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

$\longrightarrow$ mainly: microwaves

$\longrightarrow$ e.g., 2.4 GHz for IEEE 802.11b WLAN

$\longrightarrow$ 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

  $\longrightarrow$ lack of physical shielding

- Inter-user interference cannot be localized at switch

  $\longrightarrow$ cannot use buffering

  $\longrightarrow$ problem for QoS (e.g., VoIP)

- Signal propagation and variation is more complex

  ⟶ attenuation

  ⟶ refraction, absorption, reflection, diffraction

  ⟶ multi-path fading

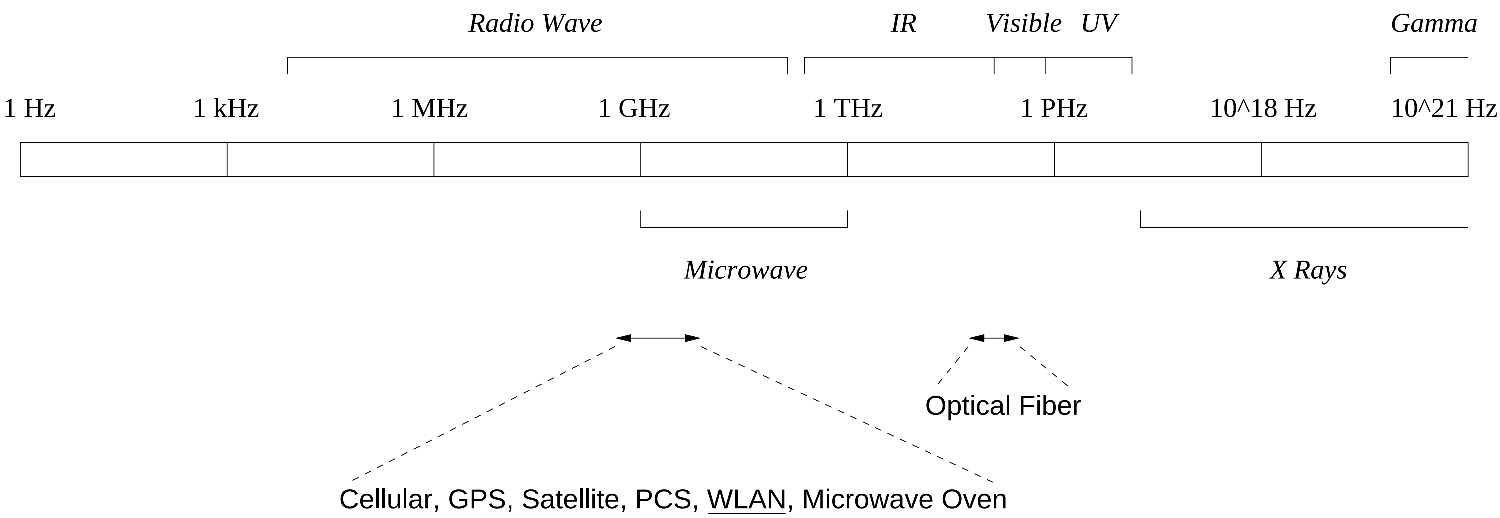
  ⟶ mobility

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

⟶ once tasted, difficult to turn back

⟶ key technology for LAN connectivity

Electromagnetic spectrum (logarithmic scale):



⟶ 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:

$\longrightarrow$ 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

  $\longrightarrow$ audio (FM), video (AM)

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

  $\longrightarrow$ DS-CDMA

  $\longrightarrow$ 24 satellites (DoD), 10900 miles

  $\longrightarrow$ navigation service: trilateration

- Cellular telephone: 824 MHz–849 MHz (upstream), 869 MHz–894 MHz (downstream)

