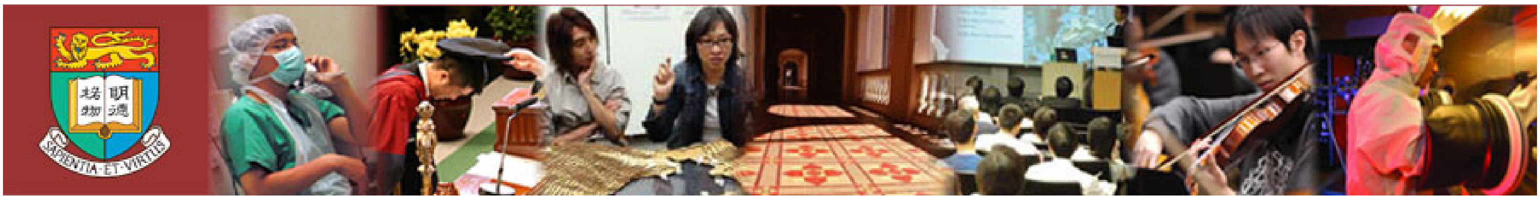

Title	Link quality based EDCA MAC protocol for WAVE vehicular networks
Author(s)	Zhu, LD; Yeung, LK
Citation	The 2013 International Conference on Communications, Circuits and Systems (ICCCAS 2013), Chengdu, China, 15-17 November 2013. In Conference Proceedings, 2013, p. 1-6
Issued Date	2013
URL	http://hdl.handle.net/10722/189904
Rights	International Conference on Communications, Circuits and Systems (ICCCAS). Copyright © IEEE.

Link Quality Based EDCA MAC Protocol for WAVE Vehicular Networks

Lidong Zhu
National Key Laboratory of Science and Technology on Communications, UESTC, Chengdu, China

Kwan L. Yeung
Department of Electrical and Electronic Engineering,
The University of Hong Kong, Hong Kong, PRC.

***Abstract*-The WAVE vehicular networks adopt the Enhanced Distributed Channel Access (EDCA) as the MAC layer protocol. In EDCA, different values of arbitrary inter-frame space (AIFS) can be used for different classes of traffic. The smaller the AIFS value is, the higher the priority a device has in accessing the shared channel. In this paper, we exploit the possibility of assigning the AIFS values according to channel/link quality. Notably a device with better link quality can transmit at a higher data rate. Therefore, our key objective is to maximize the system throughput between a roadside unit (RSU) and the onboard units (OBUs) passed by. Since IEEE 802.11p supports eight transmission rates, two schemes for mapping AIFS values to transmission rates are studied. The first one (8-level-AIFS) uses eight distinct AIFS values, one for each transmission rate. And the second one (4-level-AIFS) uses four distinct AIFS values, one for every two adjacent transmission rates. Their throughput performances are studied by simulations. It is interesting to note that OBUs tend to experience the same pattern of channel quality fluctuation, due to the similar vehicle moving pattern. To this end, assigning AIFS values according to link quality is fair.**

I. INTRODUCTION

Wireless access in vehicular environments (WAVE) provides wireless communications over short distance between roadside units (RSUs) and onboard units (OBUs) or among OBUs. In this paper, we focus on the communications between a RSU and the OBUs passed by. The two main characteristics of vehicular networks are: limited connection time and fast changing network topology.

In 1999 the Federation Communications Commission (FCC) of the United States assigned 5.9 GHz frequency bands for intelligent transportation systems (ITS), and some standards are issued, such as IEEE 802.11p and IEEE 1609 series [1-3]. IEEE 802.11p specifies both wireless LAN medium access control (MAC) and physical layer (PHY) for WAVE. IEEE 1609.4 further extends WAVE to support multiple channels.

There are two types of channels in a WAVE mode network, a single control channel and six service channels. The system operates under a synchronized frame structure. The typically envisioned frame duration is of 100 ms. In the first 50 ms of the frame, all devices (both RSU and OBUs) must tune to the control channel. In the next 50 ms, devices can tune to their preferred service channels (based on the information received from the control channel) for parallel communications.

