Wireless LAN
Centralized and AdHoc networks
Centralized and AdHoc Networks

Centralized Network

Wired network

AdHoc Network
Infrastructure and AdHoc Networks

• Some issues to consider:
  – Centralized networks
    • Integration with wired LAN
    • Network planning (access points)
    • Interoperability
    • Roaming and handover between access points
    • Security / authentication
    • Power management
  – AdHoc networks
    • Multi-hop and routing
    • Quality of service
    • Interoperability
    • Security / authentication
    • Power management
Error control and ARQ
Error-correcting and Error-detecting Codes

• In wireless systems we need error-correcting and error-detecting codes

• The quality of the wireless channel changes with time and we need to safeguard our data.
  – Data transmitted during a fading dip can (if the coding scheme is properly designed) be recovered by an error-correcting code.

• To reach very low error rates we need error detection to trap incorrectly decoded data.
Automatic Repeat Request (ARQ)

• Using error-detection codes we can reduce the error rate by applying an ARQ scheme.

• ARQ is usually not an option for time critical data over ‘slow’ channels, such as real-time audio and video.

• For high efficiency, ARQ schemes for wireless channels need to be more intricate than the ones used on wired channels
  – This is due to the fading nature of wireless channels
Digital transmission in WLANs
Some WLANs

Recent WLAN standards and specifications

The latest standards, with the highest data rates are based on OFDM (in combination with MIMO).

Increasing equalization complexity

IEEE 802.11
Bluetooth 1.0
Hiperlan/2
IEEE 802.11a
IEEE 802.11b
IEEE 802.11g
IEEE 802.11n
Bluetooth 2.0
Wireless LAN standards and specifications
Wireless LAN Standards and Specifications

• Some of the available standards and specifications
  - ETSI
    • HIPERLAN/2
  - IEEE
    • 802.11
    • 802.11a
    • 802.11b
    • 802.11g
    • 802.11n
  - BlueTooth SIG
    • BlueTooth
ETSI - HIPERLAN/2

Part of the ETSI BRAN family

HIPERACCESS

HIPERLINK

HIPERLAN
ETSI - HIPERLAN/2

• Digital transmission
  - OFDM (multicarrier) with sampling rate 20 MHz
  - 5.150-5.350 GHz & 5.470-5.725 GHz
  - 48 data carriers + 4 pilot carriers
  - Carrier spacing 0.3125 MHz
  - Symbol length 4 us (0.8 us cyclic prefix)
  - Range < 150 m.
  - TDMA/TDD

• Syncronization
  - Broadcast (base => all). Preamble 16 us.
  - Downlink (base => terminal). Preamble 8 us.
  - Uplink (terminal => base). Short preamble 12 us and long preamble 16 us.
ETSI - HIPERLAN/2

BURST STRUCTURES

Broadcast

<table>
<thead>
<tr>
<th>Preamble</th>
<th>Data</th>
<th>Data</th>
<th>...</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 us</td>
<td></td>
<td>4 us</td>
<td></td>
</tr>
</tbody>
</table>

Down link

<table>
<thead>
<tr>
<th>Preamble</th>
<th>Data</th>
<th>Data</th>
<th>...</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8 us</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Up link (short preamble)

<table>
<thead>
<tr>
<th>Preamble</th>
<th>Data</th>
<th>Data</th>
<th>...</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 us</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Up link (long preamble)

<table>
<thead>
<tr>
<th>Preamble</th>
<th>Data</th>
<th>Data</th>
<th>...</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 us</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ETSÍ - HIPERLAN/2

SIGNAL CONSTELLATIONS

- **BPSK**
  - 1 bit/symbol
- **QPSK**
  - 2 bit/symbol
- **16-QAM**
  - 4 bit/symbol
- **64-QAM**
  - 6 bit/symbol

