Wireless Networked Systems

CS 795/895 – Spring 2013

Lec #6: Medium Access Control
QoS and Service Differentiation, and Power Management

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Quality of Service (802.11e) & Service Differentiation
QoS (Quality of Service)

QoS means in practice that real-time traffic experiences **small delays** and **small delay variation (jitter)** in the network. Streaming applications assume **guaranteed bandwidth**.

One of the QoS solutions for IP networks is **DiffServ**.

- Traffic is divided into different priority classes. The priority class is indicated in the IP header. DiffServ-capable routers handle the traffic in different priority classes differently.
QoS solutions in 802.11 networks

• All 802 MAC schemes are **Best Effort**. But,
  • Voice traffic : rather loss than delay
  • Data traffic : no loss, less stringent delay

• Since traffic routing in WLAN networks is not based on IP, there must be different QoS solutions available:
  • The 802.11 standard defines **the Point Coordination Function (PCF)** for carrying real-time traffic. This solution has not been widely implemented.
  • There are **proprietary solutions** that try to differentiate real-time and non-real-time traffic in the WLAN.
  • A number of advanced QoS solutions have been defined in the **802.11e standard** (approved in 2005).
PCF (Point Coordination Function)

Included in the 802.11 specifications, PCF was especially designed for delay-sensitive real-time services.

Intended for non-real-time traffic (Web browsing, file transport …)

Point Coordination Function (PCF)

Distributed Coordination Function (DCF) based on CSMA/CA
PCF Operation

B = Beacon frame (sent by AP to indicate start of CFP)

 CPF = Contention-Free Period (reserved for real-time traffic)

 CP = Contention Period (normal DCF operation)

Note the foreshortening of the CFP due to the busy medium (it is not possible to cut off active DCF transmissions)
Undisturbed CFP operation is guaranteed in two ways:

- The NAV value in the beacon signal = length of CFP
- Usage of PIFS within CFP (instead of DIFS), PIFS < DIFS
PCF is based on polling, not CSMA/CA

Poll WS1
Poll WS2
Poll WS3 + data
CFP end

PC (AP)
Other
NAV

Set by beacon frame

SIFS
SIFS
SIFS
PIFS
SIFS
SIFS

Poll WS1
Poll WS2
Poll WS3 + data

B
CFP
Why 802.11e?

• The PCF option has never become popular in the industry.

• The PCF – although designed for real-time applications – does not offer extensive QoS. The shortcomings of PCF are:
  • Differentiation between traffic classes is not possible
  • No mechanisms for wireless stations to communicate QoS requirements to the access point
  • The contention free period (CPF) length cannot be dynamically changed according to traffic needs
  • Different maximum packet lengths cannot be enforced.
IEEE 802.11e

- The major enhancement of 802.11e
  - Traffic differentiation
  - Concept of Transmission Opportunity (TXOP)
  - Enhanced DCF (contention-based)
  - HCF controlled channel access (contention free)
  - Burst ACK (optional)
  - Direct link protocol (DLP)
IEEE 802.11e

The 802.11e standard defines a new Hybrid Coordination Function (HCF) that offers two modes of operation:

- **Enhanced DCF (EDCF)** is like DCF, but introduces different priority levels for different services.
- **HCF Controlled Channel Access (HCCA)** is a CSMA/CA-compatible polling-based access method (like PCF but without the shortcomings listed on the previous slide).
IEEE 802.11e EDCF

EDCF is based on dividing the traffic in the WLAN into different priority levels. Channel access is controlled by using four differentiating parameters:

- Minimum contention window size (CWmin)
- Maximum contention window size (CWmax)
- Arbitration Interframe Space (AIFS) = variable DIFS
- Transmission Opportunity (TXOP) specifies the time (maximum duration) during which a wireless station can transmit a series of frames.
IEEE 802.11e EDCF

- The IEEE 802.1D standard defines four Access Categories (AC) for differentiating users corresponding to 8 priority levels
  - Priorities are numbered from 0 (the lowest priority) to 7 (the highest priority)

