Direct Link Communication: Wireless Technology and MAC

Basics of wireless communication

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

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

$\longrightarrow$ mainly: radio waves, microwaves, and IR

Key differences with wired communication:

- increased exposure to interference and noise
- same frequency spectrum must be shared among all users
- inter-user interference cannot be localized at switch

  $\longrightarrow$ cannot use buffering

  $\longrightarrow$ cannot use routing isolation

  $\longrightarrow$ fundamental problem for QoS control

  $\longrightarrow$ requires more than RF engineering
- signal propagation and variation is much more complex

  $\longrightarrow$ attenuation (propagation loss)

  $\longrightarrow$ refraction, absorption, reflection, diffraction

  $\longrightarrow$ multi-path fading

  $\longrightarrow$ aggregavated by mobility

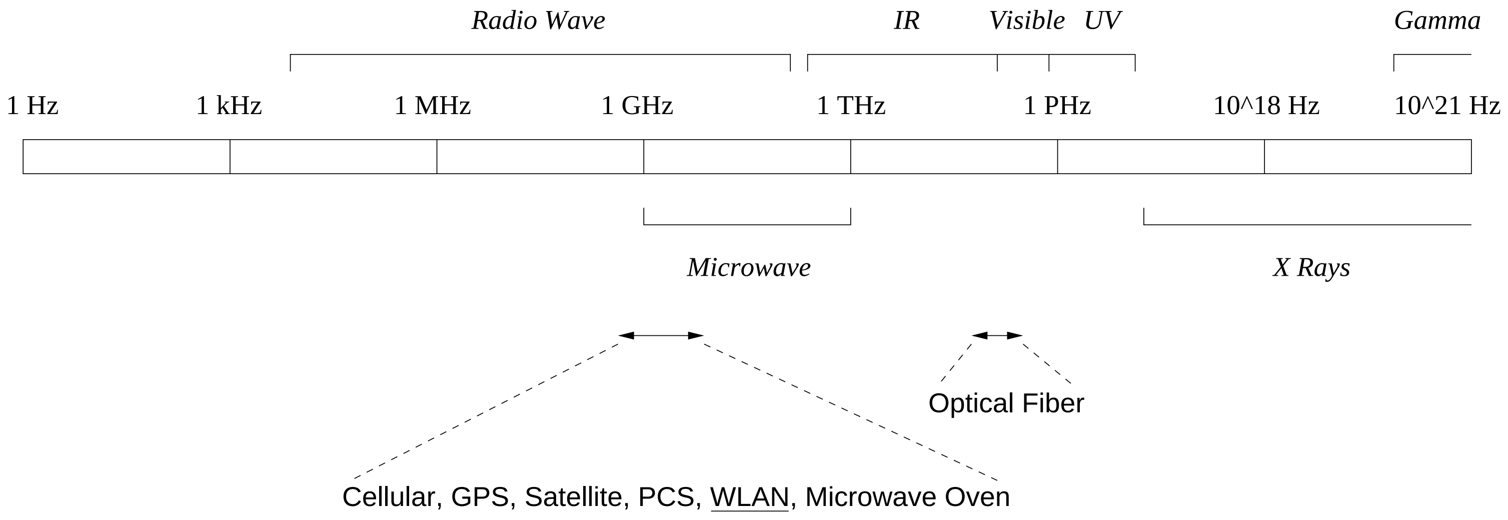
- good sides: mobility, low deployment cost, and frequency reuse

  $\longrightarrow$ once tasted, difficult to turn back

  $\longrightarrow$ key technology for LAN connectivity

  $\longrightarrow$ wired LAN: may become supporting role

Electromagnetic spectrum (logarithmic scale):



- $\longrightarrow$ Note: SOL = frequency $\times$ wavelength
- $\longrightarrow$ e.g., 1 GHz $\leftrightarrow$ 0.3 meters
- $\longrightarrow$ 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 & uses:

