Selected Topics on Networking

Basic Concepts

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Computers for the next decades?

- **Computers are integrated**
  - small, cheap, portable, replaceable - no more separate devices
- **Technology is in the background**
  - computer are aware of their environment and adapt ("location awareness")
  - computer recognize the location of the user and react appropriately (e.g., call forwarding, fax forwarding, "context awareness"))
- **Advances in technology**
  - more computing power in smaller devices
  - flat, lightweight displays with low power consumption
  - new user interfaces due to small dimensions
  - more bandwidth per cubic meter
  - multiple wireless interfaces: wireless LANs, wireless WANs, regional wireless telecommunication networks etc. („overlay networks")

Mobile communication

- **Two aspects of mobility:**
  - *user mobility*: users communicate (wireless) "anytime, anywhere, with anyone"
  - *device portability*: devices can be connected anytime, anywhere to the network
- **Wireless vs. mobile** Examples

Wireless	Mobile	Examples
✘	✘	stationary computer
✘	✓	notebook in a hotel
✓	✘	wireless LANs in historic buildings
✓	✓	Personal Digital Assistant (PDA)

- **The demand for mobile communication creates the need for integration of wireless networks into existing fixed networks:**
  - local area networks: standardization of IEEE 802.11, ETSI (HIPERLAN)
  - Internet: Mobile IP extension of the internet protocol IP
  - wide area networks: e.g., internetworking of GSM and ISDN

Wireless Computing Vision

- Future of computing includes
  - portable computers
  - wireless communication

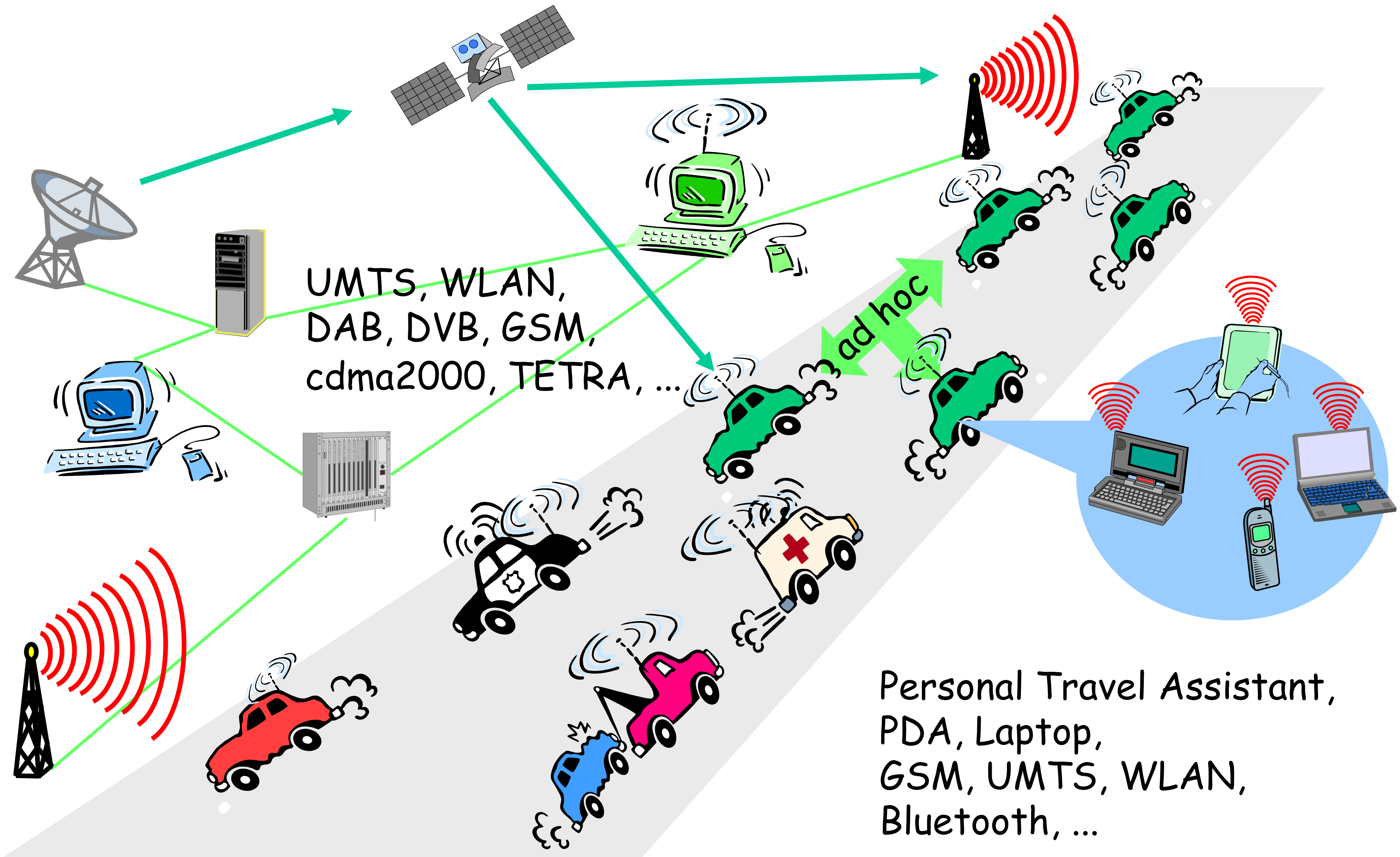
- Why portable computers? Many devices are designed to move with people:
  - cell phones, PDAs, cars, planes

- Why wireless communication?
  - quick, for temporary purposes (e.g., tradeshow)
  - unintrusive, for delicate situations (e.g., historic bldg)
  - useful when no infrastructure (countryside, terrain, after a natural disaster)

