

VANET에서 IEEE 802.11p MAC 프로토콜의 성능 분석

(Performance Analysis of
IEEE 802.11p MAC Protocol
in VANETs)

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요 약 VANET(Vehicular Ad hoc Networks)는 운전의 안전성, 편안함과 효율성을 향상시키는 지능형 교통 시스템(ITS: Intelligent Transportation System)을 위한 기술로 각광받고 있다. IEEE 802.11p/WAVE는 VANET에서 무선 접속을 지원하는 것을 목표로 하는 표준이다. IEEE 802.11p/WAVE MAC은 긴급을 요하는 트래픽을 위한 신뢰성 있는 브로드캐스팅과 성능적인 면에서 서비스 트래픽을 위해 높은 전송률을 지원해야 한다. 따라서 본 논문에서는 2-D 마코브 체인 모델을 사용하여 IEEE 802.11p에서 포화상태의 성능을 분석하고자 한다. 수치적인 결과를 통해 서비스 트래픽의 포화상태 처리량, 패킷 전송률, 그리고 긴급 트래픽의 평균 지연율과 같은 파라미터들이 망 성능에 어떻게 영향을 미치는지 확인할 수 있다.

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Abstract Vehicular Ad hoc Network (VANET) is emerging as a potential technology for the Intelligent Transportation System (ITS) to enhance the safety, comfort and efficiency of driving. The IEEE 802.11p/WAVE is a standard intended to support wireless access in VANETs. The IEEE 802.11p/WAVE MAC needs to provide the reliable broadcast for emergency traffic and high throughput for service traffic as the performance metrics. Accordingly, in this paper we study on the saturation performance of the IEEE 802.11p by using the 2-D Markov chain model. The numerical results show how the network parameters impact the network performance: normalized saturation throughput of service traffic; packet delivery ratio and average delay of emergency traffic.

Keywords: IEEE 802.11p, MAC protocol, performance analysis, Vehicular Ad hoc networks

1. Introduction

The main goal of the Intelligent Transportation System (ITS) is to improve the quality, effectiveness and safety of the future transportation systems. VANET is developed as a part of ITS with two types of communications: Vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I). They are also known as Inter-Vehicle Communications (IVC) and Roadside-to-Vehicle Communications (RVC), respectively. The applications of VANETs fall into two categories, namely safety applications and non-safety applications. Safety applications provide drivers information about critical situation in advance to improve the driving safety. On the other hand, non-safety applications are used for improving driving comfort and the efficiency of transportation system. Therefore, safety applications have strict requirements on communication reliability and delay while non-safety applications are more throughput-sensitive.

The IEEE 802.11p [1] uses an Enhanced Distributed Channel Access (EDCA) MAC sublayer based on the IEEE 802.11e. The saturation performance of the IEEE 802.11 Distributed Coordination Function is evaluated by Bianchi [2]. And the performance of the IEEE 802.11e EDCA has been analyzed in [3,4] under saturation condition. Ma *et al.* [5] evaluate the per-

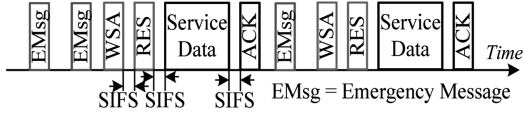


Fig. 1 Emergency and service transmissions

formance of broadcast service in the IEEE 802.11, including the throughput, delay and packet delivery ratio. In the literature, there are some studies about the performance of VANET [6-8]. The authors in [6, 7] studied only about broadcasting in VANETs while Han *et al.* analyzed the IEEE 802.11p with four different access categories in [8]. In this paper, we consider two types of traffic: emergency traffic with high priority and service traffic with low priority. The 2-D Markov chain is used to model the back-off procedure for each traffic type.

2. Analytical Model

In our analytical model, we consider the emergency and service applications as shown in Fig. 1. There are N vehicle nodes in the network; each node always has both emergency (EMsg) and service messages to transmit. By having a small contention window, the emergency traffic has high priority to be transmitted. Since the broadcast communication mode is used for the emergency traffic, the vehicle node will not send an acknowledgement for the received emergency messages. The sender could not detect the failure of the emergency transmission and hence there is no retransmission.

The service provider can also broadcast the WSA (WAVE Service Announcement) packets, and the node that need the service replies with the RES (Reservation). Then the service data is transferred and acknowledged by the ACK (Acknowledgement).

