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A Location-aided Intelligent Repetition Routing Protocol for Sparse VANETs

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Abstract. Traffic safety is one of the most important applications in Vehicular Ad Hoc Networks (VANETs), which basically depends on the inter-vehicle communications. However, in sparse VANET environment, vehicles cannot keep continuous wireless link with those neighbour vehicles, and it becomes very difficult to achieve real-time message transmission. In this paper, in view of the fact that traditional wireless network routing protocols cannot guarantee reliability and effectiveness of transmission, we analyze the factors that affect the packet delivery ratio of communications between a pair of vehicles, and accordingly present an effective routing strategy based on Location-Aided Routing (LAR) in sparse networks in order to improve the ratio as much as possible. Finally, we compare our strategy and the original LAR, and the simulation results show that our strategy can effectively improve the performance in sparse VANETs.

Keywords: intelligent repetition, mobility model, routing protocol, sparse vehicular ad hoc networks

1 Introduction

Vehicular Ad Hoc Networks (VANETs) is proposed mainly for achieving safety and efficiency. In various traffic scenarios, with the help of VANETs, drivers may easy to get information about surroundings and collision warnings. And vehicles may exchange information through hop-by-hop instead of relying on infrastructure. On the other hand, there are some new challenges in sparse environment.

From the studies of VANETs, it concludes that the main reason of the decrease of network connectivity, link duration and routing effectiveness is caused by sparse environment [1-3]. First of all, sparse feature means that the traffic density is relatively low, which leads to no enough nodes in the network, moreover it is difficult to form a multi-hop network effectively; secondly, sparse is also caused by relatively fast moving speed, according to the common sense, the less vehicles on the road there are, the faster driving speed there is. Fast speed directly causes the link duration to become shorter, and affects the routing effectiveness; thirdly, there is no infrastructure supporting in sparse environment, therefore the vehicles are easy to form the information island, and result in increasing the delay and the forwarding times in a certain extent.

The fast moving behavior of vehicles increases the difficulties of communication between vehicles. However, the tight restriction of road and the application of GPS can offer more opportunities. Location-Aided Routing (LAR) adds the location information and velocity information into the link establishment phase [4]. Then the hop-by-hop process can be optimized with these mobility information. It has been proved that the packet delivery ratio of LAR is higher than AODV and DSR. Unfortunately, the original LAR cannot satisfy the requirements of Vehicle-to-Vehicle communication, especially in sparse networks.

Considering the traditional routing protocols are not suitable for sparse VANETs, there have been some studies in literatures about analysis of routing performance in sparse VANETs, which can be classified into two major dimensions.

The first dimension primarily studies how to increase the packet delivery ratio in sparse networks. Low traffic density contributes to intermittent connectivity of the network, most of these researches involve the so-called Delay Tolerant Networks (DTN) or Store-Carry-and-Forward scheme [5]. Bulut, Geyik and Szymanski proposed a method to route messages in DTN over shortest path that is defined by the inter-contact time [6]. Li and Sun present an effective Trend-Prediction-Based Geographic forwarding scheme for sparse vehicular networks [7]. Wisitpongphan et al., Ros Ruiz and Stojmenovic thought that optimal rebroadcast probability and optimal timer for retransmission could be helpful.

The second dimension mainly focus on the analysis of routing protocols with fast moving vehicles. The impact of density on routing protocols was researched by Tounoux et al. [10]. The results showed that lower density is more likely to result in higher speed and more severe communication environment. Karagiannis et al. studied the delay based on analysis of inter-contact time, whose complementary cumulative distribution function (CCDF) was proved by simulation to obey the power law and exponential decay [11]. Other researches involved analysis of some similar concepts, such as conditional residual time [12] and the inter-contact time in opportunistic vehicular communications [13].

This paper is inspired by the fact that critical analysis of LAR performance in VANETs has never been done based on numerical mobility results. Therefore, in this paper, we plan to study the LAR and improve it by utilizing the analysis results of mobility. Obviously, proper employment of mobility model is a critical step for verifying the feasibility of analysis. And then we establish our mobility model based on highway and drive the relations among the elements of the model. And the numerical results are used in the improved routing strategy and then we get the intelligent repetition strategy. The intelligent point lies on the application of the numerical results into the routing design and in each transmission source node determines the number of replicates and the waiting time automatically and independently. By simulation comparison, the location-aided intelligent repetition routing protocol which proposed in this paper has better performance in terms of delay, delivery rate and overhead.

The remainder of this paper is organized as follows. In Section 2 and Section 3, we discuss the mobility models in sparse VANETs and analysis the quantitative relationships between variables. In Section 4, we introduce the Location-Aided Routing protocol, including our preliminary improved LAR. Based on the previous research results, the intelligent repetition strategy is presented in Section 5, followed by extended simulations and comparisons in Section 6. Finally, we draw our conclusions in Section 7.

2 Mobility Models in Sparse VANETS

The application system model for sparse VANETs usually chooses an ordinary road model. In this section, the Normal Random Model and the Semi-Markov Mobility Model will be modified as Random Velocity Mobility Model in highway and the Semi-Markov Mobility Model in highway respectively. And then combining the conclusion of two models, we redesign Semi-Markov Smooth Mobility Model based on State Transition Probability of Vehicle Spacing.

2.1 Random Velocity Mobility Model in Highway

Without loss of generality, it makes the following assumptions:

(1)Two lane for the same direction;

(2)The minimum velocity is $V_{\min}$, the maximum velocity is $V_{\max}$;

(3)During a time unit Tout, the velocity of each vehicle keeps constant.

Where the total length of road is L, the arrival rate of vehicles at the starting point is λ, the safety distance between two adjacent vehicles is D_{safe}, the communication distance is R, as shown in the Fig. 1, the vehicles with solid lines represent the location at the time of T_0, the vehicles with dotted lines represent the location at the time of T_1. Obviously, those vehicles which are within the transmission range at previous moment, may move out of the transmission range at next moment.