$\longrightarrow$ US: FCC (Federal Communications Commission)

- Voice: 300 Hz–3300 Hz
- AM Radio: 0.535 MHz–1.7 MHz

  $\longrightarrow$ amplitude modulation!
- 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

  $\longrightarrow$ CSMA/CA

- WLAN: Bluetooth 2.4 GHz–2.4835 GHz

  $\longrightarrow$ FH with TDD

- WLAN: IEEE 802.11a 5.725 GHz–5.850 GHz

  $\longrightarrow$ CSMA/CA

- Microwave oven: 2.45 GHz

  $\longrightarrow$ it's unevenly cooked!

  $\longrightarrow$ wave chaos in cavities

- 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

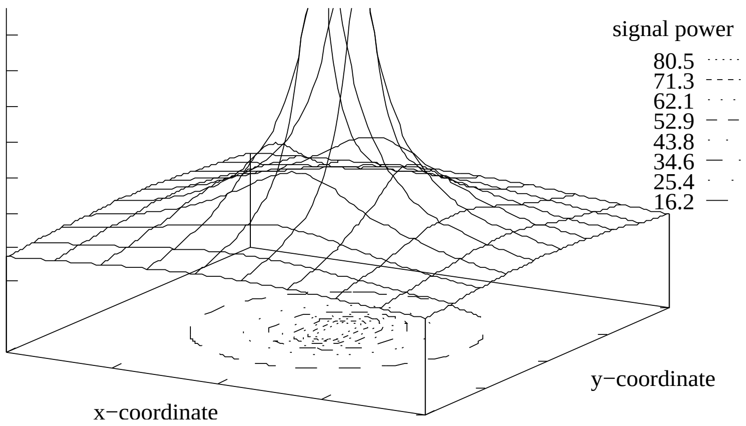
Signal propagation and power

Free space loss:

- transmitting antenna: signal power P_{in}
- transmitting 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



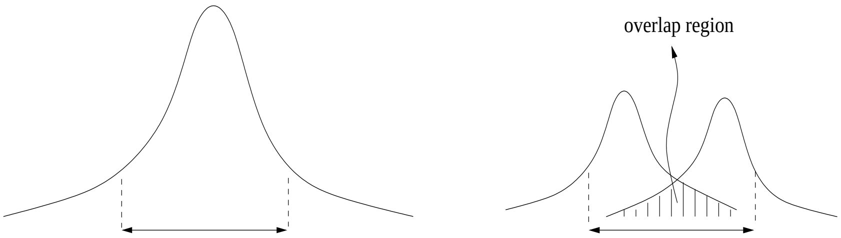
Antenna gain:

- antenna gain: G
- frequency: f
- effective area: A

$$G \propto A f^2$$

Design implications:

- effective coverage (SNR) limited by distance



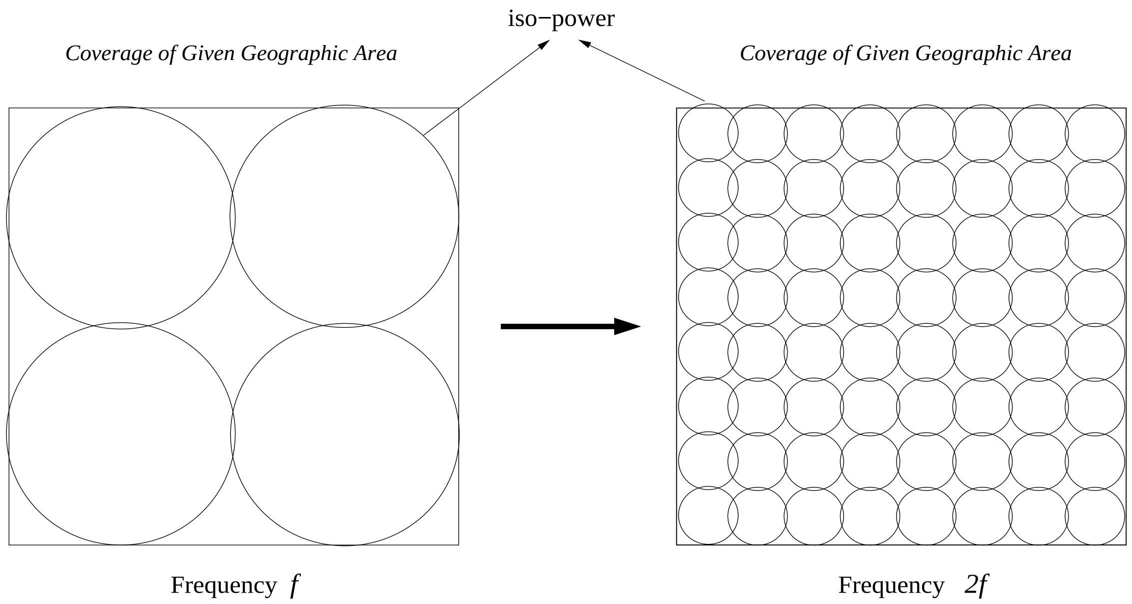
spatial coverage by one high−power antenna

spatial coverage by two low−power antennas

$\longrightarrow$ what to do in overlap?

- $f \uparrow$ implies smaller antenna
- $f \uparrow$ implies smaller coverage

- for example, if f is doubled:



$\longrightarrow$ 16-fold increase in cell density

$\longrightarrow$ due to distance dependence: 4-fold increase

$\longrightarrow$ good and bad

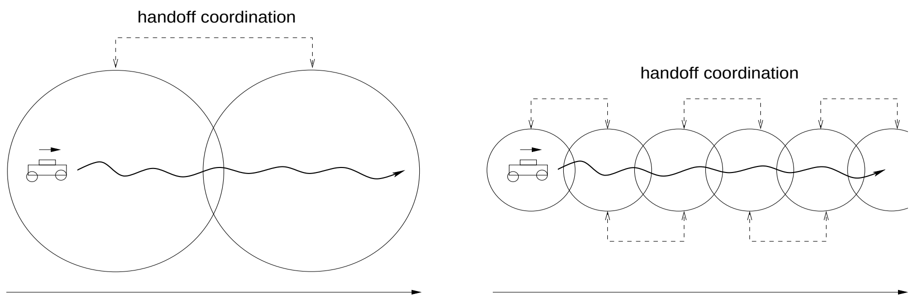
- what other performance impact of $f \uparrow$ (good)?

- low power output further increases cell density

  $\longrightarrow$ more antennas required

  $\longrightarrow$ enables frequency reuse

  $\longrightarrow$ handoff coordination overhead



- low power output reduces power consumption of mobile

  $\longrightarrow$ increased battery life

Hence: Up to some point, high frequency/low power combination is effective.

$\longrightarrow$ "catch two birds with one stone"

Cellular networks

Hexagonal cells:

⟶ both affect tiling of the plane

⟶ why hexagonal?

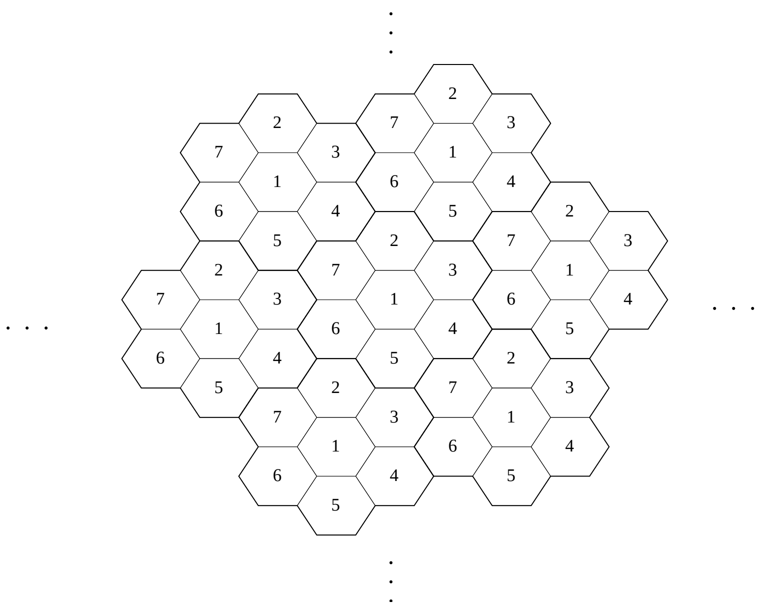
Frequency reuse: Adjacent cells do not use common carrier frequency.

