An Efficient and Reliable Message Dissemination Mechanism for Vehicular Networks on Urban Roads

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Abstract

The performance of reliability and efficiency are very important for message dissemination in vehicular networks. However, due to the high mobility of vehicles and the complexity of urban road environment, it is difficult to achieve good performance. In this paper, to solve these problems, we propose an effective message dissemination mechanism based on link lifetime and link utility. With full consideration of the characteristics of urban road, we present a new link lifetime prediction method in various scenarios. Furthermore, to evaluate the quality of the communication link between vehicles, a new link utility calculation method is proposed and the effects of different parameters involved on link utility are analyzed in details. Finally, simulation experiments are conducted to illustrate the performance of the proposed mechanism with the metrics of message coverage ratio, average delay and forwarding node ratio.

Keywords: Vehicular networks, Message dissemination, Residual link lifetime prediction, Link utility

1 Introduction

As an important enabled technology for Intelligent Transport Systems (ITS), vehicular networks have attracted great attentions from academia and industry in recent years. Vehicular networks can provide communication capability in support of transportation safety and efficiency and can enhance user comfort and convenience. Message dissemination is one of the most promising applications in vehicular networks. The messages may be traffic related information, such as sudden traffic accidents, traffic congestion, parking information, etc. Also, they may be advertisements and promotions from hotels or restaurants along the road [1].

Broadcasting is an effective method for message dissemination. With the limited communication range of vehicle, relay vehicles will be needed to forward message to the destination vehicles that are not in the direct communication range of the sender. Relay vehicles are responsible for rebroadcasting message to next-hop relay vehicles until all vehicles in target areas receive the message. Therefore, in VANETs multi-hop broadcasting mechanism is usually used to broadcast message to the vehicles in target areas with the lowest latencies. However, the highly mobility of vehicles and dynamic network topology make the link connections unstable [2-3]. The frequent interruptions of link connections between vehicles may bring high packet loss and transmission latencies. Increasing the number of relay vehicles can improve the transmission reliability, but may cause serious channel contentions in wireless environment. Especially when the destination vehicle is far away from source vehicle, the increased forwarding hops will also increase the risk of path breaking [1]. Thus, the selection of relay vehicles becomes one of the most important issues for message dissemination in VANETs.

Link failure prediction can be used to mitigate the effect of frequently link interruption on message transmission, which has been verified in mobile ad hoc networks [4-5]. It mainly refers to predict link lifetime. In VANETs, link lifetime or residual link lifetime is the time that two vehicles are in the direct communication range of each other. Link lifetime not only is closely related to many performance parameters, but also can assist routing decision and network performance optimizing [6-7].

Vehicular networks have its unique characteristics. The mobility of vehicles brings unstable link connection. Fortunately, restricted by road layout and traffic regulations, the movement of vehicles is regulated and can be predicted [8]. Vehicles move along the road and vehicle speed is constrained by other vehicles around it. The trajectory of the nodes in vehicular networks can be predicted easily. In addition, the prediction of link lifetime on urban road is more complicated than on highway. There are many intersections on urban road. The prediction of link lifetime at the intersection needs to take into account many factors, such as traffic lights, the directions that vehicles will drive to. Existed research on link lifetime

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prediction was mostly made in highway scenario. In the paper, we analyze in details link lifetime prediction in urban road scenario.

The reliability of message dissemination is based on link lifetime prediction. Usually, vehicle pairs with short distance may have long link lifetime. If this kind of vehicle is selected as relay vehicle, message will be disseminated slowly via much more reply hops and message dissemination efficiency is low. To alleviate this problem, we introduce link utility into the selection of relay vehicle. Here, link utility is a function of distance between vehicles, vehicle density and relative speed. The efficiency of message dissemination can be improved greatly by using link utility to select relay vehicles. On the basis of link lifetime prediction and link utility calculation, we design an effective method to select relay vehicles, thus realizing reliable and efficient message dissemination.

The organization of the remainder of the paper is presented as follows. Section 2 gives an overview of some related works. Message dissemination mechanism is discussed in detail in Section 3. Performance of the proposed mechanism is evaluated by simulation in Section 4. Finally, we conclude the paper in Section 5.

2 Related Works

Until now, a few works have been done for establishing reliable and efficient transmission link. R. Bauza et al. took transmission parameter and receiving rate of vehicles into consideration and proposed link quality estimation methods based on power-awareness [9]. These methods were used to select reliable relay node and improve the performance of multi-hop forwarding. Alsharif et al. used information like the minimal estimation of link lifetime, real-time service and latencies to improve routing performance on the condition of guaranteeing connectivity [10]. With the mobility for vehicular networks, link lifetime had been an important research problem for transmission link.

Different methods have been proposed by researchers to predict link lifetime. In [11], the authors proposed a link lifetime prediction method based on Kalman filtering. And vehicle that has the maximum duration in candidate set will be selected as next-hop forwarding node. In [12], space-time planar graph approach was used to predict the connectivity of each road section and the future lifetime of the path was obtained.

In vehicular networks, vehicle state information like vehicle speed, the position of the vehicle, was often used to predict link lifetime. Kamboj et al. [13] proposed a link lifetime based routing protocol, and designed potential score estimation method to select next-hop relay vehicles. In the scheme, link lifetime prediction is related with the speed and position of vehicle. In [14], the authors proposed a prediction-based routing (PBR) protocol based on the predictable mobility pattern under highway scenario. They introduced a mobile gateway architecture, in which vehicles can connect to the Internet with the help of other vehicles (acting as mobile gateways). The route usually consists of one link or more links, and the route lifetime is the minimum of all the link lifetime. The route lifetime between ordinary vehicle and mobile gateway vehicle can be predicted with the location and speed information of vehicles. New available route will be established before the old one fails. Noureddine et al. [15] proposed a new link lifetime prediction method for mobile ad hoc networks (MANETs). Different from vehicular networks, the movement directions of the nodes in MANETs are random. In the proposed prediction method, link lifetime is a function of position, speed and direction of the sender, the neighbors and the destination. Based on link lifetime, a stability-based greedy routing algorithm was been proposed to select forwarding node, where nodes with the longest link lifetime will be selected as next forwarding hop.