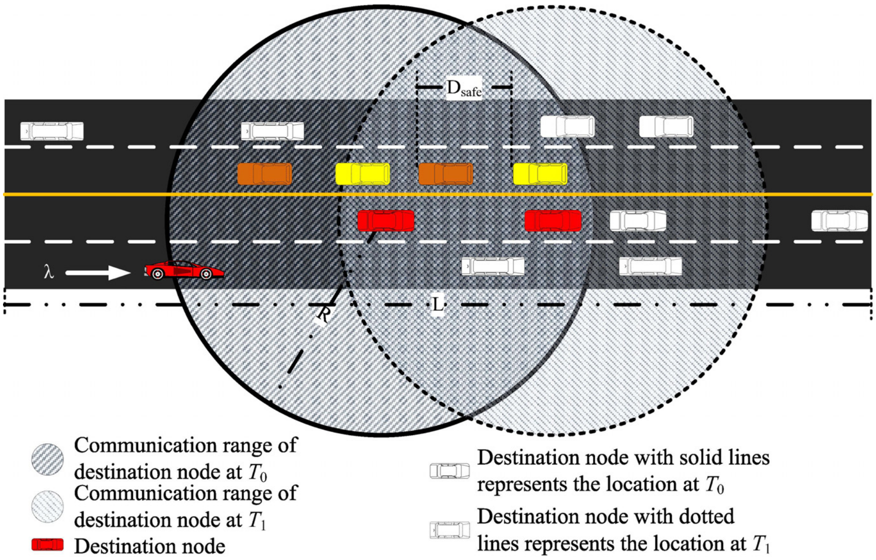

Fig. 1. Random Velocity Mobility Model in highway

This mobility model can be applied in a very wide range of scenarios, most of the sections in highway are restricted to the minimum and maximum velocity, and two-way multi-lane model conforms to the characteristics of the highway. The length of the road L set by the model can be regarded as the length of two adjacent entrances on the highway.

2.2 Semi-Markov Mobility Model in Highway

The defect of Random Velocity Mobility Model is unable to overcome the vehicle velocity mutation, so a Semi-Markov Mobile Model with acceleration is applied to highway.

In addition to the above assumptions in random velocity mobility model, there are more hypothesis in this model.

(1)Each vehicle has four kinds of states, that is, low-speed, high-speed, acceleration and deceleration;

(2)when a vehicle wants to transfer state, it can only follow the direction of the arrow in the Fig. 2;

(3)when a vehicle wants to overtake other vehicles, it has to be in high-speed state, and other vehicle is in low-speed state.

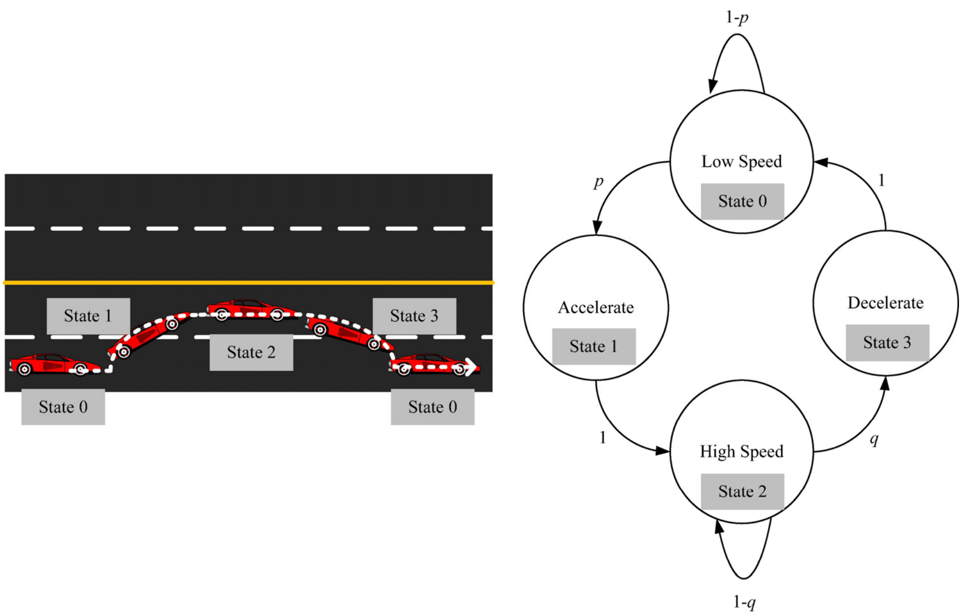

Fig. 2. Semi-Markov Mobility Model in highway

Fig. 2 is a simple illustration of the mobility model of highway with double lanes. The state transition diagram is also shown in Fig. 2, in which the *p* and *q* represent the probability of accelerate and decelerate, respectively. The vehicle state transition matrix is given as follow.

$$J = \begin{bmatrix} 1-p & p & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1-q & q \\ 1 & 0 & 0 & 0 \end{bmatrix} \tag{1}$$

The transition probabilities *p* and *q* in the state transition matrix are preset in the experimental environment, which represent the vehicle acceleration probability and the deceleration probability respectively. The value of preset is based on real road traffic statistical data and reasonable inference.

Due to one of the assumptions of the model is double-lane with the same direction, and in actual highway, different lane respectively complies with the range of driving speed, so the assumption in speed has two states. On the one hand, it is consistent with the actual situation, and if the lanes are increased, it can increase the number of speed states correspondingly; on the other hand, vehicle speed corresponds to lanes, acceleration or deceleration of vehicle causes the change of driving speed and lanes, which is also regarded as the premise of overtaking vehicles. For more than double-lane highway, the model can be extended to multi-speed Semi Markov Mobility Model, including acceleration state, deceleration state and *M* speed states. For vehicles, transferring states between different speed states has to through the acceleration or deceleration state first. This model can be applied to multi-lane highway model, each speed corresponds to each lane, the transition probability is set by the actual statistics of frequency of vehicle changing lanes.

2.3 Semi-Markov Smooth Mobility Model based on State Transition Probability of Vehicle Spacing

In application of aforementioned Semi-Markov Mobility Model, state transition probability of vehicle can only use the history or experience data, which cannot generate automatically and change in real-time. The final archived steady state has limited practical value. So we combine with the quantitative research results of the Random Velocity Mobility Model and Semi-Markov Mobility Model in highway scenarios, provide an improvement model which is suitable for research and in accordance with actual situation, namely Semi-Markov Smooth Mobility Model based on state transition probability of vehicle spacing.

This model is similar to the Semi-Markov Mobility Model described above. Notice the only difference is that the state transition probability is no longer preset by statistic data. In fact, vehicles accelerate or decelerate on highway depending largely on their distances with the vehicles in front. When the distance is huge, the probability of accelerate will increase, while that of decelerate will decrease. Otherwise, the probability of decelerate will increase and that of decelerate will decrease. In addition, when the leading vehicle accelerate or decelerate, the distance will begin to change and the following vehicle is more likely to do the same behavior.

