# Improving fairness index between data flows in 802.11e EDCA Wireless Ad Hoc Network by adjusting the dynamic TXOP parameter

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**Summary**
IEEE 802.11 protocol is the de facto standard for media access control in wireless ad hoc network. In particular, the 802.11e is an approved amendment to the IEEE 802.11 standard that defines a set of quality of service (QoS) enhancements for wireless LAN applications through modifications to the media access control (MAC) layer. The standard is considered of critical importance for delay-sensitive applications, such as Voice, Video over Wireless LAN and streaming multimedia. The 802.11e standard is based on the EDCA method (Enhanced Distributed Channel Access) to access transmission environment with different priority for each type of data flow. Based on the analysis of the parameter impact of EDCA, we evaluates the adaptability of TXOP parameter in the single and multi hop ad hoc network environments based on the criteria of fairness between multimedia flows. The article introduces a new method aiming to adjust the TXOP parameter according to dynamic mechanism that suits the priority of each data type from the existing limitations with TXOP parameter in EDCA. The simulation results show that our proposed method will help to improve the throughput and the fairness index between data flows suitable for ad hoc networks and better than the original IEEE 802.11e EDCA method. The proposed method will be evaluated and verified by Network Simulator (NS-2) software.

***Key words:***
*IEEE 802.11, IEEE 802.11e, EDCA, MAC, quality of service (QoS), queue, wireless network, throughput, throughput according to the ratio*

## 1. Introduction

In recent years, the field of wireless network in general and ad hoc network in particular has been increasingly paid attention to by the broad application domain, which directly impacts on important fields such as military, security, health care, aviation, etc. In particular, the studies [2, 4] focus on resolving QoS problems at the MAC access control layer in the 802.11 protocol in order to improve performance for real-time applications.
The IEEE 802.11e protocol has now become the de facto standard for media access control in the ad hoc wireless network. However, many studies [5, 6] have shown that the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF) do not have any mechanism to distinguish the data flows for priority processing, thus it does not ensure the quality of service (QoS) for multimedia applications. In support of those limits, the 802.11e standard was introduced to enable the data processing based on a differentiated service [3, 4, 12, 13]. The highlight of IEEE 802.11e with Hybrid Coordination Function (HCF) is a combination of DCF and PCF. The HCF includes two transmission access control mechanisms, including the Enhanced Distributed Channel Access (EDCA) based on the contention-based mechanism. The contention-based and HCCA (HCF Controlled Channel Access) mechanisms are based on polling mechanism.
The EDCA mechanism installed on IEEE 802.11e standard entities uses the multiple queues to receive and process the frames that need to be transmitted, classified according to each type of AC (Access Category) [11] as depicted in Figure 1.

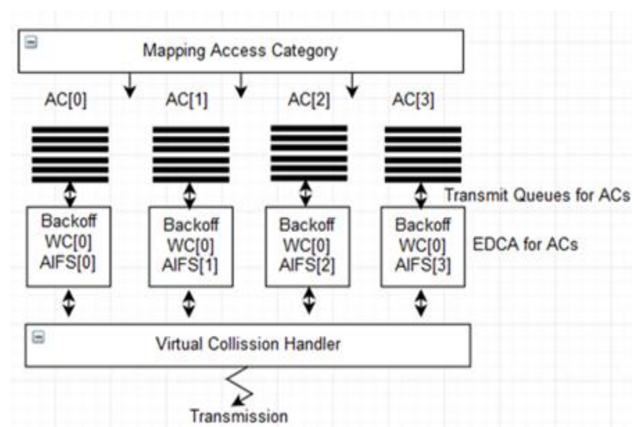


Fig. 1 Types of AC and queues in the EDCA

Each frame from the upper layer moving down to the MAC layer is given a UP (User Priority) weight based on the application that generated that frame. There are 4 data types with priority as described in Table 1.

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Table 1: Table of data flows according to priority order

| Priority | AC | Type of data |
|---|---|---|
| The lowest | BK | Background |
| - | BE | Best-effort |
| - | VI | Video |
| The highest | VO | Voice |

EDCA applies independent sets of parameter for each queue. These parameters include: AIFS (Arbitration Inter-Frame Space) is the waiting time before transmitting the next packet or initiating back-off algorithm; CWmin and CWmax are the maximum and minimum limits of the contention window (CW), used in the back-off algorithm; TXOPLimit (Tranmission Opportunity Limit) is the maximum transmission time when the flow gains the right to participate in data transmission.

