Wireless Local Area Networks (WLANs) and Wireless Sensor Networks (WSNs)
Wireless Local Area Networks

- The proliferation of laptop computers and other mobile devices (PDAs and cell phones) created an obvious application level demand for wireless local area networking.
- Companies jumped in, quickly developing incompatible wireless products in the 1990’s.
- Industry decided to entrust standardization to IEEE committee that dealt with wired LANs
  – namely, the IEEE 802 committee!!
IEEE 802 Standards Working Groups

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic</th>
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<tr>
<td>802.1</td>
<td>Overview and architecture of LANs</td>
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<td>802.2</td>
<td>Logical link control</td>
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<td>802.3</td>
<td>Ethernet</td>
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<tr>
<td>802.4</td>
<td>Token bus (was briefly used in manufacturing plants)</td>
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<td>802.5</td>
<td>Token ring (IBM's entry into the LAN world)</td>
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<td>802.6</td>
<td>Dual queue dual bus (early metropolitan area network)</td>
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<td>802.7</td>
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<td>802.12</td>
<td>Demand priority (Hewlett-Packard's AnyLAN)</td>
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<td>802.13</td>
<td>Unlucky number. Nobody wanted it</td>
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<td>802.14</td>
<td>Cable modems (defunct: an industry consortium got there first)</td>
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<td>802.17</td>
<td>Resilient packet ring</td>
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Figure 1-38. The important ones are marked with *. The ones marked with ↓ are hibernating. The one marked with † gave up.
6.4 IEEE 802.11 list of Standards:

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 measurement enhancements
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
IEEE 802.11w - Protected Management Frames
Classification of Wireless Networks

- **Base Station** :: all communication through an *Access Point (AP)* {note hub topology}. Other nodes can be fixed or mobile.
- **Infrastructure Wireless** :: AP is connected to the wired Internet.
- **Ad Hoc Wireless** :: wireless nodes communicate directly with one another.
- **MANETs** (Mobile Ad Hoc Networks) :: ad hoc nodes are mobile.
Wireless LANs

Figure 1-36. (a) Wireless networking with a base station. (b) Ad hoc networking.
The 802.11 Protocol Stack

Figure 4-25. Part of the 802.11 protocol stack.

Note – ordinary 802.11 products are no longer being manufactured.
Wireless Physical Layer

- Physical layer conforms to OSI (five options)
  - 1997: 802.11 infrared, FHSS, DSSS {FHSS and DSSS run in the 2.4GHz band}
  - 1999: 802.11a OFDM and 802.11b HR-DSSS
  - 2001: 802.11g OFDM
- **802.11 Infrared**
  - Two capacities: **1 Mbps or 2 Mbps**.
  - Range is 10 to 20 meters and cannot penetrate walls.
  - Does not work outdoors.
- **802.11 FHSS (Frequency Hopping Spread Spectrum)**
  - The main issue is *multipath fading*.
  - [P&D] *The idea behind spread spectrum is to spread the signal over a wider frequency to minimize the interference from other devices.*
  - 79 non-overlapping channels, each 1 Mhz wide at low end of 2.4 GHz ISM band.
  - The same pseudo-random number generator used by all stations to start the hopping process.
  - Dwell time: min. time on channel before hopping (400msec).
Wireless Physical Layer

- **802.11 DSSS (Direct Sequence Spread Spectrum)**
  - The main idea is to represent each bit in the frame by multiple bits in the transmitted signal (i.e., it sends the XOR of that bit and \( n \) random bits).
  - Spreads signal over entire spectrum using pseudo-random sequence (similar to CDMA see Tanenbaum sec. 2.6.2).
  - Each bit transmitted using an **11-bit** chipping Barker sequence, PSK at 1Mbaud.
  - This yields a capacity of 1 or 2 Mbps.

![Diagram](image)

**Figure 2.37 Example 4-bit chipping sequence**

Computer Networks: Wireless Networks
Wireless Physical Layer

- **802.11a OFDM (Orthogonal Frequency Divisional Multiplexing)**
  - Compatible with European HiperLan2.
  - **54 Mbps** in wider 5.5 GHz band ➞ transmission range is limited.
  - Uses 52 FDM channels (48 for data; 4 for synchronization).
  - Encoding is complex (PSM up to 18 Mbps and QAM above this capacity).
  - E.g., at 54 Mbps 216 data bits encoded into into 288-bit symbols.
  - More difficulty penetrating walls.
Wireless Physical Layer

- **802.11b HR-DSSS (High Rate Direct Sequence Spread Spectrum)**
  - 11a and 11b shows a split in the standards committee.
  - 11b approved and hit the market before 11a.
  - Up to **11 Mbps** in 2.4 GHz band using 11 million chips/sec.
  - Note in this bandwidth all these protocols have to deal with interference from microwave ovens, cordless phones and garage door openers.
  - Range is 7 times greater than 11a.
  - 11b and 11a are incompatible!!
Wireless Physical Layer

• 802.11g OFDM (Orthogonal Frequency Division Multiplexing)
  – An attempt to combine the best of both 802.11a and 802.11b.
  – Supports bandwidths up to 54 Mbps.
  – Uses 2.4 GHz frequency for greater range.
  – Is backward compatible with 802.11b.
In 802.11 wireless LANs, “seizing the channel” does not exist as in 802.3 wired Ethernet.

Two additional problems:
- Hidden Terminal Problem
- Exposed Station Problem

To deal with these two problems 802.11 supports two modes of operation:
- DCF (Distributed Coordination Function)
- PCF (Point Coordination Function).

