Direct Link Communication II: Wireless Media

Current Trend

- WLAN explosion (also called WiFi)

  → took most by surprise

- cellular telephony: 3G/4G

  → cellular providers/telcos/data in the same mix

- self-organization by citizens for local access

  → free WiFi hot spots

- large-scale hot spots: coffee shops, airport lounges, trains, university/enterprise campuses, cities, etc.

  → part of everyday life

  → difficult to turn back

- boundary between local and wide area wireless blurring

  → cellular: long-distance vs. WLAN: local

  → 802.16 (WiMax): designed to compete with cellular

- also very short distances ("wireless personal area networks")

  → bluetooth, UWB, Zigbee: in general, 802.15

  → multi-use: cordless phones, WLANs, etc.

  → 2.4 and 5 GHz spectra: very busy

Integral part of the Internet: where it's happening

⟶ good news and bad news

⟶ good old #$%&? radio technology

Basics of Wireless Communication

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

$\longrightarrow$ NIC: air interface

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

$\longrightarrow$ mainly: microwaves

$\longrightarrow$ e.g., 2–66 GHz

Key differences with wired communication:

- increased exposure to interference and noise

  → lack of physical shielding

- same frequency spectrum must be shared among all users

- inter-user interference cannot be localized at switch

  → cannot use buffering

  → problem for QoS (e.g., VoIP)

⟶ information is inherently exposed

⟶ bad for networking

⟶ bad for security

⟶ good for convenient access

- signal propagation and variation is more complex

  $\longrightarrow$ attenuation

  $\longrightarrow$ refraction, absorption, reflection, diffraction

  $\longrightarrow$ multi-path fading

  $\longrightarrow$ mobility

Network bandwidth: two extremes

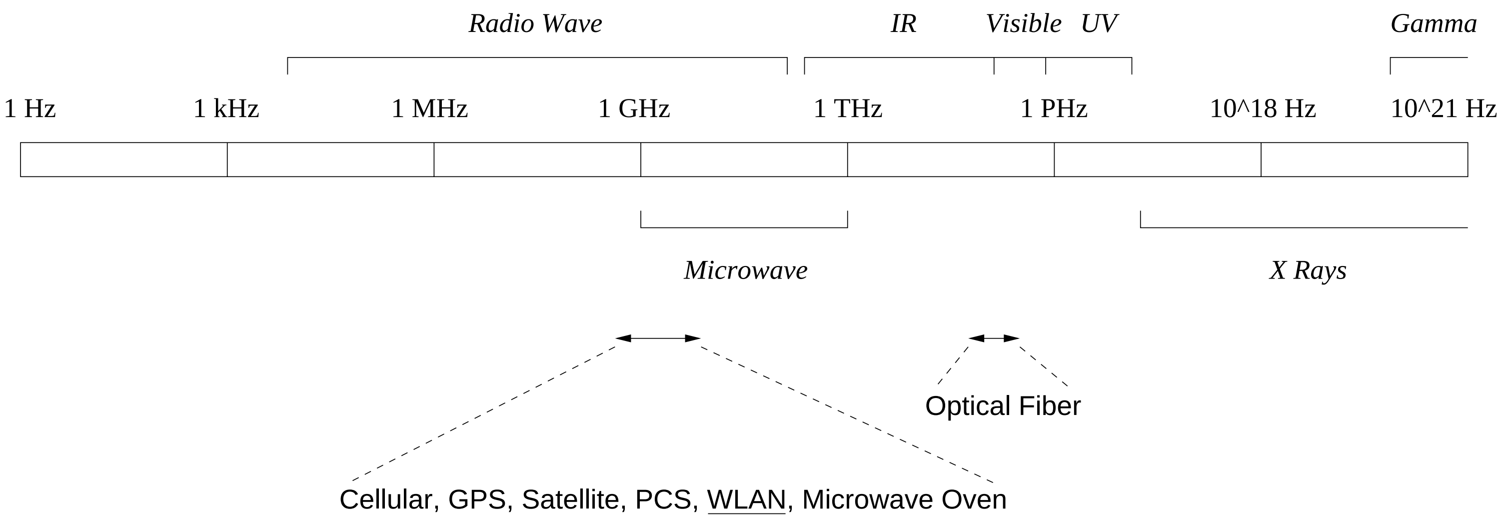
$\longrightarrow$ high and low bandwidth coexist

