Analysis of IEEE 802.11e for QoS Support in Wireless LANs

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Abstract

□ The IEEE 802.11e medium access control protocol is an emerging standard for wireless local area networks providing quality of service.

□ An overview of this standard based on the current draft is presented in this article.

□ We analyze the enhancements in 802.11e and compare its performance to the legacy 802.11 standard.

□ The new hybrid coordination function of IEEE 802.11e with its contention-based and contention-free (controlled) medium access control schemes is evaluated.
The IEEE 802.11 WLAN is being deployed widely and rapidly for many different environments, including enterprise, home, and public access networking.

The main characteristics of the 802.11 standard are simplicity and robustness against failures due to the distributed approach of its medium access control (MAC) protocol.

There is a diverse set of versions of WLANs in the market, which apply different transmission schemes and operate in different frequency bands.

Operating in the industrial, scientific, and medical (ISM) band at 2.4 GHz, the 802.11b version provides data rates up to 11 Mb/s on the wireless medium, applying complementary code keying (CCK) and direct sequence spread spectrum (DSSS) as transmission schemes.

The 802.11a version operates in the unlicensed 5 GHz band, and is able to achieve data rates up to 54 Mb/s on the wireless medium, applying the multicarrier technique orthogonal frequency-division multiplexing (OFDM) as the transmission scheme.
The 802.11g version applies the same multicarrier transmission scheme as 802.11a, but operates in the 2.4 GHz ISM band like 802.11b.

It is worth noting that due to channel conditions and protocol overhead, the maximum achievable throughput on the MAC layer is less than the data rate available on the wireless medium.

Today, 802.11 WLAN (referred to as legacy 802.11 in this article) can be interpreted as a wireless version of Ethernet supporting best effort service.

However, the interest in wireless networks supporting quality of service (QoS) has recently grown.

There are already mechanisms available in the legacy 802.11 to support QoS that have not yet been implemented in real hardware because of their limitations.

Accordingly, the 802.11 working group initiated an activity to enhance the current 802.11 MAC protocol to enable support of applications requiring QoS.
In this article we discuss the upcoming enhancements of the 802.11e standard as specified in the current draft.

Limitations of QoS support in the legacy 802.11 are discussed.

New mechanisms for QoS support being defined in 802.11e.

A performance evaluation of the described mechanisms with the help of simulations.

Analysis of the main results of this activity.
Legacy 802.11

- Its limitations to support QoS are highlighted.
- We consider an infrastructure basic service set (BSS), which is composed of an access point (AP) and a number of stations associated with the AP.
- The AP connects its stations with the infrastructure such as the Internet, and each associated station communicates only via the AP in legacy 802.11.
Key Point No. 1

- The IEEE 802.11 WLAN is being deployed widely and rapidly for many different environments including enterprise, home, and public access networking.

- The main characteristics of the 802.11 standard are simplicity and robustness against failures due to the distributed approach of its MAC protocol.
Key Point No.2

☐ Since collisions may occur due to the nature of the CSMA/CA protocol, a station that has transmitted an MPDU needs to be informed about the success of its transmission.

☐ Therefore, in legacy 802.11 using the DCF, each transmitted MPDU requires an acknowledgment.
Key Point No. 3

- A superframe starts with a beacon management frame transmitted by the AP.

- This beacon frame is transmitted irrespective of whether or not the PCF is used.

