REFF: REliable and Fast Forwarding in Vehicular Ad-hoc Network

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Abstract. Vehicular Ad-Hoc Network (VANET) has emerged as an increasingly dominant technology for future connected vehicle and vehicular networks, where the focus of the development of VANET lies in the standardization of message transmission and dissemination via multi-hop broadcasting. However, the current communication protocols concerning VANET face many challenges, including data flooding and collision, transmission delay and other problems. Most of the challenges are closely related to next-hop selection. Therefore, this paper proposes a new routing protocol named REliable and Fast Forwarding (REFF) to optimize the selection of nodes in VANET. In this protocol, node filtering and node evaluation are two main steps. Distance between previous node and candidate node, relative velocity between previous node and candidate nodes, included angle between direction of target node's velocity and candidate node's velocity and transmission power of candidate node are adopted as indexes to help select a specific node as the next hop using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). By using this technique, the number of candidates as next-hop is largely reduced, avoiding the data flooding and resulting transmission relay. In addition, simulations based on experiments are done to verify the feasibility. The results show that message achieves a faster and more reliable transmission using REFF.

Keywords: VANET · Multi-hop broadcasting · Next-hop selection · TOPSIS

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1 Introduction

Fifth Generation Mobile Networks (5G) has emerged as a more advanced way in telecommunications with faster speed, broader coverage and higher capacity. In recent years, 5G have also extended its use in the field of connected vehicles [4]. 5G serve as an important kind of networking wireless technology in Vehicular Ad-hoc Network (VANET). Cooperative transmission is an effective approach for vehicular networks to improve wireless transmission capacity and reliability in the fifth-generation small-cells networks, as denser and smaller cells are expected to provide a higher transmission rate for users [6, 19]. 5G technologies also propose a device-to-device (D2D) approach for direct and short-range communications between vehicles since the data transmission is easily influenced by surrounding environment. D2D communications can also enhance the communication capacity by allowing nearby devices to establish links, thusly accommodating a large number of data-heavy mobile devices and multiapplication services to face the challenge of dealing with an ever-increasing demand of mobile traffic [18]. Therefore, 5G can be adopted as a critical network technology supporting VANET.

Vehicular Ad-hoc Network (VANET) is an embranchment of Mobile Ad-hoc Network (MANET), which is the spontaneous establishment of a wireless network for the purpose of real-time data transmission and exchange in the fields of vehicle networks. In recent years, Vehicular Ad-hoc Network (VANET) has become an increasingly important component in Connected Vehicle in Intelligent Transportation System (ITS). Communication in ITS consists of two parts, the Vehicle-to-Vehicle (V2V) communication and the Vehicle-to-Infrastructure (V2I) communication. VANET is mainly adopted as the paradigm in V2V communication. In the future, V2V, V2I and D2D network are expected to be interworking as the integrated network so as to support Intelligent Transportation Space (ITSP) and Intelligent Transportation System-Smart Grid (ITS-SG) [14].

In order to realize the real-time transmission of data and information in VANET, two essential conditions are required in V2V network; firstly, every vehicle is required to be equipped with on-board wireless network devices and multiple sensors, such as GPS, Bluetooth, monocular camera and radar, secondly, one type of networking wireless technology is needed as the basis for VANET. One type of prominent technology is Dedicated Short Range Communication (DSRC), under which 75 MHz in 5.9 GHz band in IEEE 802.11p is allocated to the fields of vehicular network. In addition, cellular technologies can also be used as the basis, both the Long-term Evolution Vehicle (LTE-V) and Fifth Generation Mobile Networks (5G) are promoted, while 5G achieves a faster speed, broader coverage, higher capacity and reduced latency [1].

With the V2V technology, a safer and well-organized traffic environment is presumed. Several specific scenarios and applications have been proposed, including reliable traffic density estimation and the detection and avoidance of forward obstacle and approaching emergency vehicle warning [7]. Vehicle chain cooperative collision avoidance (CCA) systems or cooperative adaptive cruise control (CACC) are typical safety applications of inter-vehicle communications (IVC) [15]. As VANET develops, some non-safety applications are also expected, mostly aiming at the optimization of traffic flow like platooning and some additional entertainment.

