Analysis on Merging Collision Probability in TDMA Based VANET

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Abstract. Dynamical channel allocation schemes for TDMA based on Media Access Control (MAC) Protocols usually depend on network topology to allocate slot. However, The nodes in the network are allowed to move freely, which causes dynamic changes in the network topology and merging collisions. As the application of wireless ad hoc network in intelligent traffic system (ITS), vehicle in the network has typical characteristics of high-speed movement. Based on the model of vehicle movement, this paper analyzes the collision problem caused by the mobility of vehicle and it's probability and verifies the correctness of theoretical analysis through simulation. The simulation result shows that a larger access probability or a smaller standard deviation of brings a smaller probability of merging collision.

Keywords: Access protocol · Ad-hoc network · Merging collision

1 Introduction

Vehicular Ad hoc Networks (VANET) is a significant application of wireless ad hoc networks in Intelligence Traffic System (ITS), providing a multitude of services such as security information, traffic management, and infotainment as stated in paper [1] and [2]. Due to the movement of vehicle in network, topology of network changes dynamically, and the speed of vehicle in the network is different which causes the presence of difference of relative speed. It's inevitable that vehicles within different communication sections will enter the communication range of other vehicle. In the protocol based on TDMA, merging collision problem will inevitably occur, exerting a great impact on the performance of the entire network. The problem of merging collision takes the leads in analysis of throughput of network. Due to the particularity and complexity of this problem, the analysis of merging collision is pretty rare, and the relevant research is not taken detailed. And a few articles analyze the issue of probability in practice. The impact of mobility is studied in detail in paper [3]. In paper [4], the problem of merging collision and its cause have been introduced, and a method is proposed to alleviate this. In paper [5], the problem of collision is divided into two types: merging collision and access collision, and the cause is introduced. A novel protocol is proposed in this paper taking the problem of merging collision into consideration. In paper [6], a novel method is proposed to reduce the problem of merging collision. The problem is introduced in detail early in paper [7].

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Based on the analysis above, this paper analyzes the probability of merging collision based on two model along with the access protocol.

The rest of the paper is organized as follows. The model adopted in this paper is introduced in Sect. 2. A slew of related parameters of the model is described in Sect. 4. The analysis of the merging collision is accomplished in Sect. 4. The simulation and related analysis is presented in Sect. 5. The paper is concluded in Sect. 6.

2 The Model

In the actual circumstance, there are two common traffic road models: one-way unidirectional lane and two-way bidirectional lane, which will be modeled and analyzed in detail. In the saturated state, each vehicle accesses channel based on TDMA protocol with the scheme of dynamic allocation, and the interval between the node allocated to slot and the data sending is T.

2.1 One-Way Unidirectional Lane

As shown in Fig. 2, the vehicle is uniformly distributed on road, and the radius of communication is R The road is divided into several two-hop sections with length $L = 2R$. As shown in Fig. 1, there are three two-hop sections –TH1, TH2, TH3. The number of nodes in each section is M. Each node in the two-hops section is allocated a different slot in a frame while each node in the different two-hop section can be allocated a same slot in a frame.

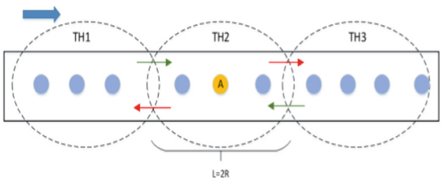

Fig. 1. The vehicle movement model of one-way unidirectional lane.

As mentioned above, the speed of the vehicle follows a special Gaussian distribution $V \sim N(\mu, \sigma^2)$, $V \in [V_{\min}, V_{\max}]$ and the speed is maintained. Thus, the difference of velocity between any two vehicle follows the Gaussian distribution $\Delta V \sim N(0, 2\sigma^2)$, $\Delta V \in [V_{\min} - V_{\max}, V_{\max} - V_{\min}]$. The maximum of distance that a vehicle can reach within time T is $S = V_{\max} T$.

2.2 Two-Way Bidirectional Lane

In two-way bidirectional lane, vehicle locates on different roads moving in opposite directions, as shown in Fig. 2. The upper lane is regarded as right lane. Assuming the density of vehicles in two lanes is identical, the nodes in each lane follow uniformly distribution, and the radius of communication of the vehicle is R. The section is also divided into two-hop section with the length of $L = 2R$. The total number of nodes in each two-hop section is M, and the number of nodes in unidirectional lane in the two-hop section is $2M$.