Vehicular networks support both safety and non-safety applications. Safety applications include road safety and emergency services, which are mission-critical and delay sensitive. Their associated MAC frames 1 are normally transmitted on the control channel, and their timely delivery is ensured by design (i.e. by reserving sufficient channel resources). Non-safety applications include web browsing, e-mail, e-maps download, audio/video streaming etc. They are typically transmitted over the service channels. Although they are not mission-critical, they can be delay sensitive (audio/video streaming) as well as delay insensitive.

In this paper, we focus on carrying delay insensitive traffic, and our objective is to maximize the throughput on the service channels using innovative cross-layer optimization techniques. Notably, all MAC frames are exchanged on both control and service channels using the EDCA MAC protocol specified in IEEE 802.11e, and IEEE 1609.4 [2] allows the EDCA parameter set for service channels to be adjusted. The EDCA parameters include arbitrary inter-frame space (AIFS), minimum and maximum backoff window size (CWmin and CWmax), and transmission opportunity limit (TXOP_limit). They are set according to the class of traffic carried (see Tables I & II). In this paper, with the objective of maximizing the system throughput, we propose to set the EDCA parameters by also taking the link quality of individual devices into account. A device with better link quality can transmit at a higher data rate. The device with a stronger received signal strength indication (RSSI) is assigned to use a lower AIFS, such that it can grab the channel with higher probability and send data at a higher rate.

Some salient points of our work are summarized below:

- For delay insensitive traffic, based on the received signal strength indication (RSSI), two schemes for mapping AIFS values to transmission rates are designed and studied, 8-level-AIFS and 4-level-AIFS.
- The EDCA protocol with the modified AIFS mapping is fully compliant with IEEE 802.11p and IEEE 1609 series standard, and will not interfere with the delay sensitive traffic (of non-safety applications).
- The modified EDAC protocol is fair because while OBUs passing by, they experience a similar pattern of link quality variation, due to their similar moving pattern.

The (MAC) frame here is a PDU at the MAC layer. It should not be mixed with the synchronized frame structure adopted by WAVE

II. RELATED WORK

The basic MAC protocol for WAVE vehicular networks is the same as Enhanced Distributed Channel Access (EDCA) of 802.11e. Four priority levels are defined and mapped to access category for WAVE implementations，including voice, video, best effort and background. Priority levels are differentiated by using different values of AIFS, CWmin, CWmax and TXOP_limit.. For the first three parameters, a smaller value implies a higher priority. The vice versa is true for TXOP limit. In this paper, we focus on adjusting the values of AIFS for maximizing the system throughput performance. In EDCA, a device has to wait for the channel to be idle for at least AIFS seconds before it can access it. Under normal operation loads, AIFS is the most effective parameter in determining the priority level of a device. It is interesting to note that AIFSN is shown in Table I instead of AIFS. Their relationship is

$$AIFS = AIFSN \times TimeSlot + SIFS \qquad \textbf{(1)}$$

where SIFS is short inter-frame space and TimeSlot is the duration of one empty slot time. The values of SIFS and TimeSlot are pre-determined in WAVE mode vehicular networks (see Table VI).

WAVE provides two protocol stacks [3]: standard Internet Protocol (IPv6) and the unique WAVE Short Message Protocol (WSMP) for optimized operation in the WAVE environment. The EDCA parameter set used on the control channel [2], as shown in Table I, is optimized for WSMP data transfer, which shall be used for all WAVE devices when operating on the control channel.

TABLE I EDCA PARAMETER SET USED ON THE CONTROL CHANNEL [2]

ACI	Service	CWmin	CWmax	AIFSN	TXOP Limit
1	Background	15	1023	9	0
0	Best Effort	7	15	6	0
2	Video	3	7	3	0
3	Voice	3	7	2	0

Both IP and WSMP data frames are permitted on a service channel [3]. The default EDCA parameter set is shown in Table II. A service provider may adapt it according to its own requirements or change in offered load [2].

