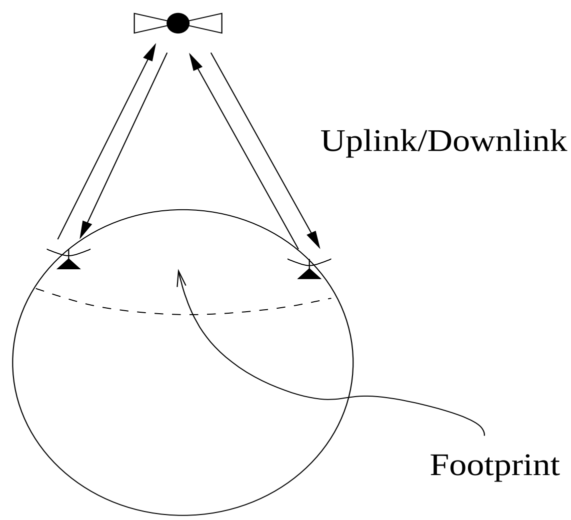
Long Distance Wireless Communication

Principally satellite communication:



- LOS (line of sight) communication

  → satellite base station is relay

- Effective for broadcast
- Limited bandwidth for multi-access

  → 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

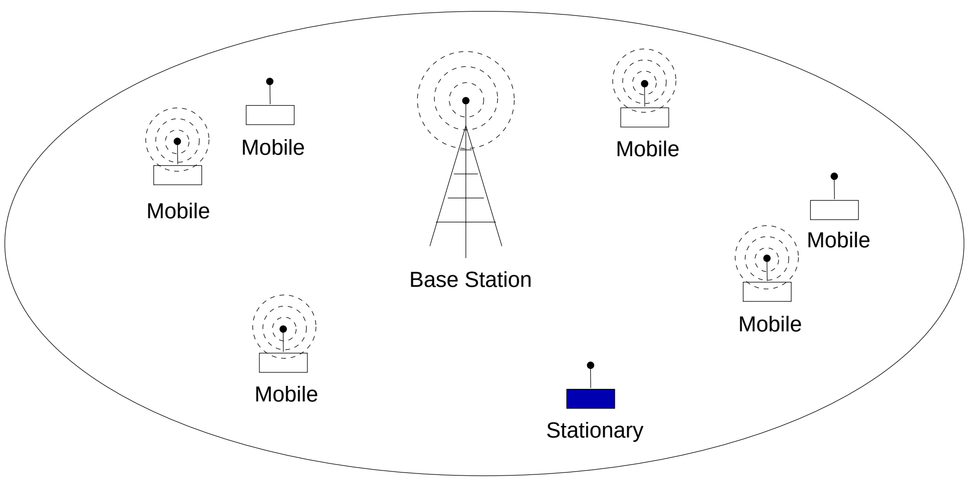
Long-distance wireless communication: effective when broadcasting

$\longrightarrow$ special applications

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

Short Distance Wireless Communication

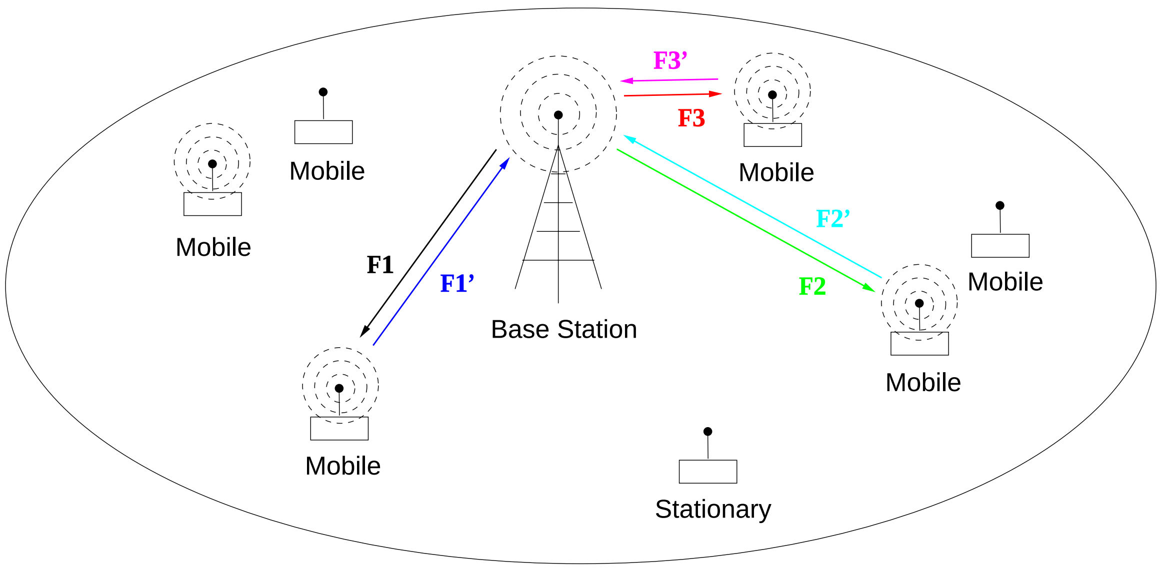
- very short: wireless PAN
- short: wireless LAN
- medium: wireless MAN



⟶ 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

  $\rightarrow$ TDM portion

- total of 1000 possible user channels

  $\rightarrow 125 \times 8$ (124×8 realized)

- codec/vocoder: 13.4 kb/s

- compare with T1 standard

  $\rightarrow$ 24 users at 64 kb/s data rate each

Dedicated channels workable because data traffic is speech:

- Low bit rate & approximately CBR (constant bit rate)

  $\longrightarrow$ flat

  $\longrightarrow$ good/bad?

