An Adaptive EDCA TXOP with Rate Adaptation For QoS Provision

MIN LI HUANG, SEUNGBEOM LEE and SIN-CHONG PARK
Information and Communication University
119, Munjiro, Yuseong-Gu, Daejeon, 305-732
KOREA

Abstract: - With the explosive growth of multimedia services in today's wireless communications, this paper addresses the Quality of Service (QoS) issue focusing on satisfying the throughput requirement for real-time multimedia applications. An Adaptive Transmission Opportunity (AD-TXOP) scheme for a distributed Wireless Local Area Network (WLAN) system based on IEEE 802.11e Enhanced Distributed Channel Access (EDCA) mechanism is proposed. This proposed method enables an IEEE 802.11e based Quality of Service Station (QSTA) with rate adaptation capability to dynamically configure its TXOP limit within the maximum TXOP value designated by IEEE 802.11e Medium Access Control (MAC) Standard based on varying data rate and collision ratio to achieve the required QoS throughput. On top of this, our extensive simulation results clearly demonstrate that this scheme maximizes network capacity, promotes channel utilization fairness among QSTA, and ensures a more stabilized throughput performance across time.

Key-Words: - 802.11e, EDCA, TXOP, Rate Adaptation, QoS

1 Introduction

In recent years, multimedia technology has become pervasive on the mobile platform. This is evident from the timely emergence of IEEE 802.11e standard [3] which emphasizes on QoS enhancement at the MAC layer for real-time multimedia services in wireless communications.

The IEEE 802.11e standard, defines a new Hybrid Coordination Function (HCF) for QoS enhancement. HCF is always present in a QSTA. QSTA is defined as a station which implements QoS facility in an Independent Basic Structure Set (ISSS) or infrastructure network. HCF offers both a contention-based channel access mechanism, known as EDCA for contention-based transfer, and a controlled channel access method, referred to as HCF Controlled Channel Access (HCCA) for contention-free transfer. Under HCF, a new basic unit of time allocation that gives a station the right to initiate a transmission onto the wireless channel called Transmission Opportunity (TXOP) is introduced. In this work, we focus on the TXOP for contention-based channel access, called EDCA-TXOP. An essential overview of the 802.11 MAC and PHY protocol is duly covered in Section 2.

Today's real-time multimedia applications, such as Voice over IP (VoIP), audio streaming, and video conferencing require superior QoS provision in terms of minimum throughput per QSTA to enhance user experience. This motivates us to propose an Adaptive TXOP (AD-TXOP) scheme for 802.11e EDCA which enables a QSTA to dynamically adjust the TXOP limit within the maximum TXOP value specified in the IEEE 802.11e standard based on (i) transmission rate, (ii) network load and (iii) channel conditions.

To-date, there are immense research such as [4-6] involving transfer delay reduction and aggregate throughput enhancement to meet QoS delay bound requirements. However, there is insufficient study directed on achieving the throughput requirement per QSTA. Besides this, admission control schemes such as [5], are often based on a fixed Physical Layer (PHY) rate, which do not reflect real life 802.11 based WLAN implementations. and these facts drive the motivation for this paper.

This paper is arranged as follows. Section 1.1 states the related work and key contributions of this paper. A detailed description on the proposed AD-TXOP scheme is elaborated in Section 3 with extensive and thorough simulation results included in Section 4 to show the effectiveness of our proposed scheme before concluding the paper in Section 5.

1.1 Related Work and Key Contributions

Rate adaptation is an active research area with Automatic Rate Fallback (ARF) algorithm developed for Lucent Technologies' WaveLAN-II WLAN devices [7] being the most widely implemented scheme in wireless communication market [4]. In this study, we chose ARF for its simplicity and effectiveness in enhancing throughput. We then show that the throughput performance of a QSTA decreases exponentially as network load increases when ARF is applied.

Although there are good admission control schemes such as [8] that guarantees the required throughput per QSTA for QoS data. QoS data refers to voice or video data. These schemes are less effective as they lack the ability to determine the root cause behind a failed transmission. Based on the profound idea behind CARA [4], we incorporated Request-To-Send (RTS) / Clear-To-Send (CTS) frames into ARF, enabling a QSTA to effectively distinguish bad channel conditions or collision as the most likely cause of a failed transaction.

