Analysis of the Impact of Communication Link Outage on Throughput of VANETs Based on TDMA

Guiting Li, Xuan Zhang, Junyu Guo, and Qi Yang(✉)

Xiamen University, Xiamen 361005, Fujian, China
yangqi@xmu.edu.cn

Abstract. In vehicular ad hoc network, the random movement of nodes leads to constant changes in the network topology, in turn causing communication link outage (others is not consider in this paper). This paper will analyze the link outage caused by vehicular motion and the impact on the overall network throughput based on the vehicular movement model and the TDMA dynamic allocation access protocol. And the simulation results show that the increase of velocity standard deviation and the decrease of access probability will increase the probability of vehicle communication link outage, resulting in a decrease in the network throughput.

Keywords: Dynamic allocation TDMA · VANET · Link outage

1 Introduction

Vehicular Ad hoc Networks (VANET) in the paper [1] is an important part of the Intelligent Transport System (ITS), providing security for vehicles on the road and entertainment service for in-vehicle personnel. At the same time, the velocity of nodes are different, there is a velocity difference between nodes making communication link outage, that is the question we discussed in this paper. A large velocity difference will have a great distance between nodes, causing the problem of link outage. The influence on its performance in the entire network will be very high. Therefore, this problem has to be considered in the practical application of VANET. However, due to the particularity of this problem, the analysis of link outage problem in the actual research work is very small and the research is not deep enough.

The mobility of nodes will have different effects on the performance of the MAC protocol. Paper [2] shows that with the node moving faster, the delivery rate of network packets is gradually reduced and the transmission delay is gradually increased. Paper [3] analyzes the impact of nodes' mobility and the problem of hidden terminal on the performance of IEEE 802.11 protocol. Paper [4] analyzed the effects of different motion models on the throughput of IEEE 802.11 protocol.

M. Jia et al. (Eds.): WiSATS 2019, LNICST 281, pp. 79–88, 2019.
https://doi.org/10.1007/978-3-030-19156-6_8

Based on the above analysis, this paper analyzes the problem of link outage and its probability caused by the node's movement in the network, and the impact of the whole network throughput based on two common vehicular motion models under the dynamic allocation of TDMA channel access protocol mechanism.

2 The Dynamic Allocation of TDMA Access Protocol

The time is divided into frames, frames are divided into slots of equal length. One frame is divided into a RF (reserved frame) and K IF (information frames). In RF, the node with data to be sent competes for a slot in IF with an access probability p by using the slotted-ALOHA random access method. If there is only one node in RF contends to access in the *ith* slot, the node must successfully subscribe to the slot. Otherwise it will causes a collision. Then these nodes will continue to compete for other slots. After the end of RF, nodes can transmit data in IF in the corresponding slot that the node successfully subscribes to in RF. After one frame, the process will repeat in a new frame. Therefore, the analysis of the number of slots successfully accessed in the RF also reflects the number of slots successfully occupied in each IF (Fig. 1).

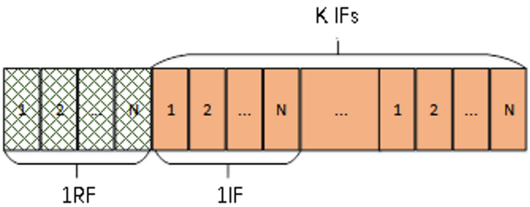

Fig. 1. The structure of a frame based on dynamic allocation with TDMA access protocol.

3 Model Description

One-way unidirectional and two-way bidirectional lane are two common traffic models. Assuming that nodes are evenly distributed in the lane, the road is divided into many two-hop regions with length $L = 2R$, the communication radius of vehicles is R. Vehicles travel at a constant velocity and their velocities are independent of each other. In the saturated state, each vehicle accesses the channel based on TDMA protocol with dynamically allocated, the interval between nodes from allocating slot to sending data packet is T.

3.1 One-Way Unidirectional Lane

The number of nodes in each region is M. The velocity of nodes follow a special Gaussian distribution: $V \sim N(\mu, \sigma^2)$. Thus the difference of velocity between any two nodes should be subject to the Gaussian distribution $\Delta V \sim N(0, 2\sigma^2)$ and $\Delta V \in [V_{\min} - V_{\max}, V_{\max} - V_{\min}]$.

