The IEEE 802.11p Performance for Different Packet Length and Arrival Rate in VANETs

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***Abstract*—The IEEE 802.11p standard uses Enhanced Distributed Channel Access (EDCA) mechanism for the contention-based prioritized Quality of Service (QoS) at the Media Access Control (MAC) layer. The IEEE 802.11p is MAC and physical (PHY) layer standard for Vehicle Ad Hoc Networks (VANETs), which uses the Enhanced Distributed Channel Access Function (EDCAF) to support contention-based prioritized QoS in the MAC layer. VANET aims to provide users with a better, safer and more coordinated approach to their destination. This paper provides an analytical model to compute the performance of the IEEE 802.11p EDCAF for Vehicular Network based on packet size.**

Keywords—IEEE 802.11p; EDCA; performance analysis; VANET

I. Introduction

An Intelligent Transportation System (ITS) is an advanced application, which intelligence as such, aims to provide innovative services relating to different modes of transport, traffic management. ITS allows users to be better informed and use safer, more coordinated and smarter transport networks [1].

ITS is working to increase road safety and to provide on-site information services to improve transport efficiency. For these applications, the vehicles can be equipped with sensors and communication devices to form a network called the Vehicle Ad Hoc Network (VANET).

The IEEE 802.11p standard [2] known as Wireless Access in Vehicular Environments (WAVE) is specially developed to adapt VANETs requirements and supports ITS. The performance of WAVE physical layer is one of the important factors that play a great role in the communication process [3]. The IEEE 802.11p uses an Enhanced Distributed Channel Access (EDCA) mechanism, which is designed for the contention-based prioritized Quality of Service (QoS) support at the MAC layer. The IEEE 802.11p EDCA mechanism defines four access categories (ACs); AC_VO (Voice), AC_VI (Video), AC_BE (Best effort) and AC_BG (Back ground). The priority among ACs is set by different EDCA parameters. An enhanced distributed channel access function (EDCAF) is used for each AC queue at the MAC sublayer to contend for transmission opportunities using its own EDCA parameters. EDCA parameters include the minimum contention window (CW_{min}), maximum contention window (CW_{max}) and Arbitration Interframe Space Number (AIFSN).

Recently performance modeling of the IEEE 802.11p EDCA mechanism has been studied in [1]. In this paper, the performance model was developed considering all important factors that may affect the performance of the IEEE 802.11p EDCA mechanism for different ACs. In these calculations, the effect of the package size on performance and delay has been examined. Strong approximations are avoided to ensure the accuracy of the model. Markov Chain modeling based theoretical analysis is presented where the relationship between EDCA parameters and EDCA performance metrics are shown. Simulation results are provided to demonstrate the accuracy of the analytical model. Simulations were done using MATLAB. The rest of the paper is organized as follows. Section II describes the analytical model and performance analysis. Section III presents the simulation results. Section IV concludes the paper.

II. Analytical Model and Performance Analysis

The 802.11 standard defines EDCA as a mechanism by which one class of frames can be given priority over another in their competition to access the medium. The relationship between EDCA parameters and performance metrics are also established for all AC queues. Based on Markov model, the performance of the IEEE 802.11p EDCA mechanism for all ACs is derived. According to the package size changes, throughput and delay analysis were performed

A. Overview of the Enhanced Distributed Channel Access

The EDCA is a channel access mechanism designed for the contention-based prioritized QoS support at the MAC layer. The EDCA mechanism defines four ACs. The four ACs have four priorities, including CW_{min}, CW_{max} and AIFSN. The contention window parameters are shown in Table I.