Moreover, our proposed adaptive TXOP scheme is capable of adjusting the TXOP limit based on collision ratio and PHY rate through analytical model.

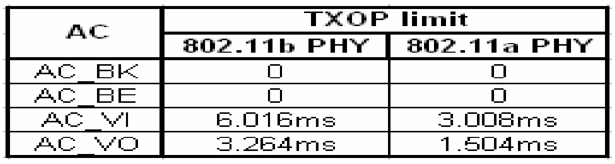
2 IEEE 802.11 System Overview

Our proposed AD-TXOP is based on IEEE 802.11e MAC and IEEE 802.11a PHY.

2.1 The EDCA of IEEE 802.11e MAC

IEEE 802.11e MAC standard [3] amends the legacy IEEE 802.11 MAC standard [1] by introducing EDCA TXOP that allows the EDCA mechanism to access the wireless medium in a differentiated and distributed manner and transmit frames using the TXOP.

TXOP limit is the parameter which limits the number of MAC Service Data Units (MSDUs) within an EDCA TXOP. The maximum TXOP limit values for Voice Access Category (AC_VO) and video Access Categories (AC_VI) are provided in Table 1. TXOP limit is updated by Quality of Service Access Point (QAP) through Beacon and Probe Response Frame.



AC	TXOP limit	
	802.11b PHY	802.11a PHY
AC_BK	0	0
AC_BE	0	0
AC_VI	6.016ms	3.008ms
AC_VO	3.264ms	1.504ms

Table 1. The maximum TXOP limit values specified in IEEE 802.11e [3].

2.2 The IEEE 802.11a Physical Layer

The IEEE 802.11a PHY [2] based on Orthogonal Frequency Division Multiplexing provides eight PHY rates from 6Mbps, 9Mbps, 12Mbps, 18Mbps, 24 Mpbs, 36Mbps, 48Mbps to 54Mbps.

3 An Adaptive EDCA TXOP (AD-TXOP) with Rate Adaptation

Channel condition and network load are the two major factors that impact throughput performance significantly. Bad channel condition increases Packet Error Rate (PER), and number of stations in a network affects the collision probability.

3.1 ARF with RTS/CTS

ARF [7] is heuristic and conservative in nature by stepping through the PHY rates based on missing ACK regardless of collision or bad channel conditions.

Knowing that the error probability of RTS frame transmission is negligible because of its small frame size [4], RTS/CTS is incorporated into ARF. We can then conclude that a failed transmission corresponding to a failed CTS reception is more likely caused by the occurrence of collision rather than bad channel condition.

Using the less overhead BlockAck acknowledgement mechanism, a QSTA now increases transmission rate after receiving ten consecutive BlockACKs and only decreases the PHY rate after two consecutive BlockACK reception failures preceded by successful CTS receptions as shown in Fig.1.

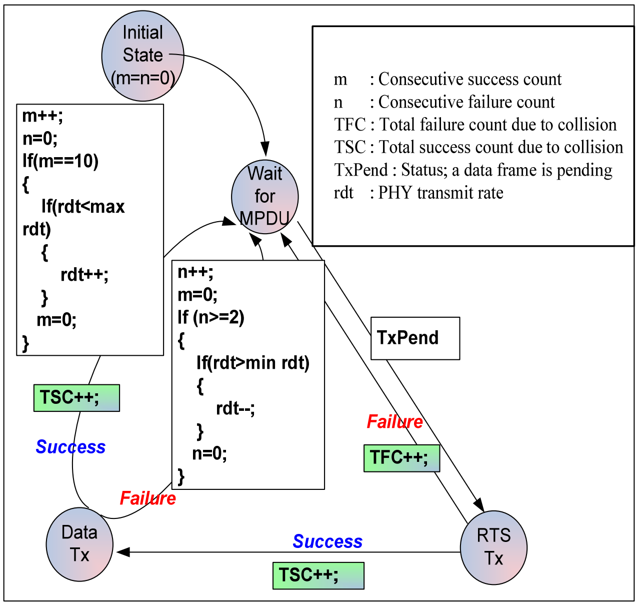


Fig. 1. A modified ARF with RTS/CTS frame exchange

ARF with RTS/CTS prevents unnecessary rate fallback and acts as a reliable source in providing a QSTA with collision information through the TFC parameter which counts the number of failed CTS as in Fig.1 TFC is maintained by individual QSTA.