All implementations must support DCF, but PCF is optional.
Figure 4-26. (a) The hidden terminal problem. (b) The exposed station problem.
The Hidden Terminal Problem

• Wireless stations have transmission ranges and not all stations are within radio range of each other.
• Simple CSMA will not work!
• C transmits to B.
• If A “senses” the channel, it will not hear C’s transmission and falsely conclude that A can begin a transmission to B.
The Exposed Station Problem

• This is the inverse problem.
• B wants to send to C and listens to the channel.
• When B hears A’s transmission, B falsely assumes that it cannot send to C.
Distribute Coordination Function (DCF)

- Uses **CSMA/CA** (**CSMA** with **Collision Avoidance**).
  - Uses one of two modes of operation:
    - **virtual carrier sensing**
    - physical carrier sensing
- The two methods are supported:
  1. **MACAW** (Multiple Access with Collision Avoidance for Wireless) with virtual carrier sensing.
  2. 1-persistent physical carrier sensing.
Wireless LAN Protocols

[Tan pp.269-270]

- **MACA** protocol solved hidden and exposed terminal problems:
  - Sender broadcasts a Request-to-Send (**RTS**) and the intended receiver sends a Clear-to-Send (**CTS**).
  - Upon receipt of a **CTS**, the sender begins transmission of the frame.
  - RTS, CTS helps determine who else is in range or busy (**Collision Avoidance**).
  - Can a collision still occur?
Wireless LAN Protocols

- **MACAW** added ACKs, Carrier Sense, and BEB done per stream and **not** per station.

Figure 4-12. (a) A sending an RTS to B. (b) B responding with a CTS to A.

_Tanenbaum slide_
Virtual Channel Sensing in CSMA/CA

Figure 4-27. The use of virtual channel sensing using CSMA/CA.

- C (in range of A) receives the RTS and based on information in RTS creates a virtual channel busy NAV (Network Allocation Vector).
- D (in range of B) receives the CTS and creates a shorter NAV.
Virtual Channel Sensing in CSMA/CA

What is the advantage of RTS/CTS?

RTS is 20 bytes, and CTS is 14 bytes. MPDU can be 2300 bytes.

• “virtual” implies source station sets the *duration field* in data frame or in RTS and CTS frames.

• Stations then adjust their NAV accordingly!
• High wireless error rates ➞ long packets have less probability of being successfully transmitted.
• Solution: MAC layer fragmentation with stop-and-wait protocol on the fragments.
1-Persistent Physical Carrier Sensing

• The station **senses** the channel when it wants to send.
• If idle, the station transmits.
  – *A station does not sense the channel while transmitting.*
• If the channel is busy, the station defers until idle and then transmits (**1-persistent**).
• Upon collision, wait a *random time* using binary exponential backoff (**BEB**).
Point Coordinated Function (PCF)

• PCF uses a base station to poll other stations to see if they have frames to send.
• No collisions occur.
• Base station sends *beacon frame* periodically.
• Base station can tell another station to *sleep* to save on batteries and base stations holds frames for sleeping station.
**DCF and PCF Co-Existence**

- Distributed and centralized control can co-exist using InterFrame Spacing.
- **SIFS (Short IFS)** :: is the time waited between packets in an ongoing dialog (RTS,CTS,data, ACK, next frame)
- **PIFS (PCF IFS)** :: when no SIFS response, base station can issue beacon or poll.
- **DIFS (DCF IFS)** :: when no PIFS, any station can attempt to acquire the channel.
- **EIFS (Extended IFS)** :: lowest priority interval used to report bad or unknown frame.
Figure 4-29. Interframe Spacing in 802.11.

- SIFS
- PIFS
- DIFS
- EIFS

Control frame or next fragment may be sent here
PCF frames may be sent here
DCF frames may be sent here
Bad frame recovery done here
A Few Wireless Details

- 802.11b and 802.11g use *dynamic rate adaptation* based on ?? (algorithms internal to wireless card at the AP)
  - e.g. for 802.11b choices are: 11, 5.5, 2 and 1 Mbps
- RTS/CTS may be turned off by default [Research has shown that RTS/CTS degrades performance when hidden terminal is not an issue].
- All APs (or base stations) will periodically send a beacon frame (10 to 100 times a second).
  - Beacon frames are also used by DCF to synchronize and handle nodes that want to *sleep*. The AP will buffer frames intended for a sleeping wireless client.
- AP downstream/upstream traffic performance is *asymmetric*.
- Wireless communication quality between two nodes can be asymmetric due to *multipath fading*. 
Wireless Sensor Networks

• Sensors – small devices with low-power transmissions and energy limitations (e.g., battery lifetime is often a **BIG** concern.)

• The main distinction from traditional wireless networks is that the data traffic originates at the sensor node and is sent **upstream** towards the access point (AP) or base station that collects the data.

• While the nature of data collection at the sensor is likely to be **event driven**, for robustness, the generation of sensor packets should be **periodic** if possible.
Tiered Architecture

- Smaller sensors on the leaves of the tree
  1. Motes, TinyOS
  2. Strong ARM PDA running Linux
     - Battery powered, lifetime is critical.
     - Need to be able to adjust transmission power and permit sensor to go to sleep.

- Second Tier
  - AP, base station or video aggregator
  - Data sent from sensors to more powerful computers for storage and analysis.
The Berkeley System

Multiple hop tree topology
The Berkeley System

AP

Sensor

sensor

sensor

sensor

sensor

sensor

Sensor range

AP range

Computer Networks: Wireless Networks