We set a minimum distance as the safe distance between adjacent vehicles, for example, we must keep more than 100m away from the vehicle in front when we are driving on highway. Following formula (2) and (3) represent the dynamic transmission probability of accelerate and decelerate, respectively.

$$p_{(t=T_n)} = \begin{cases} e^{10D_{safe}-L} \cdot \left[\dfrac{d_{(t=T_n)} - d_{(t=T_{n-1})}}{2\left|d_{(t=T_n)} - d_{(t=T_{n-1})}\right|} + \dfrac{1}{2} \right], & D_{safe} < d < 10 \cdot D_{safe} \\ e^{d-L}, & 10 \cdot D_{safe} < d < L \end{cases} \tag{2}$$

$$q_{(t=T_n)} = \begin{cases} e^{10D_{safe}-L} \cdot \left[\dfrac{1}{2} - \dfrac{d_{(t=T_n)} - d_{(t=T_{n-1})}}{2\left|d_{(t=T_n)} - d_{(t=T_{n-1})}\right|} \right], & D_{safe} < d < 10 \cdot D_{safe} \\ \alpha, & 10 \cdot D_{safe} < d < L \end{cases} \tag{3}$$

where the total road length is L, the distance between a pair of vehicles is d, and the safety distance is D_{safe}, p and q respectively represent the probability of vehicle acceleration and deceleration at the moment of T_n. When the distance between vehicles is more than 10 times of the safe distance, the acceleration probability is greater than the deceleration probability α; while the distance between vehicles is less than 10 times of the safe distance, with the change of the vehicle spacing intervals, the probability of vehicle acceleration and deceleration will correspondingly be changed.

3 Quantitative Analysis of Mobility for Sparse VANETs

3.1 Relationship between Average Speed and Density of Traffic Flow

Firstly, the relationship between traffic density and vehicle speed is analyzed. Traffic density ρ is a parameter that has not been mentioned in the above model. Obviously, there is a certain relationship between traffic density and average speed. As we can imagine, if the traffic density is high, the average speed will be slow, whereas the traffic density is low, the average speed will be improved easily. In sparse scenario, the traffic density is very low, therefore the vehicle speed is relatively fast, but we need to analyze the specific internal relations between density and speed.

According to the Random Velocity Mobility Model in highway scenario, the vehicle speed is selected in the range between the maximum speed and the minimum speed randomly.

$$\bar{v} = \frac{\sum_{i=1}^{N} v_i}{N} \tag{4}$$

where v_i represents the speed of the ith vehicle, N is the total number of vehicles within the distance L, and N is related with the traffic density ρ which is set by model, v_i obeys uniform distribution whose range of values is from $V_{\min}$ to $V_{\max}$, and the probability density function is defined as formula (5).

$$p(v_i = v) = \frac{1}{V_{max} - V_{min}}, \qquad V_{min} < v < V_{max} \tag{5}$$

From the model, we may draw that the moving speed of each vehicle is independent, so it can obtain the distribution of average velocity according to the inference that the probability of sum of random variables equals to the sum of each random variable probability. The density function of average velocity probability is shown in (6).

$$\begin{aligned} p(\bar{v} = v) &= p(\frac{1}{N}\sum_{i=1}^{N} v_i = v) = \frac{1}{N}\sum_{i=1}^{N} p(v_i = v) \\ &= \frac{1}{V_{max} - V_{min}}, \qquad V_{min} < v < V_{max} \end{aligned} \tag{6}$$

Therefore, there is no relation between the density of the traffic flow and the average speed in the Random Velocity Mobility Model.

Through this conclusion, we can boldly infer that when the velocity of each vehicle in the mobility model is independent of other vehicles, the traffic density is not related to the average speed. Apparently, this does not conform to the actual situation.

Then we study our proposed model, i.e., the Semi-Markov Mobility Model based on the State Transition Probability of Vehicle Spacing. In this model, the speed change of each vehicle is related to the distance spacing and the change trend. For example, at a certain time t_0, the speed relationship of the adjacent two vehicles is shown as (7).

$$\begin{aligned} \overline{v_{i+1}} = {} & p[v_i T_{out} + d_{i,i+1}(t = t_0)] \cdot v_{max} + \\ & q[v_i T_{out} + d_{i,i+1}(t = t_0)] \cdot v_{min} \end{aligned} \tag{7}$$

In formula (7), p and q represent the accelerated probability and the deceleration probability which are mentioned above in the Semi-Markov Mobility Model. The expression in the bracket is vehicle space for the two vehicles at time t_0. Additionally, vehicles are only set two moving speed, i.e., high-speed $V_{\max}$, low speed $V_{\min}$. Using the steady-state characteristic, that is, all running speed of vehicles achieve a dynamic balance. The average speed can be derived as (8).

$$\begin{aligned}\bar{v} &= \bar{v_i} = \overline{v_{i+1}} \\ &= p(\bar{v}T_{out} + \bar{d}) \cdot V_{max} + q(\bar{v}T_{out} + \bar{d}) \cdot V_{min}\end{aligned} \quad \textbf{(8)}$$

where $\bar{d} = 1/\rho$.

This is an equation, and the mean of vehicle spacing is set to the reciprocal of the density of traffic flow, the relationship between vehicle spacing and the density of traffic flow, the average speed will be described in detail (2) and (3), we can see that the probability of acceleration and deceleration of vehicles is set by segment, so the expression of average velocity in Semi-Markov Mobility Model is also segmented. Having deduced and proved in detail, this equation is unable to obtain the analytical root, therefore we provides a new train of thought to solve this equation and obtain the numerical solution.

$$\bar{v} = \begin{cases} V_{max} & \rho < \dfrac{1}{10D_{safe}} \\ \dfrac{V_{max} + V_{min}}{2} + Acos\omega\rho + Bsin\omega\rho & \dfrac{1}{10D_{safe}} < \rho < \dfrac{1}{D_{safe}} \\ V_{min} & \rho > \dfrac{1}{D_{safe}} \end{cases} \quad \textbf{(9)}$$

where the middle expression is a numerical approximation in accordance with the Fourier series. Set the simulation parameters $V_{\max}$=30m/s, $V_{\min}$=15m/s, and D_{safe} = 100m. By using MATLAB for curve fitting, we obtained that expression parameters A, B, and ω respectively, which are 7.507, 102.9 and 342.6. And the fitting degree approximately can achieve 96.73%.

3.2 Analysis of Vehicle Spacing, Density of Traffic Flow and the Average Velocity

The key factor that affecting the success ratio of communication in vehicle communications is the instantaneous vehicle spacing, that is, when the information is being transmitted, the distance between two vehicles. For this we do the following analysis.

First we analysis the Random Mobility Model in highway scenarios. Select any two adjacent vehicles as the research object, assuming at time t_0, these two vehicles have a random distribution and one car is in the transmission range R of another car, the distance between the two vehicles is d_{ini}. The instantaneous speed of the car behind is v_i, and the instantaneous speed of the car in front is v_{i+1}.

