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A Link Quality Prediction Metric for Location based Routing Protocols under Shadowing and Fading Effects in Vehicular Ad Hoc Networks

Chi Trung Ngo[a], Hoon Oh[a,*]

[a]*Department of Electrical and Computer Engineering, University of Ulsan, P.O. Box 18, Ulsan 680-749, Republic of Korea*

Abstract

The location-based routing protocol has been chosen as one of the efficient routing approaches in vehicular ad hoc networks in terms of low overhead and high scalability. Its critical advantage lies in performing a pathless routing such that a node having a packet forwards it to its neighbor node that provides the shortest physical distance to destination and this process continues until the packet reaches destination. The problem lies in that the link stability of the neighbors varies largely depending on the mobility of vehicles and the environmental factors that incur shadowing and fading effects. In this paper, we propose a new link quality prediction metric associated with location based protocols to improve the selection of next hop, that consider both the link quality assessment based on the transmission success rate and the link quality assessment based on the prediction of the future locations of vehicles. Simulation results are presented to demonstrate the efficiency of the proposed metric.

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Keywords: Location based Routing Protocol; Link Quality; Forwarding Progress Distance, Vehicular Ad Hoc Networks

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1. Introduction

Over the last two decades, much attention has focused on the application of mobile ad hoc network (MANET) technology to the Vehicular Ad Hoc Networks (VANETs) that consists of vehicles (nodes) with high mobility. The routing protocols designed for MANETs were tried for their application to VANETs with evaluation[1],[2]. However, the effectiveness of those trials was limited due to the unique characteristics of VANET such as high node mobility, movement constraints, the mobility pattern of vehicles, and the road conditions with high building forest. Some location based routing protocols such as the GPSR[3], the CFG[4], and the GOAFR[5] tried to overcome these limitations. In these approaches, each node periodically broadcasts a hello message that includes its node identification number and the geographic location to its neighbors. Then, every node can maintain the geographical location information of its neighbors.

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[*] Corresponding author. Tel.: +82-52-259-1257.
E-mail address: chitrung218@gmail.com (Chi Trung Ngo), hoonoh@ulsan.ac.kr (Hoon Oh)

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Based on the geographical location information, a node having data packet chooses a neighbor node which provides the shortest physical distance to destination as next hop and then forwards the packet to the selected node. However, because of node mobility and hello interval, the selected node may have moved out of the transmission range of a sender, thereby breaking the corresponding link. One simple way of improving this problem is to decrease the hello interval so that every node can maintain more accurate motion information for its neighbors; however, it will increase control overhead. In addition, a link can be broken temporally due to variation of environmental factors such as path loss, shadowing and multipath fading. Consequently, if the next hop selection process does not take link quality into account, a forwarding node may frequently fail to forward a packet to the selected neighbor. As a result, a forwarding node may have to select next hop multiple times before forwarding data packet. Sometimes, it may exclude some node with a good link quality. This will degrade network throughput and increase packet end-to-end delay.

To resolve the two above mentioned problems, we propose a new link prediction metric that considers two link quality evaluation techniques - the past link quality is obtained from the link quality assessment based on the success rate of packets and the future link quality is obtained from the link quality assessment based on the prediction of the future locations of nodes. Then, next hop is selected by applying the combined link quality metric to each forwarding node. The past link quality is given in terms of the *Expected Transmission Count* (ETX) that indicates how many retransmissions have to be made before a forwarding node forwards a packet to next hop successfully. Whereas, the future link quality is given in terms of the *Predicted Forwarding Progress Distance* that is determined by the relative locations of a forwarding node and next hop. The mobility prediction mechanism[6] is employed to predict the future locations of a forwarding node's neighbors based on the motion information included in the last hello messages. Then, a node which is predicted to stay in the transmission range of the sender and has a good link quality will be given higher priority to be chosen as next hop.

The rest of the paper is organized as follows. In Section 2, we briefly review a radio propagation model. Then, we present some works related to link quality estimation and forwarding progress distance and describe a new quality metric in Section 3. In Section 4, the performance of the proposed approach is compared with those of some popular approaches. Finally, we make concluding remarks in Section 5.

2. Radio Propagation Model

The radio propagation model is used to predict the average signal strength at a given distance from a transmitter. Each radio propagation model of mobile radio system must reflect the effects of path loss, shadowing and multipath fading. While the path loss predicts the decay of the received power as a function of the distance between a transmitter and a receiver, and sometimes includes the effect of the antenna gains, the shadowing model considers effects of surrounding obstacles on the mean signal attenuation at a given distance. The multipath fading is caused by interference between multiple versions of the transmitted signal which arrive at a receiver at slightly different times.