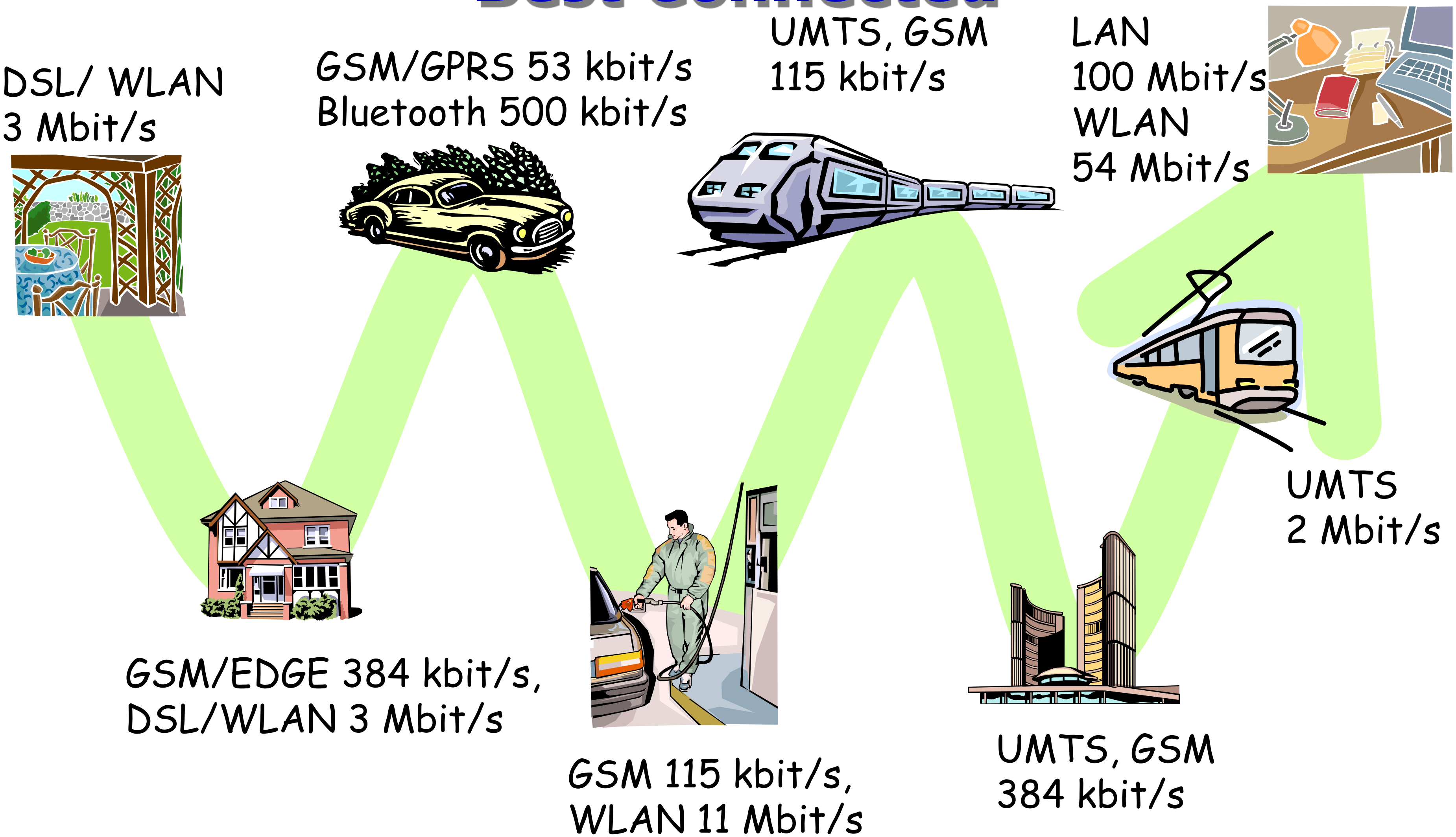
Applications

- car of the future: cars driving in same area build a local ad-hoc network, use to learn about emergencies, keep safe distance
- emergencies: ambulance can send info about injuried people to hospital from accident scene
- business: traveling salesman can keep laptop in constant synch with company's database
- infotainment: as you travel, get up-to-date info about nearby goods and services; buy tickets, etc.

Typical application: road traffic



Mobile and wireless services – Always Best Connected



From Vision to Reality

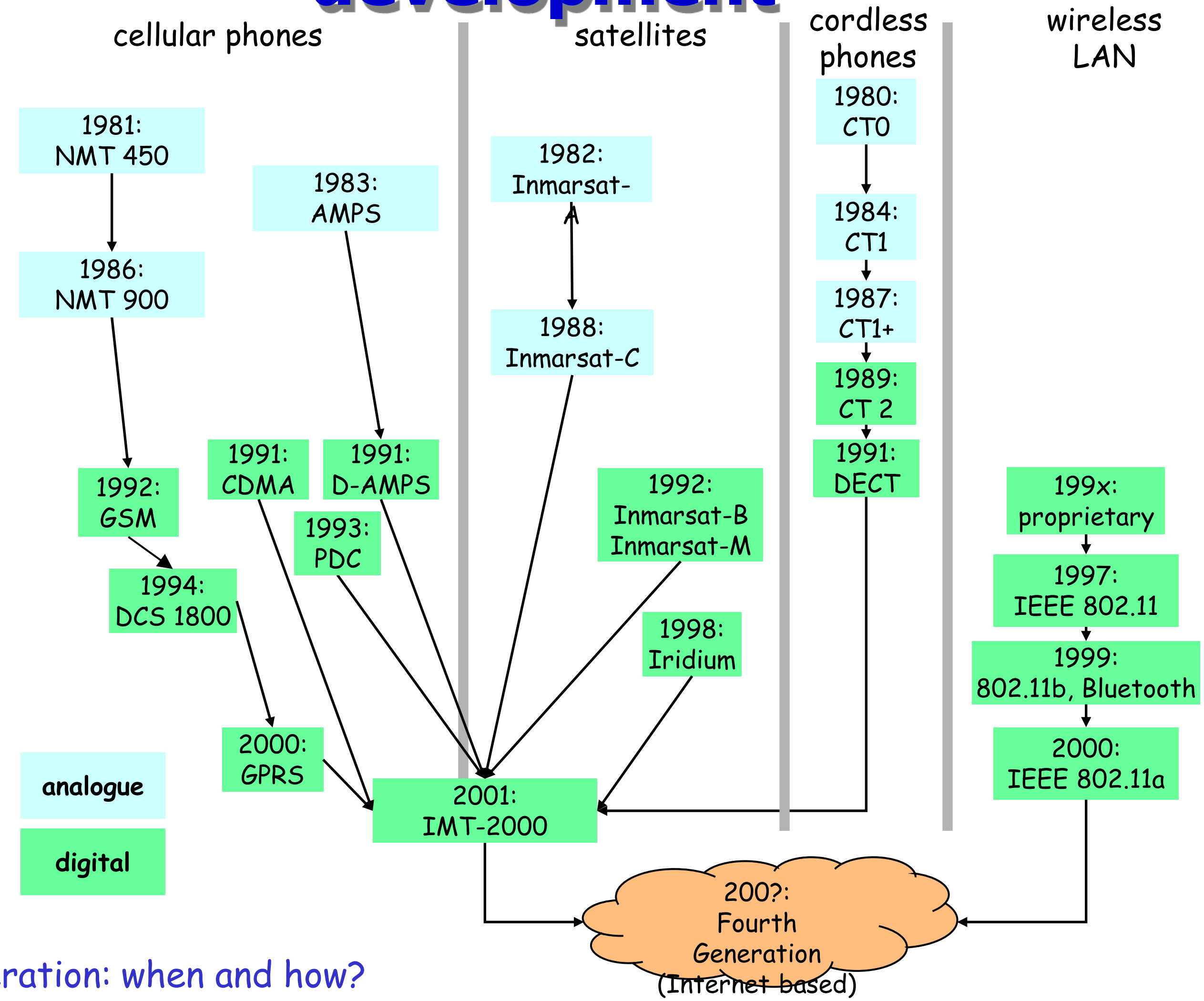
- System support for such applications is in its infancy

- Open research areas:
  - handle interference of radio transmissions
  - use radio frequencies more efficiently
    - political and social issues regarding control of the spectrum
  - tolerate high delays and variation in delays
  - security (easier to eavesdrop on wireless)
  - coordinate access to shared medium well
  - routing, service discovery, etc.

From Vision to Reality

- **Higher loss-rates due to interference**
  - emissions of, e.g., engines, lightning
- **Restrictive regulations of frequencies**
  - frequencies have to be coordinated, useful frequencies are almost all occupied
- **Low transmission rates**
  - local some Mbit/s, regional currently, e.g., 53kbit/s with GSM/GPRS
- **Higher delays, higher jitter**
  - connection setup time with GSM in the second range, several hundred milliseconds for other wireless systems
- **Lower security, simpler active attacking**
  - radio interface accessible for everyone, base station can be simulated, thus attracting calls from mobile phones
- **Always shared medium**
  - secure access mechanisms important