Next time t_1=t_0+T_{out}, and the two car spacing can be calculated as (10).

$$z = d_{ini} + (v_{i+1} - v_i)T_{\text{out}} \quad \textbf{(10)}$$

For the random selected two vehicles, which can communicate with each other at a random time, the spacing d_{ini} obeys a uniformly distribution, which the domain of definition is from 0 to R. v_i and v_{i+1} obey a uniform distribution, which the domain of definition is from $V_{\min}$ to $V_{\max}$. In order to simplify the expression, set $V_{\min}$=0, and the speed difference between two cars x=v_{i+1}-v_i. The probability density function of x is described as (11).

$$f_X(x) = \frac{V_{\max} - |x|}{V_{\max}^2} \quad \textbf{(11)}$$

The range of x is from -$V_{\max}$ to $V_{\max}$, set u=d_{ini}, v=$x \cdot T_{\text{out}}$, and then get the probability density function of z=u+v, omit derivation process in details, the derivation results are in (12) and (13).

$$f_V(v)=\frac{T_{out}V_{\max}-|v|}{T_{out}^2V_{\max}^2},\ f_U(u)=\frac{1}{R} \tag{12}$$

$$f_Z(z)=\int_{-\infty}^{+\infty}f_V(v)f_U(z-v)dv \tag{13}$$

Next, due to the division of the integral interval causes positive and negative issues, so we need to discuss it on different situations.

(1) For the case of $R\geq 2T_{\text{out}}V_{\max}$,

$$\begin{aligned}f_Z(z)&=\int_{-\infty}^{+\infty}f_V(v)f_U(z-v)dv\\&=\frac{\int_{-\infty}^{z}(T_{out}V_{\max}-z+v)dv+\int_{z}^{+\infty}(T_{out}V_{\max}+z-v)dv}{RT_{out}^2V_{\max}^2}\\&=\begin{cases}\frac{(z-R-T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R-T_{out}V_{\max}\leq z\leq R+T_{out}V_{\max}\\ \frac{1}{R}, & R+T_{out}V_{\max}\leq z\leq 2R-T_{out}V_{\max}\\ \frac{1}{R}-\frac{(z-2R+T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & 2R-T_{out}V_{\max}\leq z\leq 2R+T_{out}V_{\max}\\ 0, & \text{others}\end{cases}\end{aligned} \tag{14}$$

(2) For the case of $R\leq T_{\text{out}}V_{\max}$,

$$\begin{aligned}f_Z(z)&=\int_{-\infty}^{+\infty}f_V(v)f_U(z-v)dv\\&=\begin{cases}\frac{(z-R+T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R-T_{out}V_{\max}\leq z\leq 2R-T_{out}V_{\max}\\ \frac{R(2z-3R+2T_{out}V_{\max})}{2RT_{out}^2V_{\max}^2}, & 2R-T_{out}V_{\max}\leq z\leq 2R\\ \frac{1}{R}-\frac{(z-2R+T_{out}V_{\max})^2+(z-R-T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R\leq z\leq 2R\\ \frac{R(-2z+3R+2T_{out}V_{\max})}{2RT_{out}^2V_{\max}^2}, & 2R\leq z\leq R+T_{out}V_{\max}\\ \frac{(z-2R-T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R+T_{out}V_{\max}\leq z\leq 2R+T_{out}V_{\max}\\ 0, & \text{others}\end{cases}\end{aligned} \tag{15}$$

(3) For the case of $T_{out}V_{\max}\leq R\leq 2T_{out}V_{\max}$,

$$f_Z(z)=\int_{-\infty}^{+\infty} f_V(v) f_U(z-v)dv$$

$$=\begin{cases} \dfrac{(z-R+T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R-T_{out}V_{\max}\le z\le R \\ \dfrac{1}{R}-\dfrac{(z-R-T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R\le z\le 2R-T_{out}V_{\max} \\ \dfrac{1}{R}-\dfrac{(z-R-T_{out}V_{\max})^2+(z-2R+T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & 2R-T_{out}V_{\max}\le z\le R+T_{out}V_{\max} \\ \dfrac{1}{R}-\dfrac{(z-2R+T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & R+T_{out}V_{\max}\le z\le 2R \\ \dfrac{(z-2R-T_{out}V_{\max})^2}{2RT_{out}^2V_{\max}^2}, & 2R\le z\le 2R+T_{out}V_{\max} \\ 0, & \text{others} \end{cases} \quad \textbf{(16)}$$

It can be seen that the distribution of vehicle spacing is related with communication range and vehicle speed, since the former can be considered preset, vehicle spacing is mainly related to vehicle speed. In addition, before our derivation, we emphasize the distribution of two cars is within communication range of each other, if two cars randomly distribute within the whole road, R can be replaced by $1/\rho$. Therefore, it can be deduced that vehicle spacing is mainly related with the speed and density of traffic flow.

Then, we analyze the distribution of vehicle spacing in the Semi-Markov Mobility Model based on the Probability Of State Transition.

Make the same premise as the previous Random velocity Mobility Model, so $z=d_{ini}+(v_{i+1}-v_i)T_{out}$. The distribution of initial spacing can still be considered as a random uniform distribution, i.e., $\overline{d_{ini}}=1/\rho$.

On the other hand, the velocity distribution of two cars is no longer random uniform distribution, and the velocity only has two values of $V_{\max}$ for high speed and $V_{\min}$ for low speed, and the speeds of the car in front and the car behind have a certain correlation.

$$v_{i+1}=p[v_iT_{out}+d_{ini}]\cdot V_{max}+q[v_iT_{out}+d_{ini}]\cdot V_{min} \quad \textbf{(17)}$$

Therefore, it has three values for $x=v_{i+1}-v_i$ respectively, i.e., 0, $V_{\max}-V_{\min}$ and $V_{\min}-V_{\max}$, and the probability is uncertain, but it is not difficult to conclude that the distribution of vehicle spacing is closely related with the speed and density of traffic flow.

We use this model and find that distance between adjacent vehicles are distributed in some law. We made three groups of simulation experiments. In the first group there are 90 cars distributed in length of 10000 m without boundary road according to the movement of Semi-Markov Mobility Model, the high speed is 30m/s, and the low speed is 15m/s, experimental time is about 100s, 10 pairs of adjacent vehicles are selected randomly per second and the vehicle spacing numerical value can be obtained; the second group experiment is on the same road, and 90 cars conform the semi-Markov distribution, however, we set the high speed as 20m/s, the low speed as 15m/s, and also take 1000 samples of vehicle spacing; In the third group of experiment, there are 50 cars distributed in the same road, speed value is set same as the first group and the samples for vehicle spacing is obtained by the same way. Moreover, the distribution of the data obtained from the three simulation experiment, is shown in the Fig. 3 below. And we fit the three groups of data with several distribution functions, including Rayleigh, log-normal, G0 and gamma function. Log-normal turns out to fit highest up to 85.66%. Higher velocity and lower density lead to larger distance.

