**Direct Link Communication II: Wireless Media**

**Motivation**

- WLAN explosion
- cellular telephony: 3G/4G
  → cellular providers/telcos in the mix
- self-organization by citizens for local access
- large-scale hot spots: Starbucks, airport lounges, trains, university/enterprise campuses, etc.
- integral part of global IP Internet
  → where it’s happening

→ good news: good old radio technology!
→ bad news: radio technology #$%&!
Basics of Wireless Communication

Use electromagnetic waves in wireless media (air/space) to transmit information.

- directed signal propagation: e.g., directed antenna or IR (infrared)

- undirected signal propagation: e.g., omni-directional antenna

  → mainly: microwaves

  → e.g., 2.4 GHz for IEEE 802.11b WLAN

  → also, microwave oven, cordless phones, etc.
Key differences with wired communication:

• Increased exposure to interference and noise
• Same frequency spectrum must be shared among all users
  \[\rightarrow\] lack of physical shielding
• Inter-user interference cannot be localized at switch
  \[\rightarrow\] cannot use buffering
  \[\rightarrow\] problem for QoS (e.g., VoIP)
• Signal propagation and variation is more complex
  
  $\rightarrow$ attenuation

  $\rightarrow$ refraction, absorption, reflection, diffraction

  $\rightarrow$ multi-path fading

  $\rightarrow$ mobility

Good sides: mobility, low deployment cost, and frequency reuse

  $\rightarrow$ once tasted, difficult to turn back

  $\rightarrow$ key technology for LAN connectivity
Electromagnetic spectrum (logarithmic scale):

- **Radio Wave**: 1 Hz–1 GHz
- **IR**, **Visible**, **UV**: 1 GHz–1 THz
- **Microwave**: 1 GHz–1 THz
- **Gamma**: 10^18 Hz–10^21 Hz
- **Optical Fiber**: ∼200 THz; 25 THz bandwidth

→ RF: 9 kHz–300 GHz
→ Microwave: 1 GHz–1 THz
→ Wireless: concentration ∼0.8 GHz–6 GHz
→ Optical fiber: ∼200 THz; 25 THz bandwidth
Miscellaneous spectrum allocations (U.S.) & uses:

→ FCC (Federal Communications Commission)

- Voice: 300 Hz–3300 Hz
- AM Radio: 0.535 MHz–1.7 MHz
- FM Radio: 88 MHz–108 MHz
- TV: 174 MHz–216 MHz, 470 MHz–825 MHz

→ audio (FM), video (AM)

- GPS (Global Positioning System): 1.2276 GHz–1.57542 GHz

→ DS-CDMA

→ 24 satellites (DoD), 10900 miles

→ navigation service: trilateration
• Cellular telephone: 824 MHz–849 MHz (upstream), 869 MHz–894 MHz (downstream)
  → AMPS: FDM, analog
  → GSM: TDMA, digital
  → IS-95: CDMA, digital

• PCS: 1.85 GHz–1.99 GHz
  → CDMA, TDMA
• WLAN: IEEE 802.11b 2.4 GHz–2.4835 GHz
  \[\rightarrow\] DSSS or FHSS with CSMA/CA
• WLAN: Bluetooth 2.4 GHz–2.4835 GHz
  \[\rightarrow\] FH with TDD
• WLAN: IEEE 802.11a 5.725 GHz–5.850 GHz
  \[\rightarrow\] OFDM with CSMA/CA
• Satellite: C-band 3.7 GHz–4.2 GHz (downlink), 5.925 GHz–6.425 GHz (uplink)
  → FDMA/TDMA

• Satellite: Ku-band 11.7 GHz–12.2 GHz (downlink), 14 GHz–14.5 GHz (uplink)

• Many other frequency bands
  → cf. FCC chart
Signal propagation and power

Free space loss:

- transmitting antenna: signal power $P_{\text{in}}$
- receiving antenna: signal power $P_{\text{out}}$
- distance: $d$
- frequency: $f$

\[
P_{\text{out}} \propto P_{\text{in}} \frac{1}{d^2 f^2}
\]

$\rightarrow$ quadratic decrease in distance & frequency
Design implications:

- effective coverage limited by distance

  → SNR: signal-to-noise ratio

  → SIR: signal-to-interference ratio

→ pros & cons?
- low power output decreases cell size
  \[\rightarrow\] increased battery life
  \[\rightarrow\] enables frequency reuse
  \[\rightarrow\] more antennas required
  \[\rightarrow\] handoff coordination overhead
  \[\rightarrow\] e.g., I65 from Lafayette to Indy
Cellular networks

Hexagonal cells:

\[ \rightarrow \text{both affect tiling of the plane} \]

\[ \rightarrow \text{why hexagonal?} \]

Frequency reuse: adjacent cells do not use common carrier frequency.

\[ \rightarrow \text{avoid interference} \]

\[ \rightarrow \text{how many frequencies are required?} \]
For example, using seven frequencies:

→ why does it work?

→ in general, coloring problem
4-coloring of U.S. map:

\[\rightarrow \text{ Y. Kanada, Y. Sato; Univ. of Tokyo}\]
CS Building:

First floor frequency reuse:
Second floor frequency reuse:

Ground floor frequency reuse:
Non-uniform covering:

\[ \rightarrow \text{directional antenna} \]

\[ \rightarrow \text{non-uniform density} \]
Non-uniform frequency allocation:

→ total carrier frequency budget: 35

→ frequency borrowing

uniform frequency allocation

non-uniform frequency allocation
Cell sizes:

- Macrocell: < 35 km; < 10 W
- Microcell: < 1 km; < 3 W
- Picocell: < 100 m; < 100 mW
- Satellite footprint: e.g., 30–40 % (GEO); 4000 km (LEO)

\[\rightarrow\] e.g., GEO satellites at 35786 km

\[\rightarrow\] e.g., LEO satellites at \(\sim\)1000 km
Note: 2-way propagation delay (RTT)

\[ 2 \times \frac{35786}{300000} \approx 0.24 \text{ sec} \]

\[ \rightarrow \text{ optimistic based on closest distance} \]

\[ \rightarrow \text{ RTT can be: } \sim 500 \text{ msec} \]