# Performance Analysis of The IEEE 802.11p for Different Packet Length in VANETs

**Osman TOKER**
**Havelsan A.S.**
**Istanbul, Turkey**
**osmantoker@hotmail.com**

**A.F.M. Shahen SHAH**
**Department of Electronics & Communication Engineering**
**Yildiz Technical University**
**Istanbul, Turkey**
**shahen.shah@hotmail.com**

**M.S. Ufuk TURELI**
**Department of Electronics & Communication Engineering**
**Yildiz Technical University**
**Istanbul, Turkey**
**utureli@yildiz.edu.tr**

**ABSTRACT**

The IEEE 802.11p standard defines the specification of Medium Access Control (MAC) and physical layer (PHY) of Vehicle Ad Hoc Networks (VANETs) which uses the Enhanced Distributed Channel Access Function (EDCAF) to support contention-based prioritized Quality of Service (QoS) in the MAC layer. The EDCA (Enhanced Distributed Channel Access) mechanism defines four access categories (ACs). Each AC queue works as an independent DCF station (STA) with Enhanced Distributed Channel Access Function to contend for Transmission Opportunities (TXOP) using its own EDCA parameters. This paper provides an analytical model to compute the performance of the IEEE 802.11p Enhanced Distributed Channel Access Function for Vehicular Network and provides an analytical model to compute the performance of the IEEE 802.11p EDCAF for vehicular network based on packet size. The derived performance model is verified by simulation.

**Keywords:** IEEE 802.11p; EDCA; performance analysis; VANET.

## I. Introduction

The IEEE 802.11p standard known as wireless access in vehicular environments (WAVE) is specially developed to define medium access control (MAC) and PHY layer specification for VANETs [1].

Vehicular Ad Hoc Network is a type of Mobile Ad Hoc Network (MANET) based on short range communications among moving vehicles and between vehicles and roadside units (RSUs) [8]. IEEE 802.11p radio frequency LAN system is initially aimed for the 5.15-5.25, 5.25-5.35 GHz and 5.725-5.825 GHz unlicensed national information infrastructure band. The support of sending data at 6, 12, and 24 Mbit/s are mandatory while 9, 18, 36, 48, 54Mbit/s are optional data rates [9]. IEEE 802.11p is referred to as dedicated short-range communications (DSRC) standard for wireless access in vehicular environment. 75 MHz of licensed spectrum at 5.9 GHz has been allocated for DSRC. This bandwidth is divided into one central control channel (CCH) and six service channels (SCHs). CCH is dedicated for transmission of traffic safety messages while SCHs are dedicated to transfer of various application data. Figure 1 shows DSRC frequency spectrum [8].

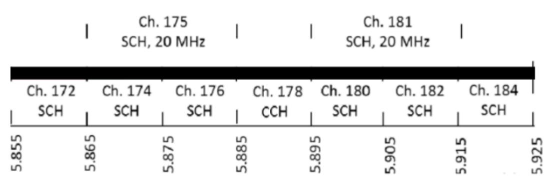


Figure. 1. DSRC Frequency Spectrum

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]. An ITS technical architecture based on IEEE 1609 WAVE standards must define a complementary set of services that enable secure vehicle-to-vehicle and vehicle-to-infrastructure wireless communication. The IEEE 1609 family of standards provides the foundation for a broad range of applications in the transportation environment, including vehicle safety, public safety, communication fleet management, automated tolling, enhanced navigation, traffic management and other operations as mentioned above [10].

The performance of the WAVE physical layer is one of the factors that play an important 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 between ACs is determined 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. The EDCA parameters are as follows; minimum contention window (CWmin), maximum contention window (CWmax), Arbitration Inter-Frame Space (AIFS) and Arbitration Interframe Space Number (AIFSN).

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 includes conclusion and future work for the paper.

## II. ANALYTICAL MODEL AND PERFORMANCE ANALYSIS

The IEEE 802.11p standard defines EDCA as a mechanism by which one class of frames can be given priority.

### A. *Overview of the Enhanced Distributed Channel Access*

The duration of AIFS for each AC is derived from the value of AIFSN of that AC. SIFS is the duration of the short inter-frame space and Tslot is the duration of a slot time [4]. The contention window parameters are shown in Table I.

TABLE I. DEFAULT EDCA PARAMETERS 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 |

AIFS [AC] can be expressed as follows;

$$AIFS\,[AC] = AIFSN\,[AC] \times Tslot + SIFS \quad (1)$$

Prioritization mechanism is shown in Figure 2.

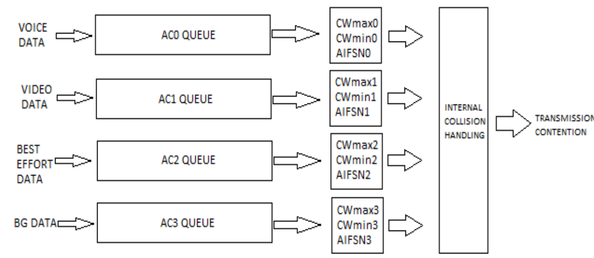


Figure. 2. Demonstration of EDCA Mechanism

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]. 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 [2]. The flowchart of the EDCA mechanism for 802.11P is shown in Figure 3.