The maximum distance which a vehicle can travel within time T is $S = V_{\max}T$. Given the time value is small and the maximum velocity of a vehicle is bounded, generally, the maximum distance of a vehicle can reach within time T is smaller than the length of the two-hop region (Fig. 3).

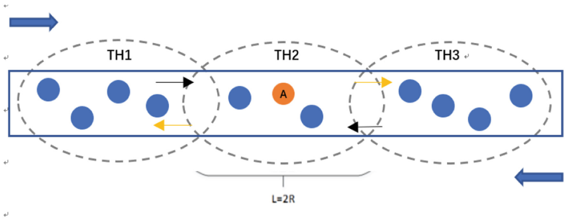

Fig. 2. The vehicle movement model in One-way unidirectional lane.

3.2 Two-Way Bidirectional Lane

The total number of nodes in each two-hop region is *2M*, the number of nodes in one lane in the two-hop section is *M*.

The moving velocity of a vehicle in the upper lane (i.e. the rightward direction) considered as positive, follows a special Gaussian distribution: $V \sim N(\mu, \sigma^2)$, $V \in [V_{\min}, V_{\max}]$. The other lane follows distribution $V \sim N(-\mu, \sigma^2)$, $V \in [V_{\min}, V_{\max}]$.

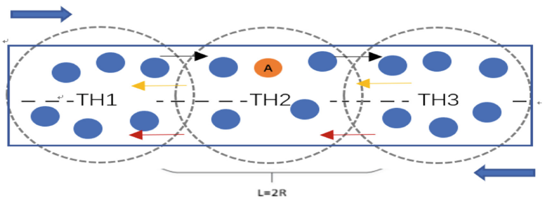

Fig. 3. The vehicle movement model of Two-way bidirectional lane.

3.3 System Parameter

3.3.1 The Distribution of Velocity

A number of related studies show that the driving velocities on the rural roads and the highway generally follow the normal distribution as stated in the paper [5].

Considering the actual scene, velocity of a vehicle is bounded, approximately following the special Gaussian distribution. Therefore, velocity distribution of vehicles can be approximately expressed as $V \sim N(\mu, \sigma^2)$, $V \in [V_{\min}, V_{\max}]$ (Fig. 4).

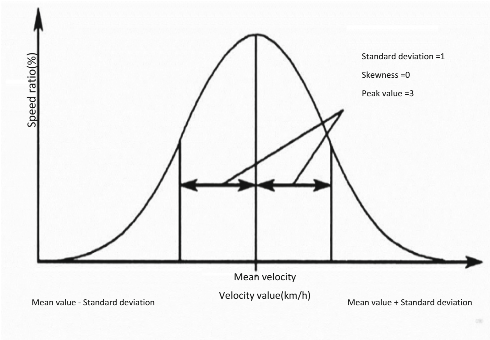

Fig. 4. The velocity distribution of nodes on the road.

3.3.2 The Arrival of Vehicle

Based on the existing knowledge of traffic flow theory, the number of vehicles' arrival within a certain interval or distributed on a certain road segment is also regarded as a random variable. Poisson distribution and binomial distribution are usually used to describe the statistical law of such random variable as stated in the paper [6]. The discrete distribution should be adopted to describe the process of nodes' arrival in this paper.

4 The Analysis of Communication Link Outage

4.1 One-Way Unidirectional Lane

As shown in Fig. 2, if the moving velocity of node relative to A is v, only the node distributed at the right distance vT from the edge of TH2 will leave TH2 after T time. Assuming that the node velocity traveling to the right relative to A is ΔV_R, obeying the special Gaussian distribution (Fig. 5).

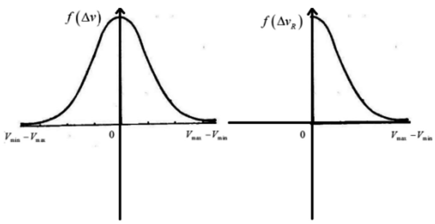

Fig. 5. The probability density map of velocity.

