Link Layer: Wireless Media

Current Trend

- WLAN explosion

  → took many by surprise (close to a decade now)

- cellular telephony: 3G/4G

  → cellular providers, telcos, data in the same mix

  → all-in-one handheld: e.g., iPhone, Android

  → special purpose handhelds: e.g., Kindle ebook, iPad tablet

- 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

- boundary between local and wide area wireless blurring

  → cellular (long-distance) vs. WLAN (short-distance)

  → 802.16 (WiMax): competition to cellular

  → aiming at 4G speed: 1 Gbps

  → cellular (900 MHz–2 GHz), 2.4 and 5 GHz spectra: very busy

  → super WiFi (or WiFi 2.0): sub-900 MHz spectrum (old analog TV), esp. 700 MHz; next frontier?

  → typical devices: multiple air interfaces

- very short distances (wireless personal or home area networks)

  → bluetooth, UWB, Zigbee: in general, 802.15

  → e.g., UWB (802.15.3): 3.1–10.6 GHz

  → wireless USB: get rid of pesky wires!

  → also 60 GHz wireless networks

  → 802.11n in the mix (e.g., entertainment networks—Apple TV)

  → RFID (radio frequency identification): passive RFID does not require power

  → many applications: bus/train card, wireless epay/credit card, inventory control, etc.

Wireless networks: where it's happening

Technology perspective:

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

  $\rightarrow$ can quickly get confusing

- Good news: wireless broadband technology

  $\rightarrow$ based on what we already covered

  $\rightarrow$ <u>OFDM</u>, FDMA/TDMA, CDMA, CSMA

What remains:

$\longrightarrow$ networking features unique to wireless

$\longrightarrow$ specific wireless technologies

Wircless Communication: 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 to switch doesn't apply

  → can be problem for QoS (e.g., VoIP, IPTV)

$\longrightarrow$ information is inherently exposed

$\longrightarrow$ bad for networking

$\longrightarrow$ bad for security

$\longrightarrow$ wireless transmission: peculiar properties

But: good for convenient access

$\longrightarrow$ trumps 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

  $\longrightarrow$ CDMA

  $\longrightarrow$ ∼30 satellites (DoD), 10900 miles

  $\longrightarrow$ navigation service: trilateration

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

  → AMPS: FDM, analog

  → GSM: TDMA, digital

  → IS-95: CDMA, digital

  → 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

⟶ loosely called: 800, 900, 1800, 1900 MHz

- WLAN: IEEE 802.11b 2.4 GHz–2.4835 GHz

  $\rightarrow$ CSMA/CA

  $\rightarrow$ same frequency range for 802.11g

  $\rightarrow$ 802.11g also uses OFDM: does it make sense?

- WLAN: Bluetooth 2.4–2.4835 GHz
- WLAN: IEEE 802.11a 5.725–5.850 GHz

  $\rightarrow$ same for 802.11n

- WiMax: IEEE 802.16 2–66 GHz

  $\rightarrow$ 2.3, 2.5, 3.5 Ghz,

  $\rightarrow$ OFDM and TDMA based

- RFID: 902–928 MHz (aka 915 MHz)

  $\rightarrow$ CDMA's spread spectrum based

- 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 Wirelss Networks

Signal propagation in wireless media: first, outdoors

Free space loss:

