Wireless Communication

Unique features that differentiate from wired communication

Current Trend

- wireless communication explosion

  → initially driven by WLAN

  → took many by surprise

  → large component of Internet access

  → hot spots everywhere

  → also content streaming (e.g., Netflix), VoIP

- cellular telephony: 5G and enhancements

  → 4G: stationary 1 Gbps, mobile 100 Mbps

  → deferred to 5G

Key Features

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

$\longrightarrow$ NIC: also called air interface

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

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

  → approximate

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

  → target range: 100 MHz–10 GHz

Main differences compared to wired communication:

- increased exposure to interference and noise

  → lack of physical shielding

  → fundamentally different from wires

  → e.g., reason behind 3-4 addresses in WiFi frame header

- inter-user interference cannot be localized at switch

  → Ethernet evolution from bus to switch can't happen

  → potential problem for QoS (e.g., VoIP, multimedia streaming, IPTV)

Since information is inherently exposed:

- bad for networking: interference
- bad for security: sniffing
- additional features with negative influence on performance

Convenient network access:

→ supercedes other concerns

→ enables today's ubiquitously connected world

→ driving force

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

  → ∼30 satellites (DoD), 10900 miles

  → navigation service: trilateration
- Cellular: 824–849 MHz, 869–894 MHz, 1.85–1.99 GHz, other ranges

  → OFDMA

  → 4G, 3.5G: TDMA/FDMA, CDMA

- 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 of wireless communication:

First, signal propagation in wireless media: outdoors

→ free space

Free space loss:

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

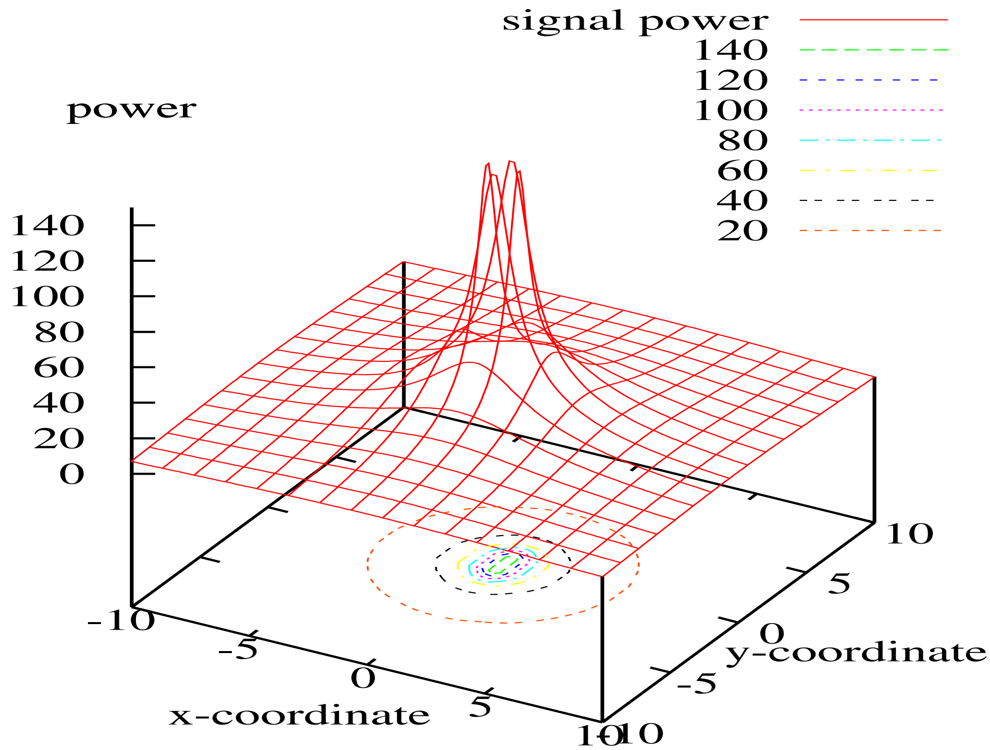
$$P_{\mathrm{rcv}} \propto P_{\mathrm{snd}} \frac{1}{d^2 f^2}$$