3 Message Dissemination Mechanism

In this section, we will present the new message dissemination mechanism based on two components: residual link lifetime prediction and link utility calculation. Firstly, we will predict residual link lifetime according to the information about vehicle speed, direction, and location. Then, link utility formula will be given and some key parameters in the formula will be analyzed. At last, the proposed message dissemination mechanism will be introduced.

3.1 Residual Link Lifetime Prediction

Before predicting residual link lifetime, we first make some reasonable assumptions. Assume that the adjacent vehicle pairs have similar channel condition, thus factors that degrade channel quality like channel fading and shadowing can be simplified. All vehicles in network have the same communication range R. Vehicles can communication with each other in the effective communication range R; when distance between vehicles is larger than R, communication link will break off. Figure 1 shows the basic communication scenario between vehicles. In the figure, vehicle i is the sender and vehicle j represents vehicle that situated at the candidate forwarding areas of vehicle i. $p_i(0)$ and $p_j(0)$ denote the location of vehicle i and vehicle j at present moment respectively. d_0 denotes the distance between vehicle i and vehicle j at present moment, $d_0 = \| p_i(0) - p_j(0) \|$. $\|\cdot\|$ is Euclidean distance. $X_i(t)$ and $X_j(t)$ denote the distance that vehicle i and vehicle j move in time interval t, respectively. Vehicle maximum speed and minimum speed are usually limited in urban road; moreover, vehicle speed is also limited by other vehicle around it. In general, an normally running vehicle seldom vary its speed abruptly. Therefore, we ignore the effect of speed variation on link lifetime prediction and assume that vehicle moves with constant speed in a very short time interval. Assuming that the average speed of vehicle i and vehicle j is s_i and s_j , respectively. Then, we have $X_i(t) = s_i \cdot t$, $X_j(t) = s_j \cdot t$. Because communication range of vehicle is far more than the road width, the effect of different lanes on link lifetime prediction can be ignored in the model. It may result in the underestimation of link lifetime, but the reliability of the link is not influenced.

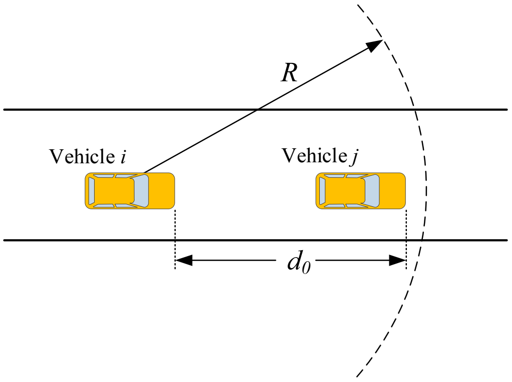


Figure 1. The basic scenario

According to the urban road characteristic, roads can be divided into two patterns: road segment and intersection. In these two scenarios, duo to the different driving directions, there exists multiple movement pattern. Residual link lifetime is mainly influenced by distance, speed, direction, and traffic light. Next we will discuss in detail residual link lifetime prediction in various scenarios and different movement pattern.

3.1.1 Road Section

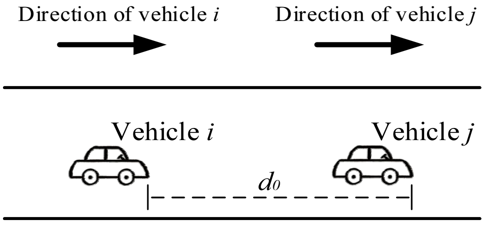
We analyze residual link lifetime prediction in road section scenario. As shown in Figure 2, the sending vehicle and the receiving vehicle may drive in the same direction or the opposite direction on road.

Scenario one. In Figure 2(a), vehicle i and vehicle j drive in the same direction. The initial distance between vehicles is d_0, $0 < d_0 \leqslant R$.

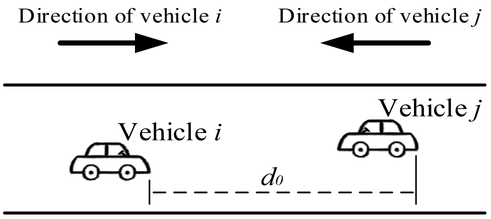
If $s_j > s_i$, the distance between vehicle i and vehicle j increases. The link will break when the distance is larger than R .

$$X_j(t) - X_i(t) + d_0 = R \tag{1}$$

$$t = \frac{R - \| p_j(0) - p_i(0) \|}{s_j - s_i} \tag{2}$$



(a) Driving with same directions



(b) Driving with inverse directions

Figure 2. Some cases of the vehicle pair movement on the road segment

If $s_j < s_i$, the distance between vehicle i and vehicle j gradually decreases, until two vehicles encounter. Then, vehicle j drives out of the candidate forwarding area of vehicle i and would not act as candidate vehicle.

$$X_j(t) - X_i(t) + d_0 = 0 \tag{3}$$

$$t = \frac{\| p_j(0) - p_i(0) \|}{s_j - s_i} \tag{4}$$

If $s_j = s_i$, the vehicle j keeps stationary to the vehicle i . The link lifetime will be infinite, i.e., $t = +\infty$.

Scenario two. As shown in Figure 2(b), the vehicle i and the vehicle j drive in opposite directions.

$$X_j(t) + X_i(t) = d_0 \tag{5}$$

$$t = \frac{\| p_j(0) - p_i(0) \|}{s_j + s_i} \tag{6}$$

In general, due to the large relative speed, the link lifetime of vehicles driving in the opposite directions is much shorter than that in the same directions. Therefore, vehicles in the opposite directions should not be selected as relay vehicle.