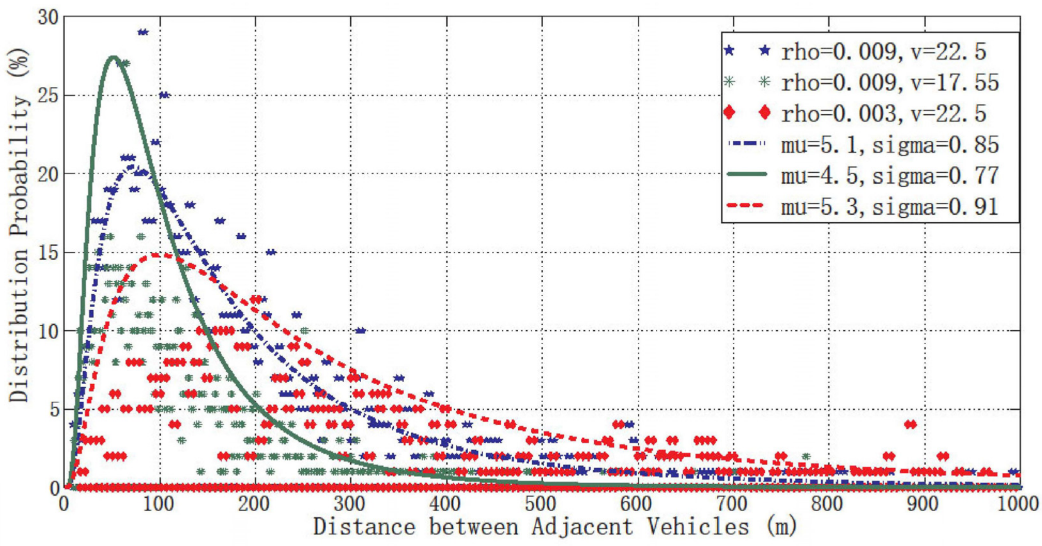

Fig. 3. Distribution of distance between adjacent vehicles

The distribution of inter-contact time can also be deduced from the distribution of distance, which is similar to the log-normal function curves [9]. It concludes that the higher traffic density is the lower average velocity and the wider average inter-contact time is, and vice versa.

4 Location-Aided Routing Protocols

4.1 Original LAR

Location-Aided Routing (LAR) protocol is one of the important research achievements in VANETs. In the initialization phase, location service process is started, namely each vehicle with GPS broadcasts its moving information, including the node moving velocity and position, to surrounding vehicles [14].

Routing establishment phase is divided into three steps:

Step 1. the source node initiates a route request, including data and information of the destination node and etc.;

Step 2. selecting next-hop forwarding node according to the predicted location of the next moment of all neighbor nodes, the node which is still in relay node's neighbor range and closer to the destination node will be chosen;

Step 3. whenever a node receives a route request, first of all, check whether the destination node is itself, if yes, terminate the routing establishment phase, if not, add its location information, routing address and select the next-hop forwarding node.

The LAR protocol shows better performances over the traditional protocols such as AODV and DSR [15]. However, there is still a certain gap between the requirements of VANETs and the original LAR.

4.2 Improved LAR

An improved method of LAR has been studied in our previous work. The main improvement is that each node finds the next-hop forwarding node after estimating the best forwarding node in next moment, rather than this moment.

The principle of the selecting strategy of intermediate nodes based on position prediction is as follows. First, according to the information of current location and velocity of destination node, source node and other intermediate nodes, it predicts the delay of information transmission; then predicts the position of each intermediate node and destination node after a while through a certain algorithm, so as to select the best forwarding nodes. It not only improves the reliability of information transmission, but also reduces the time delay and improves the efficiency of information transmission.

As Fig. 4 shown above, solid vehicle represents the current position, according to common sense, and source node should send information to the intermediate node A, because it is much closer to the destination vehicle. Actually, intermediate node A is moving at a low speed, and destination node is moving faster. At next moment, the destination node may easily be out of the communication range of intermediate node A. And at the current moment, if information is sent to intermediate node B first, which can move faster, at next moment the information will be sent to the destination node successfully.

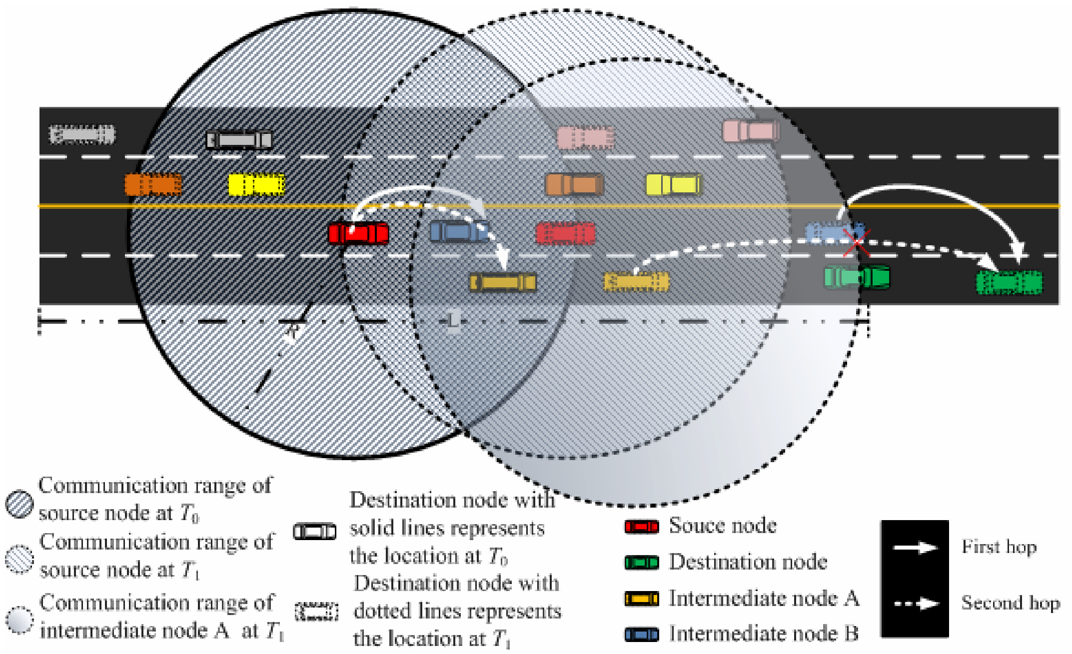

Fig. 4. Selecting strategy of intermediate nodes based on position prediction

First, according to position, velocity and density of all vehicles, source node vehicle estimates the transmission hops that transmitting information required. Secondly, the source node predicts position of the best intermediate node for first hop, and in multi-hop transmission, each intermediate node executes a prediction of the best forwarding node for next hop. Finally, the information is delivered to the destination node. The specific flow chart is as follows.