In VANET, the most noticeable characteristic is its high changeability and instability, which make it different from the traditional MANET. The velocity of nodes in VANET can achieve up to 40 [m/s] while the average velocity of nodes in traditional MANET is 5 [m/s] [10]. Due to the high mobility of vehicles in VANET, the topology network is highly active and changing all the time [20]. And in a typical vehicular environment, the number of vehicles is always huge, which can lead to congestion in traffic environment, making the data transmission and rebroadcasting even more complex [2]. In addition, the vehicular networks may not have connections all the time. Furthermore, large numbers of vehicles are usually restricted to a certain spatial pattern. These reasons lead to the failing of some protocols in MANET to be applied in VANET [16]. Thusly, the study and performance evaluation of routing protocols in vehicular networks are of great importance [11]. Among many aspects, the study of VANET performance is critical in evaluating the performance in V2V communication; experts and professionals have also proposed a series of methods working on vehicular networks such as stochastic learning model, environment-specific propagation model and etc. [5, 8, 9, 21].

In VANET, multi-hop broadcasting is adopted as a primary method to realize the transmission of messages. Since the messages in the domain of vehicular network are mostly related to safety fields, it is required that the transmission of messages to related vehicles has to be punctual and allows little delay and few mistakes. Considering the process of message transmission, next-hop selection is a key section. However, the current routing protocols of VANET still face many problems in next-hop selection. The most prominent one is that due to the large number and high density of vehicles within an area, the nodes for rebroadcasting messages can be plentiful, which can cause several undesirable scenarios, i.e. (i) data flooding, which will lead to the chaotic collisions in data transmission and further lead to the delay and latency of safety-related messages, (ii) repetition of message transmission; a node is likely to implement an unnecessary repeated transmission while a neighboring node has already received and subsequently rebroadcasted the message and (iii) instability in rebroadcasting; stability and reliability are compromised in message transmission in VANET in order to realize the longest distance of a single transmission, connectivity is less stable as the distance between two nodes increases. Other problems are related to the different level of network capacity and transmission power in each vehicle.

In this paper, we bring forward a new routing protocol named *REliable and Fast Forwarding* (REFF), targeting at solving the redundancy of nodes as next hop and increasing the level of stability in message rebroadcasting in VANET. This routing protocol optimizes the total multi-hop broadcasting process by reducing the nodes in message transmission, therefore avoiding the data flooding and collision. Before a vehicle initiates its message transmission to the next hop, two steps are proceeded. A node-filtering step and a calculation step are proceeded by the vehicle to wipe out redundant unnecessary nodes and evaluate the suitability of the rest potential node to be chosen as the next hop. Then the suitability of every potential node as the next hop is ranked in descending order, and the node that ranks the top will be finally selected as the exclusive next-hop in the vicinity, thusly reducing the number of nodes used in a complete message transmission from the original node to the target node. We name this type of node as the Optimal Node (ON). This preliminary work is indeed a decision-making process, which plays an essential role in the relay selection in cooperative communication considering the selfish and greedy behavior of users in reality [13].

We organize this paper as follows. In Sect. 2, we introduce *REliable and Fast Forwarding* (REFF), containing the two major phases in next-hop selection, indexes we choose as evaluation criteria and the process of evaluation using TOPSIS. In Sect. 3, we present and assess the performance of REFF by adopting it in different traffic scenarios; both the simulation environment and simulation results are shown, confirming the feasibility and advancement of this routing protocol. In Sects. 4, conclusions are drawn and outlooks are put forward.

2 REliable and Fast Forwarding

In a real traffic environment, there are multiple scenarios in which sudden change in the velocity of traffic flow can happen. Assume a situation where an accident happened in the front of a traffic flow, due to hindrance of drivers' eyesight in the rear,message notifying the occurrence of the traffic accident in the front should reach vehicles in the back in time to function in these two way, i.e., (i) to remind drivers in the rear to decelerate the vehicle to avert severe brakes and collisions and (ii) to notify drivers in the rear of the accident to spare them some time to choose and change to an alternative path to avoid heavier congestion in the accident spot. By adopting the REFF method, situations like this can be efficaciously assuaged.