→ quadratic decrease in distance

→ quadratic decrease in frequency

→ real-world: more complicated

Power profile in 2-D space:



→ sender located at center

Real-world scenarios: www.cs.purdue.edu/∼park/cs422/pics

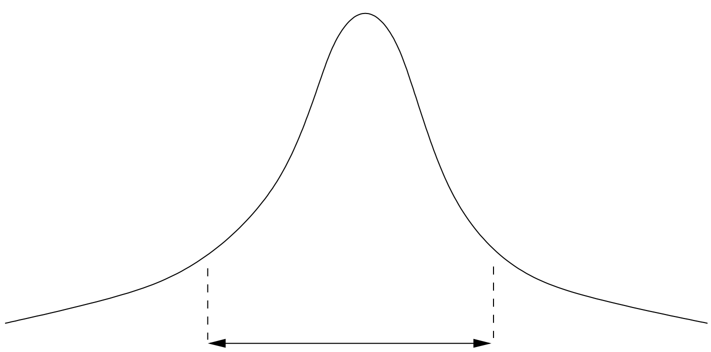
Design implications:

- coverage limited primarily by distance

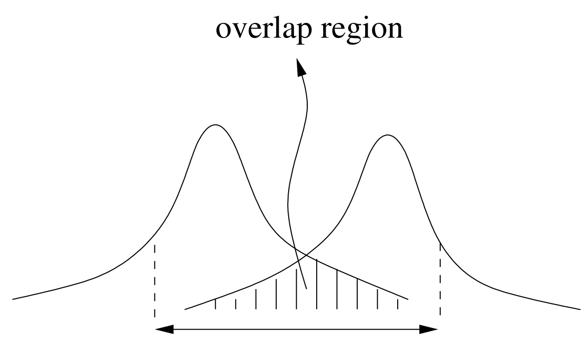
  → the farther away, the weaker the signal

  → impacts SNR (signal-to-noise ratio)

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

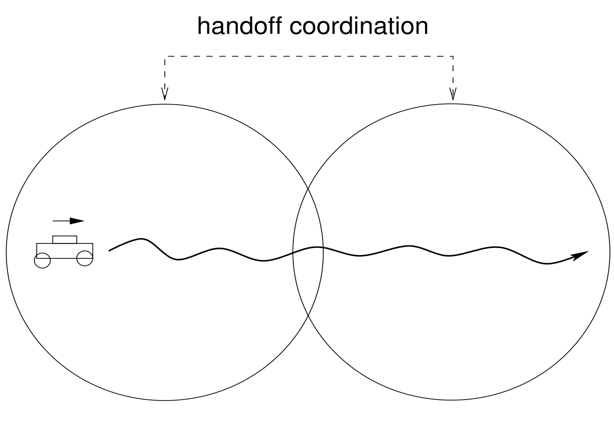


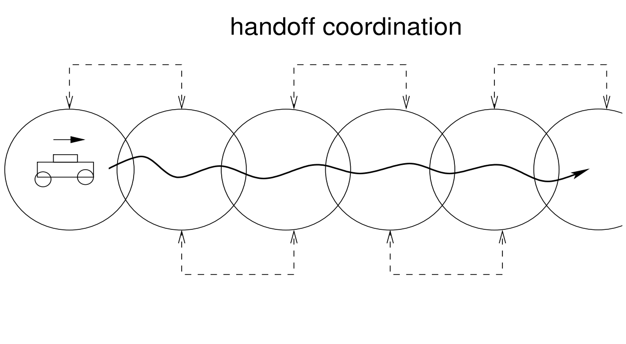
spatial coverage by one high−power antenna



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)



