Wireless Communication

Unique features that differentiate from wired communication

Ubiquitous technology:

- Wireless communication explosion

  → initially driven by WLAN

  → took many by surprise

  → high-speed cellular Internet access

- Cellular telephony: 5G, 4G

  → 5G (formerly 4G): stationary 1 Gbps, mobile 100 Mbps

  → 3G phased out

  → cellular, telcos, data providers: in the same mix

  → all-in-one handhelds

- NFC and RFID

  → low bandwidth apps

- wireless PAN (personal area networks): tens of feet or less

  → e.g., get rid of wires: wireless USB, UWB, Bluetooth (802.15)

  → home and automobile entertainment systems

  → high (and low) bandwidth apps

- special purpose wireless: GPS, satellite radio, digital TV, 60 GHz wireless networks

- LoRa

  → long-range (tens of miles), low power

  → 902–928 MHz (US)

Wireless signal propagation

→ NIC: air interface

- directed signal propagation: directed antenna or IR (infrared)

  → target range: 10+ GHz; e.g., 60 GHz

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

  → target range: 100 MHz–10 GHz

- increased exposure to interference and noise

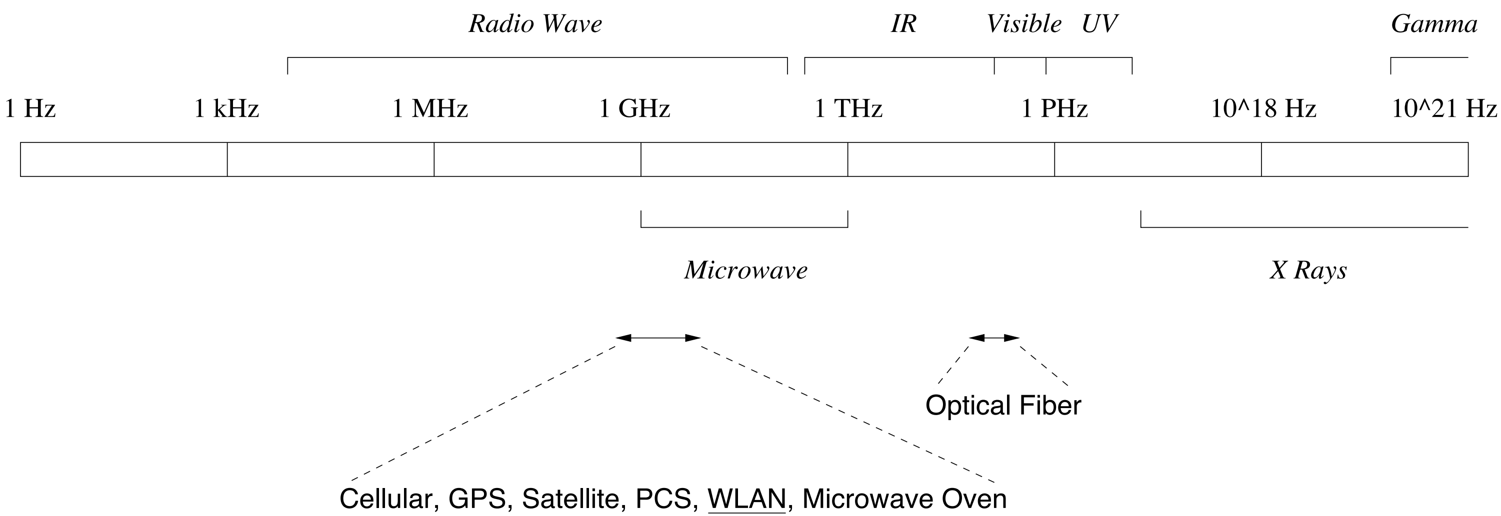
  → lack of physical shielding

  → fundamentally different from wires

- inter-user interference cannot be localized at switch

  → potential problem for QoS-sensitive apps

Electromagnetic spectrum (logarithmic scale):



$\longrightarrow$ RF: 9 kHz–300 GHz

$\longrightarrow$ Microwave: 1 GHz–1 THz

$\longrightarrow$ Wireless: concentration $\sim$0.8 GHz–6 GHz

$\longrightarrow$ Optical fiber: THz

Miscellaneous spectrum allocations (U.S.):

→ FCC (Federal Communications Commission)

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

  → analog TV spectrum: VHF, UHF

  → audio (FM), video (AM)
- Cellular: 824–849 MHz, 869–894 MHz, 1.85–1.99 GHz
- GPS (Global Positioning System): 1.2276–1.57542 GHz