Although 802.11e has good support for multimedia data flows through the access parameter set according to the priority. However, many research results [14, 15] show that when the network load reaches saturation state, the high priority flows will tend to occupy the entire bandwidth of low priority flows, leading to unfairness in the network.

Our important contribution in this paper is to propose a method of adjusting the TXOP parameter according to the dynamic control in accordance with the changing network topology to ensure the fairness of low priority flows in the case of large load, contributing to improve the quality of service for applications in the ad hoc network.

## 2. Related Works

The problem of improving the performance in ad hoc network has been researched for many years, but to this day, the issues like ensuring the throughput and fairness between data flows have not been completely resolved. There are currently two research directions related to improving the quality of data transmission at the MAC access control layer according to the EDCA distributed access method. The first is to improve the control mechanism of CW contention window [7, 8] in order to increase transmission access opportunities for less priority flows. The majority of studies in this direction are accessed through a mathematical model based on the Markov diagram. However, this method is mostly mathematically proven with many assumptions, it is not feasible when applying in practice.

The second is to improve the retention mechanism of TXOP to enhance the throughput and fairness between data flows. A number of studies approaching through the adjustment of TXOP parameter introduced in recent years have provided many positive results. The authors Kim, S., & Cho, Y. J [9] proposed to adjust TXOP based on CBR (Channel Busyness Ratio) to resolve the fairness issue. In this method, CBR is calculated by dividing the length of the busy channel and the frame transmission time. Then, according to the comparison of the channel busyness ratio and the threshold value, the new TXOP value is calculated. The authors Hu, J., Min, G., & Woodward [10] introduced a dynamic TXOP adjustment mechanism, based on the current state of the queue. Each queue will be compared with the threshold value to adjust increase or decrease of TXOP parameter depending on the traffic of the network. The authors Lee, J. Y., Hwang, H. Y., Shin, J. & Valaee [17] introduced adaptive distributed algorithm to flexibly determine TXOP based on the required throughput at each network node. Each station will measure its throughput in a time frame to compare with the expected value in order to reset the new TXOP value. The authors Mohammad Namazi, Neda Moghim, Mahdieh Ghazvini [18] introduced the method of adjusting the TXOP parameter according to the dynamic mechanism based on the fair weight of the WFR (Weighted Fair Queuing) queue and the average traffic rate of data flow to set new TXOP value.

The common point of the approaches through the adjustment of the TXOP parameter presented above is to aim at improving the throughput and increasing the fairness which have not yet supported well by the 802.11e standard. Although some results have been improved compared to the 802.11e standard, the criteria of fairness have not shown the superiority. The 802.11e standard is created to support the quality of service, but no basic method of the standard is proposed to improve the fairness of data flow, so resolution of this problem in depth is still continue to research and introduce. Inheriting this research direction, we introduce the method of adjusting the TXOP parameter according to the dynamic mechanism in Part 3 with a new algorithm based on the actual bandwidth sharing level of the network nodes.

## 3. Proposal of a method according to dynamic TXOP parameter

The goal of the method is to prevent the unfairness from happening when flows with high priority tend to occupy the entire bandwidth. In order to divide the bandwidth according to the desired ratio of 3: 2: 1 with priority, Voice, Video, Best-effort [14] we propose three modules that undertake the following functions.