Let $b_e(t)$ be the random process representing the back-off counter value at time slot t ; p_e be the collision probability. The state transition diagram is shown in Fig. 2. The non-null transition probabilities are given as

$$\begin{cases} P\{k | 0\} = 1/W_e, \text{ for } 0 \leq k \leq W_e - 1 \\ P\{k | k\} = p_e, \text{ for } 1 \leq k \leq W_e - 1 \\ P\{k | k+1\} = 1 - p_e, \text{ for } 0 \leq k \leq W_e - 2 \end{cases} \quad (1)$$

Let $b_{e,k} = \lim_{t \rightarrow \infty} P\{b_e(t) = k\}$, for $0 \leq k \leq W_e - 1$ be the

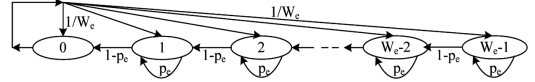


Fig. 2 Markov Chain of emergency traffic.

stationary distribution of the Markov chain, where W_e is the contention window size of emergency traffic. From the Markov chain, we can obtain

$$b_{e,k} = \frac{W_e - k}{W_e} \frac{1}{1 - p_e} b_{e,0}, 1 \leq k \leq W_e - 1 \quad (2)$$

Using Eq. 2 and normalization condition $1 = \sum_{k=0}^{W_e-1} b_{e,k}$,

we have

$$b_{e,0} = \frac{2(1 - p_e)}{(1 - 2p_e + W_e)} \quad (3)$$

Let τ_e be the probability that a node transmits an emergency message in a time slot

$$\tau_e = b_{e,0} = \frac{2(1 - p_e)}{1 - 2p_e + W_e} \quad (4)$$

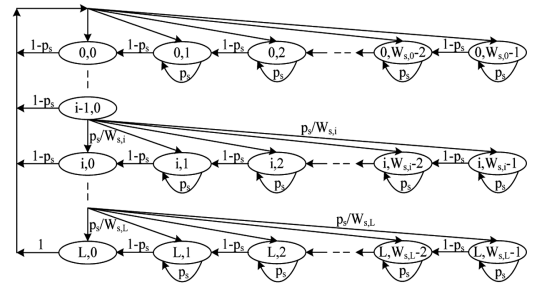


Fig. 3 Markov Chain of service traffic.

Let $b_s(t)$ and $s_s(t)$ be the stochastic process representing the back-off counter and back-off stage for the service data at time slot t , respectively. Let L be the retry limit, the maximum number of trials before the packet is dropped and $W_{s,i} = 2^i W_{s,0}$ be the contention window (CW) of i^{th} back-off stage, where $i \in [0, L]$.

We assume the collision probability p_s is constant and independent. The bi-dimensional process $\{s_s(t), b_s(t)\}$ is modeled with the discrete-time Markov chain as shown in Fig. 3. The only non-null one-step transition probabilities are

$$\left\{ \begin{array}{l}
P\{0, k | i, 0\} = (1 - p_s) / W_{s,0}, \\
\quad k \in [0, W_{s,0} - 1], i \in [0, L - 1], \\
P\{0, k | L, 0\} = 1 / W_{s,0}, \\
\quad k \in [0, W_{s,0} - 1], \\
P\{i, k | i - 1, 0\} = p_s / W_{s,i}, \\
\quad k \in [0, W_{s,0} - 1], i \in [1, L - 1], \\
P\{i, k | i, k + 1\} = 1 - p_s, \\
\quad k \in [0, W_{s,0} - 2], i \in [0, L], \\
P\{i, k | i, k\} = p_s, \\
\quad k \in [1, W_{s,0} - 1], i \in [0, L],
\end{array} \right. \quad (5)$$

Let $b_{s,i,k} = \lim_{t \rightarrow \infty} P\{S_s(t) = i, b_s(t) = k\}$ be the stationary distribution of the Markov chain. Since the chain is regularity, for each $k \in [1, W_{s,i-1}]$, we have

$$b_{s,i,k} = \frac{W_{s,i} - k}{W_{s,i}} \frac{b_{s,i,0}}{1 - p_s}, \quad 0 \leq i \leq L, 1 \leq k \leq W_i - 1 \quad (6)$$

Using the normalization condition $1 = \sum_{i=0}^L \sum_{k=0}^{W_{s,i}-1} b_{s,i,k}$,

$b_{s,0,0}$ is determined as follows

$$b_{s,0,0} = \left(\sum_{i=0}^L p_s^i \left(1 + \frac{1}{1 - p_s} \frac{W_{s,i} - 1}{2} \right) \right)^{-1} \quad (7)$$