Based on the analysis before, considering the limited number of nodes in the TH2, this paper uses the binomial distribution to analyze the nodes' distribution from TH2 to

TH3 and TH1. In summary, after the period of one frame T, the number of nodes leaving TH2 should be $X_{OUT} = X_L + X_R$.

Since the link outage problem occurs in nodes occupying slots, the number of nodes who have link outages is equivalent to the number of nodes occupying the slots among the nodes leaving from the TH2 range after time T. The probability distribution of the slot allocation result is $P(S = i|T = N)$, where N is the number of slots.

4.2 Two-Way Bidirectional Lane

Compared with the one-way unidirectional lane, the total number of nodes left from TH2 during T time, in addition to the number of nodes discussed above on the one-way unidirectional lane, should also add the number of nodes in TH2 leaving from the left side of the lane on the left-travel lane. And the velocity of nodes on the left-travel lane relative to A following the Gaussian distribution $\Delta V_2 \sim N(2u, 2\sigma^2)$, $\Delta V_2 \in [-2V_{\max}, 2V_{\max}]$. Then, the number of nodes in the two-way lane that driving out of the TH2 during time T is $X_{double\_OUT} = X_{OUT} + X_{reverse}$.

5 The Throughput Based on Dynamic Allocation TDMA

Assuming that when the kth slot of an RF, there have been successfully allocated i slots. If the access is successful, status i is transferred to the next status j. If the access fails, status i is transferred to itself. If the current slot is the last slot in the RF, then the next slot corresponds to the first slot of the next RF. Since at the beginning of a frame, all nodes will release the original occupied slots and reschedule the slots, each state can only be transferred to state 0 or state 1 (Fig. 6).

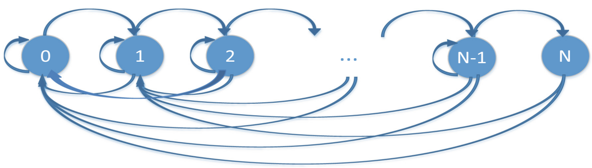

Fig. 6. First-order Markov process state transition diagram.

Based on the above analysis, the throughput of network can be determined as:

$$Throughput = \frac{c \cdot \sum_{i=0}^{N} iP(S = i|T = N)}{N} \quad (1)$$

where $c = L_{packet}/t_{slot}$ is the number of bits sent per unit time, L_{packet} is the length of the packet sent at a slot, t_{slot} is a slot's length.

Due to the space reasons, the formula detailed analysis will be discussed in other place.

6 Simulation

6.1 Simulation Scenario

Node 2 and node 3 who are the neighbor nodes of node 1 leave the communication radius of node 1 over a period of time. So that the link between node 1 and node 2 or node 1 and node 3 is invalid (Fig. 7).

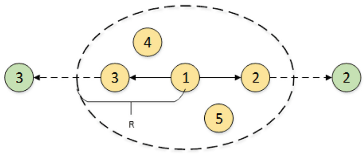

Fig. 7. The problem of communication link outage.

Assuming that in the actual scenes, the communication between nodes in the network is in the ideal channel. Since the actual two-hop communication range is limited, when each node is communicating, the signal is transmitted at its maximum transmission power (all nodes are the same). Then the velocity difference between nodes, the problem of link outage is inevitable when nodes move on the road. Moreover, based on the dynamically allocated TDMA channel access protocol, this paper analyze the problem of link outage, only two nodes are communicating at a specific time in the two-hop communication range, and there is no interference problem caused by other nodes communicating at the same time (combine Sect. 3).

6.1.1 One-Way Unidirectional Lane

Assuming nodes are uniformly distributed on a one-way unidirectional, their velocity follows a Gaussian distribution $V \in [V_{\min}, V_{\max}] > 0$, $\mu = (V_{\min} + V_{\max})/2 > 0$ and $\sigma^2 = (V_{\max} - V_{\min})^2/12$.

6.1.2 Two-Way Bidirectional Lane

Supposing that nodes are uniformly distributed on a two-way bidirectional. The velocity distribution of nodes on the right-travel lane are the same as the one-way unidirectional lane. The velocity of nodes travelings in the other lane follow the Gaussian distribution $V \in [-V_{\min}, -V_{\max}] < 0$, $\mu = (-V_{\min} + V_{\max})/2$ and $\sigma^2 = (V_{\max} - V_{\min})^2/12$.

