# Dynamic Polling Management for QoS Differentiation in IEEE 802.11e Wireless LANs

Xiyan Ma, Yanfeng Zhu, Zhisheng Niu
State Key Laboratory on Microwave and Digital Communication
Department of Electronic Engineering, Tsinghua University
Beijing 1000084, P. R. China

*Abstract* – **Upcoming IEEE 802.11e standard aims to support Quality of Service (QoS) for multi-priority services, which is not yet available in current Wireless Local Area Network (WLAN) systems. In this paper, we propose to combine the Enhanced Distributed Coordination Function (EDCF) and Point Coordination Function (PCF) of IEEE 802.11e protocols. The scheme dynamically adds and deletes voice station IDs in polling list, utilizing the talkspurt-silence alternation characteristic of speech traffic. Meanwhile, the real-time and non real-time traffic are also differentiated by means of different EDCF parameters during contention period. Extensive simulation results demonstrate that the dynamic polling management in combination with EDCF is able to achieve satisfying QoS differentiation, while at the same time significantly improve the system performance in terms of throughput and data drop rate.**

## I. Introduction

The past few years have seen an explosion in the deployment of Wireless Local Area Networks (WLANs) conforming to the IEEE 802.11 standard. Since they dispense the restriction of wired transmission medium, WLANs are more convenient to be laid out and extended than Ethernet, and easier to support users with terminal mobility. As a result, WLANs are expected to support the same applications as the Ethernet that they are replacing. While Quality of Service (QoS) issues in Ethernet have been considered uninteresting due to the huge improvements in the physical layer bandwidths, it is difficult for current WLANs to achieve satisfying performance when delivering real-time traffic. The reason is not only the limited bandwidth allocated to WLAN and fading characteristic of wireless medium, but also the standard itself.

Legacy IEEE 802.11b Medium Access Control (MAC) protocols defined two modes of operation characterized by coordination functions: Distributed Coordination Function (DCF) and Point Coordination Function (PCF) [12]. PCF is only optional and still not available in products nowadays. DCF is contention-based and more suitable for delay insensitive traffic instead of time-bounded services, e.g., Voice over IP (VoIP). Since the contention among terminals is distributed without central control, packet delays are unpredictable, which is not acceptable for real-time services. What is more, in those standards each user contends for the shared medium with identical parameters (initial contention window size, interframe space etc.) during contention period (CP). No service differentiation is achieved in the case of multiple types of traffic with dissimilar QoS requirements. IEEE 802.11e draft specification [1] is an emerging supplement to original 802.11b standard to support QoS. It provides differentiated channel access to frames with different priorities, by setting different contention parameters of Enhanced Distributed Coordination Function (EDCF) mode [2, 7-11].

In our opinion, however, contention-free transmission is an important delay guarantee for delay-sensitive traffic, in particular under the heavy traffic load conditions. As we know, PCF is based on centralized polling, where the Access Point (AP) acts as the coordinator in charge of forwarding packets and controlling polling process. In an infrastructure WLAN, all delivered packets must pass through AP. AP is also responsible for managing polling list, initiating and ending Contention Free Period (CFP). Nevertheless, original standards do not specify how to manage polling list, including polling order by which each terminal is polled, exhaustive or limited service policy etc. Ziouva *et al.* proposed to transmit voice packets using silence detection for the sake of handling more transmissions by PCF [3], but the process of detection are not described. The authors of [4] proposed an activity detection mechanism called Statistical Activity Detection (SAD). It makes AP start polling the voice terminal whose sojourn time of *silence* state exceeds parameter $T_{thresh}$. However, the delay of first voice packet in *talkspurt* state and throughput of non-real-time traffic transmitted in CP, become a tradeoff that greatly relies on $T_{thresh}$. The optimal value of $T_{thresh}$ is difficult to find. Activity contention mechanism using DCF and PCF is proposed in [5], where the first voice packet contends for transmission in CP. The method may suffer unacceptable delay if the network load is heavy. Last but not least, all the above research work does not considerate the appropriate setting of protocol parameters as well as QoS differentiation issue.

