to turn right when arriving at a crossroad (blind intersection).

4.2. Results. We used the following metrics to compare the performances of the RB-GP, the RB-MP, and the flooding: packet arrival rate, average delay, forwarding count, and throughput. Each simulation result corresponds to an average over 50 independent of experiments.



(a) Step 1. Computing gain values of all neighbors (b) Step 2. Select the next hop at each direction

(c) Step 3. Broadcasting the packet (d) Step 4. Receiving the broadcast packet

Figure 2: An example for RB-GP.

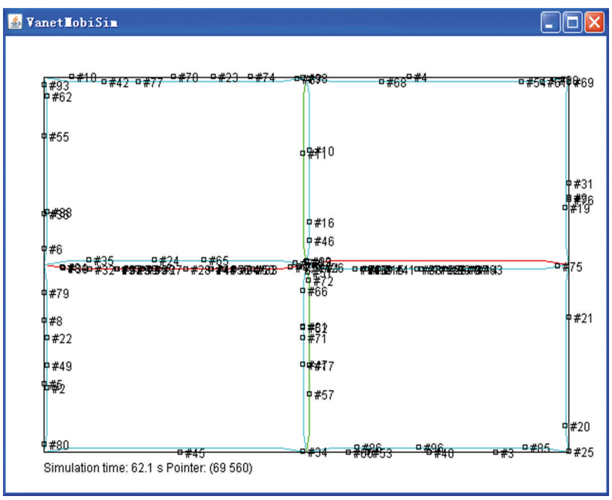


Figure 3: An example for highway scenario.

We first investigate the performances of different models, and the results are shown in Figure 4. In Figure 4(a), RB-GP model is superior to the other two models in packet arrival rate. This is because RB-GP model chooses the node with the maximum gain as the next hop on the every direction so that each selected node can cover most nodes and receive the broadcasting packet successfully, resulting in a high packet arrival rate. Although the flooding model has a high packet arrival rate at initial simulation because it requires all nodes to rebroadcast the received packets again, the packet arrival rate is quickly decreasing because of a large number of redundant information and channel conflict