6.2 Simulation Results and Analysis

There are three two-hop disjoint section, the parameters satisfy the following conditions: $R = 10$ m, $T = 0.5$ s, $M = 10$. Their range is TH1 = [0 m, 20 m], TH2 = [20 m, 40 m], TH3 = [40 m, 60 m]. The number of slots in one frame is $N = 10$, and average vehicles' velocity are $v = 5$ m/s.

The simulation is performed 10000 iteration in different scenarios, then the average of the simulation results is taken as 10,000. The final result is compared with the theoretical derivation value, and the relationship between the standard deviation of the vehicle velocity and the access probability to the link outage probability is observed.

Figures 8 and 9 both show that as the standard deviation of velocity increases, the probability of link outage increases. The shorter the link is, the greater the probability of link outage is. The link outage probability curve with a small access probability is higher than the curve with a large-access probability. The probability of link outage in Fig. 9 is significantly higher than the probability in Fig. 8.

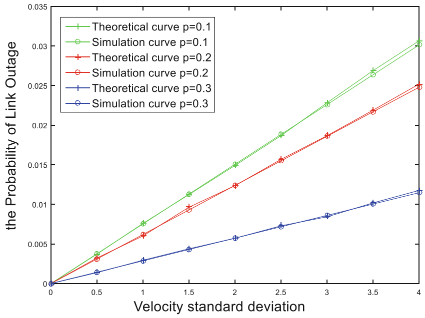

Fig. 8. The influence of the standard deviation of velocity on the one-way unidirectional lane on the link outage probability.

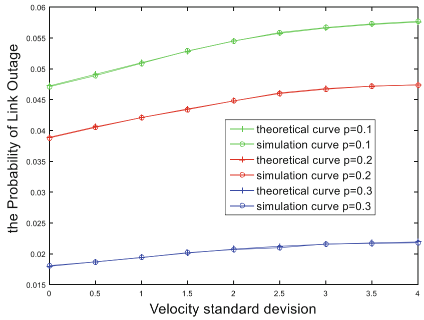

Fig. 9. The influence of the standard deviation of velocity on the two-way bidirectional lane on the link outage probability.

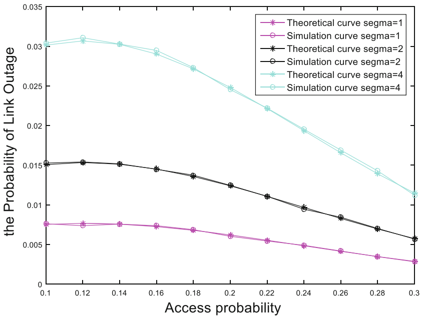

Fig. 10. The influence of the access probability on the one-way unidirectional lane on the link outage probability.

Figure 11 shows that the probability of link outage occurs when the number of nodes that want to transmit data and the standard deviation of velocity are constant, decreases with the increase of the access probability. Compared with Fig. 10, it can be found that under the same parameters, the probability of link outage occurring on the two-way bidirectional lane is higher than that of the one-way unidirectional lane (Figs. 12 and 13).

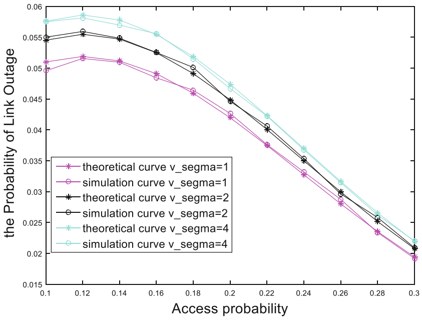

Fig. 11. The influence of the access probability on the two-way bidirectional lane on the link outage probability.

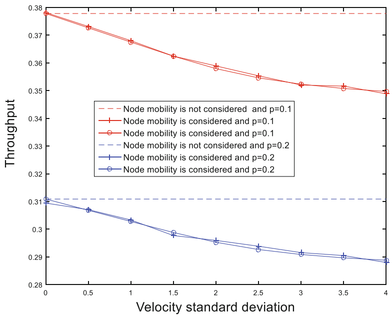

Fig. 12. The influence of the velocity standard deviation on the one-way unidirectional lane on the probability of link outage.