802.11e is backward compatible, as 802.11e terminals are still allowed to support PCF [7]. Hence we propose in this work to combine EDCF with dynamic management of polling list in PCF, to provide QoS differentiation for real-time VoIP and non-real-time (FTP, HTTP) services in an 802.11e infrastructure WLAN. While voice stations are dynamically served in CFP according to the talkspurt-silence alternation characteristics of speech traffic, FTP and HTTP packets are delivered in CP with prioritization. Extensive simulations are also carried out to illustrate the influence of PCF parameters.

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including CFP interval and CFP repetition interval.

The rest of this paper is organized as follows. In section II, we briefly introduce the 802.11e MAC specifications. Our dynamic polling management method for transmitting voice traffic is described detailedly in section III, along with the differentiation scheme for FTP and HTTP traffic. Section IV depicts our simulation scenarios and analyzes the simulation results. Finally, the conclusions are drawn in section V.

## II. IEEE 802.11E MAC

IEEE 802.11 Task Group E is currently defining enhancements to legacy 802.11 MAC, called 802.11e, which introduces EDCF and HCF (Hybrid Coordination Function). Stations, which operate under the 802.11e, are called QoS stations (QSTAs) [9]. A QoS station, which works as the centralized controller for all other stations within the same QBSS, is called the Hybrid Coordinator (HC). A QBSS is a BSS (Basic Service Set), which includes an 802.11e-compliant HC and QSTAs. The HC will typically reside within an 802.11e AP. In the following, we mean an 802.11e-compliant QoS station by a station for simplicity.

EDCF is contention-based channel access mechanism, which supports differentiated and distributed channel accesses for frames with up to eight different priorities (from 0 to 7). With EDCF, QoS support is realized through the introduction of Access Categories (ACs). An 802.11e station shall implement four ACs, where an AC is an enhanced variant of the DCF 0. Each frame from the higher layer arrives at the MAC along with a priority value. Then, each QoS data frame carries its priority value in the MAC frame header.

Different AC contends for the channel with different AIFS (Arbitration Inter-Frame Space), $CW_{min}$ and $CW_{max}$, which are referred to as the EDCF parameters. $CW_{min}$ and $CW_{max}$ are minimum and maximum contention window size, respectively. AIFS has the same meaning with DIFS (Distributed Inter-Frame Space) in legacy 802.11 DCF. The AIFS length of AC $i$ is set according to following formula:

$$T_{AIFS_i} = T_{SIFS} + aAIFS_i \times T_{SlotTime}$$

where the minimum value of $aAIFS_i$ is one. Therefore, the minimum setting for $T_{AIFS}$ is equivalent to PIFS (Point Inter-Frame Space) [1].

Basically, the smaller AIFS and $CW$, the shorter the channel access delay for the corresponding priority, and hence the more capacity share for a given traffic condition. All these EDCF parameters are announced by the AP via beacon frames, and can be dynamically adapted by AP depending on network conditions.

In addition to EDCF, IEEE 802.11e terminals are still allowed to support PCF [7]. The alternation of CFP and CP constitutes a superframe, which is called CFPR (Contention Free Period Repetition) interval. One thing to mention is that, EDCF is only a part of a new coordination function called HCF, which combines the aspects of DCF and PCF. But the detailed aspects of the HCF are beyond the scope of this paper, so we focus on the EDCF and PCF in our work.

## III. DYNAMIC POLLING MANAGEMENT AND QOS DIFFERENTIATION

In this section, we propose to combine the EDCF and PCF to support three types of services, which are VoIP, FTP and HTTP, respectively. Generally speaking, people will regard VoIP services as real-time traffic, whereas FTP and HTTP services as non-real-time type. For convenience, we term FTP and HTTP as data traffic, though the QoS requirements of them are different as far as delay is concerned. Basically, users may require much less delay for HTTP services. As for the FTP services, however, throughput is paramount. Consequently, we propose to deliver VoIP packets with PCF, while FTP and HTTP frames are transmitted during CP by means of EDCF. Meanwhile, FTP and HTTP services are offered prioritized EDCF parameters for the sake of QoS differentiation. Actually, the priority of HTTP frames is higher than that of FTP.