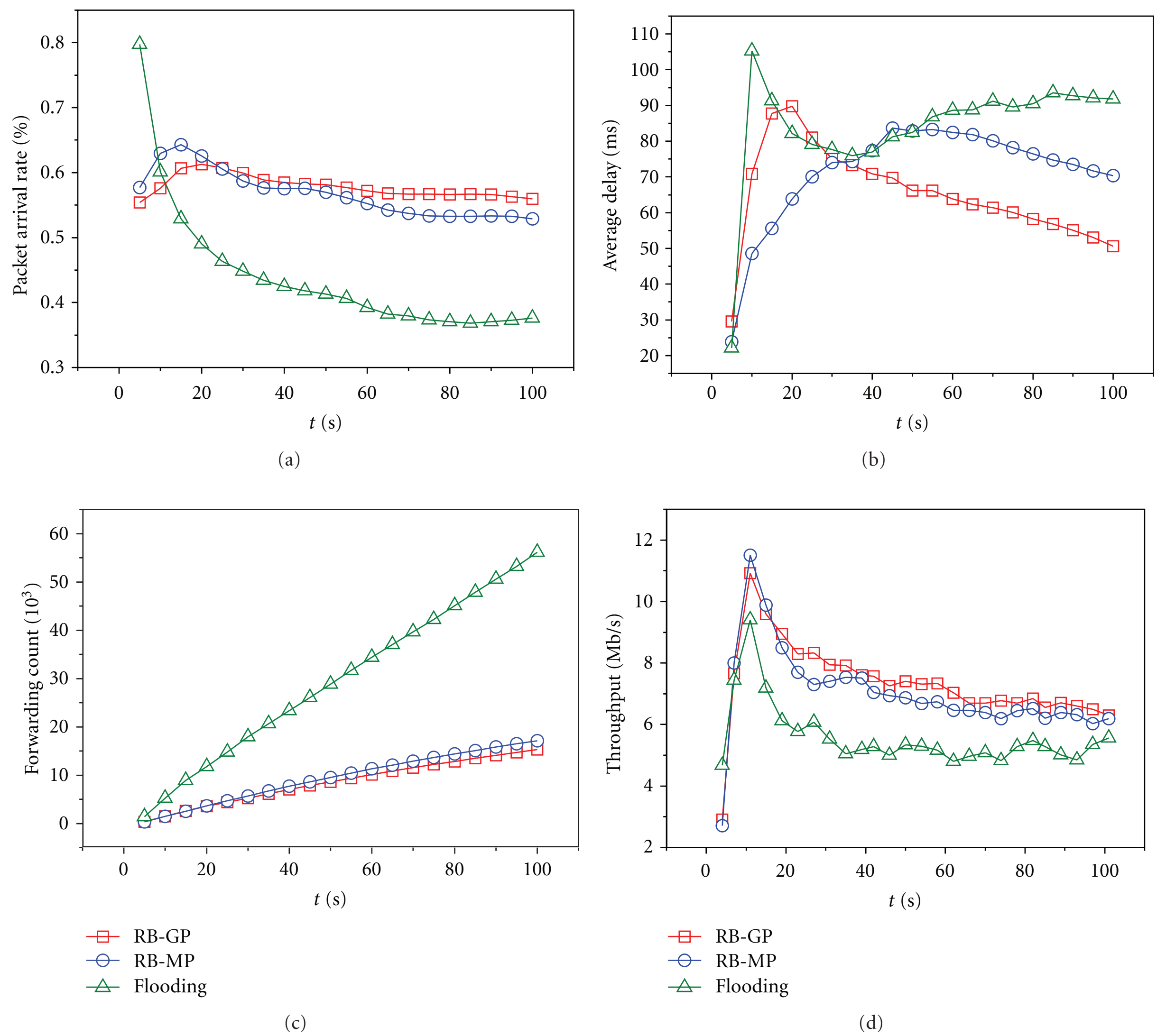


FIGURE 4: The comparisons of the RB-GP (□), the RB-MP (◯) and the flooding (△) in (a) average packet rate, (b) packet delay, (c) forwarding count, and (d) throughput with parameter $\alpha = 0.5$.

as system running. The RB-MP model selects the node with the maximum speed as the next hop, so the coverage difference of the neighboring vehicles may be small, resulting in lower packet arrival rate than that of the RB-GP model. In Figure 4(b), RB-GP model shows a slightly higher average delay than RB-MP model at initial simulation because of the incompleteness of node information, but the average delay is gradually decreasing with information exchange and finally has the smallest average delay in three models. Figure 4(c) illustrates the forwarding count of three models. As aforementioned, selecting a node in the short range as the next hop will increase the forwarding count, but, in the converse case, the selected link may become instable because of quick movement and signal interference. RB-GP model balances the link reliability and the transmission distance and reduces the unnecessary information retransmission and the probability of channel conflict, so resulting in the smallest forwarding counts. Figure 4(d) reflects the changing trend of end-to-end throughput. The curves of all the models reach the peak at initial simulation due to network instability, but the throughputs begin to fall back and steady with system running; RB-GP model behaves better than the other two models because of a high packet arrival rate.

We now turn to explore the impacts of only introduced parameter α on RB-GP model, and the results are shown in Figure 5. The parameter α represents the weight that the direct gain and the indirect gain contribute to calculating the total gain of a given node. $\alpha = 0$ means that the selection of forwarding nodes is determined entirely by the indirect gain, and $\alpha = 1$ expresses the opposite selecting rule. From Figure 5, one can conclude that the packet arrival rate gets to the maximum when $\alpha = 0.7$; the average delay arrives at minimum when $\alpha = 0.3$; the parameter α has little effects on the forwarding count and the throughout.