TABLE I. DEFAULT EDCA PARAMETER FOR DIFFERENT ACS

AC	CW_{min}	CW_{max}	AIFSN	TXOP Limit
AC_BK	aCW_{min}	aCW_{max}	9	0
AC_BE	aCW_{min}	aCW_{max}	6	0
AC_VI	$(aCW_{min}+1)/2-1$	aCW_{min}	3	0
AC_VO	$(aCW_{min}+1)/4-1$	$(aCW_{min}+1)/2-1$	2	0

Each AC queue uses different AIFS, CW_{min} and CW_{max}. Prioritization of transmission in EDCA is implemented by a new Inter-Frame Space (IFS), namely, Arbitration Inter-Frame Space (AIFS). The duration of AIFS for each AC is derived from the value of AIFSN of that AC. SIFS is the duration of

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the short inter-frame space and T_{slot} is the duration of a slot time [4]. AIFSN can be expressed as follows

$$AIFS\ [AC] = AIFSN\ [AC] \times T_{slot} + SIFS \quad (1)$$

Prioritization mechanism is shown in Figure 1.

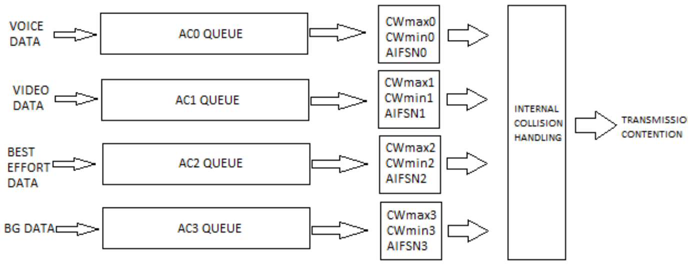

Figure 1. Demonstration of EDCA Mechanism

The EDCA mechanism relies on the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) technique to contend and access channel, which a station must probe the channel before transmission to determine whether it is busy or idle. If only one AC queue has backlogged data at a time in a station, and the station will sense the channel idle for the duration of AIFS[AC] before attempting to transmit it. If the channel is sensed as busy, then the station defers its transmission of an additional back-off interval. The back-off interval is calculated as a random number of slot times uniformly selected from [0, CW[AC]]. At the first transmission attempt, the back-off interval for an AC in EDCA is randomly selected from [0, CW_{min}[AC]], and it is doubled at every retransmission with an upper limit equal to CW_{max}[AC]. The smaller is AIFS[AC] or CW_{min}[AC], the higher is the priority in channel access. If the channel is sensed idle in a slot, the back-off counter will be decremented by 1. The packet will be transmitted when the back-off counter becomes 0. For priority reasons, EDCA mechanism employs a separate time for back-off. Therefore, an internal collision occurs inside a station, also called virtual collision. If an internal collision occurs, the station will grant the transmission to the AC queue with the highest priority. In the meantime, the AC queue with lower priorities will start to back-off and then the packet will be transmitted.

B. Markov Model Analysis

A Markov chain is a stochastic model describing a sequence of possible events in which the probability of each event depends only on the state attained in the previous event. The Markov chain describes the withdrawal procedure of any AC. In this Markov chain, k is the value of a back-off counter. The value of k is initially set to from 0 [0, W−1] and is decremented by 1 if the channel is sensed idle in a slot, frozen at the current value when the channel sensed busy. The packet will be transmitted when k becomes zero[7]. T_{slot} is the slot time size. P_c and P_b is the collision probability and channel busy probability in a slot. Figure 2 shows the Markov chain model

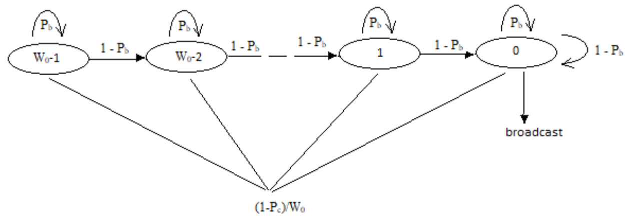

Figure 2. Back-off Process via Markov Chain Model

The back-off time is decremented by 1 when the channel is sensed idle, the calculation is specified in Equation (2). The back-off time is frozen at the current value when the channel is sensed busy, is specified in Equation (3). The packet will be transmitted when the back-off counter becomes 0, is specified in Equation (4).