3.2 The PHY Layer Overheads

Let r* be the control frame rate (typically the lowest basic PHY rate) and r be the corresponding PHY transmission rate for data. Each frame packet shall be preceded by a common PHY header (H_{PHY}). We summarize the transmission time duration for all PHY frame types (in us) in Table 2.

	RTS	CTS	ACK	DATA	H_{PHY}	BAR	BA
802.11a	$\frac{160}{r^*}$	$\frac{112}{r^*}$	$\frac{112}{r}$	$4\left\lceil\frac{248+P}{r}\right\rceil$	20	$\frac{192}{r}$	$\frac{1216}{r}$

Table 2. PHY frame type transmission time based on 802.11e MAC and 802.11a PHY.

3.3 AD-TXOP

AD-TXOP allows each QSTA to dynamically allocate TXOP through a set of local parameters, (i) Collision Ratio (CR), (ii) Total Failure Count (TFC), (iii) Total Success Count (TSC) and (iv) Expected Throughput (Exp_throughput) maintained for voice and video ACs respectively. The proposed Adaptive EDCA TXOP is grouped into 3 steps; bearing in mind that Step 1 is only computed once during the initiation of a QSTA (when a QSTA joins a network system).

3.3.1 Step 1

TXOP limit is set based on the number of burst transmission required to meet the throughput requirement per QSTA. The number of burst transmission is obtained by selecting the Exp_throughput that meets the throughput requirement for each PHY rates. We justify the algorithm as following.

(i) At initialization, the Default Expected Throughput (Thr) value in Table 3 and 4 are computed from (3) obtained through (1) and (2). Equation (2) is the analytical throughput of a single successful EDCA TXOP transmission based on transmission time in Table 2. It is dependant on the n Number of Burst Transmission within the TXOP.

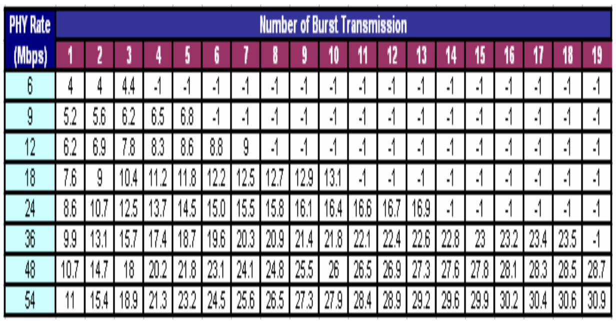
$$\mathrm{Thr} = \frac{n \times L}{BK + RTS + CTS + n \times TxDATA + BAR + BA + (n+3) \times SIFS} \quad (1)$$

BK represents average backoff duration, BAR is the BlockAckReq duration, BA represents BlockAck frame duration, TxDATA is the duration of transmitted data packets and SIFS takes 16us.

$$\mathrm{Thr} = \frac{n \times L}{\frac{7+15}{2} \times 9 + 47 + 39 + n \times TxDATA + BAR + BA + 3 \times 16 + n \times 16} \quad (2)$$

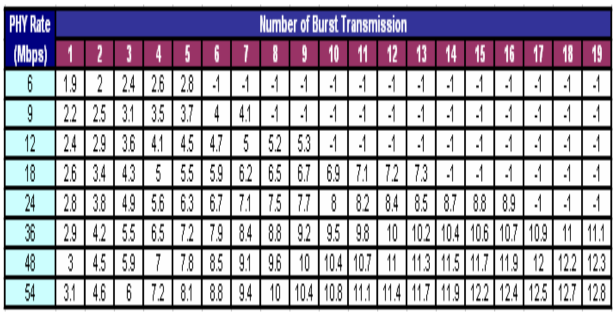
$$\mathrm{Thr} = \frac{n \times L}{233 + n \times TxDATA + BAR + BA + n \times 16} \quad (3)$$

(ii) The number of Burst Transmission and PHY Rate which determines Thr can be stored as a lookup table inside a QSTA as it requires small memory usage and they are constantly referred at each beacon interval.