In REFF, we leverage on several preconditions, i.e. (i) vehicles driving in the lanes come in a Poisson Distribution, (ii) all the vehicles have a constant transmission range and (iii) all vehicles are installed with GPS and sensors to acquire basic information about positions and routes.

2.1 Node Filtering

In a common situation where a vehicle needs to transmit the Cooperative Awareness Message (CAM) to designated vehicles, the transmission is unidirectional in most cases. Since the transmission range of vehicles is circular, nodes that are unnecessary in this unidirectional transmission should be filtered out primarily, this step can effectively prevent data flooding and redundant transmission, which also help to save some network capacity. We filter these redundant nodes out by drawing two circles, i.e. (i) circle A with the position of the original vehicle (which is ready to rebroadcast the message to the next node) as the center and its transmission length as the radius, and (ii) circle B with the position of the target vehicle as the center and distance between the original vehicle and the target vehicle as the radius. Then the overlapping range of these two circles are determined and chosen, we define this overlapping range as *valid vicinity* (VV) in this paper. Every node in the valid vicinity qualifies as a potential next hop for the rebroadcasting of messages. We define these nodes as *candidate node* (CN). A further next-hop selection and decision is based on the completion of this node-filtering phase. After a vehicle finishes one next-hop selection, the node selected becomes the new 'original' vehicle, initiating a new round of next-hop selection by using the same node-filtering method, drawing circles with new center and new radius and determining new valid vicinity.

In a typical two-way four-lane highway as shown in Fig. 1, we assume the source node (where the message transmission initiates) and destination node (where the message transmission terminates) of a complete transmission to be fixed in our simulation environment. The vehicle in blue is a message carrier, preparing to select its next hop and rebroadcast the message to it. By using node-filtering method, we can draw the cross range of these two circles and define it as valid vicinity (VV) in this paper. Vehicles inside this valid vicinity (which are in red) are identified as candidate nodes. After a next-hop selection by using TOPSIS, optimal node can be determined and message can be rebroadcasted to the target node.

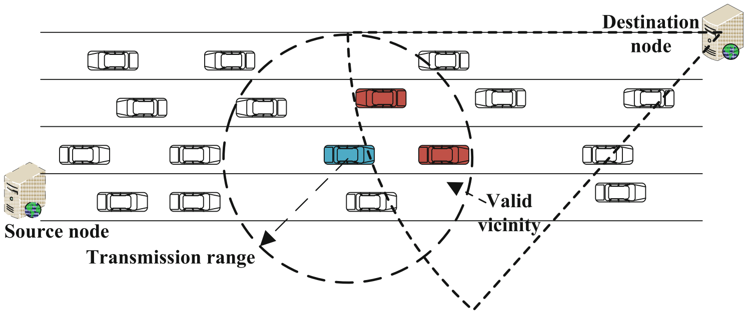


Fig. 1. Two-way four-lane road map. (Color figure online)

2.2 Next-Hop Selection Using TOPSIS

After the primary node-filtering phase, the original vehicle will firstly send a Request-To-Broadcast (RTB) message to all candidate nodes and establish a link with all candidate nodes in the valid vicinity, so that basic information about the candidate nodes can be achieved to make further evaluation and comparison. At this time, cooperative awareness message (CAM) packets are at state of readiness to be transmitted. But the original vehicle preparing to rebroadcast CAM is required to execute a calculating process firstly to evaluate the suitability of every candidate node for potential rebroadcasting, then the matching degree and performance level of every node are ranked in descending order. Finally, the node that performs the best is selected as the only candidate for next hop, sending back a Clear-To-Broadcast message to the original vehicle, then realizing a reliable and fast forwarding.

To execute the calculation process, several indexes are picked to form a comprehensive evaluating system.

Notation: Throughout this paper, we use boldface letter to denote vectors, which are all column vectors. We use regular font letters to denote random quantities (such as D_i, θ_i). We use $\|\cdot\|_2$ to denote operator of Euclidean norm (norm-2). The original node is denoted as o in the subscript, candidate node is denoted as i in the subscript and target node (which is ready to receive message from candidate node) is denoted as t.

