THROUGHPUT ANALYSIS OF ACTIVE NODE BACK-OFF ALGORITHM FOR AIFS QOS WLAN

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ABSTRACT

This paper, we propose a new technique for calculated Contention Window (CW) size for back-off algorithm mode. We use maximum function theory for improved performance of contention window algorithms for IEEE802.11e quality of service (QoS) wireless local area network (WLAN). The proposed algorithm is named as Active Node Back-off Algorithm (ANBA). The performance of ANBA is compared with the legacy back-off algorithms as Binary Exponential Back-off (BEB) and Estimation Based Back-off (EBB) algorithm. The throughput and fairness index of ANBA is analyzed in arbitration inter-frame space (AIFS) priority technique in enhanced distribute channel access function (EDCAF). In this research, the channel access scheme is based on carrier sense multiple access collision avoidance with request-to-send and clear-to-send (CSMA/CA RTS CTS) protocol. Our numerical results show that the performance of ANBA algorithm is better than old back-off algorithm in terms throughput and fairness index parameters.

KEY WORDS

ANBA, BEB, EBB, QoS, IEEE802.11e, AIFS, EDCA, WLAN

1 INTRODUCTION

In recent years, wireless transmission technology is widely applied for the applications of data, voice, video and even multimedia. Quality of service must be considered while priority issues are applied in difference kinds of traffics. IEEE802.11e standard is proposed to achieve the guaranteed QoS requirement [1].The IEEE802.11e consists of two channel access schemes: the enhanced distributed channel access (EDCA) and the hybrid coordination function (HCF) controlled channel access (HCCA). In this research, we consider only IEEE802.11e enhanced distributed channel access (EDCA) and the channel access method use carrier sense multiple accesses with collision avoidance and request- to-send clear-to-send (CSMA/CA RTS CTS) protocol. We focus on the throughput and fairness properties of IEEE802.11e EDCA by using Ziouva's model in [2]; however, the previous results show that the performances of systems are degraded when the number of nodes is increased and also as best effort traffic becomes higher. In this research, we extend previous work in Ref. [2]. We use maximum function theory to modify the contention window (CW) in [2]. We find the optimal contention window under saturated condition to achieve the maximum aggregate throughput and good fairness index. This paper is organized as follows: in section 2, we give a description in system model for performance analysis of WLAN system. In section 3, we introduce a new back-off algorithm for improved throughput efficiency of QoS WLAN; moreover, we brief the arbitration inter-frame space priority for QoS. The numerical results and summaries are presented in section 4 and 5 respectively.

2 SYSTEM MODEL

In Ref. [2], Eustathia Ziouva and Theodore Antonakopoulos have developed a simple two dimension discrete Markov chain model that is showed in Fig.1.

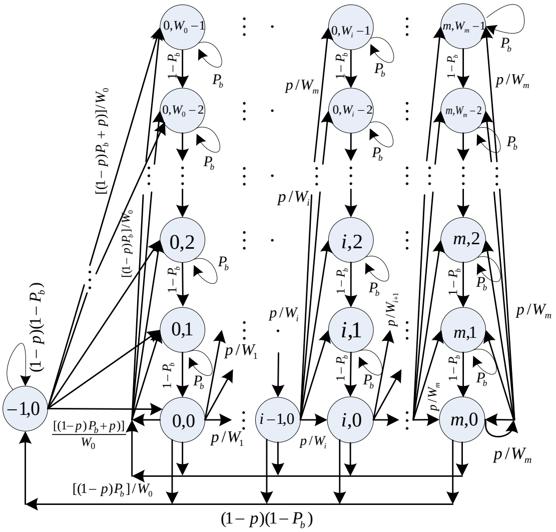


Fig.1 The state transition diagram for two dimension discrete Markov model

From Fig.1, we can compute the transmission probability (τ) that depends on the collision probability *p*, busy channel probability *Pb* and contention window *W*. The transmission probability is given by:

$$\tau = \frac{2(1-Pb)(1-2p)}{2(1-Pb)^2(1-2p)(1-p) + (Pb + p(1-Pb))(1-2p)(W+1) + pW(Pb + p(1-Pb))(1-(2p)^m)} \quad (1)$$

