15-441
15-641 : Computer Networking

Lecture 25: Wireless

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Fall 2015

www.cs.cmu.edu/~prs/15-441-F15

Overview

- Internet mobility
- TCP over noisy links
- Link layer challenges and WiFi
- Cellular

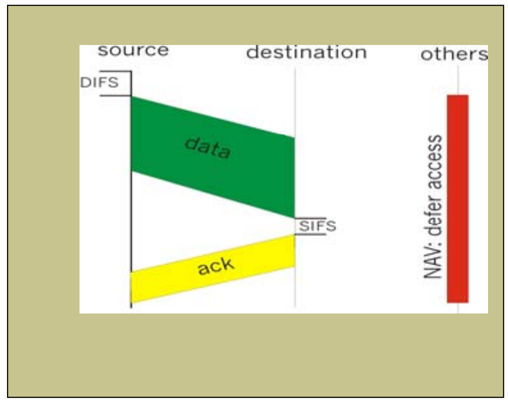
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender

- If sense channel idle for **DIFS (Distributed Inter Frame Space)** then transmit entire frame (no collision detection)
- If sense channel busy then binary backoff

802.11 CSMA receiver:

- If received OK return ACK after **SIFS (Short IFS)**
- ACK is needed due to lack of collision detection
- SIFS < DIFS: priority



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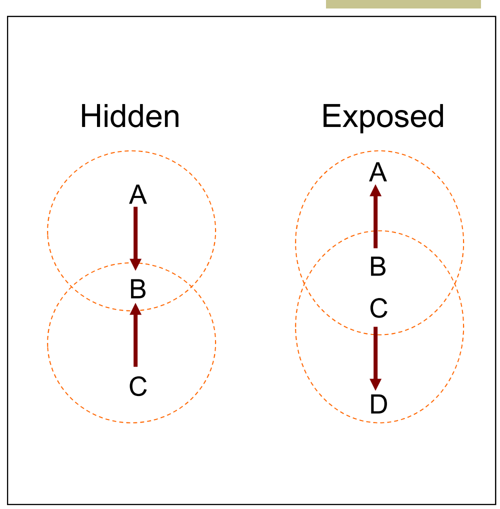
But CSMA Does Not (Always) Work

- Carrier Sense problems
- Relevant contention at the receiver, not sender
  - Hidden terminal
  - Exposed terminal



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Collision Avoidance Mechanisms

- Problem:
  - Two nodes, hidden from each other, transmit complete frames to base station
  - Wasted bandwidth for long duration !
- Solution:
  - Small reservation packets
  - Nodes track reservation interval with internal "network allocation vector" (NAV)

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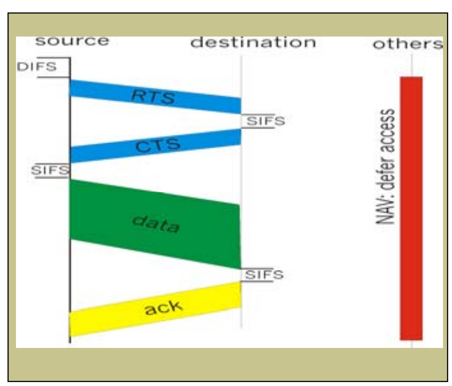
Collision Avoidance: RTS-CTS Exchange

- Explicit channel reservation
  - Sender: send short RTS: request to send
  - Receiver: reply with short CTS: clear to send
  - CTS reserves channel for sender, notifying (possibly hidden) stations
- RTS and CTS short:
  - collisions less likely, of shorter duration
  - end result similar to collision detection
- Avoid hidden station collisions
- Not widely used
  - Overhead is too high
  - Not a serious problem in typical deployments