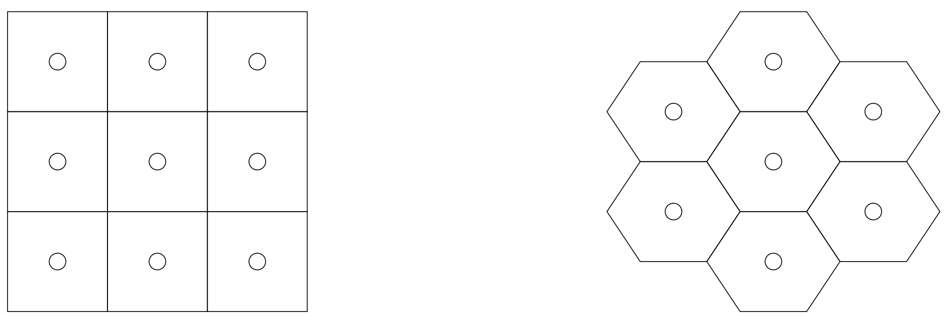


Cellular networks:

→ network of wireless base stations

→ provide coverage

Can view as:



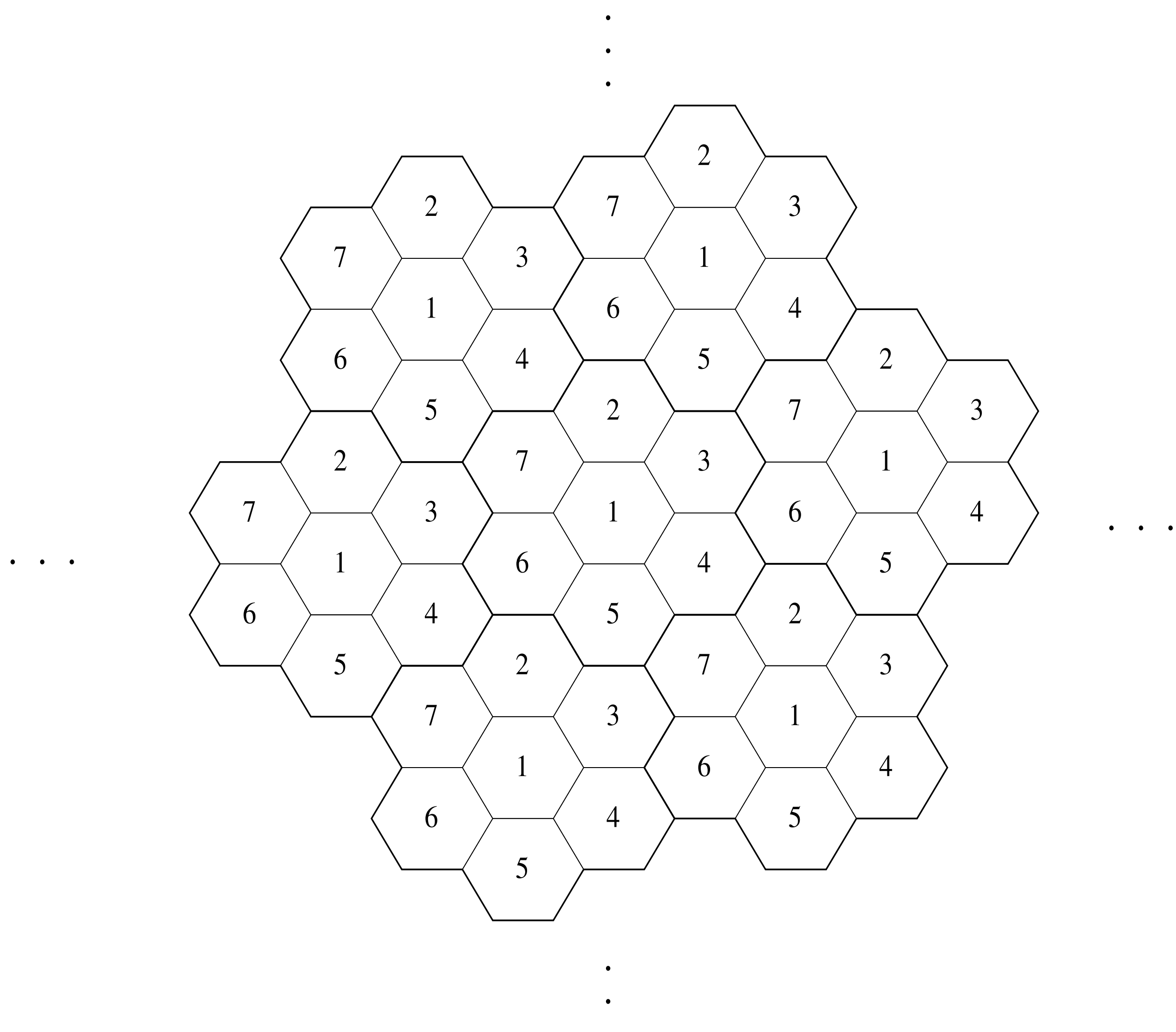
→ tiling of the plane (also called tesselation)