PHY Rate (Mbps)	Number of Burst Transmission																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	4	4	4.4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9	5.2	5.6	6.2	6.5	6.8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
12	6.2	6.9	7.8	8.3	8.6	8.8	9	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
18	7.6	9	10.4	11.2	11.8	12.2	12.5	12.7	12.9	13.1	-1	-1	-1	-1	-1	-1	-1	-1	-1
24	8.6	10.7	12.5	13.7	14.5	15.0	15.5	15.8	16.1	16.4	16.6	16.7	16.9	-1	-1	-1	-1	-1	-1
36	9.9	13.1	15.7	17.4	18.7	19.6	20.3	20.9	21.4	21.8	22.1	22.4	22.6	22.8	23	23.2	23.4	23.5	-1
48	10.7	14.7	18	20.2	21.8	23.1	24.1	24.8	25.5	26	26.5	26.9	27.3	27.6	27.8	28.1	28.3	28.5	28.7
54	11	15.4	18.9	21.3	23.2	24.5	25.6	26.5	27.3	27.9	28.4	28.9	29.2	29.6	29.9	30.2	30.4	30.6	30.9

Table 3. Lookup table containing Thr values for AC_VI.



PHY Rate (Mbps)	Number of Burst Transmission																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	1.9	2	2.4	2.6	2.8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9	2.2	2.5	3.1	3.5	3.7	4	4.1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
12	2.4	2.9	3.6	4.1	4.5	4.7	5	5.2	5.3	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
18	2.6	3.4	4.3	5	5.5	5.9	6.2	6.5	6.7	6.9	7.1	7.2	7.3	-1	-1	-1	-1	-1	-1
24	2.8	3.8	4.9	5.6	6.3	6.7	7.1	7.5	7.7	8	8.2	8.4	8.5	8.7	8.8	8.9	-1	-1	-1
36	2.9	4.2	5.5	6.5	7.2	7.9	8.4	8.8	9.2	9.5	9.8	10	10.2	10.4	10.6	10.7	10.9	11	11.1
48	3	4.5	5.9	7	7.8	8.5	9.1	9.6	10	10.4	10.7	11	11.3	11.5	11.7	11.9	12	12.2	12.3
54	3.1	4.6	6	7.2	8.1	8.8	9.4	10	10.4	10.8	11.1	11.4	11.7	11.9	12.2	12.4	12.5	12.7	12.8

Table 4. Lookup table containing Thr values for AC_VO. Note: '-1' denotes invalid number of burst transmission, whereby maximum TXOP limit of 802.11e is exceeded

3.3.2 Step 2

At the begining of each beacon interval, the QSTA pre-evaluate the effective Exp_throughput for that beacon interval based number of collisions to estimate the network load condition.

(i) Current Collision Ratio (CRcur) in (4) gives a QSTA the insight into the latest network condition. A high CRcur signifies high collision occurences when the network is loaded.

$$CR_{cur} = \frac{TFC}{TFC + TSC} \quad (4)$$

(ii) Collision Ratio (CRt) takes previous beacon history into account in Equation (5). This is needed if a short beacon interval is used. Wireless medium such as Hotspot may experience temporary volatile channel fluctuations due to the sudden changes in the number of QSTAs that joins a Hotspot. The alpha (α) value is explained in Secion 3.4.

$$CR_t = \alpha CR_{cur} + CR_{t-1}(1 - \alpha) \quad (5)$$

CR_{t-1} is the collision ratio of the previous beacon interval.