  $\longrightarrow$ AMPS: FDM, analog

  $\longrightarrow$ GSM: TDMA, digital

  $\longrightarrow$ IS-95: CDMA, digital

- PCS: 1.85 GHz–1.99 GHz

  $\longrightarrow$ CDMA, TDMA

- WLAN: IEEE 802.11b 2.4 GHz–2.4835 GHz

  $\longrightarrow$ DSSS or FHSS with CSMA/CA

- WLAN: Bluetooth 2.4 GHz–2.4835 GHz

  $\longrightarrow$ FH with TDD

- WLAN: IEEE 802.11a 5.725 GHz–5.850 GHz

  $\longrightarrow$ OFDM with CSMA/CA

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

  $\longrightarrow$ FDMA/TDMA

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

- Many other frequency bands

  $\longrightarrow$ cf. FCC chart

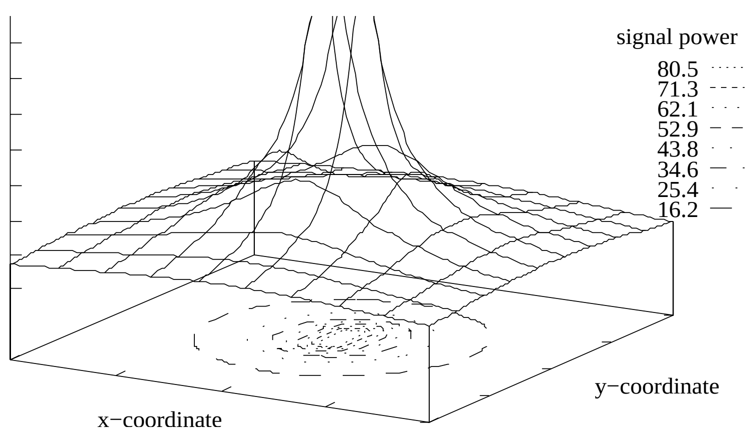
Signal propagation and power

Free space loss:

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

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

$\longrightarrow$ quadratic decrease in distance & frequency



Design implications:

- effective coverage limited by distance

  $\longrightarrow$ SNR: signal-to-noise ratio

  $\longrightarrow$ SIR: signal-to-interference ratio

spatial coverage by one high−power antenna

spatial coverage by two low−power antennas

$\longrightarrow$ pros & cons?

