Wireless Communication Links

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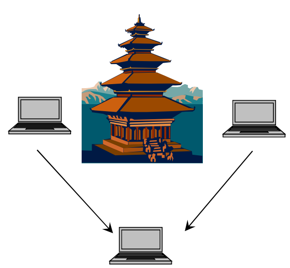
Types of Wireless Links

- IEEE 802.11 wireless LAN (WiFi)
  - Range up to 100 meters; speed up to 54Mbps
  - Intend to function as Ethernet without wires
  - Longer range (tens of kilometers) in point-to-point mode
- IEEE 802.15 Bluetooth
  - Shorter range (~10 meters); slower speed (up to 3Mbps)
  - But less power; easier setup
  - Appropriate for simple appliances: phone, game console
- Cellular wireless access, IEEE 802.16 WiMAX
  - Longer distance, but typically lower rate than WiFi

Wireless Media Access Control

- Collision if 2 or more nodes transmit at same time
- Can we use CSMA/CD?
  - hidden terminal problem ⇨ carrier sense and collision detection don't work
- Repair collision detection:
  - add acknowledgement
- Repair carrier sense:
  - carrier sense with random backoff
  - carrier probing



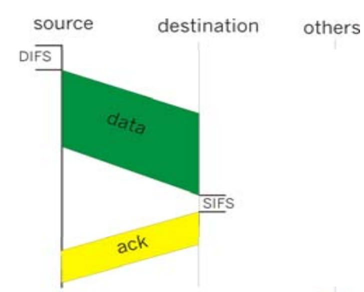
802.11 Media Access Control

802.11 sender

- if sense channel idle for DIFS sec; then transmit entire frame (no collision detection)
- if sense channel busy; then wait for it become idle and then backoff with random delay (collision avoidance)

802.11 receiver

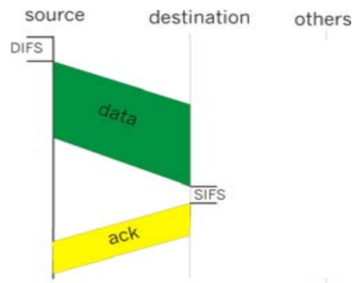
- if received OK; return ACK after SIFS



Inter-Frame Spacing

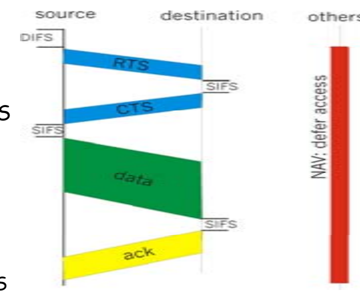
Short inter-frame spacing:
- give transmitter time to switch to receive mode and get ready to decode

Distributed inter-frame spacing:
- DIFS>SIFS, why?



Better Collision Avoidance through Carrier Probing

- sender transmits short RTS (request to send) packet:
  - indicates transmission and its duration
- receiver replies with short CTS (clear to send) packet
  - notifying (possibly hidden) nodes
- nodes hearing either RTS or CTS will defer access
- Collision of RTS/CTS?
  - less likely with short RTS/CTS



802.11 Media Access Control

- CSMA/CA (Collision Avoidance)
- Repair collision detection:
  - add acknowledgement
- Repair insufficient carrier sense:
  - carrier sense with random backoff
  - carrier probing
- Inter-frame spacing
  - prioritize different types of frames

802.11 Sub-standards

- 802.11b
  - Up to 11Mbps; frequency range 2.4-2.85 GHz
- 802.11a
  - Up to 54Mbps; frequency range 5.1-5.8 GHz – shorter range or higher power consumption
- 802.11g
  - Up to 54Mbps; frequency range 2.4-2.85 GHz
- 802.11n
  - Even higher rate; still in the midst of standardization

Power and Range

- Power is of paramount importance in wireless devices
  - Many devices are on battery power
  - Power usage is directly related to range
- Friis transmission equation:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

  - P_r and P_t are received power and transmission power
  - G_r and G_t are antenna gains at receiving and transmission sides
  - R is the range
  - λ is the signal wavelength

⇨ Quadratic relation between transmission power and range

Power/Range-to-Signal Frequency

- Friis transmission equation:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

