Unique Features of Wirelss Networks

Signal propagation in wireless media: first, outdoors

Free space loss:

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

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

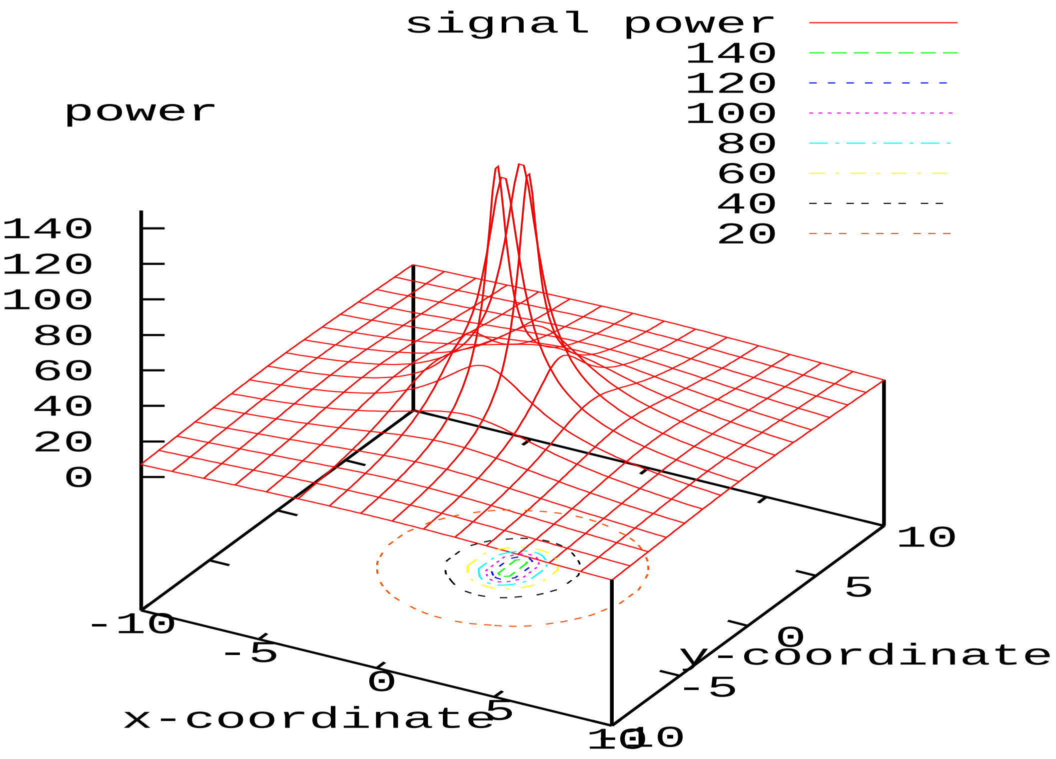
→ quadratic decrease in distance

→ quadratic decrease in frequency

→ idealized case: free space

→ in-doors and mobility: more complicated

Power profile in 2-D space:



→ sender located at the center

Real-world illustration: www.cs.purdue.edu/∼park/cs422-wireless-pic

Design implications:

- coverage limited primarily by distance

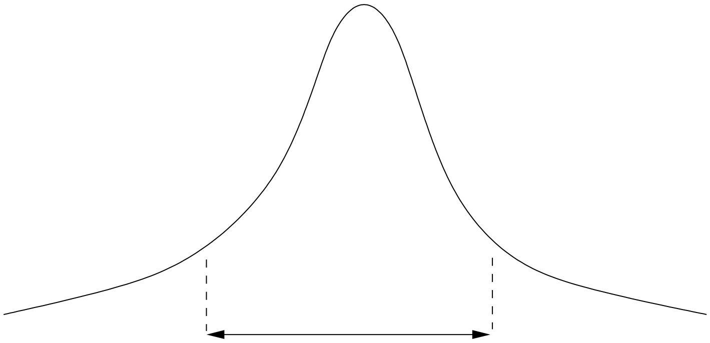
  → impacts SNR (signal-to-noise ratio)