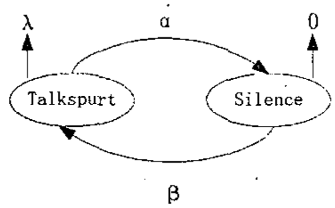


Fig. 1 A two-state Markov chain voice activity model [4]

Typically, a voice source alternates between *talkspurt* state and *silence* state. According to the general model in [6], the voice activity can be described with a two-state Markov process as shown in Fig. 1. In this model, *talkspurt* period and *silence* period are exponentially distributed with mean values of $1/\alpha$ and $1/\beta$. The packet generation rate ($\lambda$) during *talkspurt* period is usually fixed and depends on the codec (See Table I), whereas the packet generation rate is zero during *silence* period. In other words, a station in *talkspurt* generates frames periodically, but no frames are generated in *silence* period. If a certain station is polled when its voice source is in *silence* state, traditional round-robin polling method of PCF will cause valuable bandwidth wastes and incur unnecessary delay to other terminals with packets to transmit. The reason is that, AP has to poll every terminal in its polling list in sequence and check if each terminal has packet(s) to transmit. In this case, the efficiency of PCF is quite low. As a result, we propose dynamic polling management for uplink VoIP transmission according to the talkspurt-silence alternation characteristics of speech traffic. That is, AP will dynamically add and delete the voice terminals in the polling list.

TABLE I SYSTEM PARAMETERS FOR DIFFERENT AUDIO CODECS [4]

| Codec | Bit rate (kbps) | Frame duration (ms) | Pkts (1/s) |
|---|---|---|---|
| G.711 | 64 | 20 | 50 |
| G.723.1 | 5.3 | 30 | 33 |
| G.723.1 | 6.4 | 30 | 33 |
| GSM | 13.2 | 20 | 50 |

Firstly, if a voice station already in polling list replies the *CF_Poll* from AP with *Null* frame for consecutive three times, AP will remove the station from polling list. Y. Kim and Y. Suh proposed to use the *more-data* field in MAC header for AP to detect the transition from *talkspurt* to *silence* state of a voice source [4]. This in-band signaling method may cause detection error if AP deletes the terminal from polling list once the *more-data* field is set to zero. Because this field can only indicate the queue state at the moment the terminal sends this uplink packet, it is very possible that a new voice frame is generated after a while but before the next *CF_Poll*. In this case, immediate removing action may cause repeated and unnecessary association during CP to increase the labor of AP.

Secondly, when a voice source transits from *talkspurt* to *silence* state, the first packet should contend for transmission during CP. Once the packet succeeds in contention, AP will detect the continuation of the traffic flow and reassign the terminal automatically into the polling list. Distinct from [5], this packet will be given the highest priority in EDCF mode, with smaller *AIFS* and $CW_{min}$ parameters than FTP and HTTP packets. This is due to the consideration that method in [5] could suffer from an unpredictable access delay of the first packet of each *talkspurt*, especially when the DCF has a high traffic load. Another method for comparison is SAD in [4]. Actually, the SAD is based on activity prediction. The authors of [4] also proposed HAD (Hybrid Activity Detection) method to combine SAD and activity contention method in [5].

## IV. Simulations and Results Analysis

### A. Simulation scenarios

The WLAN system in our simulation is based on IEEE 802.11e draft. Both the AP and all the terminals are QoS-capable. Since the overlapping BSS is out of the scope of this paper, only one BSS with one AP is assumed. Without loss of generality, we also assume that each terminal supports only one type of traffic source, so the terminal is denoted according to its source type. For instance, a terminal delivering VoIP packets is termed as VoIP or voice station. We assume altogether twelve terminals in our simulation, among which the number of VoIP, FTP and HTTP stations is the same. That is, we have four VoIP stations, four FTP stations and four HTTP stations in the BSS.