3.1.2 Intersection not Taking Traffic Lights into Consideration

Considering that there are a lot of intersections on urban roads, we firstly will analyze the link lifetime at intersection without effect of traffic lights. The effect of traffic lights on link lifetime will be discussed later. The following scenarios will be divided according to the relationship of segment that the sender i will drive to and the segment that vehicle j is situated in. The initial position of vehicle i and vehicle j is shown in Figure 3(a).

Scenario three. As shown in Figure 3(b), the vehicles i and j drive to the same segment. In this case, the analysis of link lifetime is similar to scenario one and scenario two.

Scenario four. As shown in Figure 3(c), the vehicles i and j drive to the opposite segments. If vehicle i and vehicle j have the opposite driving directions:

$$X_j(t) + X_i(t) + d_0 = R \tag{7}$$

$$t = \frac{R - \| p_j(0) - p_i(0) \|}{s_j + s_i} \tag{8}$$

If vehicle i and vehicle j have the same directions, the situation that vehicle i drives out of the candidate forwarding area should be considered. Once vehicle leaves the area, it will not be selected as relay node. If the link between vehicles fails before vehicle j drives out of candidate forwarding area, we have

$$X_i(t) - X_j(t) + d_0 = R \tag{9}$$

$$t = \frac{R - \| p_j(0) - p_i(0) \|}{s_i - s_j} \tag{10}$$

If vehicle j has driven out of the candidate forwarding area before the link fails, we have

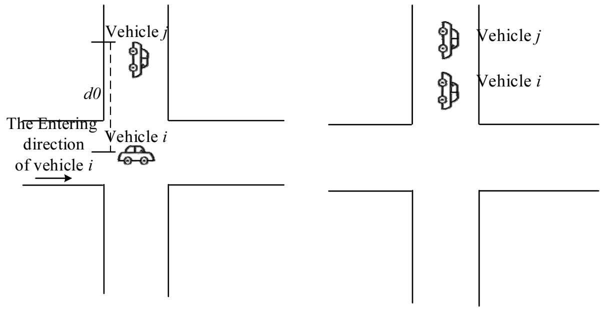
$$t = \frac{\| p_j(0) - p_i(0) \|}{s_j} \tag{11}$$

Therefore, if vehicle i and vehicle j have the opposite driving directions, the residual link lifetime will be:

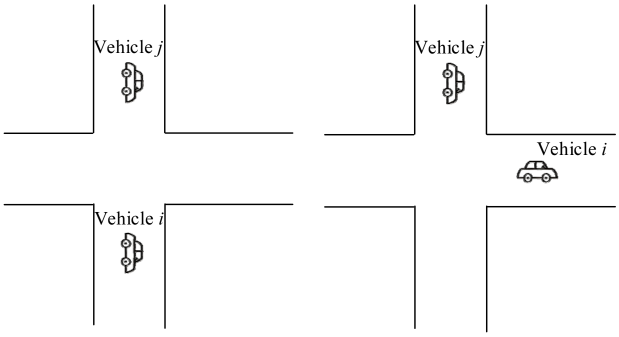
$$t = \min\left(\frac{\| p_j(0) - p_i(0) \|}{s_j}, \frac{R - \| p_j(0) - p_i(0) \|}{s_i - s_j} \right) \tag{12}$$

Scenario five. As shown in Figure 3(d), the vehicle i drives into the segment that is perpendicular to the segment that vehicle j is on. If vehicle j leaves the intersection, then

$$\left[X_j(t) + d_0 \right]^2 + X_i(t) = R^2$$



(a) Initial time (b) Same case



(c) Inverse case (d) Vertical case

Figure 3. Some cases of the vehicle pair movement at the intersection

For those vehicles located in vertical segments, communication signals are more likely to be blocked by nearby buildings or other obstacles [16-17]. Thus, assuming that the Non-Line-Of-Slight(NLOS) communication range at intersection is R_{NLOS}, then we have

$$\left[X_j(t) + d_0 \right]^2 + X_i(t) = R_{NLOS}^2 \tag{14}$$

$$t = \frac{\sqrt{\left(s_i^2 + s_j^2\right) R_{NLOS}^2 - s_i^2 d_0^2} - s_j d_0}{s_i^2 + s_j^2} \tag{15}$$

If vehicle j is driving into the intersection, we have

$$\left[d_0 - X_j(t) \right]^2 + X_i(t) = R_{NLOS}^2 \tag{16}$$

$$t = \frac{\sqrt{\left(s_i^2 + s_j^2\right) R_{NLOS}^2 - s_i^2 d_0^2} + s_j d_0}{s_i^2 + s_j^2} \tag{17}$$

3.1.3 Intersection Taking Traffic Lights into Consideration

We further consider the effect of traffic lights on the residual link lifetime. Assume that a full traffic light cycle consists of red phase and green phase.

If the vehicle i drives into the intersection in green phase, residual link lifetime is predicted by adopting the same methods as the scenario without considering traffic lights.

Next we discuss the scenario that the vehicle i drives into the intersection in red phase. Assuming that the residual time of red phase is t_r. During the period that vehicle i waits for green light, the vehicle j may be selected as relay vehicle only if it is in candidate forwarding area. When the vehicle j leaves the intersection, speed should satisfy $s_j < d_0 / t_r$. When the vehicle j drives into the intersection, speed should satisfy $s_j < (R - d_0) / t_r$. Based on this, the residual link lifetime will be analyzed under different scenarios.