The system throughput is the fraction of expected successful length over the expected cycle length as following equation

$$Throughput = S = \frac{P_S P_{tr} MSDU}{(1-P_{tr})T_{slot} + P_{tr}P_S T_S + P_{tr}(1-P_S)T_C} \quad (2)$$

$$P_{tr} = 1-(1-\tau)^n \quad (3)$$

$$P_S = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \quad (4)$$

Where $P_{tr} =$ The probability that in a slot time there is at least one transmission
$P_s =$ The probability that in a slot time there is successful
$P_b =$ The probability that the channel is busy
$MSDU =$ MAC service data unit size (bytes)

$T_C =$ The collision transmission time of CSMA/CA RTS CTS (μs)

$T_S =$ The Successful transmission time of CSMA/CA RTS CTS (μs)

$T_{slot} =$ Slot time (μs)

$m =$ Maximum back off stages

$n =$ The number of active nodes

The fairness of throughput efficiency is measured by Jain's fairness index in [5]. The fairness index is given by

$$Fairness\ \ Index(x_1, x_2 \ldots x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n\sum_{i=1}^{n} x_i^2} \tag{5}$$

Where, x_i is the throughput of contending node *i* and *n* is the number of contending nodes. The fairness index gets values between zero and one.

3 ACTIVE NODE BACK-OFF ALGORITHM (ANBA)

From Eustathia Ziouva and Theodore Antonakopoulos's model in [2], we modify the contention window algorithm based on the number of active nodes by used maximum function theory. We assume that all transmissions are broadcasted to all nodes in service area. The optimum value of contention window is the partial derivative of equation (4) with respected to W by the following equation:

$$\frac{\partial P_S}{\partial W} = \frac{\partial}{\partial W}\frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} = 0 \tag{6}$$

From equation (1), we assign $A = 2(1-P_b)(1-2p),\quad B = 2(1-P_b)^2(1-2p)(1-p),$ $C = (P_b + p(1-P_b))(1-2p)$ and $D = p(P_b + p(1-P_b))(1-(2p)^m)$.The equation (1) is becomed

$$\tau = \frac{A}{B + C + W(C + D)} \tag{7}$$

At the same way, we assign $E = B + C,\ F = C + D$ and $H = E - A$ so the transmission probability and successful transmission probability are given by

$$\tau = \frac{A}{E + WF} \tag{8}$$

$$P_s = \frac{nA(E+WF)^{-2}(H+WF)^{n-1}}{(E+WF)^{n+2} - (E+WH)^2(H+WF)^n} = \frac{nA}{(E+WF)^{n+2}(H+WF)^{-n+1} - (E+WH)^2(H+WF)} \tag{9}$$

From (6) and (9), the partial derivative of successful transmission probability (*Ps*) with respected to contention window (*W*) is given by

$$\begin{aligned}\frac{\partial P_S}{\partial W} = \frac{-nA}{[(E+WF)^{n+2}(H+WF)^{-n+1} - (E+WH)^2(H+WF)]^2}\frac{\partial}{\partial W}[(E+WF)^{n+2}(H+WF)^{-n+1} \\ -(E+WH)^2(H+WF)] = 0\end{aligned} \tag{10}$$

$$\vdots$$

$$\begin{aligned}&[-nAF(-n+1)(E+WF)^{n+2}(H+WF)^{-n} - nAF(n+2)(H+WF)^{-n+1}(E+WF)^{n+1} + nAF(E+WH)^2 + \\ &2nAH(H+WF)(E+WH)]/[(E+WH)^{n+2}(H+WF)^{-n+1} - (E+WH)^2(H+WF)]^2] = 0\end{aligned} \tag{11}$$

From (11), term $[(E+WH)^{n+2}(H+WF)^{-n+1}-(E+WH)^{2}(H+WF)]^{2}$ must not equal to zero because the result is converged on infinite; therefore, we have

$$\begin{aligned}&[-nAF(-n+1)(E+WF)^{n+2}(H+WF)^{-n}-nAF(n+2)(H+WF)^{-n+1}(E+WF)^{n+1}\\&+nAF(E+WH)^{2}+2nAH(H+WF)(E+WH)]=0\end{aligned} \tag{12}$$