Wireless systems: overview of the development

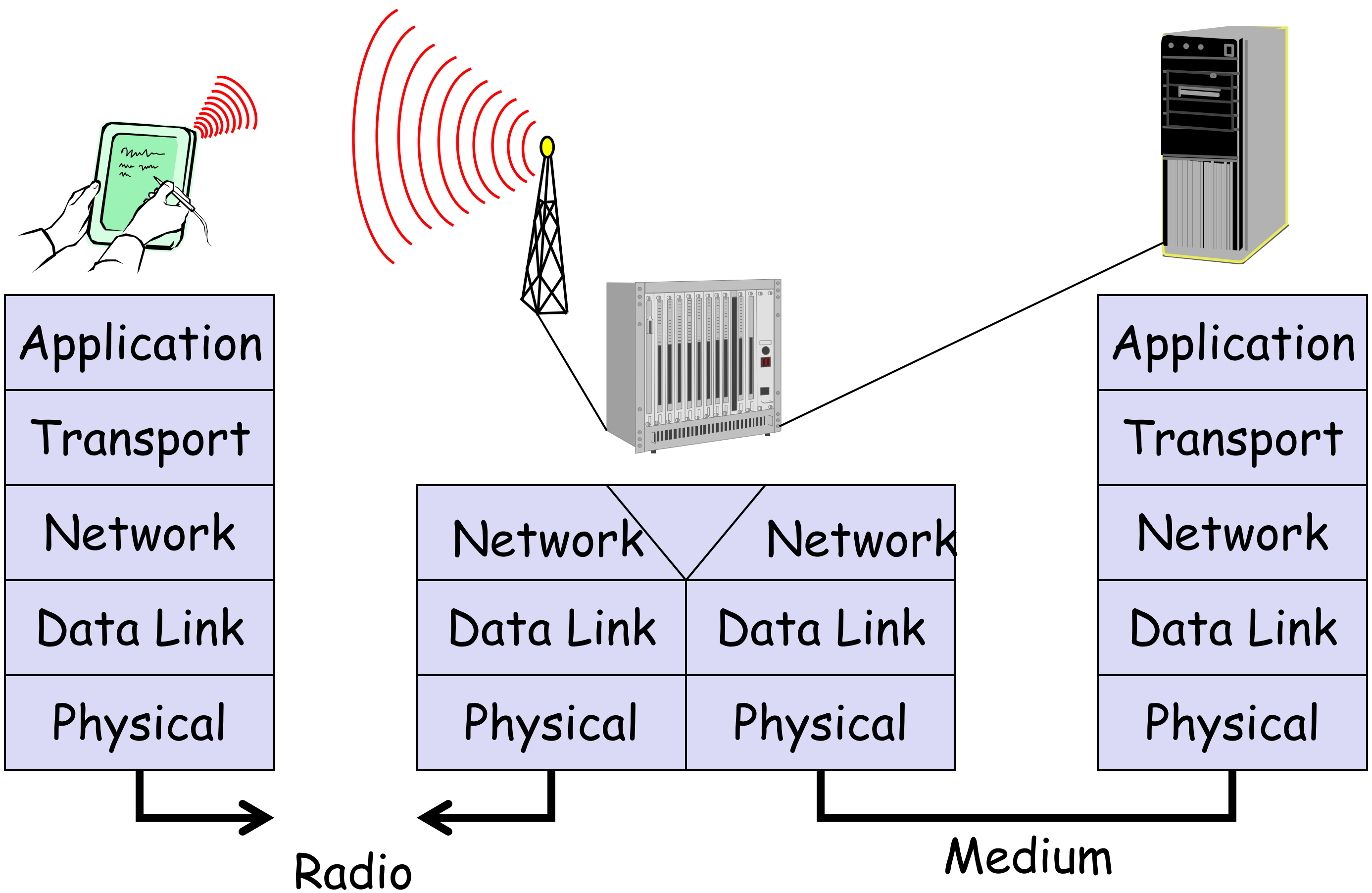


4G – fourth generation: when and how?

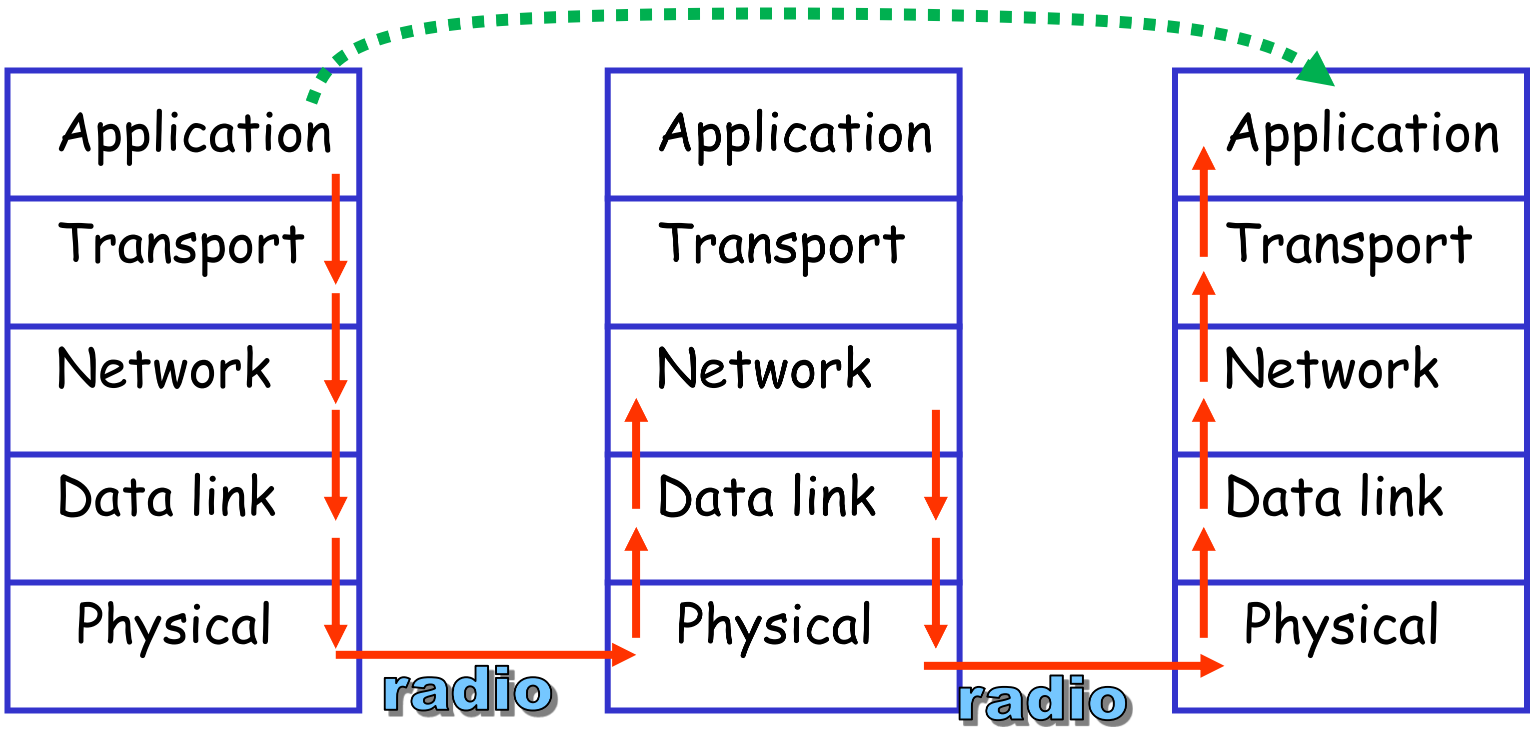
Protocol Stack

- Physical layer
  - convert bit stream into (analog) signals and back
- Data link layer
  - provide reliable connection between a sender and one or more receivers (w/in range)
- Network layer (cf. IP)
  - route packets from sender to receiver (not necessarily w/in range)
- Transport layer (cf. TCP and UDP)
  - establishes an end-to-end connection
- Application layer

