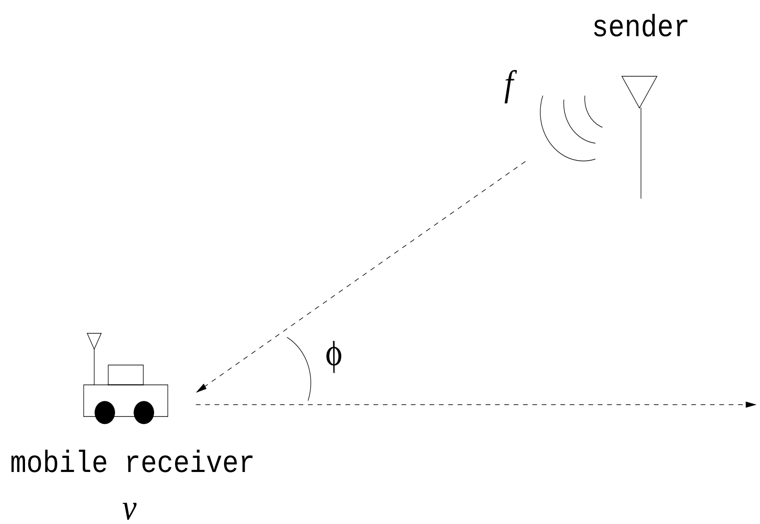
Impact of mobility: Doppler frequency shift and fading

First, Doppler frequency shift

Set-up:

- mobile (e.g., car, train, pedestrian) travels in straight line at speed v mph
- sender transmits data on carrier frequency f Hz
- angle between mobile and sender is θ



$\rightarrow$ frequency experienced by mobile is not f but distorted version of f: call it f'

Distorted frequency under Doppler effect:

$$f' = f + f\left(\frac{v}{\text{SOL}}\cos\phi\right)$$

Hence:

- $\phi = 0$ deg: "head-on collision"

  → frequency experienced: fastest

- $\phi = 180$ deg: "going on oppostive direction"

  → frequency experienced: slowest

- $\phi = 90$ deg: "at right angle"

  → no distortion

Ex.: carrier frequency f 1.8 GHz

→ 4 mph: 10 Hz, 40 mph: 100 Hz

Depending upon PHY layer encoding:

→ bit flips may occur

Second, fading

→ fading: means that signal is changing, often weakening

→ consider city environment with many buildings and no direct line of sight between sender and receiver

Assumption: received signal is comprised of bounced off copies (i.e., echos) from buildings and other reflective obstructions

→ called multi-path propagation

Clarke's fading model:

if there are many echos and the echos are independent of each other

then the average signal strength of the echos has a Gaussian (i.e., normal) distribution

$\rightarrow$ central limit theorem

$\rightarrow$ called Rayleigh fading

Thus: mobile's signal strength fluctuates erratically

→ fading plus Doppler shift

→ may lead to bit flips

→ knowing the statistical properties of signal fluctuation helps with applying error correction

→ FEC is common in wireless networks (e.g., WiFi)

What about the case when the mobile (in a city environment) becomes stationary?

→ e.g., sitting at a coffee shop and checking e-mail on pre-4G phone?

Outdoors: signal strength rapidly decreases with distance

→ recall: signal diminishes as $1/d^2$

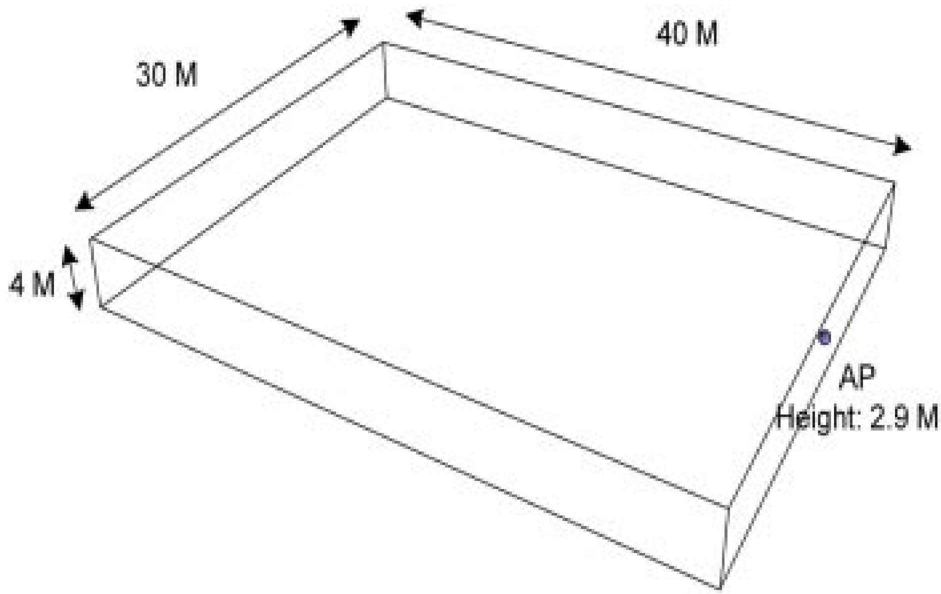
→ plus signal fluctuation: Rayleigh fading