$$P\{k|k+1\} = 1 - P_b \qquad k \in (0, W_0 - 2) \quad (2)$$

$$P\{k|k\} = \frac{P_b}{W_0} \qquad k \in (0, W_0 - 1) \quad (3)$$

$$P\{k|0\} = \frac{1-P_c}{W_0} \qquad k \in (0, W_0 - 1) \quad (4)$$

The solutions can be obtained from the Markov chain. b(t) be the stochastic process representing the back-off counter for a given vehicle at timeslot t. $b(t) \in (0, W_0 - 1)$. The Markov chain is constructed to describe the back-off procedure of an AC [7]. As the sum of all possible states equal to one, so following relations can be derived

$$1 = \sum_{k=0}^{W_0-1} b_k = \sum_{k=0}^{W_0-1} \frac{W_0 - k}{W_0} b_0$$

from which

$$b_0 = \frac{2}{W_0+1} \quad (5)$$

A vehicle transmits a packet in a randomly chosen slot time probability P_t can be expressed as follows

$$P_t = b_0 = \frac{2}{W_0+1} \quad (6)$$

Considering n number of vehicle, P_c is the probability that, in a slot time, at least one of the n-1 remaining vehicles transmit packet. Each remaining vehicle transmits a packet with probability P_t., the collision probability is given by

$$P_c = 1 - (1 - P_t)^{n-1} \quad (7)$$

If the vehicle competes on the channel and each transmits the probability via P_t., the probability of channel busy can be written as

$$P_b = 1 - (1 - P_t)^{n-1} \quad (8)$$

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P_s is the successful transmission probability that a transmission occurring on the channel is successful, which can be calculated as

$$P_s = \frac{2n}{\frac{(W_0+1)^n}{(W_0-1)^{n-1}} - W_0 + 1} \quad (9)$$

P_q is the packet arrival probability that follows a Poisson distribution with a constant arrival rate λ, which can be calculated as

$$P_q(n\ arrivals\ in\ interval\ T_e) = \frac{(\lambda T_e)^n e^{-\lambda T_e}}{n!} \quad (10)$$

where n number of arrivals and T_e is the expected time that a vehicle spends in each Markov state [5]. For n=0

$$P_q = 1 - e^{-\lambda T_e} \quad (11)$$

$$T_e = (1-P_b)T_{slot} + P_b P_s T_s + P_b(1-P_s)T_c \quad (12)$$

where T_s and T_c are the time duration when a packet is transmitted collision free and transmitted with collision respectively. Due to vehicular networks broadcast nature T_s and T_c are equal, which can be expressed as

$$T_s = \frac{L_h + L}{R_d} + SIFS + AIFS + T_{delay} \quad (13)$$

where L_h is the MAC layer and physical layer header lengths, L is the packet size, R_d is the system data transmission rate and T_{delay} is the propagation delay.

C. Throughput Analysis

The normalized system throughput S is the average information payload transmitted in a slot time over the average duration of a slot time

$$S = \frac{E[payload\ info]}{E[length\ of\ a\ slot\ time]} \quad (14)$$

The normalized system throughput S can be expressed as follows

$$S = \frac{P_s P_b L}{(1-P_b)T_{slot} + P_b P_s T_s + P_b(1-P_s)T_s} \quad (15)$$

L is the packet size, T_{slot} is the duration of a slot time [6].

For all transmission protocols with CSMA base, the throughput variation equation based on the offered traffic load of the environment can be expressed as follows

$$S = \frac{Ge^{-\propto G}}{(1-e^{-\propto G}) + \propto} \quad (16)$$

where G offered traffic load, T packet transmission time, τ propagation delay through the air. The offered traffic load of a cell is typically characterized by average number of mobile stations requesting the service and average length of time the mobile stations requiring the service [8]. The offered traffic load $\propto$ is normalized time unit and can be expressed as $\propto = \frac{\tau}{T}$.

