15-441 / 15-641: Computer Networking

Lecture 25: Wireless

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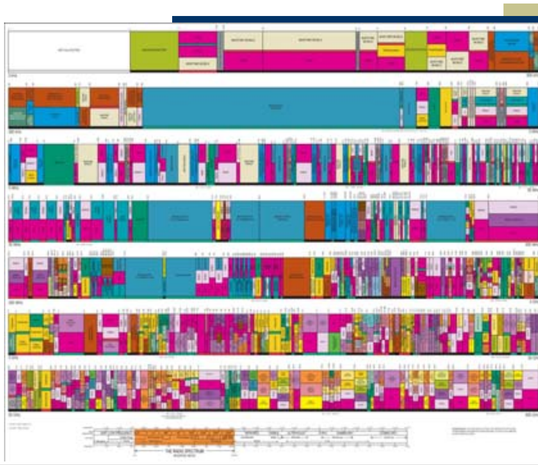
Overview

- Link layer challenges and WiFi
- Cellular

Spectrum Allocation in US

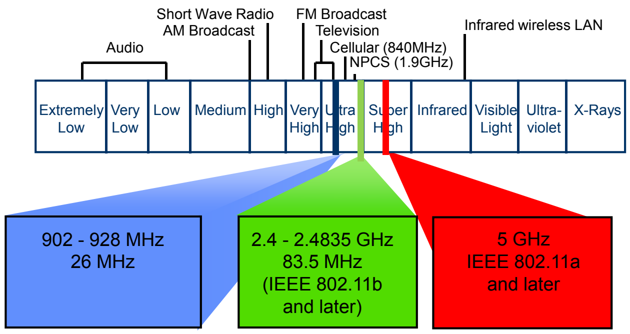


Some IEEE 802.11 Standards

- 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: 3 channels : 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 : significant improvements in throughput
- IEEE 802.11ac
  - Support for multi-user MIMO
- IEEE 802.11ad
  - WiFi in the 60 GHz band

Frequency Bands

- Industrial, Scientific, and Medical (ISM) bands
- Unlicensed, 22 MHz channel bandwidth



IEEE 802.11 Overview

- Adopted in 1997 with goal of providing
  - Access to services in wired networks
  - High throughput
  - Highly reliable data delivery
  - Continuous network connection, e.g. while mobile
- The protocol defines
  - MAC sublayer
  - MAC management protocols and services
  - Several physical (PHY) layers: IR, FHSS, DSSS, OFDM
- Wi-Fi Alliance is industry group that certifies interoperability of 802.11 products

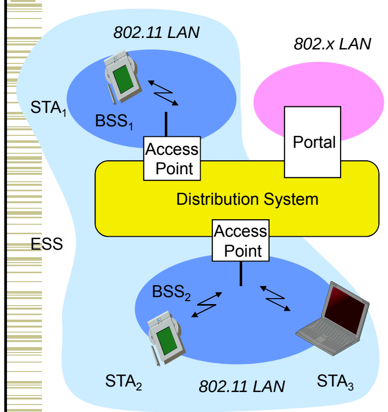
Features of 802.11 MAC protocol

- Supports MAC functionality
  - Addressing
  - CSMA/CA
- Error detection (FCS)
- Error correction (ACK frame)
- Flow control: stop-and-wait
- Fragmentation (More Frag)
- Collision Avoidance (RTS-CTS)

Infrastructure and Ad Hoc Mode

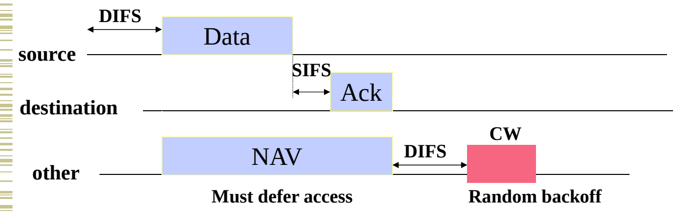
- Infrastructure mode: stations communicate with one or more access points which are connected to the wired infrastructure
  - What is deployed in practice
- Two modes of operation:
  - Distributed Control Functions - DCF ← Our Focus
  - Point Control Functions – PCF
  - PCF is rarely used - inefficient
- Alternative is "ad hoc" mode: multi-hop, assumes no infrastructure
  - Rarely used, e.g. military
  - Hot research topic!