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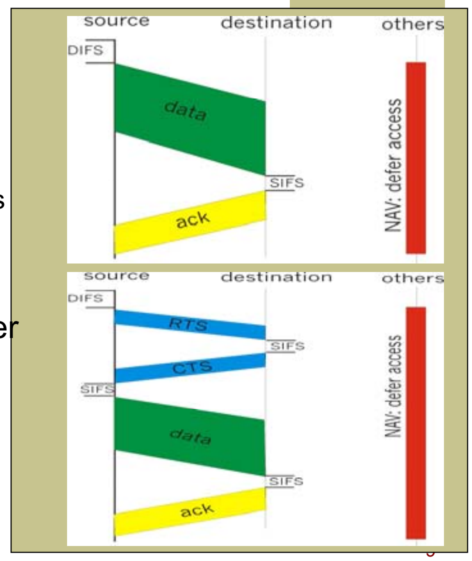
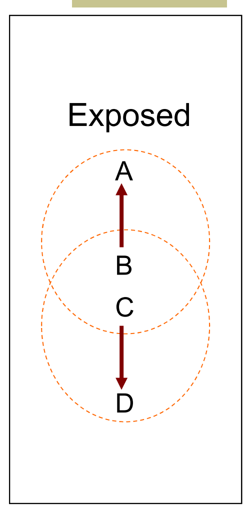
IEEE 802.11 MAC Protocol

- RTS/CTS implemented using **NAV**: Network Allocation Vector
  - Also used with data packets
- 802.11 frame has transmission time field
- Others (hearing data) defer access for NAV time units



How About Exposed Terminal?

- Can increase the “carrier-sense” threshold
  - Signal needs to be stronger before node defers
- Could this create other problems?
- Exposed terminals are difficult to deal with
  - Even hard to detect them!



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Some IEEE 802.11 Standards

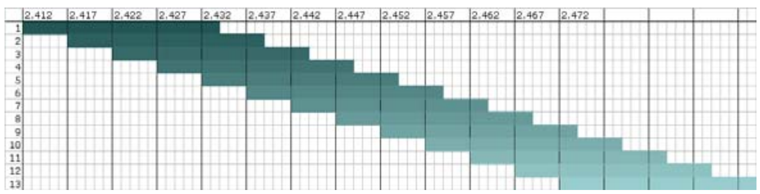
- IEEE 802.11a
  - PHY Standard : 8 channels : up to 54 Mbps : some deployment
- IEEE 802.11b
  - PHY Standard : 3 channels : up to 11 Mbps : widely deployed.
- IEEE 802.11d
  - MAC Standard : support for multiple regulatory domains (countries)
- IEEE 802.11e
  - MAC Standard : QoS support : supported 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 : standardization expected late 2008

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	200 Mbps	600 Mbps	~50 m

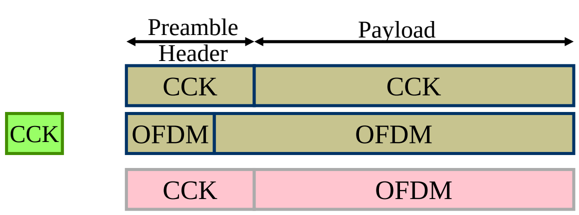
802.11b Channels

- 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 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 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

Beyond CSMA: Scheduled Access

- What's wrong with random access?

802.11 Power Save Mode

- Core idea: Client sleeps, AP buffers data until client wakes up.
  - Beacons include traffic information map (TIM)
  - (awake) clients request their packets
  - What about broadcast / multicast?

802.11 Power Save Mode

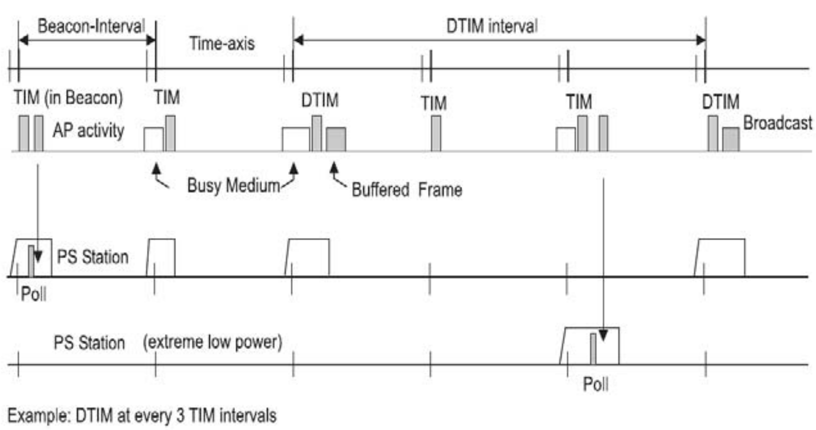
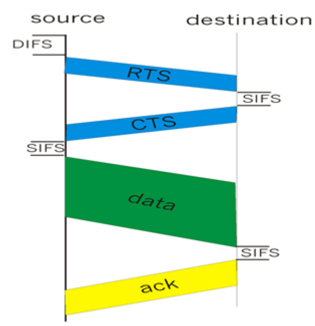