Indoor environment: more complex

→ distance need not be dominant factor

→ a new factor: spatial diversity

Consider an empty room:



→ large lecture room

→ no obstructions

→ e.g., 802.11 WLAN hot spot

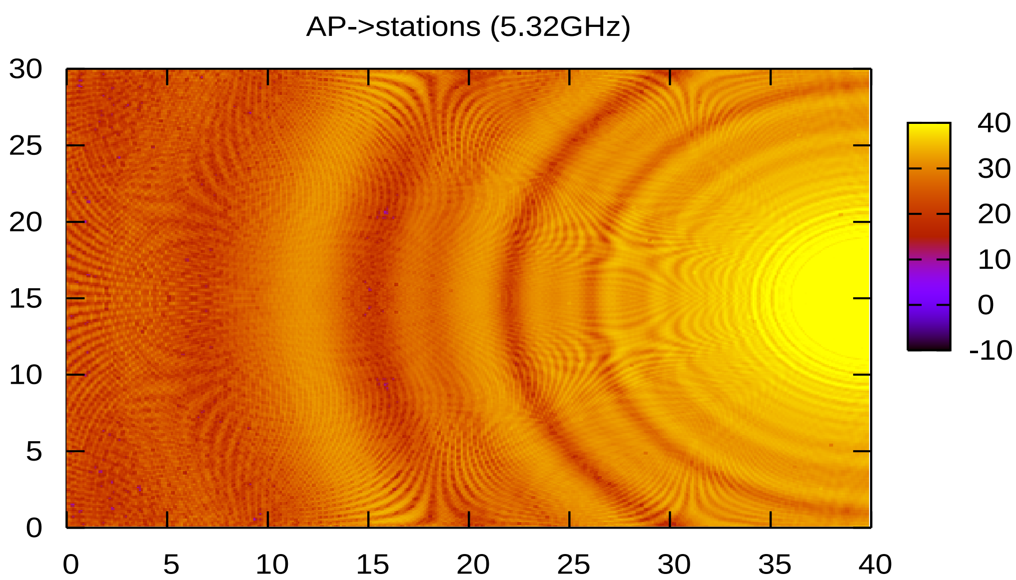
→ AP sends out signal at 2.4 (802.11b/g) or 5 GHz (802.11a/n) frequency

→ how does indoor signal reception look like?

Signal strength reception at table height 0.7 m:

→ carrier frequency: 5.32 GHz

→ channel 8 in U.S. (12 channels in 5 GHz 802.11a/n)