D. Delay Analysis

E[Tw] is the average waiting time of an AC queue at the back-off stage can be calculated by using Equation (12)

$$E[T_w] = \frac{W_0 - 1}{2} T_e \quad (17)$$

is the average access delay of an AC queue that is the average time for a packet transmission starts to contend for the channel until the packet successfully transmitted or dropped can be derived by using Equation (7) and Equation (17)

$$E[D_{access}] = E[T_w]P_c(1-P_c) + E[T_w]P_c \quad (18)$$

There are two events may occur, either the packet will be transmitted successfully if a collision occurs and no collision occurs, or the packet is dropped due to collision.

E[Tinterval] is the average packet interval time between two successfully received packets at one receiver can be calculated by using Equation (12)

$$E[T_{interval}] = nT_e \quad (19)$$

E[Tdrop] is the average time to drop a packet can be expressed as

$$E[T_{drop}] = E[X_{drop}]T_e \quad (20)$$

where E[Xdrop] is the average number of slot times for a dropped packet

$$E[X_{drop}] = \frac{W_0 + 1}{2} \quad (21)$$

E[D] is the average packet delay of an AC queue that is the average delay for a successfully transmitted packet which can be calculated as

$$E[D] = E[T_{interval}] - \frac{P_{fdrop}}{1 - P_{fdrop}} E[T_{drop}] \quad (22)$$

where Pfdrop is the probability that a packet will finally be dropped.

III. SIMULATION RESULTS

In previous sections, the performance of the IEEE 802.11p EDCAF and the verification of the theoretical analysis were calculated. The simulations are conducted in MATLAB. The data packets arrive at each AC queue following the mean of the process is 0.5 Mbps. The simulation model includes MAC behavior of IEEE 802.11p in vehicular networks. In this simulation, the number of vehicles is fixed and is calculated as 10. Packet arrival probability is defined as vector. Pfdrop is fixed and calculated as 0.03. Table II provides the parameters value used in the simulation.

TABLE II. VALUE OF PARAMETER USED IN SIMULATION

Parameter	Value	Parameter	Value
CW_{min} [0]	3	CW_{max} [0]	7
CW_{min} [1]	3	CW_{max} [1]	15
CW_{min} [2]	7	CW_{max} [2]	1023
CW_{min} [3]	15	CW_{max} [3]	1023
AIFSN [0]	2	AIFSN [1]	3
AIFSN [2]	6	AIFSN [3]	9
T_{slot} , T_{delay} (μs)	20, 1	SIFS, AIFS (μs)	10, 64
L_h	46	R_d , λ (Mbps)	11, 0.5

Figure 3 shows throughput versus packet arrival probability when the packet size (L) is 512 bytes. The scenario was simulated with the average packet length planned to be used in vehicle-2-vehicle communication. The packet size can contain at least 64 bytes with the header and at most 1518 bytes in the 802.11 standards. Figure 4 and Figure 5 show throughput versus packet arrival probability when the packet size (L) is 64 bytes and 1500 bytes respectively. Figure 3, Figure 4 and Figure 5 shows that the increase of length of the packet size affects the throughput in the right direction. So using largest packet is more efficient. Figure 6 shows the average access delay versus packet arrival probability when the packet size is 64 bytes. Figure 8 shows the average access delay versus packet arrival probability when the packet size is 1518 bytes. According to the Figure 6 and Figure 8, AC [0] provides minimum latency while the packet arrival probability increases. In the calculations, AC [2] and AC [3] values are very close to each other. But we can see that if we use AC [2] and AC [3], we should try to send packages with minimum size. Figure 9 shows the throughput change graph depending on the offered load if 10 vehicles in the environment request are generated during a minute when $\tau = 0.1$.

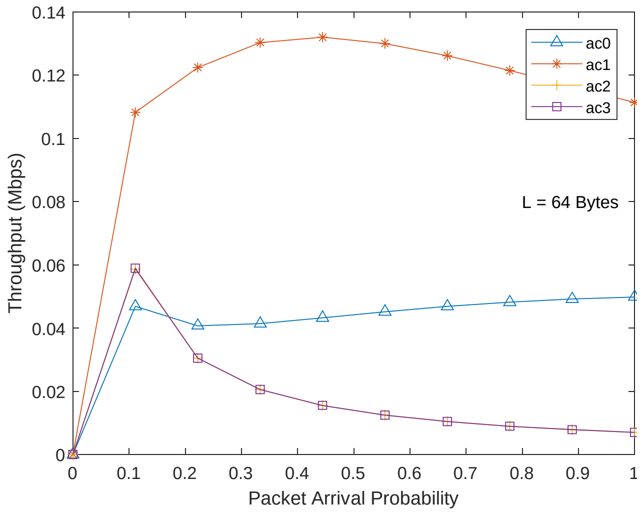

Figure 3. Throughput versus packet arrival probability (L=64)