- Beacon frames are used to maintain the synchronization of the local timers in the stations and to deliver protocol-related parameters.
### 802.11e Frame Structure and QoS

<table>
<thead>
<tr>
<th>Frame Control (2 octets)</th>
<th>Duration /ID (2)</th>
<th>Address 1 (6)</th>
<th>Address 2 (6)</th>
<th>Address 3 (6)</th>
<th>Sequence Control (2)</th>
<th>Address 4 (6)</th>
<th>QoS Control (2)</th>
<th>Frame Body</th>
<th>FCS (4)</th>
</tr>
</thead>
</table>

#### Application Frame Type

<table>
<thead>
<tr>
<th>QoS CF-Poll Frames sent by HC</th>
<th>QoS Data, QoS CF-ACK and QoS Data+CF-ACK frames sent by HC</th>
<th>QoS data type frames sent by non-AP QSTAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 0–3</td>
<td>TID (UP, TSID)</td>
<td>0</td>
</tr>
<tr>
<td>Bit 4</td>
<td>End of Service Period (EOSP)</td>
<td>1</td>
</tr>
<tr>
<td>Bit 5–6</td>
<td>ACK Policy</td>
<td>1</td>
</tr>
<tr>
<td>Bit 7</td>
<td>Reserved</td>
<td>0</td>
</tr>
<tr>
<td>Bit 8–15</td>
<td>TXOP limit (32us)</td>
<td>Queue size (256 octets)</td>
</tr>
</tbody>
</table>

Analysis of IEEE 802.11e for QoS Support in Wireless LANs
802.11e MAC Structure

- Required for Prioritized QoS Services
- Required for Contention-Free Services for non-QoS STA
  - optional
- HCF (Hybrid Coordination Function)
  - Required for Parameterized QoS Services
  - Used for Contention Services basis for PCF and HCF

- Point Coordination Function (PCF)
- HCF Contention Access (EDCA)
- HCF Controlled Access (HCCA)

Distributed Coordination Function (DCF)
802.11 DCF Channel Access

- Immediate access when medium is idle ≥ DIFS
- DIFS
- PIFS
- SIFS
- Contention Window
- Backoff Window
- Next Frame
- Slot Time
- Select Slot and decrement backoff as long as medium stay idle
- Defer Access
- Busy Medium
802.11e EDCA Channel Access

Immediate access when medium is idle >= AIFS[AC]

AIFS[AC] → Busy Medium

AIFS[AC] → PIFS

SIFS

Contention Window from [0, CW[AC]]

Backoff Window

Next Frame

SlotTime

Defer Access

Select Slot and decrement backoff as long as medium stays idle
802.11 RTS/CTS Frame Exchange

- Source
  - DIFS
  - RTS
  - DATA
- Destination
  - SIFS
  - CTS
  - SIFS
  - SIFS
  - ACK
- Other
  - NAV(RTS)
  - NAV(CTS)
  - DIFS
  - Backoff
  - Backoff after Defer
PCF channel access during a CFP

Contention Free Period Repetition Interval (CFPRI) OR Superframe

Contention Free Period (CFP) for PCF

Downlink
- Beacon
- D1 + Poll
- U1 + Ack
- SIFS
- NAV

Uplink
- SIFS

Dx-downlink frame to STA x
Ux-uplink frame from STA x

CF_MAX_Duration

Reset NAV
Inter frame spaces and backoff procedure with random contention window size. Here the transmitting station uses $CW = CW_{\text{min}}$ (15 slots) of 802.11a, and has selected a random backoff time of 12 slots.
Figure 2.

- Timing of frame exchanges and NAV settings of the 802.11 DCF [3]. Station 6 cannot detect the RTS frame of transmitting station 2, but receives the CTS frame of station 1. Although station 6 is hidden to station 1, it refrains from medium access because of the NAV.
An example of PCF operation. Station 1 is the PC and polls station 2. Station 3 detects the beacon frame and updates the NAV to the whole CFP. Station 3 has learned from earlier beacons that a CFP starts after the TBTT shown here.
### 8 Priorities and 4 Access Categories