Scenario six. After the red phase terminates, vehicle i drives into the segment same as vehicle j, which is shown in Figure 3(b). If the vehicles i and j have the same driving directions, we have

If $s_j > s_i$,

$$X_j(t) - X_i(t - t_r) + d_0 = R \tag{18}$$

$$t = \frac{R - \| p_j(0) - p_i(0) \| \; C s_i t_r}{s_j - s_i} \tag{19}$$

If $s_j < s_i$,

$$t = \frac{\| p_j(0) - p_i(0) \| \; C s_i t_r}{s_i - s_j} \tag{20}$$

If $s_j = s_i$, $t = +\infty$

If vehicle i and vehicle j have the inverse driving directions, we have

$$t = \frac{\| p_j(0) - p_i(0) \| + s_i t_r}{s_i + s_j} \tag{21}$$

Scenario seven. As shown in Figure 3(c), the vehicle i drives into the segment inverse with vehicle j after the red phase terminates. If the vehicles j and i have same driving directions,

$$t = \frac{R - \| p_j(0) - p_i(0) \| + s_i t_r}{s_j + s_i} \tag{22}$$

If vehicle j and vehicle i have inverse driving directions,

$$t = \min\left(\frac{\| p_j(0) - p_i(0) \|}{s_j}, \frac{R - \| p_j(0) - p_i(0) \| + s_i t_r}{s_i - s_j} \right) \tag{23}$$

Scenario eight. As shown in Figure 3(d), after the red phase terminates, the vehicle i drives into the segment perpendicular to vehicle j. If the vehicle j is leaving the intersection, we have

$$t = \frac{\sqrt{F - \left(2d_0 + s_j t_r\right) s_i^2 s_j t_r} - s_j d_0 + s_i^2 t_r}{s_i^2 + s_j^2} \tag{24}$$

where $F = \left(s_i^2 + s_j^2\right) R_{NLOS}^2 - s_i^2 d_0^2$.

If vehicle j is driving into the intersection, we have

$$t = \frac{\sqrt{F + \left(2d_0 - s_j t_r\right) s_i^2 s_j t_r} + s_j d_0 + s_i^2 t_r}{s_i^2 + s_j^2} \tag{25}$$

3.2 Link Utility

In the previous section, the paper introduces methods of residual link lifetime prediction in detail. The reliability of the link can be improved with the help of residual link lifetime prediction, but the message dissemination efficiency may be still low. The candidate vehicle with short distance and low relative speed has long link lifetime. If relay vehicles are selected merely based on link lifetime measurement, message dissemination path may be established that consists of vehicles with short distance between adjacent vehicles [11, 15]. The message will be forwarded over much more hops from the source to destination, and message transmission latencies will be increased greatly. The problem may become bad when there is high density of vehicles on the road. In order to improve message dissemination efficiency, greedy algorithms are often used to forward messages in the most of existing works [18-20]. The farthest adjacent vehicles will be selected as relay node to reduce the number of hops. However, the existed methods normally form an unstable link and cannot guarantee transmission reliability.

In fact, information like distance between vehicles, density of vehicle on the road, vehicle speed, are underutilized. In addition to being used to compute link lifetime, these information can also be further mined to build an efficient message dissemination path. In this section, link utility based on the information is proposed to indicate the quality of communication link between vehicles. Then both link lifetime and link utility are taken into consideration in the selection of relay node, so as to realize reliable transmission link and low message dissemination latencies.

The computation of link utility should take into account both reliability and efficiency. Intuitively, there is more communication time when the pair of vehicles drive at close speeds (low relative speed), and if the distance between two relay vehicles is longer the efficiency of message dissemination is higher. The ideal situation is that two vehicles are at the same speed and the distance is the farthest communication range of vehicle. Link utility should be capable of reflecting all of the situations above very well.

Link utility (LU) is a value between 0 and 1. The closer the value of LU is to 1, the better the link quality is. Link with high quality are efficient. When establishing message dissemination path, the priority should be given to those vehicles with high LU. It is indicated that the link has bad quality when LU approaches to 0. Vehicles that have low LU should avoid being selected as relay nodes if possible.

In the paper, LU can be calculated by Eq. (26). From the.formula, we can see that LU is a function of distance between vehicles, traffic density, and vehicle speed. The information needed for link utility calculation can be obtained via periodic information exchange between vehicles. $LU_{i,j}$ denotes the link utility between vehicle i and vehicle j, where vehicle i is message sender and vehicle j is candidate relay vehicle. In the formula, R denotes effective communication range that vehicle can achieve. ρ denotes vehicle density. $\alpha \in (0,1]$ is a parameter used to adjust transmission reliability and forwarding efficiency. $d_{i,j}$ denotes the Euclidean distance between vehicles. Vectors v_i and v_j represent the speed of vehicle i and vehicle j respectively. $\frac{|v_j - v_i|}{|v_i|}$ is relative speed factor, which is used to indicate the effect of vehicle speed on link utility.

$$LU_{i,j} = exp\left\{-\left[\rho\cdot\left(\alpha R - d_{i,j}\right)\right]^2 \cdot \frac{\left|v_j - v_i\right|}{\left|v_i\right|}\right\} \qquad \textbf{(26)}$$

In the following, we will analyze the effects of different parameters on LU. Plots of LU versus the distance between vehicles, $d_{i,j}$, are shown when α, the relative speed factor and vehicle density ρ take different values respectively. Here, the effective communication range, R, is set to 300 meters.