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

→ avoid interference

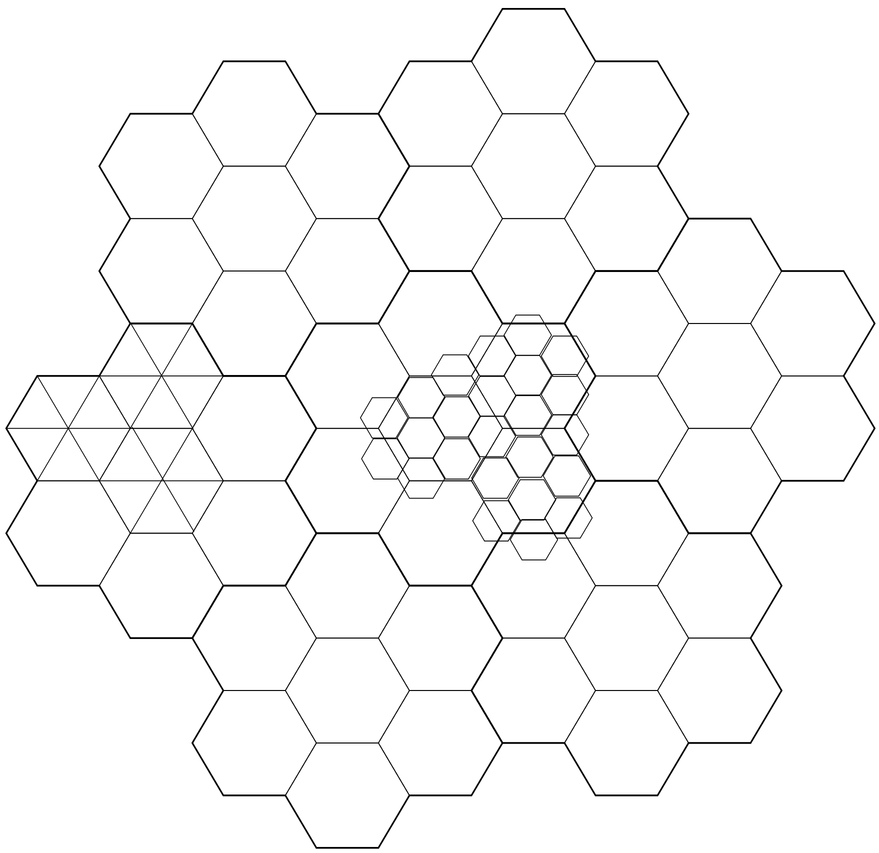
→ how many frequencies are required?

For example, using seven frequencies:



$\longrightarrow$ in general, coloring problem

Non-uniform covering:



→ directional antenna: triangular shape (like cone)

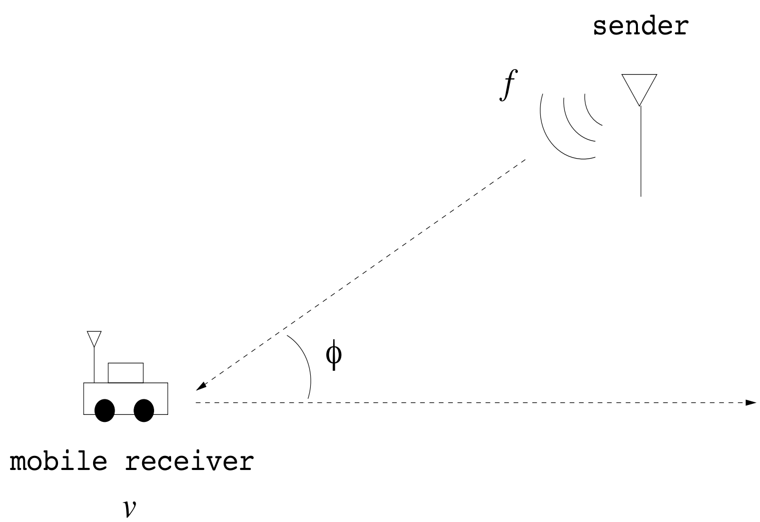
→ non-uniform density (e.g., city center, stadium)

