# A COMPARATIVE STUDY OF 802.11 AND 802.11E WIRELESS LAN STANDARDS

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Abstract: Quality of service (QoS) is a key problem in wireless environments where bandwidth is scarce and channel conditions are time varying and sometimes highly loss. Although IEEE 802.11 wireless LAN (WLAN) is the most widely used WLAN standard today, and the upcoming IEEE 802.11e QoS enhancement standard exists and introduces the QoS for supporting multimedia applications. This paper compares the propositions of standard IEEE 802.11e with the standard IEEE 802.11 without QoS, a simulation of these standards is performed by using the NS simulator. A discussion is presented in detail using simulation-based evaluations and we let us confirm the QoS of IEEE 802.11e compared to IEEE 802.11, but we have detected some weaknesses of 802.11e. It starves the low priority traffic in case of high load, and leads to higher collision rates, and did not make a good estimate of weight of queues, so there is an unbalance enters the flows with high priorities. We finish with a conclusion.

## 1 INTRODUCTION

IEEE 802.11 wireless LAN (WLAN) (IEEE 802.11 WG, 1999) is one of the most deployed wireless technologies all over the world and is likely to play a major role in next generation wireless communications networks. The main characteristics of 802.11WLAN technology are simplicity, flexibility and cost effectiveness. This technology provides people with a ubiquitous communications and computing environment in offices, hospitals, campuses, factories, airports, stock markets, etc. Simultaneously, multimedia applications have experienced an explosive growth. People are now requiring to receive high speed video, audio, voice and Web services even when they are moving in offices or travelling around campuses. However, multimedia applications require some quality of service support such as guaranteed bandwidth, delay, jitter and error rate. Guaranteeing those QoS requirements in 802.11 WLAN is very challenging due to the QoS unaware functions of its medium access control (MAC) layer and the noisy and variable physical (PHY) layer characteristics. In this paper we compare the two standards 802.11 and 802.11e by using a simulation with Network Simulator (NS) and present a detailed discussion of results. The paper is organized as follows. Section 2 introduces an overview of IEEE 802.11 WLAN and section 3 introduces the QoS enhancement standard 802.11e. In section 4, we present the model of simulation with its parameters and a detailed discussion of results. We finish with a conclusion.

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# 2 DESCRIPTION OF 802.11 STANDARD

## 2.1 Introduction

The IEEE 802.11 WLAN standard covers the MAC sub-layer and the physical (PHY) layer of the open system interconnection (OSI) network reference model (IEEE 802.11 WG, 1999). Logical link control (LLC) sub-layer is specified in the IEEE 802.2 standard. This architecture provides a transparent interface to the higher layer users: stations (STAs) may move, roam through an 802.11 WLAN and still appear as stationary to 802.2 LLC sub-layer and above. This allows existing TCP/IP protocols to run over IEEE 802.11 WLAN just like wired Ethernet deployed. We can show (Aad I, Castelluccia C., 2001) different standardization activities done at IEEE 802.11 PHY and MAC layers. The standard comprises three PHY layers, which are an InfraRed (IR) base band PHY; a frequency hopping spread spectrum (FHSS) radio and direct sequence spread spectrum (DSSS) radio. These entire choices support both 1 and 2Mbps PHY rate. In 1999, the IEEE define two high rate: 802.11b in the 2.4GHz band with 11Mbps, based on DSSS technology; and 802.11a in the 5GHz band with 54Mbps, based on orthogonal frequency division multiplexing (OFDM) technology. Recently, 802.11g is finalized to be an extension of 802.11b with 54Mbps in the 2.4GHz band.

## 2.2 The MAC Sub-Layer of 802.11

It defines two medium access coordination functions, the basic Distributed Coordination Function (DCF) and the optional Point Coordination Function (PCF) (IEEE 802.11 WG, 1999). Asynchronous transmission is provided by DCF which operate in contention-based period, and synchronous transmission is provided by PCF that basically implements a polling-based access which operate in contention free period. A group of STAs coordinated by DCF or PCF is formally called a basic set (BSS). The area covered by BSS is the basic service area (BSA), like a cell in a cellular mobile network. Two modes exist: ad-hoc mode and infrastructure mode. The first mode forms an Independent BSS (IBSS) where the STAs can directly communicate with each other by using only the DCF, without any connectivity to any wired backbone. In the second mode, the STAs communicate with the wired backbone through the bridge of access point (AP), which can use both DCF and PCF.