  - P_r and P_t are received power and transmission power
  - λ is the signal wavelength
- Wavelength relates directly to signal frequency
  - What relation?
  - assume electro-magnetic signal at speed of light
    2.4GHz ⇨ 12.5cm; 5GHz ⇨ 6cm
  - 5GHz signals require more than four times transmission power, or reaches less than half of the range

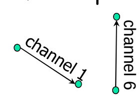
Wireless Channel

- 802.11 operates in specific frequency band
- at 2.4GHz band: 11 channels (5MHz sep.) centered at:
  - 2.412GHz (channel 1)
  - 2.417GHz (channel 2)
  - … …
  - 2.462GHz (channel 11)
- Each channel operates at a width of 22MHz (11MHz on each side of the center)
  - How many interference-free channels we have?
  - Channel 1 interferes with channels 2/3/4/5, but not 6

http://en.wikipedia.org/wiki/File:2.4_GHz_Wi-Fi_channels_%28802.11b,g_WLAN%29.svg

Utilization of Multiple Channels

- Utilization of multiple channels reduce interference



- In an infrastructured wireless network
  - Multiple access points (at different channels) can be put near each other without interference

  ⇨ good coverage and strong signal strength

A Case Study

- Channel usage at 6th floor CSB:
  - three department APs (channels 1/6/11); three university APs (channels 1/6/11)
- Outside this classroom (measurement by Amal):
  - CS, channel 1, power 0.000020uw
  - CS, channel 6, power 0.000016uw
  - CS, channel 11, power 1.3uw
  - UR, channel 1, power 0.0040uw
  - UR, channel 6, power 0.000020uw
  - UR, channel 11, power 0.00032uw
- Outside 703, strong power from two channel-6 APs

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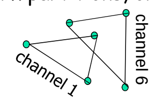
Channel Hopping in Ad Hoc Networks

- Use multiple channels in a wireless ad hoc networks
  - Problem: network partitions, one at each channel



  - Nodes dynamically hop between multiple channels
  - Challenge: coordinate sender/receiver at same channel
- [Bahl et al. 2004]
  - Each node maintains a channel hopping schedule; nodes learn each other's schedule
  - A sender adjust its channel to match receiver
  - Issues: What if the receiver wants to send to somebody else and change its channel? How about broadcast?

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Partially Overlapped Channels

[Mishra et al. 2006]

- More channels if we allow partial interference
  - Channels 1 and 6 are interference-free
  - Channels 1 and 4 have partial interference
- I-factor: amount of overlap between two channels
  - Measurement: P_i/P_j
    Given a signal sent at channel j, P_j is the received power at channel j, P_i is the received at channel i.
  - ⇨ I-factor ≈ 0.1 for 3-channel separation
- Range:
  - range ratio = 0.32 for 3-channel separation [error in the paper?]
  - ⇨ If same channel signal disappears into noise at 100M, then 32M distance is enough for 3-channel separation

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Power/Range-to-Antenna Gain

- Friis transmission equation:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

  - P_r and P_t are received power and transmission power
  - G_r and G_t are antenna gains at receiving and transmission sides
- Antenna gain [wikipedia] – the ratio between:
  - the radiation intensity of an antenna in a given direction
  - the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions
- Point-to-point WiFi can go very long distance

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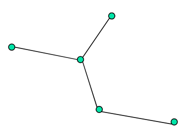
Long-Distance Point-to-Point WiFi

- Particularly suited for under-developed, rural areas
  - Local-cost WiFi equipment
  - Use unlicensed frequency spectrum and require no base stations (unlike cellular networks)
- [Raman and Chebrolu 2005/2007]
  - Wireless mesh networks formed over long-distance WiFi in rural India



- Less inter-node interference
- Mixed send/receive over multiple links at a node causes unacceptable interfere
- New wireless MAC protocol (2P): coordination to prevent mixed send/receive

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Long-Distance Point-to-Point WiFi

[Patra et al 2007]

- Long latency over long distance ⇨ transmit/acknowledge turns into inefficient stop-and-wait
  - Solution: bulk transmissions with a single acknowledgement
- High loss rate due to external WiFi interference (long-distance WiFi interfere with regular short-distance WiFi near receiver)
  - Solution: repeated retransmission or redundancy coding

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