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

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

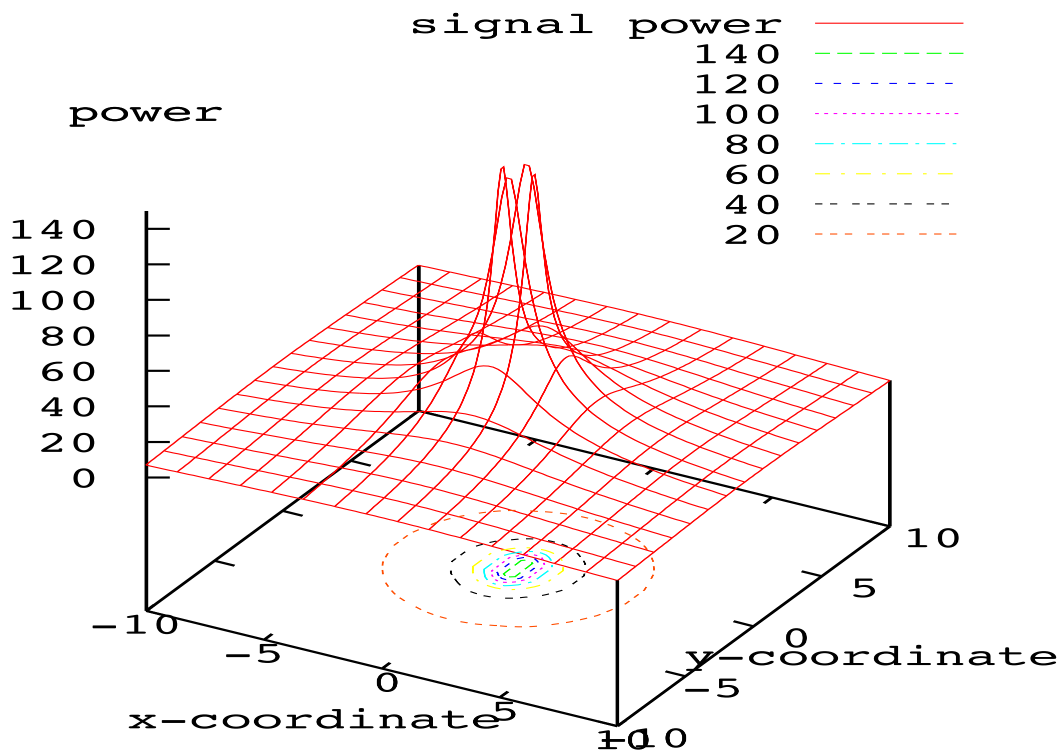
$\rightarrow$ quadratic decrease in distance

$\rightarrow$ quadratic decrease in frequency

$\rightarrow$ idealized case: free space

$\rightarrow$ in-doors and mobility: more complicated

Power profile in 2-D space:



$\rightarrow$ sender located at the center

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

Design implications:

- coverage limited primarily by distance

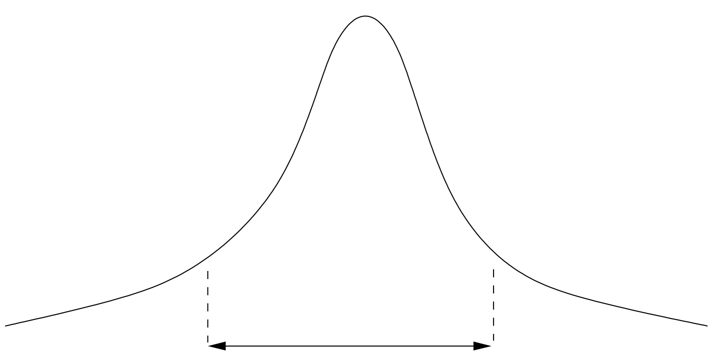
  → impacts SNR (signal-to-noise ratio)

  → the farther away, the weaker the signal

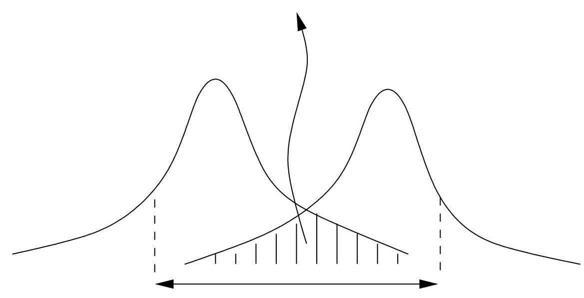
  → in CSMA: SIR (signal-to-interference ratio)