### 2.2.1 Distributed Coordination Function

DCF is a distributed medium access scheme based on carrier sense multiple accesses with collision avoidance (CSMA/CA) protocol. In this mode, the STAs must sense the medium before transmitting a packet, if the medium is found idle for an interval of time longer than a Distributed InterFrame Space (DIFS); the STA can transmit the packet immediately (IEEE 802.11 WG, 1999), meanwhile other STAs defer their transmission and adjusting their Network Allocation Vector (NAV) which is a local timer. Then the backoff process starts, the STA compute a random Backoff_timer=rand [0, CW]*slot time, where CWmin ≤ CW (window contention parameter) ≤ CWmax and slot time depends on the PHY layer type. The backoff timer is decreased only when the medium is idle. Each time the medium becomes idle, the STA waits for a DIFS and continuously decrements the backoff timer. As soon as the backoff expires, the STA is authorized to access the medium. Obviously, a collision occurs if two or more STAs start transmission simultaneously. If the acknowledgement, used to notify that the transmitted frame has been successfully received (see Figure 1), is not received, the sender assumes that a collision was occurred, so it schedules a retransmission and enters the backoff process again. To reduce the probability of collisions, after each unsuccessful transmission attempt, the CW is doubled until a predefined maximum value CWmax is reached. But after each successful transmission, the CW is reset to a fixed minimum value CWmin. Two carrier sensing mechanisms are possible, PHY carrier sensing at air interface and virtual carrier sensing at PHY MAC layer. Virtual carrier sensing can be used by an STA to inform all other STAS in the same BSS how long the channel will be reserved for its frame transmission. On this purpose, the sender can set a duration field in the MAC header of data frames. Then other STAS can update their NAVS to indicate this duration, and will not start transmission before the updated NAV timers reach zero.

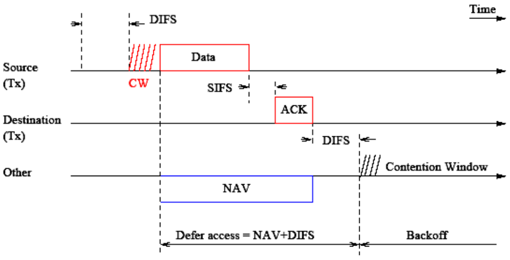

Figure 1: Basic DCF CSMA/CA.

#### 2.2.2 PCF: Point Coordination Function

PCF uses a centralised polling scheme, which requires the AP as a point coordinator (PC) in a BSS. The channel access time is divided into periodic intervals named beacon intervals, see Figure 2. The beacon interval is composed of a contention-free period (CFP) and a contention period (CP). During the CP, the PC maintains a list of registered STAs and polls each STA according to its list. Then, when a STA is polled, its gets the permission to transmit data frame. Since every STA is permitted a maximum length of frame to transmit, the maximum CFP duration for all the STAs can be known and decided by the PC, which is called CFP_max_duration. The time used by the PC to generate beacon frames is called target beacon transmission time (TBTT). In the beacon, the PC denotes the next TBTT and broadcast it to all the others in the BSS. In order to ensure that no DCF STAs are able to interrupt the operation of the PCF, a PC waits for a PCF InterFrame Space (PIFS), which is shorter than DIFS, to start the PCF. Then, all the others STAs set their NAVs to the values of CFP_max_duration time, or the remaining duration of CFP in case of delayed beacon. During the CP, the DCF scheme is used, and the beacon interval must allow at least one DCF data frame to be transmitted. A typical medium access sequence during PCF is shown in Figure 2. When a PC polls an STA, it can piggyback the data frames to the STA together with the CF-poll, then the STA sends back data frame piggybacked with an ACK after a SIFS interval. When the PC polls the next STA, it piggybacks not only the data frame to the destination, but also an ACK to the previous successful transmission. Note that almost all packet transmissions are separated by the SIFS except for one scenario: if the polled STA does not respond the AP within a PIFS period, the AP will poll the following STA. Silent STAs are removed from the polling list after several periods and may be polled again at beginning of the next CFP. At any time, the PC can terminate the CFP by transmitting a CF-end packet, then all the STAs in the BSS should reset their NAVs and attempt to transmit during the CP. Normally, PCF uses a round robin scheduler to poll each STA sequentially in the order of polling list, but priority based polling mechanisms can also be used if different QoS levels are requested by different STAs.