In this paper, the *Groud Reflection* (2-ray) is used to model the path loss. This model is based on geometric optics and considers both direct path and a ground reflected propagation path between a transmitter and a receiver. The 2-ray path loss model is expressed in dB as follows[7].

$$PL(dB) = 10\log\left[\frac{d^4}{{h_t}^2{h_r}^2}\right] \tag{1}$$

where, h_t is the transmitter antenna height, and h_r is the receiver antenna height.

In addition, the log-normal distribution with a zero mean and a standard deviation σ describing the shadowing in dB is employed to model effects of shadowing. Therefore, taking into account the shadowing effects, the path loss of a transmitted signal at an arbitrary distance d in the far field region of the transmitter ($d > d_f$) is expressed as follows[7].

$$PL(d) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \tag{2}$$

where, $PL(d_0)$ is the path loss in dB at a reference distance d_0, n is the path loss exponent, and X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ

With the multipath fading model, we use the *Rician*, which is applicable when one of the signal paths, typically a line-of-sight signal dominates the others. The *Rician* distribution is given as follows[7]

$$pdf(r) = \begin{cases} \frac{r}{\sigma^2} exp(-\frac{r^2+A^2}{2\sigma^2}) I_0(\frac{Ar}{\sigma^2}) & (A \geq 0, r \geq 0) \\ 0 & (r < 0) \end{cases} \tag{3}$$

where, r is the received signal envelope voltage; the parameter A denotes the peak amplitude of the dominant signal and $I_0(.)$ is the modified Bessel function of the first kind and zero-order. The *Rician* distribution is often described in terms of a parameter K which is defined as the ratio between the deterministic signal power and the variance of the multipath. K is given in terms of dB as follows.

$$K = 10 \log \frac{A^2}{2\sigma^2}$$

3. A New Link Metric for Selecting a Next Hop Node in Location-based Routing Protocol

3.1. Link Quality Estimation

In order to measure the quality of a link, we want to obtain the *expected transmission count* (*ETX*) defined as the expected number of transmissions to successfully deliver one data packet to a receiver on the given link. Since data transmission is successful only if a sender receives acknowledgement (ACK) from a receiver after transmitting data packet, we need to consider the bidirectional stability of a link.

Let $ETX(x, y)$ denote the ETX of a link between node x and node y. Then, $ETX(x, y)$ is given as follows.

$$ETX(x, y) = \sum_{i=1}^{\infty} i \times p_f(x, y)^{i-1} \times p_s(x, y) = \frac{1}{(1 - p_f(x, y))^2} \times p_s(x, y) = \frac{1}{p_s(x, y)} = \frac{1}{d_f(x, y) \times d_r(x, y)} \tag{4}$$

where, $d_f \times d_r$ is the measured success probability of data transmission, d_f is the forward delivery ratio that is defined as the ratio of the number of Hello's that node y has received successfully to the number of Hello's that node x has transmitted, and d_r is the reverse delivery ratio on the same link.

In this paper, d_f and d_r are measured using the Hello message that each node broadcasts at regular intervals, which is structured as follows.

Hello = (*NodeId*, *Pos*,*Speed*, *Dir*, *HHT*(*x*)): *HHT*(*x*), the hello history table of node *x*, indicates the number of Hello messages that node *x* has received from each of its neighbors within the specified time window. *Pos*, *Speed* and *Dir* indidate the postion, the speed, and the moving direction of a sender node, respectively.

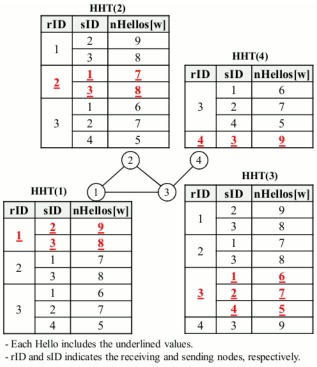
Each node counts the number of Hello's received from its neighbors during the last w seconds. In the Hello message, $HHT = \{i, y, nHellos(t - w, t) \mid y \in N[i], i \neq y\}$ where, $nHellos(t - w, t)$ or shortly $nHellos[w]$ indicates the number of Hello's that node i has received from node y within the last w seconds. In figure 1, HHT(2) = {(2, 1, 7), (2, 3, 8)}. Then, every node i can maintain a hello history table, $HHT = \{x, y, nHellos(t-w, t) \mid x \in N[i], y \in N[x], x \neq y\}$. From this table, we can obtain d_f and d_r at time t as follows.

$$d_k = \frac{nHellos(t - w, t)}{{}^{w}/_{\tau}}, k = f \text{ or } r \tag{5}$$

where, τ is the time interval of Hello. Fig. 1 gives an example of HHT's in the network of four nodes when $\tau = 1$ second. Based on the counted values, node 1 can obtain ETX(1, 2)=1.587, ETX(2, 3)=1.785 and so on.