  → 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

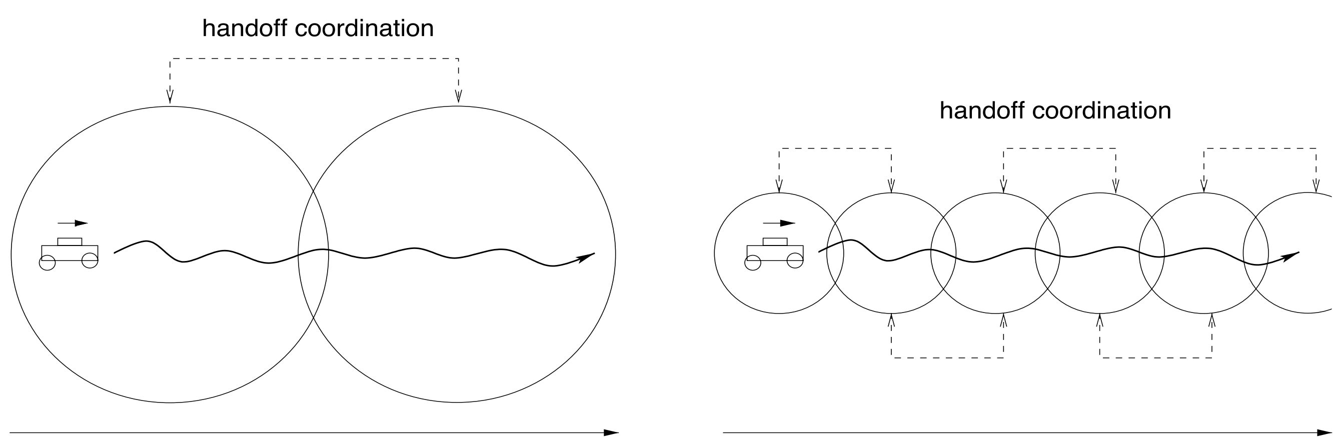
  → but good because less crowding

  → also enables frequency reuse (think of radio station)

  → good: increased battery life if base station is mobile

  → bad: more antennae required

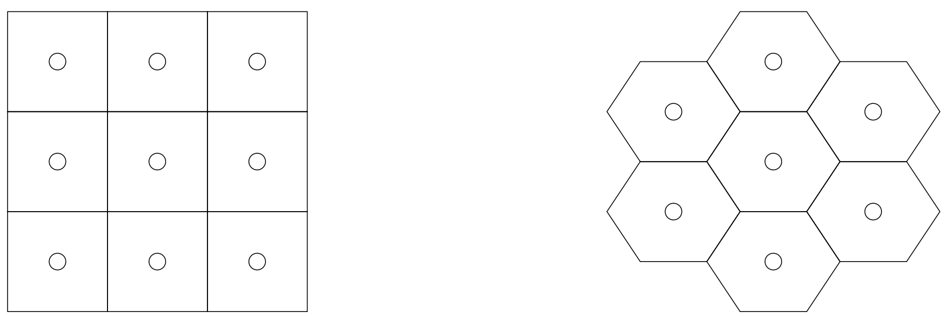
  → also creates handoff coordination overhead (e.g., I65)



Cellular Networks:

→ network of wireless base stations

Can view as:



→ both affect tiling of the plane

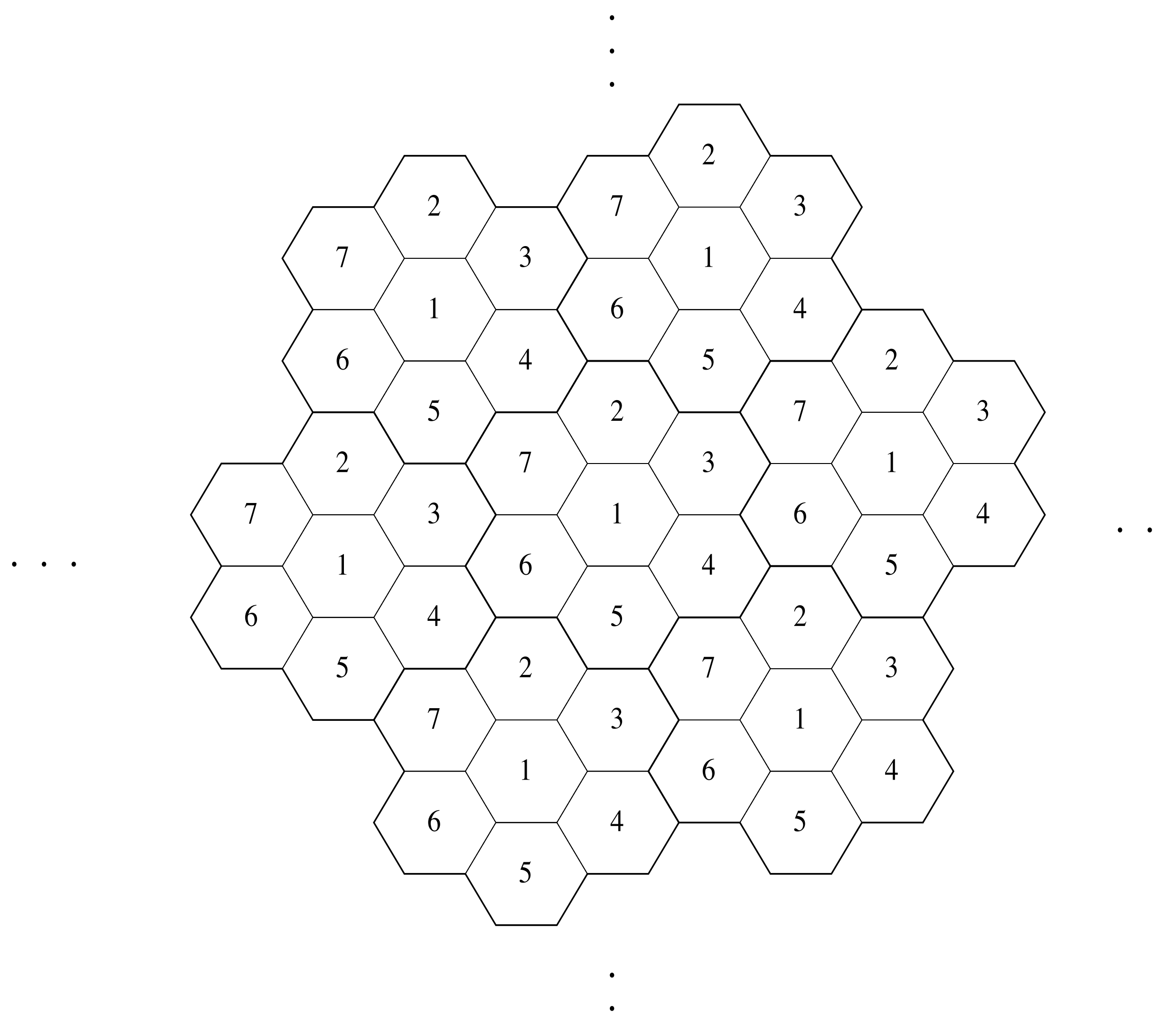
→ why hexagonal?

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

→ avoid interference

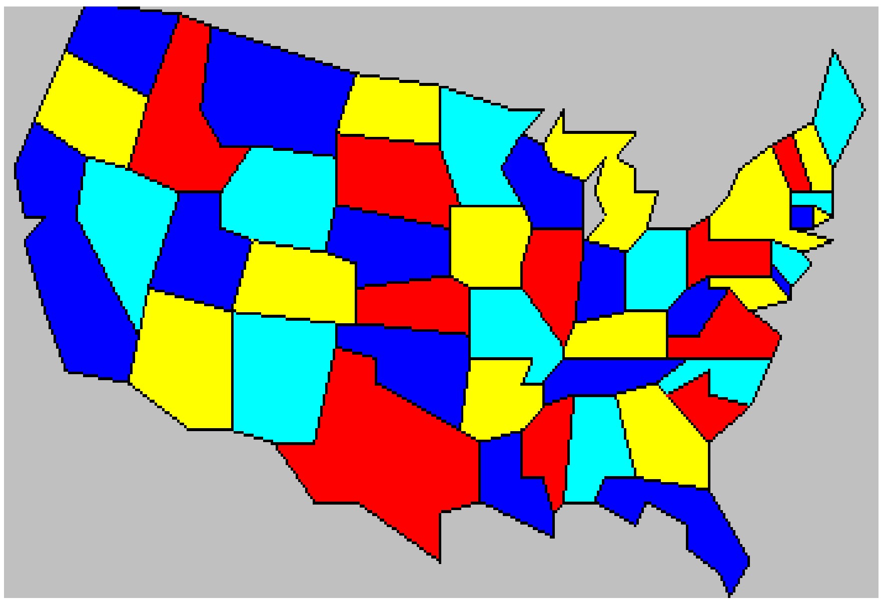
→ how many frequencies are required?

