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An Adaptive Link Quality Based Safety Message Dissemination Scheme for Urban VANETs

Xinming Zhang, *Member IEEE*, Qingliang Miao, and Yongzhen Li

***Abstract*—In urban vehicular ad hoc networks (VANETs), signal propagation experiences severe attenuation from obstacles especially at intersections. Multi-hop broadcast schemes are often used to disseminate safety messages to Region of Interest (RoI). However, existing multi-hop broadcast schemes either neglected the impact of realistic physical channels or just considered part of it. In this letter, we propose a link quality based safety message dissemination scheme for urban VANETs. A comprehensive physical channel connectivity calculation method is proposed for accurately estimating the connectivity probability among vehicles. A score-based priority allocation mechanism for candidate forwarders (CFs) is proposed to coordinate the contention among CFs. Finally, we calculate the minimum waiting time and contention window size for each vehicle in CFs. Simulation results show that our proposed scheme outperforms existing multi-hop broadcast schemes for urban VANETs.**

***Index Terms*—Link quality, safety message dissemination, vehicular ad hoc networks**

I. Introduction

A large number of applications in vehicular ad hoc networks (VANETs) rely on vehicle-to-vehicle (V2V) communication. These applications range from safety to traffic management and entertainment [1]. Traditional V2V communication in VANETs works in the 5.9GHz band, which is known as the dedicated short-range (DSRC) frequency band. In this letter, we mainly focus on the safety message dissemination in DSRC frequency band.

In order to disseminate safety messages, plenty of protocols have been proposed. Depending on whether the network forms clusters or not, existing safety message dissemination protocols can be classified as cluster-based and noncluster-based schemes. In cluster-based protocols, like [2], vehicles have to elect cluster head and exchange extra control packets to maintain the stability of clusters, which may increase the network overhead. In noncluster-based schemes [3], according to whether the forwarding decision is made at the receiver or sender, the protocols can further be categorized into receiver-oriented and sender-oriented. In receiver-oriented schemes, when candidate forwarders (CFs) receive messages from the current forwarder, they will contend to forward the message in a distributed manner. However, in sender-oriented schemes, the current forwarder assigns the forwarding priority of CFs in a global manner, in which, based on the receiving neighbor information, the current forwarder piggybacks the decision in the original message to CFs. After the CFs receiving the broadcast packets, they determine their rebroadcast order according to the pre-defined decision, which reduces the collision among CFs to a great extent.

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The authors are with the School of Computer Science and Technology, University of Science and Technology of China, Hefei, 230027, P. R. China, and the National Mobile Communications Research Laboratory,Southeast University, Nanjing 210096, P. R. China (e-mail: xinming@ustc.edu.cn; qlm2016@mail.ustc.edu.cn; lyznk@mail.ustc.edu.cn).

Recently, there are two state-of-art sender-oriented broadcast schemes which consider different factors being proposed. First, Yoo *et al.* [4] analyzed the empty space problem in most existing multi-hop broadcast protocols and proposed a robust and fast forwarding protocol (ROFF). ROFF allows candidate forwarders to set vehicular waiting time inversely proportional to their forwarding priorities which are related to spatial distribution of vehicles. Afterwards, Rehman *et al.* [5] proposed an adaptive relay nodes selection scheme (BDSC) which tried to balance estimated link quality and distance when assigning priority of CFs. However, the link quality estimation in BDSC [5] is calculated by successfully received *HELLO* packets over a pre-defined duration, which just reflects the average link quality among vehicles in a large time scale, ignoring the dynamic nature of channels in the small time scale.

In this letter, we propose a link quality based safety message dissemination (LQBD) scheme for urban VANETs. We not only consider the free space path loss, but also take signal shadowing and fading effect into account. In contrast to BDSC [5], we build a comprehensive channel model taking more granular information about physical channel into account. LQBD tries to give priorities to vehicles with better physical channels and farther distances to current forwarder in directional broadcast. However, with regard to broadcast at intersection, the current forwarder assesses the average channel environment firstly before deciding how to assign priorities of vehicles in CFs. The contributions of this letter are as follows: First, we propose a comprehensive physical channel connectivity calculation mechanism for estimating the connectivity probability among vehicles. Second, based on the metric which considers the link quality and distance, we propose a score-based priority allocation mechanism for CFs to coordinate the contention among vehicles and calculate the minimum waiting time and contention window size for each vehicle in CFs.