The transmission schemes based on greedy algorithm tend to choose the farthest vehicle in message dissemination direction as relay node. By this way total forwarding hops can be reduced, but it may lead to too large one-hop distance. Although large one-hop distance can improve forwarding efficiency, the quality of wireless link may deteriorate when communication distance is large and propagation loss may increase. And it will degrade the performance indicators like message delivery ratio and delay [2], [21]. Moreover, vehicles situated in the edge of communication range of the sender are more likely to leave the communication region, which thus leads to the link connection failure. So it is necessary to control the one-hop forwarding distance and improve transmission reliability by setting the value of α. Figure 4 shows the tendency of LU for α=0.3, 0.5, 0.7, where the density of vehicle, ρ, is set to 0.04 and the relative speed factor is set to 0.5. From the figure, we can see that when the distance between the candidate relay and the sender approaches to αR, LU increases and the probability that are selected as relay increases. Therefore, the larger the value of α, the further the message can transmit in one hop. On the contrary, lower value of α makes the relay close to the sender. Although it can obtain strong reliability, the hops will increase and the efficiency becomes low. When the value of α approaches to 1, the candidate vehicle that can improve transmission efficiency and reduce end-to-end delay will be selected as relay vehicle to forward messages by LU. When the value of α approaches to 0, LU tends to guarantee reliability. But it needs more vehicles to participate in forwarding message, which increases broadcast redundancy. The value of α is selected according to the needs of practical applications.

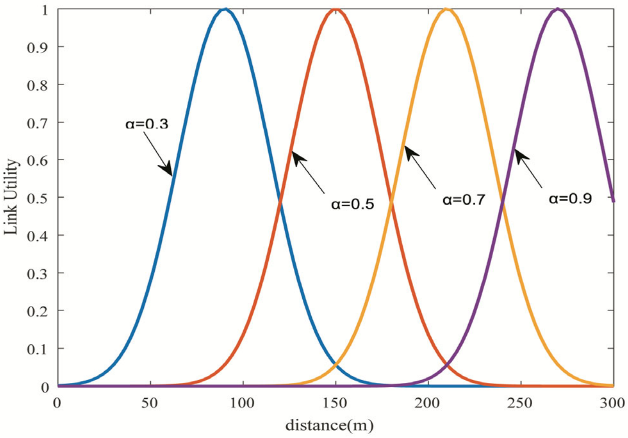


Figure 4. The effect of α on link utility

Figure 5 shows the tendency of LU when Relative Speed Factor (RSF) is set to 0.1, 0.5, 1, 2, respectively. Here vehicle density, ρ is set to 0.04 and α is set to 0.5. Relative speed factor is used to indicate the relative speed between the sender and the candidate relay vehicles. The value of relative speed factor will increase when the relative speed increases. Intuitively, the increase of relative speed will lead to unstable links and increase the risk of link failure. It can be seen from Figure 5, for the same distance, the higher the value of relative speed factor, the lower the LU will be. Low LU will reduce the chance for candidate vehicles to be selected as relay. So vehicle that has low relative speed can be selected to relay message. By doing so, the link reliability can be guaranteed.

Figure 6 shows the effect of vehicle density on link utility, where vehicle density, ρ, is set to 0.02, 0.03, 0.04, 0.05, respectively, α is set to 0.5, and relative speed factor is set to 0.5. From Figure 6 we can see that, when vehicle density has a higher value, the curve of LU becomes steep with regard to distance. While vehicles on the road are sparse the changes of LU are relatively gentle. This design method helps the

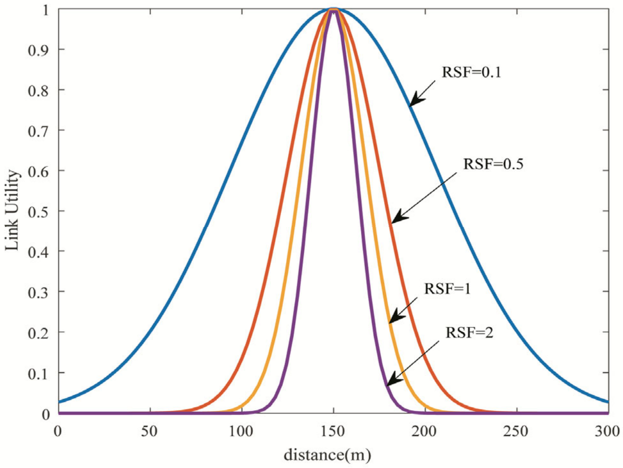


Figure 5. The effect of relative speed factor on link utility

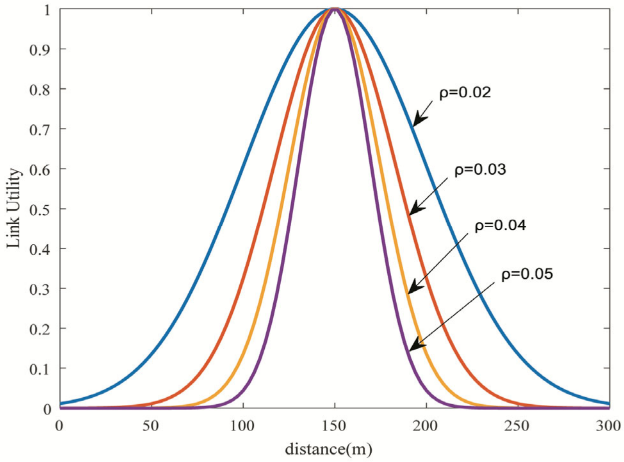


Figure 6. The effect of vehicle density on link utility

message sender to select easily optimal relay vehicle from all the candidates. When there are many vehicles on the road, candidate vehicles increase and the candidate vehicles that have αR distance with the sender also increase. This method can distinguish these candidates very well. Besides, as the distance deviates from αR, the curve of LU falls rapidly and is almost close to 0. When vehicle density is lower, the candidate vehicles distributes sparsely on the road. The slowly declined trend of LU can take more candidate vehicles into consideration.

In the process of selecting relay vehicle, the sender is responsible for calculating link utility of all the candidate vehicles. According to the calculating results, the sender will select the vehicle with the highest LU value as the relay vehicle. If multiple candidate vehicles have the same highest LU value, the vehicle that has further distance with the sender will be selected as relay vehicle. Under the premise of ensuring reliability, higher transmission efficiency can be obtained with the help of link utility.