⟶ avoid interference

⟶ assuming goal is maximal frequency reuse

⟶ how many frequencies are required?

For example, using seven frequencies:



$\longrightarrow$ correct argument why it works?

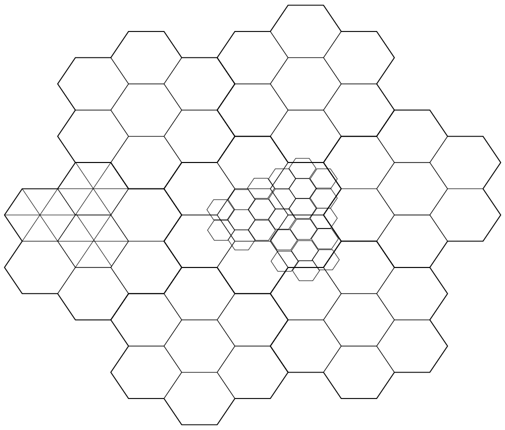
$\longrightarrow$ in general, coloring problem

Bundling: Assuming h frequencies suffice, to support m carrier frequencies in each cell, require

$$n = h \cdot m$$

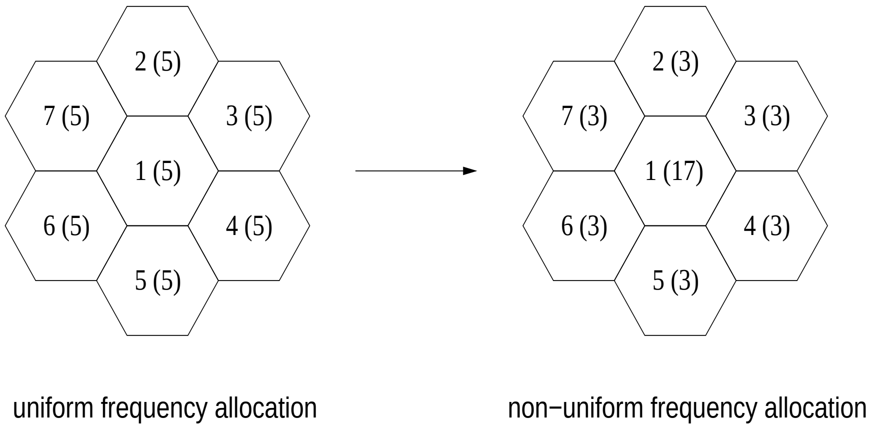
total carrier frequencies in the wireless spectrum.

Non-uniform covering:



$\longrightarrow$ channel capacity is increased selectively

Non-uniform frequency allocation:



$\longrightarrow$ total carrier frequency: 35

$\longrightarrow$ frequency borrowing

Cell sizes:

- Macrocell: < 35 km; < 10 W
- Microcell: < 1 km; < 3 W
- Picocell: < 100 m; < 100 mW
- Satellite footprint: e.g., 30–40 % (GEO); 4000 km (LEO)

