An Enhanced MAC-Layer Improving to Support QoS for Multimedia Data in Wireless Networks

Ngo Hai Anh* and Pham Thanh Giang
Institute of Information Technology, Vietnam Academy of Science and Technology, Vietnam; ngohaianh@ioit.ac.vn, ptgiang@ioit.ac.vn

Abstract

In this paper, we present some mechanisms at Medium Access Control (MAC) sub-layer to handle traffic with QoS requirements in wireless networks. We propose a method which will ensure the network’s traffic is different in ratio to suit applications in networks.

Keywords: IEEE 802.11e EDCA, MAC Control, QoS, Multimedia Traffic, Service Differentiation, Traffic Differentiation

1. Introduction

In an effort to give IEEE 802.11 networks QoS, IEEE 802.11e specification was published in 2005. 802.11e with improvements to the Point Coordination Function (PCF) and Distributed Coordination Function (DCF) mechanisms, which was corresponding called HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA).

In the EDCA method, some Media Access Control (MAC)-layer parameters are used to provide priority level to each Traffic Class (TC) in a contention access condition in channel. These parameters are the Arbitration Inter-Frame Space (AIFS), Transmission Opportunity (TxOP) and Contention Window minimum (CWmin) and Contention Window maximum (CWmax). The AIFS, TxOP, CWmin and CWmax parameters are setup as default values at each station for each Traffic Class.

As shown in Figure 1, the queue structure at MAC layer in the EDCA is created from queues. In DCF, each station has a single queue that all attached traffic sources traverse in a first-in-first-out manner, where the probability of a source being the next to transmit is dependent on the packet size and packet rate of that source. In the EDCA, a station has for each TC: a DCF queue, prioritization parameters and a transmission packet. Each transmission packet at each queue head contends for the right to transmit by decrementing a back off counter based on the parameters for its queue. When more than one queue reaches a back off counter value of zero, the packet from the Traffic Class with highest priority is chosen for transmission and the other queues has a virtual collision. This virtual collision is treated as if a real collision has occurred; the CW value for each queue will be increased two times, and after that, a new back off counter value will be selected.

The priority of one queue over another is dependent on how long it must wait before being able to transmit, and the length of time a packet must wait to be transmitted is controlled by the back off counter. The AIFS parameter contributes to this time by defining the interval which Traffic Class must delay before starting the back off counter after the medium has been sensed as free. The CWmin and CWmax parameters prioritize by adjusting the minimum and maximum values of back-off counter, respectively. Each parameter can be different within each Traffic Classes, while DCF parameters will be applied normally between the Traffic Classes within a station. The maximum value of TXOP defines the interval in which a station can transmit on behalf of a TC. A longer TXOP value contributes to higher throughput and can reduce overall contention in the network by consolidating packets of bursty traffic sources.

In EDCA, the AIFS is a length of time that is equal or greater than the DIFS, and hence the higher priori-
Figure 1. Contention free interval.

In this paper, we propose a method that allows sharing bandwidth in a flexible manner between the different types of data in IEEE 802.11e by adjusting the Contention Window value for each flow at the station. The following sections describe the methods that we used to achieve this goal.

### 2. Related Works

There are many studies about the fairness of bandwidth sharing in IEEE 802.11e EDCA. Casetti et al. evaluated EDCA performance about the integration of voice and data traffic\(^2\), and discover the inefficiencies of the dividing bandwidth based on type of Access Categories and propose solutions to change the setting of parameters such as AIFS, CWmin, CWmax for different data types, thus improving throughput and fairness for real-time data in a wireless network used EDCA. But this approach remains a fixed setting that is merely changing the values of these parameters compared with the default setting in the EDCA. Another study based on IEEE 802.11 has demonstrated that the distribution of different QoS levels can be done by only setting the parameter CWmin\(^3\), but this method was mainly proved with a lot of unrealistic depend on current conditions of network. In this paper, we propose a solution that allows sharing bandwidth in a flexible manner between the different types of data in IEEE 802.11e EDCA. Table 1 describes the methods that we used to achieve this goal.

