COMP4310/6310 Wireless Mobile Computing

IEEE 802.11 e/b/a/n/ac/ad
Review: 802.11 DCF

The length of ACK is SIFS<DIFS
Backoff Interval (measured by number of time slots)
When channel is busy, choose a backoff interval randomly from the range [0, cw-1].
- cw is called the contention window
Count down the backoff interval when medium becomes idle. Count down is suspended if medium becomes busy again. When backoff interval reaches 0, transmit
If the transmission does not succeed, double cw next time
- Next time, the transmission may wait even longer.
- That’s the reason it is called (binary) exponential backoff
- Q: Why binary exponential backoff is useful?
Synchronization using a Beacon (infrastructure)

- Beacon interval
- Access point
- Medium
- Busy
- Value of the timestamp
- Beacon frame
Contestion Windows

- choose a backoff interval randomly from the range \([0, cw-1]\), \(cw\) is doubled after each collision.

- Value of \(cw\)
  - minimum contention window, \(CW\)min=16
  - maximum contention window, \(Cw\)max=1024

- Every station/user/node uses the same \(CW\)min and \(Cw\)max.
  - Advantage?
  - Disadvantage?
802.11e

- Although designed for real-time applications, original 802.11 does not offer extensive Quality-of-Service (QoS). The shortcomings include:
  - Differentiation between traffic classes is not possible
  - No mechanisms for wireless stations to communicate QoS requirements to the access point
The 802.11e standard defines a new **Hybrid Coordination Function (HCF)** that offers two modes of operation:

- **HCF Controlled Channel Access (HCCA)** is a CSMA/CA-compatible polling-based access method (like PCF but offers better QoS).
- **Enhanced DCF (EDCF)** is like DCF, but introduces different priority levels for different services.
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.
EDCF (cont.)

- The IEEE 802.1D standard defines four **Access Categories (AC)** for differentiating users that have different priority requirements:

<table>
<thead>
<tr>
<th>AC</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Background</td>
</tr>
<tr>
<td>1</td>
<td>Best Effort</td>
</tr>
<tr>
<td>2</td>
<td>Video</td>
</tr>
<tr>
<td>3</td>
<td>Voice</td>
</tr>
</tbody>
</table>
The Access Categories can be implemented in the WLAN by using the following parameter values (in addition to using different TXOP values):

<table>
<thead>
<tr>
<th>AC</th>
<th>CWmin</th>
<th>CWmax</th>
<th>AIFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CWmin</td>
<td>CWmax</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>CWmin</td>
<td>CWmax</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>(CWmin+1)/2 - 1</td>
<td>CWmin</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>(CWmin+1)/4 - 1</td>
<td>(CWmin+1)/2 - 1</td>
<td>1</td>
</tr>
</tbody>
</table>
EDCF

• Advantages:
  - Provide QoS
  - Giving transmission priority to voice and video traffic

• Disadvantages?
WLAN: IEEE 802.11b

- **Data rate**
  - 1, 2, 5.5, 11 Mbit/s, depending on SNR
  - User data rate max. approx. 6 Mbit/s

- **Transmission range**
  - 300m outdoor, 30m indoor
  - Max. data rate ~10m indoor

- **Frequency**
  - Free 2.4 GHz ISM-band

- **Availability**
  - Many products, many vendors

- **Connection set-up time**
  - Connectionless/always on

- **Quality of Service**
  - Typ. Best effort, no guarantees (unless polling is used, limited support in products)

- **Manageability**
  - Limited (no automated key distribution, sym. Encryption)

- **Special Advantages/Disadvantages**
  - Advantage: many installed systems, lot of experience, available worldwide, free ISM-band, many vendors, integrated in laptops, simple system
  - Disadvantage: heavy interference on ISM-band, no service guarantees, slow relative speed only
IEEE 802.11b - PHY frame formats

Long PLCP PPDU format

- 128 bits synchronization
- 16 bits SFD
- 8 bits signal
- 8 bits service
- 16 bits length
- 16 bits HEC
- Variable bits payload