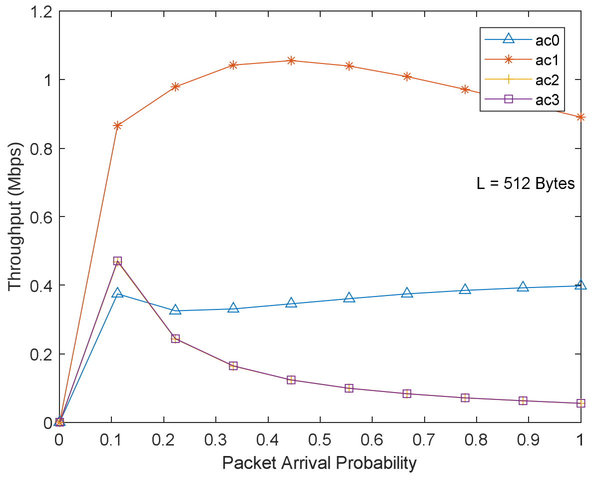

Figure 4. Throughput versus packet arrival probability (L=512)

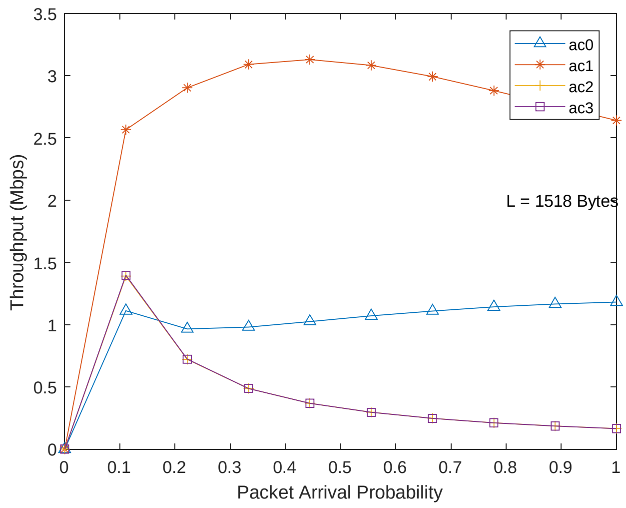

Figure 5. Throughput versus packet arrival probability (L=1518)

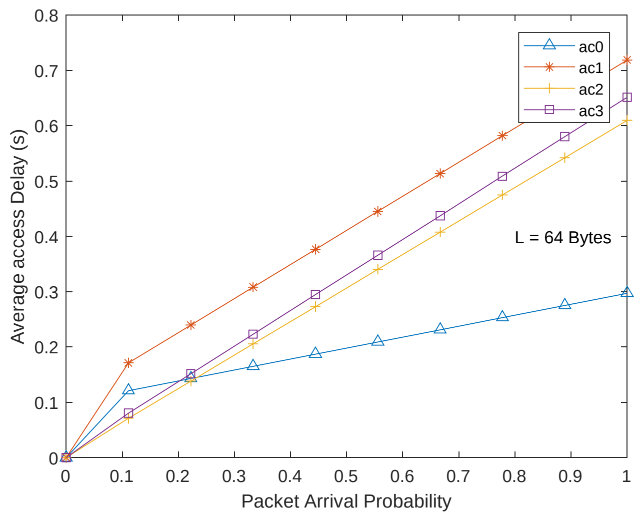

Figure 6. Average access delay versus packet arrival probability (L=64)

