Power Management

- Goal is to enhance battery life of the stations
- Idle receive state dominates LAN adapter power consumption over time
- Allow stations to power off their NIC while still maintaining an active session
- Different protocols are used for infrastructure and independent BSS
  - Our focus is on infrastructure mode

Power Management Approach

- Idle station to go to sleep
- AP keeps track of stations in Power Savings mode and buffers their packets
  - Traffic Indication Map (TIM) is included in beacons to inform which power-save stations have packets waiting at the AP
- Power Saving stations wake up periodically and listen for beacons
  - If they have data waiting, they can send a PS-Poll to request that the AP sends their packets
- TSF assures AP and stations are synchronized
  - Synchronizes clocks of the nodes in the BSS
- Broadcast/multicast frames are also buffered at AP
  - Sent after beacons that includes Delivery Traffic Indication Map (DTIM)
  - AP controls DTIM interval

Infrastructure Power Management Operation

Outline

- Brief history
- 802 protocol overview
- Wireless LANs – 802.11 – overview
  - 802.11 MAC, frame format, operations
  - 802.11 management
  - 802.11 security
  - 802.11 power control
  - 802.11 QoS
- Wireless Access – 802.16
- Personal Area Networks – 802.15
- Cellular technologies
Some IEEE 802.11 Standards

- IEEE 802.11a
  - PHY Standard: 8 channels; up to 54 Mbps; some deployment
- IEEE 802.11b
  - PHY Standard: 3 channels; up to 11 Mbps; widely deployed.
- IEEE 802.11d
  - MAC Standard: support for multiple regulatory domains (countries)
- IEEE 802.11e
  - MAC Standard: QoS support; supported by many vendors
- IEEE 802.11f
  - Inter-Access Point Protocol; deployed
- IEEE 802.11g
  - PHY Standard: OFDM and PBCC; widely deployed (as b/g)
- IEEE 802.11h
  - Suppl. MAC Standard: spectrum managed 802.11a (TPC, DFS); standard
- IEEE 802.11i
  - Suppl. MAC Standard: Alternative WEP; standard
- IEEE 802.11n
  - MAC Standard: MIMO; standardization expected late 2008

IEEE 802.11 Family

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Release</th>
<th>Freq. (typical)</th>
<th>Rate (max)</th>
<th>Range (indoor)</th>
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<tbody>
<tr>
<td>Legacy</td>
<td>1997</td>
<td>2.4 GHz</td>
<td>1 Mbps</td>
<td>2 Mbps</td>
</tr>
<tr>
<td>802.11a</td>
<td>1999</td>
<td>5 GHz</td>
<td>25 Mbps</td>
<td>54 Mbps</td>
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<tr>
<td>802.11b</td>
<td>1999</td>
<td>2.4 GHz</td>
<td>6.5 Mbps</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>802.11g</td>
<td>2003</td>
<td>2.4 GHz</td>
<td>25 Mbps</td>
<td>54 Mbps</td>
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<tr>
<td>802.11n</td>
<td>2008</td>
<td>2.4/5 GHz</td>
<td>200 Mbps</td>
<td>600 Mbps</td>
</tr>
</tbody>
</table>

Physical Layer

- Infrared
- 2.4 GHz - FHSS
- 2.4 GHz - DSSS
- 802.11b: 5.5/11 Mbs
- 5 GHz - OFDM
- 802.11d

802.11b Channels

- In the UK and most of EU: 13 channels, 5 MHz apart, 2.412 – 2.472 GHz
- In the US: only 11 channels
- Each channel is 22 MHz
- Significant overlap
- Non-overlapping channels are 1, 6 and 11

802.11b Physical Layer

- FHSS (legacy)
  - 2 & 4 GFSK
  - Using one of 78 hop sequences, hop to a new 1 MHz channel (out of the total of 79 channels) at least every 400 milliseconds
- DSSS (802.11b)
  - DBPSK & DQPSK
  - Uses one of 11 overlapping channels (22 MHz)
  - 1 and 2 Mbps: multiply the data by an 11-chip spreading code (Barker sequence)
  - 5.5 and 11 Mbps: uses Complementary Code Keying (CCK) to generate spreading sequences that support the higher data rates
  - Spreading code is calculated based on the data bits

Going Faster: 802.11g

- 802.11g basically extends of 802.11b
  - Use the same technology DSSS/CCK for lower rates
  - Uses OFDM technology for rates > 20 Mbps
- Using OFDM makes it easier to build 802.11a/g cards
  - Since 802.11a uses OFDM
- But it creates an interoperability problem since 802.11b cards cannot interpret OFDM signals
  - Solutions: send CTS using CCK before OFDM packets in hybrid environments, or use (optional) hybrid packet format