## 3 DESCRIPTION OF 802.11E STANDARD

### 3.1 HCF: Hybrid Coordination Function

There are many new features in 802.11e draft 4.2 (IEEE 802.11 WG, 2003). In this section, we will briefly describe HCF. HCF is composed of two access methods: contention-based channel access (called EDCF) and controlled channel access mechanisms. One main feature of HCF is to introduce four access category (AC) queues and eight traffic stream (TS) queues at MAC layer. When a frame arrives at MAC layer, it is tagged with a traffic priority identifier (TID) according to its QoS requirements. Which can take the values from 0 to 15. The frames with TID values from 0 to 7 are mapped into four AC queues using EDCF access rule. On the other hand, frames with TID values from 8 to 15 are mapped into eight TS queues using HCF controlled channel access rule. The reason of separating TS queues from AC queues is to support strict parameterized QoS at TS queues while prioritized QoS is supported at AC queues. Another main feature of the HCF is the concept of transmission opportunity (TXOP), which is the time interval permitted, for a particular STA to transmit packets. During the TXOP, there can be a series of frames transmitted by an STA separated by SIFS. The TXOP is called either EDCF-TXOP, when it is obtained by winning a successful EDCF contention; or polled-TXOP, when it is obtained by receiving a QoS CF-poll frame from the QoS-enhanced AP (QAP). The maximum value of TXOP is called TXOPLimit, which is determined by QAP.

### 3.2 Enhanced Distributed Coordination Function (EDCF)

The EDCF is designed for the contention-based prioritized QoS support. Each QoS-enhanced STA (QSTA) has 4 queues (ACs), to support 8 user priorities (UPs). Therefore, one or more UPs are mapped to the same AC queue. This comes from the observation that usually eight kinds of applications

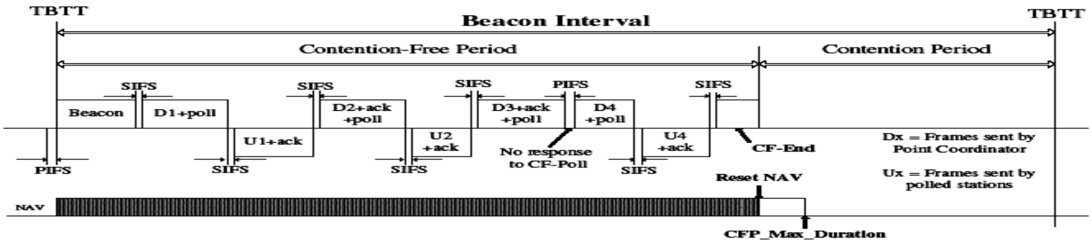

Figure 2: PCF and DCF cycles.