$\longrightarrow$ e.g., 10 Gbps and 11 Mbps

$\longrightarrow$ here to stay

$\longrightarrow$ speed mismatch: makes things interesting

Electromagnetic spectrum (logarithmic scale):



$\longrightarrow$ RF: 9 kHz–300 GHz

$\longrightarrow$ Microwave: 1 GHz–1 THz

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

$\longrightarrow$ 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

  $\longrightarrow$ same frequency range for 802.11g

- 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

- WiMax: IEEE 802.16 2 GHz–66 GHz

  $\longrightarrow$ TDMA based

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

  $\rightarrow$ FDMA/TDMA

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

- Many other frequency bands

  $\rightarrow$ cf. FCC chart

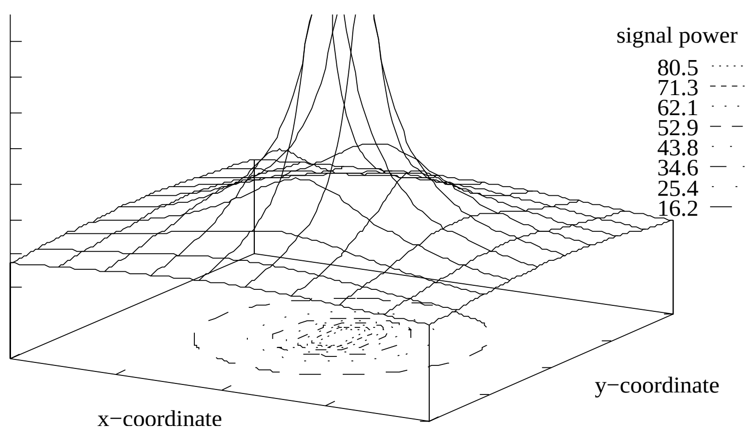
Signal Propagation and Power

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

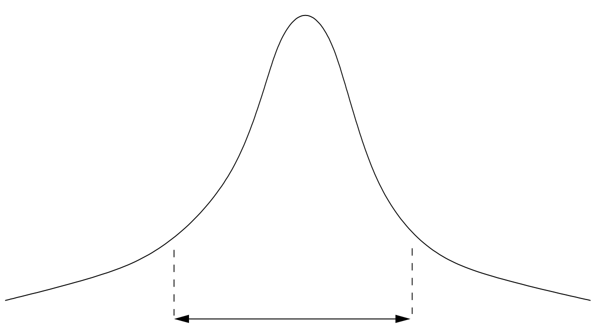


Design implications:

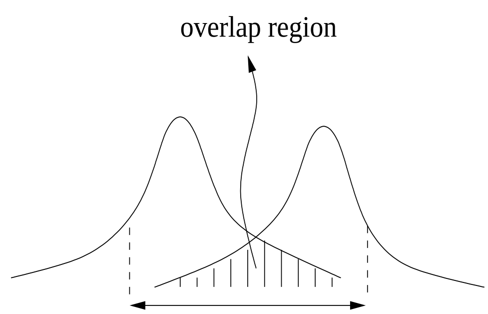
- effective coverage limited by distance

  ⟶ SNR: signal-to-noise ratio

  ⟶ SIR: signal-to-interference ratio



spatial coverage by one high−power antenna



spatial coverage by two low−power antennas

⟶ pros & cons?