*(OPTION)*

16-QAM
### TRANSMISSION MODES

<table>
<thead>
<tr>
<th>Sig.const</th>
<th>Code</th>
<th>Data bit/symbol</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>1/2</td>
<td>24</td>
<td>6 Mbit/s</td>
</tr>
<tr>
<td>BPSK</td>
<td>3/4</td>
<td>36</td>
<td>9 Mbit/s</td>
</tr>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>48</td>
<td>12 Mbit/s</td>
</tr>
<tr>
<td>QPSK</td>
<td>3/4</td>
<td>72</td>
<td>18 Mbit/s</td>
</tr>
<tr>
<td>16QAM</td>
<td>9/16</td>
<td>108</td>
<td>27 Mbit/s</td>
</tr>
<tr>
<td>16QAM</td>
<td>3/4</td>
<td>144</td>
<td>36 Mbit/s</td>
</tr>
<tr>
<td>64QAM</td>
<td>3/4</td>
<td>216</td>
<td>54 Mbit/s</td>
</tr>
</tbody>
</table>
IEEE - 802.11

- 802.11-1997
  - PHY layer
    - diffused infrared - in baseband
    - DSSS and FHSS (50 hops/sec) in 2.4 GHz ISM band
    - 1 and 2 Mbps data rate
  - MAC layer
    - Two network architectures: Infrastructure Network and Ad-Hoc Network
    - Primary services: Data transfer, Association, Reassociation, Authentication, Privacy, and Power Management
  - MISSING
    - AP-to-AP coordination for roaming, Data frame mapping, Conformance test
IEEE - 802.11

• 802.11a-1999 (supplement to 802.11-1997)
  - New PHY (and MAC) layer for 802.11
  - 5 GHz band
  - Essentially the same physical layer (OFDM) as HIPERLAN/2
  - 6-54 Mbps data rate

• 802.11b-1999 (supplement to 802.11-1997)
  - New PHY (and MAC) layer for 802.11
  - 2.4 GHz band
  - DSSS based physical layer
  - 11 Mbps data rate
IEEE - 802.11

• 802.11g-2003 (supplement to 802.11-1997)
  - Same PHY layer as 802.11a
  - 2.4 GHz band
  - New MAC layer
  - 6-54 Mbps data rate

• 802.11n (under development)
  - Up to 500 Mbit/sec
  - Proposal based on MIMO technology
IEEE 802.11 - a bigger family

- IEEE 802.11 - The original 1 Mbit/s and 2 Mbit/s, 2.4 GHz RF and IR standard
- IEEE 802.11a - 54 Mbit/s, 5 GHz standard (1999, shipping products in 2001)
- IEEE 802.11b - Enhancements to 802.11 to support 5.5 and 11 Mbit/s (1999)
- IEEE 802.11d - international (country-to-country) roaming extensions
- IEEE 802.11e - Enhancements: QoS, including packet bursting
- IEEE 802.11F - Inter-Access Point Protocol (IAPP)
- IEEE 802.11g - 54 Mbit/s, 2.4 GHz standard (backwards compatible with b) (2003)
- IEEE 802.11h - 5 GHz spectrum, Dynamic Channel/Frequency Selection (DCS/DFS) and Transmit Power Control (TPC) for European compatibility
- IEEE 802.11i (ratified 24 June 2004) - Enhanced security
- IEEE 802.11j - Extensions for Japan
- IEEE 802.11k - Radio resource measurements
- IEEE 802.11n - Higher throughput improvements
- IEEE 802.11p - WAVE - Wireless Access for the Vehicular Environment (such as ambulances and passenger cars)
- IEEE 802.11r - Fast roaming
- IEEE 802.11s - Wireless mesh networking
- IEEE 802.11T - Wireless Performance Prediction (WPP) - test methods and metrics
- IEEE 802.11u - Interworking with non-802 networks (e.g., cellular)
- IEEE 802.11v - Wireless network management

