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

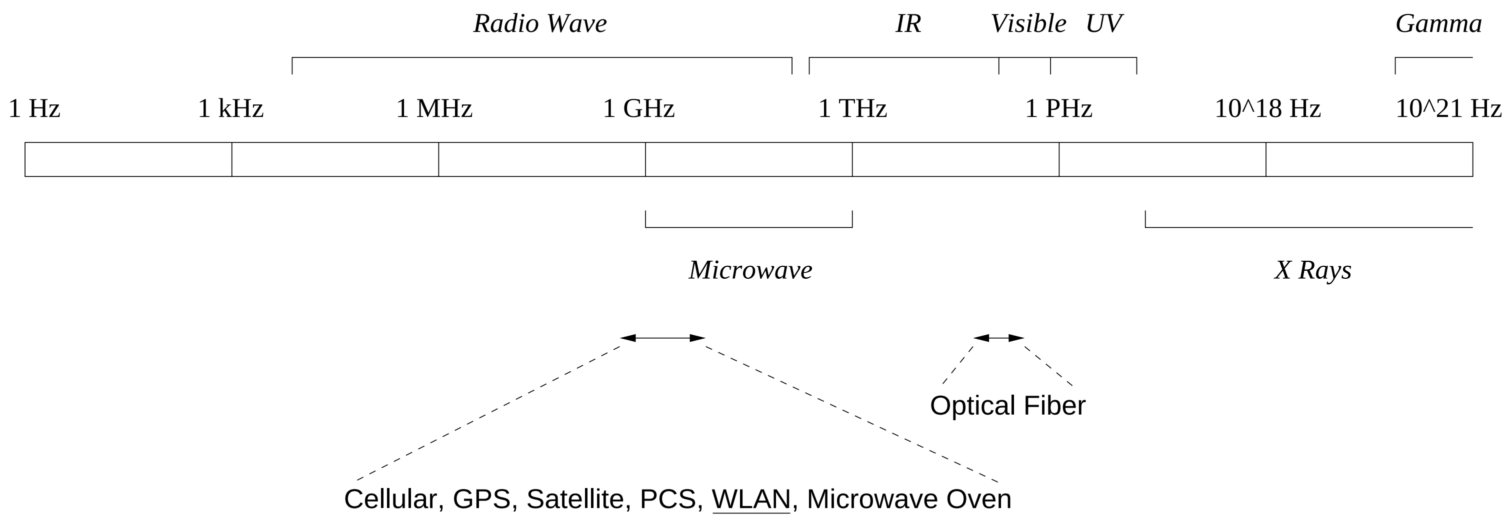
$\longrightarrow$ high and low bandwidth coexist

$\longrightarrow$ 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 $\sim$0.8 GHz–6 GHz

$\longrightarrow$ Optical fiber: $\sim$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)

  $\longrightarrow$ 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

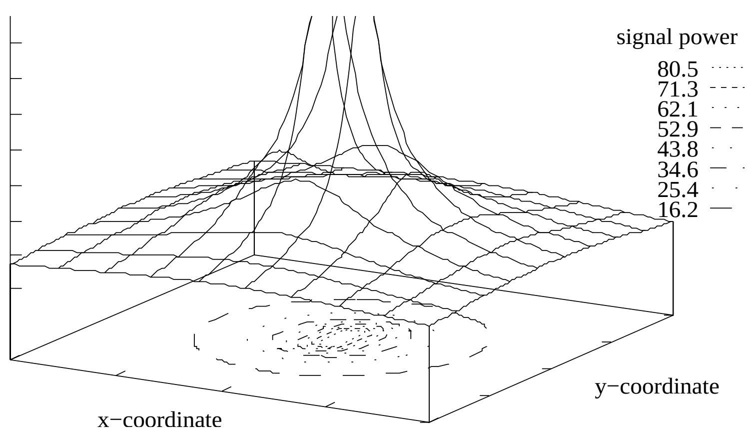
Signal Propagation and Power

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

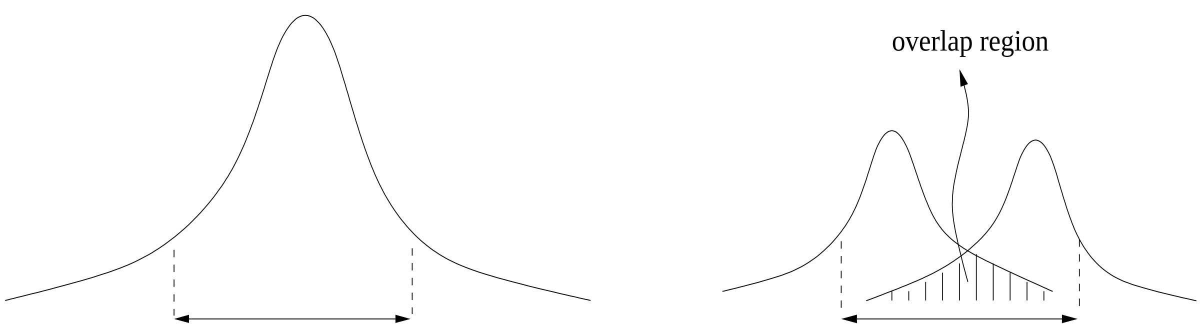


Design implications:

- 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

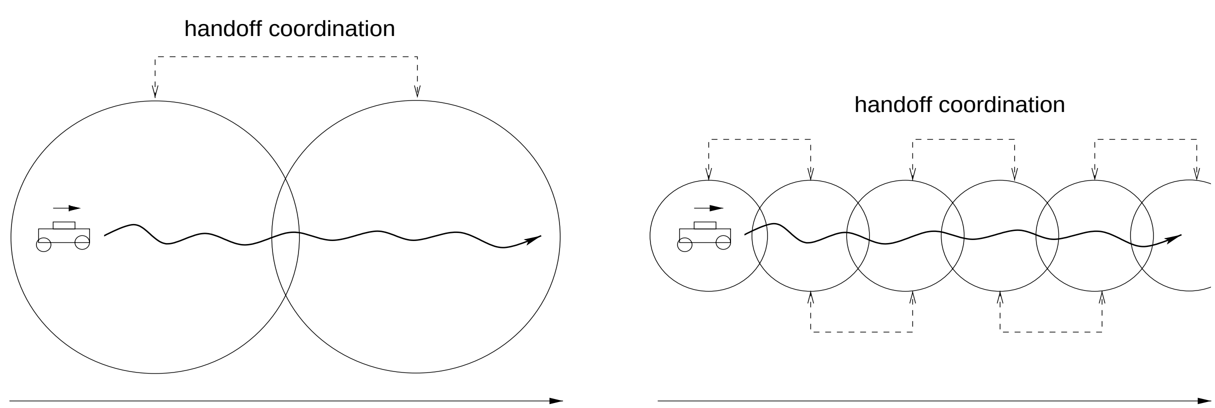
  $\longrightarrow$ increased battery life

  $\longrightarrow$ enables frequency reuse

  $\longrightarrow$ more antennas required

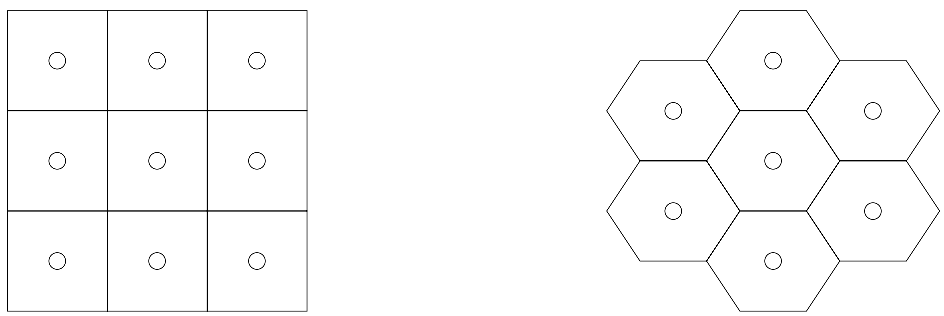
  $\longrightarrow$ handoff coordination overhead

  $\longrightarrow$ e.g., I65 from Lafayette to Indy



Cellular Networks

Hexagonal cells:



$\longrightarrow$ both affect tiling of the plane

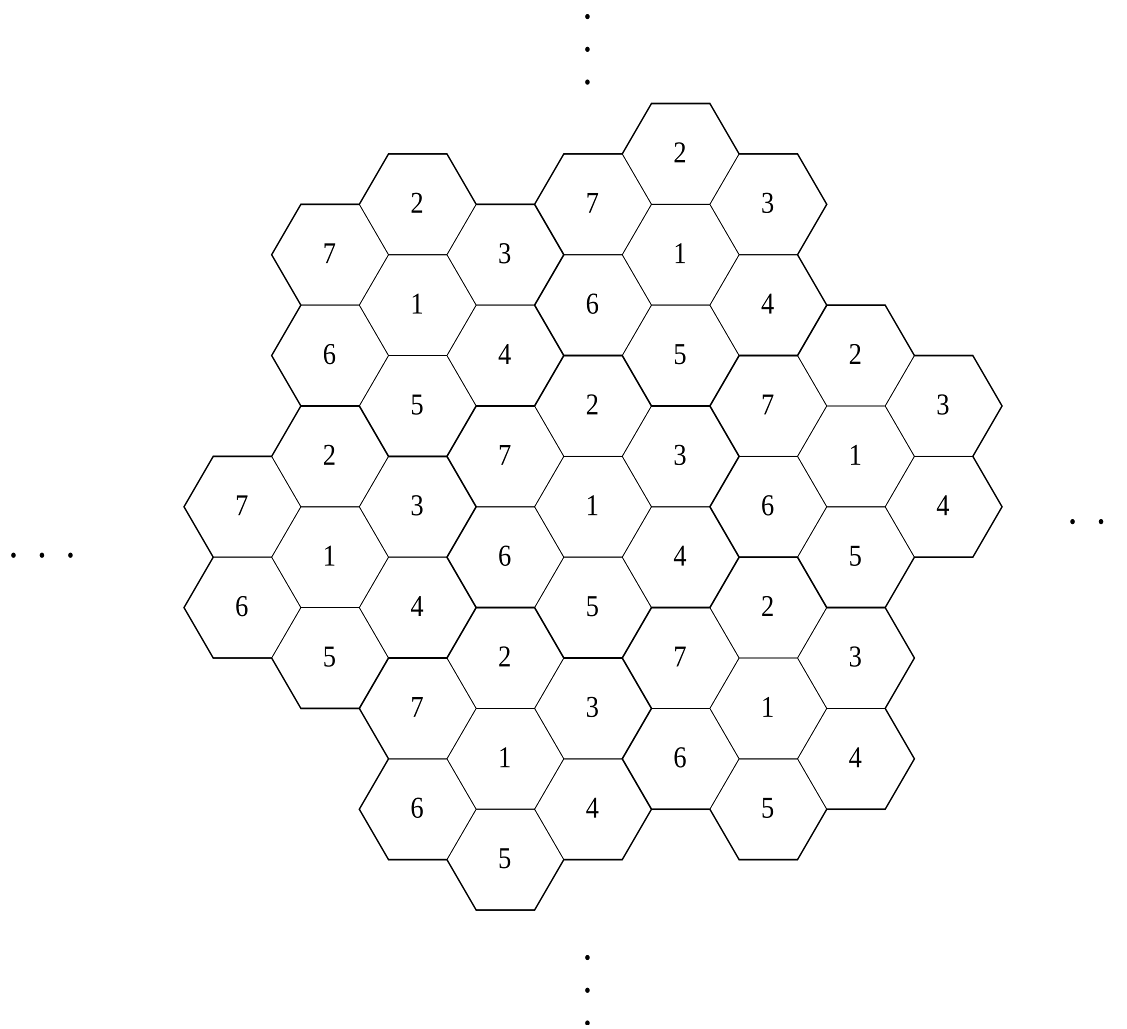
$\longrightarrow$ why hexagonal?

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

$\longrightarrow$ avoid interference

$\longrightarrow$ how many frequencies are required?

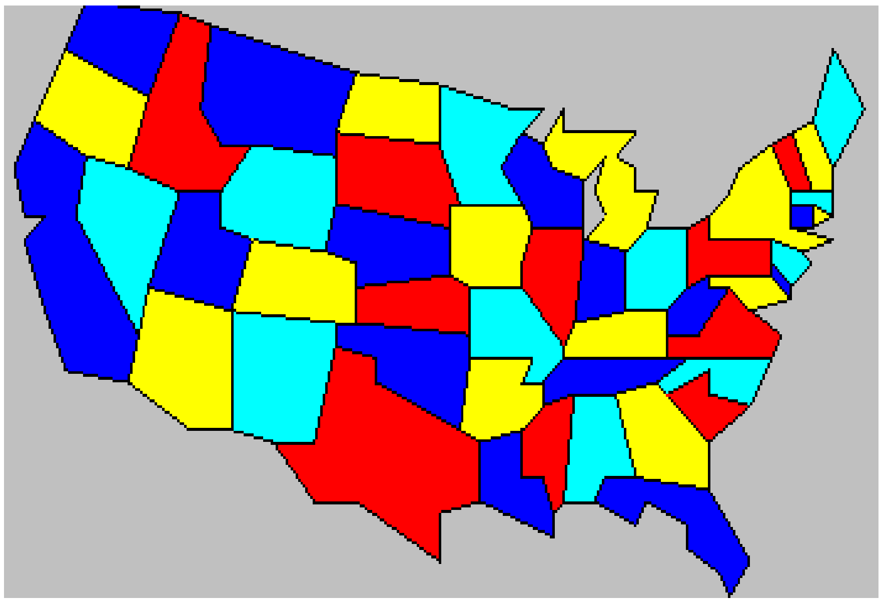
For example, using seven frequencies:



⟶ why does it work?

