Wireless Communication

Unique features that differentiate from wired communication

Current Trend

- WLAN explosion
  - → took many by surprise (close to a decade now)
  - → large component of Internet access
  - → hot spots everywhere
  - → also content streaming (e.g., Netflix), VoIP
- cellular telephony: 3G/4G
  - → 4G: stationary 1 Gbps, mobile 100 Mbps
  - → cellular, telcos, data providers: in the same mix
  - → all-in-one handhelds: e.g., iPhone, Android

- cellular telephony: 3G/4G (continued)
  - → special purpose handhelds: e.g., Kindle ebook, iPad tablet
  - → form factor that drives technology: e.g., power control, flash memory
- Near field communication (NFC): a few feet or less
  - → e.g., RFID for wireless identification, payment (credit card substitute), inventory control
  - → 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)
  - → high (and low) bandwidth apps

- special purpose wireless: e.g., GPS, satellite radio, digital TV, 60 GHz wireless networks, emergency response
- super WiFi (or WiFi 2.0): sub-900 MHz spectrum (old analog TV), e.g., 700 MHz

  $\rightarrow$ EM signals travel much farther

  $\rightarrow$ opportunities and challenges

Technology perspective:

- bad news: multiple unsettled/evolving technologies, chaotic landscape

  → can quickly get confusing

- good news: wireless broadband technology

  → based on what we already covered

  → OFDM, FDMA/TDMA, CDMA, CSMA

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

$\longrightarrow$ mainly: microwaves (2–66 GHz)

$\longrightarrow$ target range: 100 MHz–10 GHz, 60 GHz

Key differences with wired communication:

- increased exposure to interference and noise

  → lack of physical shielding

- 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)

→ wireless transmission: additional peculiarities

But: good for convenient access

→ has trumped other concerns

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

  ⟶ CDMA

  ⟶ ∼30 satellites (DoD), 10900 miles

  ⟶ navigation service: trilateration

- Cellular telephone: 824–849 MHz, 869–894 MHz

  → GSM: TDMA, digital

  → IS-95: CDMA, digital

  → now: 3G, 3.5G/pre-4G

  → TDMA and CDMA phones don't interoperate

- Cellular PCS: 1.85–1.99 GHz

  → CDMA, TDMA

Ex.: quad-band phone

  ⟶ works at different frequency bands

  ⟶ called: 800, 900, 1800, 1900 MHz

- WLAN: IEEE 802.11b 2.4 GHz–2.4835 GHz ISM (industrial, scientific, medical) band

  → CSMA

  → also has additional feature CA (collision avoidance): default—not used

  → same frequency range for 802.11g

  → 802.11g also uses OFDM: does it make sense?

- WLAN: Bluetooth 2.4–2.4835 GHz

  → IEEE 802.15.1

- WLAN: IEEE 802.11a 5.180–5.805 GHz U-NII (unlicensed national information infrastructure) band

  → same for 802.11n

- WiMax: IEEE 802.16 2–66 GHz

  → 2.3, 2.5, 3.5 GHz,

  → OFDM and TDMA based

- Near field communication (NFC) and RFID (radio frequency identification): 13.553–13.567 MHz ISM band (aka 13.56 MHz), 860–960 MHz, 902–928 MHz (aka 915 MHz)

  → multiple PHY layer specifications (ISO standards)

  → e.g., NFC uses AM

- Satellite: C-band 3.7 GHz–4.2 GHz (downlink), 5.925 GHz–6.425 GHz (uplink)

  → TDMA based

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

- Many other frequency bands

  → cf. FCC chart

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

Unique Features of Wireless 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