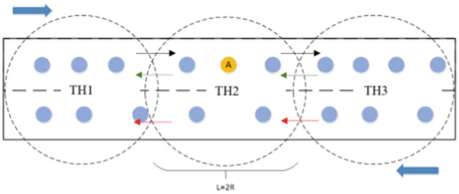

Fig. 2. The vehicle movement model of two way bidirectional lane.

The speed of vehicles in the right direction is considered as positive and follows a special Gaussian distribution $V \sim N(\mu, \sigma^2)$, $V \in [V_{\min}, V_{\max}]$. The speed of the vehicle in the left direction is regarded as negative follows a same distribution. Vehicles travel at a constant speed and their speeds are independent. Consequently, the difference of velocity between any two nodes in the same direction follows the Gaussian distribution $\Delta V \sim N(0, 2\sigma^2)$, $\Delta V \in [V_{\min} - V_{\max}, V_{\max} - V_{\min}]$. The difference of velocity between any two nodes in opposite direction follows the Gaussian distribution $\Delta V_2 \sim N(2u, 2\sigma^2)$, $\Delta V_2 \in [-2V_{\max}, 2V_{\max}]$.

The maximum of difference of speed between any two vehicles is $2V_{\max}$, and the maximum relative distance between any two nodes in time T is $S = 2V_{\max}T$, and it is also satisfy $S < L$.

3 Model Parameters

3.1 The Distribution of Velocity

Previous studies show that speed generally follows the normal distribution on the rural roads and the highway, as shown in Fig. 3.

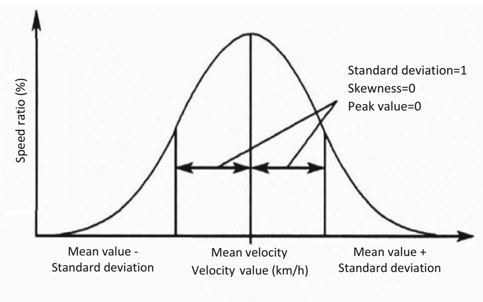

Fig. 3. The speed distribution of nodes on the road.

In the actual scene, the speed of vehicle is bounded, which follows Gaussian distribution. But considering the Gaussian distribution $V \sim N(\mu, \sigma^2)$, the probability close to 0 when vehicle speed is $V < V_{\min}, V > V_{\max}$. Therefore, the distribution of speed of vehicle can be approximately expressed as $V \sim N(\mu, \sigma^2),\ V \in [V_{\min}, V_{\max}]$. Speed distribution between any two vehicles is independent and the relative speed between any two vehicles follows $\Delta V \sim N(0, 2\sigma^2),\ V \in [V_{\min-\max}, V_{\max-\min}]$.

3.2 The Arrival of Vehicle

In the theory of traffic flow, the number of vehicles arriving within a certain time interval or distributed on a certain road segment is also regarded as a random variable, and Poisson distribution and binomial distribution are usually used to describe the statistical law of such random variables. And the Poisson distribution and binomial distribution, depicting the movement of vehicle in different scenarios, can be given as following:

$$P_k = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, k = 1, 2, \cdots n \tag{1}$$

$$P_k = C_n^k \left(\frac{\lambda t}{n}\right)^k \left(1 - \frac{\lambda t}{n}\right)^{n-k}, k = 1, 2, \cdots, n \tag{2}$$

4 The Analysis of Merging Collision

4.1 One-Way Unidirectional Lane

Nodes in TH1 and TH3 will enter to TH2 due to the movement, which will be subject to the merging collision with the nodes located in TH2. And, node in TH1 have a higher speed than the node located in TH2 with reference of the speed of node A will move into TH2 from TH2 left side. Therefore, the probability distribution of the number of vehicle which move from the TH1 into TH2 should be the same as the probability distribution of the number of nodes which move from the TH1 into TH2, both of which follows $P(X_R = \mathrm{k})$. The probability distribution of the number which move into TH2 from TH3 should be the same as the distribution of the number of nodes which leave the TH2 from the left side, which follows $P(X_L = \mathrm{k})$.