⟶ in general, coloring problem

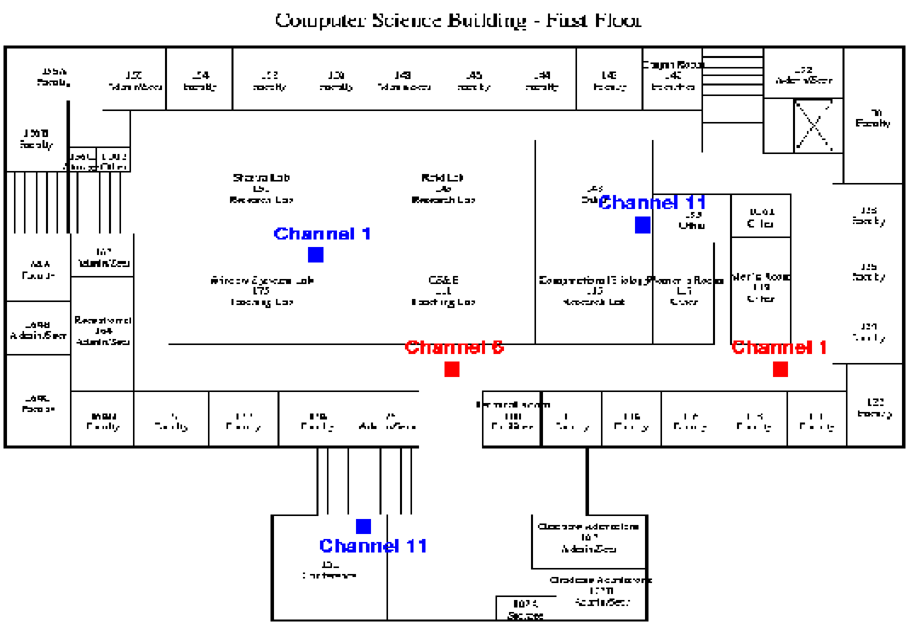
4-coloring of U.S. map:



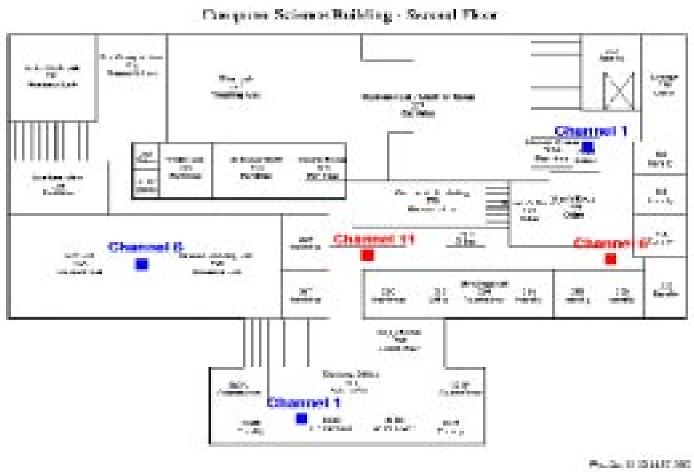
$\longrightarrow$ Y. Kanada, Y. Sato; Univ. of Tokyo

CS Building:

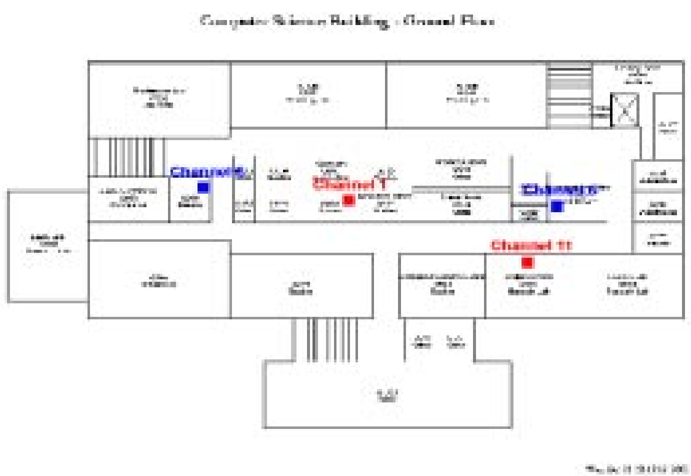
First floor frequency reuse:



Second floor frequency reuse:

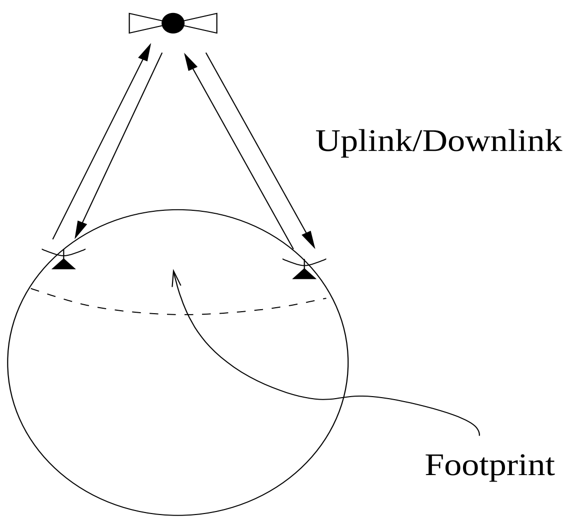


Ground floor frequency reuse:



Long Distance Wireless Communication

Principally satellite communication:



- LOS (line of sight) communication

  $\longrightarrow$ satellite base station is relay

- Effective for broadcast
- Limited bandwidth for multi-access

  $\longrightarrow$ not scalable

Multi-access protocols:

- FDM + TDMA: dominant

  $\longrightarrow$ broadband

  $\longrightarrow$ GSM cellular

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

  $\longrightarrow$ CDMA cellular (Qualcomm)