3.2. Predicted Forwarding Progress Distance

In order to minimize the number of hops data packet will travel to a destination, we also consider the forwarding progress distance of a node when selecting a next hop. Given a transmitting node x, the forwarding progress distance of a candidate node y to destination D is defined as the projection onto the line connecting x and D. The packet is forwarded to a neighbor whose progress is maximal. However, in order to adapt the high node mobility in vehicular



HHT(2)

rID	sID	nHellos[w]
1	2	9
	3	8
2	1	7
	3	8
3	1	6
	2	7
	4	5

HHT(4)

rID	sID	nHellos[w]
3	1	6
	2	7
	4	5
4	3	9

HHT(1)

rID	sID	nHellos[w]
1	2	9
	3	8
2	1	7
	3	8
3	1	6
	2	7
	4	5

HHT(3)

rID	sID	nHellos[w]
1	2	9
	3	8
2	1	7
	3	8
3	1	6
	2	7
	4	5
4	3	9

- Each Hello includes the underlined values.
- rID and sID indicates the receiving and sending nodes, respectively.

Fig. 1. An example of hello history tables

Fig. 2. The street map of New York City

environment we compute the *predicted forwarding progress distance* (PPD) of a candidate node based on its predicted position at the moment of data forwarding.

$$PPD(x,y) = \begin{cases} 0 & , d(x,D) - d_{pre}(y,D) > r \\ \frac{d(x,D)-d_{pre}(y,D)}{r} & , \text{otherwise} \end{cases}$$

where, $d(x, D)$ and $d_{pre}(y, D)$ denote the distance between node x and destination D, and the distance between the node y and destination D based on the predicted position of node y, r is the transmission range of a node.

Here, we apply the mobility prediction model proposed in[6]. Assuming that node i records some motion information such as the coordinate (x_j, y_j), the speed v_j, and the moving direction θ_j of node j at time t, then node i can predict the coordinate $(x_j^{'}, y_j^{'})$ of node j after $\Delta_t = t^{'} - t$ as follows.

$$x_j^{'} = x_j + \Delta_t \times v_j \times \cos\theta_j \text{ and } y_j^{'} = y_j + \Delta_t \times v_j \times \cos\theta_j$$

3.3. A Link Quality Prediction Metric

In order to cope with the rapidly varying mobility (i.e., high acceleration and deceleration) of vehicles as well as the effects of shadowing and multipath fading, we introduce a new formula to evaluate the link quality of a link (x, y) when node x has to choose a next forwarding node among its neighbors as follows

$$LQ(x,y) = f(ETX(x,y), PPD(x,y)) = \alpha \times LQ^p(x,y) + (1-\alpha) \times LQ^f(x,y) \tag{6}$$

where, $0 \le LQ^p(x,y), LQ^f(x,y) \le 1$. $LQ^p(x,y)$ indicates the past link quality, while $LQ^f(x,y)$ indicates the future link quality. α is the weight factor between the past and future link quality. Thus, $LQ(x,y)$ is given the arithmetic mean of both link qualities. From previous discussion, we get $LQ^p(x,y)$ and $LQ^f(x,y)$ as follows.

$$LQ^p(x,y) = \frac{1}{ETX(x,y)} \text{ and } LQ^f(x,y) = PPD(x,y)$$

Based on the link quality prediction metric LQ, a forwarding node will select a node among its neighbors with the highest link quality as a next forwarding node.

4. Performance Evaluation

4.1. Simulation Setup

We used a commercial network simulator, QualNet 5.02 to evaluate the performance of the proposed approach. The traffic model was generated by traffic simulator VanetMobiSim, which produces the mobility traces for some

Table 1. Simulation Parameters

Parameter	Value	Parameter	Value	Parameter	Value
Dimension	1500×1500 m^2	Fading	Rician (K=3)	Data rate	5 pkts/s
Simulation time	600 seconds	MAC protocol	802.11b	Path loss	2-Ray
Transmission range	250 m	Wireless bandwidth	2 Mbps	Shadowing	Log-normal
Data type	CBR	Maximum speed	40 m/s	Number of Nodes	150 nodes
Data packet size	512 bytes	Desired speed	20 m/s	Hello interval	1 second