Simple reference model



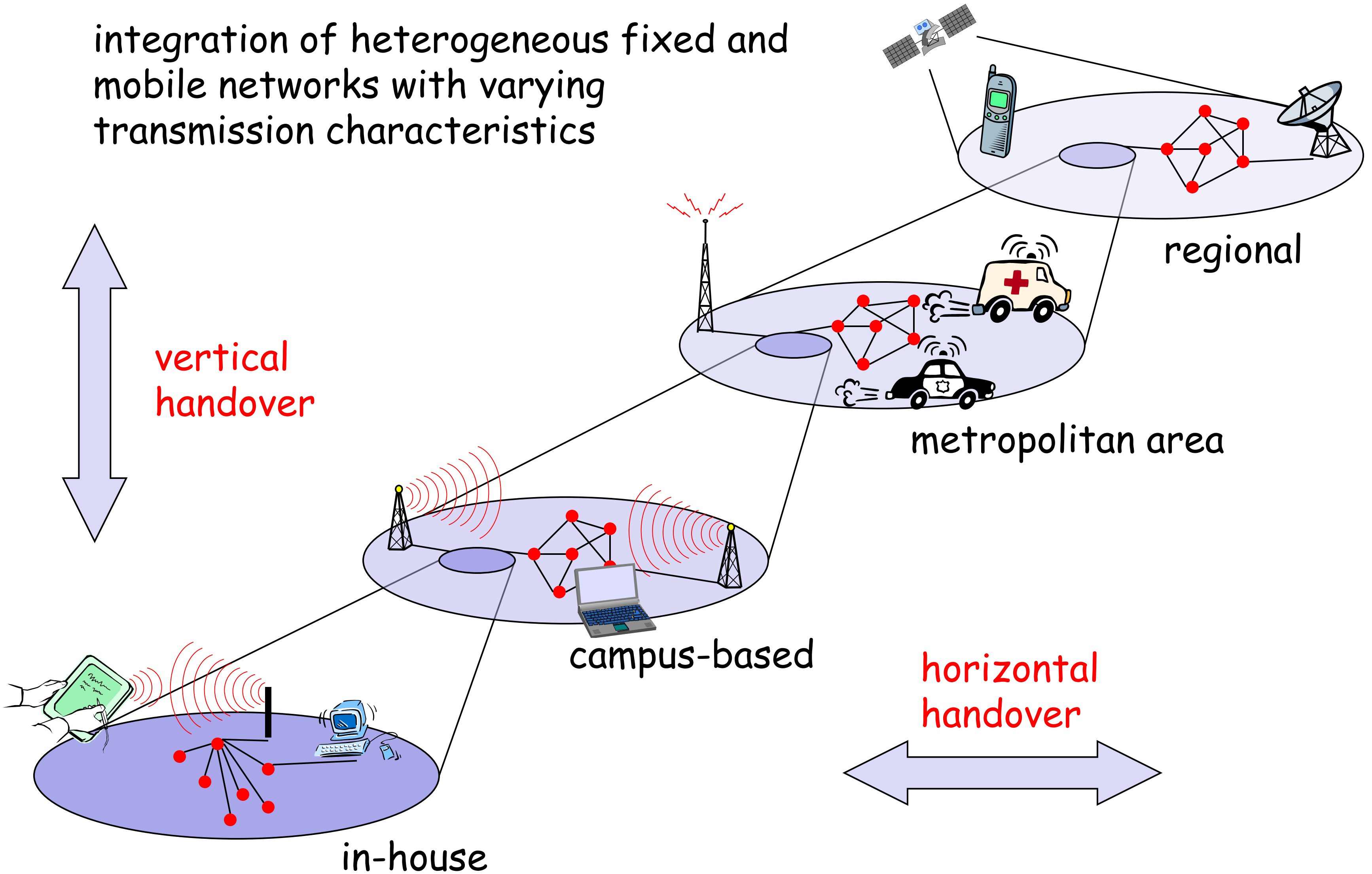
Protocol Stack



not every node needs every layer

Overlay Networks - the global goal

integration of heterogeneous fixed and mobile networks with varying transmission characteristics



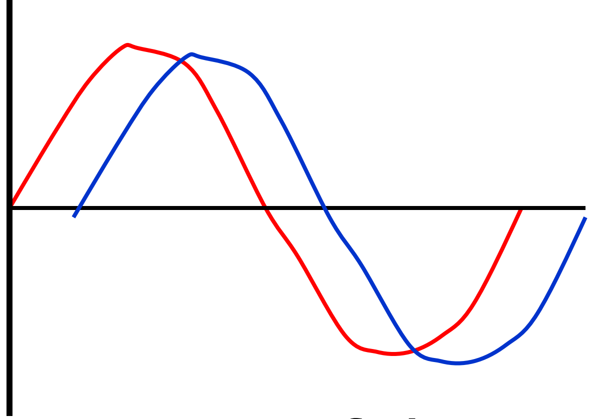
Implementing the Protocol Stack

- Physical layer: signals, antennas, etc.
- Data link layer: various "medium access control" (MAC) protocols developed to help nodes coordinate when they transmit to reduce likelihood of interference
- Network layer: Extensions to IP to deal with mobility have been developed.
  - addressing, routing, device location, handover between networks
- Transport layer: Extensions to TCP have been developed.
  - quality of service, flow control, congestion control
- Applications: new ones ("find closest parking place")
  - service location, support for multimedia, adapt to variations in transmission characteristics

Physical Layer: Overview

- Mobile devices communicate using radio broadcasts, over radio spectrum.
  - Only a limited set of frequencies for transmission.
- Communicating devices must share a common medium.
  - Concurrent communications by nearby nodes may interfere with each other, so that a receiver may hear garbled signals.
- Antennas provide the coupling between the transmitter and space, and between space and the receiver.
- What is actually transmitted is an analog signal.
  - Discrete information has to be encoded into analog signals.

Physical Layer

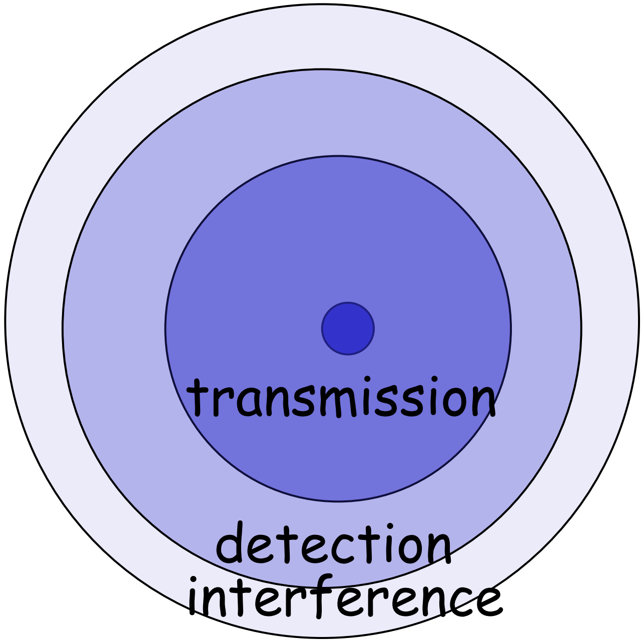


- Wireless transmission uses certain frequencies of the electromagnetic spectrum
  - very low: submarines, underwater
  - infrared: connecting laptops and PDAs
- Data is encoded in signals
- Signals in radio transmission are usually sine waves
- Amplitude, frequency and/or phase shift of a sine wave are changed to represent different information: called modulation

Physical Layer: Antennas

- Antennas convert electromagnetic energy between space and a wire.
- Ideal antenna radiates equal power in all directions from a point in space

- transmission: receiver gets signal with sufficiently low error rate
- detection: receiver can detect signal but error rate is too high
- interference: receiver cannot detect signal but signal may interfere with other transmissions by adding to background noise



Physical Layer: Attenuation

- In a vacuum, received power is proportional to $1/d^2$, where d is distance of receiver from sender
  - signal travels away from sender at speed of light
  - signal is a wave with spherical shape
  - sphere keeps growing and energy is equally distributed over the sphere's surface
  - surface area $s = 4 \pi d^2$
- In non-vacuum, signal decreases even faster due to atmosphere ("path loss" or "attenuation")
  - exponent between 2 and 4

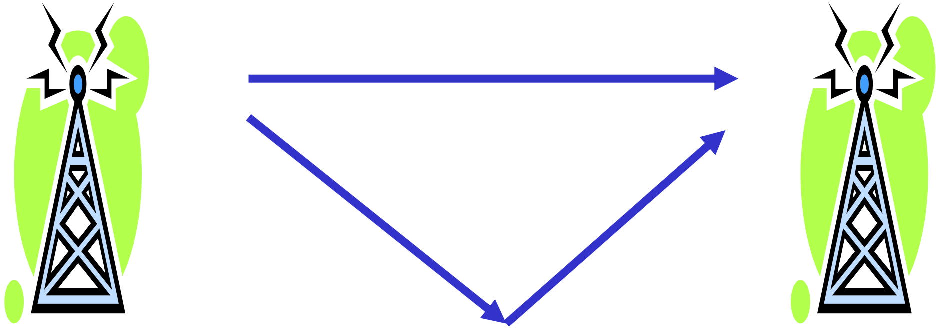
Physical Layer: Propagation

- Types of propagation behaviors:
  - **groundwave (< 2 MHz):** follow earth's surface; can propagate long distances, penetrate objects (ex: submarine communication)
  - **sky wave (2-30 MHz):** waves bounce b/w ionosphere and earth's surface, traveling around world (ex: short wave radio)
  - **line-of-sight (> 30 MHz):** waves follow a straight line (ex: mobile phones, satellites)

- Obstacles are problem for line-of-sight:
  - blocked, reflected, refracted, scattering, diffraction
  - solution: additional antennas to fill in coverage gaps

Physical Layer: Propagation

- Because of all these physical effects, radio signal behavior is highly variable
  - depends on type of antenna and environment
- Example problem: 2-ray ground propagation model:



Physical Layer: Bottom Line

- Not every message sent is received
- Loss due to noise and interference
- Not easy to model in a realistic way
- Mathematical models for propagation are not accurate representations of real channel behavior.
- In practice, we want algorithms that can adapt to real channel characteristics.
- Models are useful mainly for analysis and simulation: get general idea of algorithms' behavior, in some ideal cases

Physical Layer: Multiplexing

- Share the electromagnetic spectrum w/o undue interference along several dimensions:
  - space, time, frequency, code

- **Space division:** senders are so far apart they don't interfere
  - Ex: FM radio stations in different towns w/ same frequency (90.9)
  - Disadvantages: wastes space, what if senders are close to each other?