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

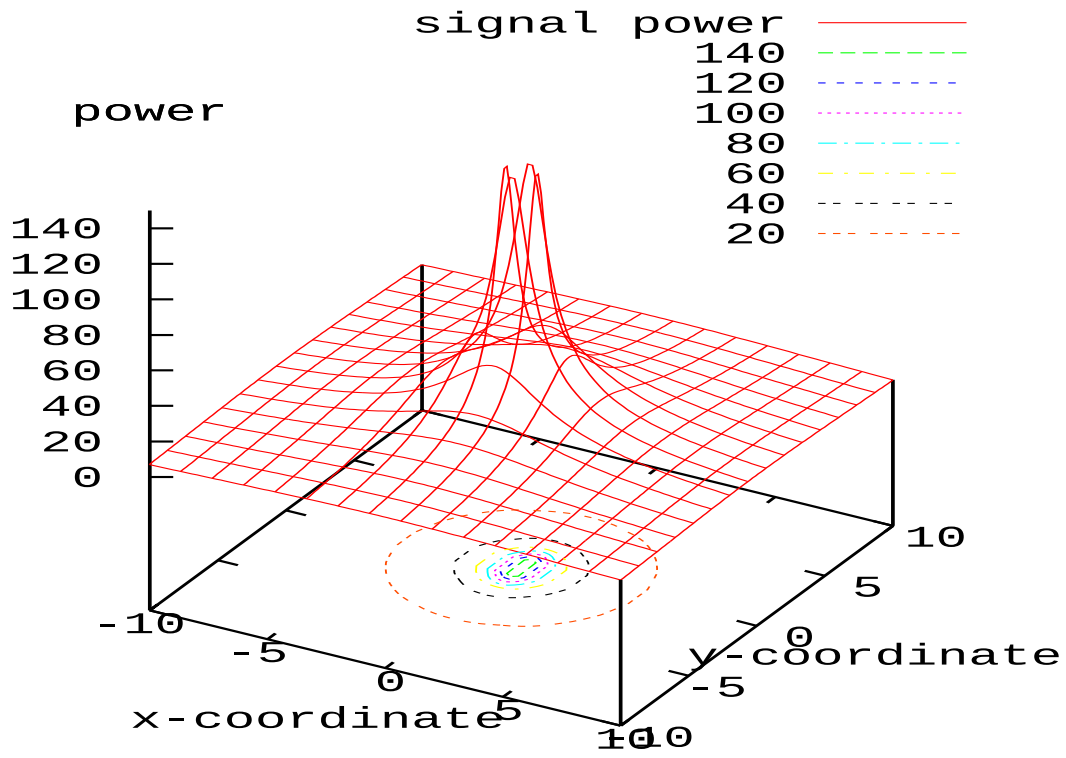
→ quadratic decrease in distance

→ quadratic decrease in frequency

→ idealized case: free space

→ in-doors and mobility: more complicated

Power profile in 2-D space:



→ sender located at center

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

Design implications:

- coverage limited primarily by distance

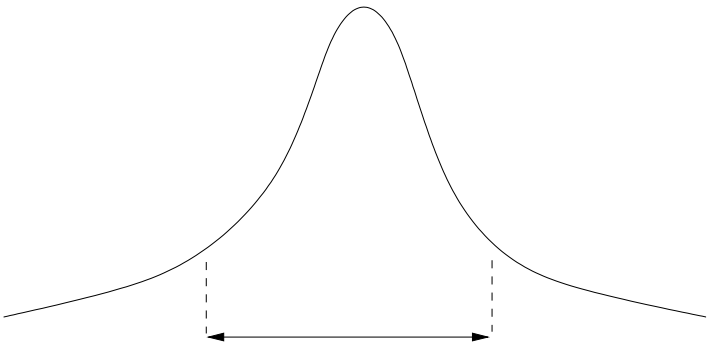
  → impacts SNR (signal-to-noise ratio)