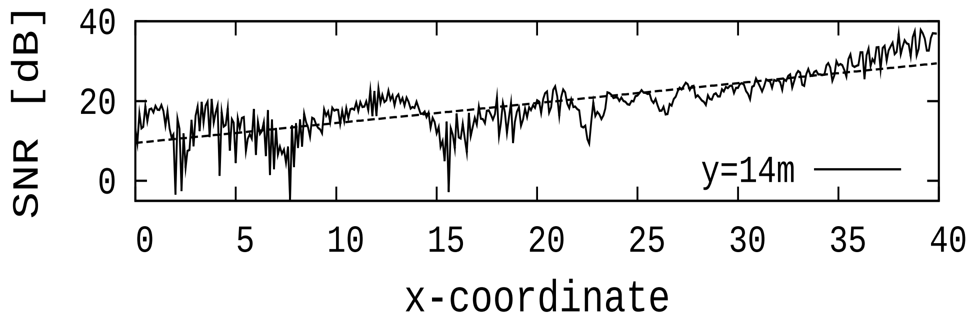


→ distance does not determine signal strength

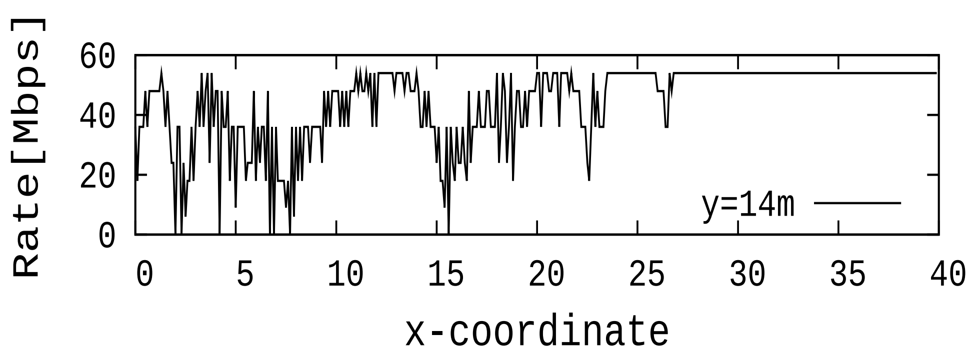
→ signal irregularity: called spatial diversity

Impact on throughput:

→ SNR and throughput along straight line



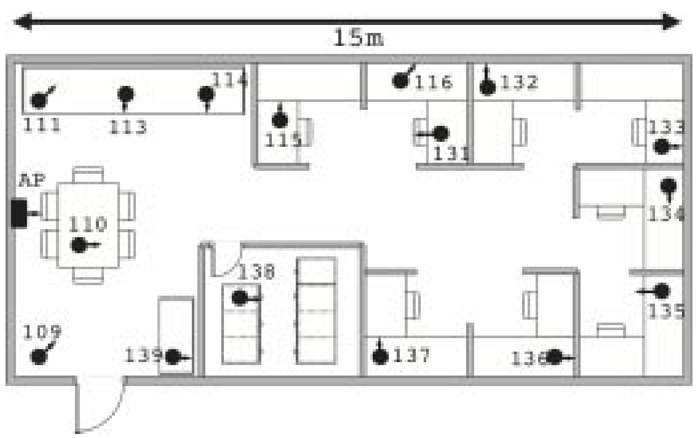
→ SNR: significant variation



→ good locations, bad locations

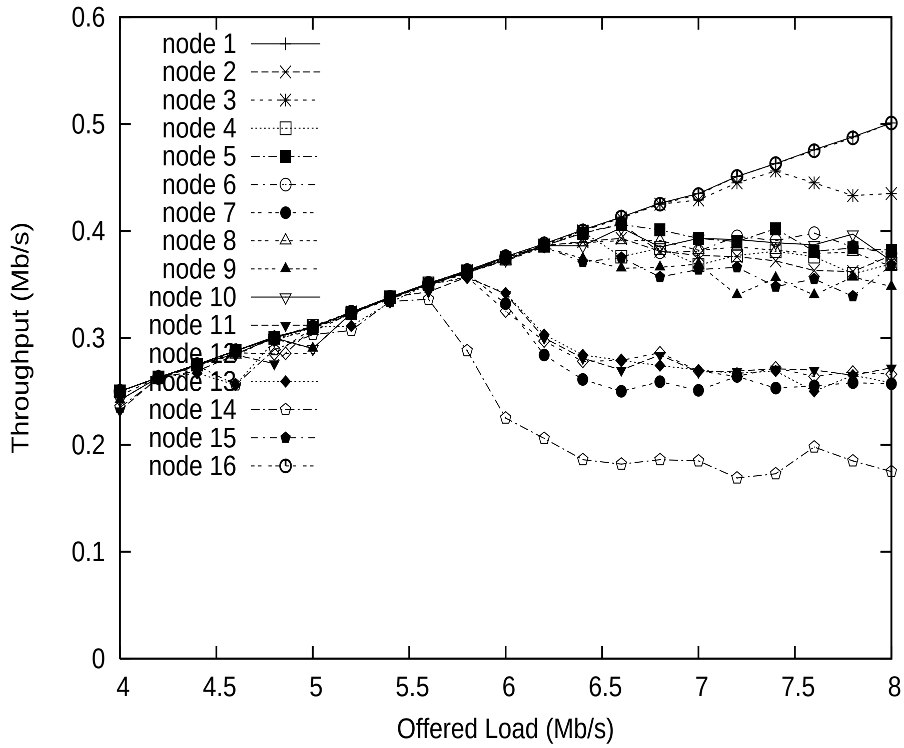
→ can lead to unfairness and even starvation