Physical Layer: Multiplexing

- **Frequency division:** divide spectrum into several non-overlapping frequency bands
  - Ex: radio stations in same town use different frequencies (90.9 vs. 89.1)
  - Disadvantages: wastes frequency (unless senders transmit all the time); fixed assignment of frequency to sender is inflexible and limits number of senders

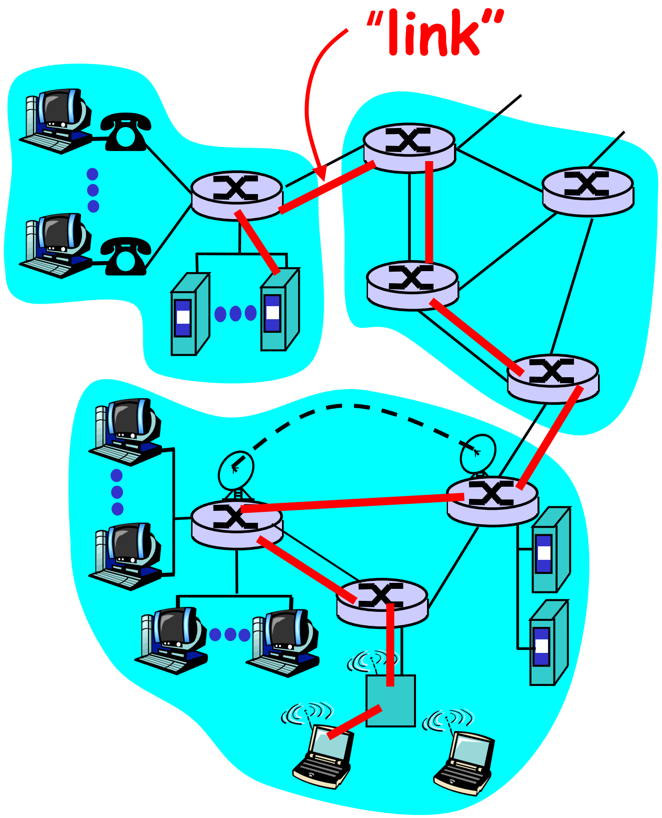
Physical Layer: Multiplexing

- **Time division:** all senders use same frequency but at different times
  - Ex: different radio shows on the same station but at different times
  - Disadvantages: need precise synchronization; receiver has to listen at right time
  - Advantage: can assign more sending time to senders with heavier load

Physical Layer: Multiplexing

- **Code division:**
  - all users use same frequency at same time, each user has different "code".
  - With right choice of codes, transmissions can be done simultaneously
    - constructive interference properties of radio signals allow the codes to be separated at receives
  - Advantages: code space is huge, good protection against interference and tapping
  - Disadvantages: receiver must know code and separate the desired information from background noise; receiver must be synchronized with sender

Data Link Layer: Introduction



Some terminology:

- **hosts** and **routers** are **nodes**
- **communication channels** that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
- Layer 2 PDU is a **frame**, encapsulates **datagram**

data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

Link layer: context

- Datagram transferred by different link protocols over different links:
  - 802.3 (Ethernet)
  - 802.11 (WLAN)
  - …
- Each link protocol provides different services

transportation analogy

- trip from **Linkou** to **Lyon**
  - limo: Linkou to CKS
  - plane: CKS to Paris
  - train: Paris to Lyon
- tourist = datagram
- transport segment = communication link
- transportation mode = link layer protocol
- travel agent = routing algorithm

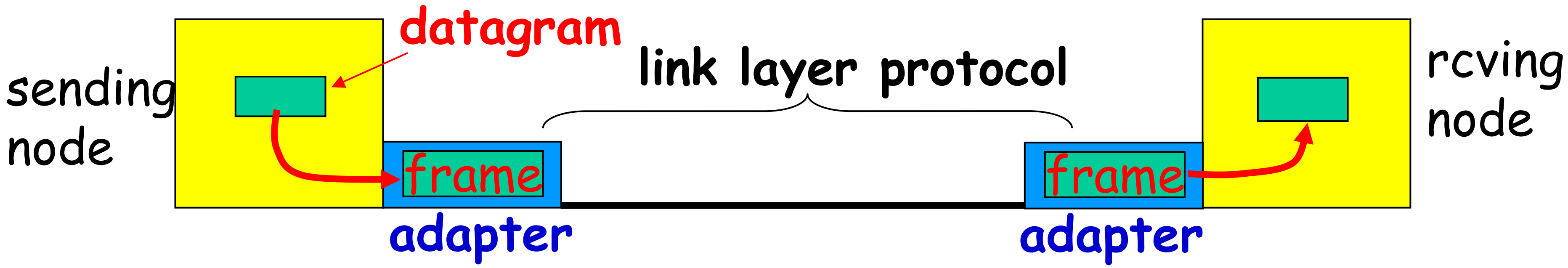
Link Layer Services

- Framing, link access:
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium (later)
  - 'physical addresses' used in frame headers to identify source, destination
    - different from IP address!
- Reliable delivery between adjacent nodes
  - seldom used on low bit error link (fiber, some twisted pair)
  - wireless links: high error rates

Link Layer Services (more)

- **Flow Control:**
  - pacing between adjacent sending and receiving nodes
- **Half-duplex** and **full-duplex**
  - with half duplex, nodes at both ends of link can transmit, but not at same time

Adapters Communicating



- **link** & **physical** layers
- link layer implemented in "adapter" (aka NIC)
  - Ethernet card, 802.11 card, …
- sending side
  - encapsulates datagram in a frame
  - adds error checking bits, rdt, flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc
  - extracts datagram, passes to rcving node

Challenge for MAC Protocols

- Communication provided by physical layer is not very reliable:
  - Messages might not get delivered, because of noise or interference (collisions).
- MAC layer should improve the reliability.
  - Won't make it perfect, in spite of many tricks.
- Main job of MAC layer: Manage contention among nearby transmitters and receivers.
- Q: What are reasonable statements of the guarantees of a MAC layer?
  - Probabilistic delivery guarantees? Conditional?
  - Layer should be efficiently implementable.
  - Should support higher-level programming.

Multiple Access Links and Protocols

Two types of "links":

- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch & host
- broadcast (shared medium)
  - traditional Ethernet
  - 802.11 wireless LAN
  - Wireless communication

Single Shared Broadcast Channel

- Only one node can send successfully at a time
  - Interference: two or more simultaneous transmissions by nodes

Multiple access protocol

- distributed algorithm that determines
  - How nodes share channel
  - When node can transmit