- Distance between candidate node and original node D_i:

$$D_i = \|\boldsymbol{p}_i - \boldsymbol{p}_o\|_2 \tag{1}$$

A longer distance between the candidate node and original node ensures a longer broadcasting length, reducing the number of nodes used in a single complete transmission and precipitating the transmission.

- Relative velocity between candidate node and original node ΔV_i:

$$\Delta V_i = \|\boldsymbol{v}_i - \boldsymbol{v}_o\|_2 \tag{2}$$

A lower relative velocity improves the stability between these two nodes, preventing the candidate node from suddenly leaving the valid vicinity and improving the reliability of forwarding.

- Angle-related criteria C_i: we use the Sigmoid function to calculate the criteria related to the included angle θ_i between velocity direction of candidate node and velocity direction of target node:

$$\theta_i = arccos\left\|\frac{\boldsymbol{v}_i \cdot \boldsymbol{v}_t}{|\boldsymbol{v}_i| \times |\boldsymbol{v}_t|}\right\|_2 \tag{3}$$

If $0^\circ \leq \theta_i \leq 90^\circ$, a smaller included angle between the direction of v_i and v_t is preferred because it ensures a more reliable and stable transmission, while a larger angle implies a larger probability to disconnect.

If $90^\circ < \theta_i \leq 180^\circ$, a larger included angle between the direction of v_i and v_t is preferred because it ensures a faster and more robust transmission, while a smaller angle implies a larger probability to disconnect.

Thusly,

$$C_i(\theta) = \begin{cases} \frac{1}{1+exp\left(\frac{4a}{\pi}\theta_i - a\right)} \left(0 \leq \theta_i \leq \frac{\pi}{2}\right) \\ \frac{1}{1+exp\left(-\frac{4a}{\pi}\theta_i + 3a\right)} \left(\frac{\pi}{2} < \theta_i \leq \pi\right) \end{cases} \tag{4}$$

in this equation, a is used as the calibration parameter. A larger C_i brings about a more stable and faster transmission (Fig. 2).

Results of C_i are shown in a different variation degree as we change the calibration parameter a. But a general variation tendency is sure in these two ways, i.e., (i) if θ_i is near 0° or 180°, C_i will appear near 1, which is the best condition and (ii) if θ_i is near 90°, C_i will appear near 0, which is the worst condition.

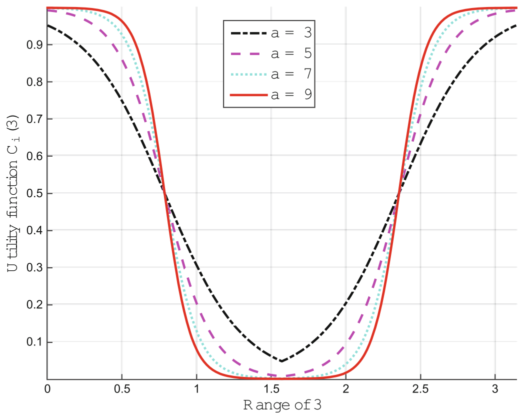


Fig. 2. Variation trend of $\boldsymbol{C}_i$ with different value of parameter a

- Transmission power of the candidate node P_i: an increase in the transmission power improves the probability of successful data transmissions if the link reliability is below a certain threshold. With a higher transmission power, the physical layer can use modulation and coding schemes with a higher bit ratio, increasing the bandwidth under heavy workloads [3].

Considering the conflicting characteristics in these indexes, we adopt the Technique for Order of Performance by Similarity to Ideal Solution (TOPSIS) as the calculating principle in consideration of its compensatory property that one poor result in one criterion can be negated by a good result in another criterion. Then an optimal candidate node can be confirmed and selected. The calculation is conducted in the following way:

- Step 1. Creating an evaluation matrix consisting of m CNs and 4 indexes

$$X_{ij} = \begin{pmatrix} x_{1,1} & \cdots & x_{1,4} \\ \vdots & \ddots & \vdots \\ x_{m,1} & \cdots & x_{m,4} \end{pmatrix} \tag{5}$$

- Step 2. Normalizing the matrix considering incongruous dimensions of four indexes

$$R = (r_{ij})_{m \times 4} \tag{6}$$

by using the normalization method, $r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} (i = 1, 2, \cdots, m; j = 1, 2, 3, 4)$.