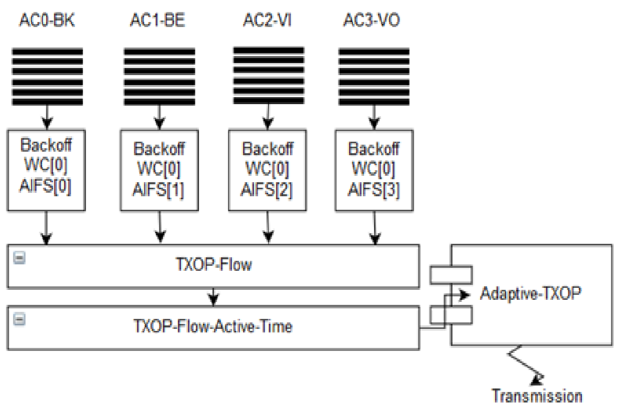


Fig. 5 The proposed module

*TXOP-Flow module:* Operating at MAC layer, which functions to count the number of flows in the transmitter domain. A flow is determined based on the source IP address, destination IP address, source MAC address, destination MAC address and AC in the beginning of the frame. The symbol of the number of flows is $n$, $k_i$ is the weight for each type of data flow. We set up $k_{voice}$ = 3, $k_{video}$ = 2, $k_{best\ effort}$ = 1. The module gives the total weight of the flows at the survey node according to the formula.

$$W_{total} = \sum_{i=1}^{n} k_i \times n_i \qquad (1)$$

*TXOP-Flow-Active-Time module*: There is a function to evaluate the true linkage performance of a flow within the Estimation Period EP (Estimation Period). The link performance is determined by analyzing the time used to deliver information packets in $i$ flow with 80% of the current send and receive time and 20% of the previous send and receive time.

$$U_{Actime\text{-}Time}=0.8*T_{ActiveTime[i]}+0.2*T_{Active[i]} \qquad (2)$$

In which, $\mathbf{U_{Actime\text{-}Time}}$ is the actual linkage performance of $i$ flow, $\mathbf{T_{Active\ Time[i]}}$ is the total time to send the current information packets of $i$ flow. $T_{Active\ [i]}$ is the total time of sending and receiving the previous packet of $i$ flow. The Active-Time calculation function is used according to the method defined in [13].

$$TXOP'[i] = \frac{FSR[i]}{RSR[i]} TXOP[i] \qquad (3)$$

*AdaptiveTXOP*: Module contains algorithm to adjust TXOP parameters based on actual bandwidth sharing ratio. RSR (Real Share Ratio) and fair bandwidth sharing ratio of FSR (Fair Share Ratio). TXOP adjustment value [i] will be determined by formula (3).

**Algorithm 3.1**

**Input:** An adhoc network topology. Data flows Voice, Video, Best Effort.
**Output:** The value W sums the weight of the data flows collected
**Begin**
**Init**
int W = 1; $k_{voice}$ = 3; $k_{video}$ = 2; $k_{Besteffort}$ = 1
int EP = 2000
for each interval time EP do

$$W = \sum_{i=1}^{n} k_i \times n_{tx}[i]$$

**End for**
**End**

**Algorithm 3.2**

**Input**: An adhoc network topology. Data flows Voice, Video, Best Effort.
**Output**: Calculate the link utilization Active_Time utilization of the flow.
**Begin**
Active_Time[i] = 0
$T_{Active[i]}$ = 0
**for** each interval time EP **do**
Active_Time[i] = 0.8*Active_Time[i] + 0.2*$T_{Active[i]}$
$T_{Active[i]}$ = 0
**for** each packet p **do**
if p → destID == localID then
if p → Type == CTS then
$T_{Active[i]}$ = $T_{Active[i]}$ + TRTS + TCTS
**else** if p → Type == ACK **then**
$T_{Active[i]}$ = $T_{Active[i]}$ + $T_{DATA}$ + $T_{ACK}$
**end if**
**end if**
**end for**
**end for**
**End**

**Algorithm 3.3**

**Input:** An adhoc network topology. Data flows Voice, Video, Best Effort.
**Output:** The value Fair Share Ratio FRS
**Begin**
int W = 1; $k_{voice}$ = 3; $k_{video}$ = 2; $k_{Besteffort}$ = 1
int EP = 2000
Call Function 2.1
**for** each interval time EP **do**

$$FSR = \frac{\sum_{i=1}^{n} k_i \times n_{TX}[i]}{W}$$

**End for**
**End**

**Algorithm 3.4**

**Input:** An adhoc network topology. Data flows Voice, Video, Best Effort.
**Output:** The value Real Share Ratio RSR
**Begin**
int W = 1; $k_{voice}$ = 3; $k_{video}$ = 2; $k_{Besteffort}$ = 1
int EP = 2000
Call Function 2.1
**for** each interval time EP **do**