- Not so for:

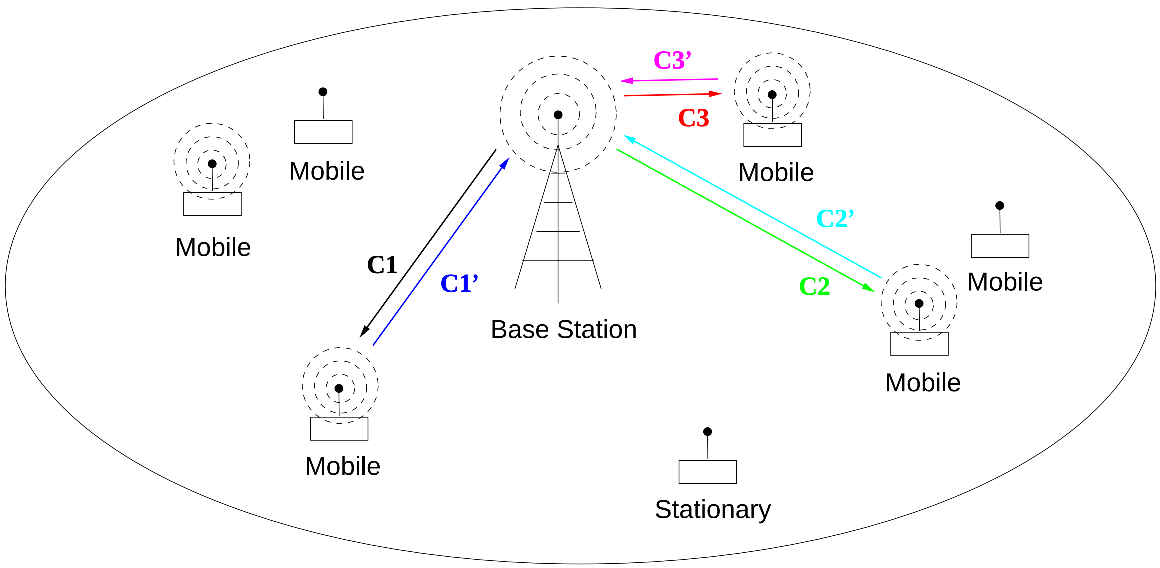
  $\longrightarrow$ different for compressed video (e.g., MPEG, H.261)

  $\longrightarrow$ cf. Terminator video

  $\longrightarrow$ VBR (variable bit rate)

  $\longrightarrow$ data files?

Cellular telephony: code division multiplexing



FDD & CDMA

$\longrightarrow$ same frequency band; different codes

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

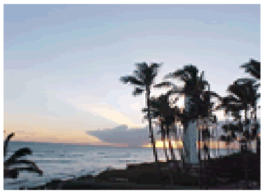
- uplink: 824–849 MHz; downlink: 869–894 MHz

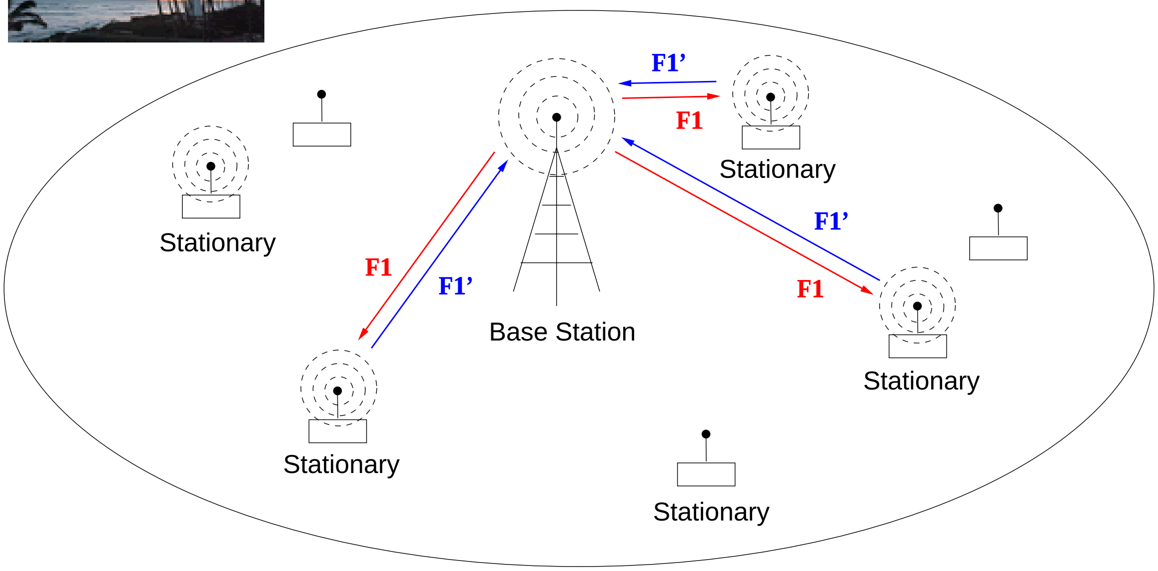
  $\rightarrow$ downlink: prepared; uplink: physical diversity

  $\rightarrow$ 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

ALOHA protocol:

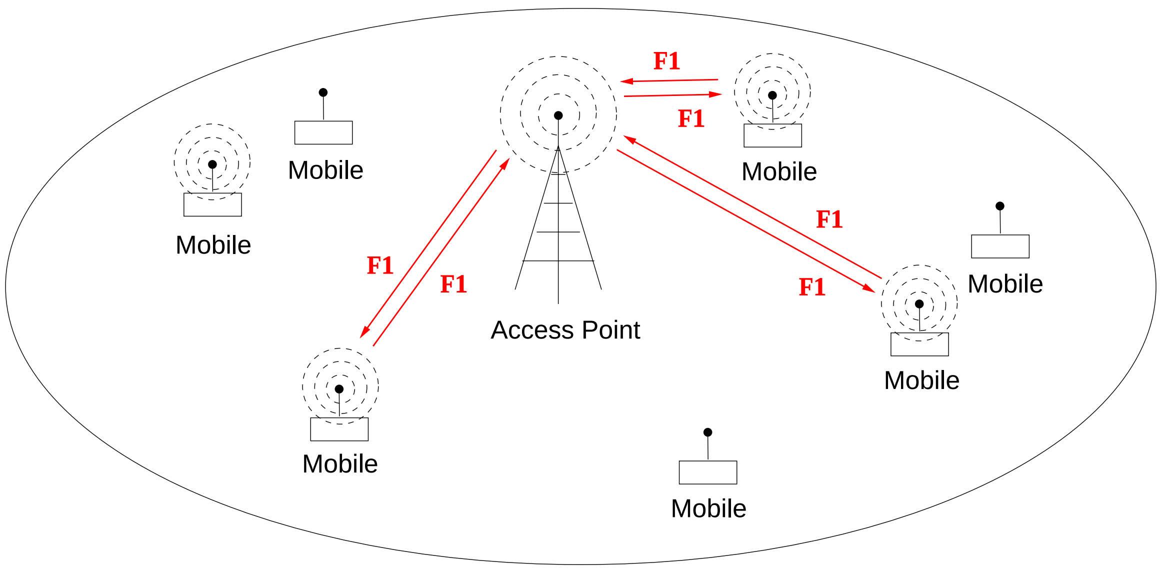
- send frame (no carrier sense)
- wait for ACK