... and more!
Bluetooth Special Interest Group - Bluetooth

• FHSS in the 2.4 GHz band
  - max 1600 hops/sec (much faster than IEEE 802.11 FHSS)
  - 1 MHz channels
  - 79 frequency channels

• Modulation
  - Version 1.x
    • GFSK (BT=0.5)
    • 1 Mbps (raw)
  - Version 2.x
    • Additionally differential 4PSK and 8PSK
    • 2 & 3 Mbps

• Range
  - 10 cm -- 10 m (for Class 2)
Blue

Blue

Master

Slave 1

Slave 2

Slave 3

PICONET
Bluetooth Special Interest Group - Bluetooth

SCATTERNET

[Diagram of a network with multiple nodes and connections, labeled with 'Master' and '〈Wires〉'.]
BlueTooth Special Interest Group - Bluetooth

**MASTER**

- Master internal clock
- Frequency hop generator
- Hop freq.
- (selection of hop sequence)
- Master unit BlueTooth Device Address

**SLAVE**

- Slave internal clock
- Frequency hop generator
- Hop freq.
- Offset
- Master unit BlueTooth Device Address
Bluetooth Special Interest Group - Bluetooth

Frequency: $f(2k)$, $f(2k+1)$, $f(2k+2)$, $f(2k+3)$

Master: 
- $f(2k)$: Down
- $f(2k+1)$: Up
- $f(2k+2)$: Down
- $f(2k+3)$: Up

Slave: 
- $f(2k)$: Up
- $f(2k+1)$: Down
- $f(2k+2)$: Up
- $f(2k+3)$: Down

625 us
Packet lengths 1, 3 and 5
Gaussian-filtered Frequency Shift Keying (GFSK) [c.f. GMSK]

\[ BT_b = 0.5 \]

Mod.index = 0.32 (+/-3%)

Bitrate 1 Mbit/sec (+/-1ppm)

\[ f_d = \frac{320}{2} \text{ kHz} = 160 \text{ kHz} (+/-3\%) \]

\[ B = 500 \text{ kHz} \]

\[ T_b = 1 \text{ us} \]
Bluetooth Special Interest Group - Bluetooth

• Synchronous connection oriented (SCO)
  - Synchronous transmission
  - Symmetric data rate
  - Reserved time slots
  - Intended for voice
  - No retransmission

• Asymmetric connection less (ACL)
  - Asynchronous transmission
  - Used for asymmetric communication
  - Retransmission used (Go-back-1 ARQ)

These are the basic packet types.
Bluetooth evolution

• Bluetooth has evolved to newer versions, e.g.
  - Version 2.0 + EDR
    • Main feature: (optional) higher data rate (3 Mbit/sec)
  - Version 2.1 + EDR
    • Main feature: secure simple pairing of devices
  - Version 3.0 + HS
    • Main feature: up to 24 Mbit/sec by using 802.11 MAC/PHY
A few words about WiMAX
OFDM based multiple access

- Traditional multiple access based on sharing resources in time (TDMA), frequency (FDMA) or code (CDMA).
- The two-dimensional time-frequency grid of OFDM opens up for a more advanced sharing of the resources.
- One such system was developed for the ETSI standardization ”contest” in 1997 when WCDMA was adopted. Similar systems can be found in the LTE (long-term evolution) in 3GPP.
- Another variation on the theme is found in the WiMAX (IEEE802.16 systems).
OFDM based multiple access (cont.)

• In OFDM we can place transmission blocks in an arbitrary pattern in time and frequency:

Example:
Four users with different access patterns.
Variable data rate.

Has some similarities to CDMA, since the data rate is variable.
OFDM based multiple access (cont.)

• Pros:
  - We can get variable bandwidth/data rate by changing the transmission block sizes. (BOD – bandwidth on demand)
  - By using several smaller transmission blocks spaced in frequency we can exploit frequency diversity even at low data rates.
  - The nice orthogonality properties of OFDM can give high data rates especially in the down-link.

