Modelling and Analysis of the Safety Applications in VANETs

VanDung Nguyen and Choong Seon Hong*
Department of Computer Science and Engineering, Kyung Hee University
ngvandung85@khu.ac.kr, cshong@khu.ac.kr

Abstract

Vehicular Ad Hoc Network (VANET) is designed to enhance safety, reduce traffic accidents, and improve transportations efficiency. In addition, safety message requires fast and guaranteed access and a short transmission delay. In this paper, we discuss about performance of broadcast safety message using the IEEE 802.11p mechanism in VANETs. The simulation results are carried out by using SUMO and NS-3 and compare with analytical results.

Key word: VANET, safety message, IEEE 802.11p.

1. Introduction and relative works

VANET as one of special types of Mobile Ad-hoc NETworks (MANET) is characterized by particular features such as huge number of mobility nodes, high speed of nodes, time-varying network topology and fast network portioning. The VANET classifies of a set of vehicles equipped with communication device and a Global Positioning System (GPS) receiver, called On-Board Unit (OBU) and a set of stationary units along roads, called Road Side Units (RSUs). Based on OBU and RSU, VANET has two essential communications: Vehicle-to-Vehicle (V2V) and Vehicle-to-RSU (V2R). Based on V2V and V2R communications, the applications can be divided into three services: safety, traffic management, and user-oriented services [1], [2]. In specific, we briefly summary requirements for different applications shown in TABLE I Firstly, safety-related applications, such as the pre-crash sensing, blind spot warning, emergency electronic brake light, and cooperative information broadcast require that each vehicle periodically broadcasts information about its position, speed, heading, acceleration, and so on, to all vehicles within its one-hop neighborhood. Secondly, traffic management applications form part of a greater intelligent transportation system (ITS) and include toll collection, intersection management, cooperative adaptive cruise control and detour or delay warning. Thirdly, user-oriented services provide information, advertisements, and entertainment for users during their journey. They have two basic applications: Internet connectivity and peer-to-peer applications [1]. However, safety services require fast and guaranteed access and a short transmission delay, while user-oriented services need a broad bandwidth at the same time.

The IEEE 802.11 standard is a recently proposed MAC standard for VANETs. In IEEE 802.11 standard, the system of VANETs is employed the Enhanced Distributed Channel Access (EDCA) schemes. Additionally, the high-priority safety message will be assigned to the high-priority access categories (ACs) which contend for the wireless channel using a small contention window size. Specially, in IEEE 802.11p, vehicle will not send an acknowledgement (ACK) foe the received broadcast safety message. To analysis, Bianchi in [5] proposed model for IEEE 802.11 for unicast communication. But it cannot be used for the analysis for broadcast communication mode in IEEE 802.11p where no ACK will be sent by any of the receivers. Hence, in [6][7]

TABLE 1: DSRC application requirements [3], [4].

Applications	Packet size / Bandwidth	Latency (ms)	Network Data Type	Application Range (m)	Priority
Intersection Collision Warning/Avoidance	100 bytes	100	Event	300	Safety of life
Cooperation Collision Warning	100 bytes/10 Kbps	100	Periodic	50-300	Safety of life
Work Zone Warning	100 bytes/1 Kbps	1000	Periodic	300	Safety
Transit Vehicle Signal Priority	100 bytes	1000	Event	300-1000	Safety
Toll Collections	100 bytes	50	Event	15	Non-Safety
Service Announcements	100 bytes/2 Kbps	500	Periodic	0-90	Non-Safety
Movie Download (2 hours of MPEG 1)	> 20Mbps	NA	NA	0-90	Non-Safety

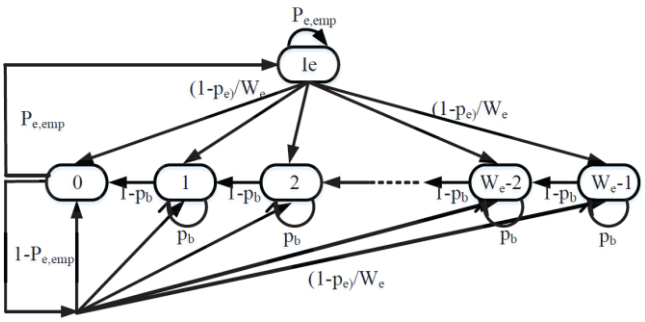

Fig. 1: Markov chain model for safety transmission

the authors studied the saturation throughput of the broadcast safety message in IEEE 802.11. Considering to the busy channel and the traffic priority, in [8], the authors proposed model with two one-dimensional Markov chains. However, this model did not consider unsaturation throughput.