If there are X slots occupied already when K node move into TH2 from TH1 in the condition that the number of nodes which successfully reserves slot is no less than x in one frame. Thus, the probability distribution of the number of slots which occupied by the node that move into TH2 from TH1 in a frame can be given as

$$P(X_{IN1} = x) = \sum_{j=x}^{N} \sum_{k=x}^{M-j+x} P(S = j | T = N) \frac{C_k^x C_{M-x}^{j-x}}{C_M^j} P(X_R = k) \tag{3}$$

where $x = 0, 1...N$. The number of nodes moving into TH2 and occupying slot is the sum of the number of nodes moving into TH2 from TH1 and TH3, namely:

$$P(X_{IN} = l) = \sum_{i=0}^{l} P(X_{IN1} = i)P(X_{IN3} = l - i) \quad (4)$$

where $L = 0, 1...N$. The probability that there are still X_{STAY} nodes in TH after one frame time is

$$P(X_{STAY} = y) = P(X_{OUT} = M - y) \quad (5)$$

Then the probability that there is still m node within TH is

$$P(X_{TH} = m) = \sum_{j=m}^{N} \sum_{k=m}^{M-j+m} P(S = j|T = N) \frac{C_k^m C_{M-m}^{j-m}}{C_M^j} P(X_{STAY} = k) \quad (6)$$

where $m = 0, 1...N$. The number of nodes entering into TH2 and occupying the slot in TH2 is $X_{IN} = y$ and the number of nodes occupying the slot in TH2 is k. k and y satisfy $0 \le k, y \le N$, where N is the number of slots in a frame, as shown in Fig. 4. The probability that there are i slots is exposed to merging collision is expressed as $P(C = i; y, k)$.

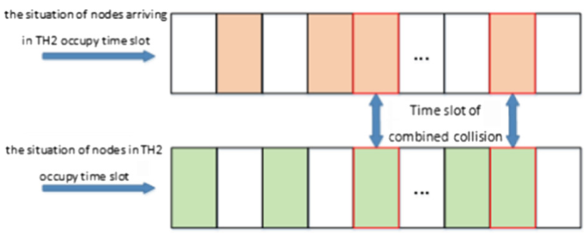

Fig. 4. The illustration of merging collision.

(1) when $y + k \le N$

$$P(C = i; y, k) = \begin{cases} \frac{C_k^i C_{N-k}^{y-i}}{C_N^y} & i \le \min(y, k) \\ 0 & i > \min(y, k) \end{cases} \quad (7)$$

(2) when $y + k > N$, the number of slots which expose to merging collision is no less than $x = k + y - N$

$$P(C=i;y,k)=\begin{cases}0 & i<y+k-N \text{ 或 } i>\min(y,k)\\ \dfrac{C_k^i C_{N-k}^{y-i}}{C_N^y} & y+k-N<i\le\min(y,k)\end{cases} \tag{8}$$

As stated above:

$$P(C=i;y,k)=\begin{cases}\frac{C_k^i C_{N-k}^{y-i}}{C_N^y} & \max(y+k-N,0)\le i\le\min(y,k)\\ 0 & i<\max(y+k-N,0)\ or\ i>\min(y,k)\end{cases} \tag{9}$$

Thus, the probability distribution of the number of occurrences of merging collision in time T can be given as

$$P(C=i)=\sum_{k=1}^{N}\sum_{y=1}^{N}P(X_{TH}=k)\,P(X_{IN}=y)\,P(C=i;k,y) \tag{10}$$

4.2 Two-Way Bidirectional Lane

In two-way bidirectional lane, vehicles located in reverse lane in TH1 travel at opposite speed with reference of node A, and nodes in this section will not enter TH2. Thus the number of nodes that move into TH2 from TH3 in T time is $X_{3\_in}=X_L+X_{reverse}$, where X_L represents the number of nodes moving into TH2 in the same direction lane of TH3 and $X_{reverse}$ the number of nodes moving into TH2 in reverse lane of TH3. The probability that k node move into TH2 from TH3 within time T is

$$P(X_{3\_in}=k)=\sum_{j=0}^{k}P(X_L=j)P(X_{reverse}=k-j) \tag{11}$$

where $k=0,1\ldots 2M$. Thus, the probability distribution of the result of slot allocation in the saturated state is $P(S=j|T=N)$, and the probability distribution of m node occupying slot move into TH2 from TH3 within time T is