802.11: Infrastructure Mode



- Station (STA)
  - terminal with access mechanisms to the wireless medium and radio contact to the access point
- Access Point
  - station integrated into the wireless LAN and the distribution system
- Basic Service Set (BSS)
  - group of stations using the same AP
- Portal
  - bridge to other (wired) networks
- Distribution System
  - interconnection network to form one logical network (ESS: Extended Service Set) based on several BSS

DCF mode transmission without RTS/CTS

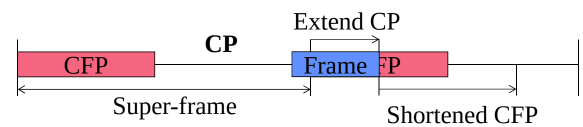


Exponential Backoff

- Force stations to wait for random amount of time to reduce the chance of collision
  - Backoff period increases exponential after each collision
  - Similar to Ethernet
- Also used when the medium is sensed as busy:
  - Wait for medium to be idle for a DIFS (DCF IFS) period
  - Pick random number in contention window (CW) = backoff counter
  - Decrement backoff timer until it reaches 0
    - But freeze counter whenever medium becomes busy
  - When counter reaches 0, transmit frame
  - If two stations have their timers reach 0; collision will occur;
- After every failed retransmission attempt:
  - increase the contention window exponentially
  - $2^i - 1$ starting with CW_{min} up to CW_{max} e.g., 7, 15, 31, …

Now What about PCF?

- IEEE 802.11 combines random access with a “taking turns” protocol
  - DCF (Distributed Coordination Mode) – Random access
    - CP (Contention Period): CSMA/CA is used
  - PCF (Point Coordination Mode) – Polling
    - CFP (Contention-Free Period): AP polls hosts
- Basestation can control who access to medium
  - Can offer bandwidth guarantees



PCF Operation Overview

- PC – Point Coordinator
  - Uses polling – eliminates contention
  - Polling list ensures access to all registered stations
  - Over DCF but uses a PIFS instead of a DIFS – gets priority
- CFP – Contention Free Period
  - Alternate with DCF
- Periodic Beacon – contains length of CFP
  - NAV prevents transmission during CFP

Association Management

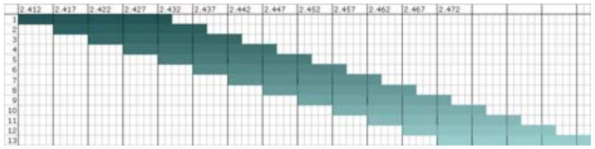
- Stations must associate with an AP before they can use the wireless network
  - AP must know about them so it can forward packets
  - Often also must authenticate
- Association is initiated by the wireless host – involves multiple steps:
  1. Scanning: finding out what access points are available
  2. Selection: deciding what AP (or ESS) to use
  3. Association: protocol to "sign up" with AP – involves exchange of parameters
  4. Authentication: needed to gain access to secure APs – manyoptions possible
- Disassociation: station or AP can terminate association

IEEE 802.11 Family

Protocol	Release Data	Freq.	Rate (typical)	Rate (max)	Range (indoor)
Legacy	1997	2.4 GHz	1 Mbps	2Mbps	?
802.11a	1999	5 GHz	25 Mbps	54 Mbps	~30 m
802.11b	1999	2.4 GHz	6.5 Mbps	11 Mbps	~30 m
802.11g	2003	2.4 GHz	25 Mbps	54 Mbps	~30 m
802.11n	2008	2.4/5 GHz 20/40 MHz	200 Mbps	600 Mbps	~50 m
802.11ac	2013	5 GHz 20→160 MHz	100s Mbps per user	1.3 Gbps	~50 m
802.11ad	2016	60 GHz	Gbps	7 Gbps	Short - room

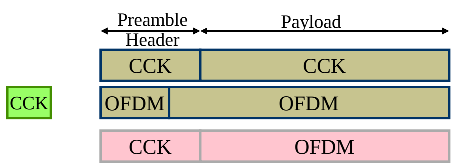
802.11b Channels

- In the UK and most of EU: 13 channels, 5MHz apart, 2.412 – 2.472 GHz
- In the US: only 11 channels
- Each channel is 22MHz
- Significant overlap
- Non-overlapping channels are 1, 6 and 11
- 1, 2, 5.5 and 11 Mbps rates using DSSS technology