We consider only term $E+WH$ which equals zero; as a result, the optimal contention window can find from $W=-E/H$. The parameter A, B, C, D, E, and H are returned into equation $W=-(B+C)/(E-A)=[-B-C]/[B+C-A]$. Finally, the optimal contention window (W) which relates the number of nodes is given by:

$$W_{ANBA}=\frac{[-2(1-P_b)^{2}(1-2p)(1-p)-(P_b+p(1-P_b))(1-2p)]\times n}{2(1-P_b)^{2}(1-2p)(1-p)+(P_b+p(1-P_b))(1-2p)-2(1-P_b)(1-2p)} \tag{13}$$

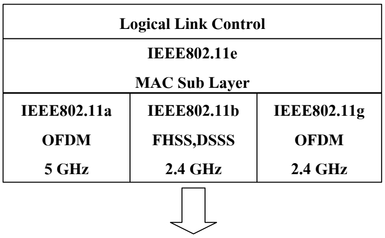
Equation (13) is called Active Node Back-off Algorithm (ANBA). From the previous researches in Ref. [3], Byung Jae Kwak et al. proved that Binary Exponential Back-off (BEB) algorithm has been the contention window size for back-off stage *i* as

$$\begin{aligned}&W_{BEB}=2^{i}(W_{\min}+1) \qquad i=0,1,2\ldots m\\&m=\log_2(W_{\max}/W_{\min})\end{aligned} \tag{14}$$

The contention window (W) is initially set to be $W_{\min}$ .If the transmission fails *i* stages, then the contention window is increased by 2^{i} where $W_{\min}$ is minimum contention window, $W_{\max}$ is the maximum contention window sizes and *m* is the maximum back-off stages or retries transmission. In Ref. [4], Seok-Won Kang et al. has showed the Estimation-Based Back-off (EBB) algorithm. The optimal contention window of EBB related to active nodes (n) is given by

$$W_{EBB}\approx n \tag{15}$$

Next section, we present about the difference access categories (AC) for priority classes in arbitration inter-frame space quality of service (AIFS-QoS). The AIFS-QoS has four classes which are named AC_VO, AC_VI, AC_BE and AC_BK for Voice, Video, Best Effort and Background respectively, where AC_BK is the lowest priority and the AC_VO is the highest priority. The time periods sequence of CSMA/CA with RTS CTS mechanism in IEEE802.11e standard is shown in Fig. 2.



Logical Link Control		
IEEE802.11e **MAC Sub Layer**		
IEEE802.11a **OFDM** **5 GHz**	**IEEE802.11b** **FHSS,DSSS** **2.4 GHz**	**IEEE802.11g** **OFDM** **2.4 GHz**

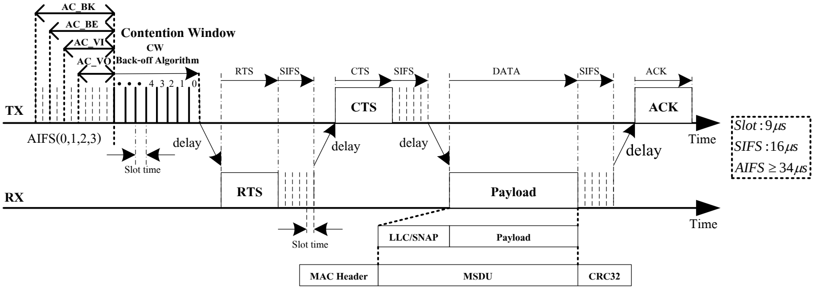


Fig. 2 Transmission periods of IEEE802.11e CSMA/CA RTS CTS Protocol

The time periods of T_S and T_C for CSMA/CA RTS CTS protocol are given by

$$T_{S[AC\_VO]} = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} + T_{AIFS(AC\_VO)} \tag{16}$$

$$T_{S[AC\_VI]} = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} + T_{AIFS(AC\_VI)} \tag{17}$$

$$T_{S[AC\_BE]} = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} + T_{AIFS(AC\_BE)} \tag{18}$$

$$T_{S[AC\_BK]} = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} + T_{AIFS(AC\_BK)} \tag{19}$$

$$T_{AIFS[AC\_VO],[AC\_VI],[AC\_BE],[AC\_BK]} = AIFSN \times T_{slot} + T_{SIFS} \tag{20}$$

$$T_{C[AC\_VO,AC\_VI,AC\_BE,AC\_BK]} = T_{RTS} + T_{delay} \tag{21}$$

$$T_{RTS} = T_{\Pr eamble} + T_{Signal} + T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8L_{RTS}}{N_{DBPS}}\right) \tag{22}$$