  $\longrightarrow$ depends on signal power

  $\longrightarrow$ e.g., GEO satellites at 35786 km

  $\longrightarrow$ e.g., LEO satellites at ~1000 km

Note: 2-way propagation delay (RTT)

$$2 \times 35786/300000 \approx 0.24 \text{ sec}$$

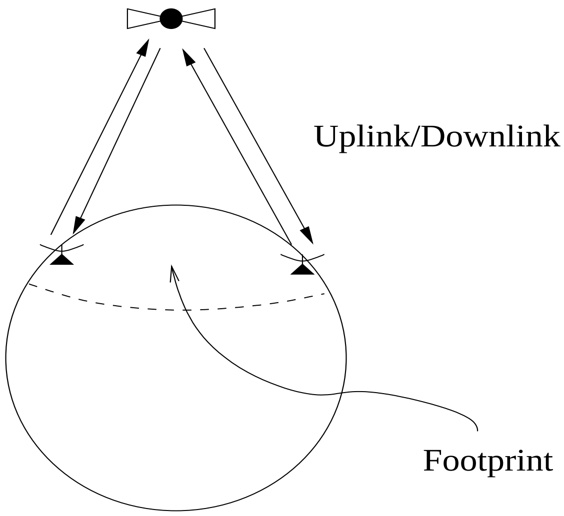
$\longrightarrow$ optimistic based on closest distance

$\longrightarrow$ typical RTT: ~500 msec

Long Distance Wireless Communication

Principally satellite communication:

$\longrightarrow$ microwaves across several thousand miles



- LOS relay
- Effective for broadcast
- Limited bandwidth for multi-access

  $\longrightarrow$ wireless LAN problem several-fold amplified

  $\longrightarrow$ not scalable for multi-access

Multi-access protocols:

- FDMA + TDMA: dominant

  $\longrightarrow$ broadband telephony principle

  $\longrightarrow$ limited channels

  $\longrightarrow$ efforts for statistical TDMA, e.g., VSAT

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

  $\longrightarrow$ mainly security concerns

- CSMA/CA: impractical due to large RTT

  $\longrightarrow$ low utilization/throughput

Long-distance wireless communication: effective when broadcasting, or multi-access multiplexing is performed at wireline system (e.g., ground station)

$\longrightarrow$ special purposes, e.g., TV, GPS

Short Distance Wireless Communication

ALOHA: ’70s Abramson et al. at Univ. of Hawaii; simplest form of multi-access system using radio waves.

$\longrightarrow$ wireless data communication

$\longrightarrow$ MA: “just do it” (worry later)

- send frame
- wait for ACK frame

  $\longrightarrow$ CSMA/CD uses physical layer negative ACK

- upon collision, retry after random waiting time.

  $\longrightarrow$ ALOHA: pure form of MA

  $\longrightarrow$ missing component: CS

- 37 % utilization (slotted; Poisson load assumption)
- subject to perils of long propagation time (in msec)

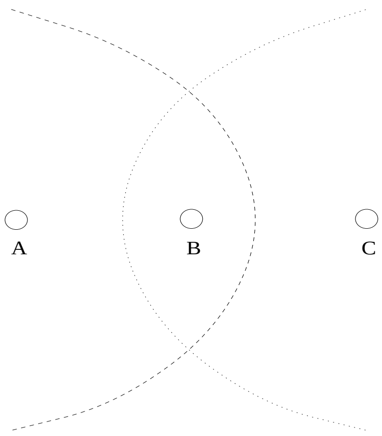
  $\longrightarrow$ distance between islands on the order of miles

  $\longrightarrow$ large delay-bandwidth product

Additional issues with CSMA in wireless domain:

$\longrightarrow$ short-range radio

$\longrightarrow$ wireless medium



Three problems with using simple CSMA

- hidden station problem
- exposed station problem
- near-far problem

Hidden station problem

1. A transmits to B
2. C does not sense A; transmits to B
3. interference occurs at B

   $\longrightarrow$ collision

Exposed station problem

1. B transmits to A
2. C wants to transmits to D (to its right) but senses B
3. C refrains from transmitting although ok

Near-far problem

1. A and C want to send to B
2. if A is closer to B than C's distance with B, A has advantage over C due to signal power and access bias