<table>
<thead>
<tr>
<th>Priority (Same as 802.1D Priority)</th>
<th>802.1D Designation</th>
<th>Access Category (AC)</th>
<th>Designation (Informative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BK</td>
<td>0</td>
<td>Best Effort</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>0</td>
<td>Best Effort</td>
</tr>
<tr>
<td>0</td>
<td>BE</td>
<td>0</td>
<td>Best Effort</td>
</tr>
<tr>
<td>3</td>
<td>EE</td>
<td>1</td>
<td>Video Probe</td>
</tr>
<tr>
<td>4</td>
<td>CL</td>
<td>2</td>
<td>Video</td>
</tr>
<tr>
<td>5</td>
<td>VI</td>
<td>2</td>
<td>Video</td>
</tr>
<tr>
<td>6</td>
<td>VO</td>
<td>3</td>
<td>Voice</td>
</tr>
<tr>
<td>7</td>
<td>NC</td>
<td>3</td>
<td>Voice</td>
</tr>
</tbody>
</table>
IEEE 802.11e EDCF

- The Access Categories can be implemented in the WLAN by using the corresponding parameter values (in addition to using different TXOP values)

<table>
<thead>
<tr>
<th>AC</th>
<th>Application</th>
<th>CWmin</th>
<th>CWmax</th>
<th>AIFSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Background</td>
<td>CWmin</td>
<td>CWmax</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Best Effort</td>
<td>CWmin</td>
<td>CWmax</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Video</td>
<td>(CWmin+1)/2 - 1</td>
<td>CWmin</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>Voice</td>
<td>(CWmin+1)/4 - 1</td>
<td>(CWmin+1)/2 - 1</td>
<td>1</td>
</tr>
</tbody>
</table>

AIFS \[AC\] = AIFSN \[AC\] * aSlotTime + SIFS
IEEE 802.11e EDCF

Voice
- 2 slots
- 0 ~ 3 slots

Video
- 2 slots
- 0 ~ 7 slots

Best Effort
- 3 slots
- 0 ~ 15 slots

Background
- 7 slots
- 0 ~ 15 slots

Minimum Wait
- Random Backoff Wait
IEEE 802.11e EDCF

- Access category (AC) as a virtual DCF
- Multiple ACs contend independently
- The winning AC transmits frames
IEEE 802.11e HCCA

HCCA is based on a Contention-Free Period (CFP) during which the access point uses polling for controlling the traffic in the WLAN, like PCF. The differences between HCCA and PCF are the following:

- HCCA can poll stations also during the Contention Period (CP).
- Stations can communicate their QoS requirements (data rate, delay, packet size...) to the access point.
- HCCA supports scheduling of packets based on the QoS requirements.
- HCCA grants a polled TXOP with duration specified in a QoS CF Poll frame.
MAC Enhancements in 802.11e

The 802.11e standard also offers MAC enhancements:

- **Contention Free Bursts (CFB)** allows stations to send several frames in a row without contention, if the allocated TXOP permits.

- **New ACK rules.** For instance in applications where retransmission cannot be used due to the strict delay requirements, the ACK frame need not be used.

- **Direct Link Protocol (DLP)** enables communication between wireless stations directly without involving the access point (802.11z).
Power Management
Motivation

• Mobile devices are battery powered
• Enhancement of battery life enhances network lifetime
• Idle/receive state dominates LAN adapter power consumption over time
• Power consumption of ORiNOCO WLAN Card

<table>
<thead>
<tr>
<th></th>
<th>Transmit mode</th>
<th>Receive mode</th>
<th>Idle mode</th>
<th>Doze mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1400mW</td>
<td>900mW</td>
<td>700mW</td>
<td>60mW</td>
<td></td>
</tr>
</tbody>
</table>
Power Management Approaches

- Power management modes
  - Active mode (AM)
  - Power Save mode (PS)

- Power management in 802.11
  - Infrastructure vs. ad hoc network
  - PCF vs. DCF
Power Management – Infrastructure DCF

• Allow idle station to go to sleep
  • Stations state are stored in AP

• AP or source hosts buffer packets for hosts in PS mode.
  • AP announces which station have frames buffered
  • AP or sources send TIM periodically in Beacon.
    • TIM = traffic indication map (a partial virtual bitmap associated with station id)
    • TIM is associated with beacon.