- CSMA/CA: impractical due to large RTT

  $\longrightarrow$ low utilization/throughput

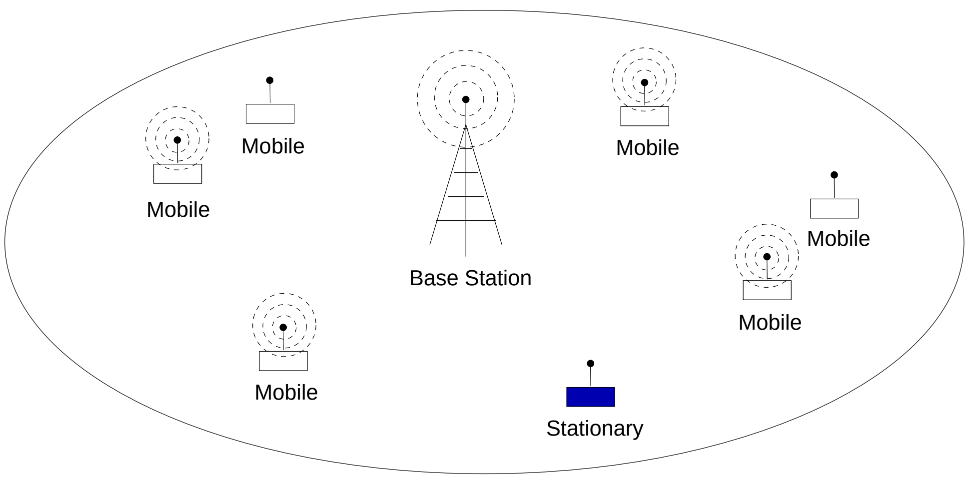
Long-distance wireless communication: effective when broadcasting

$\longrightarrow$ special applications

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

Short Distance Wireless Communication

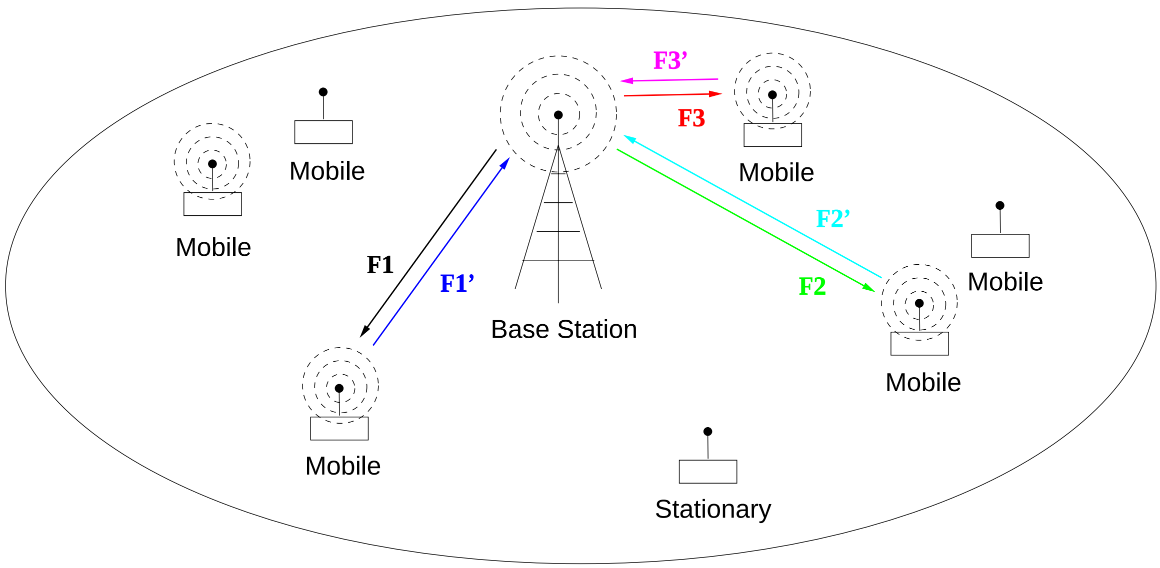
- very short: wireless PAN
- short: wireless LAN
- medium: wireless MAN



⟶ TDMA, FDMA, CDMA, polling

⟶ contention-based multiple access w/o priority

Cellular telephony: frequency & 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