  → the farther away, the weaker the signal

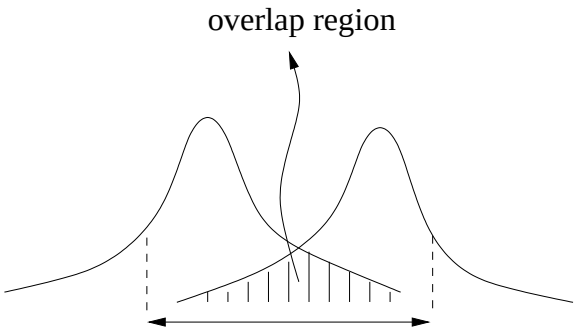
  → in CSMA: SIR (signal-to-interference ratio)

  → SINR: SIR with noise

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

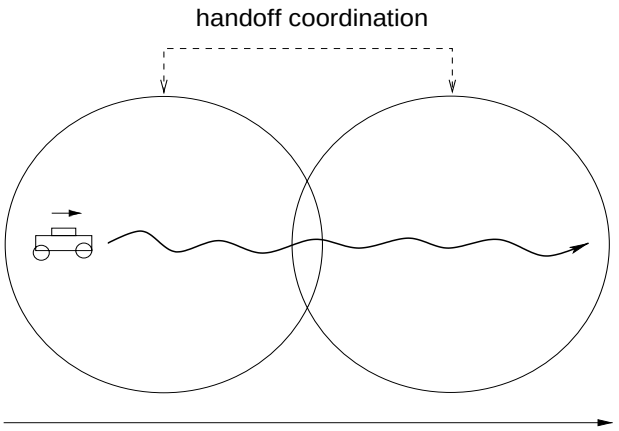


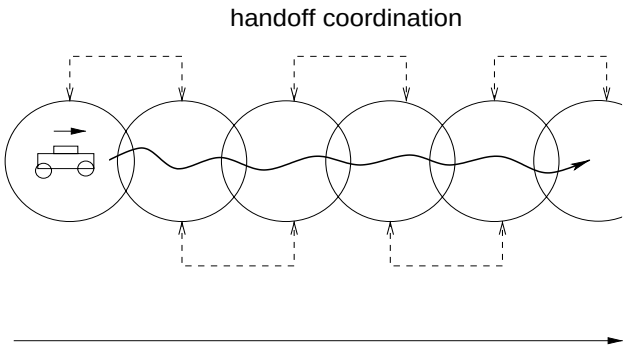
spatial coverage by one high−power antenna



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)

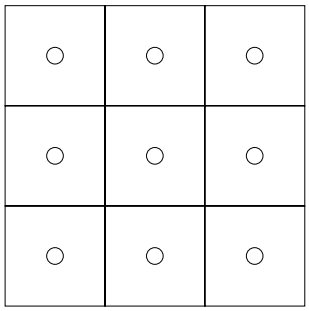


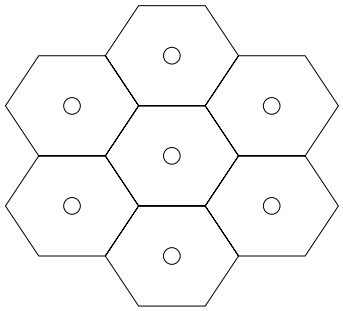


Cellular Networks:

→ network of wireless base stations

Can view as:





→ both affect tiling of the plane

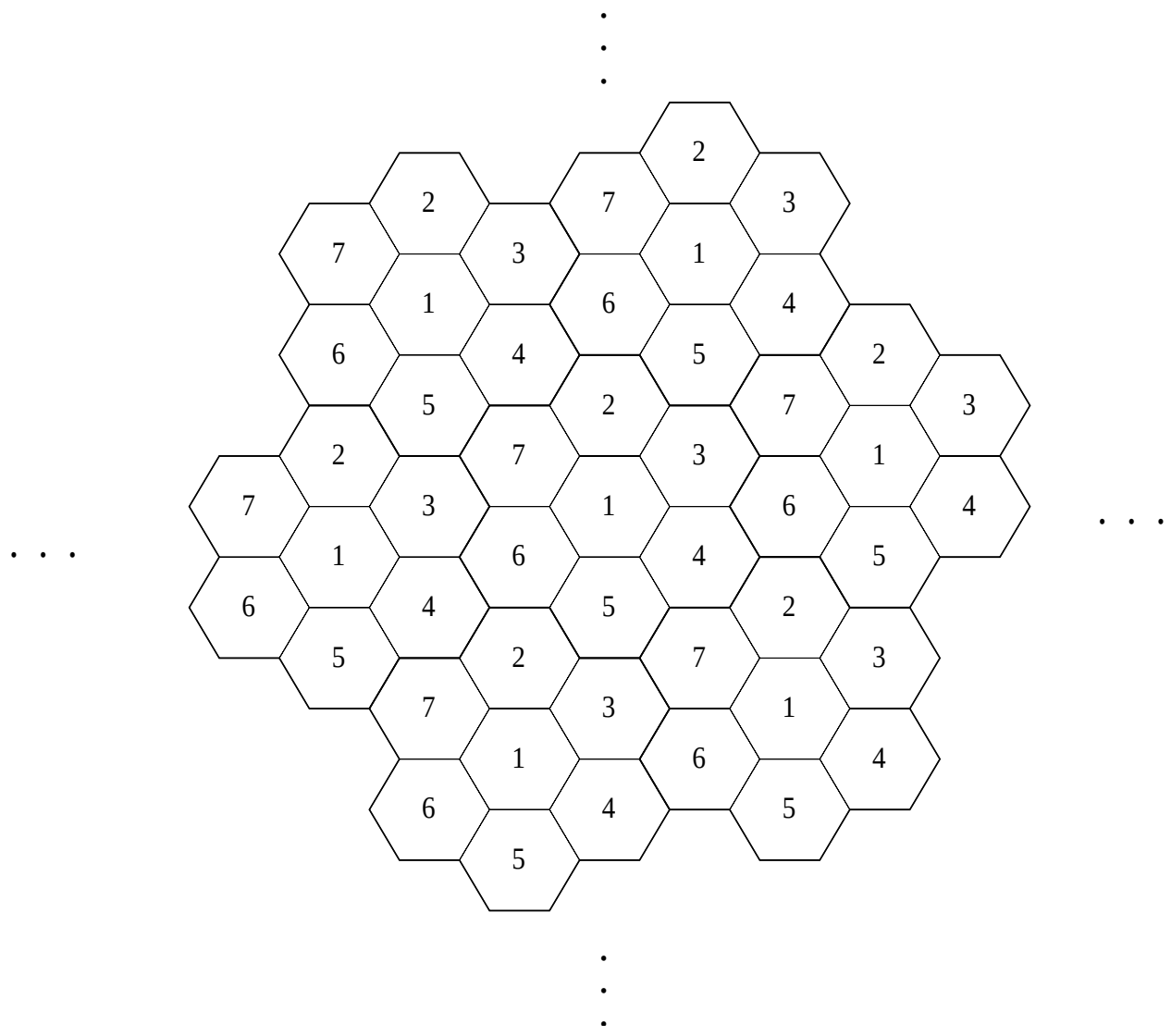
→ why hexagonal?