- Step 3. Calculating the weighted normalized decision matrix

$$t_{ij} = r_{ij} \times w_j (i = 1, 2, \cdots, m;\ j = 1, 2, 3, 4) \tag{7}$$

where $w_j = W_j / \sum_{j=1}^{4} W_j (j = 1, 2, 3, 4)$, so that $\sum_{j=1}^{4} w_j = 1$; w_j is the original weight assigned to each index.

- Step 4. Determining the worst candidate C_w and the best candidate C_b

$$C_w = \{\langle maxt_{ij}|j \in J_-\rangle, \langle mint_{ij}|j \in J_+\rangle\} \equiv \{t_{wj}|j = 1,2,3,4\} \quad (8)$$

$$C_b = \{\langle mint_{ij}|j \in J_-\rangle, \langle maxt_{ij}|j \in J_+\rangle\} \equiv \{t_{wj}|j = 1,2,3,4\} \quad (9)$$

where,
$J_+ = \{j = 1,2,3,4|j$ associated with the index having a positive impact;
$J_- = \{j = 1,2,3,4|j$ associated with the index having a negative impact.

- Step 5. Calculating the L2-distance between candidate nodes to the worst condition C_w and best condition C_b

$$d_{iw} = \sqrt{\sum\nolimits_{j=1}^{4} \left(t_{ij} - t_{wj}\right)^2} (i = 1,2,\cdots,m) \quad (10)$$

$$d_{ib} = \sqrt{\sum\nolimits_{j=1}^{4} \left(t_{ij} - t_{bj}\right)^2} (i = 1,2,\cdots,m) \quad (11)$$

where d_{iw} and d_{ib} are Euclidean norm (norm-2) distances from the candidate node i to the worst and best conditions, respectively.

- Step 6. Calculating the similarity to the worst conditions

$$s_{iw} = \frac{d_{iw}}{d_{iw} + d_{ib}} (i = 1,2,\cdots,m) \quad (12)$$

where $0 \le s_{iw} \le 1$,
$s_{iw} = 1$ if and only if the candidate node meets the best condition;
$s_{iw} = 0$ if and only if the candidate node meets the worst condition.

- Step 7. Rank m candidate nodes according to their s_{iw} in descending order $(i = 1,2,\cdots,m)$.

Finally, after the original vehicle acquires a list of all candidate nodes ranking on basis of their s_{iw} in descending order, the one that ranks the top is determined as the optimal node and then selected as the next hop for message rebroadcasting. At this time, the original vehicle will release its link with other candidate nodes and transmit CAM to the optimal node to continue message transmission. If a message transmission needs multiple rebroadcasting in VANET, the same technique is adopted every time to select the next hop.

3 Performance Evaluation

3.1 Simulation Settings

We conduct our simulation based on a real traffic scenario that vehicles arrive according to Poisson distribution in a two-way four-lane road. To evaluate the performance of REFF in such traffic scenarios, we set some factors as quantitative and some indexes as variables, comparing the final performance as indexes change and drawing the variation tendency corresponding to each index. We list the simulation environment parameters in Table 1:

Table 1. Simulation environment parameters

Simulation parameter	Value
Length of lane	3 km
Width of lane	3.75 m
Number of lane	4
Transmission range	300 m
Duration	100 s
Vehicle density	[10,60] veh/km