MACA (Multiple Access with Collision Avoidance)

$\longrightarrow$ in LAN environment with CS: CSMA/CA

- sender performs CS
- if idle, then wait for IFS (inter-frame space) and send if still idle

  $\longrightarrow$ SIFS (short IFS)

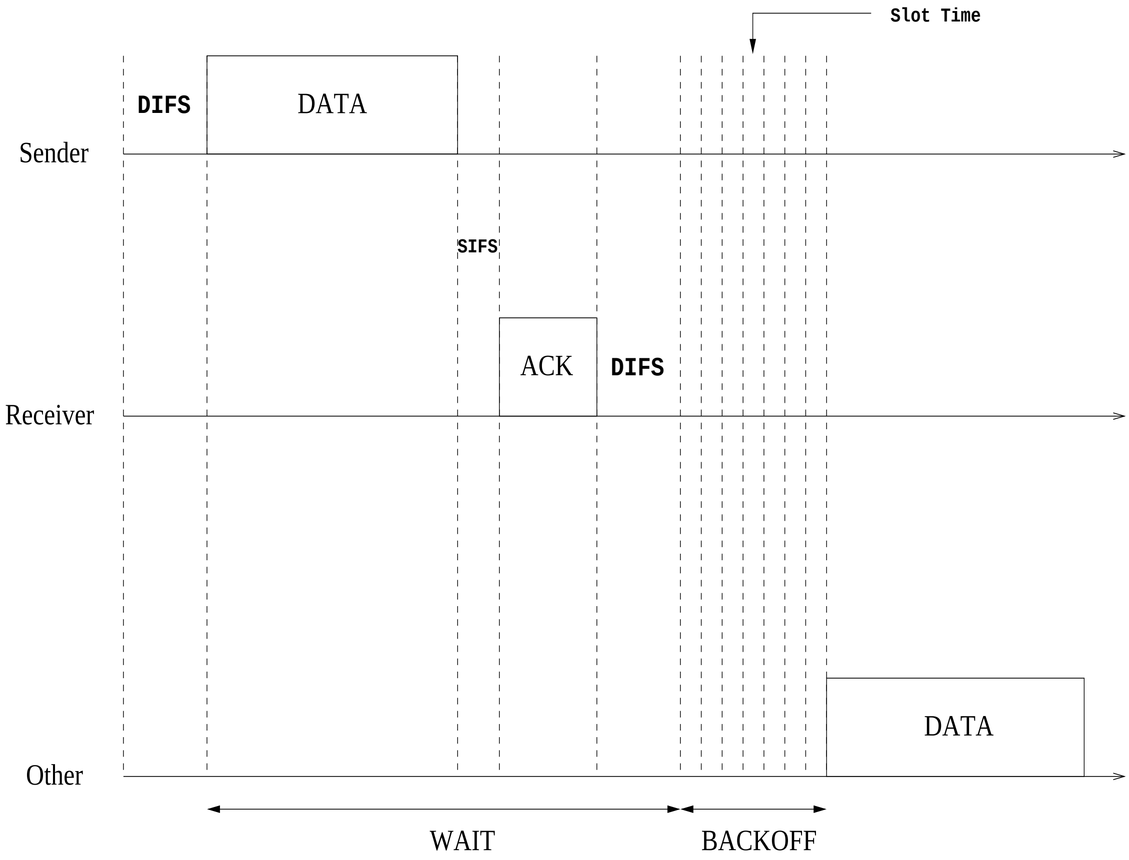
  $\longrightarrow$ DIFS (long IFS)

  $\longrightarrow$ PIFS (medium IFS)

  $\longrightarrow$ achieves a form of priority control
- if busy, then wait until channel becomes idle; wait for DIFS + random time