  → collision detection through explicit ACK
- if timeout, retry with probability p

  ⟶ looks familiar...

  ⟶ pure vs. slotted ALOHA

Wireless LAN (WLAN): infrastructure mode



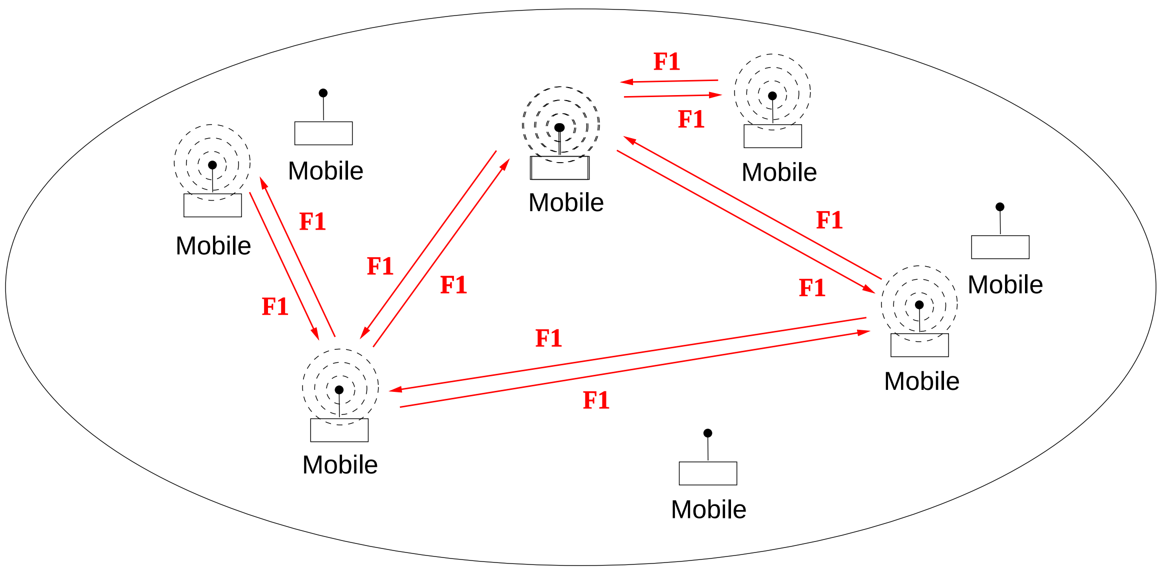
WLAN: Infrastructure Network

$\longrightarrow$ 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

⟶ homogeneous: no base station

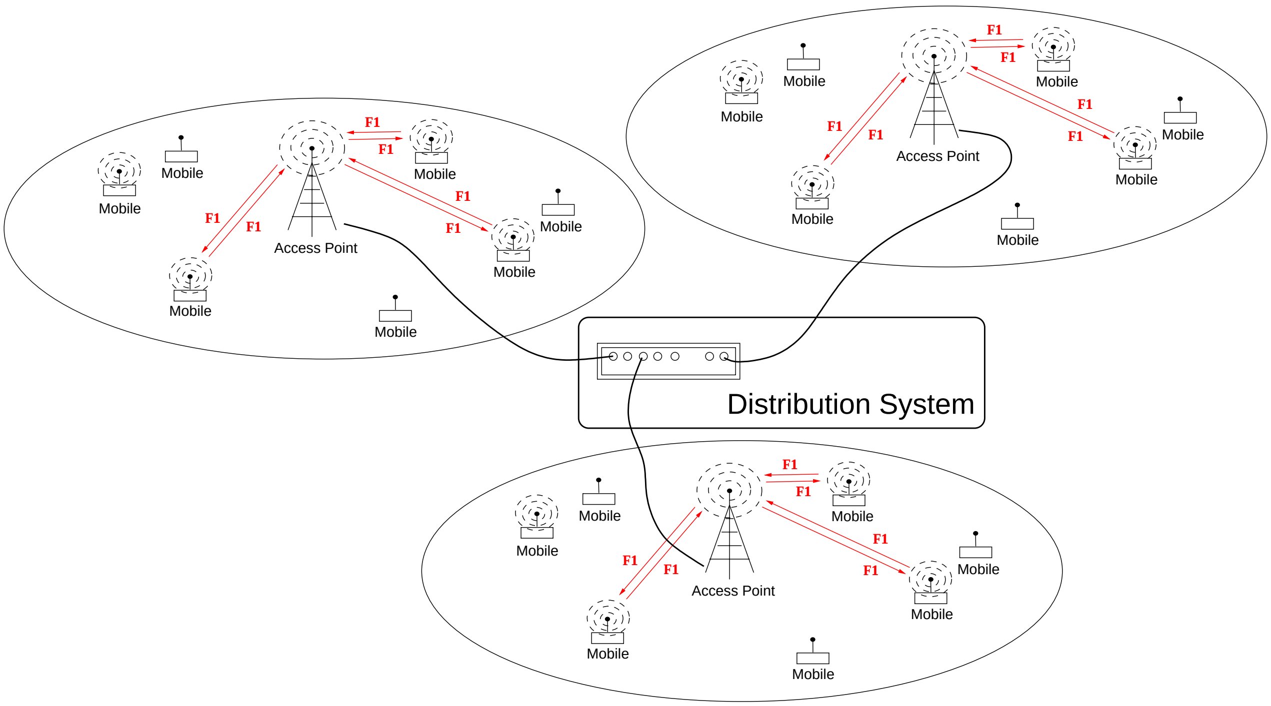
⟶ everyone is the same

⟶ share forwarding responsibility

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

→ also called peer-to-peer mode

WLAN: internetworking



`WLAN: Extended Service Set`

$\longrightarrow$ internetworking between BSS's through APs

$\longrightarrow$ mobility and handoff

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

- DS: wireline or wireless

  → common: Ethernet switch

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

  → bridge: link layer forwarding device

  → i.e., switch using MAC address relay

  → learning bridge: source address discovery

  → spanning tree: IEEE 802.1 (Perlman's algorithm)

  → distributed ST & leader election

Additional headache: mobility

⟶ how to perform handoff

⟶ mobility management at MAC

⟶ mobility management at IP (Mobile IP)

Mobility between BSSes in an ESS

- association

  → registration process

  → mobile station (MS) associates with one AP

- disassociation

  → upon permanent departure: notification

- reassociation

  → movement of MS from one AP to another

  → inform new AP of old AP

  → forwarding of buffered frames

Association, disassociation, reassociation provides necessary information for distribution service within ESS

$\longrightarrow$ distribution service implemented in AP

Compatibility with non-802.11 devices in ESS:

$\longrightarrow$ integration service: portal abstraction

$\longrightarrow$ translation service

Complicated 802.11 frame format

$\longrightarrow$ 30-byte MAC header

$\longrightarrow$ four 48-bit address fields