- low power output decreases cell size

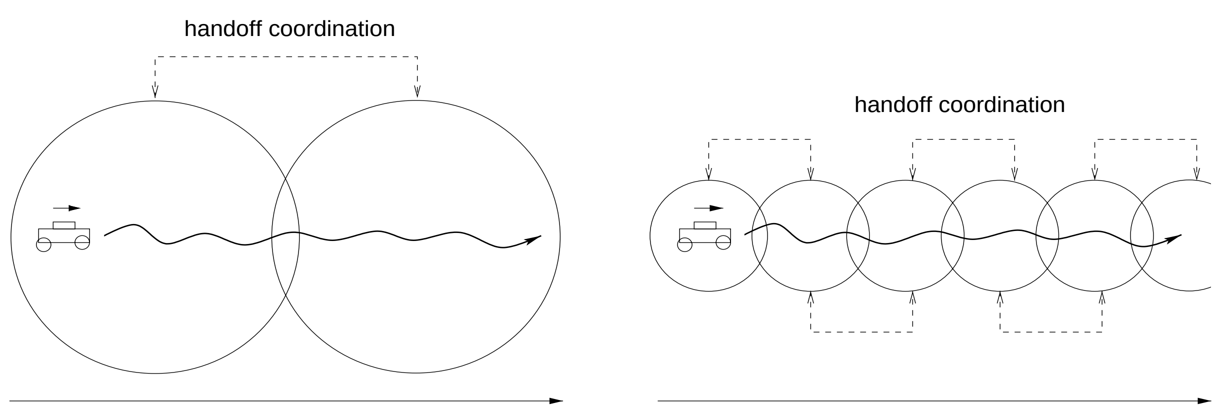
  ⟶ increased battery life

  ⟶ enables frequency reuse

  ⟶ more antennas required

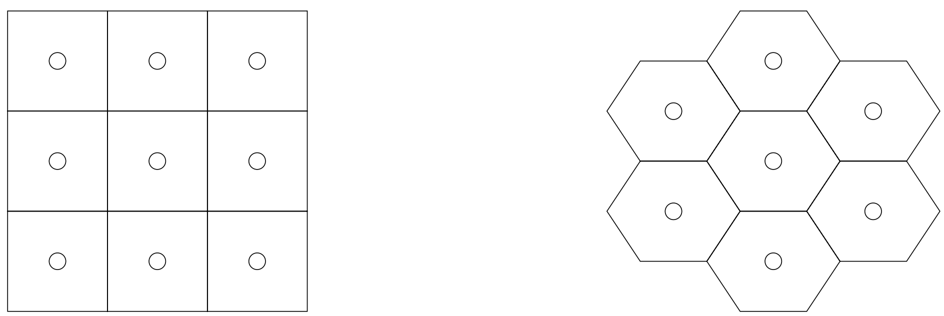
  ⟶ handoff coordination overhead

  ⟶ e.g., I65 from Lafayette to Indy



Cellular networks

Hexagonal cells:



⟶ both affect tiling of the plane

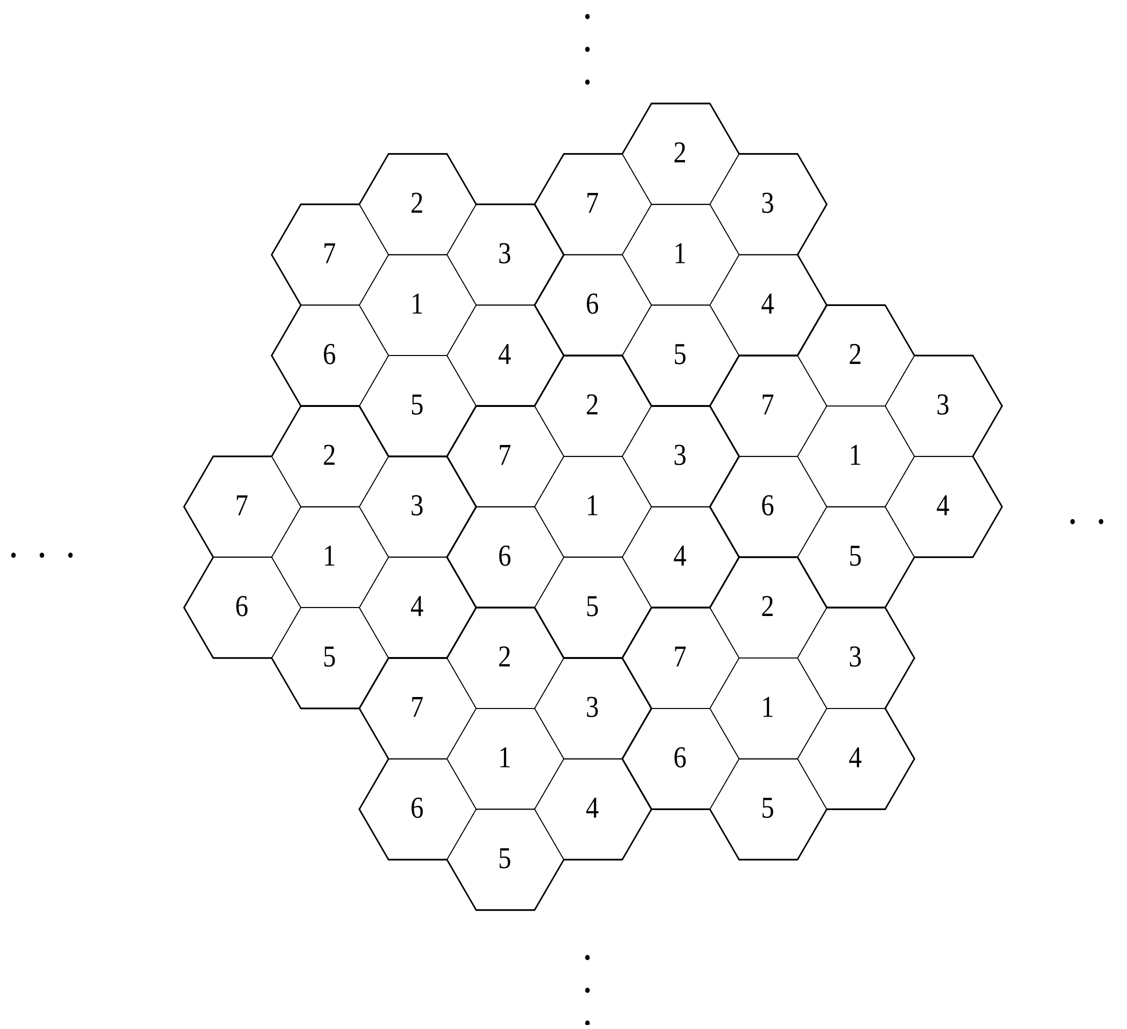
⟶ why hexagonal?