$$T_{CTS} = T_{ACK} = T_{\Pr eamble} + T_{Signal} + T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8L_{ACK}}{N_{DBPS}}\right) + T_{EX} \tag{23}$$

$$T_{MSDU} = T_{\Pr eamble} + T_{Signal} + T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8(L_{MAC} + MSDU)}{Channel\ bit\ rate}\right) + T_{EX} \tag{24}$$

$$T_{delay} \approx 1\mu s \rightarrow \frac{(Tx\ to\ Rx\ dis\tan ce \approx 300m)}{(Radio\ waves\ propagation\ speed \approx 3\times 10^8 m/s)} \tag{25}$$

The rule of transmitted observation is due to

$$AIFSN[AC\_VO] + W_{\min}[AC\_VO] \le AIFSN[AC\_BE] \le AIFSN[AC\_BK] \tag{26}$$

$$AIFSN[AC\_VI] + W_{\min}[AC\_VI] \le AIFSN[AC\_BE] \le AIFSN[AC\_BK] \tag{27}$$

$$AIFSN[AC\_VO] + W_{\max}[AC\_VO] \le AIFSN[AC\_BK] \tag{28}$$

The DIFS is Distributed Inter Frame Space (μs), SIFS is the Shot Inter Frame Space (μs), RTS is the Request-to-Send frame (*bytes*), CTS is the Clear-to-Send frame (*bytes*), AIFSN is the AIFS number and determined by the priority of the access categories (AC) and ACK is the Acknowledgement frame (*bytes*). The N_{DBPS} is the number of data bits per Orthogonal Frequency Division Multiplexing (OFDM) symbol which are 24, 48, 96 and 216 for OFDM-6, 12, 24 and 54 Mbps respectively. The Physical Layer (PHY) specified by IEEE802.11e for CSMA/CA RTS CTS protocol is shown in table 1 and table 2. [1]

Tab.1 CSMA/CA RTS CTS parameters in IEEE802.11e standard

T_{SIFS} **(µs)**	T_{SLOT} **(µs)**	$T_{Preamble}$ **(µs)**	T_{Symbol} T_{Signal} **(µs)**	L_{RTS} **(bytes)**	L_{CTS} L_{ACK} **(bytes)**	$L_{Service}$ **(bits)**	L_{Tail} **(bits)**
16	9	16	4	20	14	16	6

Tab.2 IEEE802.11e AIFS time periods

ACI/AC	**AIFSN/AIFS**	**IEEE801.11e OFDM with channels 20 MHz**
AC_VO TXOP Limit	2	34 µs 1504 µs
AC_VI TXOP Limit	2	34 µs 3008 µs
AC_BE TXOP Limit	3	43 µs 0
AC_BK TXOP Limit	7	79 µs 0

4. NUMERICAL RESULTS AND DISCUSSIONS

Our numerical results are written in the C++ programming language and MathCAD engineering calculation; then, the results are exported to plot by Excel tool. In analysis, we use same parameters for all back-off algorithms in throughput and fairness index equations by the CSMA/CA RTS CTS access method.

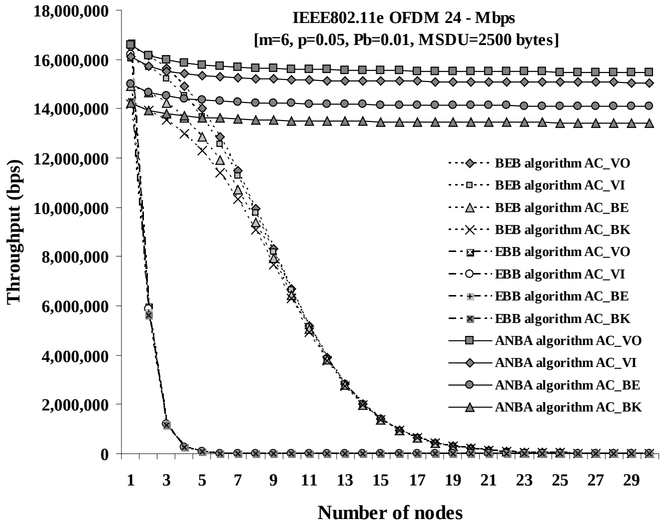


Fig.3 saturation throughput of ANBA versus the number of nodes

Figure 3 presents the throughput efficiency of ANBA algorithm that is compared with BEB and EBB algorithms. The results show that the performance of ANBA is better than BEB and EBB algorithms when the number of nodes is increased; moreover, the throughput of the highest priority access category (AC_VO) is higher than the lowest priority access category (AC_BK) for all back-off algorithms. While the number of nodes is increased, the throughput of BEB and EBB algorithms will be decreased quickly because of collisions; on the contrary, the throughput efficiency of ANBA is stable.