The rest of this letter is organized as follows. Section II introduces the system model. Section III describes the detail of our proposed protocol. Simulation results are presented in Section IV. Finally, we make the conclusion in Section V.

II. System Model

A. Network Model and Assumption

We assume that the network is two-dimensional and each street consists of multi-lanes with opposite directions. Each vehicle carries a Global Positioning System (GPS) and a digital map. The vehicles can easily know their own positions,

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directions, velocities and the surroundings from these devices. The beacon packets are exchanged periodically among vehicles and the vehicles can also obtain the information of their neighbors from the beacon packets. All vehicles have the same transmission power or the same communication ranges in free space propagation, and the range is denoted as *R*.

B. Physical Channel Connectivity

In this subsection, we characterize the connectivity of physical channel in urban VANETs. Due to the complexity of urban environment, buildings, mobile vehicles, parked vehicles and so on all have a significant impact on signal propagation. In order to precisely reflect signal propagation characteristics, we not only consider large scale distance dependent path loss, but also take mesoscale radio shadowing effect and small scale signal fading into account.

First, we directly cite the results in Ref. [6] to reflect the free space path loss as follows:

$$L_{free}[dB] = 10lg(\frac{16\pi^2 d^\alpha}{\lambda^2}), \tag{1}$$

where d is the distance between the sender and the receiver, α is the path loss exponent and λ is the wavelength.

Second, we mainly consider two types of obstacles in urban environment: static and moving obstacles in which the corresponding representatives are buildings and moving vehicles. The model of radio signal shadowing caused by buildings is cited from Ref. [1] which only relies on building outlines. Power loss that signal penetrates buildings from source to destination is estimated as:

$$L_{obs}[dB] = \beta n + \gamma d_m, \tag{2}$$

where *n* represents the times of light of sight of the sender and the receiver having intersected with walls and d_m is the total length of the obstacle's intersections. In addition, β and γ are empirical parameters, generally β = 9.6dB/wall and γ = 0.45dBm^{-1}.

The calculation of power loss by moving vehicles in Ref. [1] applies a *multiple knife edge method*:

$$L_{vehicle}[dB] = L_M[dB] + L_{M'}[dB] + L_c[dB], \tag{3}$$

where L_M is power loss caused by *major* vehicles, such as trucks, $L_{M'}$ is power loss due to *minor* vehicles for each adjacent pair of *major* vehicles and L_c is a correction term.

Therefore, we obtain the receiver power as follows:

$$\begin{aligned} P_r[dBm] =& P_t[dBm] + G_t[dB] + G_r[dB] \\ &- L_{free}[dB] - L_{obs}[dB] - L_{vehicle}[dB]. \end{aligned} \tag{4}$$

When we consider signal fading in small scale, *Nakagami-m distribution* is a suitable model. Simply, we get the successful transmission probability of a packet between the sender V_s and the receiver V_r under the *Nakagami-m distribution* [7] as follows:

$$Pr_{s,r} = 1 - F_d(R_T; m, \omega), \tag{5}$$

where $F_d(R_T; m, \omega)$ is the cumulative distribution function (CDF) of the received signal amplitude R_T, and *m* is the fading parameter, ω is an averaged reception power which can be obtained from Eq.(4). Thus, we obtain the successful transmission probability on link $L_{s,r}$ as $Pr_{s,r}$, which reflects the probability of physical channel connectivity.