  $\longrightarrow$ elementary unit: slot time (counter 1–8)
- freeze counter if channel becomes busy during wait
- exponential backoff if collision (i.e., no ACK) during send after counter reaches zero
- receiver sends ACK after SIFS

CSMA/CA:



- exponential backoff
- positive ACK (stop-and-wait principle)

When load is high, i.e., high chance of collision, implement preliminary handshake

$\longrightarrow$ address hidden station problem

- sender sends short RTS (request to send) frame
- receiver sends short CTS (clear to send) frame to sender

  $\longrightarrow$ handshake

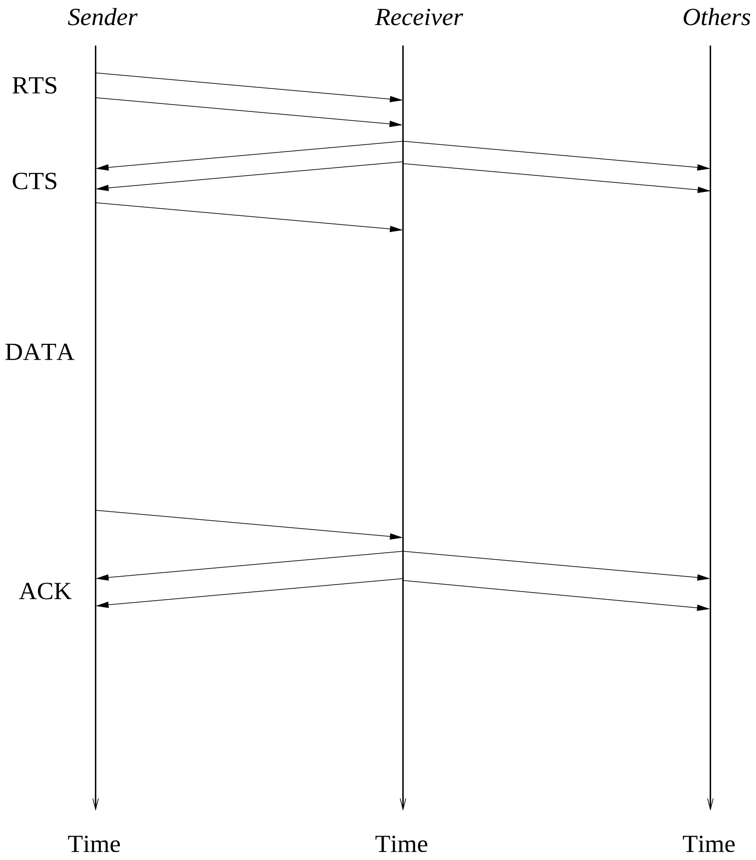
  $\longrightarrow$ logically same as acquiring channel token

  $\longrightarrow$ receiver acts as token server/moderator
- others sensing RTS or CTS wait for suitable duration

  $\longrightarrow$ duration field
- collision can still occur on control messages
- exponential backoff

  $\longrightarrow$ SIFS + random time

CSMA/CA with RTS/CTS:



- RTS/CTS optional
- implemented using RTS threshold

  $\longrightarrow$ only if data smaller than threshold engaged

IEEE 802.11 wireless LAN standard:

- ratified in 1997: 1 or 2 Mbps using either DS-CDMA or FH-CDMA

  $\longrightarrow$ CDMA used for coding, not multiple access

  $\longrightarrow$ more precise to say: DSSS or FHSS

- 11 bit chip sequence
- uses IEEE 802 address format along with LLC

  $\longrightarrow$ makes Layer 2 switching/forwarding simple

- uses 2.4–2.4835 GHz ISM band in radio spectrum
- 2.4–2.4835 GHz band is divided into 14 channels (11 channels used in US)
- guard band: 25 MHz
- IEEE 802.11b (High Rate) ratified: 5.5 or 11 Mbps using DSSS only
- others: e.g., IEEE 802.11a at 54 Mbps

  $\longrightarrow$ 5.725–5.85 GHz band