3.3 Message Dissemination Mechanism

In this section, we will introduce specific message dissemination mechanism. The mechanism mainly relies on residual link lifetime and link utility. Assume that vehicles can easily obtain their own information like location, speed and direction. They will exchange the information by broadcasting periodically beacons between vehicles. Vehicles will maintain neighbor lists, in which vehicle ID, timestamp, location, speed, direction of the neighbor vehicles will be stored. The information will be updated periodically.

When receiving a new message, the vehicle checks whether it was selected as relay vehicle. If the vehicle was selected as relay vehicle, then it enters into the phase of selecting next relay vehicle. If not, it should keep silent and do nothing. Relay selection need to go through the following steps. Firstly, the sender predicts the residual lifetime of link between itself and the neighbor vehicle and selects the neighbor vehicles that have lifetime more than T_{th} as candidate vehicles. Then, the sender calculates the link utility of these candidate vehicles respectively. At last, the sender selects candidate vehicle with highest link utility as relay vehicle. If there are more than one candidate vehicles with the same highest link utility, the sender will select the candidate vehicle furthest from the sender as relay vehicle. If all the neighbor vehicles have residual lifetime less than T_{th}, the sender will carry the message until the sender finds eligible vehicles.

4 Performance Evaluation

Now we will evaluate the performance of the proposed message dissemination scheme by simulation. In this section we will compare our scheme with other three schemes. These three schemes are the followings: (1) classical Flooding routing protocol. Flooding protocol is the most frequently used method in vehicular networks for message transmission. (2) traditional link lifetime-based scheme. Methods in [22] are used to select relay vehicle. The sender will select the neighbor vehicle furthest from itself as the relay vehicle. In the remainder of the paper, we will use lifetime-based scheme to represent the scheme that utilize link lifetime prediction merely and use “lifetime” to represent the scheme in the figure. (3) UV-CAST broadcast scheme [23], a scheme specially for vehicle networks on urban road. In the scheme, a vehicle further from the sender has more chances to be selected as next relay vehicle.

According to different calculation method, our proposed message dissemination scheme can be divided into two types: (1) link utility scheme (LU), the scheme that use both link lifetime prediction and basic link utility calculation; (2) enhanced link utility scheme (LU-E), the scheme that use both link lifetime prediction and enhanced link utility calculation. Different from basic LU scheme, the LU-E scheme takes advantage of two-hop neighbor information. Methods of calculating enhanced link utility are detailed in our previous works [24].

In the simulation, three performance indicators are used to evaluate the performance of the schemes.

(1) Message Coverage Ratio (MCR): ratio of the number of vehicles that have received message successfully to the number of all the vehicles in targeted areas. MCR is a key indicator to reflect transmission reliability.

(2) Average Delay (AD): the average time taken for a message to be transmitted from message source to the last vehicle to receive the message in targeted areas. AD can indicate the message dissemination efficiency.

(3) Forwarding Node Ratio (FNR): ratio of the number of relay vehicles to the number of all the vehicles in the targeted areas. FNR is used to indicate the overheads of message dissemination. More relay vehicles that participate in forwarding message mean lager message dissemination overheads.

4.1 Simulation Settings

Performance of the proposed scheme is evaluated with OMNeT++ simulator [25]. The mobility pattern is obtained from SUMO [26]. In the simulation, Manhattan mobility model is used. Vehicles move in an area of 2000*m**2000*m* for a period of 100 seconds. The area presents a grid layout and consists of four horizontal roads and four vertical roads. The maximum vehicle speed is set to 15*m/s*. Default vehicle density is set to 40 vehicles per kilometer.

All vehicles have the same transmission rate, 6Mbps, and the same communication range, 300*m*. Default size of the packet is set to 512 bytes. The interval of generating packets is set to 0.2*s*. Source vehicle is selected randomly and the destination is all other vehicles in the area. At the intersection messages are forwarded according to the following rules. Relay vehicle divided neighbor vehicles into different groups based on the road where they situated. Then relay vehicle selects one vehicle from each group respectively as next relay vehicle. Each plotted point is averaged over 10 runs at 95\% confidence intervals. More details of the parameters are summarized in Table 1.

4.2 Results Analysis

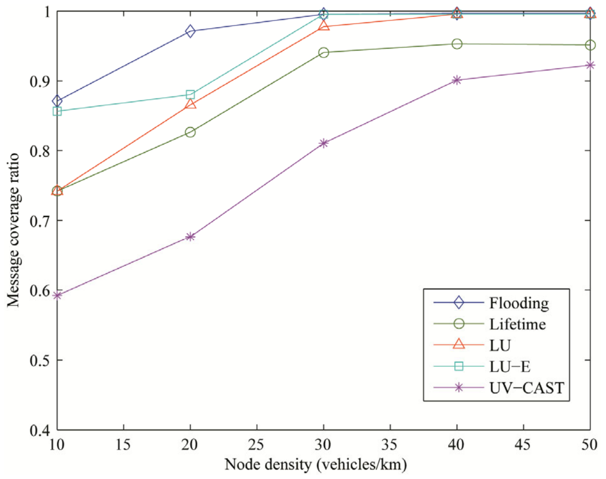
4.2.1 Message Coverage Ratio

In this section, we compare the performance of our proposed schemes with Flooding, lifetime-based scheme, UV-CAST in terms of message coverage ratio and examine how it is affected by vehicle density and vehicle speed.