In this paper, we discuss two one-dimensional Markov chains under unsaturation throughput condition and use the backoff counter consecutive freeze process (CFP) (If the channel is sensed busy, the backoff timer is frozen). In addition, we compare between results which are carried out by using SUMO [9] and NS-3 [10] and analytical results.

2. Performance analysis

Since the transmission method of safety packets is broadcast without backoff stage, one-dimensional Markov chain is represented for safety transmissions. In addition, the fixed contention windows (CW) is denoted by W_e. The state of safety transmission is described $b_{e,k}$ $\{k : k \in [0, W_e - 1]\}$.

We assume that the generated safety packets at the MAC layer following a Poison process with rate λ_e. The stationary distribution of the idle state and the backoff state k are denoted by b_{Ie} and $b_{e,k}$, respectively. At each time slot, the backoff timer subtracts one and shown in Fig.1. The meaning of Fig.1 represents five facts as follows.

1. If the channel is idle, the backoff timer subtracts one
2. If the backoff timer value is zero and the queue is not empty, then the backoff timer is initially uniformly chosen in [0, W_e−1]
3. If the channel is sensed busy, the backoff timer is frozen
4. If the backoff timer value is zero and the queue is empty, the node is under idle state
5. If the queue is empty, a new arriving packet makes the backoff timer uniformly chosen in [0,W_e−1]

Theorem: The stationary probability τ_e that a node transmits a safety packet in a generic time slot is

$$\tau_e = \left(\frac{W_e - 1}{2(1-P_b)} + \frac{1}{1-P_{e,emp}} \right)^{-1} \quad (1)$$

Proof

From Markov chain, we can derive that

$$\begin{cases} b_{I_e} = P_{e,emp} b_{e,0} + P_{e,emp} b_{I_e} \\ b_{e,k} = \dfrac{W_e - k}{W_e(1-p_b)} (b_{e,0}(1-P_{e,emp}) + b_{I_e}(1-P_{e,emp})), \\ 1 \le k \le W_e - 1 \end{cases}$$

The normalization condition

$$b_{I_e} + \sum_{k=0}^{W_e - 1} b_{e,k} = 1$$

Let τ_e be the transmission probability of the type of safety packet at each time slot. τ_e can be obtained as

$$\tau_e = b_{e,0} = \left(\frac{W_e - 1}{2(1-P_b)} + \frac{1}{1-P_{e,emp}} \right)^{-1} \blacksquare$$

Let p_b be the probability that the channel is busy. The p_b is given as

$$p_b = 1 - (1-\tau_e)^N \quad (2)$$

Let $P_{e,suc}$ and $P_{e,col}$ be the probability of successful and collision dissemination of a safety packet, respectively. They can be calculated as follows

$$\begin{cases} p_{e,suc} = N\tau_e(1-\tau_e)^{N-1} \\ p_{e,col} = 1 - (1-\tau_e)^N \end{cases}$$

The transmission of a safety packet can be represented as

$$T_{e,suc} = T_{e,col} = SAFE + \sigma + DIFS$$

Each state may be a state of the channel being idle, successful transmission or a collision. The expected time spent per state

$$E[T_{e,s}] = (1-P_b)\sigma + P_{e,suc}.T_{e,suc} + P_{e,col}.T_{e,col}$$

The estimate of $P_{e,emp}$ can be obtained as

$$P_{e,emp} = 1 - e^{-\lambda_e E[T_{e,s}]} \quad (3)$$

Consequently, based on (1)-(3), variable τ_e and p_b can be solved by the numerical methods. Note that $0 < p_b < 1$ and $0 < \tau_e < 1$.