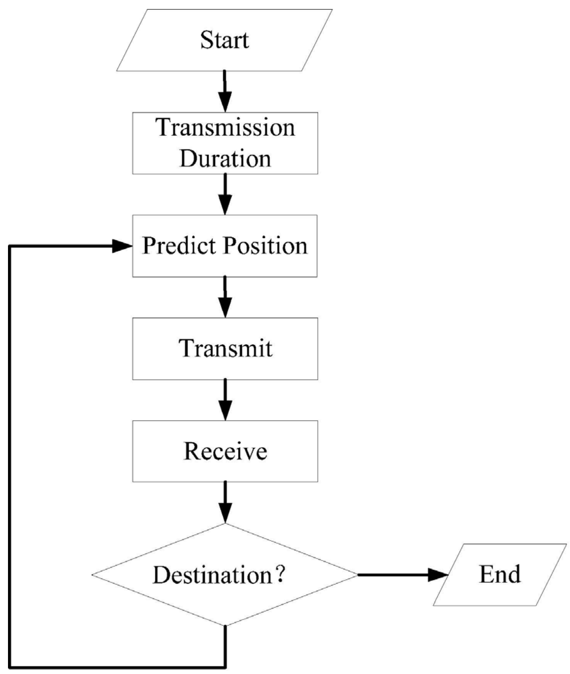

Fig. 5. Flow chart of intermediate node selection strategy based on position prediction

The number of hops K and the longest transmission duration T_{out} can be calculated by iterative formulas.

$$K = \left[\frac{d_{des} - d_{sou} + T_{out}(v_{des} - v_{sou})}{R} + 1 \right] \quad \textbf{(18)}$$

In formula (18), $[x]$ represents the largest integer no more than x, d_{des} and v_{des} represent vehicle position and velocity of destination node, and d_{sou} and v_{sou} represent vehicle position and velocity of source node, as the longest transmission duration, T_{out} can be expressed as (19).

$$T_{out} = \frac{T_{delay}}{K} \quad \textbf{(19)}$$

The numerator of the fractional expression is the maximum value of the system delay. Since we have set the maximum speed and the minimum speed, this iteration is convergent, and the maximum iteration number is 3. The formula for calculating position of the next hop best forwarding node is as follow.

$$\begin{aligned} d_{next}(t = t_0 + T_{out}) = \underset{i=1}{\overset{n}{Max}} \{ & d_i(t = t_0 + T_{out}) = d_i(t = t_0) + T_{out} \cdot v_i(t = t_0) \\ & | \, d_i(t = t_0 + T_{out}) - d_0(t = t_0 + T_{out}) < R \} \end{aligned} \quad \textbf{(20)}$$

where n represents the number of all neighbor nodes of current node, subscript 0 represents the current node, $v_i\,(t{=}t_0)$ stands for the vehicle speed of the i neighbor node at time t_0, and $d_i(t{=}t_0)$ stands for the vehicle position of the i neighbor node at time t_0, the position of the next hop best forwarding node is the maximum distance to current node for all its neighbor nodes, who is still within the communication range of the current node.

Because of the existence of delay, the topology is most likely to be different between this moment and next moment. The preselected forwarding node may be out of the transmission range or even overtaken by others, and it may no longer be suitable to forward the message. Although this improved LAR can increase the effectiveness of routing, when it applies in the sparse network, because there are fewer forwarding nodes, this strategy has no obvious improvement.

5 Intelligent Repetition Strategy

Vehicles on highway have similar characteristics, and the distance between adjacent vehicles obeys the log-normal distribution. As the density of vehicles gets smaller, the average distance between adjacent vehicles becomes greater. Meanwhile, it will also get greater with increasing velocities, or average velocities. Consequently, we may use the results in the Location-Aided Routing protocol.

At the beginning of LAR, the location service is conducted as the first phase. All vehicles get the location information of their neighbors. As soon as the source node gets the location information of the destination node, the transmission duration is estimated according to the mobility distribution. After that the transmission replicates is set by the source node and so as the time interval between two replicates.

Next phase is routing establishment. Each node selects the best next-hop forwarding node when it receives the message, which needs to be transmitted, except the destination node. And the node makes a judgment right after transmitting the message to the forwarding node that whether it has sent the same message repeatedly for enough times, which is already set by the source node. If the answer is yes, then its mission is accomplished. Whereas, as long as it hasn't sent for enough times, it should wait for the set time interval and rediscover the best next-hop forwarding node and send the message to the new forwarding node.

Fig. 6 is the flow chart of the intelligent repetition strategy. The difference between this strategy and the original LAR is that the transmission duration is estimated through iterations whose maximum number is around three. And the maximum replicates K and time interval T_k are both determined by the estimated transmission duration.

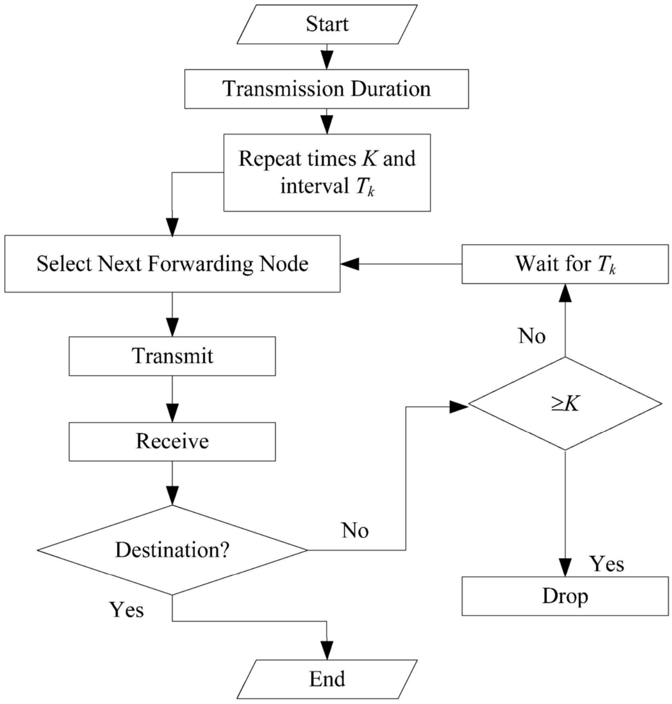

Fig. 6. Flow chart of intelligent repetition strategy

$$T_s = \left[\frac{d_{des} - d_{sou} + T_s(v_{des} - v_{sou})}{R} + 1 \right] \cdot T_{max} \quad \textbf{(21)}$$

$$K = \left[\frac{d_{des} - d_{sou}}{R} + 1 \right] \quad \textbf{(22)}$$

$$T_k = \frac{T_{max}}{K} \quad \textbf{(23)}$$

where the estimated transmission time T_s could be achieved by iterations, and $[x]$ represents the largest integer no more than x, and d_{des} and v_{des} represent the vehicle position and velocity of the destination node, and d_{sou} and v_{sou} represent the vehicle position and velocity of the source node, and the communication radius between vehicles is R. The T_{max} represents the max duration that any vehicle is allowed to carry packets. Anytime some intermediate node needs resend message, it calculates the best forwarding node of the present moment as the above formula. The simulations and comparisons are made and the results will be shown in next section.