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

→ avoid interference

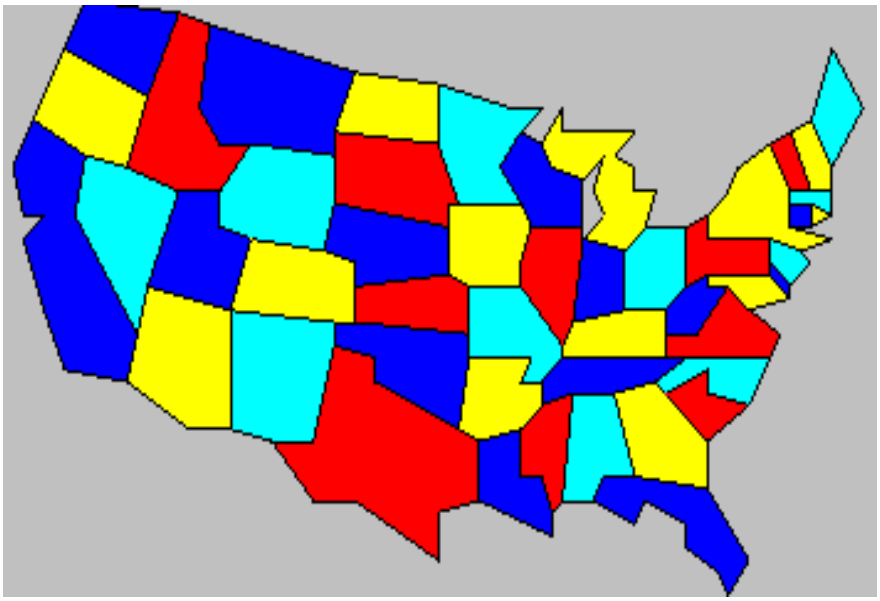
→ how many frequencies are required?

For example, using seven frequencies:



$\longrightarrow$ in general, coloring problem

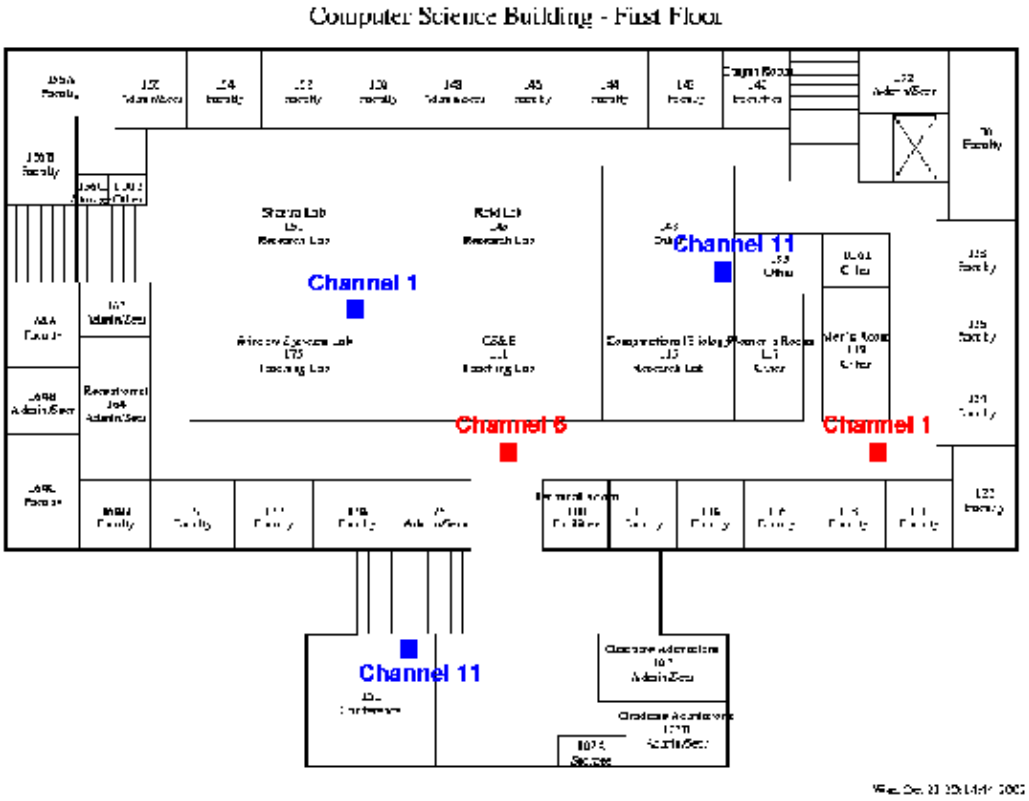
4-coloring of U.S. map:



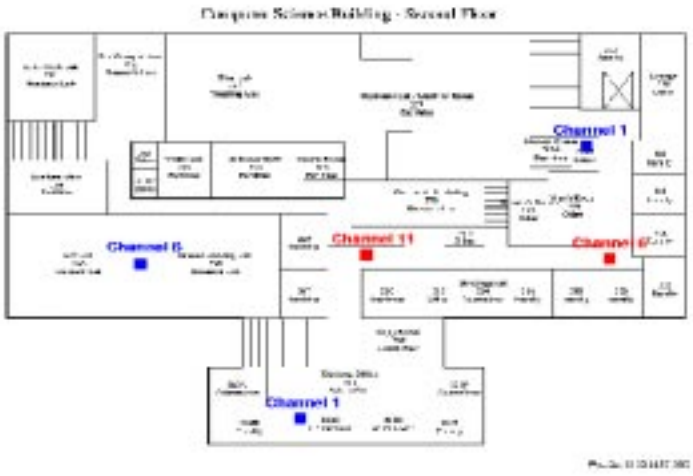
$\longrightarrow$ Y. Kanada, Y. Sato; Univ. of Tokyo

Old CS Building (aka HAAS):

First floor frequency reuse:

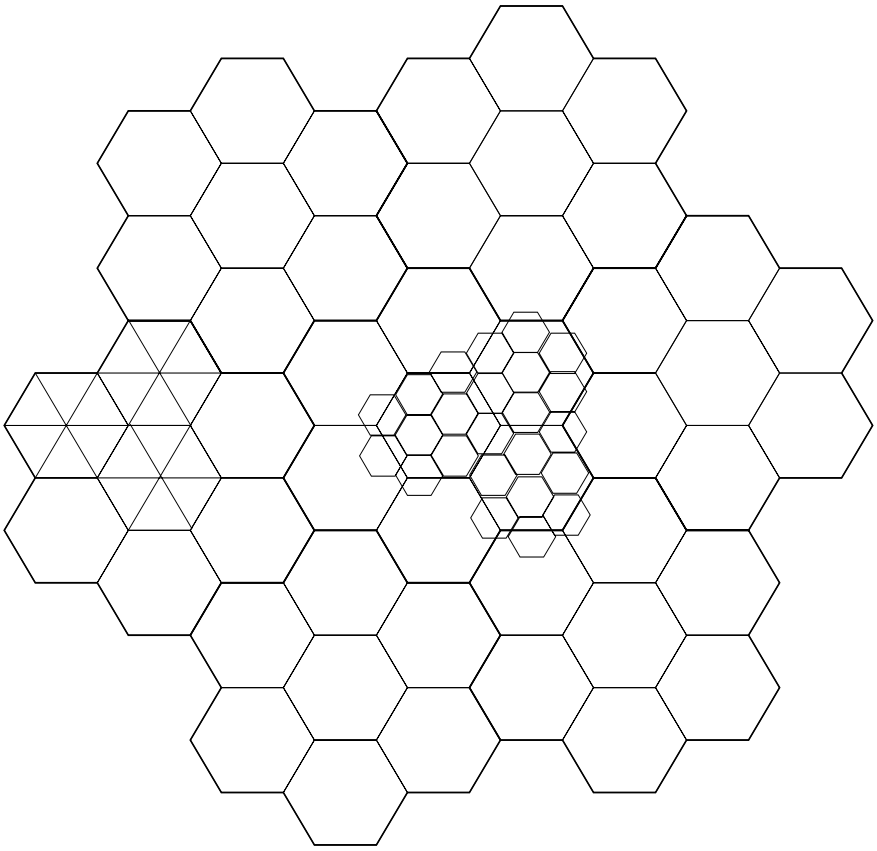


Second floor frequency reuse:



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