  $\longrightarrow$ FDM portion

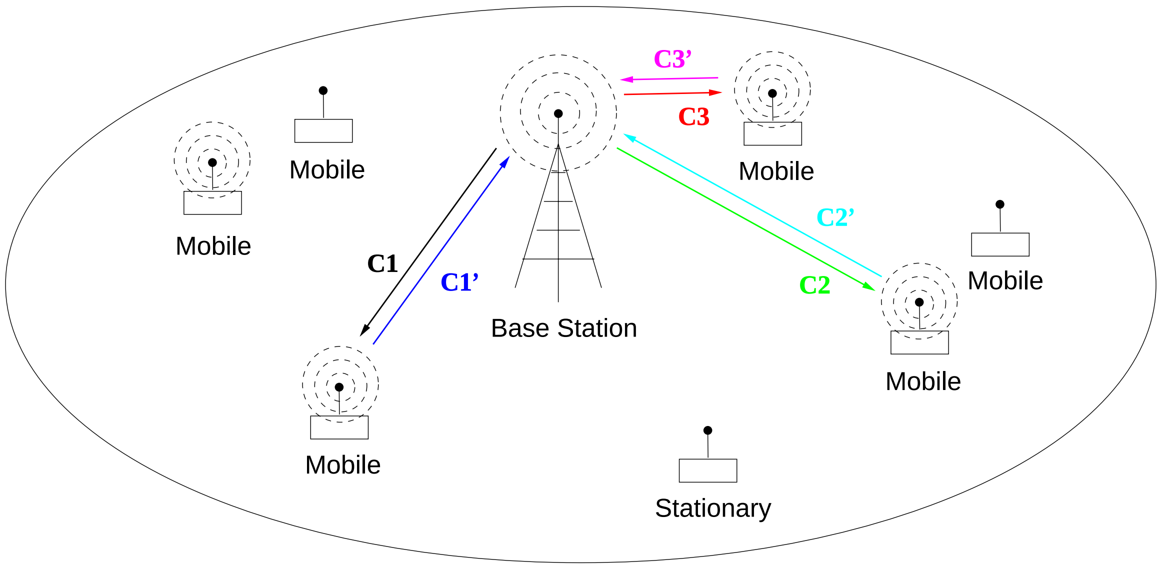
- 8 time slots within each channel

  → TDM portion
- total of 1000 possible user channels

  → 125×8 (124×8 realized)
- codec/vocoder: 13.4 kb/s
- compare with T1 standard

  → 24 users at 64 kb/s data rate each

Cellular telephony: code division multiplexing



FDD & CDMA

$\longrightarrow$ same frequency band; different codes

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

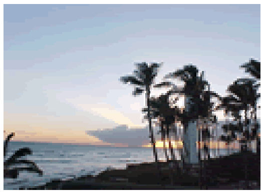
- uplink: 824–849 MHz; downlink: 869–894 MHz

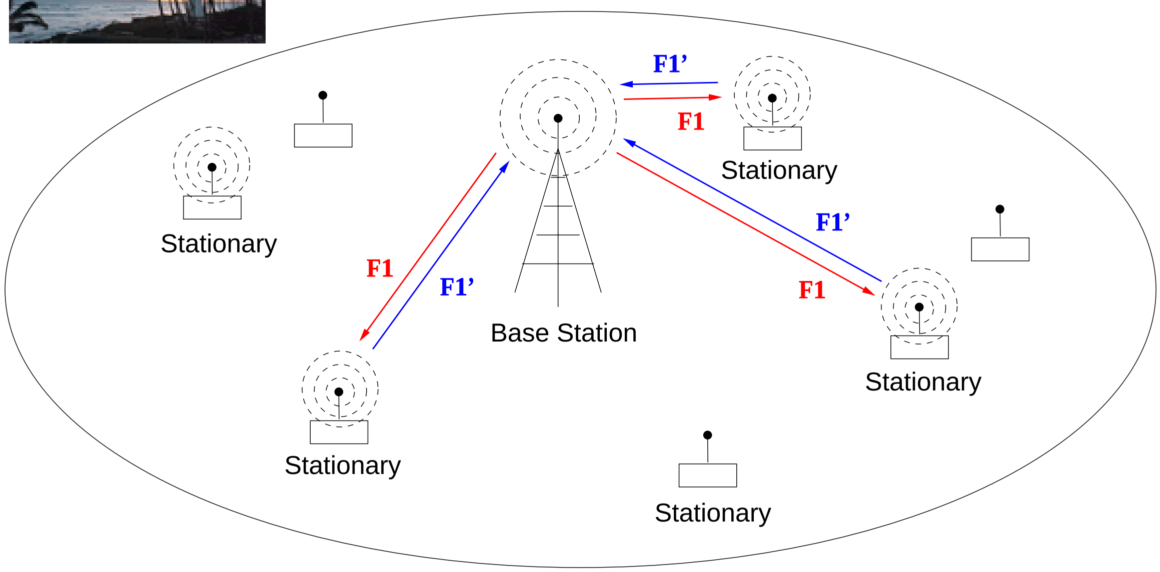
  $\rightarrow$ downlink: prepared; uplink: physical diversity

  $\rightarrow$ capture effect: closer station has advantage

- codec: 9.6 kb/s

Packet radio: ALOHA





ALOHA

$\longrightarrow$ downlink broadcast channel $F1$

$\longrightarrow$ shared uplink channel $F1'$

$\longrightarrow$ both baseband

Ex.: ALOHANET

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

- Norm Abramson

  → precursor to Ethernet (Bob Metcalfe)