• Power Saving stations wake up periodically
  • Listen for Beacons to monitor TIM
Power Management – Infrastructure DCF

• If TIM indicates frame buffered
  • station sends PS-Poll and stays awake to receive data
  • else station sleeps again
• Broadcast/multicast frames are also buffered at AP
  • These frames are sent only at delivery traffic indication map (DTIM)
  • DTIM = time when multicast frames are to be delivered by AP, determined by AP
    - This time is indicated in the Beacon frames as DTIM
• Power Saving stations wake up prior to expected DTIM
• TSF assures AP and Power save stations are synchronized
  • TSF timer keeps running when stations are sleeping
Infrastructure Power Management Operation

**Beacon-Interval**

**DTIM Interval**

**TIM (in Beacon):**

**AP activity:**

**Busy medium:**

**DTIM:**

**Broadcast:**

**Poll**

**PS station**
Traffic Indication Map (TIM)

- To inform stations that frames are buffered, APs periodically assemble a TIM and transmit it in Beacon frames.
- The TIM is a virtual bitmap composed of 2,008 bits.
- Offsets are used to transmit only a small portion of the virtual bit-map.
- Each bit in the TIM corresponds to a particular AID.
- Setting the bit indicates that the AP has buffered unicast frames for the corresponding station.
- Stations must wake up to listen for Beacon frames to receive the TIM.
- By examining the TIM, a station can determine if the AP has buffered traffic on its behalf.
- To retrieve buffered frames, MSs use PS-Poll control frames.
Traffic Indication Map (TIM)

- When multiple stations have buffered frames, stations use the random backoff algorithm before transmitting the PS-Poll.
- The buffered frames must be positively acknowledged before it is removed from buffer.
- If multiple frames are buffered for a station, then the More Data bit in the Frame Control field is set to 1.
- Stations can then issue additional PS-Poll to AP until More Data bit is set to 0.
- After transmitting the PS-Poll, a mobile station must remain awake until either
  - The polling transaction has concluded or
  - The bit corresponding to its AID is no longer set in the TIM
Delivery TIM (DTIM) for Multicast/ Broadcast

• Frames are buffered whenever any station associated with the AP is sleeping.

• Buffered broadcast and multicast frames are saved used AID = 0.

• APs set the first bit in the TIM to 0.

• At a fixed number of Beacon intervals, a DTIM is sent.

• Buffered broadcast and multicast traffic is transmitted after a DTIM Beacon.
Power Management – Infrastructure PCF

• AP broadcasts beacon with TIM.
• Stations in PS mode checks TIM for their IDs.
  • If there are buffered packets in AP, the host must remain in Active Mode until being polled.
    • O/w, the station goes back to PS mode.
• Then AP polls those PS stations.
• When being polled, the station (in PS mode) sends PS-Poll to AP.
  • Then AP sends buffered packets to the station.
  • (See next page.)
• AP must poll stations in PS mode first.
Power Management – Infrastructure PCF

- All CF-pollable stations need be in Active Mode when AP broadcasts DTIM.
- Immediately after DTIM, AP sends out the buffered broadcast/multicast packets.

Diagram:
- AP
- STA 1 in PS mode
- STA 2 in PS mode
- DTIM
- TIM
- Beacon Interval
- Broadcast Data
Power Management – Ad Hoc (IBSS)

• Power management is less efficient.

• Far more of the burden is placed on the sender to ensure that the receiver is active.

• Receiver must also be more available and cannot sleep for the same lengths of time.

• The Announcement TIM (ATIM) frame is a message to keep the transceiver on because there is a pending data frame.

• All stations in an IBSS listen for ATIM frames during specified periods after Beacon transmissions.

• In ATIM window, each source station having buffered packets to be sent contends to send out its ATIM.

• Stations that do not receive ATIM frames are free to conserve power.
Power Management – Ad Hoc (IBSS)

ATIM Window

Beacon Interval

Beacon

Station A

Transmit ATIM

Receive ATIM

Receive Frame

Transmit Frame

Receive ACK

Receive ACK

Transmit ACK

Transmit ACK

Station B
ATIM Window

- Only certain control and management frames can be transmitted during the ATIM window.
  - Beacons, RTS, CTS, ACK and ATIM frames.
- ATIM frames may be transmitted only during the ATIM window.
- ACKs are required for unicast ATIM frames.
- ACKs are not required for multicast ATIM frames.
- Buffered broadcast and multicast frames are transmitted after the conclusion of the ATIM window.
- After that, a station may attempt to transmit unicast frames announced with an ATIM and for which an ACK was received.
- Then, stations may transmit unbuffered frames to others that are known to be active.
Questions