$\longrightarrow$ 16-bit frame control field: 11 fields

$\longrightarrow$ e.g., version, type, subtype, to DS, from DS, . . .

$\longrightarrow$ type (2-bit): mgt (00), control (01), data (10)

$\longrightarrow$ subtype (4-bit): association (mgt), ACK (ctl)

$\longrightarrow$ payload: 0–2313 bytes

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. . .

Examples:

Purdue Univ.: IEEE 802.11b (11 Mbps) WLAN network

⟶ PAL (Purdue Air Link)

⟶ partial mobility: MAC roaming (within ESS)

⟶ no mobile IP

⟶ but football scores at Ross-Ade through PDAs

Dartmouth College: IEEE 802.11b WLAN (500+ APs)

⟶ full VoIP

⟶ free long distance

Seattle, SF, San Diego, Boston, etc.: WiFi communities

⟶ free Internet access

⟶ roof-top mesh networks

⟶ cable & DSL companies don't like it

Graffiti: warchalking

$\longrightarrow$ some cities

$\longrightarrow$ benevolent kids with lots of free time

Soon: integrated WLAN + cellular phones

$\longrightarrow$ use VoIP when near WLAN network

$\longrightarrow$ use cellular when outside WLAN coverage

$\longrightarrow$ automatic switch-over

IEEE 802.11 MAC

$\longrightarrow$ CSMA/CA with exponential backoff

$\longrightarrow$ almost like CSMA/CD

$\longrightarrow$ drop CD

$\longrightarrow$ CSMA with explicit ACK frame

$\longrightarrow$ added optional feature: CA (collision avoidance)

Two modes for MAC operation:

- Distributed coordination function (DCF)

  $\rightarrow$ multiple access

- Point coordination function (PCF)

  $\rightarrow$ polling-based priority

. . . neither PCF nor CA used in practice

CSMA: (i) explicit ACK and (ii) exponential backoff

Sender:

- MAC (firmware in NIC) receives frame from upper layer (i.e., device driver)
- Goto `Backoff` procedure
- Transmit frame
- Wait for ACK
- If timeout, goto `Backoff` procedure

Receiver:

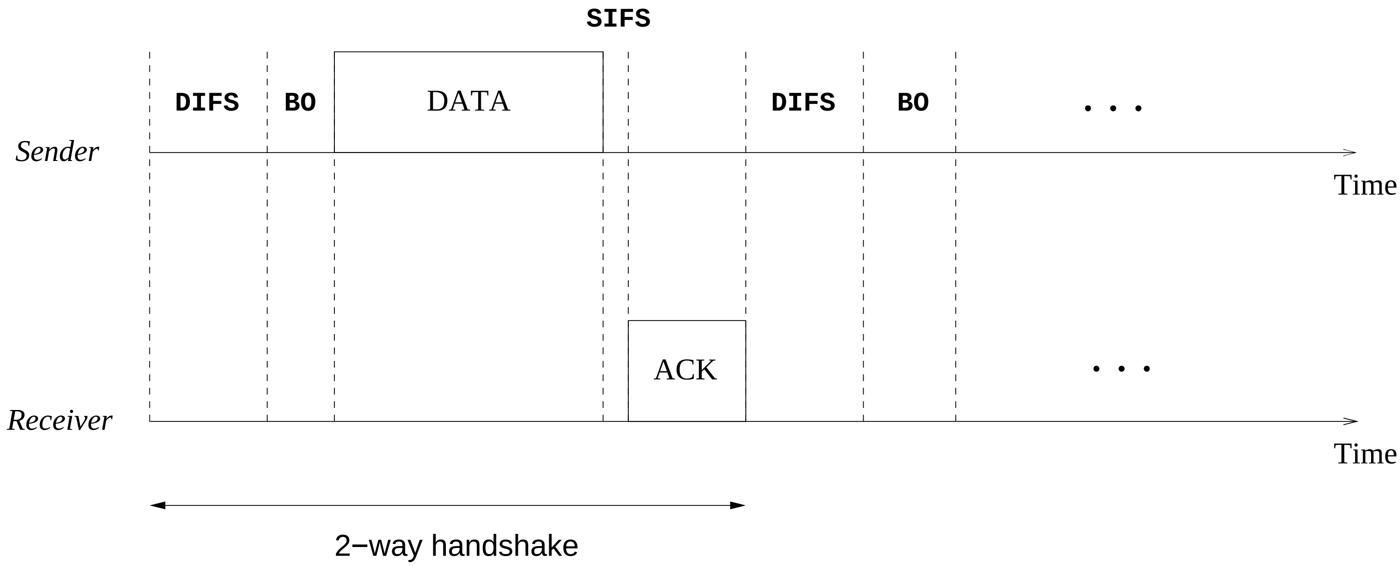
- Check if received frame is ok
- Wait for SIFS
- Transmit ACK