$$RSR = \frac{k_i}{W_{total}}$$

**End for**
**End**
**End**

**Main Algorithm**

**Initialization:**
*EP* = 2000
RSR = 0 // Real Share Ratio
FSR = 0 //Fair Share Ratio
**Begin**
Active_Time = Call **Function 3.2**
W = Call **Function 3.1**
**for** each interval time *EP* **do**
FSR = Call **Function 3.3**
RSR = Call **Function 3.4**

$$TXOP'[i] = \frac{FSR[i]}{RSR[i]} TXOP[i]$$

**End for**
**Return TXOP'**
**End Begin**

## 4. Simulation and Analysis of the Results

To evaluate the performance of the proposed method, we use the NS2 simulation tool. The simulation uses two measurement indicators in 4.1 and 4.2 to evaluate the effectiveness between the fixed TXOP value method and the proposed dynamic TXOP value method. Common simulation parameters used according to table 4. Parameter EP = 2 (s). Weight of data types, VoiceWeight: 3, VideoWeight: 2, BestEffortWeight: 1. The offered load of the Voice flow is 3G, of the Video flow is 2G and Best Effort is 1G. The offered load speed G increases in steps with a step of 0.4 [Mbps] until it reaches a maximum speed of 8 [Mbps].

Table 3: Parameters for ns-2 simulation

| *Parameter* | *Value* |
|---|---|
| Channel data rate | 11 Mbps |
| Antenna type | Omni direction |
| Radio Propagation | Two-ray ground |
| Transmission range | 250 m |
| Carrier Sensing range | 550 m |
| MAC protocol | IEEE 802.11e |
| Connection type | UDP/CBR |
| Buffer size | 100 packet |
| Simulation time | 150s |

### 4.1 Fairness Index

To evaluate the fairness of throughput between different priority data flows in the ad hoc network. We propose the weight $\boldsymbol{k_i}$ corresponding to the data types with different priority. The network reaches an ideal fairness:

$$\frac{x_1}{k_1} = \frac{x_2}{k_2} = \cdots = \frac{x_n}{k_n}. \quad (4)$$

Where n is the number of flows in the network, $\boldsymbol{x_i}$ is the throughput of data flow $\boldsymbol{i}$ with the corresponding weight $\boldsymbol{k_i}$. Applying the fairness index formula defined by R. Jain [16], the fairness index formula in the network has different priority data flows, which we give expression as follows:

$$Fairness\ Index = \frac{(\sum_{i=1}^{n} \frac{x_i}{k_i})^2}{n \times \sum_{i=1}^{n} (\frac{x_i}{k_i})^2}. \quad (5)$$

In the best case, when the throughput of the flows is equal, the fairness index will approach as asymptotic as 1. In the worst case, when one flow occupies the entire bandwidth and the remaining flow is zero, the fairness index in this time is ***1/n***.

### 4.2 Total throughput

The total throughput value is defined as the sum of the throughput of all flows in the simulation

$$Total\ throughput = \sum_{i=1}^{n} x_i. \quad (6)$$

Where $\boldsymbol{n}$ is the number of flows and $\boldsymbol{x_i}$ is the throug hput of the data flow ***i.***

### 4.3 Single-stage topology

In this scenario, we set up a simple gingle-stage topology, including an play button S and a receiver button D, as shown in Figure 3.


Fig. 3 Single hop topology

The S source node sends the flow with three data types: BestEffort, video, and voice to the destination node.