do not transmit frames simultaneously, and using less ACs than UPs reduces the MAC layer overheads. Each AC queue works as an independent DCF STA and uses its own backoff parameters. In EDCF, two main methods are introduced to support service differentiation: The first one uses different InterFrame Space (IFS) sizes for different ACs. A new kind of IFS called Arbitrary IFS (AIFS) is used in EDCF, instead of DIFS in DCF. AIFS[AC] = AIFSN[AC] * SlotTime + SIFS, where the default value of the arbitration inter frame spacing number (AIFSN) is defined as either 1 or 2 (IEEE 802.11 WG, 2003).When AIFSN=1, high priority queues AC1, AC2 and AC3 have AIFS value equal to PIFS. When AIFSN=2, the low priority queue AC0 has AIFS value of DIFS. When a frame arrives at an empty AC queue and the medium has been idle longer than AIFS [AC]+SlotTime, the frame is transmitted immediately .If the channel is busy, the arriving packet in each AC has to wait until the medium becomes idle and then defer for AIFS+SlotTime. So the AC with the smaller AIFS has the higher priority. For example, the earliest transmission time for high priority queue is to wait for PIFS+SlotTime=DIFS, while the earliest transmission time for best effort queue is to wait for DIFS+ SlotTime. The second method consists in allocating different CW sizes for different ACs. Assigning a short CWsize to high priority AC ensures that in most cases, high-priority AC is able to transmit packets ahead of low-priority one. If the backoff counters of two or more parallel ACs in one QSTA reach zero at the same time, a scheduler inside the QSTA will avoid the virtual collision by granting the EDCF-TXOP to the highest priority AC. At the same time, the other colliding ACs will enter a backoff process and double the CW sizes as if there is an external collision. In this way, EDCF is supposed to improve the performance of DCF under congested conditions. The default values of AIFSN [AC], CWmin [AC], CWmax [AC] and TXOPLimit [AC] are announced by the QAP in beacon frames, and the 802.11e standard also allows the QAP to adapt these parameters dynamically depending on network conditions (IEEE 802.11 WG, 2003). But how to adapt to the channel has not been defined by the standard and remains an open research issue.

## 3.3 HCF Controlled Channel Access

The HCF controlled channel access mechanism is designed for the parameterized QoS support, which combines the advantages of PCF and DCF. HCF can start the controlled channel access mechanism in both CFP and CP intervals, whereas PCF is only allowed in CFP. A typical 802.11e beacon interval , is composed of alternated modes of optional CFP and CP. During the CP, a new contention-free period named controlled access phase (CAP) is introduced. HCF can start a CAP by sending downlink QoS-frames or QoS CP-Poll frames to allocate polled-TXOP to different QSTAs after the medium remains idle for at least PIFS interval. Then the remaining time of the CP can be used by EDCF. This flexible contention-free scheme makes PCF and CFP useless and thus optional in the 802.11e standard. For example, in order to support audio traffic with a maximum latency of 20 millisecond (ms) using PCF, the beacon interval should be no more than 20 ms since the fixed portion of CP forces the audio traffic to wait for the next poll. On the other hand, the HCF controlled channel access can increase the polling frequency by initiating CAP at any time, thus guarantee the delay bound with any size of beacon interval. So there is no need to reduce the beacon interval size that increases the overheads. In HCF controlled channel access mechanism, QoS guarantee is based on the traffic specification (TSPEC) negotiation between the QAP and the QSTAs. Before transmitting any frame that requires the parameterized QoS, a virtual connection called traffic stream (TS) is established. In order to set up a TS, a set of TSPEC parameters (such as mean data rate, nominal frame size, maximum service interval, delay bound, etc.) are exchanged between the QAP and the corresponding QSTAs. Based on these TSPEC parameters, the QAP scheduler computes the duration of polled-TXOP for each QSTA, and allocates the polled-TXOP to each QSTA. Then the scheduler in each QSTA allocates the TXOP for different TS queue according to the priority order. A simple round-robin scheduler is proposed in the IEEE 802.11e draft 4.2 (IEEE 802.11 WG, 2003). The simple scheduler uses the following mandatory TSPEC parameters: mean data rate, nominal MAC frame size and maximum service interval or delay bound. Note that the maximum service interval requirement of each TS corresponds to the maximum time interval between the start of two successive TXOPs. If this value is small, it can provide low delay but introduce more CF-Poll frames. If different TS have different maximum service interval requirements, the scheduler will select the minimum value of all maximum service interval requests of all admitted streams for scheduling. Moreover, the QAP is allowed to use an admission control algorithm to determine whether or not to allow new TS into its BSS. During a CFP, the medium is fully controlled by QAP. During a CP, it can also grab the medium whenever it wants (after a PIFS idle time). After receiving a QoS CF-poll frame, a polled QSTA is allowed to transmit multiple MAC frames denoted by contention-free burst (CFB), with the total access time not exceeding the TXOPLimit.