Indoor office 802.11 WLAN hot spot (HAAS G50):



Throughput share of 16 HP/Compaq pocket PCs:

→ uplink CSMA competition



→ significant unfairness: why?

Spatial diversity:

Location—not distance from AP—is determining factor

→ switching around the handhelds doesn't change throughput

Persistent unfairness

→ bad location remains bad location, good location remains good location

What causes uneven—some say chaotic—signal strength distribution in indoor environments?

Unique feature of wireless networks: wave interference

$\rightarrow$ multi-path reflections (aka echos) interact

$\rightarrow$ constructive vs. destructive interference

Ex.: constructive

$\rightarrow$ two sine waves both of frequency f meet constructively

$$\sin f + \sin f = 2 \sin f$$

Ex.: destructive

$\rightarrow$ two sine waves of frequency f and $f + \pi$ meet destructively

$$\sin f + \sin(f + \pi) = 0$$

Note: second sine wave is phase-shifted by 180 degrees

$\rightarrow$ multi-path reflection causes phase shifting

$\rightarrow$ longer distance to travel

Consequence indoors: good and bad reception spots cause by wave interference

Significant real-world consequences:

1. Unfair throughput in WiFi hot spots

→ depends on location: good or bad spot

→ closeness to AP not determining factor (unless very close)

→ unfairness in networks is a big deal

→ a key goal of network protocols: fairness

→ e.g., CSMA is fair—if signal strengths are uniform

→ another source of throughput unfairness in networks we have seen?

2. WiFi NICs are half-duplex

→ cannot send and receive at the same time

→ recent proposal for full-duplex: echo cancellation using 3 antennas

→ two send antennas: how?

3. Indoor triangulation using signal strength is difficult

→ companies: indoor employee location tracking software

→ NIC reports RSSI (received signal strength indication)

→ full range: 0–255

→ RSSI_Max capped by different chipset vendors (e.g., 127 Atheros)

→ key problem: spatial diversity

Solutions: what can be done?

First, for sliding window whose throughput decreases with RTT

→ no good solution

→ e.g., increasing window size too much has negative side effects

Second, spatial diversity in indoor wireless networks

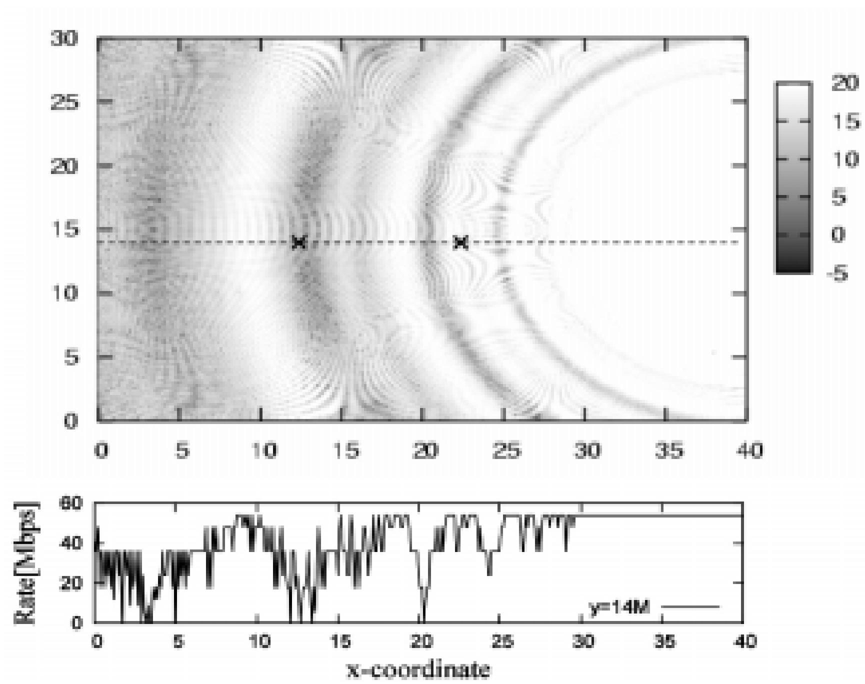
→ moving around: even a little (inches) can help

→ does increasing power help?