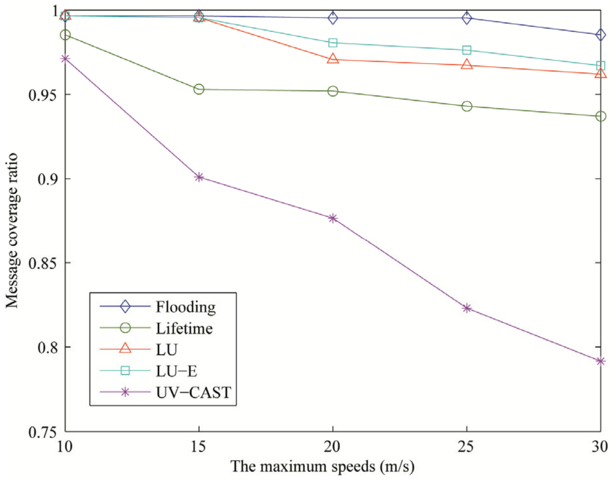
Table 1. Simulation parameters

Parameters	Values
network size (km$_2$)	2 X 2
mobility model	Manhattan
simulation time (s)	100
MAC	IEEE 802.11p
communication range (m)	300
vehicle density (vehicles/km)	10, 20, 30, 40(default), 50
maximum vehicle speed (m/s)	10, 15(default), 20, 25, 30
data transmission rate (Mbps)	6
packet size (bytes)	512
packet transmission intervals (s)	0.2
link lifetime threshold (ms)	100
default α value	0.7
ω_l ω_n	0.6, 0.4

Figure 7(a) shows the effect of vehicle density on MCR. The maximum vehicle speed is set to the default value, 15*m/s*. The vehicle density is set to 10, 20, 30, 40 and 50 respectively. The unit is vehicles per kilometer. As shown in the figure, the Flooding scheme always keeps high MCR. LU scheme and LU-E scheme can reach MCR close to the Flooding scheme. When the vehicle density varies from 30 to 50 vehicles per kilometer, the MCR of all previous three schemes is larger than 97\%. The UV-CAST scheme does not take link reliability into consideration in relay selection and packets loss is more likely to happen in message dissemination, so the UV-CAST has the lowest MCR in all schemes. When there is a low vehicle density (10 vehicles per kilometer), MCR of the LU scheme and LU-E scheme increase by about 26.5\% and 15.1\% respectively comparing with the UV-CAST scheme. From the figure we can see, when vehicle density is low, the LU scheme has similar MCR with the lifetime-based scheme. However, as the vehicle density increase, MCR of the LU scheme increases higher. The main reason is that large vehicle density brings more candidate vehicles and it will increase the chance of selecting more robust and effective relay vehicles. Compared with traditional lifetime-based scheme, the LU scheme and LU-E scheme adopt scenario-awareness link lifetime prediction method. Thus they are capable of adapting well to complicate urban road environment and can increase the MCR by 4.1\%-11.5\%. Besides, we also can find that the LU-E scheme can provide higher MCR than the LU scheme when vehicle density is low. The reason is that, when vehicles on the road are sparse, the provision of two-hop link state information can further guarantee the reliability of message dissemination. As vehicle density increases, the number of eligible vehicles also rises and this advantage is no longer obvious.



(a) Node desity



(b) Vehicle speed

Figure 7. The effect of node density and speed on message coverage ratio

Figure 7(b) shows the effect of vehicle speed on MCR. In the simulation, the vehicle density is set to 40 vehicles per kilometer and the maximum vehicle speed is set to $10m/s$, $15m/s$, $20m/s$, $25m/s$ and $30m/s$ respectively. As the maximum speed increases, the difference of speed between two vehicles also increases, which leads to the large fluctuation range of the relative speed. In the figure we can see that the vehicle speed variation has a little influence on the flooding scheme. However, the flooding scheme obtains high MCR at the expense of large network overheads. The LU scheme and LU-E scheme can also provide high MCR (reaching 96\%). The speed variation has less influence on these two schemes because of the consideration of speed factor in residual link lifetime prediction and link utility calculation. The MCR of the UV-CAST scheme decreases apparently when the maximum vehicle speed increases. In the process of relay selection, the UV-CAST scheme only takes distance into consideration and does not pay attention to vehicle speed, which leads to fragile link under the circumstances of large relative speed. Our proposed scheme has advantages in dealing with large difference of the vehicle speed and can achieve high MCR. In addition, owning to considering two-hop link utility, the LU-E scheme have better performance than the LU scheme in the aspect of coping with speed difference.

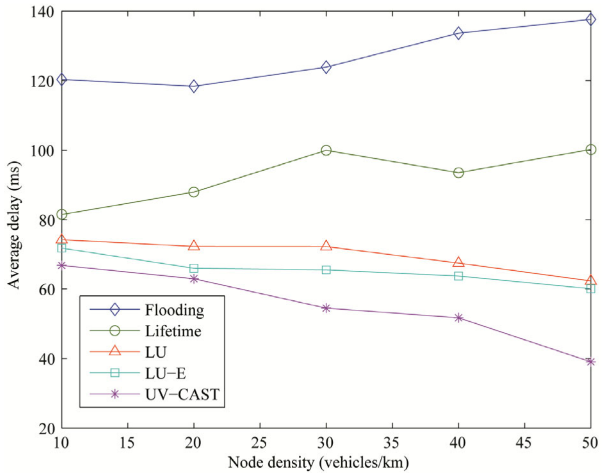
4.2.2 Average Delay

In this section, we will evaluate the performance of different schemes in terms of average delay. Figure 8(a) shows the effect of vehicle density on average delay. With the increase of vehicle density, the average delay of all schemes except flooding decreases. As the number of vehicles increase, the chance that finds optimal relay vehicle becomes larger accordingly. From the figure we can see that the average delay of three schemes that use residual link lifetime prediction is below the average delay of the flooding scheme but above the average delay of the UV-CAST scheme. In the flooding scheme, all vehicles involve in relaying messages, which causes serious channel contention. Therefore, the flooding scheme has low transmission efficiency and high average delay. The UV-CAST scheme always selects the farthest neighbor vehicle as relay vehicle and thus has lower average delay. Because of striving merely for link reliability and thus resulting in shorter one-hop forwarding distance, the traditional lifetime-based scheme leads to lower transmission efficiency and higher average delay. The LU scheme and LU-E scheme present low average delay by taking transmission efficiency factor into consideration. Compared with traditional lifetime-based scheme, the average delay of LU and LU-E scheme declines by 9.0\%-27.8\%. From the above discussion, we can see that our proposed scheme obtains high link reliability by sacrificing transmission efficiency to a certain extent, but it just brings a little influence on average delay.