TABLE II EDCA PARAMETER SET USED ON THE SERVICE CHANNEL

ACI	Service	CWmin	CWmax	AIFSN	TXOP Limit
1	Background	15	1023	7	0
0	Best Effort	15	1023	3	0
2	Video	7	15	2	0
3	Voice	3	7	2	0

Since EDCA parameter set on service channels can be changed, we propose to choose AIFS values for delay insensitive services (i.e. background and best effort services) based on link quality. When an onboard unit (OBU) has good channel condition, we choose a smaller AIFS to ensure its prioritized access. Besides, an OBU with a better link quality can send at a higher transmission rate. According to IEEE 802.11p, eight pre-defined transmission rates are supported. We summarize them in Table III together with the required receiver minimum sensitivity.

In vehicular networks, due to the high speed movement of OBUs, the link quality is changing fast and the durations of communications are short. On the other hand, moving direction of each OBU is known in advance, and all OBUs experience the same channel variation. So it tends to be fair in assigning AIFS values according to the link quality. Link quality is measured by the received signal strength indication (RSSI), which is affected by the distance between an OBU and the RSU. From Eqns (2) and (3), the RSSI is plotted against the distance between a RSU and an OBU in Fig. 1. Note that RSSI is available from the physical layer at the receiving device. Therefore, cross-layer optimization is required to pass this information to the MAC layer.

The performance of EDCA MAC protocol has been widely studied [4-9]. But only literature [4] and [5] are based on WAVE mode vehicular networks. In [4], a performance evaluation of IEEE 802.11p standard is provided according to EDCA parameter set, including collision probability, throughput and delay. In [5], Markov chains are used to analyze the performance of EDCA under the specific conditions of the control channel in WAVE environment, considering throughput, frame-error rate, buffer occupancy and delay. In [6], discrete-time Markov chains are used to model and analyze the EDCA channel mechanism, and gives throughput, delay under different traffic conditions. In [7], the optimal configuration method of parameter set of 802.11e EDCA is studied. In [8], a unified model is proposed for the performance analysis of IEEE 802.11e EDCA under the assumption of a finite number of nodes and ideal channel conditions in a single-hop WLAN environment. In [11], the author proposes an analytical model and analyzes the saturation throughput and delay of IEEE 802.11e EDCA with up to four access categories (ACs). The access categories are classified according to different traffic classes. In [9], the authors extend Bianchi's model [11] and derive the throughput and delay of IEEE 802.11e EDCA under saturation condition. Notably, all the work above [4-9] assumes that the (fixed) EDCA parameter set is assigned to a device according to its traffic class, or access category. However, in our work we just consider a single traffic class, but we give different AIFS to an OBU according to the received signal strength.

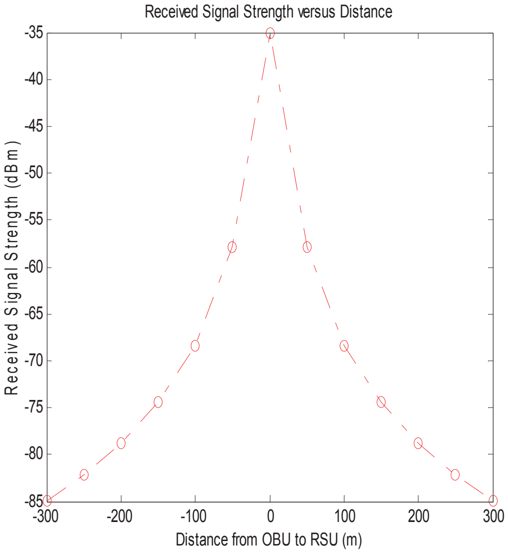

Figure 1. Relationship between received signal strength and distance

TABLE III WAVE RECEIVER PERFORMANCE REQUIREMENTS [1]

Data rate (Mbits/s)	Minimum sensitivity (dBm)
3	-85
4.5	-84
6	-82
9	-80
12	-77
18	-73
24	-69
27	-68

III. MAPPING AIFS AND ANALYSIS

A. Mapping Values to Transmission Rates

We propose to design AIFS values based on link quality. In Tables I and II, we can see that the assigned/recommended values of AIFSN for different traffic classes, voice (AC3), video (AC2), background (AC1) and best effort (AC0), are in the range of 2 to 9. In this paper, we focus on maximizing the throughput performance of delay insensitive traffic, i.e. best effort (AC0) and background (AC1). We want to keep the higher priority voice (AC3) and video (AC2) intact. Therefore, we would like to keep/reserve AIFSN=2 and 3 for their exclusive usage.