### Table 1. User priority and access category IN 802.11e EDCA

| Priority | User Priority | Access Category | Data Type |
|----------|---------------|-----------------|-----------|
| lowest   | 1             | AC_BK           | Background|
| -        | 2             | AC_BK           | Background|
| -        | 0             | AC_BE           | Best effort|
| -        | 3             | AC_BE           | Best effort|
| -        | 4             | AC_VI           | Video     |
| -        | 5             | AC_VI           | Video     |
| highest  | 7             | AC_VO           | Voice     |

### Table 2. Maximum and minimum contention window in 802.11e EDCA

| AC    | CWmin       | CWmax       | AIFS (ms) | TXOPlimit (ms) |
|-------|-------------|-------------|-----------|----------------|
| AC_BK | aCWmin      | aCWmax      | 7         | 0              |
| AC_BE | aCWmin      | aCWmax      | 3         | 0              |
| AC_VI | (aCWmin+1)/2-1 | aCWmax | 2 | 6.016 |
| AC_VO | (aCWmin+1)/4-1 | (aCWmin+1)/2-1 | 2 | 3.264 |

EDCA mechanism defines four Access Categories (ACs) that keep support for the differentiated traffic with User Priorities (UPs) at the stations. An AC which is based on UP, or frame type, is assigned to each frame before it accessed TP the MAC layer. The default ACs values of EDCA are represented in Table 1.

The default CWmin and CWmax parameters for each AC are represented in Table 2.

Normally, the values aCWmin = 15 and aCWmax = 1023, are used. The EDCA parameters are only in infrastructure (Access Point) mode. With these parameters, prioritization of traffics from different data types can be differentiated and network performance from view point of traffic prioritization can be achieved.

Finally, it is so hard to find the optimal parameters for network configuration because the parameters always vary. The main reason is that the network traffic load changes rapidly, and the wireless network medium is slow in changing its state. In this paper, we propose an algorithm that allows sharing bandwidth in a flexible manner between the different types of data in IEEE 802.11e EDCA. The main idea is to adjust the CWmin parameter for each AC according to the current network traffic load and the number of flows belonging to each AC. The algorithm consists of two phases: the initialization phase and the adjustment phase.

In the initialization phase, each AC starts with a default CWmin value, which is set to 15 for AC_VO and 1 for AC_BK. In the adjustment phase, the CWmin value for each AC is adjusted based on the current network traffic load and the number of flows belonging to each AC. The adjustment formula is as follows:

\[
\text{adjust} = \frac{\text{traffic load}}{\text{num flows}}
\]

The adjustment factor \(\text{adjust} \) is then used to adjust the CWmin value for each AC according to the following equation:

\[
\text{new CWmin} = \text{default CWmin} + \text{adjust}
\]

The adjustment factor is determined by monitoring the network traffic load and the number of flows belonging to each AC. The adjustment factor is updated periodically, and the CWmin value is adjusted every time the adjustment factor changes. This allows the algorithm to adapt to changes in the network traffic load and the number of flows belonging to each AC.

Finally, the results show that the proposed algorithm allows sharing bandwidth in a flexible manner between the different types of data in IEEE 802.11e EDCA. The algorithm is more efficient in terms of throughput and fairness compared to the default setting in the EDCA. The proposed algorithm can be used in various wireless network environments, such as wireless home networks and wireless enterprise networks.
mathematical optimization assumptions. Another study using an improved scheduling scheme compared with channel access mechanism in MAC layer in IEEE 802.11e\textsuperscript{5}, however, this approach only focuses on best-effort data type, the type of data with lowest priority compared to other types of data such as voice, video.

To the author’s knowledge there does not exist work to dynamically adjust the 802.11e EDCA parameters in such a way that only local information is needed. Using the works discussed here, a new method for prioritization was developed and is explored in the following sections of this paper.

3. The Measurement of Fairness in Wireless Ad Hoc Network

The fairness is a complex problem related to the different priorities and different requirements of QoS-based applications. Our study of fairness mainly limited aspects allocates resources between threads in a class with the same service. The solution proposed is based on the assumption that the users in the same class level ratio measures a fair share of the resources are limited.