For example, using seven frequencies:



$\longrightarrow$ in general, coloring problem

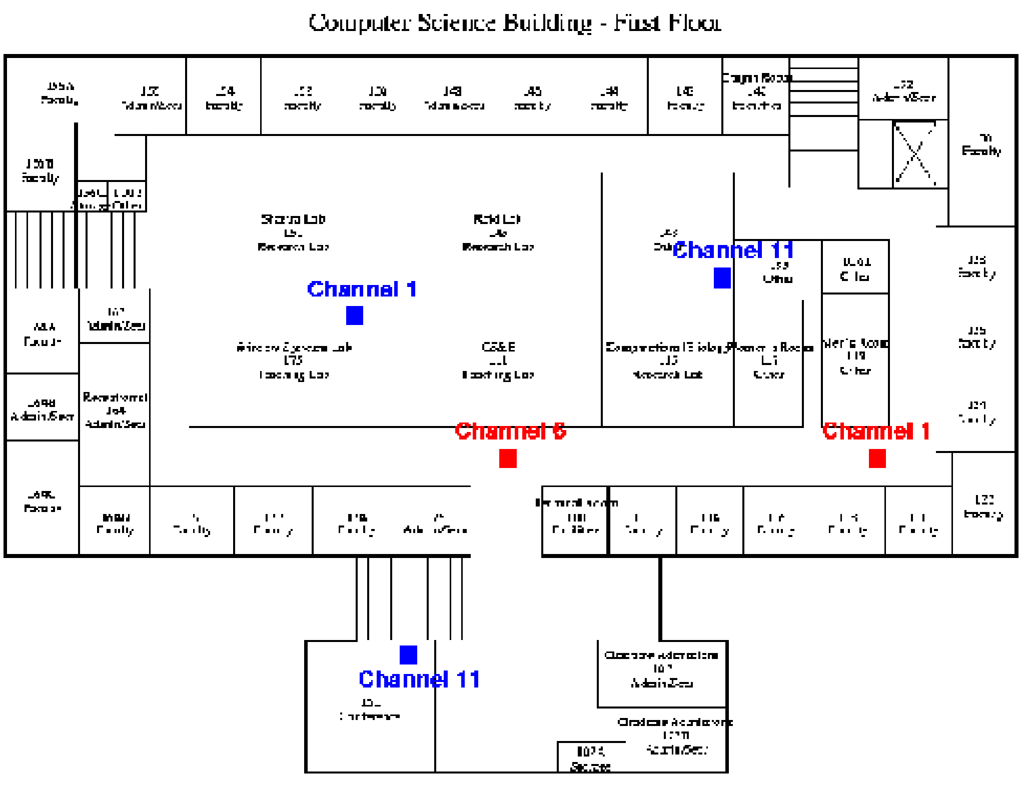
4-coloring of U.S. map:



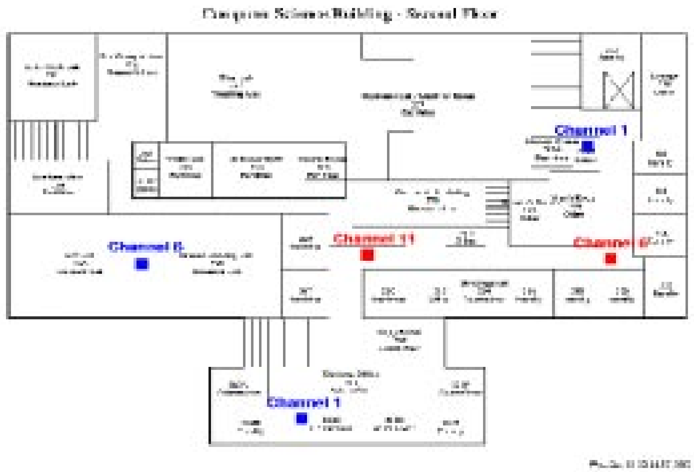
$\longrightarrow$ Y. Kanada, Y. Sato; Univ. of Tokyo

Old CS Building (aka HAAS):

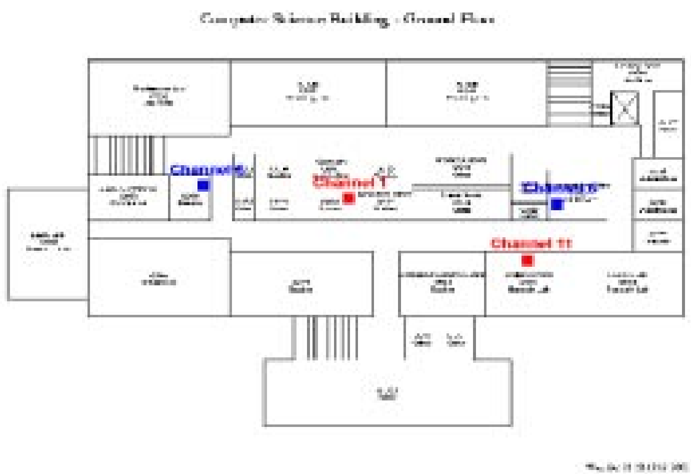
First floor frequency reuse:



Second floor frequency reuse:

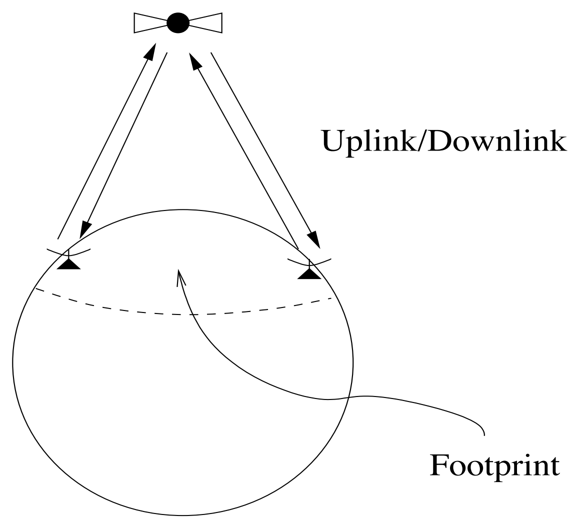


Ground floor frequency reuse:



Long Distance Wireless Communication

Principally satellite communication:



- LOS (line of sight) communication

  → satellite base station is relay
- Effective for broadcast
- Limited bandwidth

MAC protocols:

- FDMA + TDMA: dominant

  $\rightarrow$ broadband

  $\rightarrow$ GSM cellular

  $\rightarrow$ recently: OFDM

- CDMA: e.g., GPS and defense related systems
- CSMA: viable?

Long-distance wireless communication: useful for broadcast service

$\longrightarrow$ subset of killer applications

$\longrightarrow$ e.g., TV, GPS, digital radio, atomic clock

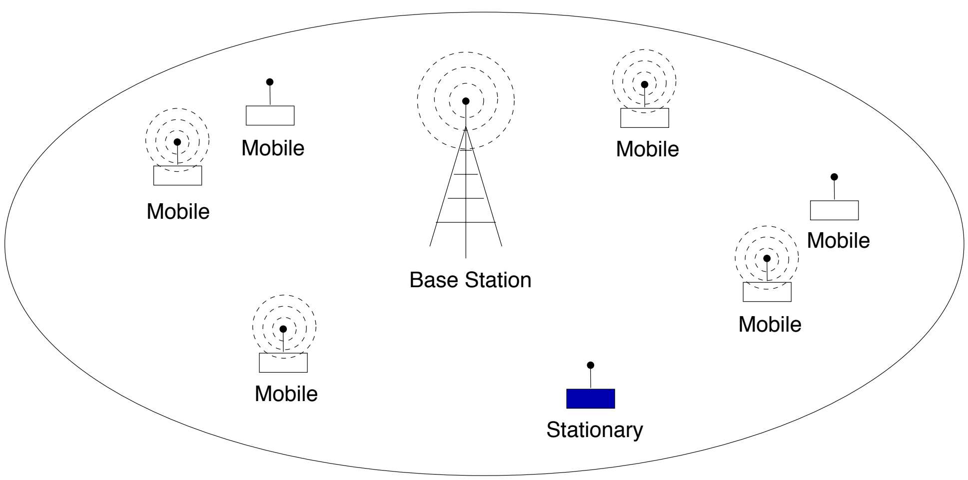
$\longrightarrow$ not suited for Internet access service!