Accordingly, we focus on assigning AIFSN values greater than or equal to 4 for delay insensitive traffic (AC0 & AC1) based on link quality. We propose two schemes for mapping AIFS values to transmission rates. As IEEE 802.11p supports eight pre-defined transmission rates, each with a minimum receiver sensitivity given in Table III, a natural choice is to have a one-to-one mapping between transmission rates and the AIFSN values. The resulting 8-level-AIFS mapping is shown in Table IV, where the maximum AIFSN value is 11.

TABLE IV EIGHT LEVELS OF AIFS (8-level-AIFS) EDCA PROTOCOL

Data rate (Mbits/s)	Received signal strength (dBm)	AIFSN
3	-85 ≤ RSSI<-84	11
4.5	-84 ≤ RSSI<-82	10
6	-82 ≤ RSSI<-80	9
9	-80 ≤ RSSI<-77	8
12	-77 ≤ RSSI<-73	7
18	-73 ≤ RSSI<-69	6
24	-69 ≤ RSSI<-68	5
27	RSSI ≥ -68	4

There are two disadvantages of using 8 levels of AIFS. First, with a maximum AIFSN value of 11, a device has to wait for a long time (even if no one else in the system) before it can access the channel. Second, due to the fast movement of vehicles, the rate of changing in link quality would cause fast changing in AIFS values as well. The frequent switching of AIFS values may cause problems in implementation, and results in high packet error rates. Based on the above reasons, we propose a 4-level-AIFS mapping as shown in Table V, where the same AIFS value is chosen for every two adjacent date rates. Note that the combined pair of adjacent rates uses the same modulation type, which helps to further reduce the implementation complexity. Besides, the maximum AIFS value used is 7, same as that in Table II.

TABLE V FOUR LEVELS OF AIFS (4-level-AIFS) EDCA PROTOCOL

Data rate (Mbits/s)	Received signal strength (dBm)	Modulation	AIFSN
3	-85 ≤ RSSI<-84	BPSK	7
4.5	-84 ≤ RSSI<-82	BPSK	7
6	-82 ≤ RSSI<-80	QPSK	6
9	-80 ≤ RSSI<-77	QPSK	6
12	-77 ≤ RSSI<-73	16QAM	5
18	-73 ≤ RSSI<-69	16QAM	5
24	-69 ≤ RSSI<-68	64QAM	4
27	RSSI ≥ -68	64QAM	4

As an aside, if the distribution of vehicles on the road as well as their mobility and traffic patterns are given, it is possible to derive an optimal mapping of AIFSN to transmission rates by also taking the EDCA protocol into account. While it is interesting, the additional performance gain could be small.

B. Analysis of Throughput

Different from [6], we classify the access categories according to link quality or the level of received signal. Higher level of received signal is assigned lower AIFSN, which means better link quality is given higher priority.

Similar to [6]， we use Markov chain to represent the state transfer of an OBU, and state (k, l) denotes the OBU has unsuccessfully attempted k times to transmit the current frame and l is the current value of its backoff counter. The period between instants in which the markov chain is allowed to change state is called as a cycle.

Suppose there are K access category and priority, and the number of i-th access category OBU is Ni. For the i-th access category, an OBU can change its state when a busy period ends and the channel remains idle for a period of AIFS[i]. According to [6], the throughput for priority-i access category is given by

$$TH_i = \frac{P_{tx,i} \cdot P_{s,i} \cdot E[P_i]}{\sum_{j=1}^{K} P_{tx,j} \cdot P_{s,j} \cdot T_{s,j} + \sum_{j=1}^{K} P_{tx,j} \cdot \left(1 - P_{s,j}\right) \cdot T_{c,j} + P_{notx} \cdot \sigma} \quad (2)$$

Where $P_{tx,j}$ and $P_{s,j}$ are respectively the probability that at least one priority-j OBU transmits, and the probability that there is a successful transmission given that at least one priority-j OBU transmits. $T_{s,j}$ and $T_{c,j}$ are respectively the average duration of a cycle in which a priority-j OBU successfully transmitted a frame, and the average duration of a cycle in which there was a collision because two or more priority-j OBUs attempted a transmission. The OBUs operates in RTS/CTS mode. P_{notx} is the probability that no OBU transmits. $E[P_i]$ is the average packet length of *i*-th access category.