3.1 The Per-Flow Fairness

Here, we consider the definition of per-flow fairness as follows. The number of flows sharing the channel bandwidth $B$ is denoted by $n$. The offered load of flow $i$ is denoted by $G_i$ and the resulting throughput is denoted by $T_h_i, i = 1, 2, ..., n$. We assume $G_1 \leq G_2 \leq ... \leq G_n$. We define per-flow fairness by the following:

$$T_h_i = \left\{ \begin{array}{ll}
G_i, & i = 1, ..., m \\
B - \sum_{j=1}^{m} T_h_j \\
\frac{B - \sum_{j=1}^{m} T_h_j}{n-m}, & i = m+1, ..., n
\end{array} \right. \quad (1)$$

Here $m$ is the index in $0, ..., n$ which satisfies:

$$B - \sum_{j=1}^{m} T_h_j > G_m \quad \text{and} \quad G_{m+1} > \frac{B - \sum_{j=1}^{m} T_h_j}{n-m}$$

We call flow $i$, $i = 1, 2, ..., m$, is “small” offered load flow and flow $i$, $i = m+1, m+2, ..., n$, is “large” offered load flow. In case that all flows are large offered load flows ($m=0$), the ideal per-flow fairness is achieved when every flow gets the same throughput. In case there are some small offered load flows ($m \geq 1$), the ideal per-flow fairness is such that the throughput of every small offered load flow is equal to its offered load, and the remaining bandwidth is shared equally by large offered load flows.

For example, if there are four flows with offered loads 0.2 Mbps, 0.5 Mbps, 0.7 Mbps and 0.8 Mbps and the channel bandwidth is 2 Mbps. Then, flows with offered load 0.2 Mbps and 0.5 Mbps are small offered load flows while flows with offered load 0.7 Mbps and 0.8 Mbps are large offered load flows. The ideal per-flow fairness is such that the throughputs are 0.2 Mbps, 0.5 Mbps, 0.65 Mbps, 0.85 Mbps, respectively.

In case the offered load is not constant and changes with time. The definition of fairness in each flow is based on the average offered load for a given period of time.

3.2 The Fairness Index between Data Flows

The fairness index, which is defined by R. Jain\textsuperscript{16} used to calculate the ratio of throughput sharing between flows as follows:

$$\text{Fairness Index} = \frac{\left( \sum_{i=1}^{n} x_i \right)^2}{n \times \sum_{i=1}^{n} x_i^2} \quad (2)$$

Here $n$ is the number of flows, $x_i$ is the end to end throughput of flow $i$.

The ranges of Fairness Index value is from $1/n$ to 1. If the throughput of all flows are equal (best case), the Fairness Index equals 1. In the opposite case (worst case), the throughput sharing is totally unfair, i.e., one flow gets all the capacity while other flows get nothing, then the Fairness Index is $1/n$.

3.3 The Priority-based Fairness between Data Flows

We propose the equation for calculating fairness by priorities based on (2) as the following:

$$\text{Fairness Index} = \frac{\left( \sum_{i=1}^{n} \frac{x_i}{k_i} \right)^2}{n \times \sum_{i=1}^{n} \left( \frac{x_i}{k_i} \right)^2} \quad (3)$$

Here, $k_i$ is the weighted number with the corresponding types of data.
4. Flow Control in IEEE 802.11e

4.1 Adjusting Contention Window (CW) in Wireless Ad Hoc Networks

In the multi-hop wireless networks, some flows have difficulty to access the channel due to the contention at both the MAC layer and link layer. Size of CW is related to the probability for accessing channel of each flow. Our cross-layer scheme is proposed to collect useful information from the physical layer, MAC, link, then adjust size of CW rely on such value. By using a flexible value of CW in back off stage, the flow which has little advantage may have more opportunities to access channels.

The CW size is only based on the conditions of network congestion, so it is not a good value for the fairy bandwidth allocation. The CW size is related to the probability for accessing channel of flow. By reducing the size of CW in the back-off state, the probability of accessing channels will be increased, and thus flow can be allocated more bandwidth. Conversely, by increasing the size of CW in the back-off state, the neighbor flows will have more opportunities to access channels. Based on the value of CW in back off mechanism of IEEE 802.11 and the conditions of the network, we have determined a better value of CW in back-off state to achieve the fairness in each flow.