PLCP preamble

- 192 µs at 1 Mbit/s DBPSK

PLCP header

- 1, 2, 5.5 or 11 Mbit/s

Short PLCP PPDU format (optional)

- 56 bits short synch.
- 16 bits SFD
- 8 bits signal
- 8 bits service
- 16 bits length
- 16 bits HEC
- Variable bits payload

PLCP preamble

- 96 µs (1 Mbit/s, DBPSK)

PLCP header

- 2, 5.5 or 11 Mbit/s

(1 Mbit/s, DBPSK)

(2 Mbit/s, DQPSK)
Channel selection (non-overlapping)

Europe (ETSI)

- Channel 1: 2400 MHz - 2412 MHz
- Channel 7: 2442 MHz - 2472 MHz
- Channel 13: 2472 MHz - 2483.5 MHz

22 MHz

US (FCC)/Canada (IC)

- Channel 1: 2400 MHz - 2412 MHz
- Channel 6: 2437 MHz - 2462 MHz
- Channel 11: 2462 MHz - 2483.5 MHz

22 MHz
WLAN: IEEE 802.11a

• Data rate
  - 6, 9, 12, 18, 24, 36, 48, 54 Mbit/s, depending on SNR
  - User throughput (1500 byte packets): 5.3 (6), 18 (24), 24 (36), 32 (54)
  - 6, 12, 24 Mbit/s mandatory

• Transmission range
  - 100m outdoor, 10m indoor
    • E.g., 54 Mbit/s up to 5 m, 48 up to 12 m, 36 up to 25 m, 24 up to 30m, 18 up to 40 m, 12 up to 60 m

• Frequency
  - Free 5.15-5.25, 5.25-5.35, 5.725-5.825 GHz

• Availability
  - Some products, some vendors

• Connection set-up time
  - Connectionless/always on

• Quality of Service
  - Typ. best effort, no guarantees (same as all 802.11 products)

• Manageability
  - Limited (no automated key distribution, sym. Encryption)

• Special Advantages/Disadvantages
  - Advantage: fits into 802.x standards, free ISM-band, available, simple system, uses less crowded 5 GHz band
  - Disadvantage: stronger shading due to higher frequency, no QoS
IEEE 802.11a - PHY frame format

<table>
<thead>
<tr>
<th>Rate</th>
<th>Reserved</th>
<th>Length</th>
<th>Parity</th>
<th>Tail</th>
<th>Service</th>
<th>Payload</th>
<th>Tail</th>
<th>Pad</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>6</td>
<td>16</td>
<td>variable</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

- **PLCP header**
- **PLCP preamble**
- **Signal**
- **Data**

- **6 Mbit/s**
- **6, 9, 12, 18, 24, 36, 48, 54 Mbit/s**
Operating channels for 802.11a

- 5150 MHz - 5350 MHz
- Channels: 36, 40, 44, 48, 52, 56, 60, 64
- 5725 MHz - 5825 MHz
- Channels: 149, 153, 157, 161
- Bandwidth: 16.6 MHz
OFDM in IEEE

- OFDM with 52 used subcarriers (64 in total)
  - A subcarrier can be considered as a wireless channel at a different (but adjacent) frequency
- 48 data channel
- 4 pilot channel

![Diagram of OFDM subcarriers]

- Subcarrier numbers: 1, 7, 21, 26
- Pilot subcarriers: -7, -11, 7, 21, 26
- Channel center frequency: 312.5 kHz
802.11n

- Both PHY and MAC layers enhancements
- Uses MIMO (Multi-input multiple-output) technology
- Up to 300Mbps on 20MHz channels (and 600Mbps in 40MHz channels)
PHY Enhancements

• 40 MHz Channel
  – Compared to its predecessor, this enhancement to 802.11n gives it the ability to double its throughput.
  – Both 20 MHz and 40 MHz wide channel operation supported. In the 40 MHz mode, the capacity of the channel is effectively double that of legacy systems (802.11 a/b/g).
  – Supports both 2.4 GHz and 5 GHz frequencies in the ISM bands and UNII bands.
  – A total of 11 non-overlapping 40 GHz channels possible in the 5 GHz band.
PHY Enhancements