$$P(X_{3\_IN}=m)=\sum_{j=m}^{N}\sum_{k=m}^{2M-j+m}P(S=j|T=N)\frac{C_k^m C_{2M-m}^{j-m}}{C_{2M}^j}P(X_{3\_in}=k) \tag{12}$$

where $m=0,1\ldots,N$. The probability distribution of m node occupying slot move into TH2 from TH1 within time T is

$$P(X_{1\_IN}=m)=\sum_{j=m}^{N}\sum_{k=m}^{2M-j+m}P(S=j|T=N)\frac{C_k^m C_{2M-m}^{j-m}}{C_{2M}^j}P(X_R=k) \tag{13}$$

Thus, the probability distribution of the number of nodes occupying slots in TH2 within time T can be obtained as

$$P(X_{double\_IN} = l) = \sum_{i=0}^{l} P(X_{IN1} = i)P(X_{IN3} = l - i) \tag{14}$$

where $l = 0, 1..., N$. Then, the probability that there are still X_{STAY} nodes in the TH2 after one frame can be given is $X_{STAY} = M - X_{OUT}$

$$P(X_{double\_STAY} = y) = P(X_{double\_OUT} = 2M - y) \tag{15}$$

Then, the probability that there are still m nodes occupying a slot in the TH2 is as follows:

$$P(X_{double\_TH} = m) = \sum_{j=m}^{N} \sum_{k=m}^{2M-j+m} P(S = j|T = N) \frac{C_k^m C_{2M-m}^{j-m}}{C_{2M}^{j}} P(X_{double\_STAY} = k) \tag{16}$$

where $m = 0, 1, \cdots, N$. Finally, the probability distribution of occurrences of merging collision within time T is i can be given as:

$$P(C_{double} = i) = \sum_{k=1}^{M} \sum_{y=1}^{M} P(X_{double\_TH} = k)\ P(X_{double\_IN} = y)\ P(C = i; k, y) \tag{17}$$

5 Simulation and Analysis

Assuming that the node B in the two hop Sect. 1 and the node E in the two hop Sect. 2 use same slot, and the node B and the node E move in opposite directions. When the Node B enters the range of the two-hop Sect. 2, the Node B and the node E become two-hop neighbors, as shown in Fig. 5. And no other factors are considered and there is no interference caused by the communication of other nodes. Moreover, it transmits signals at its same maximum transmit power.

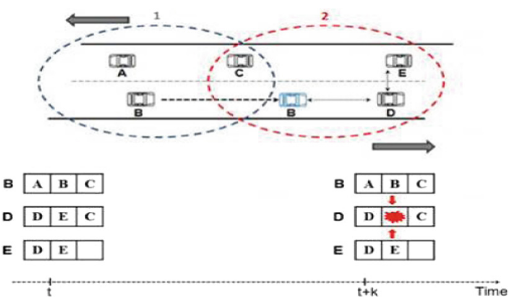

Fig. 5. The scene of merging collision.

5.1 Simulation Scenario

5.1.1 One-Way Unidirectional Lane

Supposing the nodes are uniformly distributed on a one-way unidirectional and their speed follows a Gaussian distribution $V \sim N(\mu, \sigma^2)$, where $V \in [V_{\min}, V_{\max}] > 0$, $\mu = (V_{\min} + V_{\max})/2 > 0$, $\sigma^2 = (V_{\max} - V_{\min})^2/12$, and the speed is constant. Moreover, the communication radius is R = 10 m.

There are three two-hop section: TH1, TH2 and TH3, which are disjoint. Their range is TH1 = [0 m, 20 m], TH2 = [20 m, 40 m], TH3 = [40 m, 60 m], and the number of nodes in TH1, TH2 and TH3 all are $M = 10$.