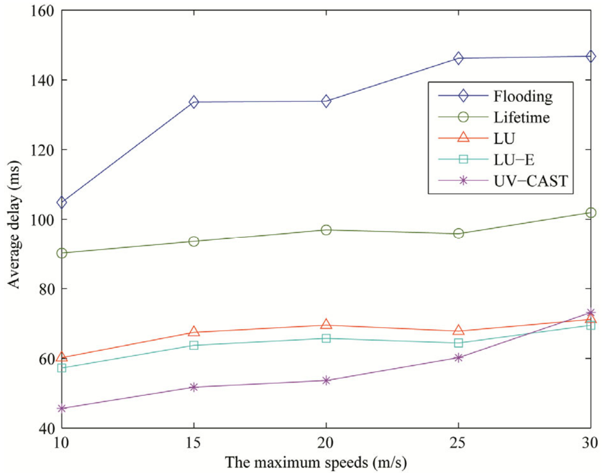
Figure 8(b) shows the effect of vehicle speed on average delay. Compared with other schemes, the LU scheme and LU-E scheme can achieve lower average delay. Under the circumstance of large difference of vehicle speeds, the LU-E scheme can decrease average delay by 31.9\% compared with traditional lifetime-based scheme. So the LU-E scheme can better adapt to the networks that the speeds of vehicle are extremely diverse.

4.2.3 Forwarding Node Ratio

In this section, the FNR of different schemes will be discussed. Figure 9(a) shows the effect of vehicle density on FNR. In the figure, the FNR of the flooding scheme is close to 100\% because the principle of flooding scheme is that every node in the networks forwards message. Because of adopting different



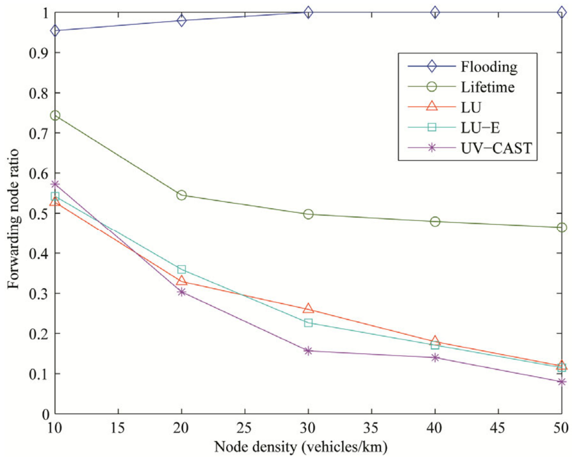
(a) Node density



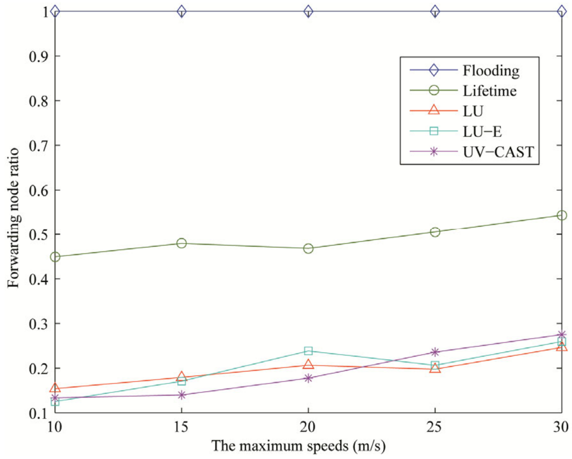
(b) Vehicle speed

Figure 8. The effect of node density and speed on average delay

method to select relay vehicle, other schemes have lower FNRs. And as vehicle density increases, the FNR decreases. Compared with traditional lifetime-based scheme, the LU scheme and LU-E scheme have lower FNRs. When the vehicle density is high (50 vehicles per kilometer), the FNR can decrease by 75\%. The reason is that, besides considering residual link lifetime prediction, the LU scheme and LU-E scheme pay attention to transmission efficiency and take link utility as one of the factors to select relay vehicle. One-hop distance can be controlled effectively and thus the sender can select further neighbor as next relay vehicle, which reduces the number of relay vehicles from source to destination. Moreover, the LU-E scheme has similar FNR with the LU scheme. The introduction of two-hop neighbor information is mainly for improving transmission reliability, so it does not exhibit obvious effect on the FNR.



(a) Node density



(b) Vehicle speed

Figure 9. The effect of node density and speed on forwarding node ratio

Figure 9(b) shows the effect of vehicle speed on FNR. As the vehicle speed increases, the FNR increases. Large difference of vehicle speed will lead to unstable transmission link. To obtain reliable transmission link, the LU scheme and LU-E scheme may select closer vehicle to forward message, which will result in high FNR. But the FNR can still remain low and is no more than 26\%.

4 Conclusion

In the paper, we study the problem of message dissemination in vehicular networks for urban road environment. We propose a reliable and efficient message dissemination mechanism on the basis of residual link lifetime and link utility. Methods of residual link lifetime prediction are given taking into account the diversity of urban roads and traffic lights. The quality of the link is measured by link utility. Our proposed mechanism is compared with existing schemes via OMNeT++ simulation. Simulation results show that the proposed mechanism can achieve high message dissemination efficiency on the premise of guaranteeing reliability.

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