6 Simulations and Comparisons

We use the NS-2 simulation platform to compare the performance of the original LAR, the improved predicted-based LAR and the intelligent repetition strategy.

6.1 Simulation A (Different Velocities and Fixed Density)

Firstly, we compare these protocols with different velocities and fixed density. In simulation A, five experiments have been done with five groups of velocity values. The parameters are shown in following Table 1.

Table 1. Parameters in simulation A

Parameters	Values
Transmitting rate(packet/s/veh)	1
Vehicle density (veh/m)	0.012
Maximum velocity (m/s)	30,30,25,15,30
Minimum velocity (m/s)	30,20,15,15,15
Total simulation time (s)	1800

Fig. 7. It is shown that the packet delivery ratio of the three protocols decreases with increasing average velocity. This is because highly dynamic topology makes it difficult for vehicles finding forwarding nodes. When the velocity is too large, the packet delivery ratio of original LAR cannot achieve 40%, while the improved LAR has 55% ratio and the intelligent repetition holds still over 65%. This strategy can make up the hard situation brought by high speed through replicates.

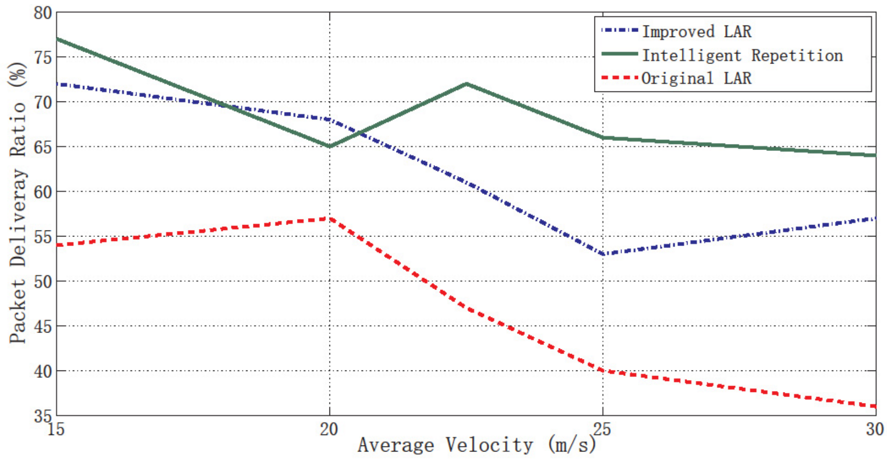

Fig. 7. Packet delivery ratio verse average velocity

In Fig. 8, the overall trend of the three protocols shows that the average delay decreases with increasing average velocity. With faster speed, each vehicle in the network can encounter other vehicles more easily, and the information that is successfully transmitted to the destination node is forwarded more quickly. And we can see that in low speed environment, the intelligent repetition strategy has larger delay. But when the speed gets larger, the average delay of intelligent repetition strategy is lower than original and improved LAR.

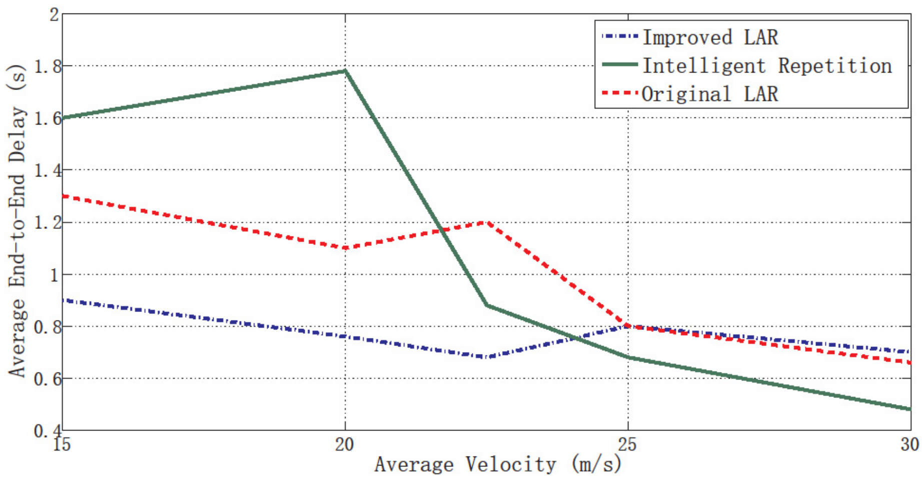

Fig. 8. Average end-to-end delay with average velocity

In Fig. 9, As the speed of vehicles get faster, the total overhead gets fewer, however, it should be noticed that the intelligent repetition strategy shows no obvious decrease.

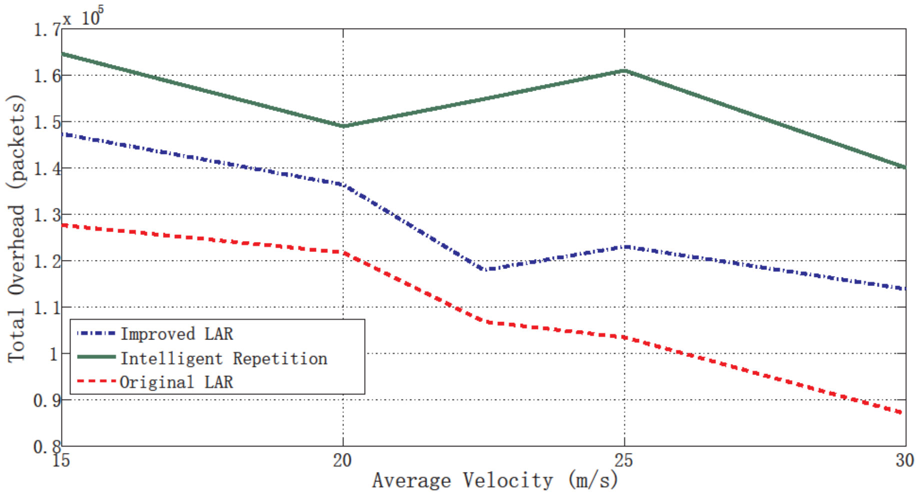

Fig. 9. Routing overhead with average velocity

6.2 Simulation B(Different Densities and Fixed Average Velocity)

These three protocols use different densities and fixed average velocity. In simulation B, ten experiments have been done with ten density values and the same maximum velocity and minimum velocity. The parameters are shown in following Table 2.