In a highly mobile and dense traffic environment, cooperation is affected by the constant addition and deletion of nodes [12]. And in such an environment, a node's position and velocity are influenced by its vicinity structure, which means that the dynamics of a node's position and velocity are denoted by the move of the node in front of it. Hence, we assume all nodes in the simulation environment moves according to the Intelligent Driver Model (IDM), which is a time-continuous car-following model. For vehicle i, X_i denotes its position and V_i denotes its velocity at time t. Furthermore, l_i denotes the length of vehicle. Net distance and velocity difference are also defined as $s_i = x_{i-1} - x_i - l_{i-1}$ and $\Delta v_i = v_i - v_{i-1}$, in which $i{-}1$ refers to the vehicle directly in front of vehicle i. Thusly, the dynamics of vehicle i can be described in these two ordinary differential equations:

$$\dot{x}_i = \frac{dx_i}{dt} = v_i \tag{13}$$

$$\dot{v}_i = \frac{dv_i}{dt} = a\left(1 - \left(\frac{v_i}{v_0}\right)^{\sigma} - \left(\frac{s^*(v_i, \Delta v_i)}{s_i}\right)^2\right) \tag{14}$$

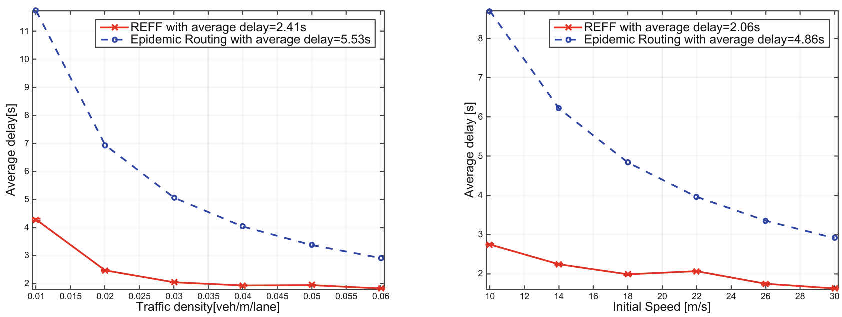
with $s^*(v_i, \Delta v_i) = s_0 + v_i \times T + \frac{v_i \times \Delta v_i}{2\sqrt{ab}}$.

v_0, s_0, T, a and b are model parameters that have the following meaning, i.e., (i) desired velocity v_0: the velocity the vehicle could drive at in free traffic, (ii) minimum spacing s_0: a minimum desired net distance. A car cannot move if the distance from the car in the front is not at least s_0, (iii) desired time headway T: the desired time headway to the vehicle in the front, (iv) acceleration a: the maximum vehicle acceleration and (v) comfortable braking deceleration b: a positive number. The exponential σ is usually set to 4.

3.2 Simulation Results

In evaluating the performance of message transmission in VANET, an important metric is the average transmission delay from one node to the next node. A longer transmission delay has a negative impact on the total performance of V2V communication considering the significance of timeliness in communication. Thusly, we comparing the average delay in message rebroadcasting from hop to hop under two different routing techniques: REliable and Fast Protocol (REFF) as a type of unicast routing and Epidemic Routing as a common type of broadcast routing.

In Fig. 3(a) the variation trend of average delay is shown with traffic density changing. As expected, the average transmission delay decreases as traffic density increases because a denser traffic environment ensures a larger number of nodes to rebroadcast messages and more stable transmission. When compared with Epidemic Routing, REFF displays a sharply decrease in average transmission delay from one node to the next. The average transmission delay under REFF is 2.41 [s] while the transmission delay under Epidemic Routing is 2.41 [s]. With initial speed of vehicles remaining constant at 25 [m/s] and as traffic density varies from 10 [veh/km] to 60 [veh/km], a 49.3% decrease in average transmission delay is seen in REFF when compared to Epidemic Routing on average. A lower traffic density experiences a larger difference in average delay between REFF and Epidemic Routing.



(a) Traffic density as variable (b) Initial speed as variable

Fig. 3. Average transmission delay under two routing protocols

In Fig. 3(b) the variation trend of average delay is shown with average vehicle velocity changing. As expected, the average transmission delay decreases as initial speed of vehicles increases because a faster speed ensures a more stable link and a faster transmission. When compared with Epidemic Routing, REFF displays an evident decrease in average transmission delay from one node to the next. The average transmission delay in REFF is 2.06 [s] while the average transmission delay is 4.86 [s]. With traffic density remaining constant at 60 [veh/km] and as initial speed of vehicles varies from 10 [m/s] to 30 [m/s], a 56.95% decrease in average transmission delay is seen in REFF when compared to the performance of Epidemic Routing. A slower speed experiences a larger difference in average delay between REFF and Epidemic Routing.