- low power output decreases cell size

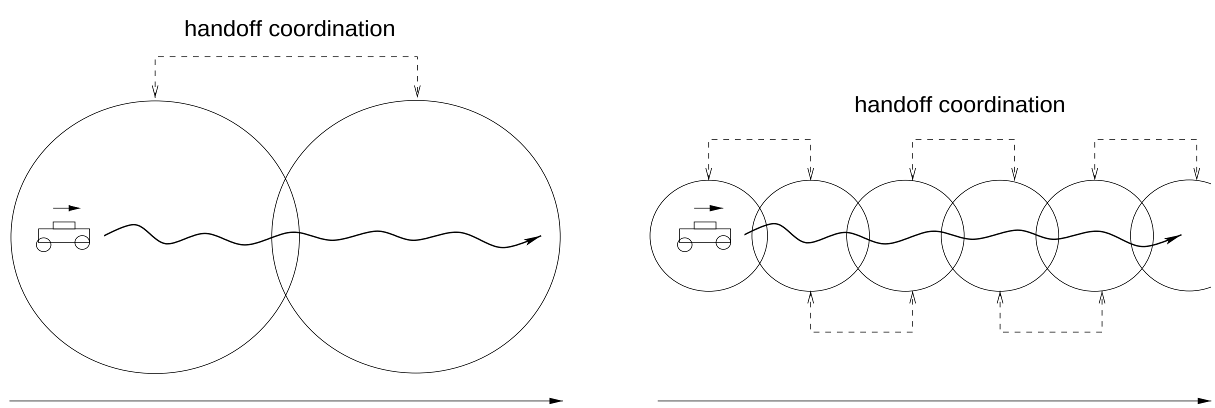
  ⟶ increased battery life

  ⟶ 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

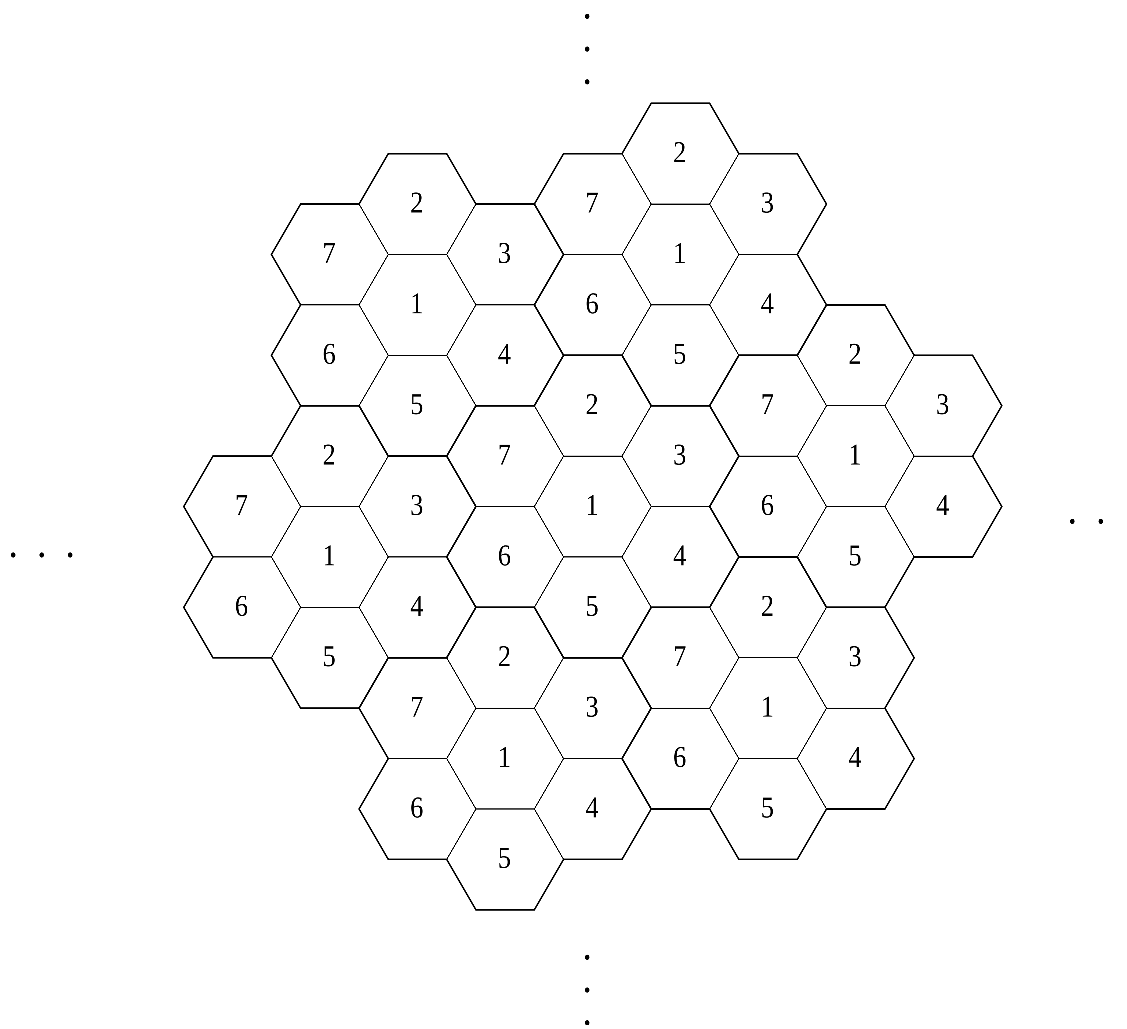
⟶ why hexagonal?