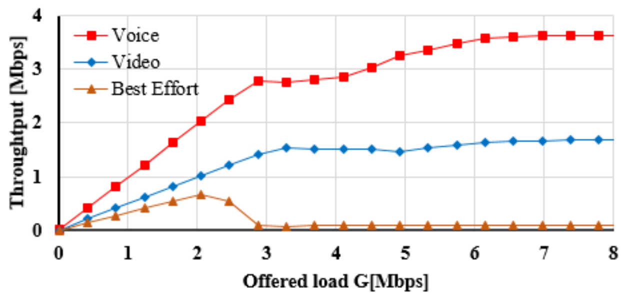


Fig. 6 Throughput of 802.11e EDCA with standard parameters

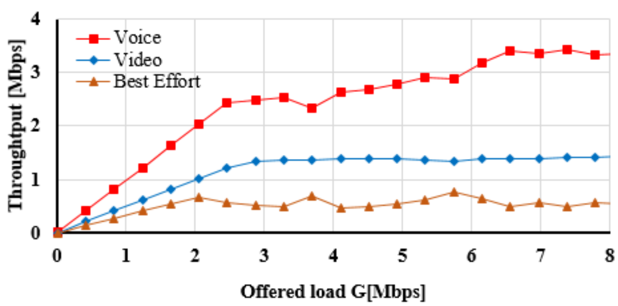


Fig. 7 Throughput of flows with proposed method

Comparing the throughput results between Voice, Video, and Best Effort flows in Figure 6 and Figure 7, we see that the throughput of Best Effort flow according to the proposed method is significantly improved while the throughput of Voice flow and Video flow is not degraded compared to the method of setting TXOP fixed parameters according to 802.11e standard.

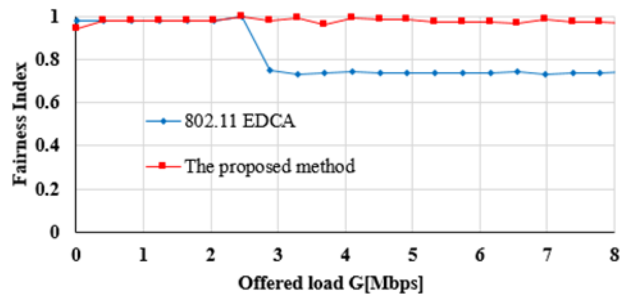


Fig. 8 Comparing the fairness index of the two methods

The fairness index between the flows is shown in Figure 8, showing that when the network load is small, the fairness index of the two methods is equivalent, but when the network load is large, the fairness index of the proposed method is superior compared with fixed TXOP parameter setting method according to 802.11 standard.

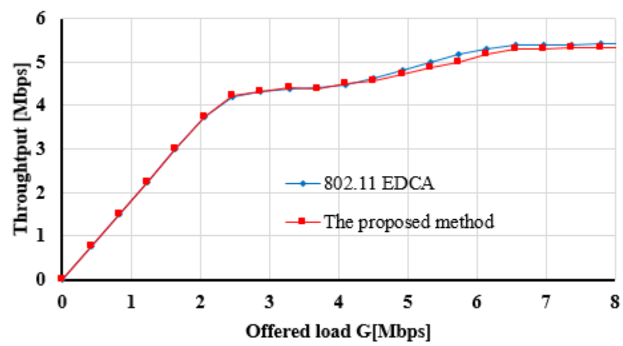


Fig. 9 Comparing the total throughput of the two methods

The graph of comparing the total throughput in Figure 9 shows that when the network load is small, the total throughput of the two methods is the same, but when the network load is large, the total throughput of the proposed method decreases slightly.

## 4.4 Multi-stage topology

In this scenario, we build 3 nodes, node S2 is in broadcast region of node S1 and node S1 is in broadcast region of node D. The S2 sends three data flows of BestEffort, Video and Voice to node D via button S1.

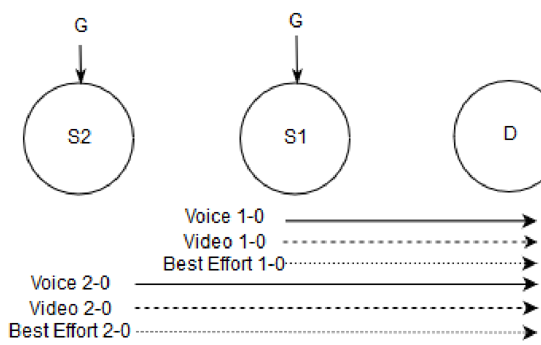


Fig. 10 Multi-stage hop topology

Simulation results of total throughput between data flows from node S2 to node S1 and from node S1 to destination node D between the proposed method and the method of fixed TXOP parameter according to 802.11e standard are shown in Figure 11 and Figure 12.