Short Distance Wireless Communication

- medium: wireless MAN (IEEE 802.16)
- short: wireless LAN (IEEE 802.11)
- very short: wireless PAN (IEEE 802.15)

  → home area networks

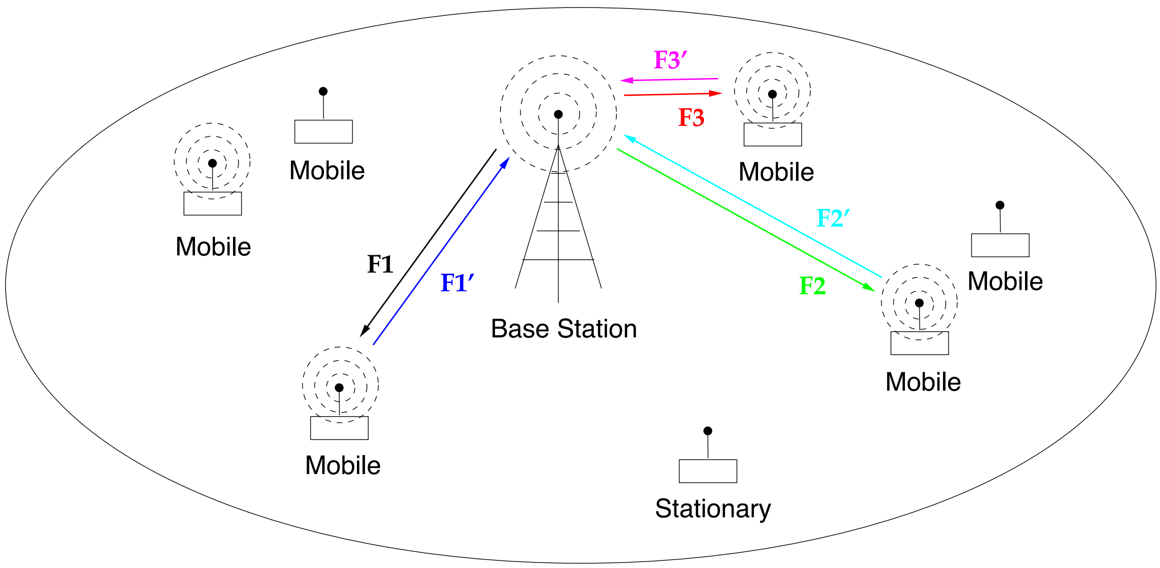
  → near field communication (e.g., RFID)



⟶ OFDM, FDMA, TDMA, CDMA, SDM/MIMO

⟶ contention-based multiple access (CSMA)

Cellular telephony: TDMA (frequency and time division)



FDD & TDMA

Ex.: GSM (U.S. IS-136) with 25 MHz frequency band

- uplink: 890–915 MHz
- downlink: 935–960 MHz
- 125 channels 200 kHz wide each ($= 25000 \div 200$)

  $\longrightarrow$ separation needed due to cross-carrier interference

  $\longrightarrow$ FDMA; higher spectral efficiency with OFDMA

- 8 time slots within each channel (i.e., carrier frequency)

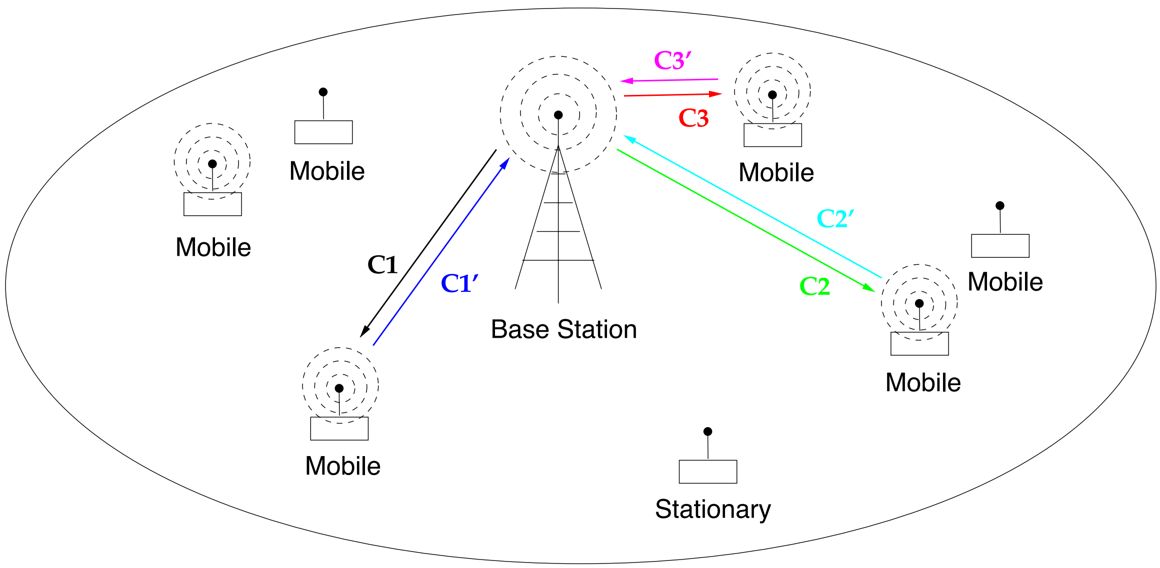
  $\rightarrow$ TDM component
- total of 1000 possible user channels