Going Faster: 802.11n

- 802.11n basically extends of 802.11n
  - Use the same technology DSSS/CCK for lower rates
  - Uses OFDM technology for rates > 20 Mbps
- Using OFDM makes it easier to build 802.11a/g cards
  - Since 802.11a uses OFDM
- But it creates an interoperability problem since 802.11b cards cannot interpret OFDM signals
  - Solutions: send CTS using CCK before OFDM packets in hybrid environments, or use (optional) hybrid packet format
### 802.11a Physical Channels

- **Indoor**
  - Center frequency = 5000 + 5 * channel number (MHz)
  - Channels: 36, 40, 44, 48, 52, 56, 60, 64

- **Point-Point**
  - Center frequency = 5000 + 5 * channel number (MHz)

### 802.11a Modulation

- **Use OFDM to divide each physical channel (20 MHz) into 52 subcarriers (20MHz/64=312.5 KHz each)**
  - 48 data, 4 pilot

- **Adaptive modulation**
  - BPSK: 6, 9 Mbps
  - QPSK: 12, 18 Mbps
  - 16-QAM: 24, 36 Mbps
  - 64-QAM: 48, 54 Mbps

### 802.11a Discussion

- Uses OFDM in the 5.2 and 5.7 GHz bands
- What are the benefits of 802.11a compared with 802.11b?
  - Greater bandwidth (up to 54 Mbps)
  - Less potential interference (5 GHz)
  - More non-overlapping channels
  - But does not provide interoperability with 802.11b, as 802.11g does

### 802.11 Physical Layer Discussion

- Antenna diversity is very common
- Can significantly reduce the effect of multipath
- RTS/CTS is almost never used
  - Overhead is too high compared with benefit
- Two key parameters are the transmit power and the Clear Channel Assessment (CCA) threshold
  - The two parameters have impact on the hidden and exposed terminal problem
  - With default settings, in most deployments, exposed terminals are a more common than hidden terminals
  - Transmit power is pretty high while CCA is pretty sensitive
- Receive threshold controls what packets you will hear or ignore

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- 802.11*
- 802.11 QoS

### 802.11n

- 802.11n extends 802.11 for MIMO
- Standardization is still ongoing, but early products are on the market
  - Supported in both the 2.4 and 5 GHz bands
  - Goal: typical indoor rates of 100-200 Mbps; max 600 Mbps
- Early products typically use either 1 or 2 non-overlapping channels
  - Maximum rate with 2 overlapping channels is ~300 Mbps
  - Not clear what you get in practice
- Tests have created interoperability problems for existing 802.11 devices
  - 802.11n does not sense their presence
  - Legacy devices end up deferring and dropping in rate
IEEE 802.11e

- Original intent was that 802.11 PCF could be used to provide QoS guarantees
  - Scheduler in the PCF prioritizes urgent traffic
  - But: overhead, “guarantees” are very soft
- 802.11e Enhanced Distributed Coordination Function (EDCF) is supposed to fix this.
  - Provides Hybrid Coordination Function (HCF) that combines aspects of PCF and DCF
- EDCF supports 4 Access Categories
  - AC_BK (or AC0) for Back-ground traffic
  - AC_BE (or AC1) for Best-Effort traffic
  - AC_VI (or AC2) for Video traffic
  - AC_VO (or AC3) for Voice traffic

IEEE 802.11: Priorities

Service Differentiation Mechanisms in EDCF

- The two types of service differentiation mechanisms proposed in EDCF are:
  - Arbitrate Inter-frame Space (AIFS) Differentiation
    - Different AIFSs instead of the constant distributed IFS (DIFS) used in DCF.
    - Back-off counter is selected from \([1, \text{CW}[AC]+1]\) instead of \([0, \text{CW}]\) as in DCF.
  - Contention Window (CWmin) Differentiation
    - Different values for the minimum/maximum CWs to be used for the back-off time extraction.

Mapping different priority frames to different AC

- Each frame arriving at the MAC with a priority is mapped into an AC as shown in figure below.

Other 802.11 MAC Improvements

- TXOP- Transmission opportunity (TXOP) is an interval of time during which a back-off entity has the right to deliver MSDUs.
  - A TXOP is defined by its starting time and duration
- CFB- In a single TXOP, multiple MSDUs can be transmitted.
  - “Contention Free Burst” (CFB)