`Backoff`:

- If due to timeout, double contention window (`CW`)
- Else wait until channel is idle plus an additional DIFS
- Choose random waiting time between [1, `CW`]

  → `CW` is in units of slot time
- Decrement `CW` when channel is idle
- Return when `CW` = 0

Timeline without collision:



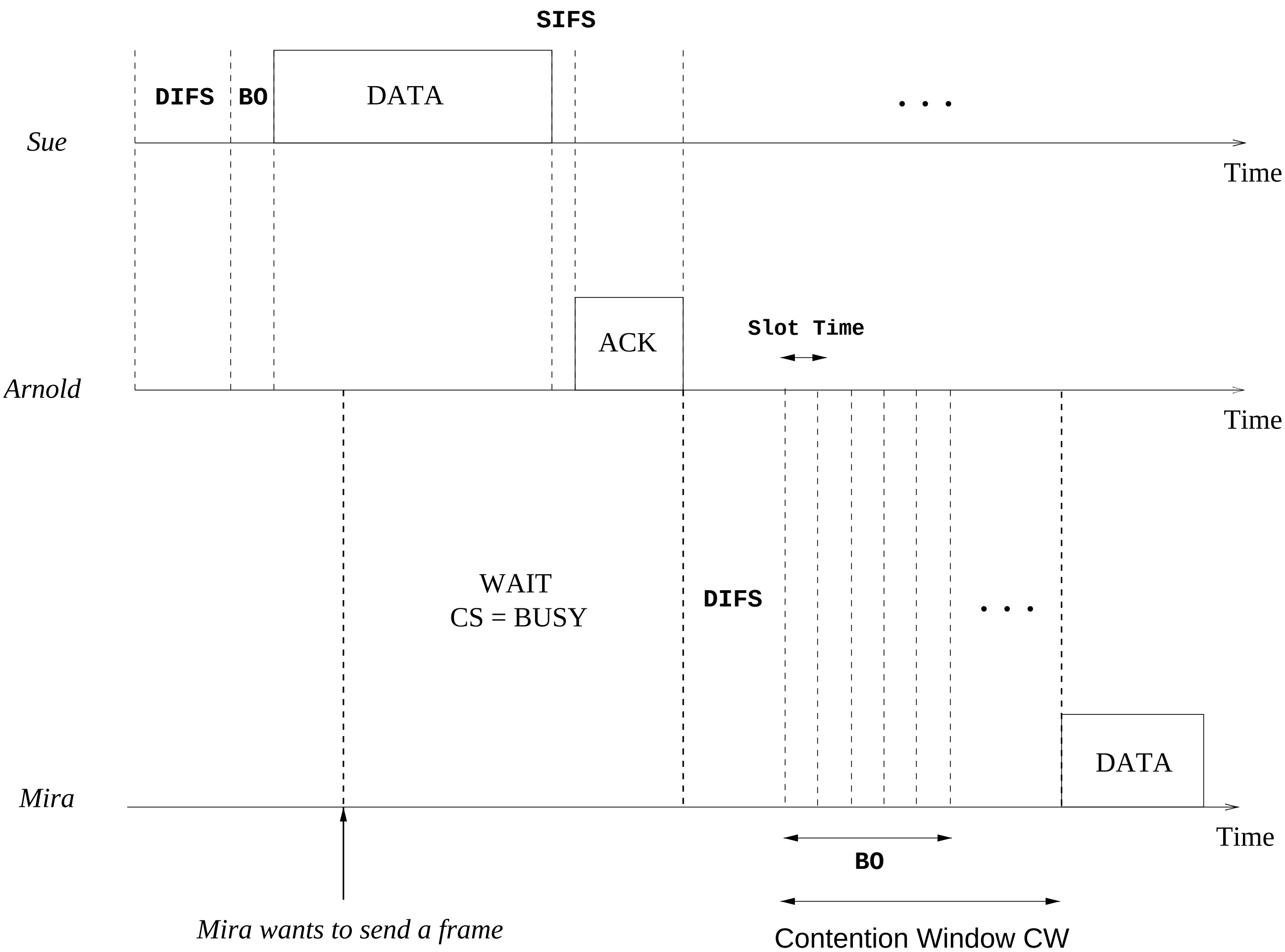
- SIFS (short interframe space): 10 μs
- Slot Time: 20 μs
- DIFS (distributed interframe space): 50 μs

  $\rightarrow$ DIFS = SIFS + 2 $\times$ slot time
- BO: variable back-off (within one `CW`)