Figure 67—Infrastructure power management operation (no PCF operating)

802.11 Prioritized Access

- Backoff-based contention:
  - Whoever goes first, wins
- DIFS -> AIFS
  - =SIFS + AIFSN[AC]*st
- CWmax, CWmin



Default EDCA Parameters for each AC

AC	CWmin	CWmax	AIFSN	Max TXOP
Background (AC_BK)	15	1023	7	0
Best Effort (AC_BE)	15	1023	3	0
Video (AC_VI)	7	15	2	3.008ms
Voice (AC_VO)	3	7	2	1.504ms
Legacy DCF	15	1023	2	0

Overview

- Internet mobility
- TCP over noisy links
- Link layer challenges and WiFi
- Cellular

Cellular versus WiFi

	Cellular	WiFi
Spectrum		
Service model		
MAC services		

Implications WiFi

	WiFi	Implication
Spectrum		
Service model		
MAC services		

Implications Cellular

	Cellular	Implication
Spectrum		
Service model		
MAC services		

Overview

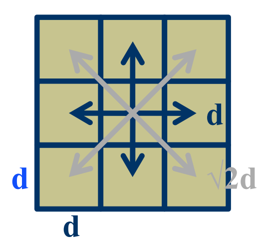
- Cellular design
- Frequency Reuse
- Capacity and Interference
- Elements of a cellular network
- How does a mobile phone take place?
- Paging
- Handoff
- Frequency Allocation
- Traffic Engineering

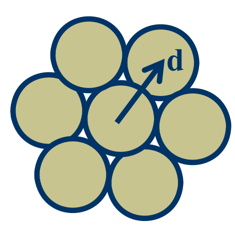
The Advent of Cellular Networks

- 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

Cellular Network Design Options

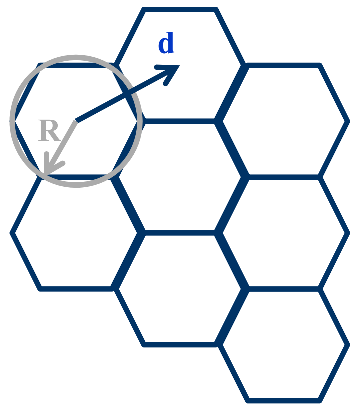
- Simplest layout
  - Adjacent antennas not equidistant – how do you handle users at the edge of the cell?
- Ideal layout model
  - Although we know signals travel whatever way they feel like
  - Hard to work with!



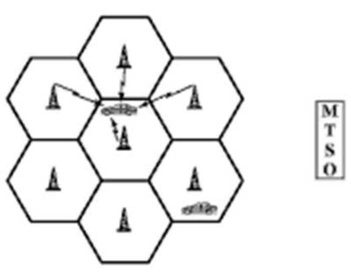


The Hexagonal Pattern

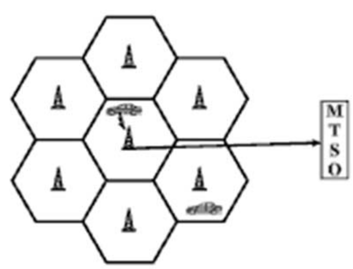
- A hexagon pattern is easier to use and can provide equidistant access to neighboring cell towers
- d = √3R
- In practice, variations from ideal due to topological reasons
  - Signal propagation, buildings, foiliage, …
  - Tower placement constraints