• MIMO (Multiple-Input, Multiple-Output)
  – Smart antenna technology.
  – Uses multiple antennas at both the transmitter end and the receiver end to make more efficient use of the RF spectrum.
  – Typically specified as M x N, where M = No. Tx antennas and N = No. Rx antennas.
  – Current 802.11n specifies configurations from 1 x 1 to 4 x 4.
  – Other common convention is M x N: S, where S is the number of spatial streams (e.g., 3 x 2: 2)
MAC Enhancements

• Frame Aggregation
  – For every 802.11 packet transmitted, there is overhead in the form of interframe space, radio preambles and ACK (acknowledgement) frames.
  – With A-MPDU, aggregated frame size changes from 2304 Bytes to 65535 Bytes and overhead is reduced from 83% to 14% with frame aggregation transmitted at 600 Mbps.

• Multiple Traffic ID Block Acknowledgement (MTBA)
  – With legacy systems, the receiver must send an acknowledgement packet to the sender for each frame received, but with 802.11n the receiver can send just one acknowledgement package for every 9 frames received.
MAC Enhancements (II)

• Legacy Support
  - Provides for backward compatibility with legacy systems by operating with 20 MHz channels, transmitting frames in sizes that are suitable for legacy devices and operating in mixed mode to facilitate 802.11b/g devices when they are present in a network that has 802.11n Access Points.
# Evolving 802.11 Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>802.11</th>
<th>802.11a</th>
<th>802.11b</th>
<th>802.11g</th>
<th>802.11n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequencies</strong></td>
<td>2.400 – 2.4835 GHz (ISM)</td>
<td>5.15 – 5.25 GHz</td>
<td>2.400 – 2.4835 GHz (ISM)</td>
<td>2.400 – 2.4835 GHz (ISM)</td>
<td>2.400 – 2.4835 GHz (ISM)</td>
</tr>
<tr>
<td><strong>Non-overlapping Channels</strong></td>
<td>3</td>
<td>4 Indoor</td>
<td>3</td>
<td>3</td>
<td>3 – 20 MHz on 2.4 GHz</td>
</tr>
<tr>
<td><strong>Data Rates</strong></td>
<td>2.1 Mbps</td>
<td>54, 48, 36, 24, 18, 12, 9, 6 Mbps</td>
<td>11, 5.5, 2, 1 Mbps</td>
<td>54, 36, 24, 22, 12, 11, 9, 6, 5.5, 2, 1 Mbps</td>
<td>7.2 to 300 Mbps on 20 MHz channels</td>
</tr>
<tr>
<td><strong>Outdoor Range</strong></td>
<td>330 ft</td>
<td>460 ft</td>
<td>400 ft</td>
<td>460 ft</td>
<td>650 ft</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>DQPSK, DBPSK</td>
<td>BPSK, QPSK, 16-QAM, 64-QAM</td>
<td>CCK, DQPSK, DBPSK</td>
<td>OFDM, CCK, DQPSK, DBPSK</td>
<td>16-QAM (4 Bit), 64-QAM (6 Bit), Backward compatible w/ OFDM</td>
</tr>
</tbody>
</table>
802.11ac

- Approved January 2014
- Multi-station WLAN throughput of 1Gbps
- Single-station WLAN 500Mbps
- More MIMO spatial streams possible (8 vs only 4 in 802.11n)
802.11ac - Features

• Even wider bandwidths - up to 160MHz bandwidth - 80+80 contiguous or not
• 256-QAM when signal strength is outstanding (vs 64-QAM max in 802.11n)
• 80 MHz mandatory in STAs
• More MIMO streams - up to 8
• Multi-user MIMO
802.11ac - Downlink Multi User MIMO
802.11ad

• Standard initially developed by the WiGig alliance

• 802.11 amendment approved Oct 2012
  - Extension for PHY working in 60GHz
  - Data rates up to 7Gbps
    • 2GHz channels,
    • ~7-9GHz total available around the world
  - 60GHz has horrible propagation beyond line of sight
  - Backward compatible (2.4GHz, 5.8GHz, 60GHz)