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

⟶ avoid interference

⟶ how many frequencies are required?

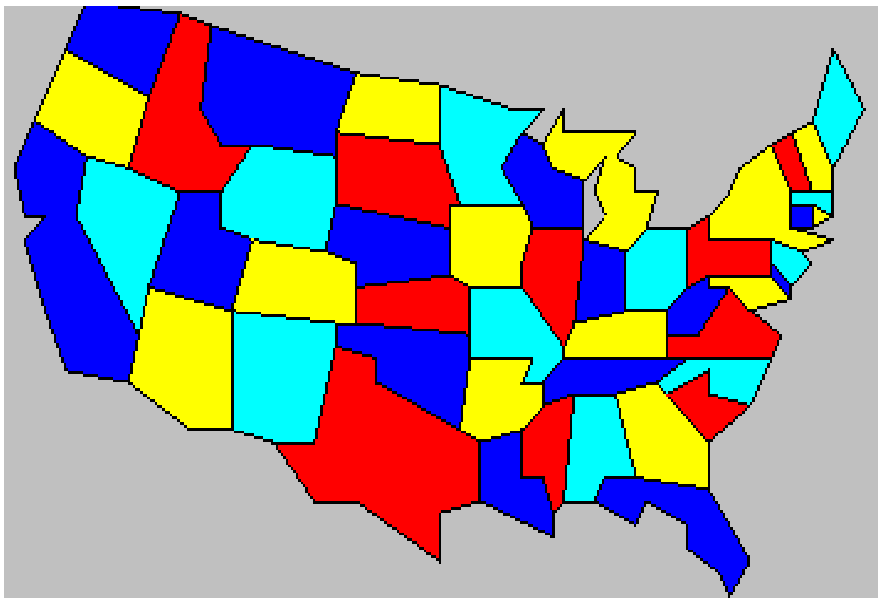
For example, using seven frequencies:



⟶ why does it work?