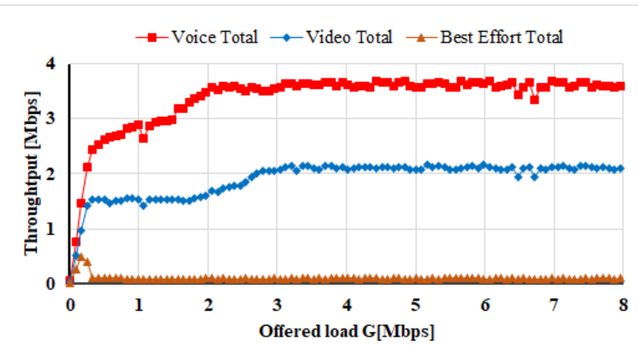


Fig. 11 The total throughput of data flows with standard EDCA parameters

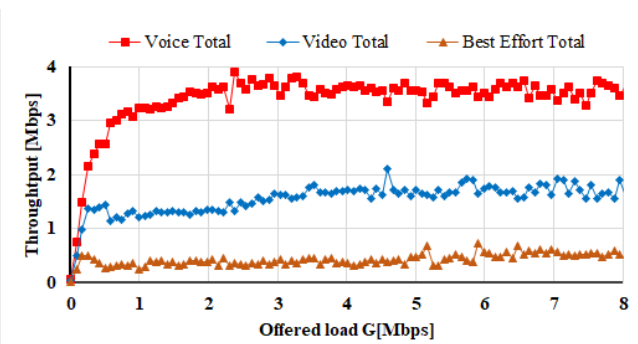


Fig. 12 Total throughput of data flows with proposed method

The comparison of the results in Figure 11 using the method of fixed TXOP parameter and the result in Figure 12 by the method of dynamic TXOP parameter suggestion, shows the total throughput of flows obtained from the proposed method makes the ratio among flows more balanced.

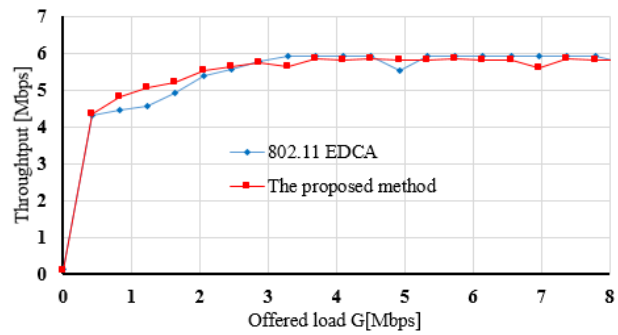


Fig. 13 Compare the total throughput of the two methods

Figure 13 The performance of the total throughput of flows by two methods. The graph shows that when the network load is small, the throughput of the two methods is the same, when the network load increases the total throughput of the proposed method has a slight difference.

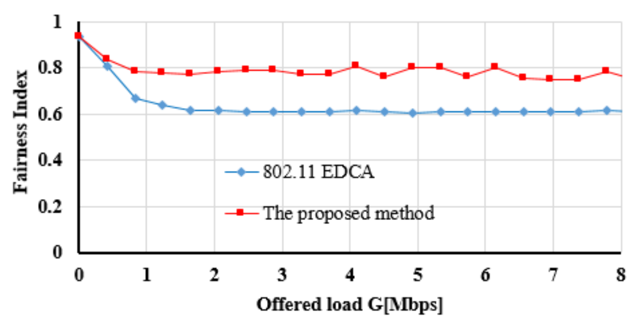


Fig. 14 The comparison the fairness index of the two methods

Figure 14, the description of the fairness index of the two methods, results show that the dynamic proposed TXOP parameter method gives a higher fairness index than the fixed TXOP parameter setting method.

## 5. Conclusion

From the previous research results [1], we found that the IEEE 802.11e standard has partly met QoS assurance for multimedia data type, but in terms of fairness, this standard is still limited very much because it only gives fixed values for the control parameter set in EDCA. The important contribution of the paper is to propose a method to adjust TXOP parameters according to dynamic mechanism based on actual bandwidth sharing, to improve the fairness between multimedia data flows suitable for ad hoc networks.

The simulation results show that our proposed method will help to improve the throughput and the fairness index between data flows suitable for ad hoc networks and better than the original IEEE 802.11e EDCA. This proves that, for complex network graphs such as ad hoc networks, the use of dynamic TXOP parameters will enable an appropriate level of fair sharing and ensure throughput between multimedia data flows, contribute to maintain stability and improve the quality of data transmission in applications on the wireless platform.

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