→ microcell, picocell, femtocell

Impact of mobility: 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



→ frequency experienced by mobile is not f but distorted version of f: call it f'

Distorted frequency under Doppler effect:

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

Hence:

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

  $\rightarrow$ frequency experienced: fastest

- $\phi = 180$ deg: "going in opposite direction"

  $\rightarrow$ frequency experienced: slowest

- $\phi = 90$ deg: "at right angle"

  $\rightarrow$ least distortion

Ex.: carrier frequency $f = 1.8$ GHz

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

$\rightarrow$ may result in bit flips

Impact of fading:

→ signal strength varies by location of mobile

→ e.g., city environment with tall buildings and no direct line of sight between sender and receiver

What happens: received signal is comprised of bounced off copies (i.e., echos) from buildings and other reflective obstructions

→ called multi-path propagation

Thus: mobile's signal strength fluctuates

- distance
- Doppler effect
- fading

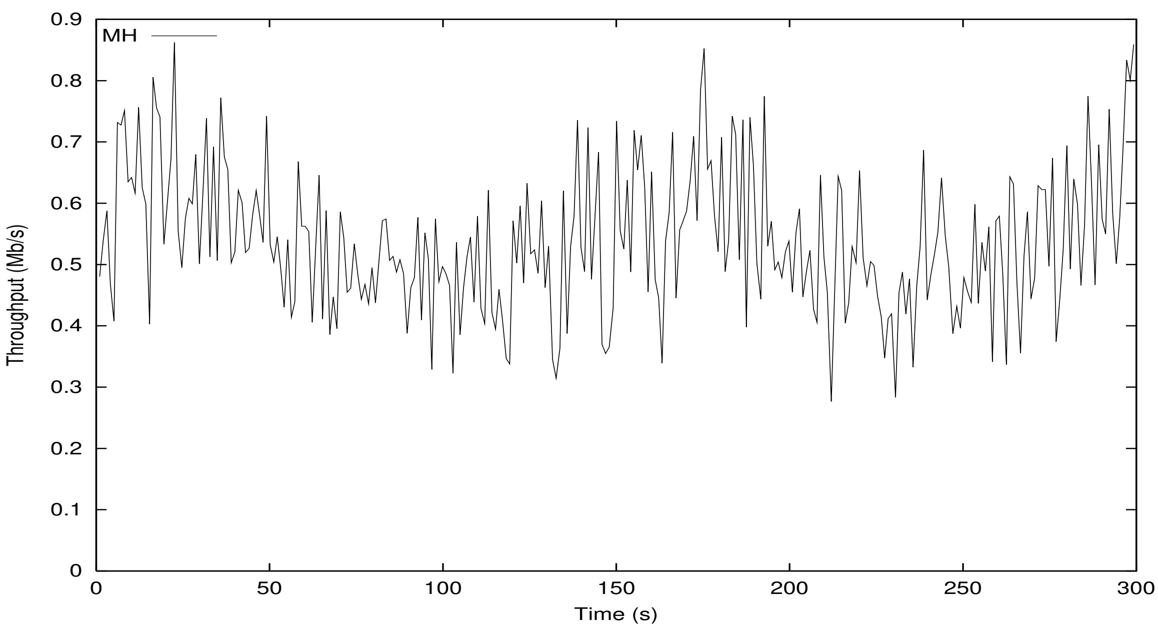
→ contributes to bit flips

→ error detection and correction essential

→ e.g., 802.11 WLAN implements adaptive error correction

Received signal strength under mobility:

→ throughput of handheld WiFi device at walking speed (HAAS corridor)



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→ walking back-and-forth from AP

→ gradual distance dependence

→ significant short-term fluctuation: fading

→ Doppler shift effect is minimal