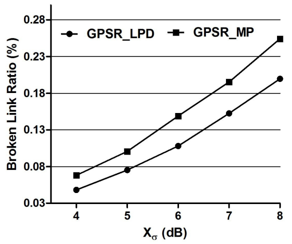


Fig. 3. Broken link ratio of GPSR_LPD and GPSR_MP with varying X_σ

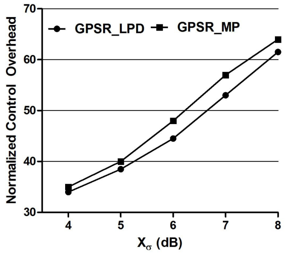


Fig. 4. Normalized control overhead of GPSR_LPD and GPSR_MP with varying X_σ

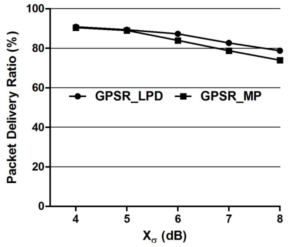


Fig. 5. Packet delivery ratio of GPSR_LPD and GPSR_MP with varying X_σ

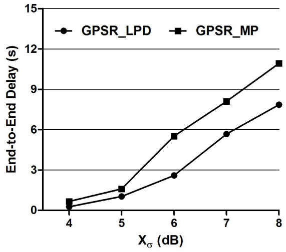


Fig. 6. End-to-end delay of GPSR_LPD and GPSR_MP with varying X_σ

network simulators such as Qualnet, ns-2 and GlomoSim. We also used the real map of the urban area of 1500 x 1500 (m^2) as shown in figure 2.

The proposed link prediction metric was applied to routing protocol GPSR[3], named GPSR_LPD, and then was compared with GPSR_MP which was an improvement of GPSR when applied the mobility prediction[8]. We assessed the performance of protocols under different effect level of shadowing and fading by changing the value zero-mean Gaussian distributed random variable X_σ (in dB) defined in Eq.2 in shadowing model from 4 to 8 dB. Due to the space limitation we can not show all simulation results to verify variations of α, thus the value of $\alpha = 0.6$, giving the best performance, is fixed in the simulation to compare with GPSR_MP. The rest of simulation parameters are listed in table 1. In addition, the performance metrics such as *Packet Delivery Ratio*, *End-to-end delay*, *Broken Link Ratio* and *Normalized Control Overhead*, are used for evaluation. We note that control packets include Hello message, RTS, CTS and ACK.

4.2. Simulation Results

Figure 3, 4, 5 and 6 show the broken link ratio, the normalized control overhead, the packet delivery ratio and the end-to-end delay with varying the value of X_σ. In general, the broken link ratio of two protocols increases according to the increase in X_σ which is shown in figure 3 since the more value of X_σ is, the more shadowing effects the transmitted signal suffers from. However, GPSR_MP incurs more broken link ratio than GPSR_LPD. This is because in GPSR_MP a node chooses next node based on the predicted physical distance without taking the link quality into account. The increase in broken link ratio translates to the increase in normalized control overhead. The explanation for this is that for any successful data packet retransmission, it requires the resending of RTS from a sender and CTS and ACK from a receiver, thereby increasing the normalized control overhead (figure 4)

It can be seen that GPSR_LPD achieves better packet delivery and end-to-end delay than GPSR_MP with the increase in shadowing effect (figure 5 and figure 6). The improvement can be explained as follows. According to the IEEE 802.11 MAC protocol, after a sender sends a packet to a receiver, the sender waits for ACK from the receiver to certify the successful transmission. If it does not receive ACK for some time, it retransmits the packet and gives up the attempt when reaching the maximum number of retransmissions. The packet retransmission not only increases contention delay, processing delay, transmission delay and propagation delay, but also wastes the wireless bandwidth since some control messages such as RTS, CTS and ACK in MAC protocol are retransmitted. Consequently, the more retransmissions a packet experiences, the more end-to-end delay it incurs. Therefore, GPSR_LPD with less number of packet retransmissions achieves better end-to-end delay and packet delivery ratio than GPSR_MP.

5. Conclusion

In this paper, we proposed a link quality prediction metric for next hop selection in the location based routing protocol under shadowing and fading effects in VANETs. The link quality prediction metric combines both past and future link quality in which past link quality is evaluated through *Expected Transmission Count*, while the future link quality is assessed via the *Predicted Forwarding Progress Distance*. Simulation results demonstrated that the proposed metric applied to GPSR can reduce control overhead and broken link ratio, and improve the packet delivery ratio and the end-to-end delay considerably.

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