  → the farther away, the weaker the signal

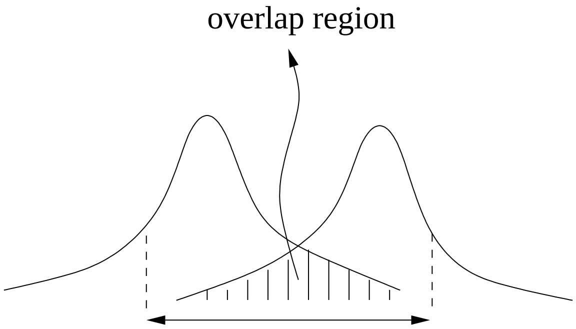
  → in CSMA: SIR (signal-to-interference ratio)

  → SINR with noise

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

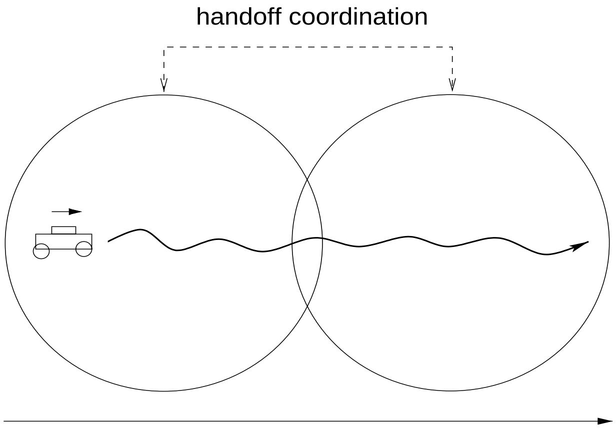


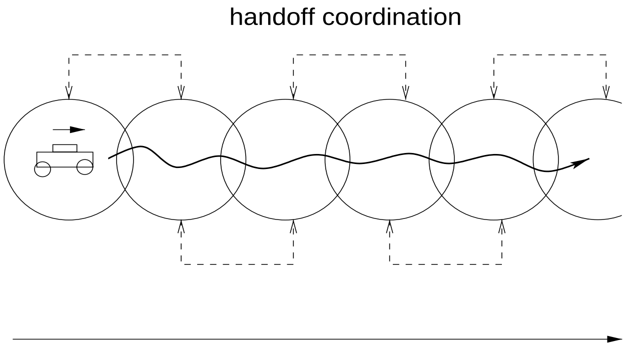
spatial coverage by one high−power antenna



spatial coverage by two low−power antennas

- low-power:
  - → decreases cell size: bad for coverage
  - → but good because less crowding
  - → also enables frequency reuse (think of radio station)
  - → good: increased battery life if base station is mobile
  - → bad: more antennae required
  - → also creates handoff coordination overhead (e.g., I65)

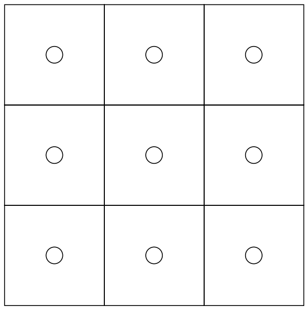


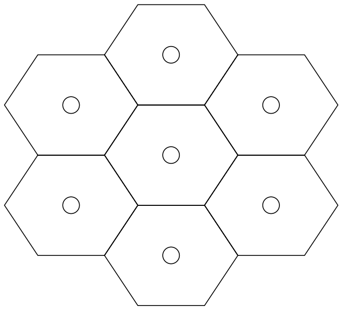


Cellular Networks:

→ network of wireless base stations

Can view as:





→ both affect tiling of the plane

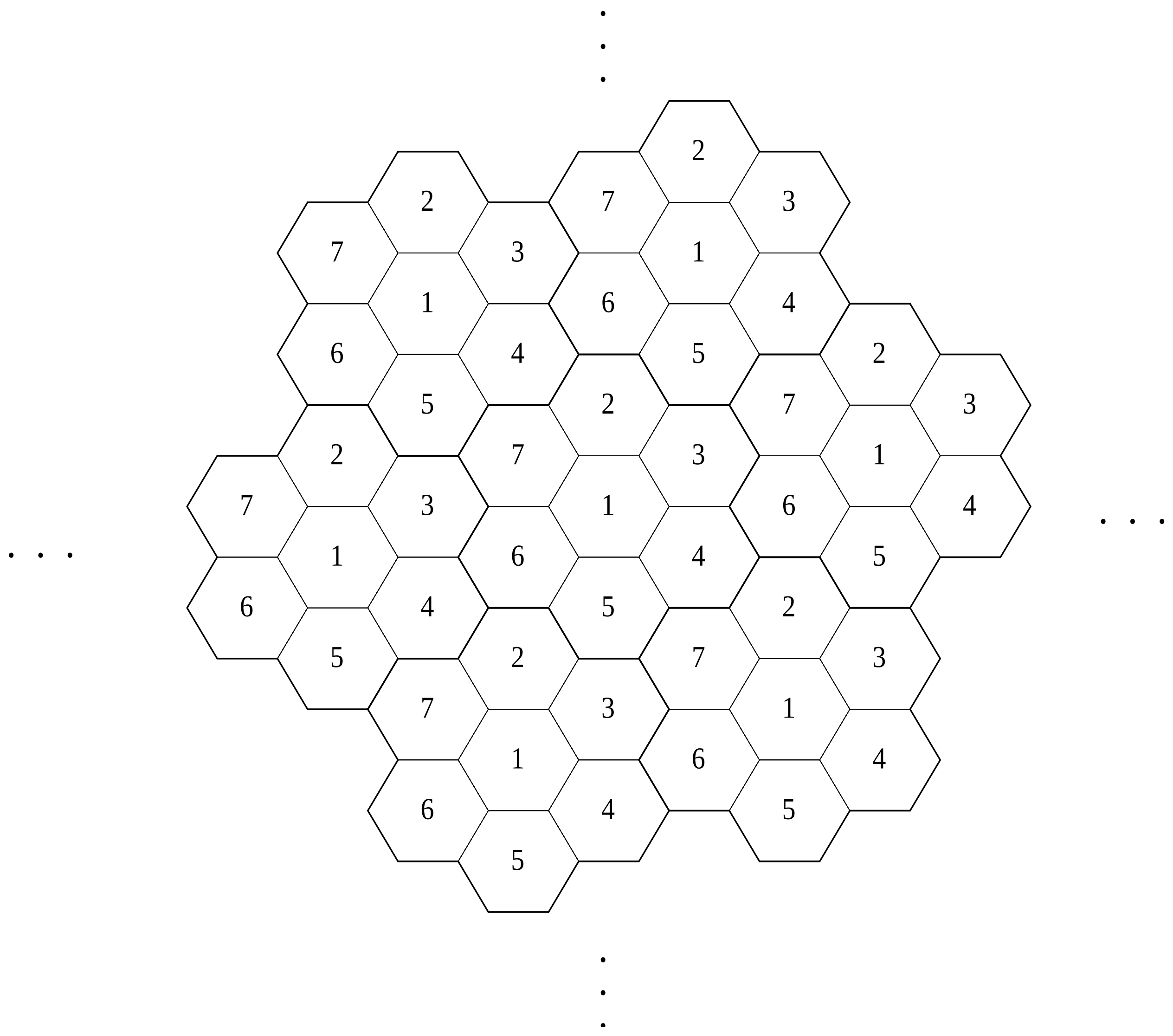
→ why hexagonal?