Ideal Multiple Access Protocol

Broadcast channel of rate: R bps

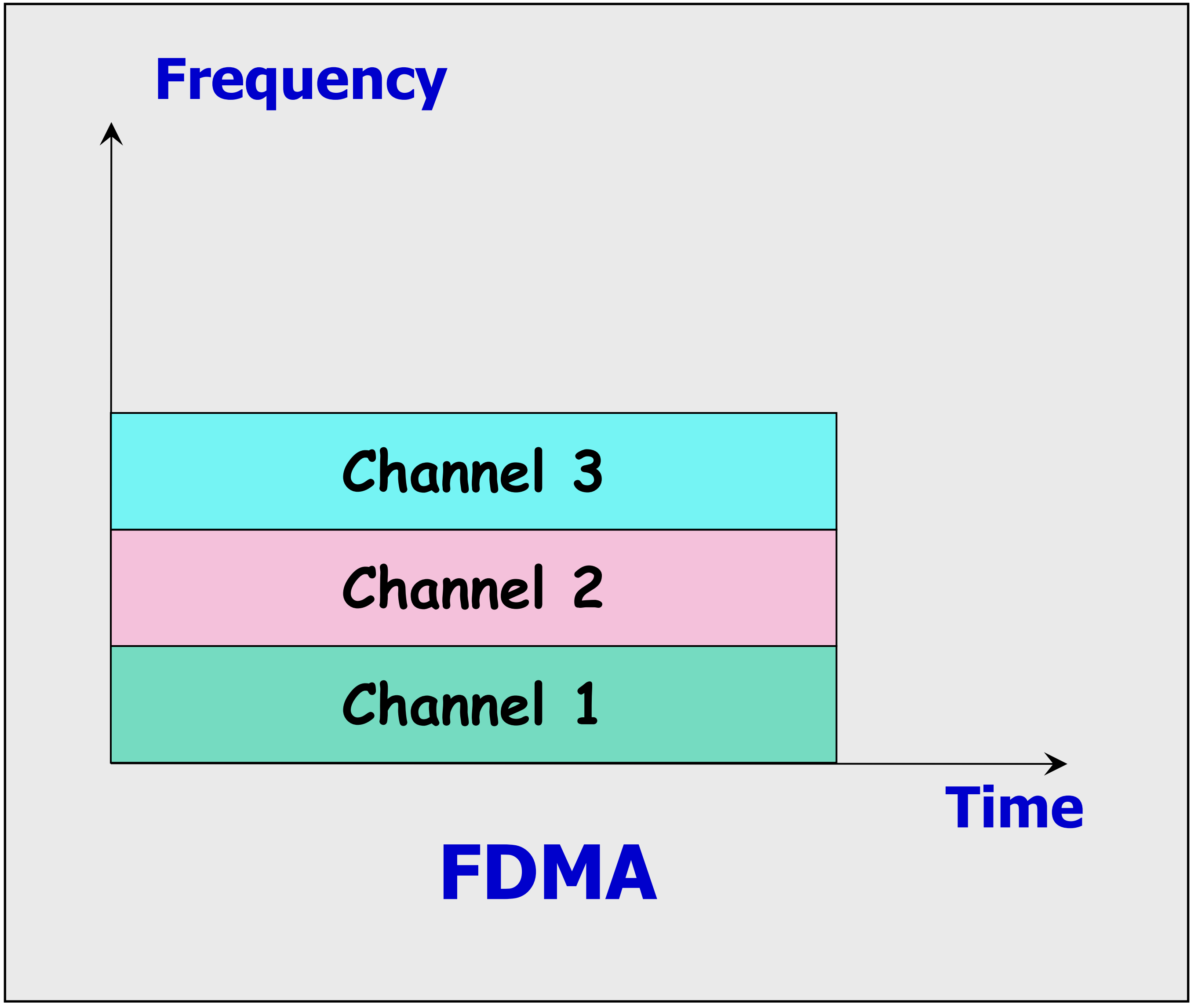
1. When one node wants to transmit, it can send at rate R.
2. When M nodes want to transmit, each can send at average rate **R/M**
3. Fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. Simple

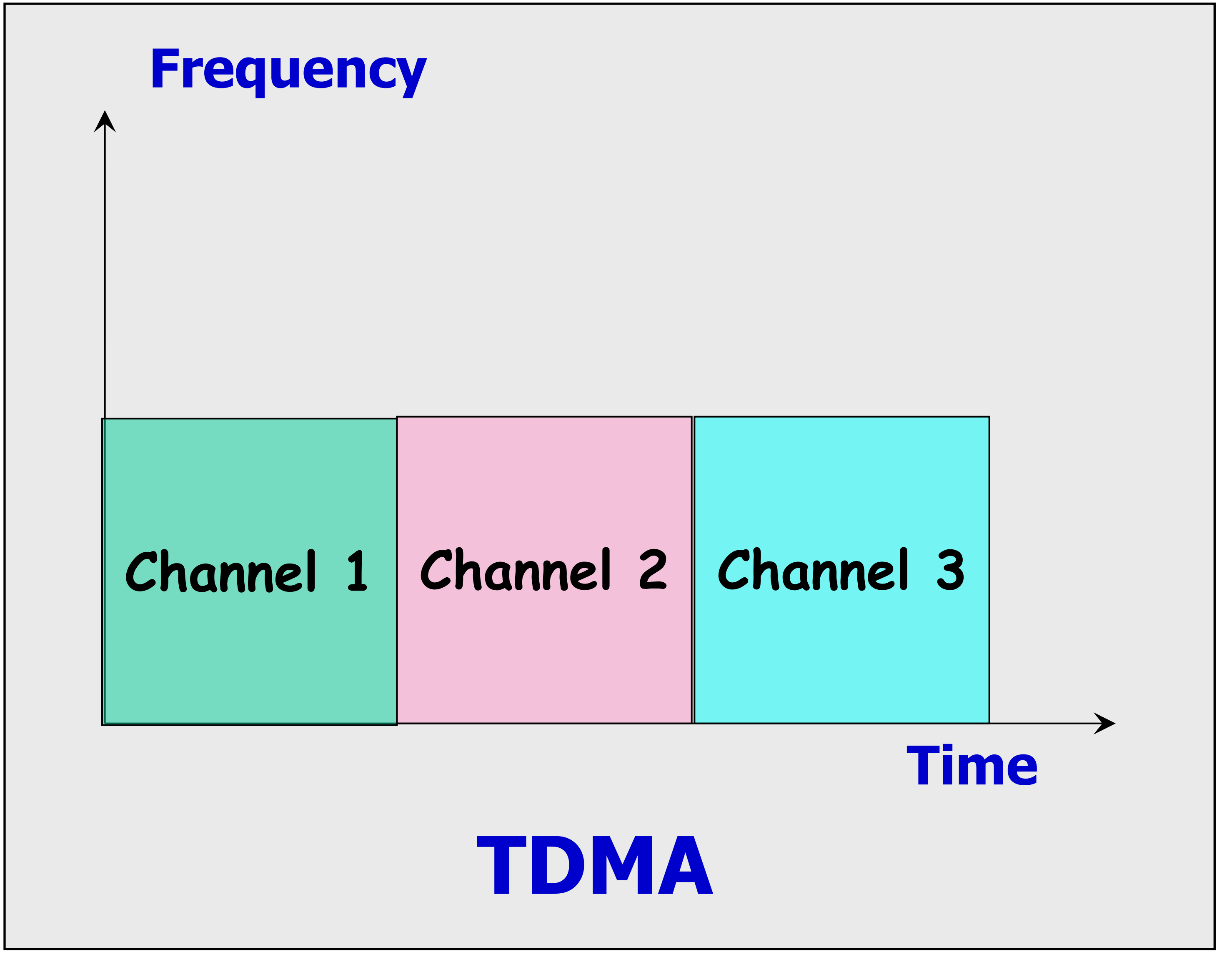
MAC Protocols

- **MAC Protocols:**
  - **Fixed Multiple Access**
  - **Random Multiple Access**

Fixed Multiple Access

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Hybrid FDMA/TDMA
- Code Division Multiple Access (CDMA)
- Taking turns (Polling, token passing)