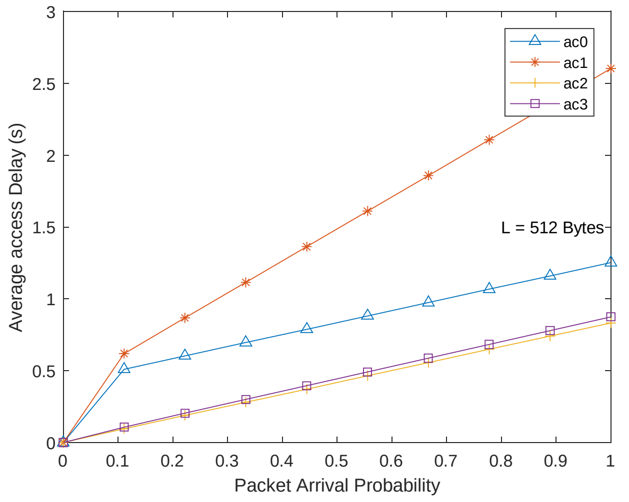

Figure 7. Average access delay versus packet arrival probability (L=512)

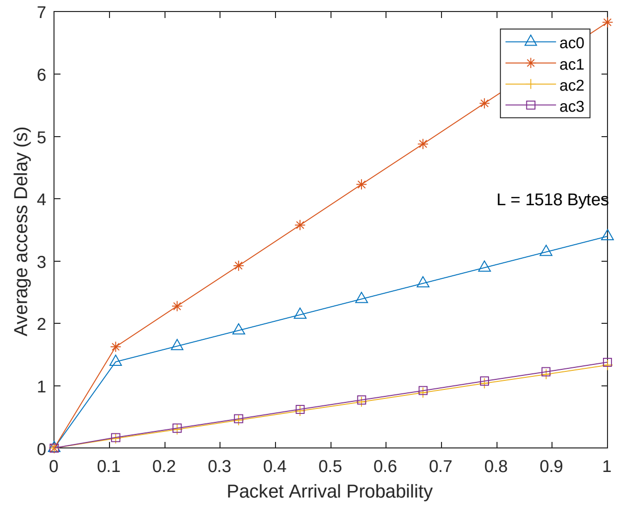

Figure 8. Average access delay versus packet arrival probability (L=1518)

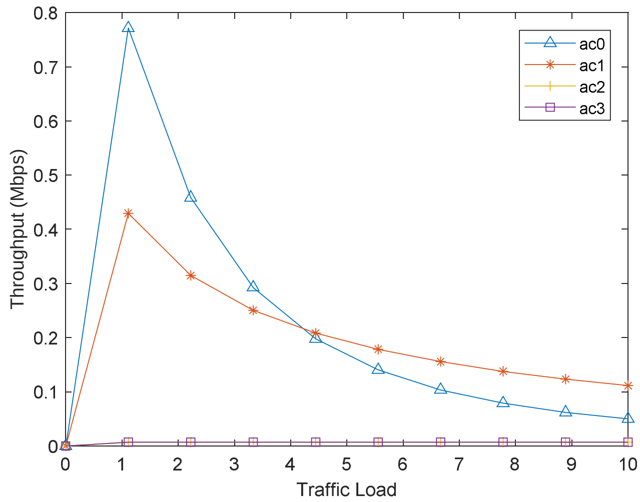

Figure 9. Throughput versus offered traffic load

IV. CONCLUSION

In this paper, a simple analytical model to compute the performance of the IEEE 802.11p EDCAF for vehicular network is presented. The performance model is derived based on Markov chain. The Markov model calculates all important factors that can affect the access performance of the IEEE 802.11p EDCA mechanism for each AC, such as the CW, AIFS and internal collisions. Equation (9), Equation (10), Equation (15) and Equation (18) shows the relationship among the EDCA parameters and performance matric considering transmission probability, collision probability, throughput and delay. Simulation results show that the packet size change affects throughput proportionally. Given the declining throughput because of increased traffic intensity, AC [0] should be preferred up to a certain density for critical messages. With increasing offered load, channel preference can shift to AC [1].

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