Lecture 4: IEEE 802.11 Wireless LANs (Cont.)
Mobile Communication Technology according to IEEE (examples)

**WiFi**
- Local wireless networks
  - **WLAN 802.11**
    - 802.11a → 802.11h
    - 802.11b → 802.11g
    - 802.11i/e/.../n/.../z/aa

**ZigBee**
- Personal wireless nw
  - **WPAN 802.15**
    - 802.15.1
    - 802.15.2
    - 802.15.3 → 802.15.3b/c
    - 802.15.4 → 802.15.4a/b/c/d/e/f/g
    - 802.15.5, .6 (WBAN)

**Bluetooth**
- Wireless distribution networks
  - **WMAN 802.16 (Broadband Wireless Access)**
    - WiMAX
    - + Mobility
      - [802.20 (Mobile Broadband Wireless Access)]
      - 802.16e (addition to .16 for mobile devices)
802.11 - Layers and functions

- **MAC**
  - access mechanisms, fragmentation, encryption
- **MAC Management**
  - synchronization, roaming, MIB, power management
- **PLCP** Physical Layer Convergence Protocol
  - clear channel assessment signal (carrier sense)
- **PMD** Physical Medium Dependent
  - modulation, coding
- **PHY Management**
  - channel selection, MIB
- **Station Management**
  - coordination of all management functions

<table>
<thead>
<tr>
<th>PHY</th>
<th>PLCP</th>
<th>MAC</th>
<th>LLC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAC Management</td>
<td>MAC Management</td>
<td>LLC</td>
</tr>
<tr>
<td></td>
<td>PHY Management</td>
<td>PHY Management</td>
<td>}</td>
</tr>
</tbody>
</table>
802.11 - MAC layer I - DFWMAC

• **Traffic services**
  – Asynchronous Data Service (mandatory)
    • exchange of data packets based on “best-effort”
    • support of broadcast and multicast
  – Time-Bounded Service (optional)
    • implemented using PCF (Point Coordination Function)

• **Access methods**
  – DFWMAC-DCF CSMA/CA (mandatory)
    • collision avoidance via randomized “back-off“ mechanism
    • minimum distance between consecutive packets
    • ACK packet for acknowledgements (not for broadcasts)
  – DFWMAC-DCF w/ RTS/CTS (optional)
    • Distributed Foundation Wireless MAC
    • avoids hidden terminal problem
  – DFWMAC- PCF (optional)
    • access point polls terminals according to a list
802.11 - MAC layer II

- Priorities
  - defined through different inter frame spaces
  - no guaranteed, hard priorities
  - SIFS (Short Inter Frame Spacing)
    - highest priority, for ACK, CTS, polling response
  - PIFS (PCF IFS)
    - medium priority, for time-bounded service using PCF
  - DIFS (DCF, Distributed Coordination Function IFS)
    - lowest priority, for asynchronous data service

Medium busy

- direct access if medium is free $\geq$ DIFS

Contention

Next frame
# 802.11 – Inter Frame Spacing

<table>
<thead>
<tr>
<th></th>
<th>802.11b</th>
<th>802.11a</th>
<th>802.11g</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textit{aSIFS} Time</td>
<td>10 usec</td>
<td>16 usec</td>
<td>10 usec</td>
</tr>
<tr>
<td>\textit{aSlot} Time</td>
<td>20 usec</td>
<td>9 usec</td>
<td>20 usec (mixed); 9 usec (g only)</td>
</tr>
<tr>
<td>\textit{aDIFT} Time</td>
<td>50 usec</td>
<td>34 usec</td>
<td>50 usec; 28 usec</td>
</tr>
</tbody>
</table>

(2xSlot+SIFS)
802.11 - CSMA/CA access method I

- station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- if the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- if the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- if another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)
802.11 - competing stations - simple version

- **DIFS**
- **bo_e** elapsed backoff time
- **bo_r** residual backoff time
- **busy** medium not idle (frame, ack etc.)
- **packet arrival at MAC**
802.11 - CSMA/CA access method II

- Sending unicast packets
  - station has to wait for DIFS before sending data
  - receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - automatic retransmission of data packets in case of transmission errors
802.11 - DFWMAC

- Sending unicast packets
  - station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - sender can now send data at once, acknowledgement via ACK
  - other stations store medium reservations distributed via RTS and CTS
Fragmentation

sender

DIFS → RTS → SIFS → frag₁ → SIFS → ACK₁ → SIFS → frag₂ → SIFS → ACK₂

receiver

other stations

NAV (RTS) → NAV (CTS) → NAV (frag₁) → NAV (ACK₁)

data

t

contention
DFWMAC-PCF I (almost never used)
DFWMAC-PCF II

- Point coordinator
- Wireless stations
- Stations' NAV
- NAV's contention free period
- Contention period