• Cons:
  - Difficult to use in the up-link since all terminals need to be very well synchronized if we want to maintain orthogonality.

These techniques are often called **OFDMA** (orthogonal frequency division multiple access), which is a term [as far as I know] introduced by *Hikmet Sari* at the Globecom conference 1997. The company RUNCOM, however, think that they own ”OFDMA” since they introduced a version of it in year 2000.
Terminals at different positions will have different channels.

**Conclusion**: If one terminal has a fading dip at a certain subcarrier, then some other terminal may have good conditions at this subcarrier.

Distribute the transmission blocks so that the terminal with "the best conditions" transmit on each subcarrier.
### IEEE 802.16 Wireless MAN / WiMax

<table>
<thead>
<tr>
<th></th>
<th>802.16</th>
<th>802.16a HiperMAN</th>
<th>802.16-2004</th>
<th>802.16e-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency band</strong></td>
<td>10-66 GHz</td>
<td>&lt; 11 GHz</td>
<td>&lt; 11 GHz</td>
<td>&lt; 6 GHz</td>
</tr>
<tr>
<td><strong>Radio environment</strong></td>
<td>Only LOS</td>
<td>Non-LOS</td>
<td>Non-LOS</td>
<td>Non-LOS and mobile</td>
</tr>
<tr>
<td><strong>Bit rates</strong></td>
<td>32-134 Mbps</td>
<td>&lt;= 75 Mbps</td>
<td>&lt;= 75 Mbps</td>
<td>&lt;= 15 Mbps</td>
</tr>
</tbody>
</table>

![WiMAX Forum](www.wimaxforum.org)
A few sOFDMA (scalable OFDMA) parameters in WiMax

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Channel Bandwidth (MHz)</td>
<td>1.25</td>
</tr>
<tr>
<td>Sampling Frequency ($F_s$ in MHz)</td>
<td>1.4</td>
</tr>
<tr>
<td>FFT Size ($N_{FFT}$)</td>
<td>128</td>
</tr>
<tr>
<td>Number of Sub-Channels</td>
<td>2</td>
</tr>
<tr>
<td>Sub-Carrier Frequency Spacing</td>
<td>10.94 kHz</td>
</tr>
<tr>
<td>Useful Symbol Time ($T_b = 1/f$)</td>
<td>91.4 microseconds</td>
</tr>
<tr>
<td>Guard Time ($T_g = T_b / 8$)</td>
<td>11.4 microseconds</td>
</tr>
<tr>
<td>OFDMA Symbol Duration ($T_s = T_b + T_g$)</td>
<td>102.9 microseconds</td>
</tr>
<tr>
<td>Number of OFDMA Symbols (5 ms Frame)</td>
<td>48</td>
</tr>
</tbody>
</table>

Scalable OFDMA means that the number of OFDM subcarriers ($N_{FFT}$) changes with the bandwidth so that the distance (in Hz) between subcarriers remain constant. This is favourable when implementing transmitters and receivers.
IEEE 802.16 Wireless MAN / WiMax

WiMax OFDMA frame structure

[from www.wimaxforum.org]
# Modulation and coding

<table>
<thead>
<tr>
<th>Code Rate</th>
<th>DL Modulation</th>
<th>UL Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td>CTC</td>
<td>1/2, 2/3, 3/4, 5/6</td>
<td>1/2, 2/3, 5/6</td>
</tr>
<tr>
<td>Repetition</td>
<td>x2, x4, x6</td>
<td>x2, x4, x6</td>
</tr>
</tbody>
</table>

- CC - Convolutional Code
- CTC - Convolutional Turbo Code

[from www.wimaxforum.org]
LTE basic transmission principles (OFDMA) show strong similarities with WiMAX ... but they are entirely different animals in many other respects.

LEARN MORE:

ETTN15 Modern Wireless Systems - LTE and Beyond (Starts in September!)