In our simulation, ITU G.711 codec with talkspurt-silence alternation is adopted for each VoIP call. The frames are sent out every 20 ms and the bit rate of the codec is 64 kbps. The mean value of exponentially distributed *talkspurt* ($1/\alpha$) and *silence* ($1/\beta$) are 0.375 s and 0.625 s, respectively. Furthermore, we assume each packet only contains one voice frame, so the payload is 160 bytes. With respect to the non-real-time application, we assume the inter-request time is exponentially distributed with mean value one second. The FTP file size is constantly 56 kbytes. Each HTTP page includes two types of object. One is constantly 10 kbytes, the other is uniformly distributed within 1 kbyte and 3 kbyte. The number of the two types is five and two, respectively.

TABLE II PARAMETERS OF SIMULATION

| | | | |
|---|---|---|---|
| WLAN parameters | Physical characteristics | | DSSS |
| | Data rate (bps) | | 11 Mbps |
| | Fragmentation threshold (bytes) | | 2304 |
| | Short retry limit | | 7 |
| | Long retry limit | | 4 |
| | CFP beacon multiple | | 1 |
| | SIFS time (us) | | 10 |
| | Slot time (us) | | 20 |
| | PIFS time (us) | | 30 |
| | DIFS time (us) | | 50 |
| EDCF paramters | VoIP | AIFS time (us) | 40 |
| | | $CW_{min}$ | 3 |
| | | $CW_{max}$ | 7 |
| | FTP | AIFS time (us) | 50 |
| | | $CW_{min}$ | 15 |
| | | $CW_{max}$ | 31 |
| | HTTP | AIFS time (us) | 60 |
| | | $CW_{min}$ | 31 |
| | | $CW_{max}$ | 1023 |

The three types of traffic sources are offered different EDCF parameters, which are listed in Table II, together with other most important parameters in our simulation. Notice that the CFPR and CFP interval are not presented in the Table, as we will use different values in our simulation to examine their impact.

### B. Simulation results

a) Comparison of schemes

For clarity, we termed our scheme as EDCF_DP (EDCF and Dynamic Polling), while activity contention method in [5] as DCF_DP. As for the HAD method, authors in [4] only examine its effect in the case of DCF and PCF. To have a more general understanding, we also simulate HAD using EDCF and PCF. Moreover, DCF_FP (DCF and Fixed Polling) scheme is simulated for comparison. In a word, we will compare our EDCF_DP with DCF_DP, DCF_FP, HAD_DCF and HAD_EDCF schemes.

The simulation results in the scenario as described above are presented in Table III. The CFPR and CFP interval for PCF is 20 ms and 15 ms, respectively. $T_{thresh}$ in HAD method is 50 ms. This value is set according to [4], which regards 8% of the average *silence* period is the optimal value. Furthermore, we collect one-way delay for all packets, i.e. from the instant that packet arrives at WLAN MAC layer to the instant it is received by AP successfully. Hence, we not only consider media access delay but also take collision and retransmission into account.

As far as delay performance is concerned, we can find that only EDCF_DP and HAD_EDCF can realize delay differenttiation among VoIP, FTP and HTTP traffic. Delay of VoIP packets in our scheme is about 10 ms. Although it is a little higher than HAD_EDCF scheme (6 ms), 10 ms is still far below critical. FTP and HTTP delay of our scheme are all lower than HAD_EDCF. As for the HAD_DCF scheme, FTP and HTTP delay is lower (around 38 ms), but no

TABLE III COMPARISON OF SCHEMES

| | EDCF_DP (ours) | DCF_DP | DCF_FP | HAD_DCF | HAD_EDCF |
|---|---|---|---|---|---|
| FTP delay (s) | 1.0554 | 0.09445 | 0.07154 | 0.03825 | 2.30597 |
| HTTP delay (s) | 0.04772 | 14.07505 | 13.27845 | 0.03703 | 0.06089 |
| Voice delay (s) | 0.01023 | 0.22785 | 0.00617 | 0.00775 | 0.00602 |
| FTP throughput (kbps) | 60.80468 | 1.32182 | 1.88181 | 103.86953 | 4.13378 |
| HTTP throughput (kbps) | 32.33191 | 5.27474 | 10.05763 | 47.16267 | 3.26479 |
| Voice throughput (kbps) | 29.94192 | 4.62291 | 29.77355 | 29.44873 | 29.15106 |
| WLAN throughput (kbps) | 876.07376 | 228.86067 | 350.64545 | 1304.31 | 675.50844 |
| WLAN data dropped (kbps) | 6.91931 | 246.47716 | 91.5338 | 0.08629 | 572.85819 |

differentiation is introduced. The voice delay of DCF_DP scheme is much higher than others. This is due to the serious contention during CP, which causes large delay for the first voice packet in *talkspurt* period.