(iii) Using CRt, the Effective Expected Throughput for this beacon interval (Exp_throughput) which takes the collision and Packet Error Rate (PER) impacts into account is calculated using equation (7), with PER of 0.1. In WLAN, a PER of 0.1 should be maintained by ensuring the transmit power is well above the required Signal-to-Noice Ratio (SNR) for that PER. Thr is from the lookup table in Table 3 and 4.

$$Exp\_throughput = Thr \times (1 - CR_t) \times (1 - PER) \quad (6)$$

$$Exp\_throughput = Thr \times (1 - CR_t) \times 0.9 \quad (7)$$

3.3.3 Step 3

(i) Prior to a transmission, the QSTA selects the Number of Burst Transmission from Table 3 and 4 based on the requirements stated in equations (8) and (9). Knowing the PHY Rate (R) obtained from ARF with RTS/CTS scheme, we calculate the Minimum Expected Throughput (min(Exp_throughput)) in (8) using equation (7) by finding the smallest Thr that can satisfy the Throughput Requirement (Req_throughput), whereby Req_throughput for AC_VO and AC_VI_is 0.0832Mbps and 4.86Mbps respectively [8]. The Number of Burst Transmission that achieves the min(Exp_throughput) which satisfies the requirement in (8) becomes the value of N[AC]s.

$$N[AC]_s = \{n[AC]_s \mid Req\_throughput \le \min(Exp\_throughput)|_{n[AC]_s, R}\} (8)$$

(ii) If the condition in (8) can not be satisfied, ie. the biggest min(Exp_throughput) value is below the Req_throughput, N[AC]s is set to the highest Number of Burst Transmission for a particular R based on Table 3 and 4.

(iii) The new TXOP limit (TXOP_limit[AC]$_{s,\,t}$) for the QSTA equivalent to the minimum duration which matches the Number of Burst Transmission (N[AC]s) based on chosen PHY rate (R) within maximum TXOP limit, denoted as the function (f) of equation (9).

$$TXOP\_limit[AC]_{s,t} = Min[f(R, N[AC]_s, TXOP[AC]_{max})] \quad (9)$$

3.2 Alpha Value, α

We emulate a Hotspot environment commonly found in a shopping complex or airport with the environment parameters from Table 6 in Section 4.1. Beacon interval is set to 100ms and simulation time is 20s. Employing the proposed adaptive EDCA TXOP, a video only system with α value of 0.2, 0.5, 0.9 is simulated in a heterogeneous (multi-rate) WLAN system.

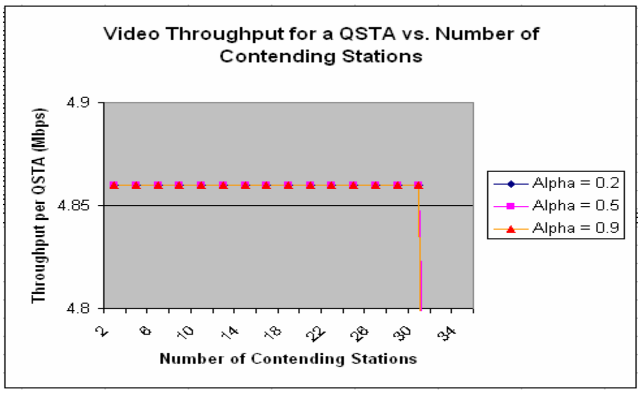


Fig. 2. Video throughput per QSTA (Mbps) with different number of contending stations.

Fig.2 shows that the α value hardly affects the throughput performance of a QSTA. Although sudden fluctuations in the channel might cause our algorithm to overestimate or underestimate at the next beacon interval; our algorithm is able to catch up with the required throughput within a short time. However, to avoid possible over estimation in Exp_throughput value, we set α to a conservative value of 0.2.

4 Performance Evaluation

In this section, we compare, analyze and evaluate the throughput performance of VO_AC and VI_AC per QSTA using our proposed AD-TXOP against the Standard 'Static' EDCA TXOP (Standard TXOP) algorithm which uses the constant maximum TXOP limit value in Table 1. This is a reasonable comparison as IEEE 802.11e states that a QAP rarely updates the TXOP limit value [3].

4.1 Simulation Environment

We tabulate our environment parameters in Table 5 below based on IEEE standards [1-3] and usage model [9].