  → pioneering Internet technology

  → parallel to packet switching technology

- FM radio carrier frequency

  → uplink: 407.35 MHz; downlink: 413.475 MHz

- bit rate: 9.6 kb/s

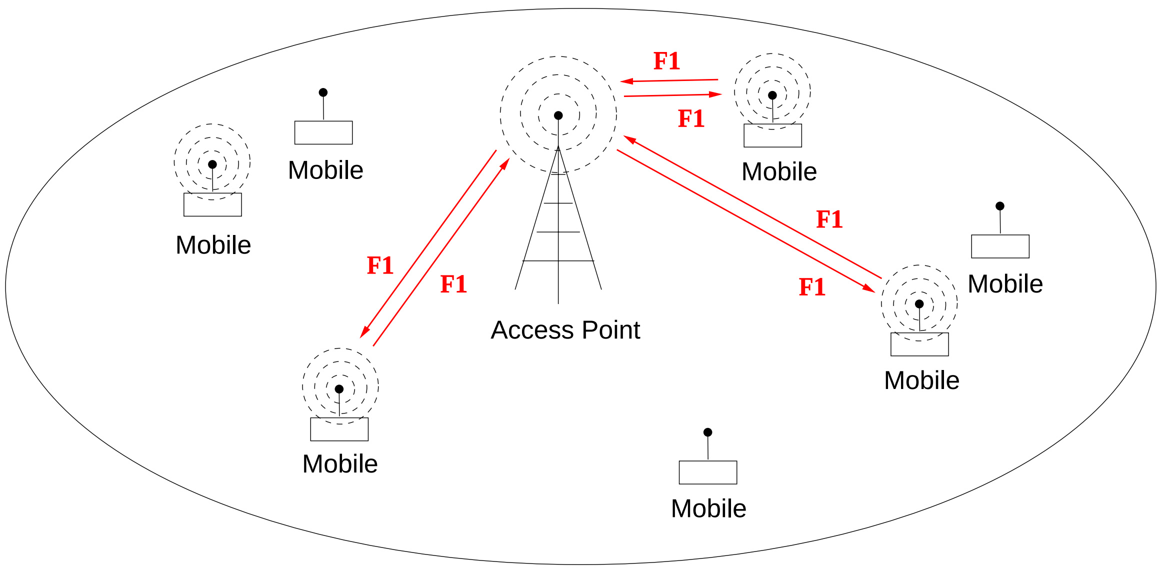
- contention-based multiple access: MA

  → plain and simple

  → needs explicit ACK frames

  → ALOHA

Wireless LAN (WLAN): infrastructure mode



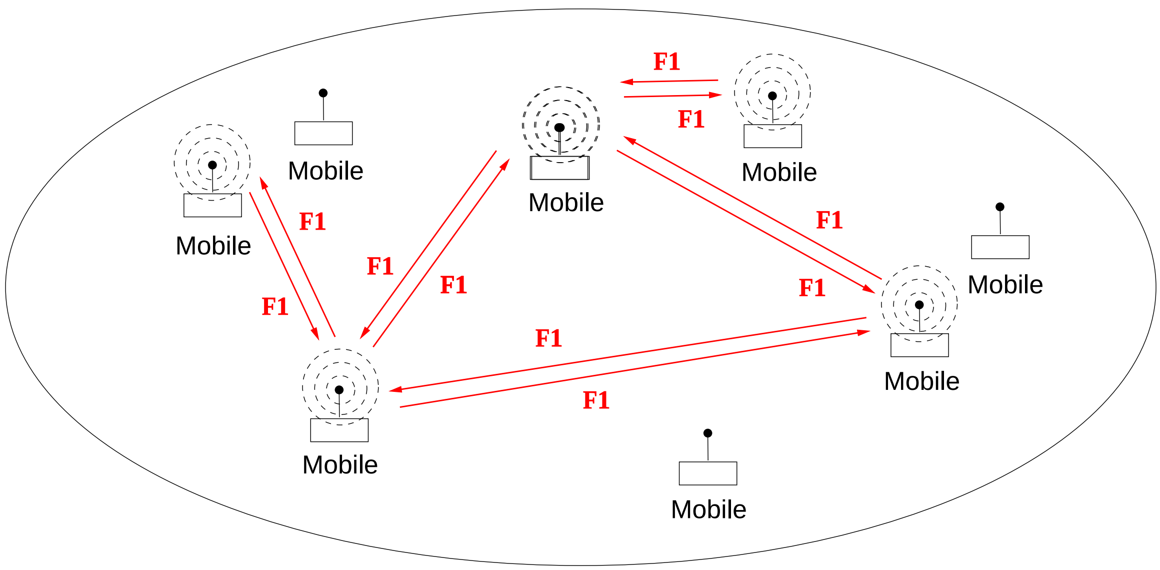
WLAN: Infrastructure Network

$\longrightarrow$ shared uplink & downlink channel $F1$

$\longrightarrow$ single baseband channel

- basic service set (BSS)
- base station: access point (AP)
- mobile stations must communicate through AP

