

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

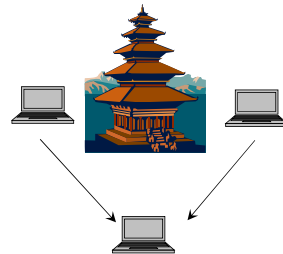
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Wireless Media Access Control

- 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



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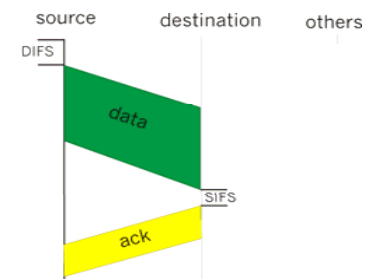
802.11 Media Access Control

802.11 sender

- if sense channel idle for **DIFS** (distributed inter-frame space); 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** (short inter-frame space)



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Inter-Frame Spacing

Short inter-frame spacing:

- give transmitter time to switch to receive mode and get ready to decode

Distributed inter-frame spacing:

- $DIFS > SIFS$
 - Higher priority for ACK than data
 - Why?

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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?
 - collision leads to less channel time loss with short RTS/CTS

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802.11 Media Access Control

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

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802.11 Sub-standards

- 802.11b
 - Up to 11Mbps; frequency band 2.4-2.85 GHz
- 802.11a
 - Up to 54Mbps; frequency band 5.1-5.8 GHz – shorter range or higher power consumption
- 802.11g
 - Up to 54Mbps; frequency band 2.4-2.85 GHz
- 802.11n
 - Up to 300Mbps, both frequency bands

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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_t and G_r are antenna gains at receiving and transmission sides
 - R is the range
 - λ is the signal wavelength
- ⇒ Quadratic relation between transmission power and range

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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

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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 are there?
 - 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

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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

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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 Fahad):
 - 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 network
 - Problem:** network partitions, one at each channel
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- 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 adjusts its channel to match receiver
 - Issues: What if the receiver wants to send to somebody else and has changed 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 .
 - \Rightarrow I-factor ≈ 0.1 for 3-channel separation
- Range:
 - range ratio = 0.32 for 3-channel separation
 - \Rightarrow 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 (several kms or more)

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A Case Deployment



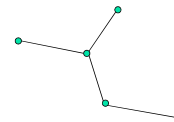
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Long-Distance Point-to-Point WiFi

- Particularly well suited for under-developed, rural areas
 - Low-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



- Little 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 \Rightarrow 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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