Changing carrier frequency (i.e., channels) can help:

→ good/bad location depends on frequency

Carrier frequency 5.805 GHz (channel 12)



→ qualitatively similar to channel 8

→ but quantitatively different

Consequence: good spot under channel 8 may become bad spot under channel 12, and vice versa

→ different from channel switching to reduce overcrowding

→ i.e., frequency reuse

Ex.: old cordless phones with manual channel switch button

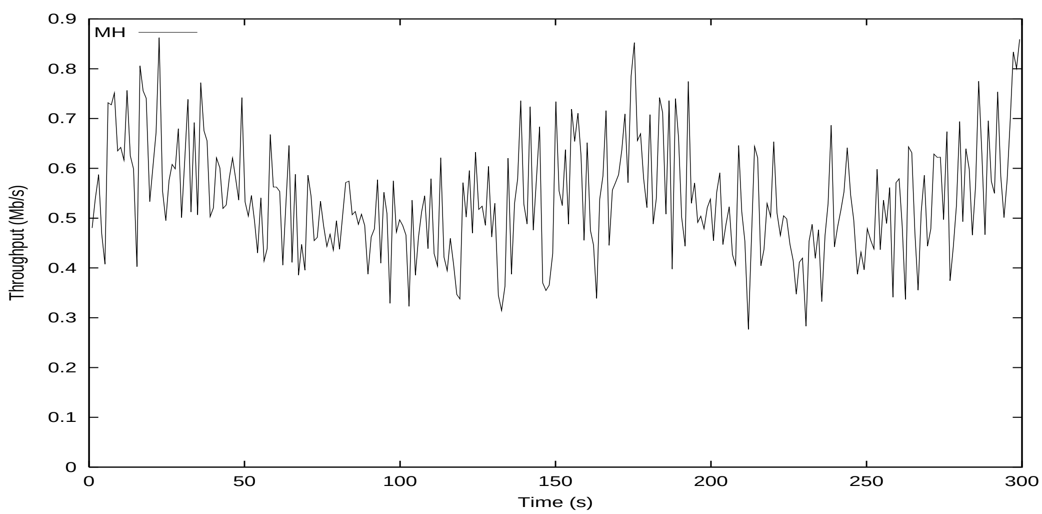
→ switch to channel that no one else is using

→ avoid multi-user interference

→ different from spatial diversity

Combined with mobility

→ mobile throughput at walking speed (HAAS corridor)



→ walking back-and-forth from AP

→ can observe gradual distance dependence

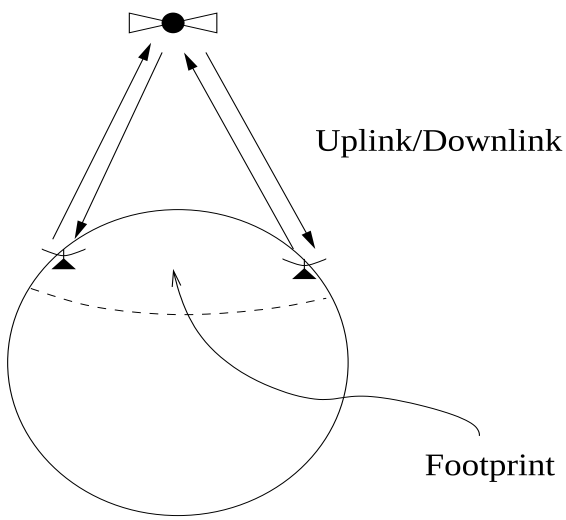
→ but significant short-term fluctuation

→ not due to Doppler shift but spatial diversity

→ i.e., moving in and out of good/bad spots

Long Distance Wireless Communication

Principally satellite communication:



- LOS (line of sight) communication

  → for good reception

- Effective for broadcast/multicast services

  → e.g., “cable” TV, satellite radio, atomic clock

Not effective for unibroadcast services:

→ video-on-demand (VoD) and Internet service

→ limited bandwidth

→ what about GPS?