The Packet Delivery Ratio (PDR) of safety application is given as

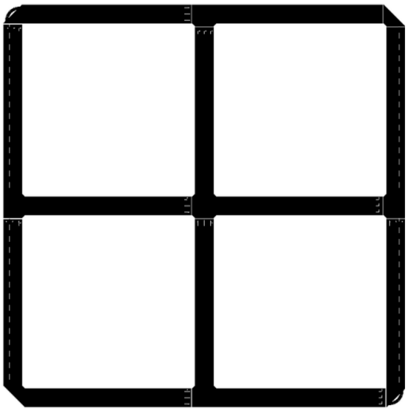
Fig. 2: A sample scenario in SUMO

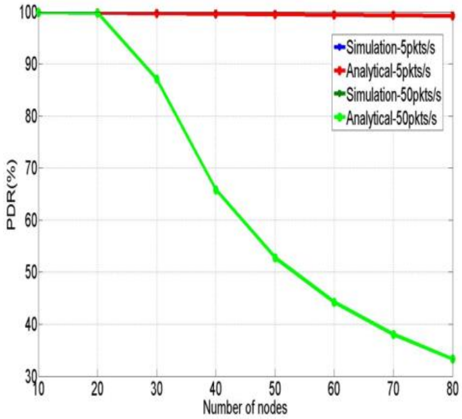

Fig. 3: PDR of safety applications

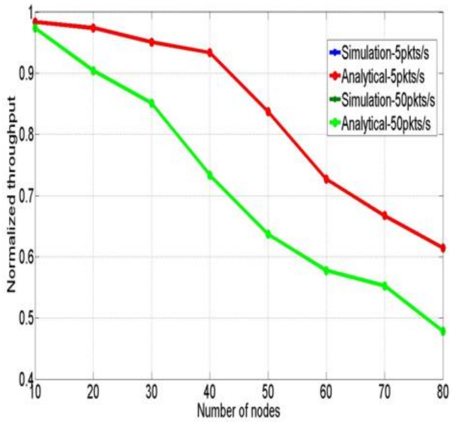

Fig. 4: Normalized throughput

$$PDR = (1-\tau_e)^N$$

The normalized throughput is calculated as

$$S_e = \frac{P_{e,suc} L_e}{E[T_{e,s}]}$$

Where L_e is the payload of safety message.

3. Simulation Result

To validate our model, we use programs written in SUMO and NS-3. The values of the parameter are summarized in Table II to obtain the numerical result for the analytical model.

TABLE II: PARAMETER SETTINGS

Parameter	Value	Parameter	Value
Safety message	100 bytes	W_e	16
Slot time	13 μs	Data rate	12 Mbps
Propagation time δ	1 μs	DIFS	58 μs

Now, we set up a sample scenario as show in Fig. 2. Figs. 3 and 4 show that the analytical results has same values with the simulations results which taken place by using both SUMO and NS-3.

4. Conclusion

This paper compares between analytical results and results which taken place in real VANETs by using SUMO and NS-3. The results show that our analytical model is approximate with real networks. In the future, we will apply this model to adjust the length of the CCH to improve the system throughput.

5. Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (NRF-2017R1A2A2A05000995). *Dr. CS Hong is the corresponding author

6. Reference

[1] H. Hartenstein and L. P. Laberteaux, “A tutorial survey on vehicular ad hoc networks,” IEEE Communications Magazine, vol. 46, no. 6, pp. 164–171, June 2008.

[2] Y. Toor, P. Muhlethaler, A. Laouiti, and A. D. L. Fortelle, “Vehicle ad hoc networks: applications and related technical issues,” IEEE Communications Surveys Tutorials, vol. 10, no. 3, pp. 74–88, Third 2008.

[3] Q. Xu, T. Mak, J. Ko, and R. Sengupta, “Vehicle-to-Vehicle safety messaging in DSRC,” in Proceedings of the 1st ACM International Workshop on Vehicular Ad Hoc Networks, ser. VANET ’04. New York, NY, USA: ACM, 2004, pp. 19–28. [Online]. Available: http://doi.acm.org/10.1145/1023875.1023879.

[4] D. N. M. Dang, H. N. Dang, V. Nguyen, Z. Htike, and C. S. Hong, “HER-MAC: A hybrid efficient and reliable MAC for vehicular ad hoc networks,” in Advanced Information Networking and Applications (AINA), 2014 IEEE 28th International Conference on, May 2014, pp. 186–193.

[5] G. Bianchi, “Performance analysis of the IEEE 802.11 distributed coordination function,” Selected Areas in Communications, IEEE Journal on, vol. 18, no. 3, pp. 535–547, 2000.

[6] X. Ma and X. Chen, "Performance Analysis of IEEE 802.11 Broadcast Scheme in Ad Hoc Wireless LANs," in IEEE Transactions on Vehicular Technology, vol. 57, no. 6, pp. 3757-3768, Nov. 2008. doi: 10.1109/TVT.2008.918731

[7] X. Ma and X. Chen, "Saturation Performance of IEEE 802.11 Broadcast Networks," in IEEE Communications Letters, vol. 11, no. 8, pp. 686-688, August 2007. doi: 10.1109/LCOMM.2007.070040

[8] K. A. Hafeez, L. Zhao, Z. Liao and B. N. W. Ma, "Performance Analysis of Broadcast Messages in VANETs Safety Applications," 2010 IEEE Global Telecommunications Conference GLOBECOM 2010, Miami, FL, 2010, pp. 1-5.

[9] SUMO [[Available]] http://sumo.dlr.de/wiki/Installing

[10] NS-3 [Available] https://www.nsnam.org/