σ is the length of a slot.

$$\begin{cases} P_{tx,j} = 1 - \left(1 - \tau_j\right)^{N_j} \\ P_{s,j} = \dfrac{N_j \cdot \tau_j \cdot \left(1 - \tau_j\right)^{N_j - 1}}{P_{tx,j}} \end{cases} \tag{3}$$

$$P_{notx} = 1 - \sum_{j=1}^{K} \left[1 - \left(1 - \tau_j\right)^{N_j}\right] \tag{4}$$

τ_j is the probability that an OBU of priority j transmits and K is the number of different priorities.

$$\begin{cases} T_{c,j} = RTS + AIFS[j] + \delta \\ T_{s,j} = RTS + SIFS + \delta + CTS + SIFS + \delta + H + E[P_j] \\ \qquad + \mathrm{SIFS} + \delta + \mathrm{ACK} + \mathrm{AIFS}[j] + \delta \end{cases} \tag{5}$$

δ is the propagation delay.

The total throughput of the system is given by

$$TH = \sum_{j=1}^{K} TH_j \tag{6}$$

IV. SIMULATION AND PERFORMANCE EVALUATIONS

A. *Simulation Model*

We model the performance of EDCA protocol with our link quality based AIFS assignment under the scenario shown in Fig. 2. We consider one RSU and multiple OBUs. All vehicles with OBUs move in a fixed direction from left to right or vice versa. The radius of the coverage area of the RSU is determined by the receiving sensitivity of the OBUs. We assume all OBUs entering the coverage area of the RSU can establish communication links with the RSU. In our simulations, to keep a stable number of OBUs, we suppose vehicles move in a circular mode. When a vehicle moves out of one side of the coverage of the RSU, it will enter the coverage area immediately from another side of the RSU with another velocity distributed uniformly during (20m/s, 35m/s). For simplicity, power control is not considered.

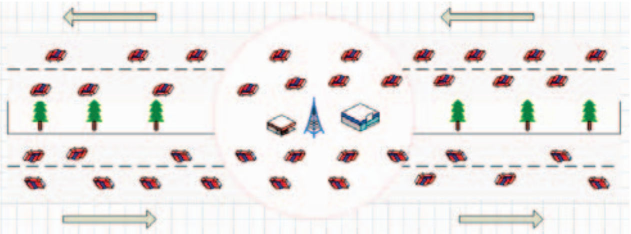

Figure 2. System scenario

We assume OBUs always have packets to send. They compete for the channel using the standard EDCA protocol except that the AIFS values are assigned based on their dynamic link quality. We focus on a single service channel, while noting that multiple service channels only requires a simple extension.

For WAVE mode vehicular networks, there are two main factors affecting channel/link quality, path loss and shadow & multi-path fading. In high-speed movement environment, path loss is the dominant factor. We consider a typical urban and suburban environment and use the channel model specified in Rec. ITU-R M.1225 [10]. The pass loss L is given by

$$L = \left[40\left(1 - 4\times10^{-3}\Delta h_b\right)\right]\log_{10} R - 18\log_{10}\Delta h_b + 21\log_{10} f + 80 \tag{7}$$

where Δh_b (m) is the antenna height of the RSU measured from the average rooftop of buildings, f (MHz) is the frequency, and R (km) is the distance from the transmitter to receiver.

The received signal strength of an OBU is given by

$$P_r = EIRP - L \tag{8}$$

where P_r is the received power of OBUs, EIRP (Equivalent isotropically radiated power) is equal to the transmit power of the transmitter plus transmit antenna gain.

B. *Simulation Parameters Setting*

The performance of EDCA with our proposed 8-level-AIFS and 4-level-AIFS mappings are studied by simulations in this section. The values of various parameters used are summarized in Table VI.