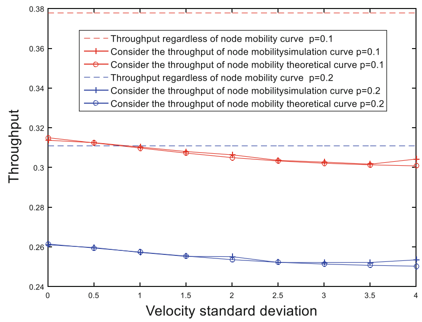

Fig. 13. The influence of the velocity standard deviation on the two-way bidirectional lane on the probability of link outage.

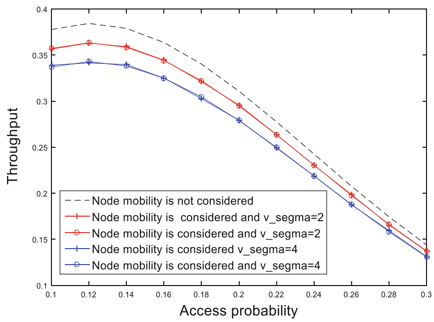

Fig. 14. The influence of the access probability on the one-way unidirectional lane on the probability of link outage.

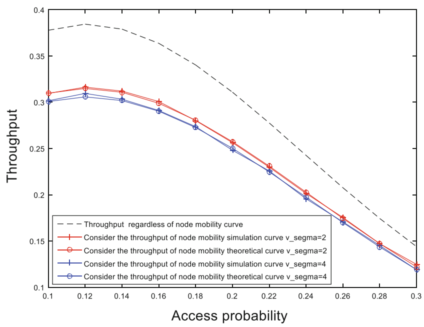

Fig. 15. The influence of the access probability on the two-way bidirectional lane on the probability of link outage.

When the node mobility is not considered, the network throughput on a one-way unidirectional lane is the same as that of a two-way bidirectional lane. When other parameters are equal, the throughput of two-way bidirectional lanes is lower than that of one-way unidirectional lanes. Figures 14 and 15 also shows that under the same access probability, the mobility of the node causes the network throughput to decrease; when considering the node mobility, under the same access probability, the throughput of the two-way bidirectional lane is lower than that of the one-way unidirectional lane.

7 Conclusion

In this paper, considering the impact of the movement of vehicles in the media access protocol with the scheme of dynamic allocation, namely the problem of link outage is taken into consideration, the throughput of the network is analyzed in this paper with the manifest of the simulation in two scenarios. It is noticeable that a greater standard deviation of velocity leads to a greater probability of link outage, and a larger probability of access brings a excellent performance, namely a smaller probability of link outage in two scenarios. Finally, we can get the probability of link outage is smaller, the throughput of whole network is greater.

References

1. Hartenstein, H., Laberteaux, K.: VANET: Vehicular Applications and Inter-Networking Technologies. Wiley, Hoboken (2009)
2. Saini, P.: Impact of mobility and transmission range on the performance of backoff algorithms for IEEE 802.11-based multi-hop mobile ad hoc networks. Int. J. Adv. Technol. **1**(1), 26 (2010)
3. Khurana, S., Kahol, A., Gupta, S.K.S., et al.: Performance evaluation of distributed co-ordination function for IEEE 802.11 wireless LAN protocol in presence of mobile and hidden terminals. In: International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems, p. 40. IEEE Computer Society (1999)
4. Ahmed, E.S.A., Ali, B.E.S., Osman, E.O., et al.: Impact of different mobility models in MANETs based on MAC 802.11. IJSRSET **1**(6), 118–122 (2015)
5. Geng, Y., Wang, X., Zhang, Y., et al.: Study on the distribution characteristics of speed of section running on expressway. Chin. J. Saf. Sci. **18**(7), 171 (2008)
6. Hu, M.: An empirical study on the statistical distribution of arrival at intersections. Road Traffic Saf. **2**, 10–15 (2009)