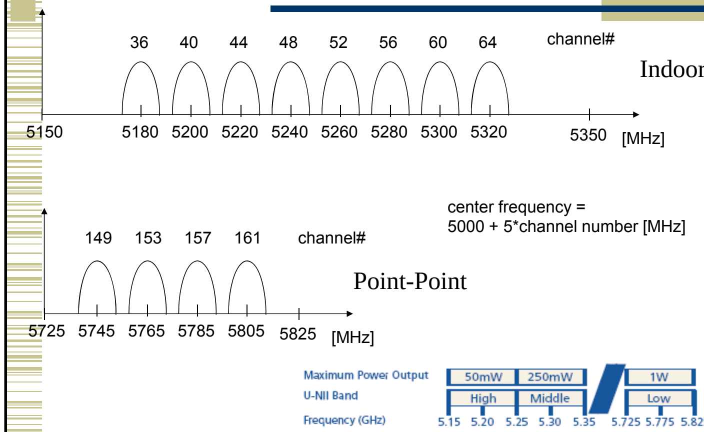


Going Faster: 802.11g

- 802.11g basically extends of 802.11b
  - Use the same technology DSSS for old rates (1,2, 5.5, 11)
  - Uses OFDM technology for new rates (6 Mbs and up)
- 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

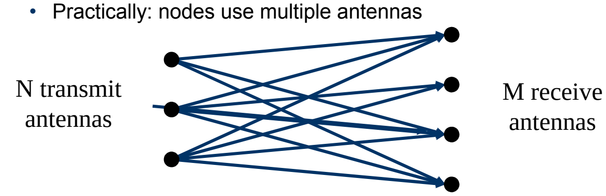


802.11a Discussion

- Uses “OFDM” in the 5.2 and 5.7 GHz bands
  - OFDM is optimized for wireless channels: fights multi-path effects and frequency selective fading
- What are the benefits of 802.11a compared with 802.11b?
  - Greater bandwidth (up to 54Mb)
    - 54, 48, 36, 24, 18, 12, 9 and 6 Mbs
  - Less potential interference (5GHz)
  - More non-overlapping channels
  - Less contention due to competition
- But does not provide interoperability with 802.11b, as 802.11g does

802.11n uses MIMO to further Increase Transmission Rates

- “Multiple-input and multiple-output
  - Practically: nodes use multiple antennas



- Can increase throughput significantly since you have multiple parallel channels between the nodes
  - Use signal processing on sender and receiver to overcome the effects of mutual interference

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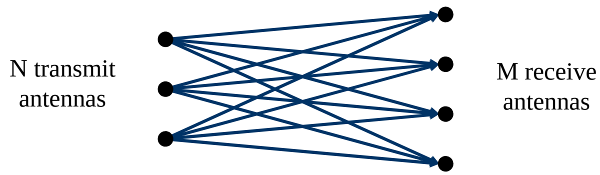
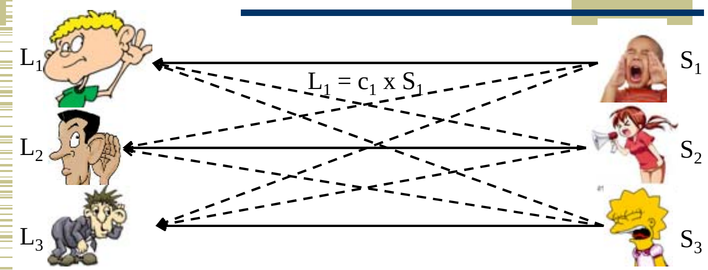
MIMO
Multiple In Multiple Out



- N x M subchannels
- Fading on channels is largely independent
  - Assuming antennas are separate ½ wavelength or more
- Combines ideas from spatial and time diversity, e.g. 1 x N and N x 1
- Very effective if there is no direct line of sight
  - Subchannels become more independent

Conceptually Simple!