- $D_3$, $D_4$, PIFS, SIFS, $U_4$, CF$_{end}$
- Times $t_2$, $t_3$, $t_4$
802.11 - Frame format

- **Types**
  - control frames, management frames, data frames

- **Sequence numbers**
  - important against duplicated frames due to lost ACKs

- **Addresses**
  - receiver, transmitter (physical), BSS identifier, sender (logical)

- **Miscellaneous**
  - sending time, checksum, frame control, data
## MAC address format

<table>
<thead>
<tr>
<th>scenario</th>
<th>to DS</th>
<th>from DS</th>
<th>address 1</th>
<th>address 2</th>
<th>address 3</th>
<th>address 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ad-hoc network</td>
<td>0</td>
<td>0</td>
<td>DA</td>
<td>SA</td>
<td>BSSID</td>
<td>-</td>
</tr>
<tr>
<td>infrastructure network, from AP</td>
<td>0</td>
<td>1</td>
<td>DA</td>
<td>BSSID</td>
<td>SA</td>
<td>-</td>
</tr>
<tr>
<td>infrastructure network, to AP</td>
<td>1</td>
<td>0</td>
<td>BSSID</td>
<td>SA</td>
<td>DA</td>
<td>-</td>
</tr>
<tr>
<td>infrastructure network, within DS</td>
<td>1</td>
<td>1</td>
<td>RA</td>
<td>TA</td>
<td>DA</td>
<td>SA</td>
</tr>
</tbody>
</table>

DS: Distribution System  
AP: Access Point  
DA: Destination Address  
SA: Source Address  
BSSID: Basic Service Set Identifier  
RA: Receiver Address  
TA: Transmitter Address
Special Frames: ACK, RTS, CTS

- **Acknowledgement**
  - **ACK**
  - **Frame Control**
  - **Duration**
  - **Receiver Address**
  - **CRC**

- **Request To Send**
  - **RTS**
  - **Frame Control**
  - **Duration**
  - **Receiver Address**
  - **Transmitter Address**
  - **CRC**

- **Clear To Send**
  - **CTS**
  - **Frame Control**
  - **Duration**
  - **Receiver Address**
  - **CRC**
Example: 802.11b Throughout

• Suppose TCP with 1460 bytes payload
  – 802.11b data frame size (not including preamble): 1536 bytes
  – TCP ACK data frame size (not including preamble): 76 bytes

• 802.11b ACK frame size 14 bytes

• Suppose 802.11b at the highest rate
  – 8 bits per symbol
  – 1.375 Msps

Q: What is TCP/802.11b throughput?

http://www.andrews.edu/~swensen/Wifi%20Throughput.pdf
Example: 802.11b Throughput

- Each transaction requires 2,084 μs. At that duration, 479 exchanges can complete per second. With a TCP payload of 1,460 bytes per exchange, the throughput is 5.7 Mbps.

<table>
<thead>
<tr>
<th></th>
<th>TCP data</th>
<th>TCP ACK</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIFS</td>
<td>50 μs</td>
<td>50 μs</td>
</tr>
<tr>
<td>802.11 Data</td>
<td>192 μs + 1536/1.375 Mspa</td>
<td>192 μs + 76/1.375 Mspa</td>
</tr>
<tr>
<td></td>
<td>= 192 μs + 1,118 μs</td>
<td>= 192 μs + 56 μs</td>
</tr>
<tr>
<td></td>
<td>= 1,310 μs</td>
<td>= 248 μs</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 μs</td>
<td>10 μs</td>
</tr>
<tr>
<td>802.11 ACK</td>
<td>192 μs + 14/1.375 Mspa</td>
<td>= 203 μs</td>
</tr>
<tr>
<td></td>
<td>= 192 μs + 11 μs</td>
<td></td>
</tr>
<tr>
<td>Frame exchange total</td>
<td>1,573 μs</td>
<td>511 μs</td>
</tr>
<tr>
<td>Transaction Total</td>
<td>2,084 μs</td>
<td></td>
</tr>
</tbody>
</table>
Backup
### 802.11b Data Rate Specifications

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>Code Length</th>
<th>Modulation</th>
<th>Symbol Rate</th>
<th>Bits/Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mbps</td>
<td>11 (Barker Sequence)</td>
<td>BPSK</td>
<td>1 MSps</td>
<td>1</td>
</tr>
<tr>
<td>2 Mbps</td>
<td>11 (Barker Sequence)</td>
<td>QPSK</td>
<td>1 MSps</td>
<td>2</td>
</tr>
<tr>
<td>5.5 Mbps</td>
<td>8 (CCK)</td>
<td>QPSK</td>
<td>1.375 MSps</td>
<td>4</td>
</tr>
<tr>
<td>11 Mbps</td>
<td>8 (CCK)</td>
<td>QPSK</td>
<td>1.375 MSps</td>
<td>8</td>
</tr>
</tbody>
</table>