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

→ avoid interference

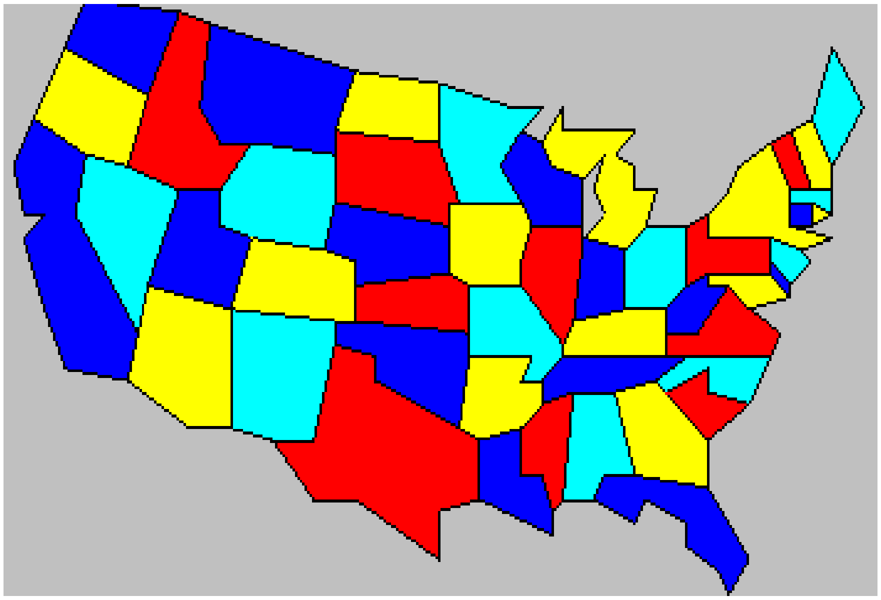
→ how many frequencies are required?

For example, using seven frequencies:



⟶ in general, coloring problem

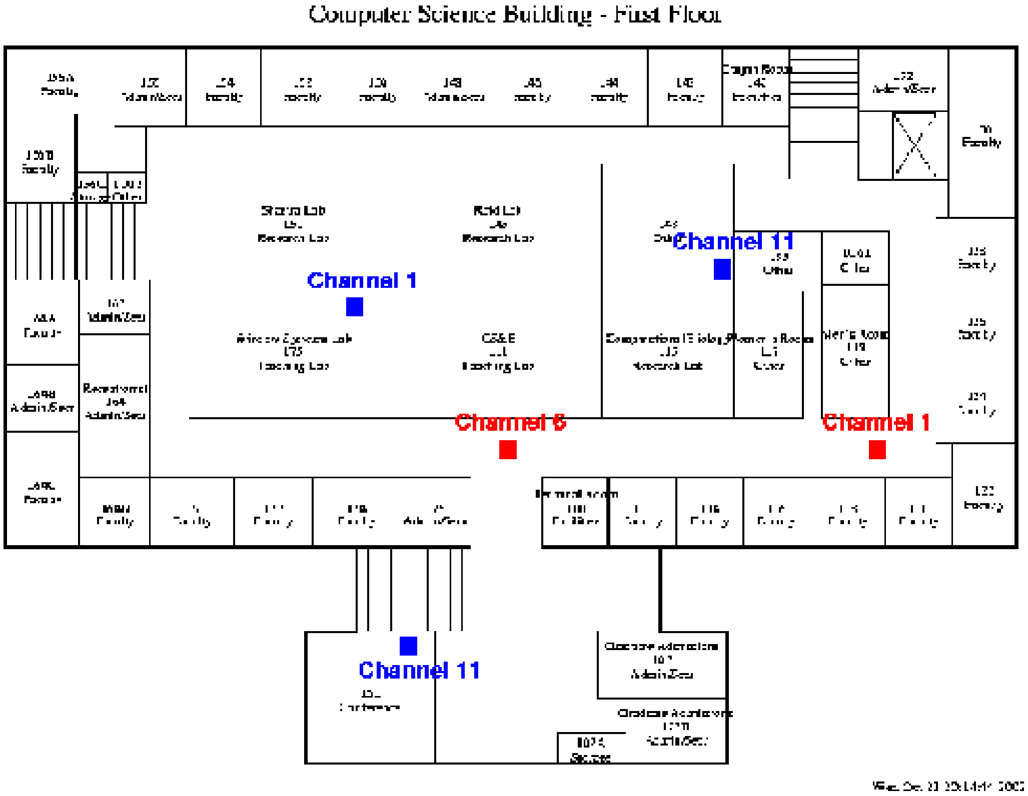
4-coloring of U.S. map:



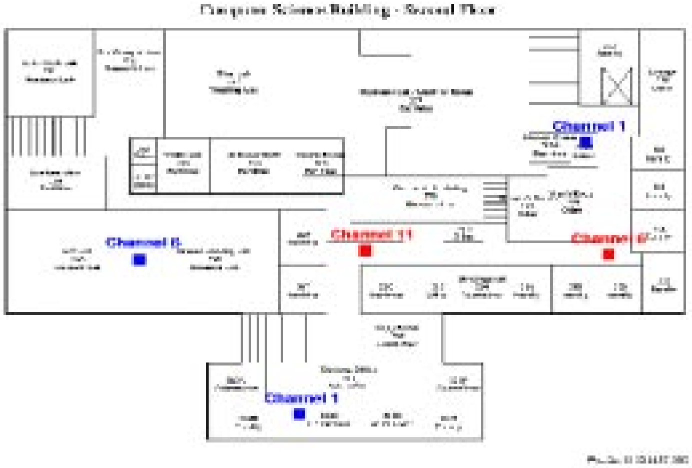
⟶ Y. Kanada, Y. Sato; Univ. of Tokyo

Old CS Building (aka HAAS):

First floor frequency reuse:

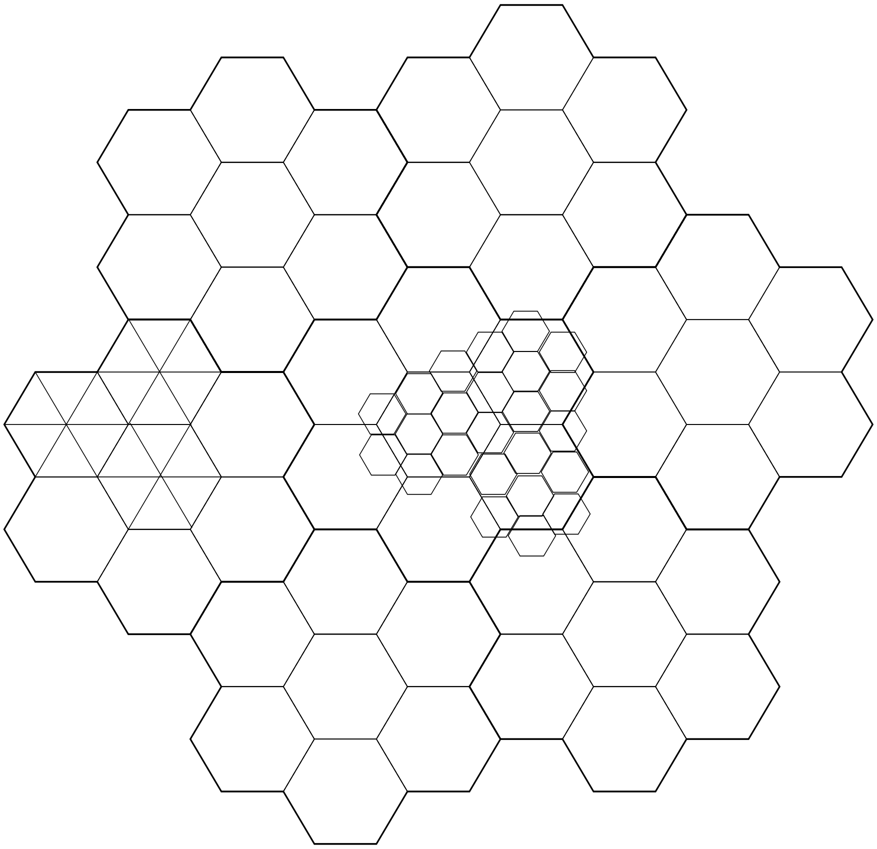


Second floor frequency reuse:



Ground floor frequency reuse:

Non-uniform covering:



→ directional antenna: triangular shape (like cone)

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

→ microcell, picocell, femtocell

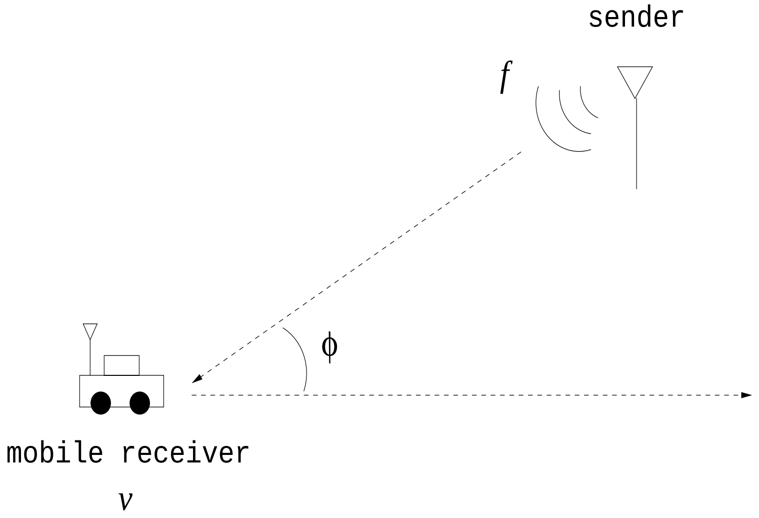
→ ex.: AT&T Wireless 3G MicroCell—targets poor reception in homes and small businesses

Impact of mobility: Doppler frequency shift and fading

First, 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 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 collision"

  → frequency experienced: fastest
- $\phi = 180$ deg: "going on oppostive direction"

  → frequency experienced: slowest
- $\phi = 90$ deg: "at right angle"

  → no distortion

Ex.: carrier frequency f 1.8 GHz

→ 4 mph: 10 Hz, 40 mph: 100 Hz

Depending upon PHY layer encoding:

→ bit flips may occur

Second, fading

→ fading: means that signal is changing, often weakening

→ consider city environment with many buildings and no direct line of sight between sender and receiver

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

→ called multi-path propagation

Clarke's fading model:

if there are many echos and the echos are independent of each other

then the average signal strength of the echos (total sum divided by the number of echos) has a Gaussian or normal distribution

→ central limit theorem

→ a form of law of large numbers

Since we know that signals used in communication are complex numbers (think of Fourier transform)

$$s = a + ib$$

the average signal strength of the echos s being Gaussian means that a and b follow Gaussian distributions

Since the magnitude of s is

$$|s| = \sqrt{a^2 + b^2}$$

by a fact from statistics $|s|$ follows a Rayleigh distribution

$$\frac{x}{r^2} e^{-x^2/2r^2}$$

→ r called scale parameter

→ infamous Rayleigh fading

→ popular staple of mobile networks

Thus: mobile's signal strength fluctuates erratically

→ fading plus Doppler shift

→ may lead to bit flips

→ knowing the statistical properties of signal fluctuation helps with applying error correction (FEC)

What about the case when the mobile (in a city environment) becomes stationary?

→ e.g., sitting at a coffee shop and checking e-mail on 3G phone?