⟶ in general, coloring problem

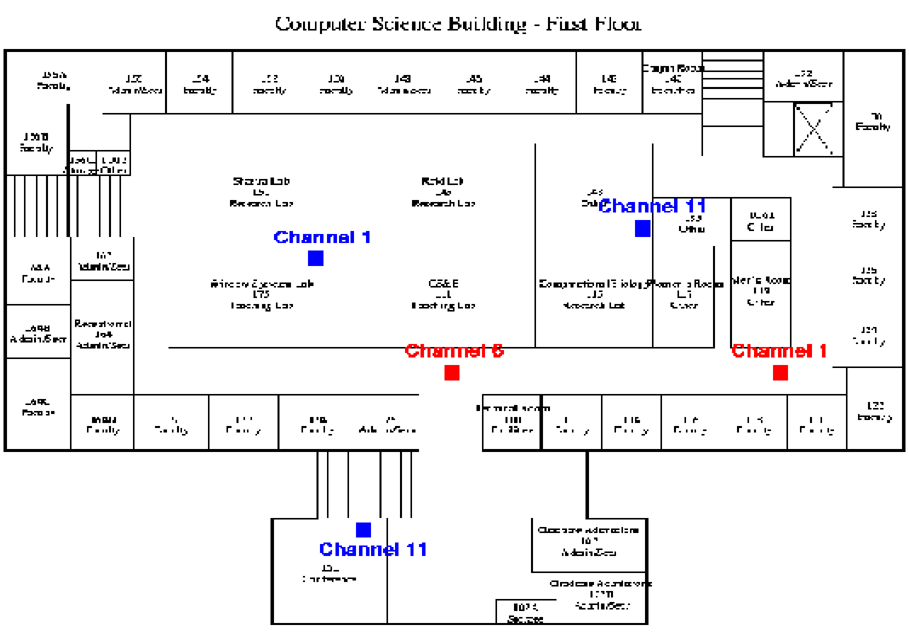
4-coloring of U.S. map:



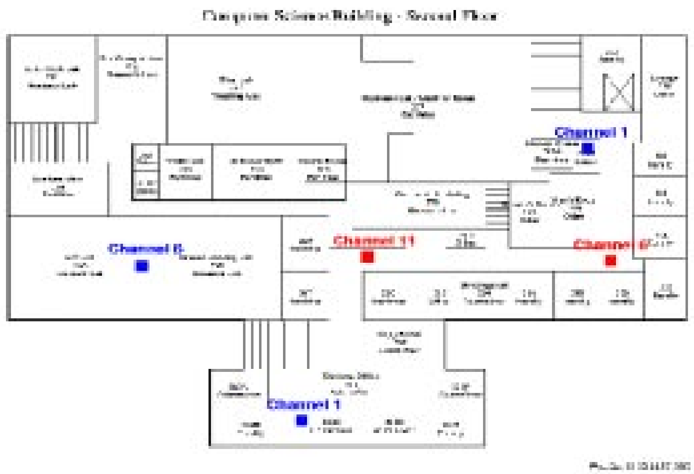
⟶ Y. Kanada, Y. Sato; Univ. of Tokyo

CS Building:

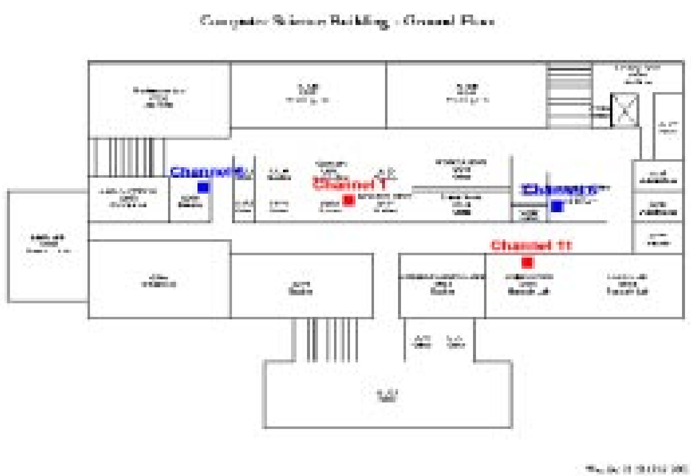
First floor frequency reuse:



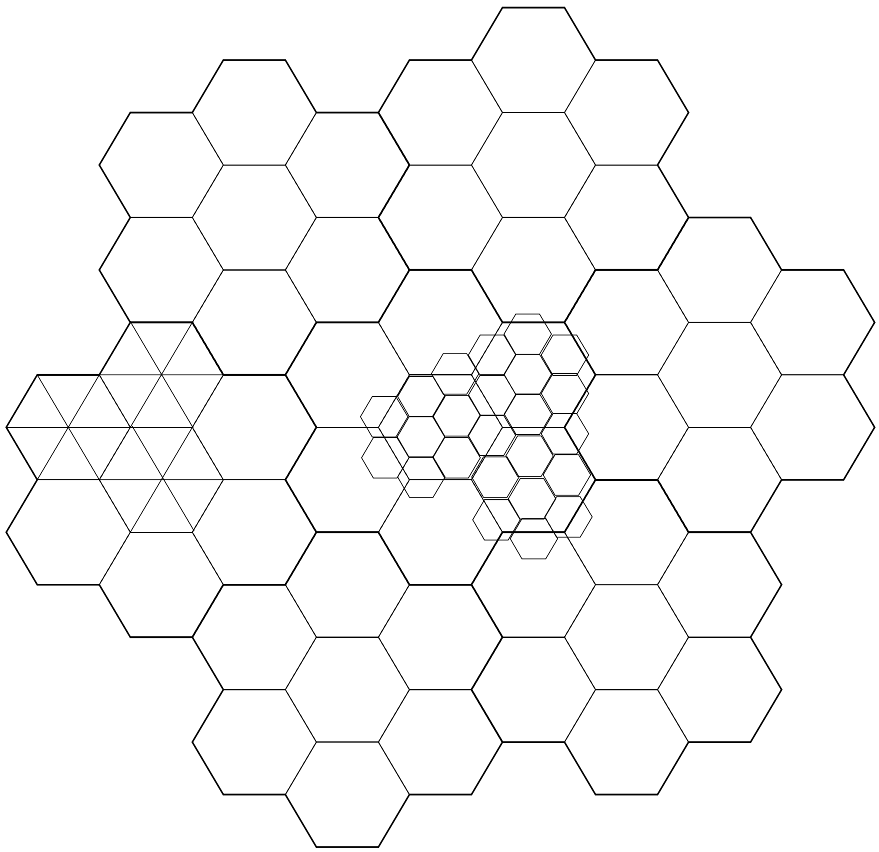
Second floor frequency reuse:



Ground floor frequency reuse:



Non-uniform covering:



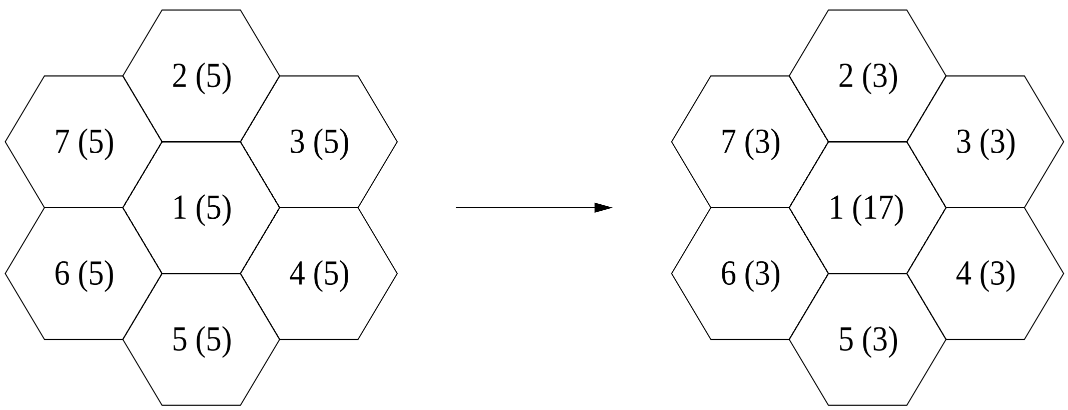
⟶ directional antenna

⟶ non-uniform density

Non-uniform frequency allocation:

⟶ total carrier frequency budget: 35

⟶ frequency borrowing



uniform frequency allocation — non−uniform frequency allocation