# 4 SIMULATION-BASED EVALUATIONS OF OS-ENHANCED SCHEMES

In (Benveniste M. et al., 2001), (Qiang Ni et al., 2004), different simulations have been conducted with different topology and parameters of EDCF. To evaluate the performance of DCF and EDCF schemes, we use NS-2 (Anelli A et al.), there is no mobility in the system, each station operates at IEEE 802.11b PHY and transmits three types of traffic (audio, video and data traffic) to each other. The DCF MAC parameters are listed in Table 1 and EDCF parameters are: for audioPCM (Wmin=7, Wmax=15, AIFSN=1, Packet size in bytes=160, Packet interval in ms=20, Sending rate in KB/s=8), for Video MPEG4 (15,35,1,1280,16,80), for Video VBV(15,31,2, 660,26,25), for Data (31,1023, 2, 1600, 12.5,128).We use CBR/UDP traffic sources. We vary the load rate by increasing the number of STAs from 0 to 6.

Table 1: DCF parameters.

| **SIFS** | **16µs** | **MAC header** | **28bytes** |
|---|---|---|---|
| **DIFS** | **34µs** | **PLCP header length** | **4µs** |
| **ACK size** | **14bytes** | **Preamble length** | **20µs** |
| **PHY rate** | **36Mbps** | **CWmin** | **15** |
| **Slot time** | **9µs** | **WCmax** | **1023** |

Figure 2 shows the simulation results for the bandwidth, and latency. We can see that average throughput of three kinds of flows per STA are stable and sufficient as long as the channel load rate is less than 70% at the 25th second, after all flows degrade themselves dramatically in DCF, but not in EDCF. And we let us notice, that there is a high rate loss of packets in DCF, and a low rate loss of packets in EDCF. We see also that latency is good for all flows, but at the 25th second, it increases significantly in DCF. On the other hand, in EDCF only data suffer by a high latency. The evolution of latency in DCF, in function of channel load rate is dramatic for all flows after 70% rate, but in EDCF after 60% only data flow degrade themselves. Figure 3 shows the advantages of HCF controlled channel access mechanism compared to EDCF, we simulate an topology with 13 STAs (STA 0 is the AP), six STAs transmit each one a audio flow, and the six others transmit a video flow (CBR MPEG4) at AP.We notice that the throughput (D) is stable and distributed well on all the STAs by HCF, which is not the case for EDCF, where D fluctuate too much quickly, what indicates a bad management of the bandwidth. For EDCF, the latency increases all gently when the channel load rate increases but only for audio flows, for the video flows, the latency increase brutally. For HCF, the evolution of latency is the same for all flows. Figure 4 shows the limitations of HCF by a simulation of 19 STAs (the STA 0 is the AP) and STA1 to STA6 transmits a PCM Audio flows with inter arrival time of 4.7ms, Packet size of 160bytes, Sending rate of 64Kbps and a priority of 6. STA7 to STA12 transmits a VBR (variable bit rate) video flows with Arrival period almost equal to 26, Packet size almost equal to 660, Sending rate almost equal to 200 and a priority of 5. STA13 to STA18 transmits a MPEG4 video flows with Arrival period=2, Packet size=800, Sending rate=3200 and a priority of 4. Let us notice that latency of VBR flows fluctuate and increase dramatically, what is not the case of the other flows. This is with the fact that the AP is unable to make a good estimate of the size of the queues for a good scheduling.