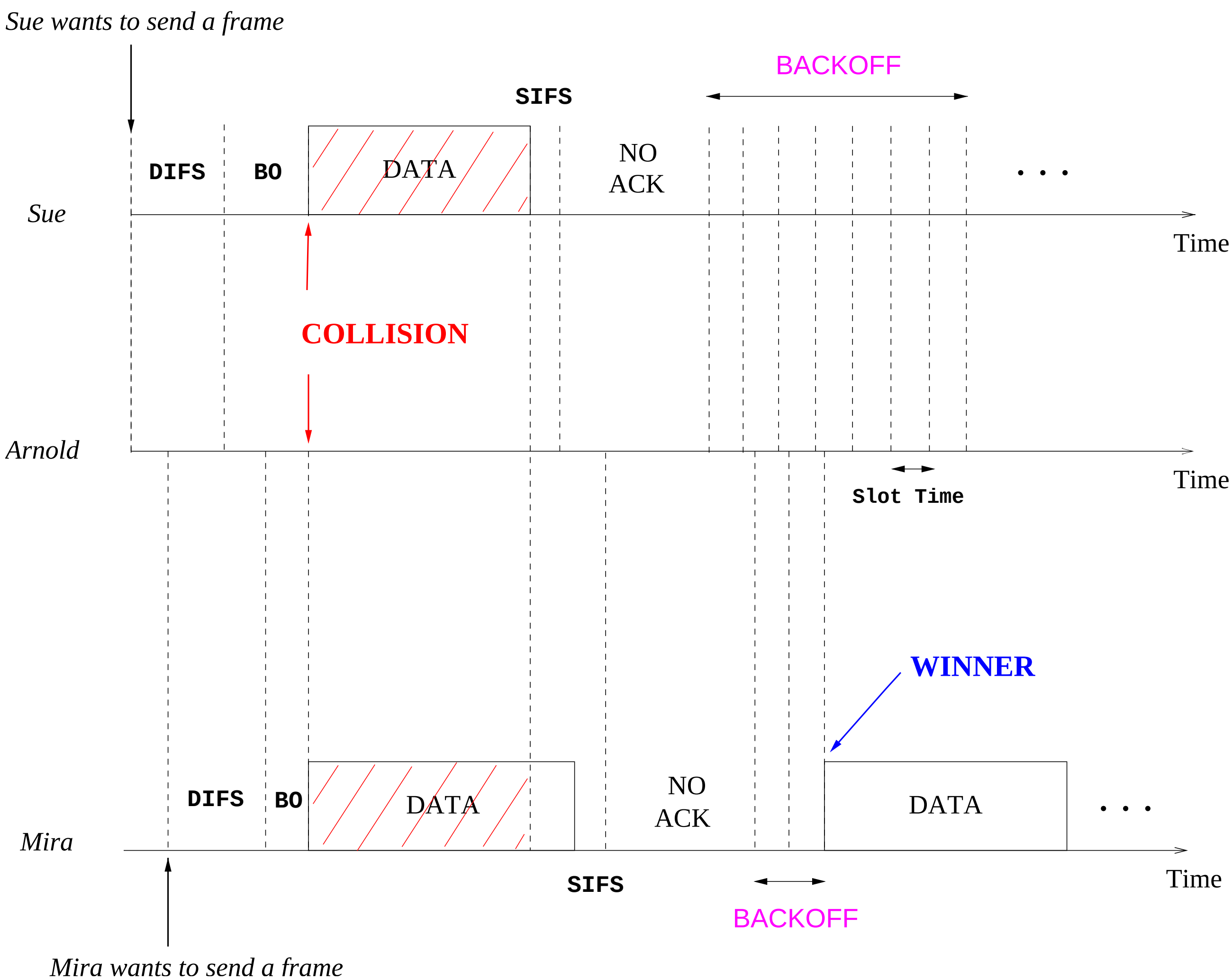
  $\rightarrow$ `CWmin`: 31; `CWmax`: 1023

Time snapshot with Mira-come-lately:

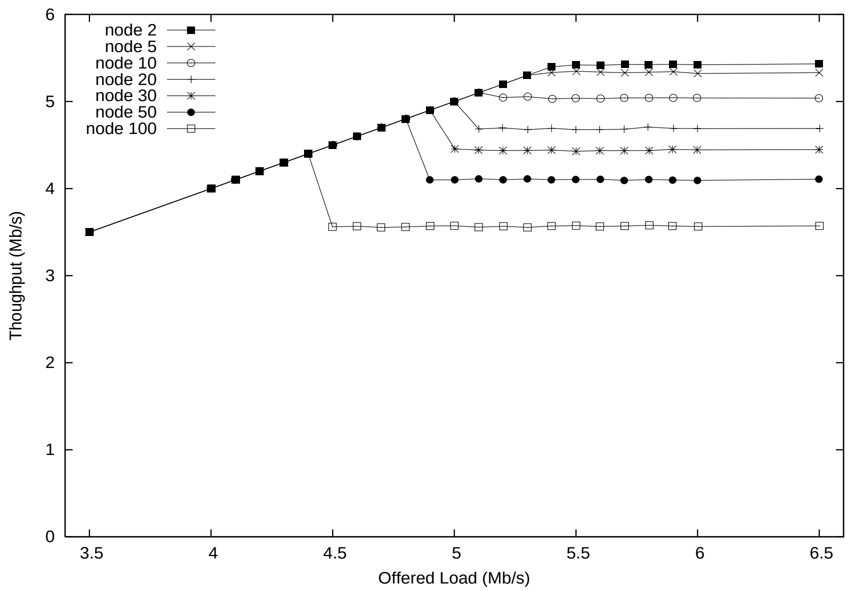
⟶ Sue sends to Arnold

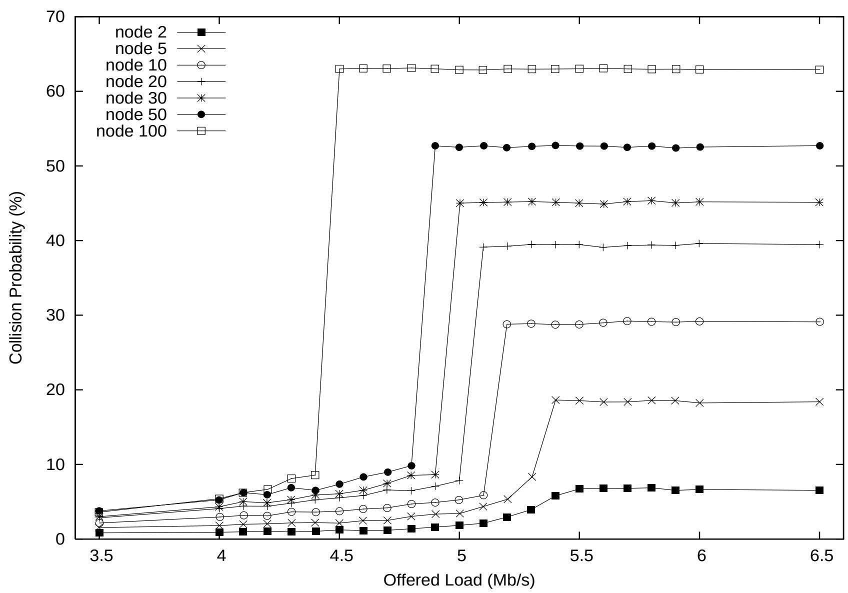


Time snapshot with collision (Sue & Mira):