III. Protocol Design

Our proposed safety message dissemination mechanism is a sender-based protocol and varies according to the position of the current forwarder. When the current forwarder is in a street, it selects the vehicles in message propagation direction of current forwarder as CFs. However, when the current forwarder enters crossroad region where the messages need to be disseminated to all other branches, it estimates the average channel environment (ACEN) firstly before allocating priorities to vehicles in CFs. If the ACEN is good enough, the current forwarder selects CFs at each branch respectively. If this condition is not met, but there are road side units (RSUs) or vehicles inside the crossroad, they will be selected as CFs. Otherwise, the current forwarder enters Store-Carry-Forward mode. This process is summarized in Algorithm 1, where the most expensive step is to calculate the link quality between the current forwarder and CFs when assigning priorities of vehicles. Compared with the situation where the current forwarder is in a street, the current forwarder needs to spend extra time calculating the power loss caused by the buildings when it is near an intersection.

Algorithm 1 The Safety Message Dissemination Scheme

if The current forwarder is in a street **then**
  $CFs \leftarrow$ vehicles in message propagation direction;
  Assign priorities of vehicles within CFs.
end if
if The current forwarder enters crossroad region **then**
  if ACEN is Good **then**
    $CFs_i \leftarrow$ vehicles in branch *i*;
    Assign priorities to vehicles in CFs_i respectively.
  else
    if There are RSUs or vehicles inside the crossroad **then**
      Forward messages to RSUs or vehicles closest to the intersection;
    else
      Enter Store-Carry-Forward mode.
    end if
  end if
end if

A. Forwarding Priority Allocation

When the current forwarder is in a street, we design the following metric which jointly considers physical channel connectivity and distance to assign priority to V_j within CFs.

$$Score_j = \eta \frac{d_{jc}}{R} + (1 - \eta) Pr_{c,j}, \tag{6}$$

where $Score_j$ represents the score of V_j, which is proportional to the distance and physical channel connectivity $Pr_{c,j}$ between V_c and V_j. η is the weight coefficient. Therefore, the higher the $Score_j$ is, the higher the priority of V_j is.

When the current forwarder V_c is approaching a crossroad, it assesses the ACEN firstly, which estimates the current

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link quality around a crossroad. The ACEN is calculated as $Pr_{ACEN} = \frac{\sum_{i=1}^{i=m_x}\sum_{j\in CFs_i} Pr_{c,j}}{\sum_{i=1}^{i=m_x}|CFs_i|}$, where CFs_i is the candidate forwarders in branch *i* and m_x is the number of branches of a crossroad, except the one in which the current forwarder is located. If Pr_{ACEN} is less than a certain threshold Pr_{th}, which indicates the current physical channel state is terrible, we adopt methods in Ref. [8] forwarding messages to RSUs or vehicles closest to the intersection, both of which have the best line of sight. Otherwise, for each branch $l \in m_x$, we calculate $Score_{lj}$ of V_j in l*th* branch and maintain a candidate vehicle priority queue (CPQ_l) respectively. The calculation of $Score_{lj}$ is as follows:

$$Score_{lj} = \eta\frac{d_{jo}}{R} + (1-\eta)Pr_{i,j}, \tag{7}$$

where d_{jo} is the distance between receiver V_j and intersection o.

B. Calculating the Minimum Waiting Time

So far, we have obtained the score and priority of each vehicle in CFs. When the current forwarder V_c is in a street, we get a range of *Score* which is defined as $S_{[low,high]}$ in the ascending order. Then, we divide this range from high to low into n_x segments supposing each segment contains approximately equal vehicles. Our waiting time allocation mechanism of vehicles in CFs is that the intra-segment access channel competitively and the inter-segment access channel orderly. Assuming that the contention window of segment *k* is CWS_k, we easily get the minimum waiting time of vehicles in segment *k* is :

$$w(k) = \begin{cases} 0, & \mathrm{k} = 1 \\ \sum_{l=1}^{k-1} CWS_l, & \mathrm{k} \neq 1 \end{cases}. \tag{8}$$