Simulation Parameters	Descriptions
Number of Contending Stations	2 - 34 Stations
Topology	Random Topology
Maximum distance from AP	70m
Transmit Power	20dBm
Background Noice	-96dBm
Channel Condition (Hotspot)	Doppler = 20 Hz
	Velocity = 4.32 km/h
Maintaining PER	0.1
TXOP Limit (ac_VO)	1.504ms
TXOP Limit (ac_VI)	3.008ms
Alpha	0.2
Video Traffic Input	Video conferencing
	MSDU Size = 512 bytes
	Offered Load = 0.128 - 4.86 Mbps

Simulation Parameters	Descriptions
Voice Traffic Input	VoIP application
	MSDU Size = 120 bytes
	Peak Load = 0.083 Mbps

Table 5. Simulation environment parameters.

4.1 Performance Evaluation of AD-TXOP

4.1.1 Video Only Network System

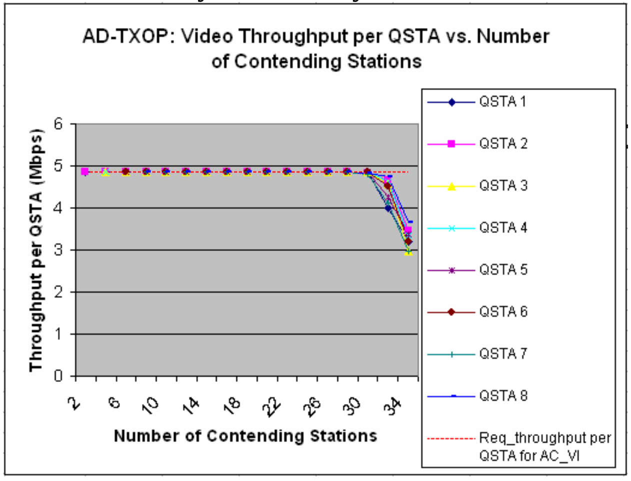


Fig. 3. Video throughput per QSTA with AD-TXOP

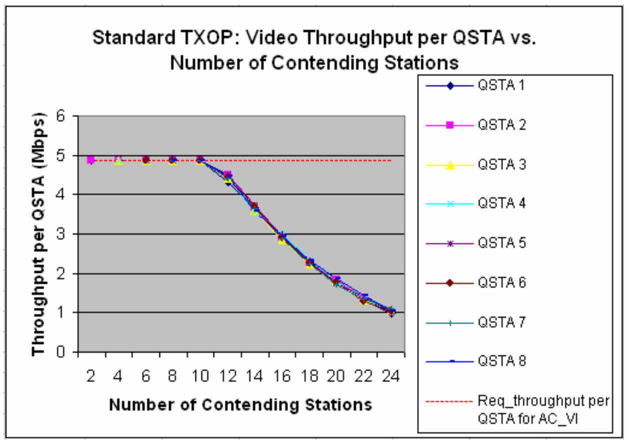


Fig. 4. Video throughput per QSTA with Standard TXOP

In a video only network, our proposed AD-TXOP clearly outperforms the Standard TXOP by significantly increasing the number of all contending stations that achieves the Throughput Requirement (Req_throughput) or otherwise known as network capacity for AC_VI from 8 stations to 30 stations.

From Fig. 5 onwards, throughput performance of one QSTA is shown for each Access Category (AC) for readability as QSTAs from the same AC exhibit similar performance characteristic as shown in Fig. 3 and Fig. 4.

In a voice and video network system with ratio 1:1 shown in Fig.5 and Fig.6, the network capacity for AC_VO using AD-TXOP increased from 18 stations to 26 stations while the network capacity for AC_VI leaps from 6 stations (based on Standard TXOP) to 16 stations (based on AD-TXOP).

4.1.2 Voice and Video Network System

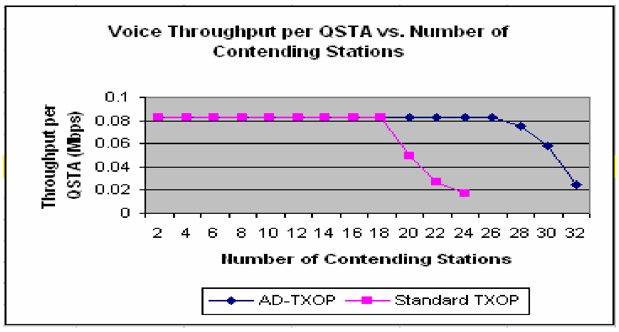


Fig. 5. Voice throughput per QSTA.