TABLE VI SIMULATION PARAMETERS

Parameter	Value
Carrier Frequency	2.0 GHz
EIRP of the roadside unit transmitter	33 dBm
Δh_b	16 m
Payload length E[P]	4092 bits
PHY header	128 bits
MAC header	272 bits
RTS	288 bits
CTS	240 bits
ACK	240 bits
SlotTime (σ)	32 us
SIFS	13 us
Propagation delay (δ)	1 us
CWmin	15
Data rate	3, 4.5, 6, 9, 12, 18, 24, 27 (Mbps)
Δt	10 ms
Simulation time	2000 seconds
Coverage radius of the roadside unit	300 m
Velocity of onboard units	20-35 m/s

We assume that the coverage radius of the roadside unit (RSU) is 300 m, and there are n onboard units (OBUs) whose initial distance to the RSU is distributed evenly during (0, 300m). The velocity of each OBU is uniformly distributed between (20 m/s, 35 m/s). Once the velocity is determined, it would remain fixed until it leaves the coverage area of the RSU.

Any OBU entering the coverage area of the RSU has always a packet available to be transmitted, and the distance between an OBU and the RSU is changing dynamically due to fast movement of OBUs. With high speed movement relative to the RSU, the AIFSN value of an OBU changes dynamically according to link quality, and this leads to dynamic variation of number of OBUs in different levels of AIFSN.

Suppose the simulation time is T, and we divide T into a large number of short periods Δt, i.e. 10 ms. During the very short period, the number of OBUs in different levels of AIFSN is approximately fixed.

C. Throughput Comparison for Several EDCA Protocols

Fig. 3 shows the system throughput versus n the number of OBUs in the system. In particular, our proposed 8-level-AIFS and 4-level-AIFS are compared with fixed-AIFS, the conventional scheme that uses the fixed AIFSN for all devices. For the fixed-AIFS, two fixed values are used, AIFSN=7 and AIFSN=4. .Although from Table II, AIFSN=7 should be used. But for a fairer comparison, we also consider AIFSN=4.

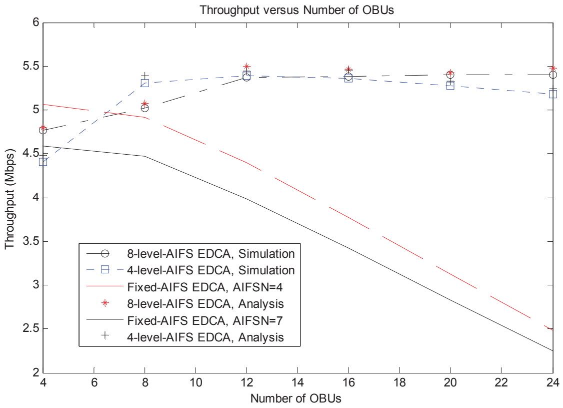

Figure 3. Throughput comparison for several EDCA MAC protocols

From Fig. 3 we know that the simulation throughput and analysis throughput for both 8-level-AIFS EDCA and 4-level-AIFS EDCA are fit well. With increment of number of OBUs, throughput of the network for fixed-AIFS EDCA protocol reduces remarkably, but that for 8-level-AIFS and 4-level-AIFS EDCA protocol have little change. Throughputs for 8-level-AIFS and 4-level-AIFS EDCA protocol are both higher than that for fixed-AIFS EDCA protocol when the number of OBUs is more than 8. Throughput for 8-level-AIFS EDCA protocol is a little higher than that for 4-level-AIFS EDCA protocol when the number of OBUs is more than 16. This can be explained that by dividing multiple levels of AIFSN, the number of OBUs in each level of AIFSN is reduced, fewer OBUs contend the channel, and thus the collision probability is reduced. But for fixed-AIFS EDCA protocol, there is just one AIFS value for all OBUs, they contend the same channel, thus leads to high collision probability especially in the case of a large number of OBUs. The average number of OBUs in each level of AIFSN for 8-level-AIFS EDCA protocol is less than that for 4-level-AIFS EDCA protocol, thus collision probability for 8-level-AIFS EDCA protocol is further reduced, and this leads to higher throughput of the network. But when the total number of OBUs is small (e.g. number of OBUs is less than 8), throughput for fixed-AIFS (i.e. AIFSN is 4) is higher than that for 8-level-AIFS and 4-level-AIFS EDCA protocol instead. This is because collision probability is low for all the three protocols when only a few OBUs contend the channel, while 4 is the minimum value of AIFSN in our protocol, which reduces waiting time for OBUs to access the channel when the medium is idle.