Table 2. The parameters in simulation B

Parameters	Values
Transmitting rate(packet/s/veh)	1
Vehicle density (veh/m)	0.003,0.005,0.007,0.009,0.011, 0.013,0.015,0.017,0.019,0.021
Maximum velocity (m/s)	30
Minimum velocity (m/s)	15
Total simulation time (s)	1800

The performance of these protocols verse different densities are shown as follows. As the density gets larger, an increase trend is shown among all three protocols, as shown in Fig. 10. The improved LAR and the intelligent repetition strategy both have higher ratio over the original LAR. However, when the density is too large, the packet delivery ratio of intelligent repetition strategy degrades from 85% to 80%.

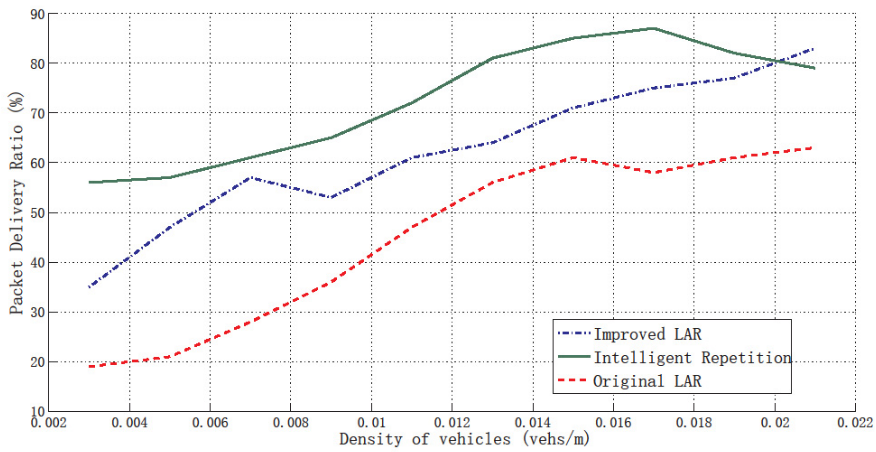

Fig. 10. Packet delivery ratio verse density of vehicles

From Fig. 11 we can see that the average delay of all three protocols decrease to a very small value as the density of vehicles becomes larger. However, in sparse environment the intelligent repetition strategy has an obvious advantage over the other two.

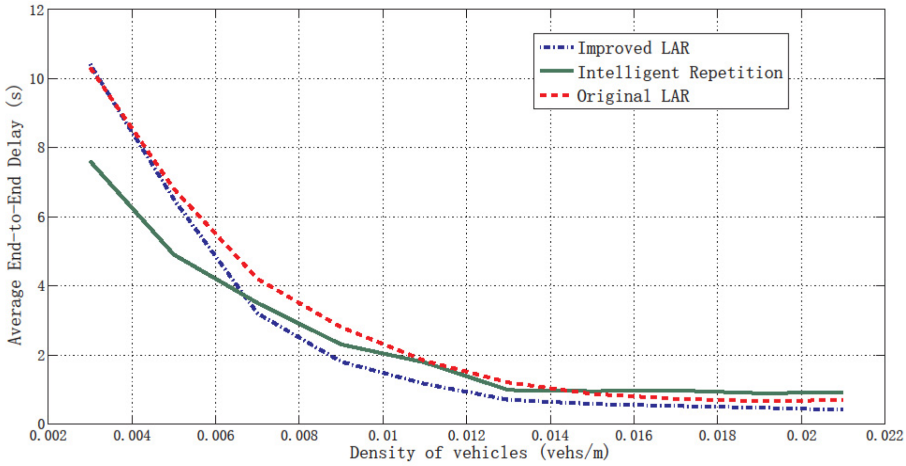

Fig. 11. Average end-to-end delay verse density of vehicles

In Fig. 12, as the density of vehicles gets larger, the total overhead of original and improved LAR both show linear growth, however, the overhead growth of intelligent repetition strategy is exponential. Hence this intelligent repetition strategy is not suitable for the dense environment.

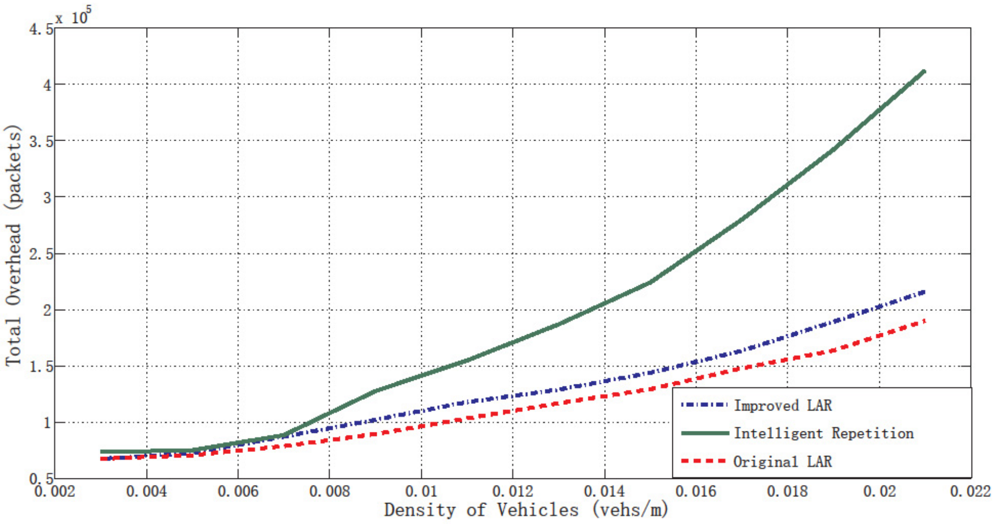

Fig. 12. Routing overhead with density of vehicles

7 Conclusions

In this paper, we mainly analyze the packet delivery ratio for Location-Aided Routing protocol in sparse VANETs and present a strategy which can effectively increase the packet delivery ratio in sparse VANETs. We propose an improved LAR by predicting the location of best next-hop forwarding node. And then establish the highway mobility model for sparse VANETs. Analysis is made based on our mobility model and we draw a conclusion that the probability density distribution of distance between adjacent vehicles is log-normal. So we put the results into use and present the intelligent repetition strategy. These protocols are compared in extended simulations and we conclude that the intelligent repetition strategy can effectively improve the packet delivery ratio in sparse networks. Through the mobility study of vehicular ad hoc networks, it is found that the movement of nodes is not independent, by this point more effective routing improvement strategies can be found. At present, the research of correlation between moving vehicles is still insufficient, however, this is a very valuable research aspect which can promote the development and research of network connectivity, MAC protocol, routing protocol.

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