Wi-Fi
- Wi-Fi:
  - name is NOT an abbreviation
  - play on "Hi-Fi" (high fidelity)
- Wireless Local Area Network (WLAN) technology
- WLAN and Wi-Fi often used synonymous
- Typically in 2.4 and 5 GHz bands
- Based on IEEE 802.11 family of standards

IEEE
- IEEE (Institute of Electrical and Electronics Engineers) established the 802.11 Group in 1990. Specifications for standard ratified in 1997.
- Initial speeds were 1 and 2 Mbps.
- IEEE modified the standard in 1999 to include:
  - 802.11b
  - 802.11a
  - 802.11g
  - 802.11n
  - 802.11ac (150Mbps (2.4GHz) and 433Mbps (5GHz or more))
  - 802.11...
IEEE 802.11 Standard

- 802.11 is primarily concerned with the lower layers of the OSI model
- Data Link Layer
  - Logical Link Control (LLC)
  - Medium Access Control (MAC)
- Physical Layer
  - Physical Layer Convergence Procedure (PLCP)
  - Physical Medium Dependent (PMD)

IEEE Standards

- Local wireless networks
  - WLAN 802.11
    - 802.11a → 802.11h
    - 802.11b → 802.11g
- Personal wireless nets
  - WPAN 802.15
    - 802.15.1
    - 802.15.2
- Wireless distribution networks
  - WMAN 802.16 (Broadband Wireless Access)
  - WiMAX
    - 802.20 (Mobile Broadband Wireless Access)
    - 802.16e (addition to 16 for mobile devices)

Wi-Fi Alliance Mission Statement

- Non-profit organization
- Certify the interoperability of products and services based on IEEE 802.11 technology
- Grow the global market for Wi-Fi® CERTIFIED products and services across all market segments, platforms, and applications
- Rigorous interoperability testing requirements
**Certificate & Logo**

- Certificate inside packaging (optional)
- Logo on product packaging (mandatory)
- Helps retailers and consumers

**IEEE 802.11b (obsolete)**

- **2.4 GHz range** (very “busy” part of spectrum)
- **ISM bands**: industrial, scientific and medical (now unlicensed use)
- Prone to interference from other devices (microwave ovens, cordless phones, etc.) and also has security disadvantages
- Limits the number of access points in range of each other to three
- Has 11 channels (3 non-overlapping) and supports rates from 1 to 11 Mbps, but realistically about 4-5 Mbps max
- Range: **100-300ft** (indoors/outdoors)

**Channel Selection (non-overlapping)**

- Width of band: 22MHz
- Channel 1 center: 2412MHz
- Channel center distance: 5MHz (2412, 2417, 2422, 2427, 2432, 2437, ...)
802.11g Standard

- Extension of 802.11b, with the same disadvantages (security and interference).
- Has a shorter range than 802.11b.
- Is backwards compatible with 802.11b so it allows for a smooth transition from 11b to 11g.
- Flexible because multiple channels can be combined for faster throughput.
- Runs at 54 Mbps, but realistically about 20-25 Mbps and about 14 Mbps when b associated.
- Uses frequency division multiplexing

IEEE 802.11a

- Completely different from 11b (& 11g).
- Flexible because multiple channels can be combined for faster throughput and more access points can be co-located.
- Shorter range than 11b.
- Runs in the 5 GHz range, so less interference from other devices.
- Has 12 channels (8 non-overlapping).
- Rates from 6 to 54 Mbps (realistically ~27 Mbps max).
- Uses frequency division multiplexing

OFDM = Orthogonal Frequency Division Multiplexing

- 52 subcarriers (64 in total)
  - 48 data + 4 pilot
  - (plus 12 virtual subcarriers)
  - 312.5 kHz spacing

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subcarrier number

channel center frequency

312.5 kHz

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subcarrier number

channel center frequency

312.5 kHz

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subcarrier number

channel center frequency

312.5 kHz

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IEEE 802.11n & ac

- IEEE 802.11n:
  - MIMO: Multiple Input Multiple Output (multiple antennas)
  - 2.4 & 5GHz
  - Data rates up to 150Mbps (single antenna)
  - Range: 230-820 ft (indoor/outdoor)

- IEEE 802.11ac:
  - 5GHz
  - Data rates of 150 (2.4GHz) – 433 (5GHz) Mbps (single antenna)
  - Range: 115 ft indoor

Infrastructure vs. Ad-Hoc Networks

- Infrastructure network
  - AP: Access Point
  - Wired network
  - Ad-hoc network

802.11 - Architecture of an Infrastructure Network

- Station (STA)
  - Terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - Group of stations using the same radio frequency
- Access Point
  - Station integrated into the wireless LAN and the distribution system
- Portal
  - Bridge to other (wired) networks
- Distribution System
  - Interconnection network to form one logical network (ESS: Extended Service Set) based on several BSS
802.11 - Architecture of an Ad-Hoc Network

- Direct communication within a limited range
- Station (STA): terminal with access mechanisms to the wireless medium
- Independent Basic Service Set (IBSS): group of stations using the same radio frequency

Infrastructure Network

- There is an Access Point (AP), which becomes the hub of a "star topology".
- Any communication has to go through AP!
  - MS1 -> AP -> MS2
- Multiple APs can be connected together and handle a large number of clients (WLAN consisting of multiple APs).
  - MS1 -> AP1 -> AP2 -> MS2
  - AP1 -> AP2 typically wired (Ethernet), otherwise "mesh network"

Roaming

- In an extended service area, a mobile station (MS) can roam from one BSS (Basic Service Set) to another.
- Roughly speaking, the MS keeps checking the beacon signal sent by each AP and selects the strongest one and connects to that AP.
- If the BSSs overlap, the connection will not be interrupted when an MS moves from one set to another. If not, the service will be interrupted.
- Two BSSs coverage areas can largely overlap to increase the capacity for a particular area. If so, the two access points will use different channels (why?).
802.11 – MAC Layer

- 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

802.11 - CSMA/CA Access Method

- 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
802.11 - CSMA/CA Access Method

- 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 - CSMA/CA Access Method

- 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

- Fragmentation
  - RTS with fragmentation
  - CTS with fragmentation
  - ACK with fragmentation
  - NAV (RTS) with fragmentation
  - NAV (CTS) with fragmentation
  - NAV (ACK) with fragmentation
Synchronization using Beacons

- Beacon interval (20ms – 1s)
- Access point busy
- Beacon frame
- Value of the timestamp

Diagram showing the synchronization process with beacons.