As a packet is transmitted when the back-off counter is zero, regardless of the back-off stage, the probability τ_s that node transmits in a time slot

$$\begin{aligned}
\tau_s &= \sum_{i=0}^L b_{s,i,0} \\
&= \frac{2(1 - p_s^{L+1})(1 - p_s)(1 - 2p_s)}{(1 - 2p_s)^2(1 - p_s^{L+1}) + W_{s,0}(1 - (2p_s)^{L+1})(1 - p_s)} \quad (8)
\end{aligned}$$

A transmitted frame collides when one more node also transmits during a time slot. The collision probabilities p_e, p_s are given as

$$\begin{aligned}
p_e &= 1 - (1 - \tau_e)^{N-1} (1 - \tau_s)^N \\
p_s &= 1 - (1 - \tau_e)^N (1 - \tau_s)^{N-1} \quad (9)
\end{aligned}$$

From Eqs. 4, 8 and 9, we can solve the unknowns τ_e, τ_s . The probability P_b that the channel is busy

$$P_b = 1 - (1 - \tau_e)^N (1 - \tau_s)^N \quad (10)$$

Let $P_{e,suc}$ and $P_{s,suc}$ be the probabilities of successful transmission for an emergency packet and a service packet, respectively. And let $P_{e,col}, P_{s,col}$, and $P_{es,col}$ be the probability of collision transmission from only emergency packet; only service packet and both, respectively.

$$\left\{ \begin{array}{l}
P_{e,suc} = N\tau_e(1 - \tau_e)^{N-1}(1 - \tau_s)^N \\
P_{s,suc} = N\tau_s(1 - \tau_e)^N(1 - \tau_s)^{N-1} \\
P_{e,col} = (1 - \tau_s)^N \left(1 - (1 - \tau_e)^N - N\tau_e(1 - \tau_e)^{N-1} \right) \\
P_{s,col} = (1 - \tau_e)^N \left(1 - (1 - \tau_s)^N - N\tau_s(1 - \tau_s)^{N-1} \right) \\
P_{es,col} = P_b - P_{e,suc} - P_{s,suc} - P_{e,col} - P_{s,col}
\end{array} \right. \quad (11)$$

The packet delivery rate (PDR) of the emergency traffic can be calculated as the probability that a packet is successfully transmitted over the average number of nodes transmitting the emergency packets.

$$PDR_e = \frac{P_{e,suc}}{N_e \tau_e} = (1 - \tau_e)^{N-1} (1 - \tau_s)^N \quad (12)$$

Let $\sigma, T_{e,suc}, T_{s,suc}, T_{e,col}$ and $T_{s,col}$ be the duration of time slot, the average time the channel is sensed busy because of the successful transmission of emergency and service traffic, the average time the channel is sensed busy during the collision caused by the emergency and service traffic, respectively. Let δ be the propagation delay, and H be the packet header.

$$\left\{ \begin{array}{l}
T_{e,suc} = T_{e,col} = H + E[P_e] + DIFS + \delta \\
T_{s,suc} = WSA + SIFS + \delta + RES + SIFS + \delta + \\
\quad H + E[P_s] + SIFS + \delta + ACK + DIFS + \delta \\
T_{s,col} = WSA + DIFS + \delta
\end{array} \right. \quad (13)$$

where $E[P_e]$ and $E[P_s]$ are the average payload length of the emergency and service packets, respectively. When the collision happens between the emergency and service traffics, the channel is sensed busy with the average time of $\max(T_{e,col}, T_{s,col})$.

Each state may be a successful transmission, a collision or the medium being idle. We assume $T_{e,col} > T_{s,col}$, the expected time spent per state E_S is

$$E_S = (1 - P_b)\sigma + P_{e,suc} T_{e,suc} + P_{s,suc} T_{s,suc} + P_{e,col} T_{e,col} + P_{s,col} T_{s,col} + P_{es,col} T_{e,col} \quad (14)$$

The normalized saturation throughput of the service traffic is defined as the fraction of time the channel is used to transmit the payload $E[P_s]$ successfully

$$S_s = \frac{P_{s,suc} \cdot E[P_s]}{E_S} \quad (15)$$

Let X_e be the random variable representing the total number of back-off slots without the taking into account the case the back-off counter freezes, and its average

$$E[X_e] = (W_e - 1) / 2 \quad (16)$$

The back-off counter decreases with probability $1 - p_e$ and freezes with the probability p_e . Let F_e be the random variable representing the total number of slots when the back-off counter freezes.

