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

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)
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?

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

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

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
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:
  \[ \frac{P_r}{P_t} = G_rG_t \left( \frac{\lambda}{4\pi R} \right)^2 \]
  - \( P_r \) 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
  - \( \lambda \) is the signal wavelength
  \( \Rightarrow \) Quadratic relation between transmission power and 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 are there?
  - Channel 1 interferes with channels 2/3/4/5, but not 6

Power/Range-to-Signal Frequency
- Friis transmission equation:
  \[ \frac{P_r}{P_t} = G_rG_t \left( \frac{\lambda}{4\pi R} \right)^2 \]
  - \( P_r \) and \( P_t \) are received power and transmission power
  - \( \lambda \) is the signal wavelength
- Wavelength relates directly to signal frequency
  - What relation?
    - assume electro-magnetic signal at speed of light
      - 2.4GHz \( \Rightarrow \) 12.5cm; 5GHz \( \Rightarrow \) 6cm
    - 5GHz signals require more than four times transmission power, or reaches less than half of the range

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
  \( \Rightarrow \) good coverage and strong signal strength

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

Channel Hopping in Ad Hoc Networks

- Use multiple channels in a wireless ad hoc network
- 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 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?

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 $j$, $P_i$ is the received power at channel $j$, $P_j$ is the received at channel $i$.
  - $I$-factor = 0.1 for 3-channel separation
- Range:
  - range ratio = 0.32 for 3-channel separation
  - If same channel signal disappears into noise at 100M, then 32M distance is enough for 3-channel separation

Power/Range-to-Antenna Gain

- Friis transmission equation:
  $$ \frac{P_r}{P_t} = G_r G_t \left( \frac{\lambda}{4\pi R} \right)^2 $$
  - $P_r$ 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)
**A Case Deployment**

![Image of deployment setup]

**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

  ![Network diagram]

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

**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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