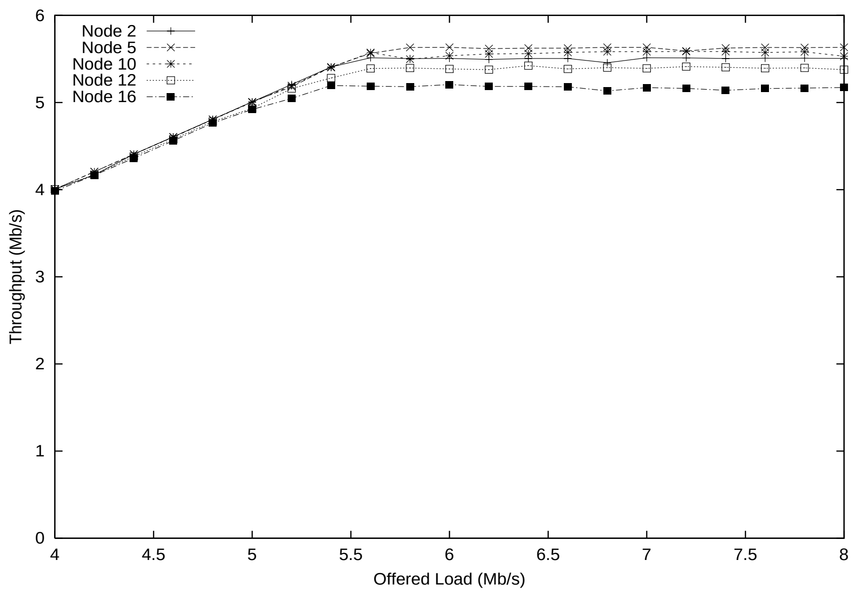
MAC throughput and collision (*ns* simulation):





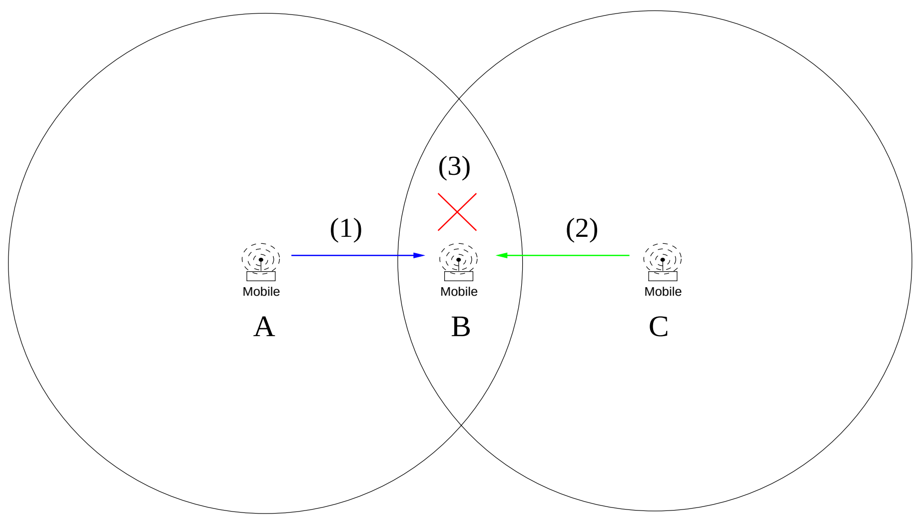
MAC throughput:

⟶ experiment: iPAQ running Linux



Additional issues with CSMA in wireless media:

Hidden station problem:



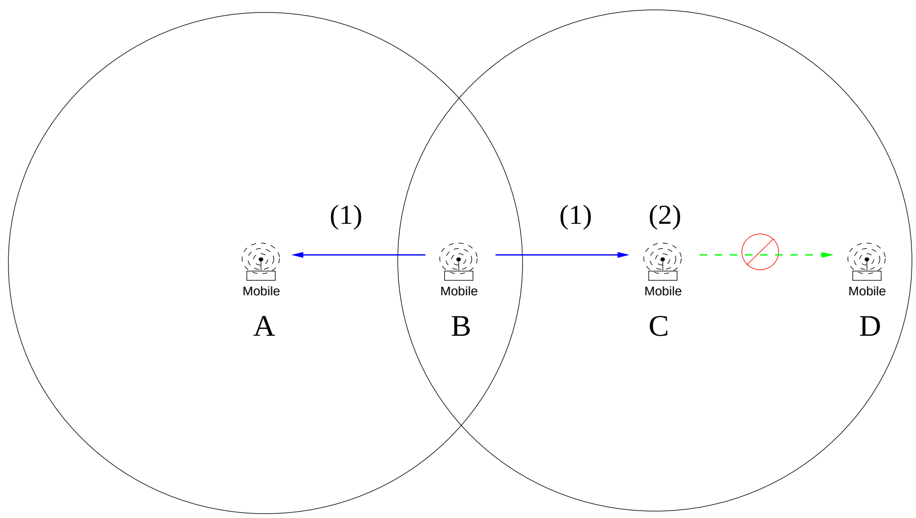
Hidden Station Problem

(1) A transmits to B

(2) C does not sense A; transmits to B

(3) interference occurs at B: i.e., collision

Exposed station problem:



Exposed Station Problem

(1) B transmits to A

(2) C wants to transmits to D but senses B

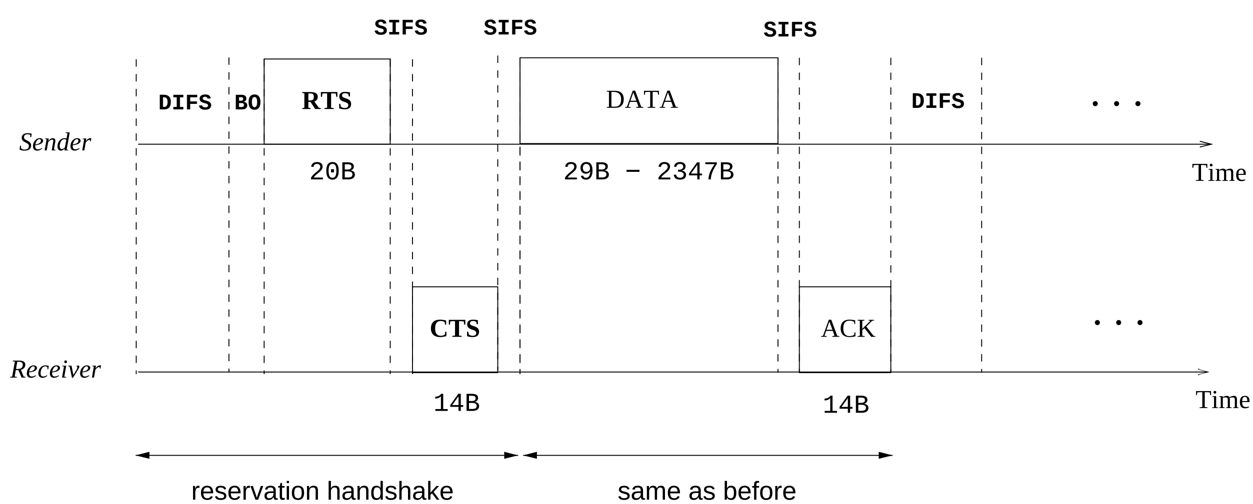
$\longrightarrow$ C refrains from transmitting to D

$\longrightarrow$ omni-directional antenna

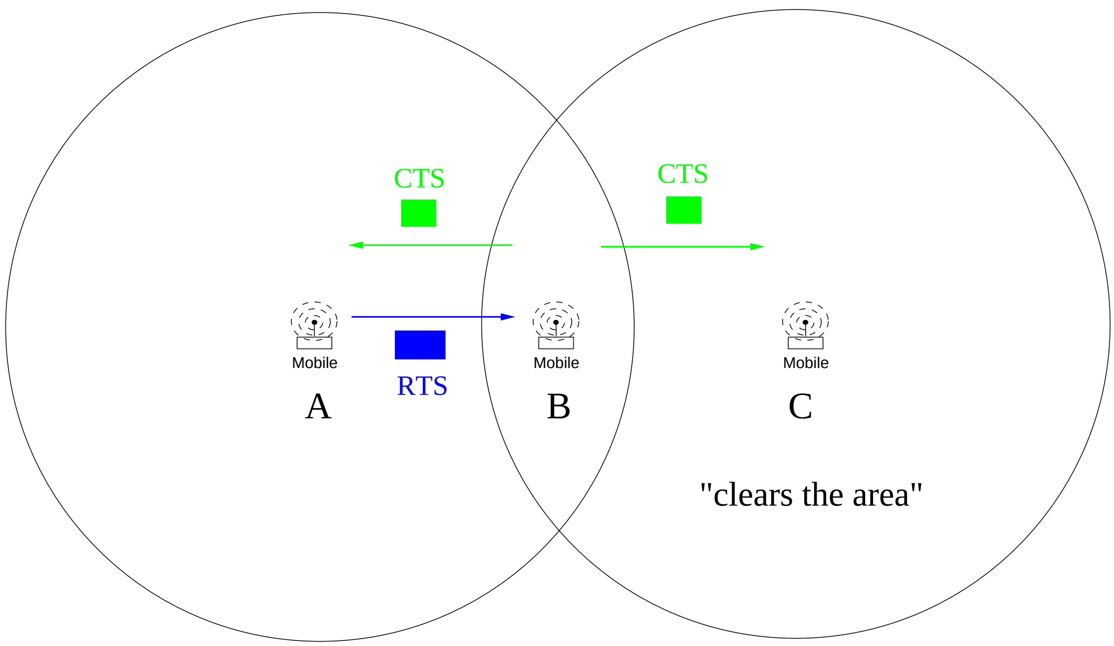
Solution: CA (congestion avoidance)

$\longrightarrow$ RTS/CTS reservation handshake

- Before data transmit, perform RTS/CTS handshake
- RTS: request to send
- CTS: clear to send



Hidden station problem: RTS/CTS handshake "clears" hidden area



RTS/CTS Handshake

RTS/CTS perform only if data > RTS threshold

$\longrightarrow$ why not for small data?

. . . feature available but not actively used

Additional optimization: virtual carrier sense

- transmit connection duration information
- stations maintain NAV (network allocation vector)

  $\longrightarrow$ decremented by clock
- if NAV $>$ 0, then do not access even if physical CS says channel is idle

IEEE 802.11 wireless LAN standard:

- ratified in 1997: 1/2 Mbps using either DSSS or FHSS
  → 11 bit chip sequence
- uses IEEE 802 address format along with LLC
  → 4 address fields for forwarding/management
- uses 2.4–2.4835 GHz ISM band in radio spectrum
  → ISM (industrial, scientific and medical): unlicensed
- IEEE 802.11b ratified: 5.5/11 Mbps using DSSS only
  → less coding overhead: good for low BER
  → BER (bit error rate) and FER (frame error rate)
- others: e.g., IEEE 802.11a and 802.11g at 54 Mbps
  → 5.725–5.85 vs. 2.4–2.4835 GHz band
  → both use OFDM

Bluetooth, 802.16, etc.; uncertain future . . .