  → CDMA

  → ∼30 satellites (DoD), 10900 miles

  → navigation service: trilateration

- Satellite: Ka-band 18.3–18.8 Ghz, 19.7–20.2 GHz (downlink), 27.5–31 GHz (uplink)
- Satellite: Ku-band 11.7–12.2 Ghz (downlink), 14–14.5 GHz (uplink)
- Satellite: C-band 3.7–4.2 GHz (downlink), 5.925–6.425 GHz (uplink)

  → TDMA/FDMA based
- Many other frequency bands

  → cf. FCC chart

  → www.ntia.doc.gov/osmhome/allochrt.pdf

Characteristic Features

Free space loss:

- transmitting antenna: signal power P_{snd}
- receiving antenna: signal power P_{rcv}
- distance: d
- carrier frequency: f

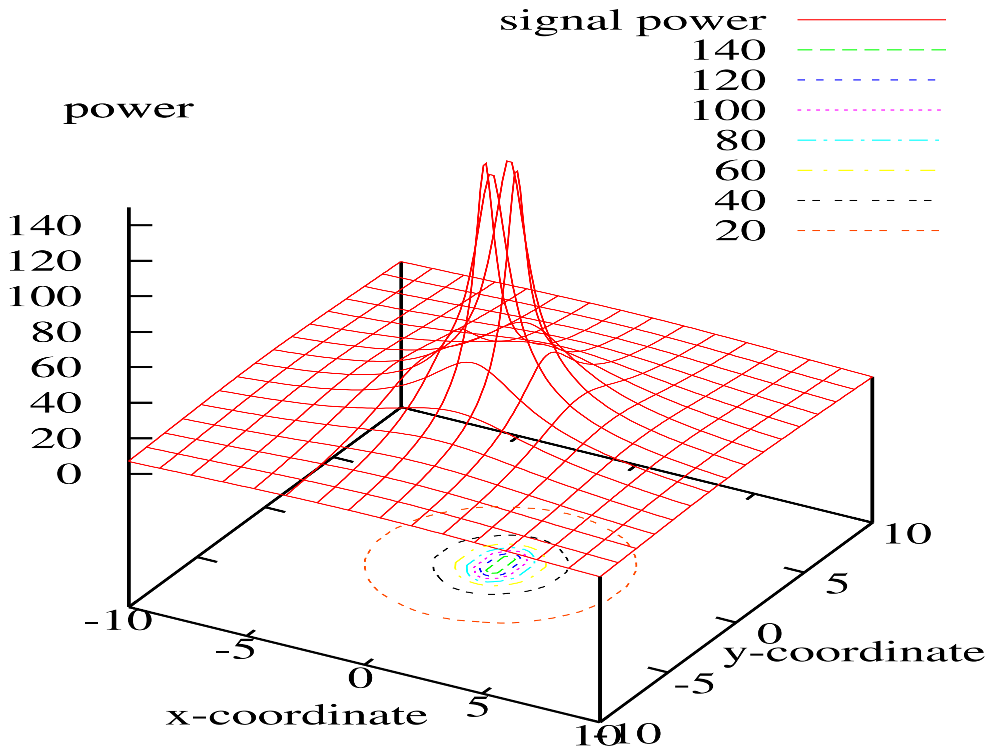
$$P_{\text{rcv}} \propto P_{\text{snd}} \frac{1}{d^2 f^2}$$

$\rightarrow$ quadratic decrease in distance

$\rightarrow$ quadratic decrease in frequency

$\rightarrow$ real-world: more complicated

Power profile in 2-D space:



→ sender located at center

Real-world illustration: www.cs.purdue.edu/∼park/cs536/pics

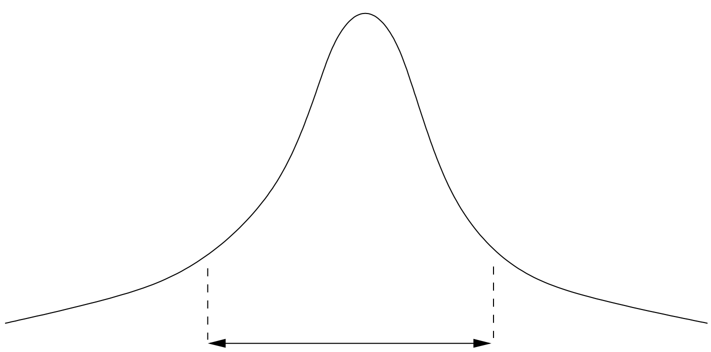
Design implications:

- coverage limited primarily by distance

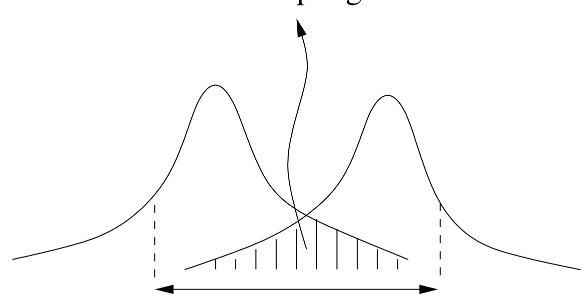
  $\rightarrow$ the farther away, the weaker the signal

  $\rightarrow$ impacts SNR

- design choice: single high-power antenna or multiple low-power antennae



spatial coverage by one high–power antenna



spatial coverage by two low–power antennas

- low-power:

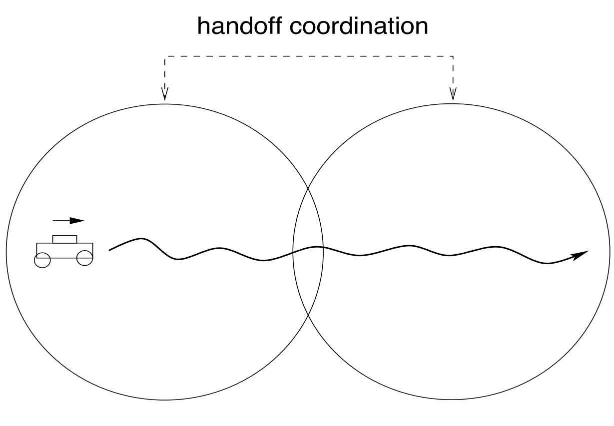
  → decreases cell size: bad for coverage

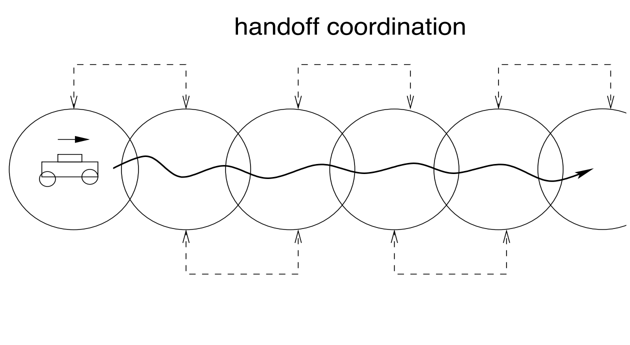
  → but good because less crowding

  → also, enables frequency reuse: similar to radio stations

  → bad: more base stations required

  → also creates handoff coordination overhead (e.g., I65)

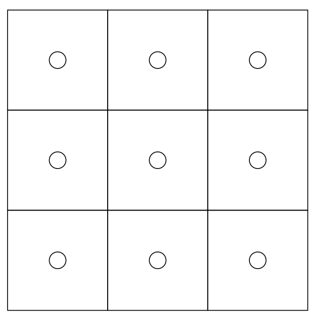


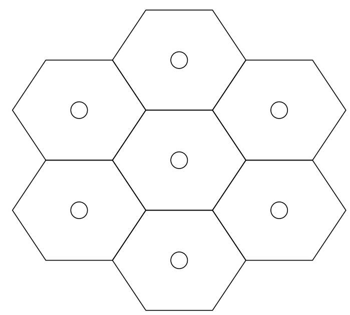


Cellular networks:

→ network of wireless base stations

Can view as:





→ tiling of the plane (also called tesselation)