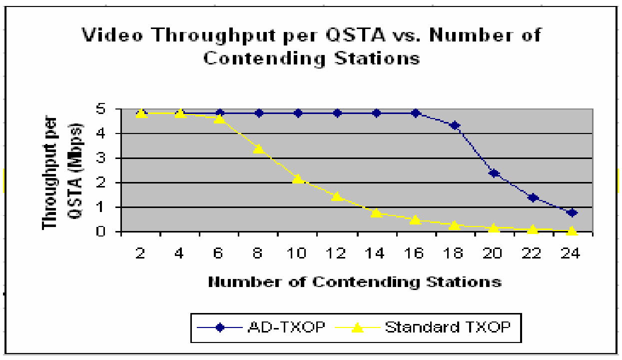


Fig. 6. Video throughput per QSTA.

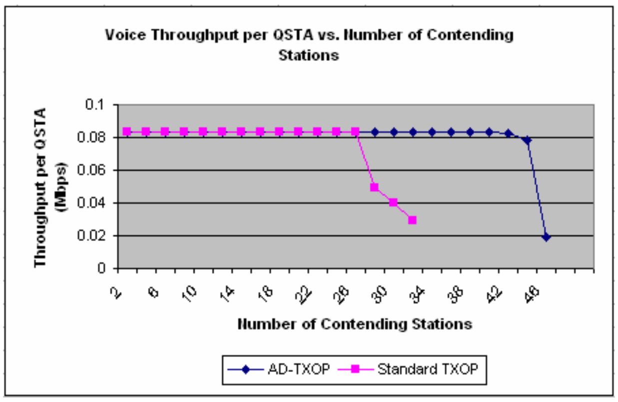


Fig. 7. Voice throughput per QSTA for ratio voice:video:data (1:1:1) with increasing network load .

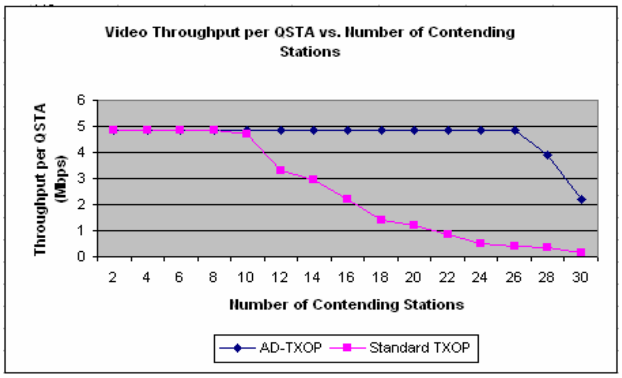


Fig. 8. Video throughput per QSTA for ratio voice:video:data (1:1:1) with increasing network load .

In a voice, video and data network system with ratio 1:1:1, the gain on network capacity for AC_VO using AD-TXOP increased from 26 stations to 42 stations as depicted in Fig.7 while the network capacity using

AD-TXOP is 2.6 times the network capacity of Standard TXOP.

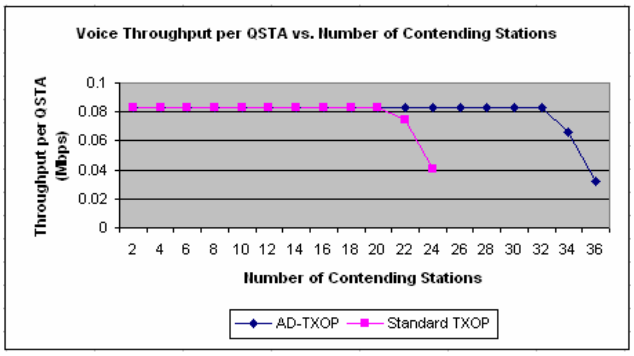


Fig. 9. **V**oice throughput per QSTA for ratio voice:video:data (2:1:1) with increasing network load.