However, when the current forwarder V_c enters crossroad region and the ACEN is greater than Pr_{th}, we get m_x ranges of *Score*, where m_x is the number of branches except the current road. Each range of *Score* in branch *i* (*i*=1,2,...,m_x) is represented as $S_{[low_i,high_i]}$ in the ascending order. Then, we divide each range of *Score* in branch *i* from high to low into n_x segment. In order to determine the minimum waiting time for a vehicle in a segment, we utilize the following contention window matrix:

$$\begin{bmatrix} CWS_{11} & CWS_{12} & CWS_{13} & ... & CWS_{1n_x} \\ CWS_{21} & CWS_{22} & CWS_{23} & ... & CWS_{2n_x} \\ ... & ... & ... & ... & ... \\ CWS_{m_x1} & CWS_{m_x2} & CWS_{m_x3} & ... & CWS_{m_xn_x} \end{bmatrix},$$

where CWS_{ij} represents the contention window size of *jth* prioritized segment in *ith* branch. To ensure the fairness of vehicles in different branches access channel, we use an alternate polling channel access method. In particular, vehicles in the first prioritized segment of each branch access channel in forward sequence firstly, then vehicles in the second prioritized segment of each branch access channel in reverse sequence and so on. Therefore, we calculate the minimum waiting time of vehicles in *jth* prioritized segment in *ith* branch as formula (9) shows.

$$w(i,j) = \begin{cases} 0, & \mathrm{i = 1, j = 1} \\ w(1,j) + \sum_{k=1}^{i-1} CWS_{kj}, & \mathrm{i \neq 1, j\%2 = 1} \\ \sum_{k=1}^{m_x}\sum_{l=1}^{j-1} CWS_{kl}, & \mathrm{(i = 1, j\%2 = 1, j \neq 1)} \\ & ||(i = m_x, j\%2 = 0) \\ w(m_x,j) + \sum_{k=i+1}^{m_x} CWS_{kj}, & \mathrm{i \neq m_x, j\%2 = 0} \end{cases}. \tag{9}$$

C. Calculating the CWS in a Segment

To coordinate the contention among vehicles in the same segment, we randomly defer the transmission of packets within a back-off time window called contention window and we must choose an appropriate *CWS* for each segment. Assume that there are N_i vehicles in i*th* segment, we can cite the results in Ref. [9] to calculate the expected collision probability in i*th* segment:

$$Pr_{c,s_i} = \sum_{k=0}^{N_i} Pr(N_i,k) * Pr(CWS_i,k), \tag{10}$$

where $Pr(N_i,k)$ is the probability that there are exactly *k* vehicles within i*th* segment successfully receiving messages from the current forwarder and $Pr(CWS_i,k)$ is the collision probability of k vehicles disseminating packets randomly within CWS_i. Finally, we let $Pr_{c,s_i} \leq \alpha_{col}$, where α_{col} can be set to 0.1 in simulations without loss of generality, leading to the lower boundary of CWS in each segment.

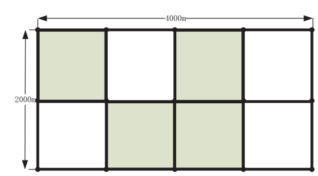
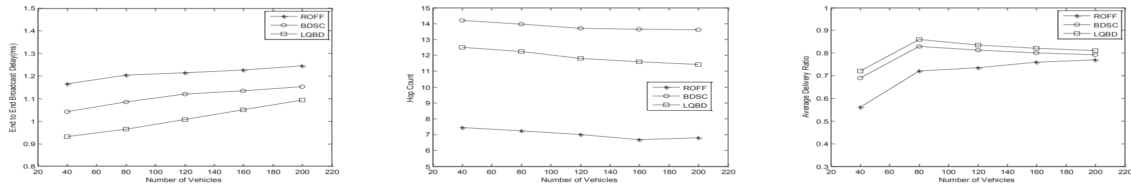