$$E[F_e] = \frac{E[X_e]}{(1 - p_e)} p_e \quad (17)$$

Let D_e denote the random variable representing the packet delay. The average delay for emergency packet without the queuing delay are given as

$$E[D_e] = T_{e,suc} + E[X_e]\sigma + E[F_e](P_{e,suc} T_{e,suc} + P_{s,suc} T_{s,suc} + P_{e,col} T_{e,col} + P_{s,col} T_{s,col} + P_{es,col} T_{e,col}) \quad (18)$$

3. Numerical results

In this section, we evaluate the performance of the IEEE 802.11p under saturation condition by varying the number of nodes and the contention window size. The MAC parameters are given in Table 1.

The saturation throughput of the service traffic when varying the number of vehicle nodes is shown in Fig. 4. When the number of vehicle nodes increases, the collision probability increases. If the collision happens, the node which has a collided service packet will perform back-off again with a new contention window value. That is why the saturation throughput decreases. When the contention window size increases, the collision probability will decrease, the service traffic has more chance to access the channel. It leads to higher normalized throughput of service traffic.

Fig. 5 shows the impact of the number of nodes and

Table 1 MAC parameters

Parameters	Value
Data rate	6 Mbps
Emergency data size	100 bytes
WSA	20 bytes
RES	14 bytes
Service data size	2048 bytes
ACK	14 bytes
SIFS	16 μ s
DIFS	34 μ s
Slot time	9 μ s

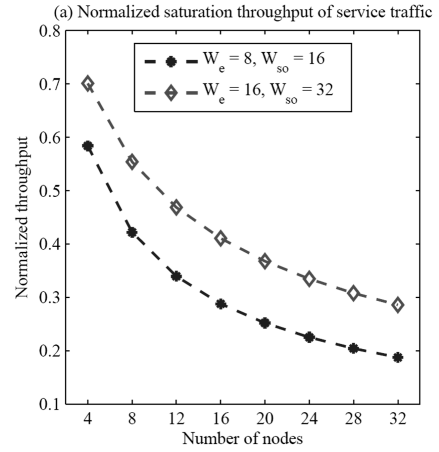


Fig. 4 Normalized saturation throughput

the contention window size on the packet delivery ratio of emergency traffic. Obviously, when the number of nodes is high or the contention window size is small, the collision probability is high. It results in the low packet delivery ratio of emergency traffic.

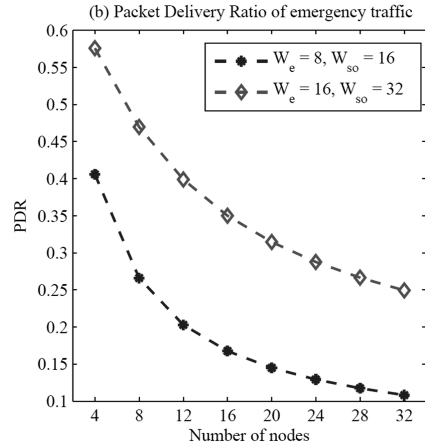


Fig. 5 Packet Delivery Ratio of emergency traffic

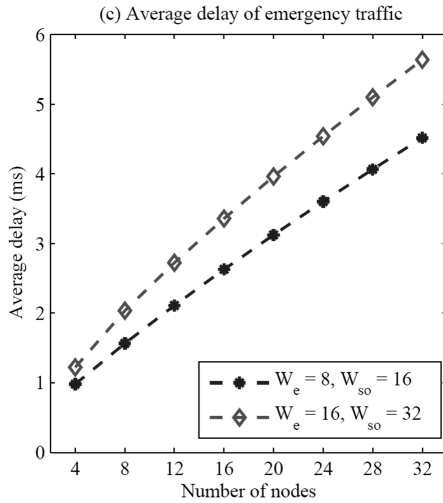


Fig. 6 Average delay of emergency traffic

Whenever the node senses the channel busy, it freezes its back-off counter. If the number of nodes is high, it takes long time for a node to transmit an emergency packet, and the delay is high. The contention window size is high; the service traffic has more chance to access the channel, the average delay of emergency traffic increases as shown in Fig. 6. It is because the duration of successful service data transmission is too long compared to the duration of the emergency data transmission.

4. Conclusions

In this paper, we proposed an analytical model to evaluate the performance of the IEEE 802.11p based MAC for VANET with emergency and service traffic. The numerical results show how the number of nodes and the contention window size affect the network performance.

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