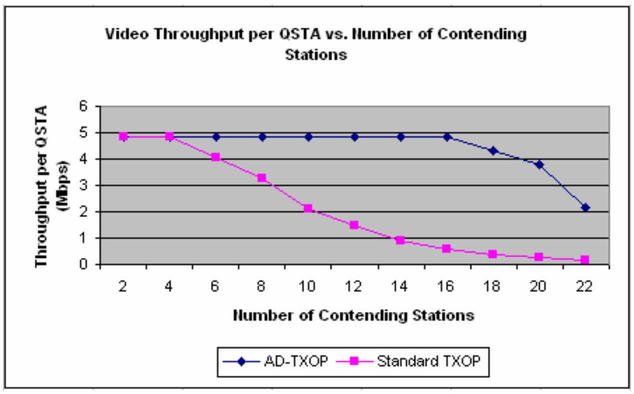


Fig. 10. **V**ideo throughput per QSTA for ratio voice:video:data (2:1:1) with increasing network load .

In a typical hotspot configuration with approximate voice to video to data ratio of 2:1:1 [9], our AD-TXOP algorithm again proves superior than Standard TXOP by outperforming the network capacity for both AC_VO and AC_VI; whereby the network capacity for AC_VO is increased 1.6 times from 20 to 32 stations and the network capacity for AC_VI using AD-TXOP achieves a significant 4 times gain compared to a network system using Standard TXOP.

Our AD-TXOP algorithm clearly enhances throughput stability while maximizing the network capacity for a multimedia based network system regardless of the ratio of voice, video and data. Another distinct advantage of our algorithm is that the throughput performance does not deteriorate in an exponential manner when network load is above the network capacity.

5 Conclusion

In this paper, an Adaptive EDCA TXOP (AD-TXOP) with rate adaptation algorithm is proposed for a distributed 802.11 WLAN system. The simulation result clearly speaks for itself. Our proposed algorithm is capable of dynamically adapting the TXOP limit to the varying (i) PHY rate (ii) channel condition and (iii) network load; to achieve a more superior and stable throughput performance that meets the required throughput (per QSTA) for both voice and video ACs, when compared to the Standard 'Static' TXOP scheme. On top of this, our AD-TXOP scheme also improves the network capacity and promotes fair channel utilization among QSTAs in a WLAN network for QoS provision.

References:

[1]IEEE 802.11, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, IEEE Std. 802.11-1999, Aug.1999.

[2] IEEE 802.11a, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High speed Physical Layer in the 5 GHz Band, Supplement to IEEE 802.11 Standard, Sep. 1999.

[3] IEEE 802.11e, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Medium Access Control (MAC) Quality of Service Enhancements, 11 Nov. 2005.

[4] J. Kim, S. Kim, S. Choi, D. Qiao, "CARA: Collision-Aware Rate Adaptation for IEEE 802.11 WLANs," *in Proc. IEEE INFOCOM'2006*, Barcelona Spain, 23-29 April, 2006

[5] E. Kim, Y. Suh, "ATXOP: An Adaptive TXOP Based on the Data Rate to Guarantee Fairness for IEEE 802.11e Wireless LANs," *in Proc.IEEE VTC2004-Fall*, 26-29 Sept. 2004, Vol. 4, pp. 2678-2682.

[6] S. Mangold, S. Choi, G. R. Hiertz, O. Klein, B.Walke, "Analysis of IEEE 802.11e for QoS Support In Wireless LANs,", *in IEEE Wireless Communications*, Dec. 2003, Vol. 10, pp. 40-50.

[7] A. Kamerman, L. Monteban, "WaveLAN-II: a high-performance Wireless LAN for the Unlicensed Band," *in Bell Labs Technical Journal*, Aug. 1997, Vol. 2, pp. 118-133.

[8] Y. Xiao, H. Li, S. Choi, "Protection and Guarantee for Voice and Video Traffic in IEEE 802.11e Wireless LANs," *in Proc. IEEE INFOCOM'2004*, 2004, Vol. 3, pp. 2152-2162.

[9] IEEE P802.11: doc: IEEE 802.11-03/802r23, Usage Model. (2004).