  $\rightarrow 125 \times 8$ (124×8 realized)
- codec/vocoder (i.e., compression): 13.4 kbps
- compare with T1 standard

  $\rightarrow$ 24 users at 64 kbps data rate each

  $\rightarrow$ 64 kbps vs. 13.4 kbps: landline has clearer sound

Cellular telephony: CDMA



FDD & CDMA

$\longrightarrow$ different code (i.e., basis vector) per user

Ex.: IS-95 CDMA with 25 MHz frequency band

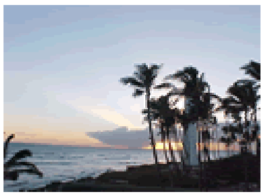
- uplink: 824–849 MHz; downlink: 869–894 MHz

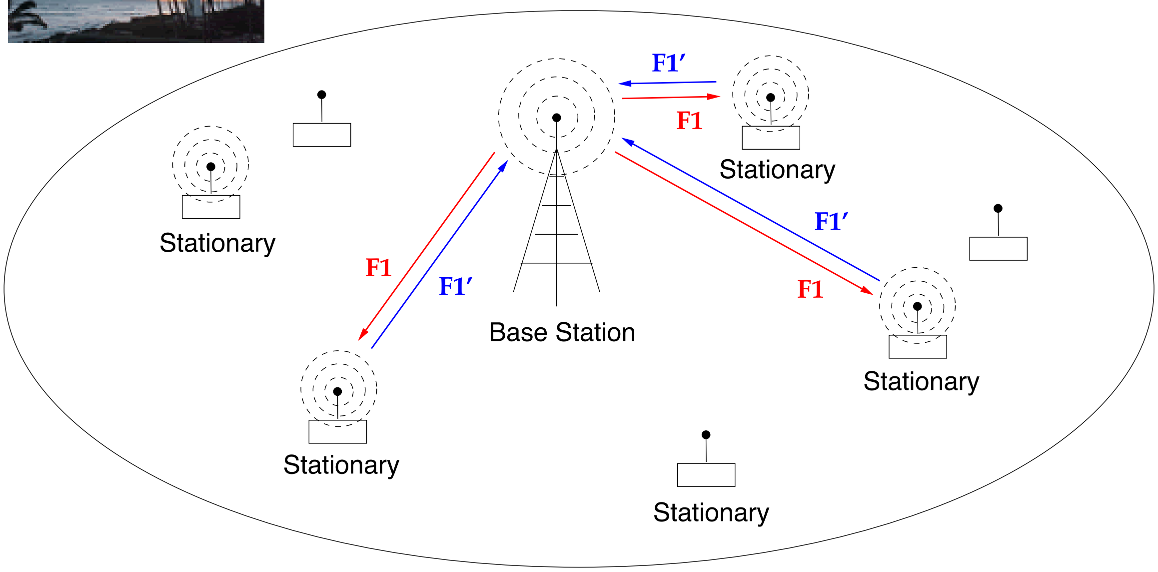
  $\rightarrow$ no separate carrier frequencies

  $\rightarrow$ everyone shares same 25 MHz band

- codec: 9.6 kb/s

Packet radio: ALOHA





ALOHA

$\longrightarrow$ downlink broadcast channel $F1$

$\longrightarrow$ shared uplink channel $F1'$

Ex.: ALOHANET

- data network over radio frequency
- Univ. of Hawaii, 1970; 4 islands, 7 campuses

- Norm Abramson

  → precursor to Ethernet (Bob Metcalfe)

  → pioneering Internet technology

  → parallel to wired packet switching technology

- FM carrier frequency

  → uplink: 407.35 MHz; downlink: 413.475 MHz

- bit rate: 9.6 kb/s

- contention-based multiple access: MA

  → plain and simple

  → needs explicit ACK frames