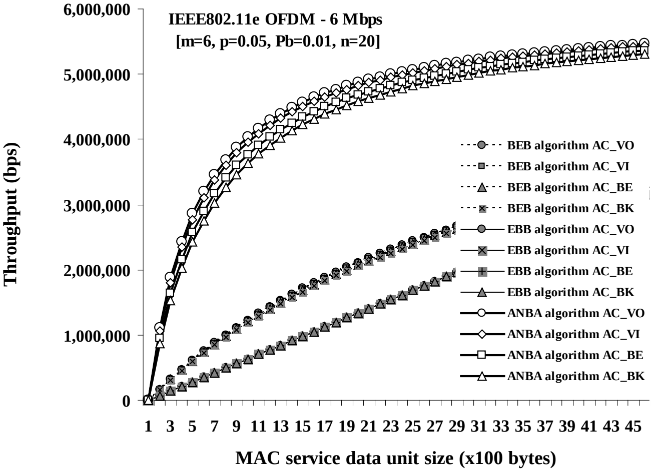


Fig.4 saturate throughput of ANBA versus MSDU sizes

Figure 4 shows the throughput efficiency of ANBA algorithm that is compared with BEB and EBB algorithms where we fix the number of nodes as 20 but we vary the size of MSDU as 0-4500 bytes. In terms of throughput, the ANBA back-off algorithm is higher than BEB and EBB back-off algorithm techniques for all different access categories (AC_VO, AC_VI, AC_BE and AC_BK).

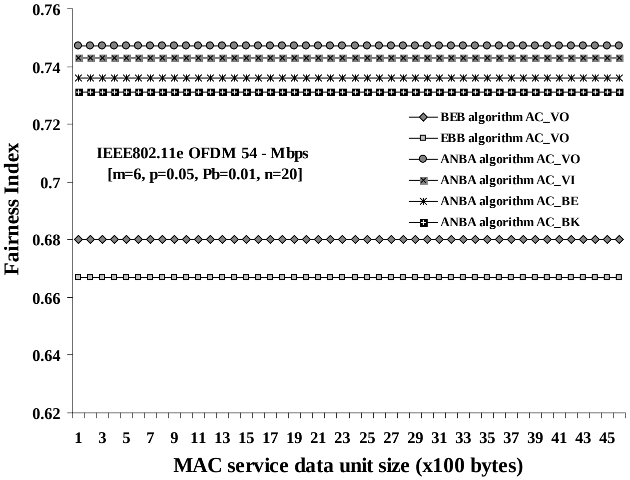


Fig.5 Fairness index versus MSDU sizes

Figure 5 presents the fairness index parameter of each back-off algorithm among the MAC service data unit sizes are changed. From the figure, it shows that the fairness index of ANBA algorithm is higher than old back-off algorithms as BEB, EBB back-off algorithms and also, the fairness of higher priority frame (AC_VO) is higher than a low priority frame (AC_BK); however, the fairness index of all access categories seem to remain constant when the MSDU sizes are increased.

5. SUMMARIES

In this research, we present a modified back-off algorithm by using maximum function theory for CSMA/CA RTS CTS protocol in IEEE802.11e WLAN standard. The proposed back-off algorithm is called Active Node Back-off Algorithm (ANBA). The numerical results show that not only the performance of ANBA is better than BEB and EBB back-off algorithms but also the fairness index of ANBA is better than old back-off algorithms when the number of nodes and the sizes of MSDU are changed. All results show that our algorithm can improve performance of AIFS QoS for different service classes. As future work, we plan to investigate the performance of ANBA in non-saturated and fading channel in IEEE802.11a/b/g/e/n wireless local area network standards.

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