With respect to the mean throughput of each station, HAD_DCF scheme works better than our scheme. The former provides high FTP and HTTP throughput, while at the same time guarantees comparable voice throughput as DCF_FP does. The FTP and HTTP throughput of our EDCF_DP scheme is not so satisfying, but it is much better than remaining three schemes. Other three schemes are so poor as to depress FTP and HTTP throughput below 10 kbps. Therefore, QoS differentiation by EDCF cannot be combined with HAD method in this case. The reason is that in order to avoid large voice delay, $T_{thresh}$ must be small. However, small $T_{thresh}$ means short transmission period for non-real-time traffic, and thus the poor throughput. The fact can be reaffirmed by high data dropped rate of HAD_EDCF. Actually, we also vary $T_{thresh}$ from 30 to 200 ms when simulating HAD. From simulation results, we find that this parameter nearly have no impact on the delay performance. (Due to the limit room here, the figures are omitted.) Finally, from the aspect of aggregated WLAN throughput and data dropped situation, our scheme still performs well, only a little worse than HAD_DCF.

b) Impact of CFPR and CFP interval

The CFPR and CFP interval are two parameters not yet specified in WLAN standards, since PCF is optional and their value must match the traffic load and QoS requirements. We simulate our proposed EDCF_DP scheme in several scenarios with different combination of CFPR and CFP interval. The results are depicted in Fig. 2 – Fig. 5.

Notice that the delay for FTP is not plotted in Fig. 2 and 3 so as to clearly show the delay performance of HTTP and VoIP traffic. (FTP delay is much higher than the latter two as Table IV lists, and its trend is similar with HTTP.) Fig. 2 demonstrates that the decrease of CFP interval is able to reduce all delay. This is due to the appropriate setting of CFPR interval, which is the same with inter-arrival time of VoIP packets (20 ms). Once a VoIP station is added into polling list, it will be polled periodically every 20 ms. Therefore, the VoIP delay is quite small during CFP, and the

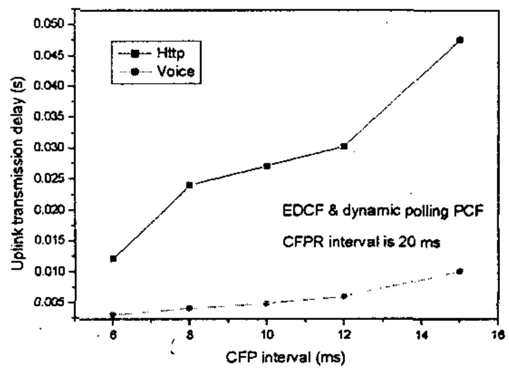


Fig. 2 Impact of CFP interval on HTTP and VoIP delay

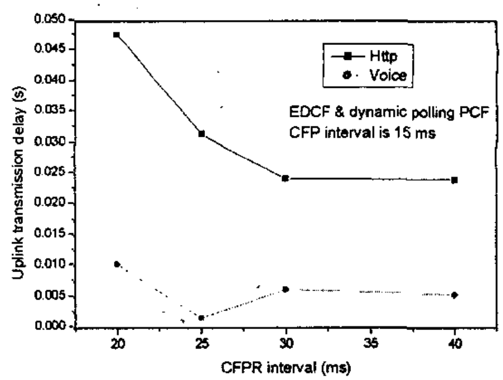


Fig. 3 Impact of CFPR interval on HTTP and VoIP delay

only possible large delay is due to the first packet in *talkspurt*. Moreover, small CFP interval means long CP period, which offers more chance to the contention and benefits all the three types of traffic source. However, as Fig. 3 depicts, 25 ms CFPR interval is optimal for VoIP traffic if the CFP interval is fixed to 15 ms. Reason for decreased HTTP delay is obvious as explained above. For VoIP packets, large CFPR interval will inevitably increase the delay again, as the packets may be queued and wait for the *CF_Poll* frame in next CFPR.