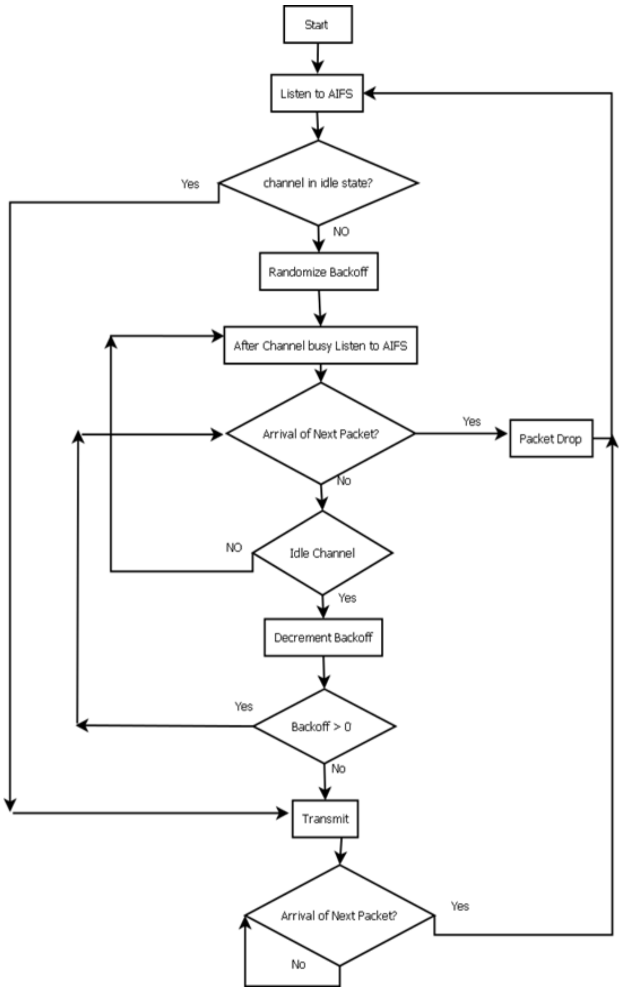


Figure. 3. Flowchart of The 802.11p Mechanism

## B. *Markov Model Analysis*

In our analytical model, the Markov chain describes the withdrawal procedure of each AC such that a state k represents the value of a back-off counter. Figure 4 shows the Markov chain model;

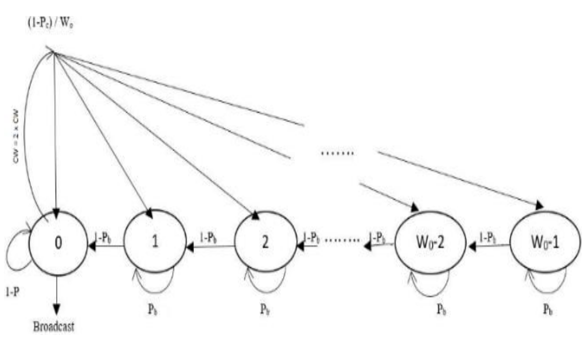


Figure. 4. Back-off Process via Markov Chain Model

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 [6]. $T_{slot}$ is the slot time size. $P_c$ and $P_b$ is the collision probability and channel busy probability in a slot. The back-off time is decremented by 1 when the channel is sensed idle, the calculation is specified in Eq. (2). The back-off time is frozen at the current value when the channel is sensed busy, is specified in Eq. (3). The packet will be transmitted when the back-off counter becomes 0, is specified in Eq. (4).

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

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

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

b(t) be the stochastic process representing the back-off counter for a given vehicle at timeslot t. $b(t) \in (0, W_0\text{-}1)$. As the sum of all possible states equal to one, so following relations can be derived

$$1 = \sum_{k=0}^{W_0-1} b_k = \sum_{k=0}^{W_0-1} \frac{W_0-k}{W_0} b_0 \tag{5}$$

from which

$$b_0 = \frac{2}{W_0+1} \tag{6}$$

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

$$P_t = b_0 = \frac{2}{W_0+1} \tag{7}$$

Considering n number of vehicles, $P_c$ is the probability that, in a slot time, at least one of the n-1 remaining vehicles transmit packet. The collision probability is given by

$$P_c=1-(1-P_t)^{n-1} \tag{8}$$

If the vehicle competes on the channel and each transmits the probability with $P_t$, then $P_b$ can be written as

$$P_b=1-(1-P_t)^{n-1} \tag{9}$$

$P_s$ is the successful transmission probability that a transmission occurring on the channel is successful which can be given as

$$P_s=\frac{2n}{\frac{(W_0+1)^n}{(W_0-1)^{n-1}}-W_0+1} \tag{10}$$

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

$$P_q=1-e^{-\lambda T_e} \tag{11}$$

where $T_e$ is the expected time that a vehicle spends in each Markov state which can be given as

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

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

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

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. The normalized system throughput S can be expressed as follows

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

The normalized system throughput S can be expressed as follows

$$S=\frac{P_sP_{bL}}{(1-P_b)T_{slot}+P_bP_sT_s+P_b(1-P_s)T_s} \tag{14}$$

L is the packet size, $T_{slot}$ is the duration of a slot time [5].