4.2 Ensuring the Fairness between Flows in 802.11e

Based on the cross-layer scheme to ensure fairness in IEEE 802.11e, we propose a number of MAC layer improvement in IEEE 802.11e to achieve the fairness between different data flows (video, audio, text,…). In general, the data flows should have the different priorities of bandwidth, for example, video data will need more bandwidth than voice data, or when calling phone over Internet (VoIP), the voice data will be prioritized more than video data. Therefore, we need to have the corresponding way to assign bandwidth usage for data flows. We did this work based on two modules named TX Flow Estimation and Utilization Estimation.

Module TX Flow Estimation works in MAC layer to count the total of flows in the transmission range. We call these flows are TX flows. A TX flow is determined based on source’s and destination’s MAC and IP addresses by analyzing the header of the packet. We define TX flows is $n_{TX}$.

Suppose that, there are $n$ data flows with $k_j$ is the weighted number of the four data types which are defined in 802.11e, assuming the background data has $k = 1$.

We calculate the total flow $n_{total}$ in TX Flow Estimation module by the following formula:

$$n_{total} = \sum_{i=1}^{n} k_j \times n_{TX}[i]$$

(4)

Next we define the fairy ratio share of the bandwidth for each flow by the formula:

$$\text{Fair\_Share\_Ratio}[i] = \frac{k_j}{\sum k_j \times n_{TX}[i]}$$

(5)

Utilization Estimation module evaluates the real link utilization of the flow. The link utilization is determined by analyzing period $\text{Active\_Time}[i]$ of the flow in a given estimation period called $\text{EP}$. The $\text{Active\_Time}[i]$ of the flow is called as the time used to transmitting packets in flow $i$. The algorithm below is used to estimate the value of $\text{Active\_Time}[i]$ of the data flow $i$.

**Algorithm 1 (Active\_Time\[i\])**

**Initialization:**

$\text{Active\_Time}[i] = 0$

$T_{Active}[i] = 0$

**Begin**

for each interval time $\text{EP}$ do

$\text{Active\_Time}[i] = 0.8 \times \text{Active\_Time}[i] + 0.2 \times T_{Active}[i]$

$T_{Active}[i] = 0$

for each packet $p$ do

if $p \rightarrow \text{destID} == \text{localID}$

if $p \rightarrow \text{Type} == \text{CTS}$

$T_{Active}[i] = T_{Active}[i] + T_{RTS} + T_{CTS}$

else if $p \rightarrow \text{Type} == \text{ACK}$

$T_{Active}[i] = T_{Active}[i] + T_{DATA} + T_{ACK}$

end

end

end

**End**

The $\text{Real\_Share\_Ratio}[i]$ is denoted as the ratio of the $\text{Active\_Time}[i]$ to the Estimation Period $\text{EP}$ as the follow:

$$\text{Real\_Share\_Ratio}[i] = \frac{\text{Active\_Time}[i]}{EP}$$

(6)
Based on the CW size which has been defined in Table 2, the adjusted value of CW will be determined by the formula:

$$CW'[i] = \frac{Real\_Share\_Ratio[i]}{Fair\_Share\_Ratio[i]} \cdot CW[i]$$

(7)

In the above formula, the fairness value Share_Ratio[i] is used as a threshold of priority for accessing channel. If flows realized that the real value Share_Ratio[i] is less than its Fair_Share_Ratio[i], it will use the CW size which is smaller than in the back-off state. Thus, the flow can have more opportunities to access channels and bandwidth allocation. On the other hand, if flow realizes that Real_Share_Ratio[i] is greater than its Fair_Share_Ratio[i], it will use a value greater than CW in back-off state. Therefore, it will have less opportunity to access channel, leading to other disadvantaged flows will have more opportunities to access the channel. In case some of flows only have a small offered load, it means that they will more easily access channel, and the remaining bandwidth will be shared by other flows. Thus, it allows the use of channel bandwidth more efficiently and ensures fair bandwidth allocation among flows.

For priorities are shown in Table 1, we propose the weighted number for each priority as represented in Table 3.

In that case, if the network bandwidth is 2 Mbps, when the required throughput of all flows is exceeded the network bandwidth; the expected result of ratio shared bandwidth by our proposed algorithm will be shown in Figure 2.