Frequency
Channel 3
Channel 2
Channel 1
Time
FDMA


Frequency
Channel 1
Channel 2
Channel 3
Time
TDMA

Hybrid FDMA/TDMA

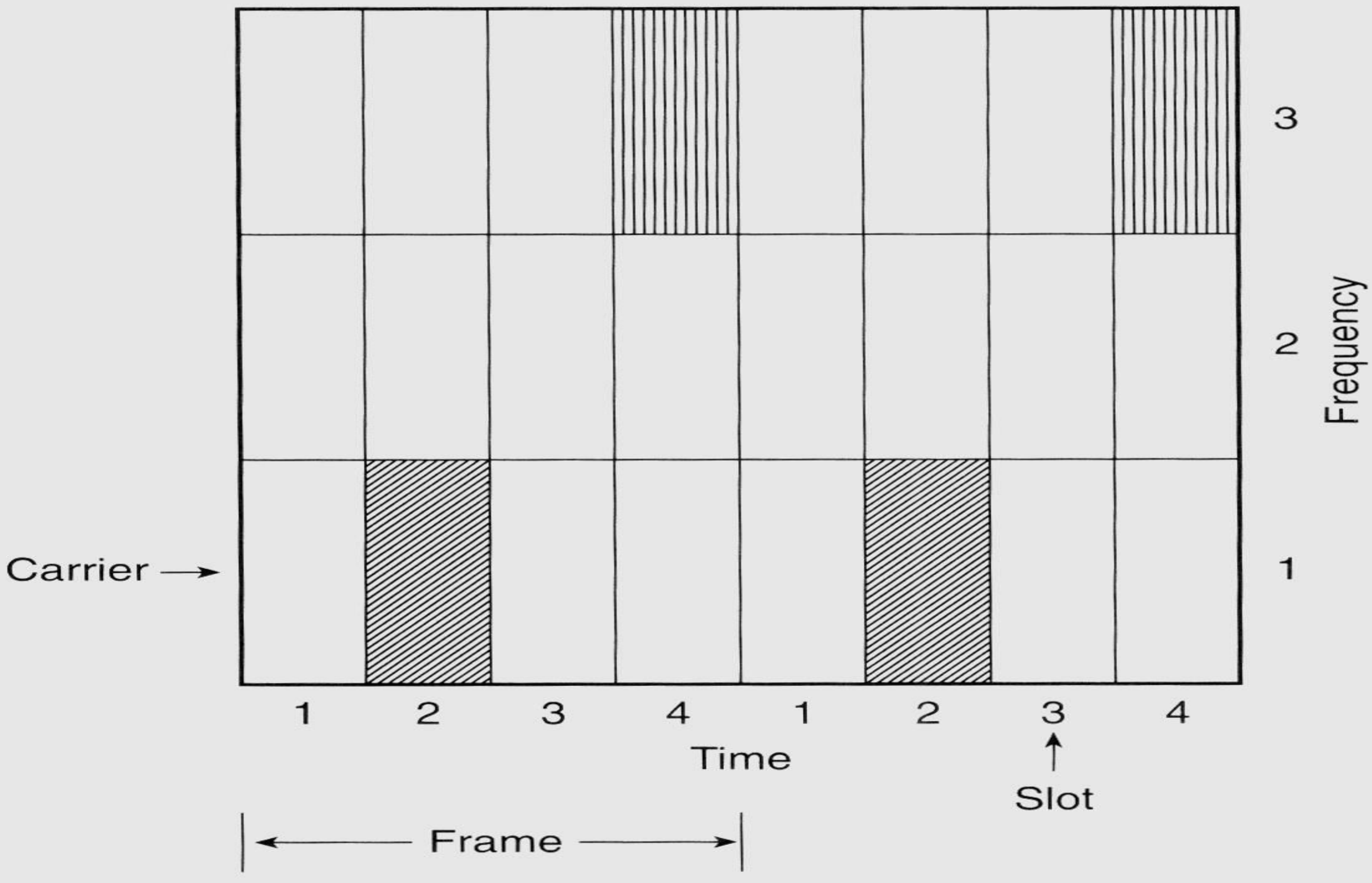
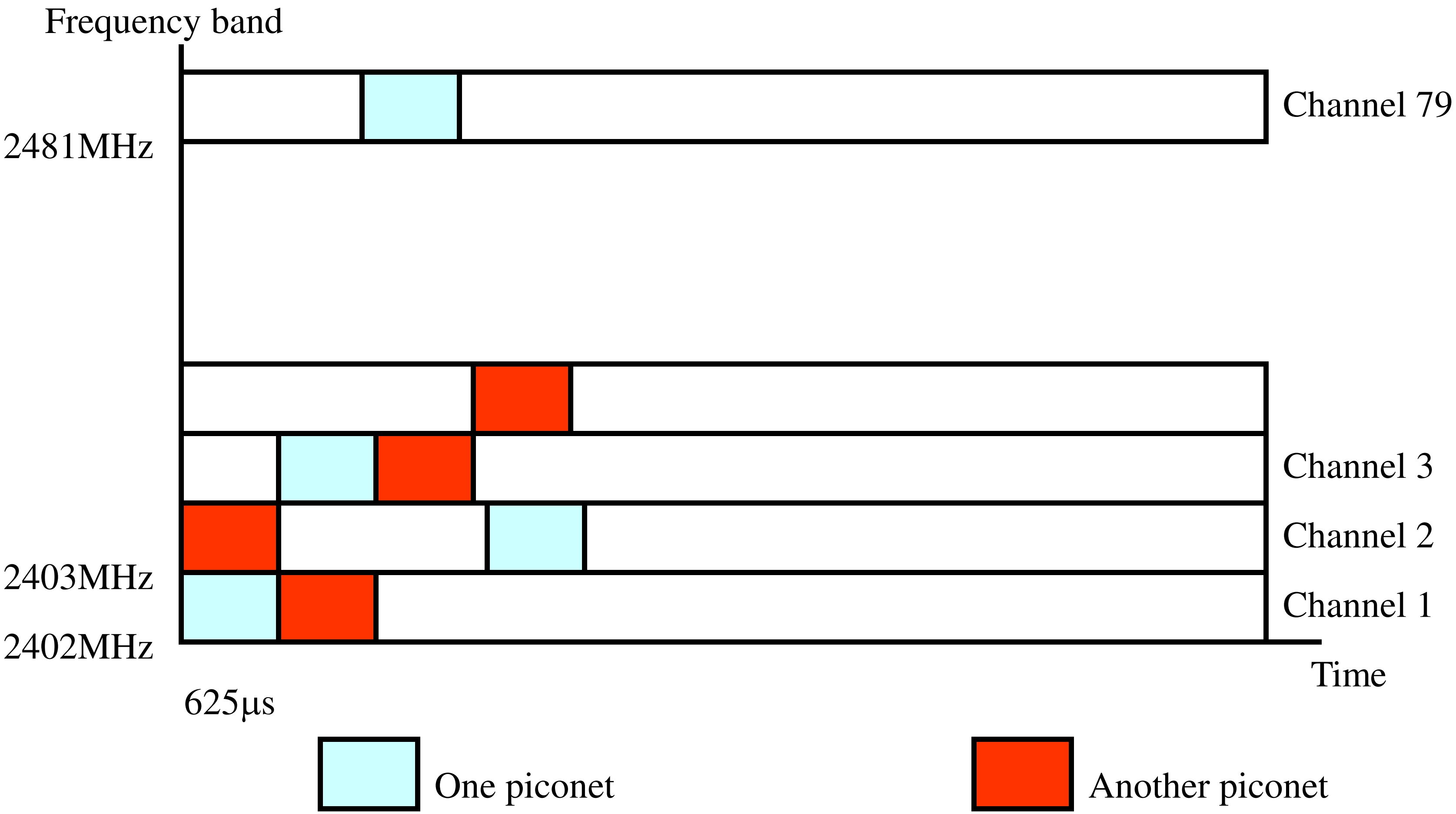
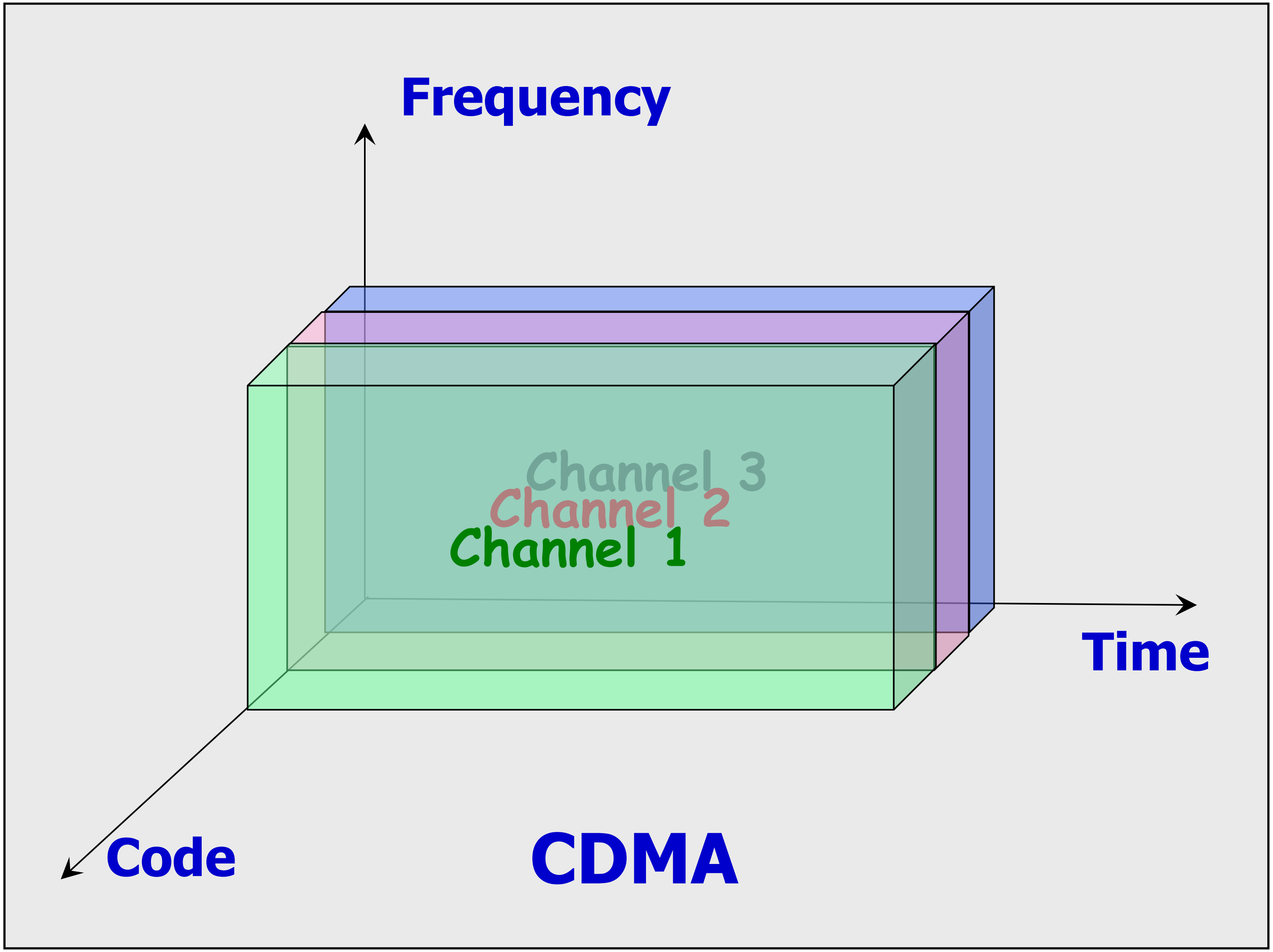