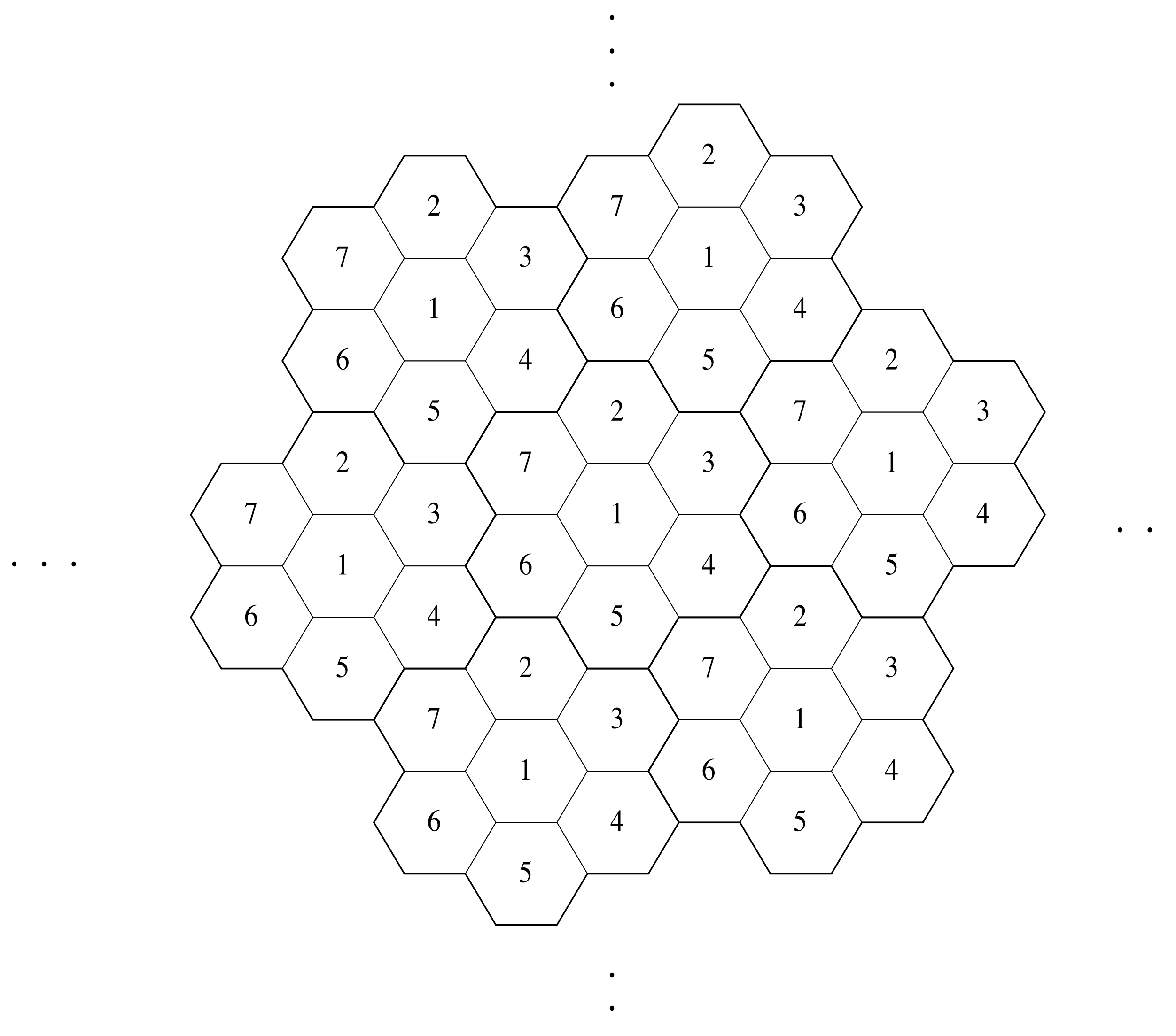
→ hexagonal

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

→ avoid interference

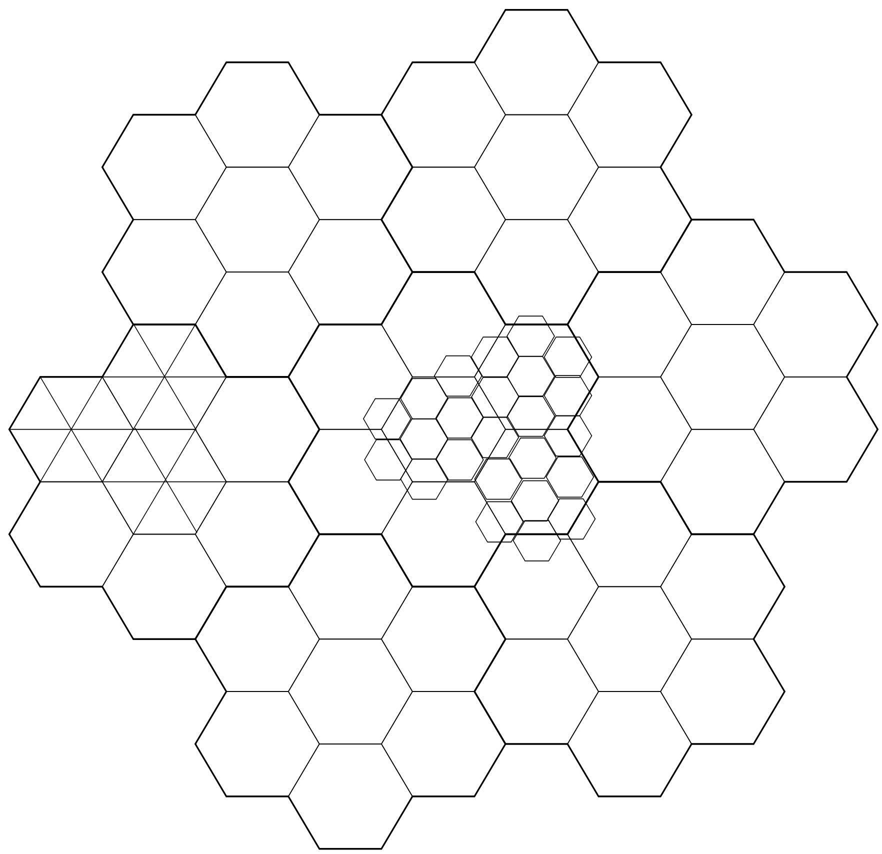
→ how many frequencies are required?