$L_1 = a_1 \times S_1 + b_1 \times S_2 + c_1 \times S_3$

$L_2 = a_2 \times S_1 + b_2 \times S_2 + c_2 \times S_3$

$L_3 = a_3 \times S_1 + b_3 \times S_2 + c_3 \times S_3$

$L = C \times S$

$C^{-1} \times L = C^{-1} \times C \times S$

$C^{-1} \times L \approx S$

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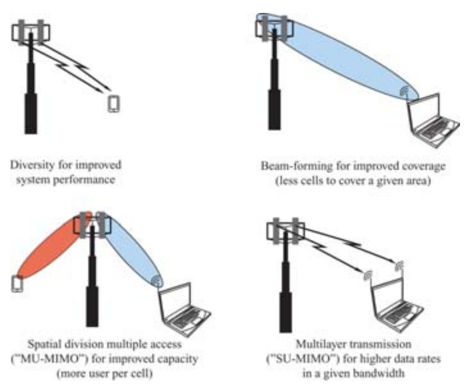
Mechanisms Supported by MIMO



And the Letter Zoo Continues

- 802.11ac uses "MU-MIMO" to further increase throughput in the network
  - Key idea: basestation can send a single signal that combines packets for several receivers
  - Receivers can extract "their" packet from the signal
  - Think: MIMO but receiving antennas are distributed over multiple nodes
- 802.11ad operates in the 60 GHz band
  - Lots of spectrum available → lots of bandwidth
  - But range is limited and must have line of sight
    - It is never easy

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Overview

- Link layer challenges and WiFi
- Cellular

Cellular versus WiFi

	Cellular	WiFi
Spectrum	Licensed	Unlicensed
Service model	Provisioned "for pay"	Unprovisioned "free" – no SLA
MAC services	Fixed bandwidth SLAs	Best effort no SLAs

Implications WiFi

	WiFi	Implication
Spectrum	Unlicensed	No control – open, diverse access
Service model	Unprovisioned "free"	No guarantees maximize throughput, fairness
MAC services	Best effort no SLAs	???

Implications Cellular

	Cellular	Implication
Spectrum	Licensed	Provider has control over interference
Service model	Provisioned "for pay"	Can and must charge + make commitments
MAC services	Fixed bandwidth SLAs	TDMA, FDMA, CDMA; access control

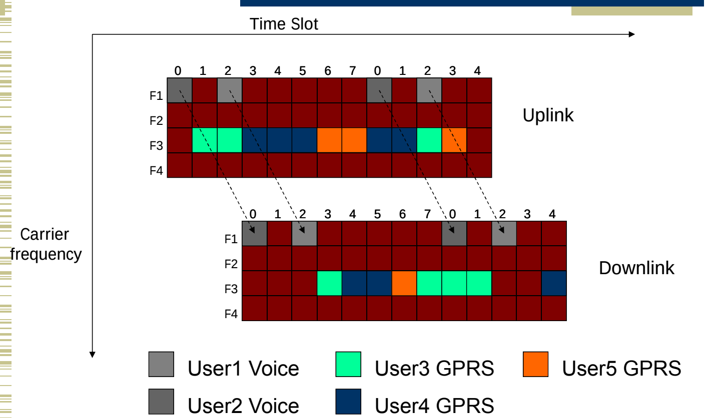
The Advent of Cellular Networks

- Mobile radio telephone system was based on:
  - High power transmitter/receivers
  - Could support about 25 channels
  - in a radius of 80 Km
- To increase network capacity:
  - Multiple low-power transmitters (100W or less)
  - Small transmission radius -> area split in cells
  - Each cell with its own frequencies and base station
  - Adjacent cells use different frequencies
  - The same frequency can be reused at sufficient distance

Cellular Standards

- 1G systems: analog voice
  - Not unlike a wired voice line (without the wire)
  - Pure FDMA: each voice channel gets two frequencies
- 2G systems: digital voice
  - Many standards
  - Example: GSM - FDMA/TDMA, most widely deployed, 200 countries, a billion people
- 2.5G systems: voice and data channels
  - Example: GPRS - evolved from GSM, packet-switched, 170 kbps (30-70 in practice)
  - Use some of the “voice slots” for data

GPRS Radio Interface



Cellular Standards

- 3G: voice (circuit-switched) and data (packet-switched)
  - Several standards
  - Most use Code Division Multiple Access (CDMA)
- 4G: 10 Mbps and up, seamless mobility between different cellular technologies
  - LTE the dominating technology
  - Completely packet switched, including voice
  - Uses Orthogonal Frequency Division Multiplexing (OFDM) for increased robustness wrt. frequency selective fading and mobility

How to Increase Capacity?

- Adding new channels
  - More spectrum – spectrum auctions
- Frequency borrowing
  - More flexible sharing of channels across cells
- Sectoring antennas
  - Split cell into smaller cells using directional antennas – 3-6 per cell
- Microcells, picocells, …
  - Antennas on top of buildings, lamp posts
  - Form micro cells with reduced power
  - Good for city streets, roads and inside buildings