Satellites can also be used as routers/switches

→ satellite phones

→ VSAT (very small aperture terminal): e.g., remote gas stations

→ low bandwidth, specialized applications

Shorter 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
- very very shot: near field communication: ISO

  → e.g., RFID
- others: wireless USB, WRAN (wireless regional area network) for white spaces—IEEE 802.22, 60 GHz (mainly indoor), etc.

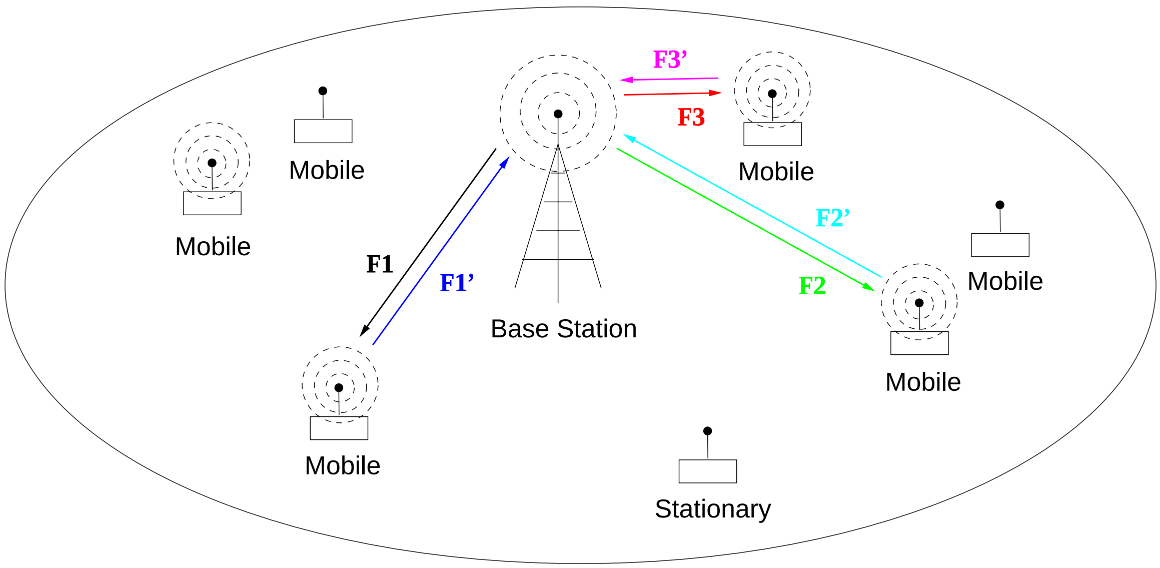
MAC protocols:

→ OFDMA, FDMA, TDMA, CDMA, CSMA

→ MIMO (multiple input multiple output): use multiple antennas

→ e.g., 802.11n: unclear how useful given extra cost

Cellular telephony: hybrid FDMA/TDMA



FDD & TDMA

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

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

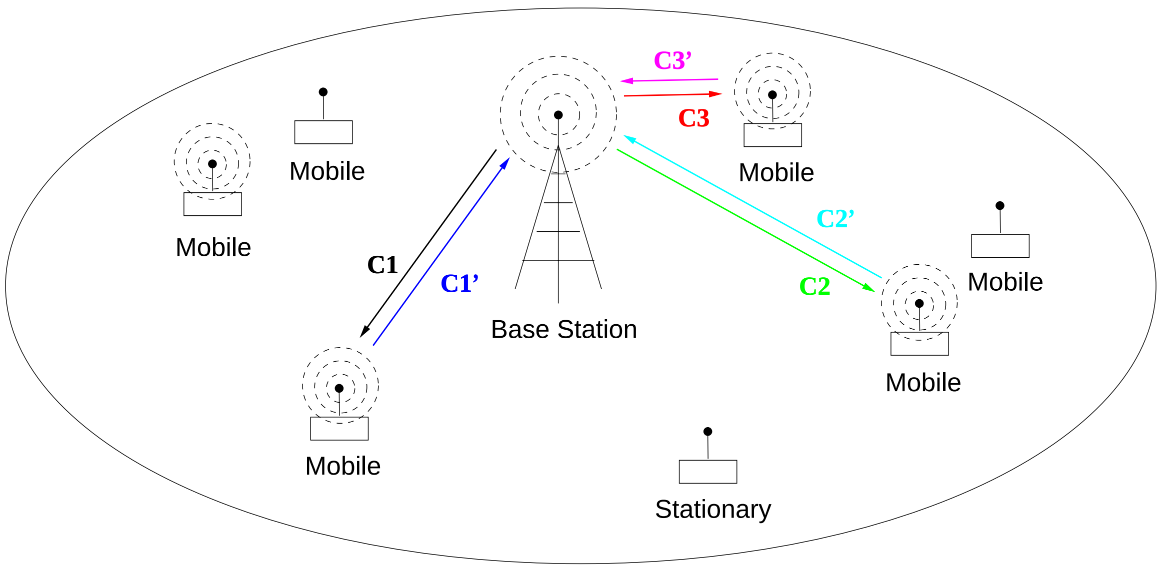
  $\rightarrow$ higher spectral efficiency with OFDMA

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

  → TDM component
- total of 1000 possible user channels

  → 125×8 (124×8 realized)
- codec/vocoder (i.e., compression): 13.4 kbps
- compare with landline toll quality (64 kbps) standard

Cellular telephony: CDMA



FDD & CDMA

$\longrightarrow$ different code 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

Recall: in CDMA each user gets a code vector

→ code vectors between users: orthogonal

→ called pseudonoise (PN) sequence or chipping code

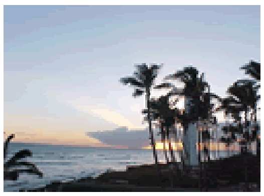
Moreover: a single data bit is encoded using $r > 1$ code bits

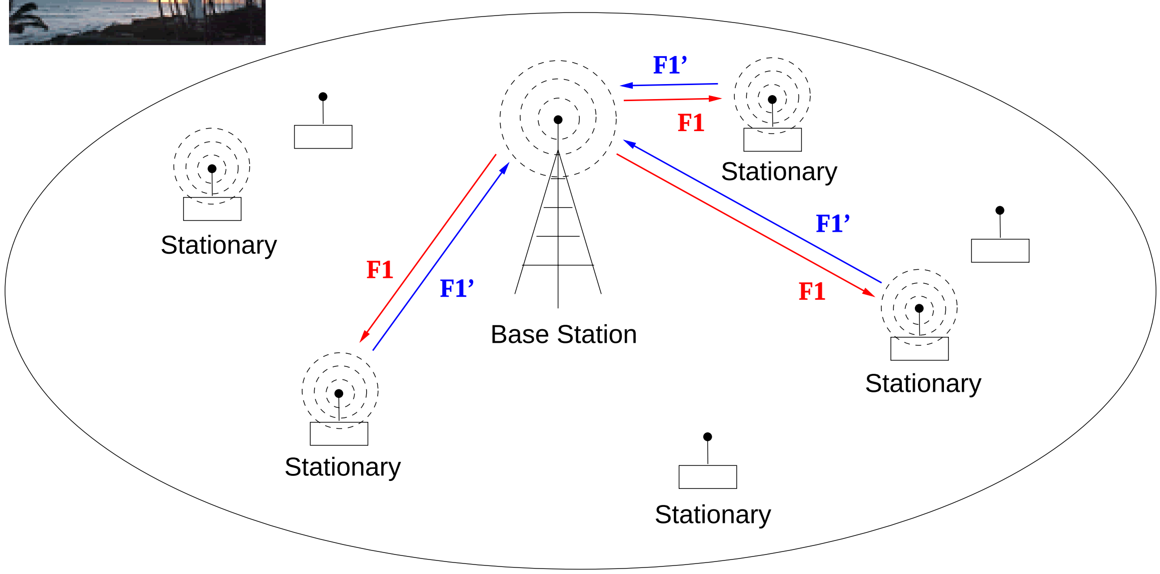
→ apply FEC

→ r is called code rate

→ common for wireless: why?

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 (stop-and-wait)