5.1.2 Two-Way Bidirectional Lane

In the same condition, the speed of the vehicle nodes traveling in the right lane follows the Gaussian distribution $V_1 \sim N(\mu, \sigma^2)$, $V_1 \in [V_{\min}, V_{\max}]$. And the Gaussian distribution is parameterized by $\mu = (V_{\min} + V_{\max})/2$, $\sigma^2 = (V_{\max} - V_{\min})^2/12$. The speed of the nodes traveling in the opposite lane follows a Gaussian distribution $V_2 \sim N(-\mu, \sigma^2)$ and $V_1 \in [-V_{\max}, -V_{\min}]$, $\mu = -(V_{\min} + V_{\max})/2$, $\sigma^2 = (V_{\max} - V_{\min})^2/12$ and the speed is constant. Other parameters are the same as mentioned above in on 4 way unidirectional lane.

5.2 Simulation

Next, the simulation is completed with 1000 iteration and the average value is taken as final result.

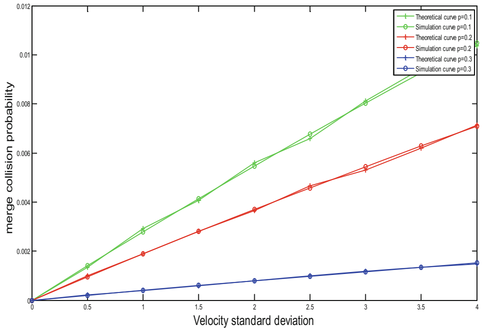

Fig. 6. The influence of the standard deviation of speed on the one-way single lane on the merging collision probability.

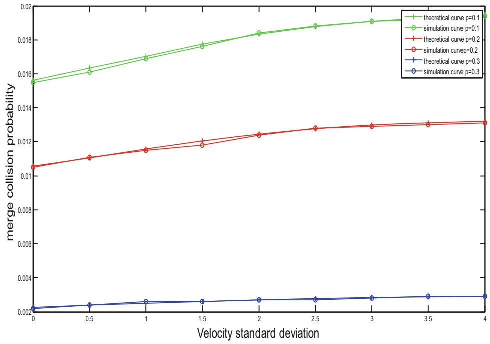

Fig. 7. The influence of the standard deviation of the speed on the two-way dual lane on the merging collision probability.

Figures 6 and 7 present influence of standard deviation of speed. Simulation shows that probability of merging collision increases with increasing of it. Further, it's evident that the difference of simulation in two model is enormous.

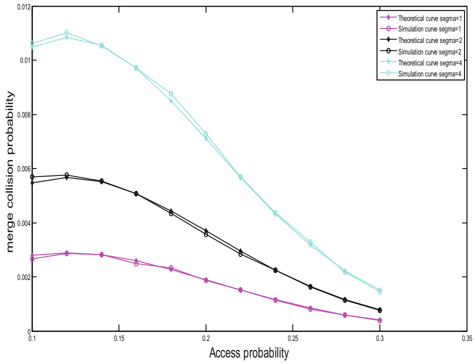

Fig. 8. The influence of the access probability on the one-way single lane on the merging collision probability.

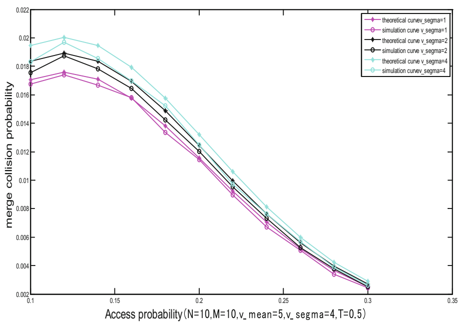

Fig. 9. The influence of the access probability on the two-way dual lane on the merging collision probability.

Figure 8 shows impact of access probability. Figure 9 shows that the probability of merging collision will decrease with increase of access probability. And a greater standard deviation of speed causes a higher probability of merging collision.

6 Conclusion

This paper accomplishes the analysis on the probability of merging collision in TDMA based VANET in detail. The movement of the vehicle in nature causes the appearance of the difference of vehicle speed, which leads to the dynamic changes in the network topology, resulting in the problem of merging collision that exerts a tremendous impact on the performance of the whole network. Two model of vehicular movement is established in this paper–one way unidirectional lane and two-way bidirectional lane. Then, the probability of merging collision is derived in two models of vehicular movement respectively and the analytic result has been given in this paper. Finally, the simulations verify the theoretical derivation results in two scenarios. It is found that a greater standard deviation of velocity leads to a greater probability of merging collision and a larger probability of access brings a excellent consequence about problem merging collision in two scenarios, namely a smaller probability of merging collision.

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