WLAN: ad hoc mode



WLAN: Ad Hoc Network

$\longrightarrow$ homogeneous: no base station

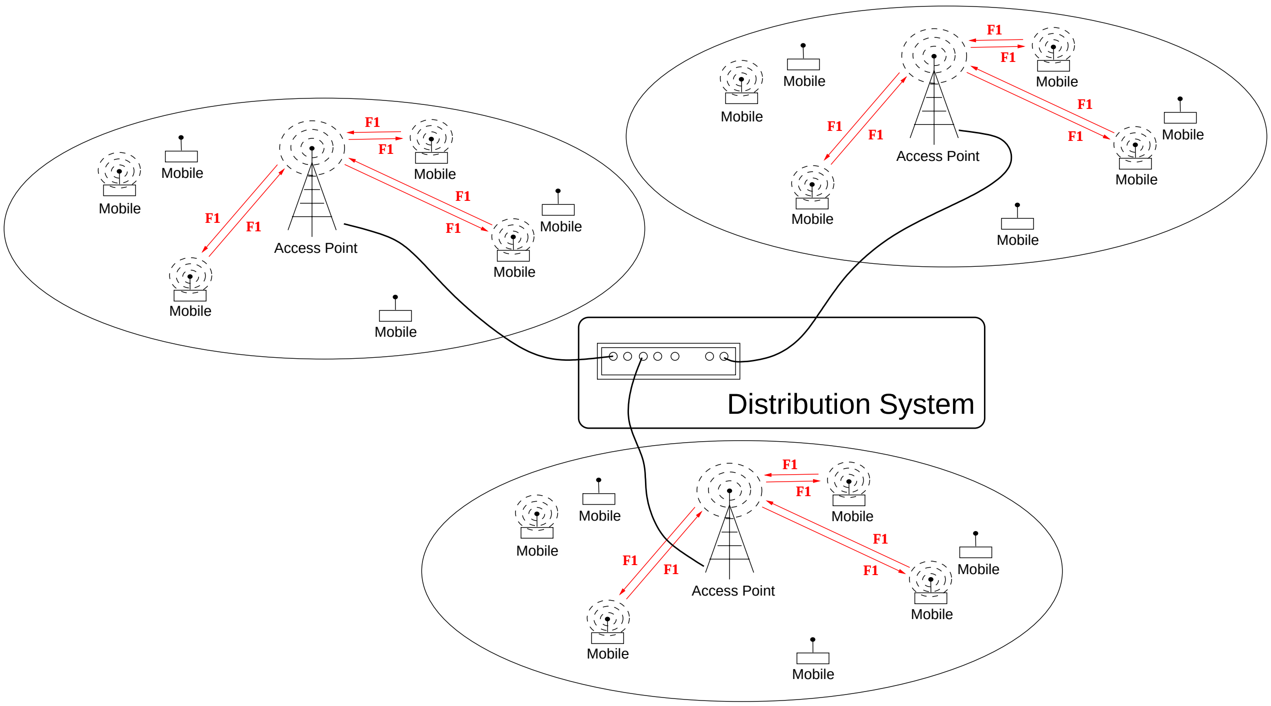
$\longrightarrow$ everyone is the same

$\longrightarrow$ share forwarding responsibility

- independent basic service set (IBSS)
- mobile stations communicate peer-to-peer

$\rightarrow$ also called peer-to-peer mode

WLAN: internetworking



WLAN: Extended Service Set

⟶ internetworking between BSS's through APs

⟶ mobility and handoff

- extended service set (ESS)
- APs are connected by distribution system (DS)

- DS: wireline or wireless

  $\longrightarrow$ common: Ethernet switch

- How do APs and Ethernet switches know where to forward frames?

  $\longrightarrow$ bridge: link layer forwarding device

  $\longrightarrow$ i.e., switch using MAC address relay

  $\longrightarrow$ learning bridge: source address discovery

  $\longrightarrow$ spanning tree: IEEE 802.1 (Perlman's algorithm)

  $\longrightarrow$ distributed ST & leader election

Additional headache: mobility

$\longrightarrow$ how to perform handoff

$\longrightarrow$ mobility management at MAC

$\longrightarrow$ mobility management at IP (Mobile IP)

Mobility between BSSes in an ESS

- association

  $\rightarrow$ registration process

  $\rightarrow$ mobile station (MS) associates with one AP

- disassociation

  $\rightarrow$ upon permanent departure: notification

- reassociation

  $\rightarrow$ movement of MS from one AP to another

  $\rightarrow$ inform new AP of old AP

  $\rightarrow$ forwarding of buffered frames

WLAN spectrum 2.4–2.4835 GHz:

$\longrightarrow$ 11 channels (U.S.)

$\longrightarrow$ 2.412 GHz, 2.417 GHz, . . ., 2.462 GHz

Non-interference specification:

- each channel has 22 MHz bandwidth
- require 25 MHz channel separation

  $\longrightarrow$ thus, only 3 concurrent channels possible

  $\longrightarrow$ e.g., channels 1, 6 and 11

  $\longrightarrow$ 3-coloring. . .