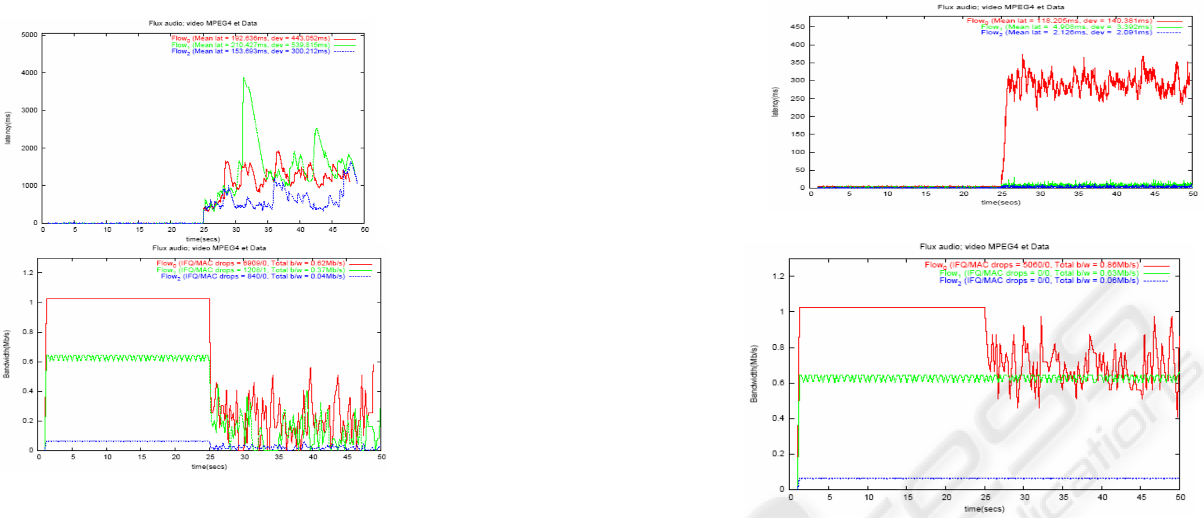

Figure 3: Throughput and latency performance for DCF and EDCF.

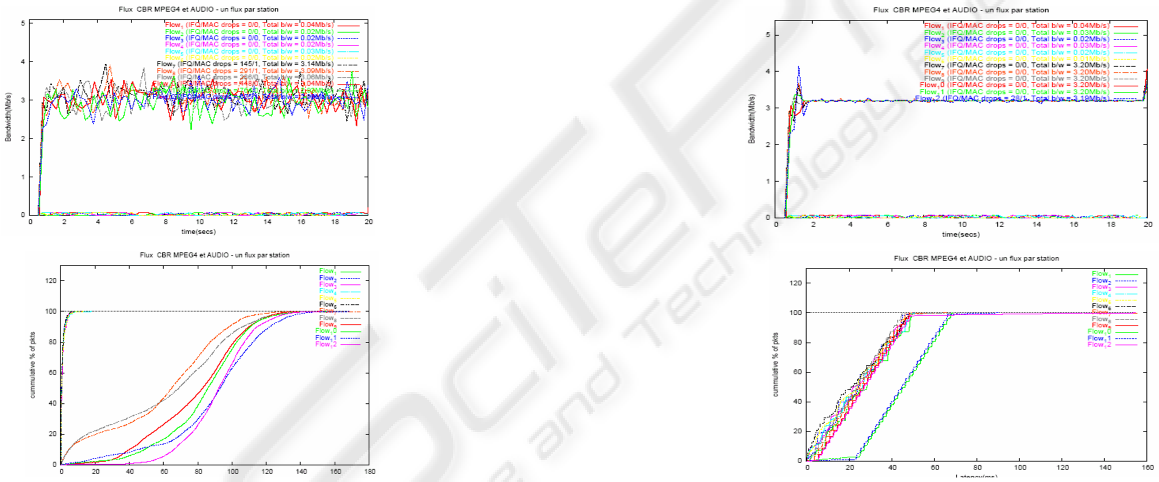

Figure 4: Throughput and channel load for EDCF and HCF Controlled channel access.

Figure 5: Throughput for EDCF and HCF Controlled channel access.

## 5 CONCLUSION

The results of simulation show that the protocol DCF can only support best-effort services, not any QoS guarantees, all the STAs in one BSS compete for the resources and channel with the same priorities. There is no differentiation mechanism to guarantee bandwidth, packet delay and jitter for high priority STAs or multimedia flows. The EDCF protocol show to be the best choice for high priority traffic, but it starves the low priority traffic in case of high load, and leads to higher collision rates. Furthermore, when channel is 90% loaded, the throughput of audio and video start to decrease, which means that admission control for audio and video is required during very high load. The HCF protocol has a drawback, that AP did not make a good estimate of weight of queues, so there is an unbalance (il y a un désequilibre dans le partage de la bp entre les flux multimedia) enters the flows with high priorities. A HCF protocol which mitigates the disadvantages of HCF was developed, and we intend to evaluate it in future research. We can also propose a new mechanisms of QoS, which can fill the faults of the standard and evaluates their effectiveness by a simulation.

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