D. Effect of Payload Length on Throughput

Let us analyze the effect of the length of payload on throughput of the network. We compare the throughput of 4-level-AIFS EDCA protocol and 8-level-AIFS EDCA protocol under different payload length. According to IEEE 802.11p, the value of payload length is chosen during the range (1 bit, 4095 bits) [1]. We assume that the number of OBUs is 24, and minimum contention window is 15.

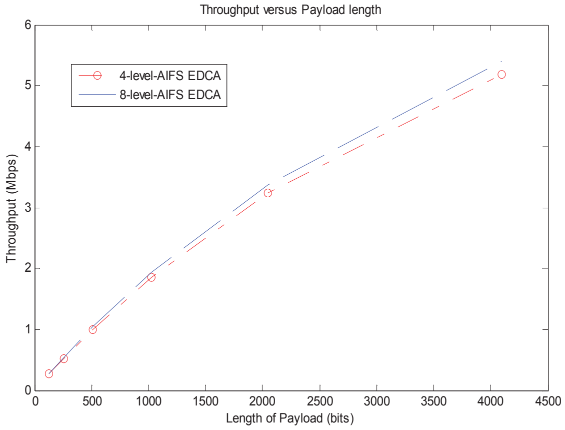

Figure 4. Throughput comparison between 4-level-AIFS EDCA and 8-level-AIFS EDCA under different length of payload

From Fig. 4 we know that throughput of the network is proportional to the length of payload for both 8-level-AIFS and 4-level-AIFS EDCA protocol. But we can not increase length of payload randomly. Under bad channel condition, longer length of payload will lead to higher bit error rate (BER).

E. Effect of TXOP-Limit on Throughput

Since TXOP-limit is related to throughput of the network, without loss of generality, we analyze the effect of TXOP-limit on the throughput for 4-level-AIFS EDCA MAC protocol, as shown in Fig. 5. For 8-level-AIFS EDCA MAC protocol and fixed-AIFS EDCA protocol, we can perform the simulation analysis by the same way.

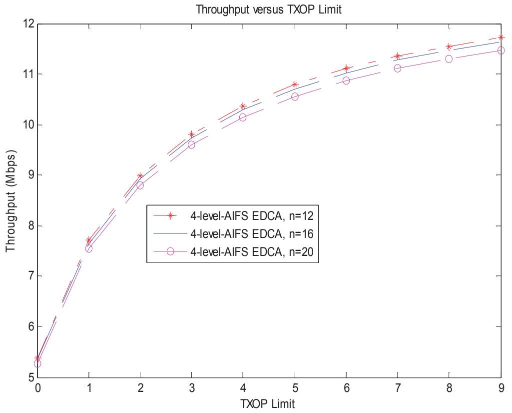

Figure 5. Throughput of 4-level-AIFS EDCA protocol under different value of TXOP-Limit

We consider different number of OBUs, n=12, 16, 20, and compare the throughput of different TXOP-Limit. Fig. 5 indicates that larger value of TXOP-Limit will lead to higher throughput. This is because larger value of TXOP-Limit will produce less overhead. However, with increment of TXOP-Limit, the throughput increases slowly.

F. *Effect of Minimum Contention Window on Throughput*

Minimum contention window also take effects on throughput of the network. Similarly, without loss of generality, we investigate the throughput for 4-level-AIFS MAC EDCA protocol under different value of minimum contention window, as shown in Fig. 6. For 8-level-AIFS EDCA MAC protocol and fixed-AIFS EDCA protocol, we can repeat the same work.