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

⟶ avoid interference

⟶ how many frequencies are required?

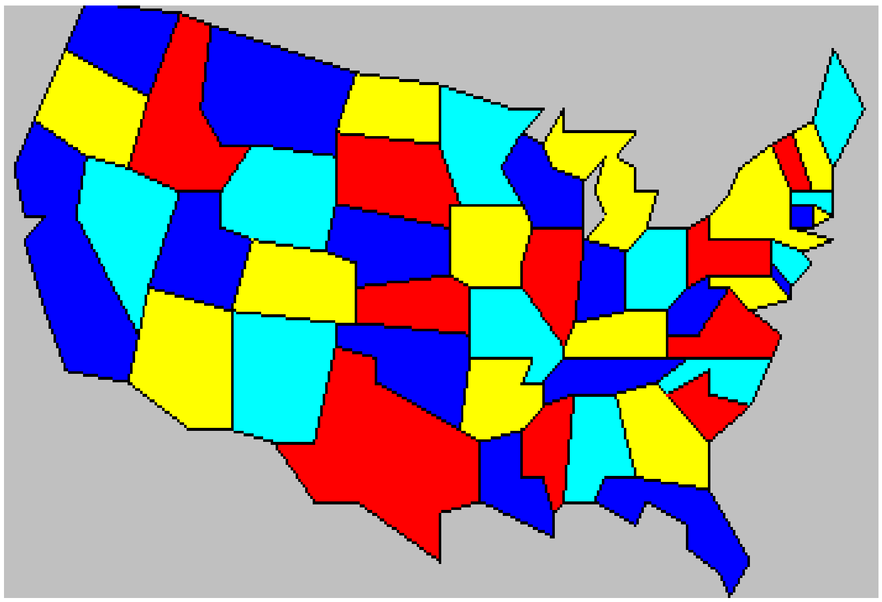
For example, using seven frequencies:



⟶ why does it work?

⟶ in general, coloring problem

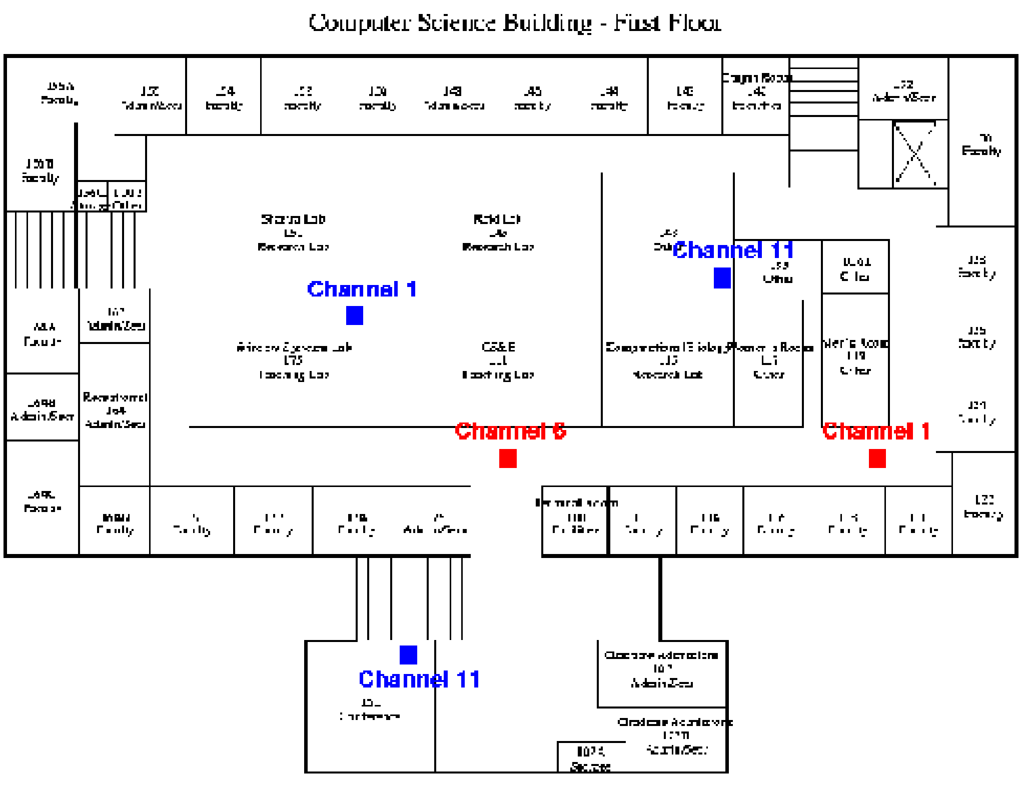
4-coloring of U.S. map:



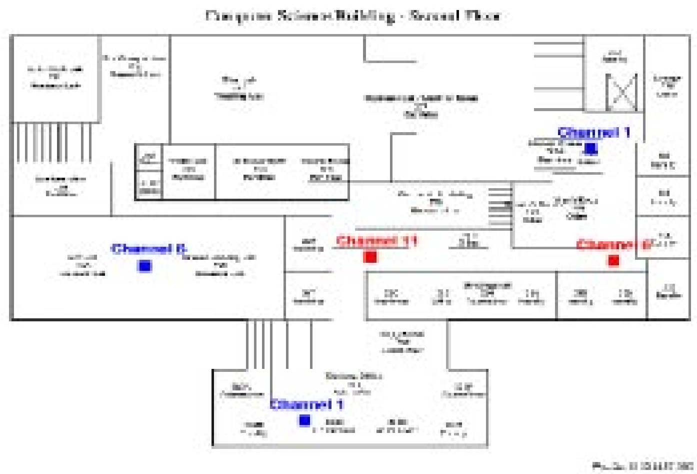
⟶ Y. Kanada, Y. Sato; Univ. of Tokyo

CS Building:

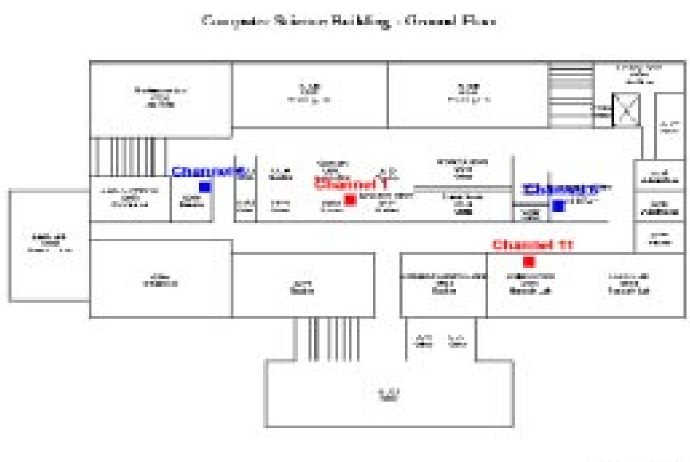
First floor frequency reuse:



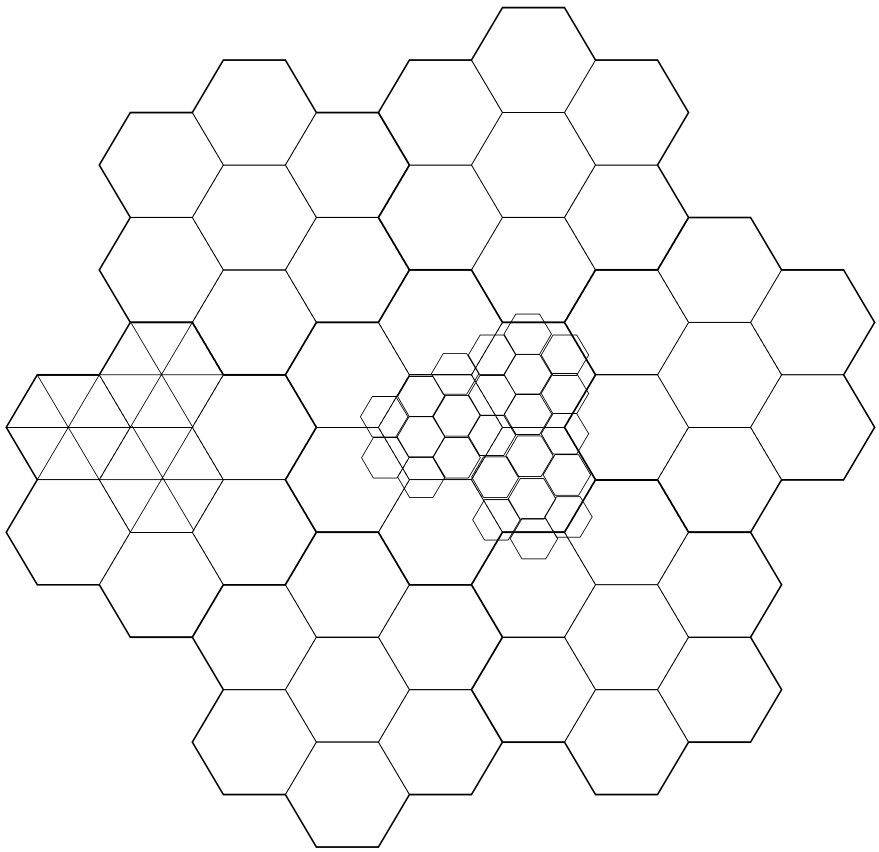
Second floor frequency reuse:



Ground floor frequency reuse:



Non-uniform covering:



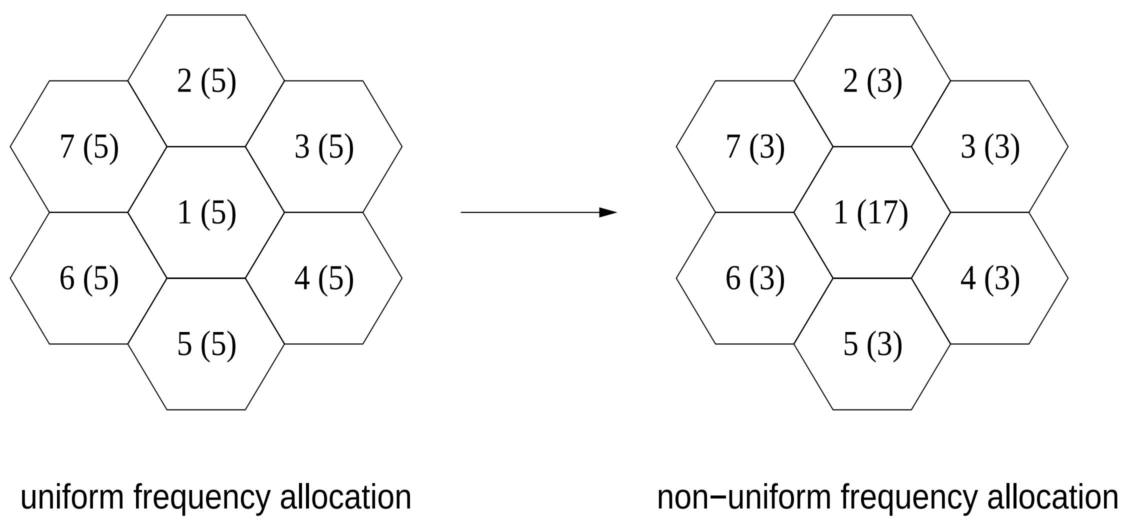
⟶ directional antenna

⟶ non-uniform density

Non-uniform frequency allocation:

⟶ total carrier frequency budget: 35

⟶ frequency borrowing



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)

$\longrightarrow$ e.g., GEO satellites at 35786 km

$\longrightarrow$ e.g., LEO satellites at $\sim$1000 km

Note: 2-way propagation delay (RTT)

$$2 \times 35786/300000 \approx 0.24 \text{ sec}$$

$\longrightarrow$ optimistic based on closest distance

$\longrightarrow$ RTT can be: $\sim$500 msec