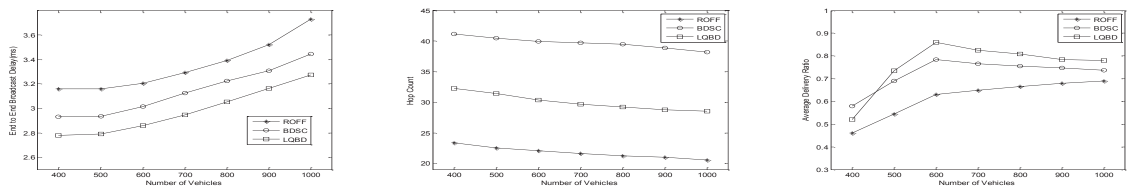
Fig. 1. Manhattan grid scenario

IV. Performance Evaluation

We implement the proposed scheme under veins [1], which integrates OMNET++ with SUMO road traffic simulator, and we compare our protocol with ROFF [4] and BDSC [5] supplemented with AMB [8] to improve the dissemination at intersections. Two network scenarios are simulated: 1) *freeway scenario* which consists of 6 2-km long lanes and the width of each lane is 5 meters. 2) *Manhattan grid scenario*: We consider the uneven distribution of buildings at crossroads, which has a great impact on the message dissemination. As shown in Fig.1, the shadows represent the buildings and their outlines are extracted in simulation. We simplify that every building is a rectangle and each black line in the figure represents a two-lane road. This scenario consists of 15 intersections and 22 roads. When a vehicle arrive at a crossroad, it will turn or go straight with equal probability. Parameters relevant to vehicles see table 3 in Ref. [1]. The data rate of message is set to 6*Mbps* and beacon intervals are 0.1s. In addition, we



(a) Average end to end delay in freeway scenario. (b) Average broadcast hop count in freeway scenario. (c) Average packets delivery ratio in freeway scenario.



(d) Average end to end delay in Manhattan grid. (e) Average broadcast hop count in Manhattan grid. (f) Average packets delivery ratio in Manhattan grid.

Fig. 2. Simulation results with varying number of vehicles.

have two system parameters Pr_{th} and η.[1] We vary the number of vehicles and observe the performance of end to end (E2E) delay, hop count and delivery ratio of our protocol (LQBD) and the comparisons.

Fig.2(a) and Fig.2(d) present the average E2E delay in different scenarios. In freeway scenario, the E2E delay is the latency from the time emergency messages generated in the one end, to its successful reception in the other end of the street, while the E2E delay in Manhattan grid scenario is the time messages experienced from the lower left to the upper right. We can see that the E2E delay of all the protocols in both scenarios are increased with the number of vehicles. However, LQBD has the lowest delay compared to the other two schemes. The reasons are as follows: First, due to the terrible physical channel, traditional message dissemination mechanisms which give priority to the farthest vehicles, like ROFF, may fail to forward messages to vehicles on the farthest zone, causing the waste of time. Second, the estimation of link quality in LQBD considering more granular information is more accurate than BDSC, which brings an appropriate waiting time allocation of vehicles in CFs. Finally, our mechanisms of CFs' priority allocation and waiting time calculation at intersections speed up the progress of message dissemination.

Fig.2(b) and Fig.2(e) show the average broadcast hop count of three schemes in freeway scenario and Manhattan grid scenario. It can be seen that all of them decrease when the number of vehicles increase due to the improvement of network connectivity. In addition, ROFF has the lowest hop count because it tends to choose the farthest vehicle to forward messages compared to link quality based scheme like BDSC and LQBD, while it has a higher delay and lower delivery rate.

Fig.2(c) and Fig.2(f) show the average packets delivery ratio. In general, LQBD and BDSC have a higher value than ROFF, because of the consideration of link quality. Due to more granular design of the link model, LQBD is slightly better than BDSC in packets delivery ratio. In addition, we can also observe that the value of LQBD and BDSC increase first, then drop off gradually, while ROFF always has an increasing trend. Because when the number of vehicles is relatively small, there exits network partition problem which slightly ameliorates with the increase of number of vehicles. However, when the number of vehicles exceeds a certain value, there will be much more collisions among vehicles. The lower bound design of waiting time difference between adjacent vehicles in ROFF prevents the average packets delivery ratio from deterioration even at a large density of vehicles.

[1]Prth represents the threshold of the ACEN and η is a weight coefficient between link quality and distance. Based on the tradeoff among experiments, we set both of them are 0.5.

V. Conclusion

In this letter, we proposed an adaptive link quality based safety message dissemination mechanism for urban VANETs. A comprehensive physical channel connectivity calculation method was built among vehicles. We proposed a score-based priority allocation mechanism and waiting time calculation mechanism for CFs. The simulation results demonstrate the superiority of our protocol.

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