We compare throughput of the network under different number of OBUs, n=16, 20, 24. From Fig. 6 we know that when minimum contention window, CWmin, is about 31, the network can achieve higher throughput. With increment of CWmin, the throughput reduces apparently. This can be explained that with increment of minimum contention window, the OBU has to wait longer back-off time.

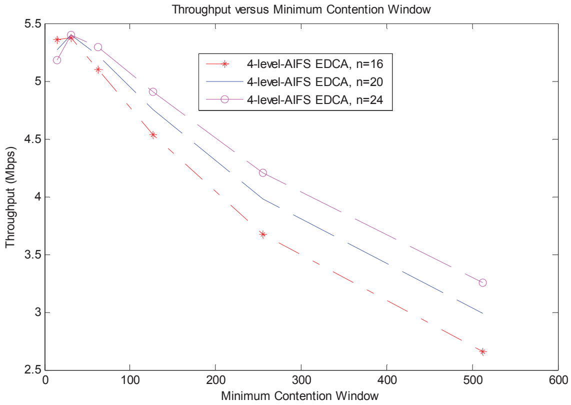

Figure 6. Throughput of 4-level-AIFS EDCA protocol under different value of minimum contention window

V. CONCLUSION

In this paper we propose two heuristic EDCA MAC protocols for delay insensitive services on service channels, which are 4-level-AIFS EDCA MAC protocol and 8-level-AIFS EDCA MAC protocol. Both of the two protocols map AIFS values to different transmission rates according to the received signal strength indication (RSSI) of OBUs. Analytical and simulation results indicate that our MAC protocols improve throughput of the network relative to conventional fixed-AIFS EDCA MAC protocol specified in IEEE 1609.4, especially under the condition with a large number of OBUs. Although only delay insensitive services are considered, our schemes are also fit for delay sensitive services by choosing different value of minimum AIFS and minimum contention window. In addition, we also analyze the effects of payload length, TXOP-Limit and minimum contention window on throughput of the network.

REFERENCES

[1] Draft Amendment to STANDARD FOR Information technology – Telecommunications and information exchange between systems – LAN/MAN Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and physical layer (PHY) specifications: Wireless Access in Vehicular Environments (WAVE), P802.11p/D1.1, January 2005

[2] IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE)- Multi-channel Operations, IEEE Std 1609.4-2006

[3] IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE)- Networking Services, IEEE Std 1609.3-2007

[4] Stephan Eichler, “Performance Evaluation of the IEEE 802.11p WAVE Communication Standard,” IEEE 66th Vehicular Technology Conference, Sept. 30 – Oct. 3 2007, pp. 2199-2203

[5] Jose R. Gallardo, Dimitrios Makrakis, and Hussein T. Mouftah, “Performance analysis of the EDCA medium access mechanism over the control channel of an IEEE 802.11p WAVE vehicular network,” IEEE ICC 2009

[6] Jose R. Gallardo, Sarai C. Cruz, Dimitrios Makrakis, Abdallah Shami, “Analysis of the EDCA Access Mechanism for an IEEE 802.11e-compatible Wireless LAN”, 13th IEEE Symposium on Computers and Communications (ISCC’08), Marrakech, Morocco, July 6-9, 2008

[7] Albert Banchs, Luca Vollero, “Throughput analysis and optimal configurations of 802.11e EDCA,” Computer Networks 50 (2006) 1749-1768

[8] Jie Hui, Michael Devetsikiotis, “A Unified Model for the Performance Analysis of IEEE 802.11e EDCA”, IEEE Transactions on Communications, Vol.53, No.9, September 2005, pp. 1498-1510

[9] Ching-Ling Huang and Wanjiun Liao, “Throughput and Delay Performance of IEEE 802.11e Enhanced Distributed Channel Access (EDCA) Under Saturation Condition,” IEEE Transactions on Wireless Communications, Vol. 6, No. 1, January 2007, pp. 136-145

[10] Recommendation ITU-R M.1225, Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000, 1997

[11] Giuseppe Bianchi, “Performance Analysis of the IEEE 802.11 Distributed Coordination Function”, IEEE Journal on Selected Areas in Communications – Wireless Service, Vol. 18, No.3, pp. 535-547, March 2000