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

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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 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[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 prior-

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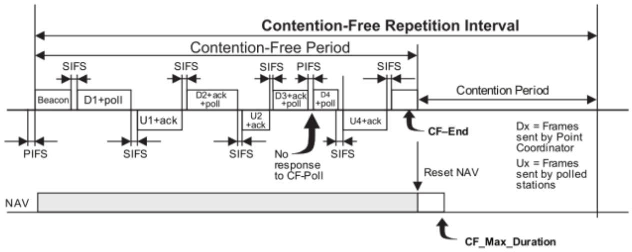

Figure 1. Contention free interval.

ity stations can be assigned low values. When this time value expires, DCF operation for a station still continues normally by decrementing the back-off counter. So that, Traffic Class which has low AIFS values will has opportunity to gain access to the channel medium. With such way, the CWmin is corresponding with the CW size of each TCs. A CWmin with small value allows the flow to access the medium earlier after the AIFS, and has more opportunity to get the medium after a collision. When a collision occurs, each Traffic Classes increases the current CW value by the Persistence Factor (PF) parameter, (its value often is 2) to calculate the next back-off value. The CWmax determines the maximum value to which a CW value of flow can increase. With a larger value, flows will have less competitive during collision and heavy load situations. With a lower priority, CW values of flows will be larger and flows must wait longer if traffic load of network having many collisions. The TXOPmax defines the interval for which a station can send data on behalf of each TC. With a larger value of TXOPmax will allow stations to transmit more data during each use of the channel medium.

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

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
-	6	AC_VO	Voice
highest	7	AC_VO	Voice

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

AC	CWmin	CWmax	AIFS	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

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 IEEEE 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. Cassetti 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 valuesof 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 mathematical optimization assumptions. Another study using a improved scheduling scheme compare with channel access mechanism in MAC layer in IEEE 802.11e[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 Th_i, i = 1, 2,..., n. We assume $G_1 \le G_2 \le ... \le G_n$. We define per-flow fairness by the following:

$$Th_i = \begin{cases} G_i, i = 1, ..., m \\ \dfrac{B - \sum_{j=1}^{m} Th_j}{n-m}, i = m+1, ..., n \end{cases} \tag{1}$$

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

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

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 ≥ 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 Mps 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 Mpbs, 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[16] used to calculate the ratio of throughput sharing between flows as follows:

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

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:

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

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 802.11[18], 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_i 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:

$$n_{total} = \sum_{i=1}^{n} k_i \times n_{TX[i]} \quad (4)$$

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

$$\text{Fair\_Share\_Ratio}[i] = \frac{k_i}{\sum k_i \times n_{TX[i]}} \quad (5)$$

Utilization Estimation module evaluates the real link utilization of the flow. The link utilization is determined by analyzing period Active_Time[i] of the flow in a given estimation period called EP. The 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 Active_Time[i] of the data flow i.

Algorithm 1 (Active_Time[i])

```
Initialization:
Active_Time[i] = 0
T_Active[i] = 0
Begin
  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
    ifp→destID == localID
      if p→Type == CTS
        T_Active[i] = T_Active[i] + T_RTS + T_CTS
      else if p→Type == ACK
    T_Active[i] = T_Active[i] + T_DATA + T_ACK
        end
      end
    end
  end
End
```

The Real_Share_Ratio[i] is denoted as the ratio of the Active_Time[i] to the Estimation Period EP as the follow:

$$\text{Real\_Share\_Ratio}[i] = \frac{Active\_Time[i]}{EP} \quad (6)$$

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

$$CW'[i] = \frac{Real\_Share\_Ratio[i]}{Fair\_Share\_Ratio[i]} CW[i] \quad (7)$$

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)[19]. For IEEE 802.11e simulation, we use the extension patch for 802.11e[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.

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

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).

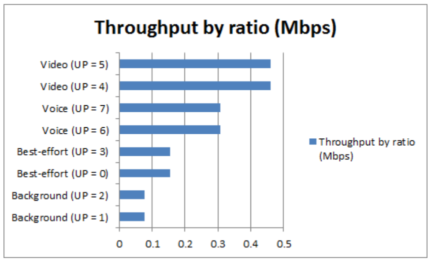

Figure 2. Throughput by ratio in proposed method.

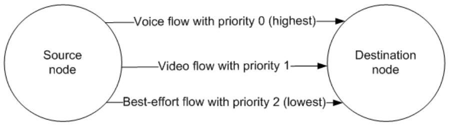

Figure 3. Two wireless nodes with three data flows scenario.

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 5. Comparison result of ratio throughput

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 6. The comparions of fairness index

	Fairness Index			Total Throughput (Mbps)
	Voice	Video	Best effort	
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

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.

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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