The throughput performance from a single station aspect is illustrated in Fig. 4 and 5, where CFP and CFPR intervals are varied, respectively. In the case of fixed CFPR interval as 20 ms, the increase of CFP interval will decrease the throughput of FTP and HTTP station. On the contrary, if the CFPR interval is increased from 20 ms to 40 ms, the FTP and HTTP throughput will become larger. Note that the throughput of a single voice station is almost constant in both cases. It is due to the contention-free access, which guarantees nearly zero loss rate for voice frames. In a word, the longer the CP, the more transmission chance for FTP and HTTP traffic, and thus the higher throughput. The same trend is with aggregated WLAN throughput.

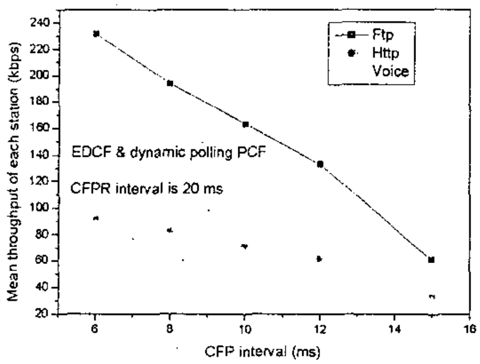


Fig. 4 Impact of CFP interval on throughput from a single station

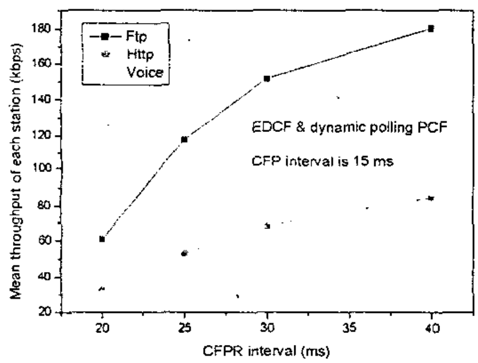


Fig. 5 Impact of CFPR interval on throughput from a single station

## V. CONCLUSIONS AND FUTURE WORK

In this paper, we propose the combination of dynamic polling management and EDCF, to provide QoS differentiation to multiple types of services. The polling list of AP is adaptive to the talkspurt-silence alternation of speech traffic source, which dynamically adds/removes the VoIP terminals into/from polling list. Furthermore, real-time and non-real-time traffic contend for the shared wireless medium during contention period with different EDCF parameters, so as to provide prioritization. Extensive simulations demonstrate that our EDCF_DP scheme not only guarantees the delay requirement of real-time voice service and the throughput requirement of non-real-time FTP and HTTP services, but also introduces excellent differentiation. The aggregated WLAN throughput and data drop rate are also satisfying. Moreover, we examine the impact of CFPR and CFP interval parameters of PCF by simulation. The results show that large CFPR and small CFP value favor non-real-time traffic delivered in contention period. But it is advisable to set CFPR interval equal or a little larger than the inter-generation time of VoIP frames. In this case, both the delay and throughput of all traffic can be well guaranteed.

Actually, the delay performance of VoIP traffic is largely deteriorated by FTP like traffic that carries large-size packets to WLAN. Because DCF mode in MAC layer of WLAN will not initiate a new backoff contention procedure until all fragments of a packet from higher layer are transmitted, large size FTP packets (the max packet length of WLAN is as large as around 18 kbytes) are quite possible to obstruct the beacon and start of CFP. In next step, we will design a virtual "more-data" scheme to restrict the fragments sent out after one successful contention. Future work is also needed to take HCF of IEEE 802.11e into account, while at the same time examine the dynamic setting of EDCF parameters according to the network load condition.

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