Call progression

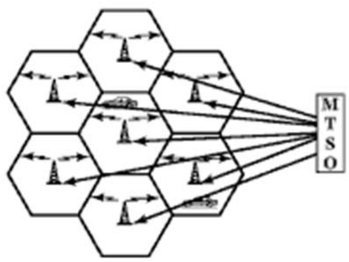


(a) Monitor for strongest signal

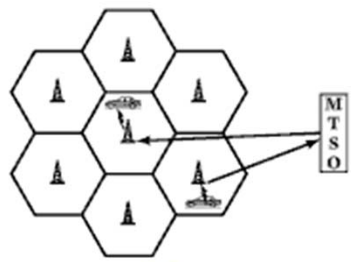


(b) Request for connection

Call progression

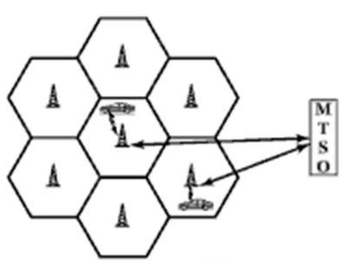


(c) Paging

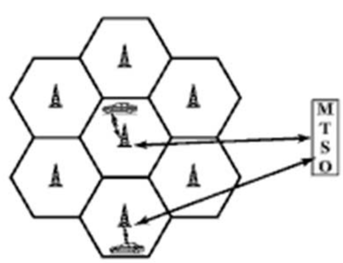


(d) Call accepted

Call progression

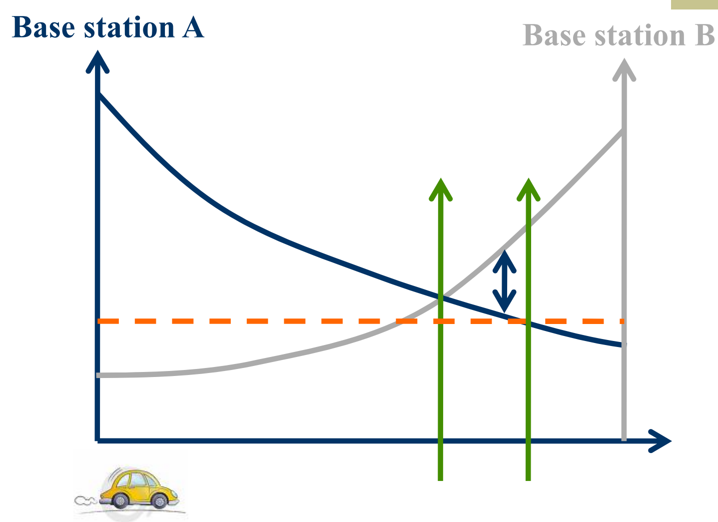


(e) Ongoing call



(f) Handoff

Handoff between 2 cells

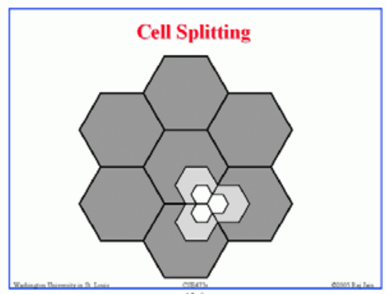


How to Increase Capacity?

- Adding new channels
- Frequency borrowing
- Sectoring antennas
- Microcells
  - Antennas on top of buildings, even lamp posts
  - Form micro cells with reduced power
  - Good for city streets, roads and inside buildings

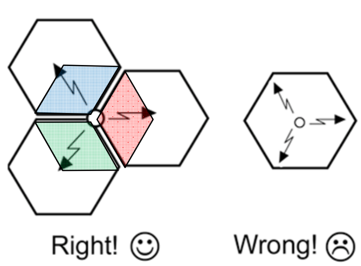
Cell splitting

- Cell size ~ 6.5-13Km, Minimum ~ 1.5Km
- Requires careful power control and possibly more frequent handoffs for mobile stations
- A radius reduction by a factor of F reduces the coverage area and increases the required number of base a factor of F^2



Cell sectoring

- Cell divided into wedge shaped sectors
- 3-6 sectors per cell, each with own channel set



Cellular Standards

- 1G systems: analog voice
  - Not unlike a wired voice line (without the wire)
- 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)

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
  - Packet switched
  - Uses Orthogonal Frequency Division Multiplexing (OFDM) for increased robustness wrt. frequency selective fading and mobility