For example, using seven frequencies:



⟶ in general, coloring problem

Non-uniform covering:



→ directional antenna: triangular shape (e.g., cone)

→ non-uniform density (e.g., city center, stadium)

→ microcell, picocell, femtocell

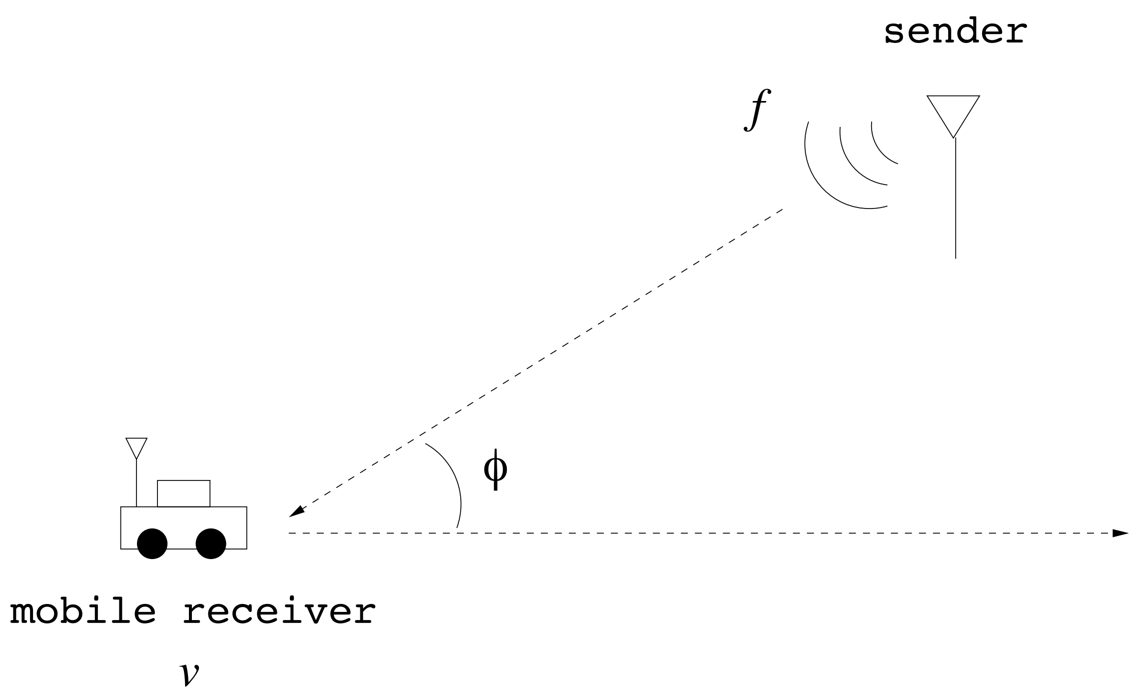
Impact of mobility on signal:

- Doppler effect
- fading

Doppler frequency shift:

Set-up:

- mobile (e.g., car, train, pedestrian) travels in straight line at speed v mph
- sender transmits data on carrier frequency f Hz
- angle between mobile and sender is θ



$\rightarrow$ frequency experienced by mobile is not f

$\rightarrow$ distorted version of f, f'

Distorted frequency under Doppler effect:

$$f' = f + f\left(\frac{v}{\text{SOL}}\cos\phi\right)$$

Impact:

- $\phi = 0$ deg: head-on

  $\rightarrow$ frequency shift: highest

- $\phi = 180$ deg: opposite direction

  $\rightarrow$ frequency shift: lowest

- $\phi = 90$ deg: right angle

  $\rightarrow$ least distortion

Ex.: carrier frequency $f = 1.8$ GHz

$\rightarrow$ 4 mph: 10 Hz, 40 mph: 100 Hz

$\rightarrow$ similar to noise

$\rightarrow$ may use FEC to protect against bit flips