<table>
<thead>
<tr>
<th>User Priority</th>
<th>IEEE 802.1d Traffic Category</th>
<th>Access Category</th>
<th>IEEE 802.1e Traffic Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BK (Background)</td>
<td>AC_BK</td>
<td>Background</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>AC_BK</td>
<td>Background</td>
</tr>
<tr>
<td>0</td>
<td>BE (Best Effort)</td>
<td>AC_BE</td>
<td>Best Effort</td>
</tr>
<tr>
<td>3</td>
<td>EE (Excellent Effort)</td>
<td>AC_BE</td>
<td>Video</td>
</tr>
<tr>
<td>4</td>
<td>CL (Controlled Load)</td>
<td>AC_VI</td>
<td>Video</td>
</tr>
<tr>
<td>5</td>
<td>VI (Video)</td>
<td>AC_VI</td>
<td>Video</td>
</tr>
<tr>
<td>6</td>
<td>VO (Voice)</td>
<td>AC_VO</td>
<td>Voice</td>
</tr>
<tr>
<td>7</td>
<td>NC (Network Control)</td>
<td>AC_VO</td>
<td>Voice</td>
</tr>
</tbody>
</table>
Figure 4.

- Legacy 802.11 station and 802.11e station with four ACs within one station.

```
Upon parallel access at the same slot, the higher-priority AC backoff entity transmits; the other backoff entity/entities act as if a collision occurred.
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```
AIFS = 2, 3, ... (for stations)
AIFS = SIFS + aSlotTime * AIFSN
```
In EDCA, multiple backoff entities contend for medium access with different priorities in parallel. The earliest possible medium access time after a busy medium is DIFS.
A polled TXOP allocation. Any 802.11e frame exchange will not take longer than the TXOP limit, which is the limit for all EDCA-TXOPs and under control of the HC.
Table 1. Values for the EDCA parameter sets as used in simulations.

<table>
<thead>
<tr>
<th></th>
<th>AC_VO</th>
<th>AC_VI</th>
<th>AC_BE</th>
<th>AC_BK</th>
<th>High (AC H)</th>
<th>Medium (AC M)</th>
<th>Low (AC L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIFS N:</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>CWmin:</td>
<td>3</td>
<td>7</td>
<td>15</td>
<td>15</td>
<td>7</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>CWmax:</td>
<td>7</td>
<td>15</td>
<td>1023</td>
<td>1023</td>
<td>7</td>
<td>31</td>
<td>255</td>
</tr>
</tbody>
</table>

(Used for throughput evaluation, EDCA parameters from [8])
(Used for delay evaluation of OQBSS [1])
Figure 7.

- An example of an 802.11e superframe where the HC grants TXOPs in contention-free period and contention period. The duration of the superframe is not specified in the standard.
Figure 8.

Throughput per AC with increasing offered traffic per AC for the illustrated scenario.
Figure 9.

Throughput per AC with increasing number of stations, and constant offered traffic per station for the illustrated scenario.
Figure 10.

- MSDU delivery delays for AC_M (EDCA) and HCCA, in isolated and overlapping QBSSs. The increase of the HCCA delay in overlapping QBSSs is not under control of an HC, and therefore undesirable.
Extra Notes

1) The MSDU can be interpreted as the data frame arriving at the MAC from the higher layer, for example, from the IEEE 802.2 logical link control (LLC) sub-layer. The MSDU is transmitted inside one or more MPDUs.

2) Originally, the phrase superframe was defined in the context of 802.11e, but can also be used for the legacy 802.11.

3) Legacy stations will only understand the fields known from the legacy standard, whereas 802.11e backoff entities additionally will understand all new information fields. The new information fields are ignored by legacy stations. Therefore, legacy stations may transmit for longer durations than allowed by the TXOP limit.
Summary and Conclusions

☐ An overview of the QoS supporting protocol extensions of 802.11e is presented in this article.

☐ New mechanisms for QoS support are evaluated, and their performance is discussed with the help of simulation results.

☐ The upcoming 802.11e standard will be an efficient means for QoS support in WLANs for a wide variety of applications, although open problems such as the overlapping QBSS still remain to be solved.

☐ The HCCA provides the means to deliver time-bounded traffic, but requires all stations within the range of the HC to follow its coordination.