When we compare the performance of REFF and Epidemic Routing in message rebroadcasting, another important fact that we cannot ignore is the collision phenomena in broadcast routing. Data collision can lead to the failure of message being transmitted to the destination vehicle.

In a complex traffic environment, due to the large number and high density of vehicles, the transmission of one node has the probability to collide with the transmission of another node if waiting time difference between them is short. Thusly, we calculate the collision probability (CP) of one node with another node under the flooding-based routing protocol by using the formula introduced in RObust and Fast Forwarding (ROFF) routing protocol [17]:

$$CP = P\left(Range \cdot \frac{minDiff}{MaxWT} > \left(d_{f_N} - d_{f_{N-1}}\right)\right) \tag{15}$$

In this equation, CP is equal to the probability that $Range \cdot \frac{minDiff}{MaxWT}$ is bigger than the space headway of vehicle f_N and f_{N-1}, where $Range$ is the transmission range of node, $minDiff$ is the minimum waiting time difference between vehicle f_N and f_{N-1}, $MaxWT$ is the maximum waiting time and d_{f_i} is the distance between f_i and previous node.

We calculate collision probability of Epidemic Routing as traffic density varies from 10 [veh/km] to 60 [veh/k], which corresponds to different traffic scenarios. In measuring the collision probability, different maximum waiting time is a critical influencing factor. As expected, from the variation trend we can tell that the collision probability when rebroadcasting a message increases as the traffic density increases because smaller vehicle headway on the road can lead to data flooding and collision. Moreover, as shown by three different curves, a smaller maximum waiting time adds to the probability of collision between nodes because a smaller maximum waiting time

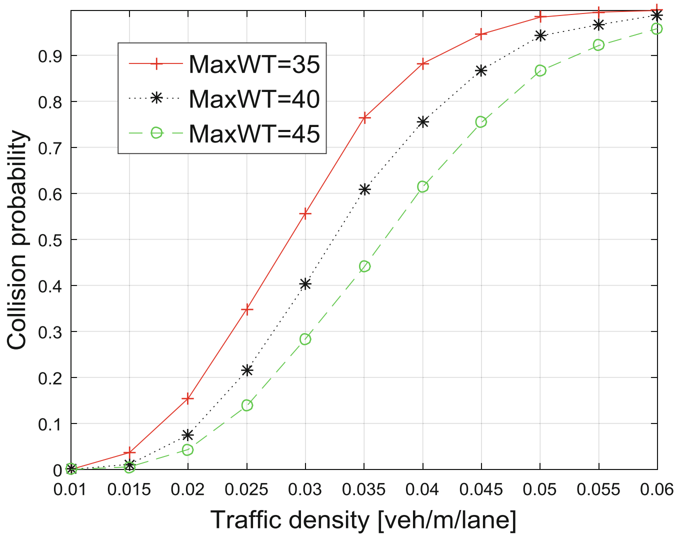


Fig. 4. Collision probability under different value of *MaxWT*

results in a smaller minimum waiting time difference between nodes in the vicinity. The result concerning collision probability is shown in Fig. 4. On the contrast, unicast routing usually displays zero probability in collision. Thusly, the REFF we propose which belongs to unicast routing outperforms Epidemic Routing when taking collision probability into account.

4 Conclusions

Aiming at solving the data flooding problem and transmission delay in VANET supported by 5G, LTE-V, DSRC and etc. in V2V communication, we introduce the REliable and Fast Forwarding (REFF) in this paper. In REFF, two phases are essential before rebroadcasting the message from one node to the next, which are node filtering and next-hop selection using TOPSIS. These two steps targets at eliminating the redundant node and determine the only optimal candidate node for rebroadcasting the message. By adopting this technique, the number of nodes in a complete message transmission is largely reduced and a more reliable and faster transmission is thusly guaranteed. Compared with some other routing protocols, REFF performs better at transmission delay and it is not disturbed by the problem of data collision. In the future, how to more effectively merging the REFF technique with cross-layer technique will be our main focus.

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