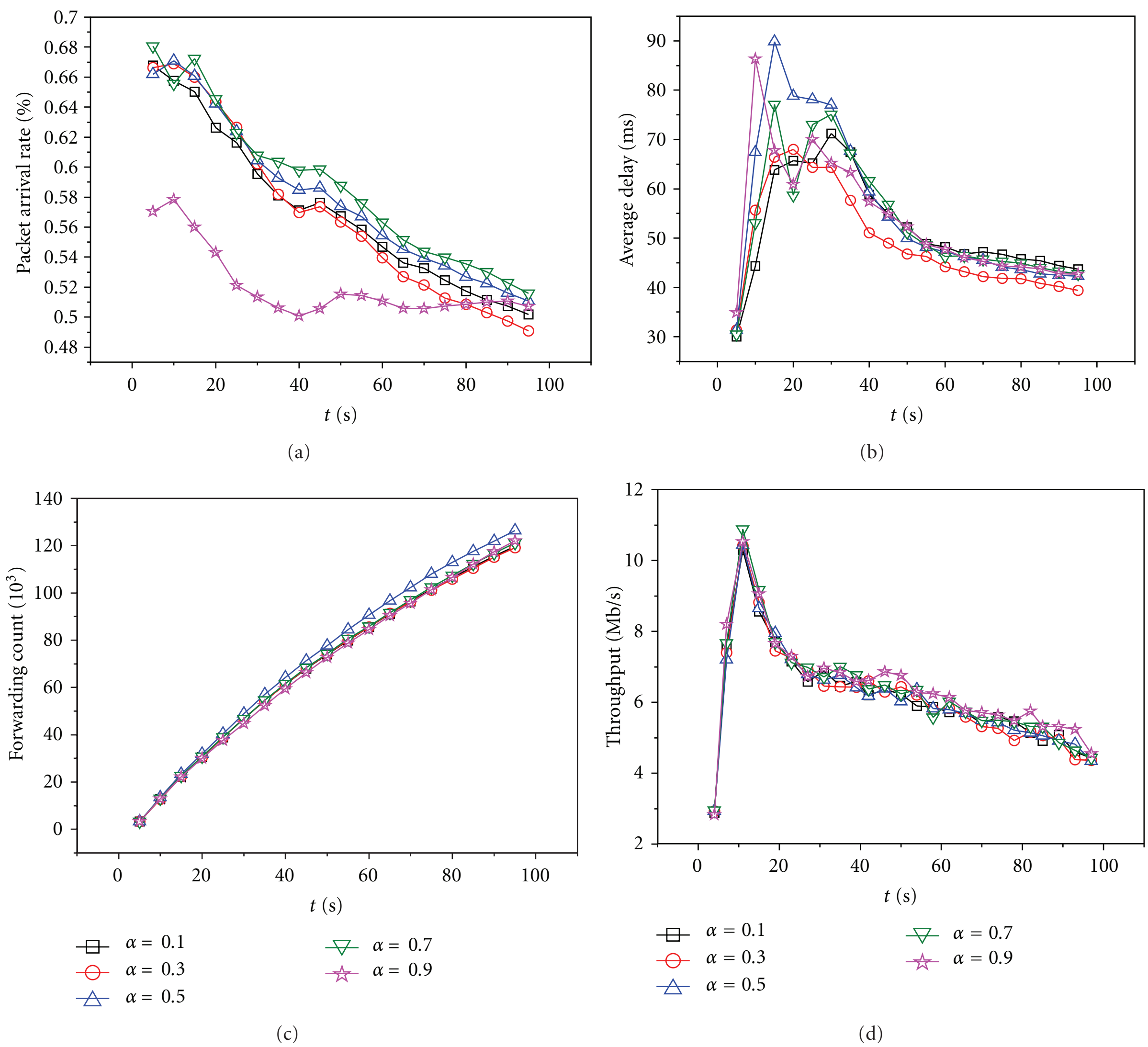


Figure 5: Effects of parameter α on the RB-GP model in (a) average packet rate, (b) packet delay, (c) forwarding count, and (d) throughput when $\alpha = 0.1$ (□), 0.3 (◯), 0.5 (Δ), 0.7 (∇), and 0.9 (star).

5. Conclusions

Due to the limited transmission range in vehicular networks, single-hop transmission usually cannot cover all destination nodes, so designing a reliable and efficient multihop broadcast model is one of the fundamental tasks in VANET. We propose a novel multihop broadcast model RB-GP for highway scenario through introducing the concept of gain prediction. The gain value is related with the relative speed, the intervehicle distance, and the coverage difference of the neighboring vehicles. RB-GP model selects the node with the biggest gain as the next hop on the every direction and meanwhile ensures that the selected node can receive the packets successfully, thus achieves decreasing channel conflict and unnecessary information retransmission. The results show that RB-GP is superior to the RB-MP and the flooding models in packet arrival rate, average delay, forwarding count, and throughput.

The future work will focus on multihop broadcast model in other road scenarios, such as urban, and, further, consider the possible broadcast pattern in hybrid networks, that is, synchronously communicating with cellular and ad hoc technologies.

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