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

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

where G offered traffic load, T packet transmission time, $\tau$ 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 [7]. The offered traffic load $\propto$ is normalized time unit and can be expressed as $\propto=\frac{\tau}{T}$.

## III. Simulation Results

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. 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 |
| n | 10 | $R_d$ , λ (Mbps) | 11, 0.5 |

Figure 5 shows throughput versus packet arrival probability when the packet size (L) is 64 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 6 and Figure 7 show throughput versus packet arrival probability when the packet size (L) is 512 bytes and 1500 bytes respectively. Figure 5, Figure 6 and Figure 9 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 8 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.

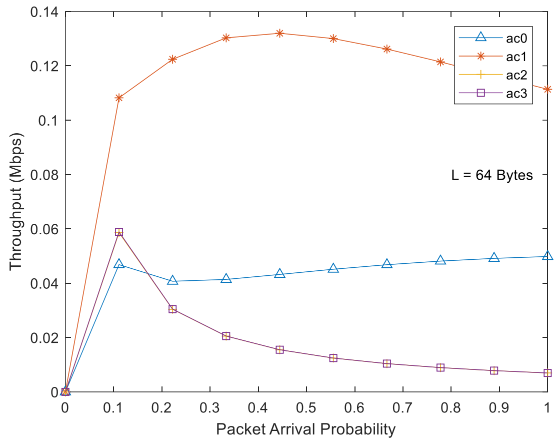


Figure. 5. Throughput versus packet arrival probability (L=64)

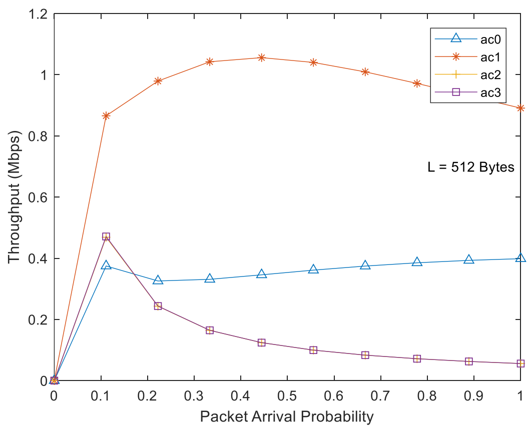


Figure. 6. Throughput versus packet arrival probability (L=512)

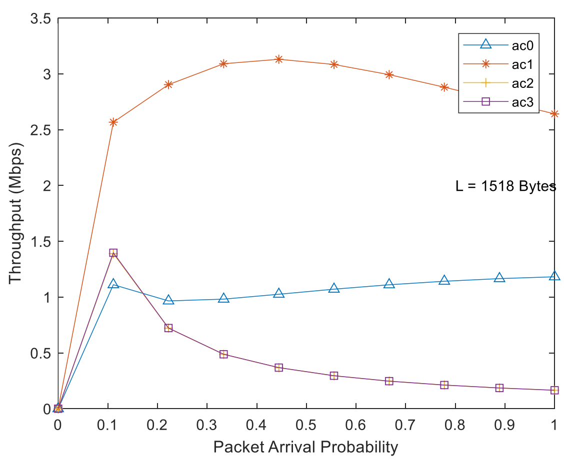


Figure. 7. Throughput versus packet arrival probability (L=1518)

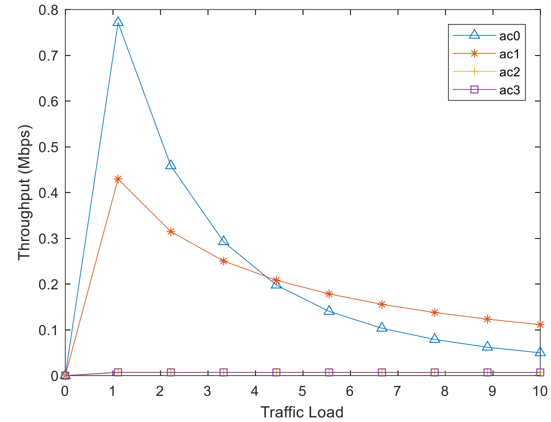


Figure. 8. Throughput versus offered traffic load

## IV. CONCLUSION AND FUTURE WORK

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. Eq. (10), Eq. (11) and Eq. (14) 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]. In simulations, the same packet size is calculated for all access channels, but analyzing the packet size, which should be calculated according to different data types, may be more useful in terms of efficiency. In addition, time-varying distance variations between nodes should also be calculated so that this analysis can give more realistic results. In simulations, the same packet size is calculated for all access channels, but analyzing the packet size, which should be calculated according to different data types, may be more useful in terms of efficiency. In addition, time-varying distance variations between nodes should also be calculated so that this analysis can give more realistic results.

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