### 5. Analysis of Simulation Results

We evaluate our proposed method by using the simulation tool Network Simulator (NS-2)\(^\text{15}\). For IEEE 802.11e simulation, we use the extension patch for 802.11e\(^\text{20}\). The topology for simulation is represented in Figure 3:

This topology includes two nodes, source and destination. The source node sends flows with three data types: background, video, and voice to destination node. The parameters for simulation are described in Table 4.

#### 5.1 Evaluation of Differentiate Throughput by Ratio

The simulation result with different values of throughput is shown in Table 5.

In this result, we can see the ratio of throughput between data types has archived as expected in our proposed method, better than original 802.11e (EDCA).

![Figure 2. Throughput by ratio in proposed method.](image)

![Figure 3. Two wireless nodes with three data flows scenario.](image)

Table 4. Parameters for ns-2 simulation

| Describe                  | Value       |
|---------------------------|-------------|
| Channel data rate         | 2 Mbps      |
| Antenna type              | Omni direction |
| Radio propagation         | Two-ray ground |
| Transmission range        | 250 m       |
| Carrier Sensing range     | 550 m       |
| MAC protocol              | EDCA        |
| Connection type           | UDP with CBR |
| Packet size               | 512 bytes   |
| Send rate                 | 2000 Kbps   |
| Simulation time           | 100 s       |

Table 3. The weighted number for data flows

| Priority | UP | AC    | Weighted number |
|----------|----|-------|-----------------|
| lowest   | 1  | AC_BK | 1               |
| -        | 2  | AC_BK | 1               |
| -        | 0  | AC_BE | 2               |
| -        | 3  | AC_BE | 2               |
| -        | 4  | AC_VI | 4               |
| -        | 5  | AC_VI | 4               |
| -        | 6  | AC_VO | 6               |
| highest  | 7  | AC_VO | 6               |
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5.2 Evaluation of Fairness Index and Total Throughput

We evaluate the proposed method by comparing simulation results with IEEE 802.11e in four cases:

- IEEE 802.11e.
- IEEE 802.11e with PCRQ queue.\(^{17}\)
- IEEE 802.11e with Round Robin queue\(^{17}\) (with weighted numbers are 0).
- IEEE 802.11e with our proposed method in part 4 of this paper.

The simulation result is shown in Table 6. We can see the result of our proposed method is better than other methods.

| Ratio          | Throughput (Kbps) |            |            |            |
|----------------|-------------------|------------|------------|------------|
|                | Voice             | Video      | Best effort|            |
| 2:1:1          | 471               | 233        | 235        |            |
| 4:1:1          | 576               | 169        | 169        |            |
| 4:2:1          | 506               | 275        | 102        |            |
| EDCA           | 846               | 378        | 177        |            |

Table 5. Comparison result of ratio throughput

| Fairness Index | Total Throughput (Mbps) |            |            |            |
|----------------|-------------------------|------------|------------|------------|
| Voice          | Video                   | Best effort|            |            |
| IEEE 802.11e   | 0.925                   | 0.949      | 0.982      | 3.478      |
| 802.11e with PCRQ queue | 0.891 | 0.999 | 0.998 | 3.488 |
| 802.11e with RR queue | 0.887 | 0.998 | 0.999 | 3.492 |
| Proposed method | 0.999 | 0.999 | 0.995 | 3.729 |

Table 6. The comparison of fairness index

5.2 Evaluation of Fairness Index and Total Throughput

6. Conclusion

IEEE 802.11 satisfy the demand for wireless connectivity for mobile devices, but after a long period of development, this standard have revealed the limitations in ensuring Quality of Service (QoS) for multimedia data applications, which require more better conditions about throughput, latency, data loss rate and jitter. Inherited from 802.11, IEEE 802.11e standard is developed in 2005 and was met in part to ensure QoS for multimedia data types, but in terms of fairness, this standard remains limitations because it uses fixed values for the QoS parameters, e.g. Contention Window (CW) size.

Our research has proposed a new method for ratio of bandwidth sharing between the data flows as well as adjusting CW value to archive a reasonable degree of fairness between flows for multimedia data communications.

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