Figure 9.3 Hybrid FDMA/TDMA. A physical channel is a time slot within one carrier.

Hybrid FDMA/TDMA




Frequency
Channel 3
Channel 2
Channel 1
Time
Code
CDMA

Spread Spectrum Modulation

- Definition: "spread" a signal's power over a wider band of frequency.

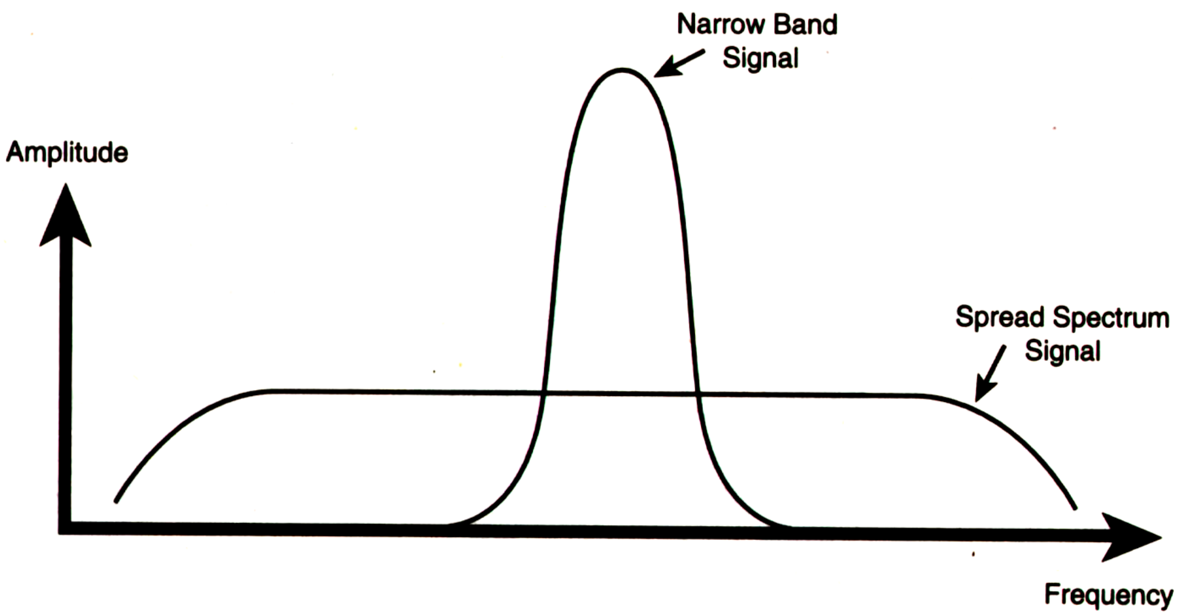


Figure 2.4
Narrow band versus spread spectrum modulation.

Spread Spectrum

- Disadv.: This contradicts with the goal of conserving bandwidth.
- Adv.: less susceptible to electrical noise (especially from narrow band sources)
  - In World War II, US Army uses spread spectrum to avoid hostile jamming.
- To spread a signal, there are two ways:
  - direct sequence **(DSSS)**
  - frequency hopping **(FHSS)**

Direct Sequence Spread Spectrum

- Use bit sequence to represent "0" and "1" (Fig. 2-5), referred to as "chipping code".
- Longer chipping codes are more resilient to noise.
- Minimum length = 10 (regulated by FCC)
- IEEE 802.11 uses 11 chips per data bit.

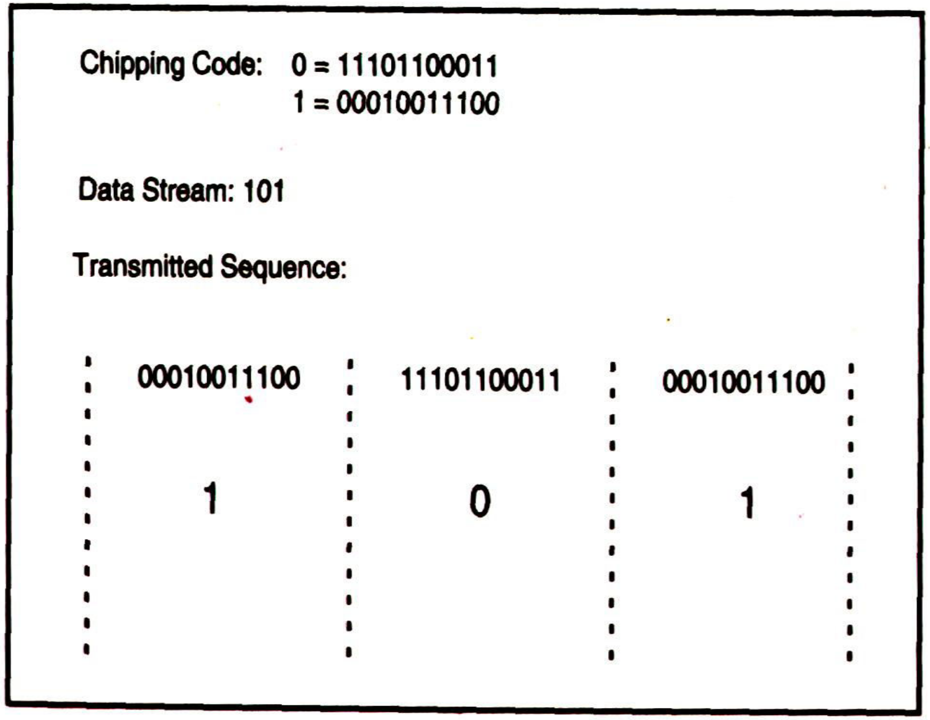


Figure 2.5
The operation of direct sequence spread spectrum.

Frequency Hopping Spread Spectrum

- Data is modulated by carrier signals that hop from frequency to frequency as a function of time, over a wide band of frequencies.

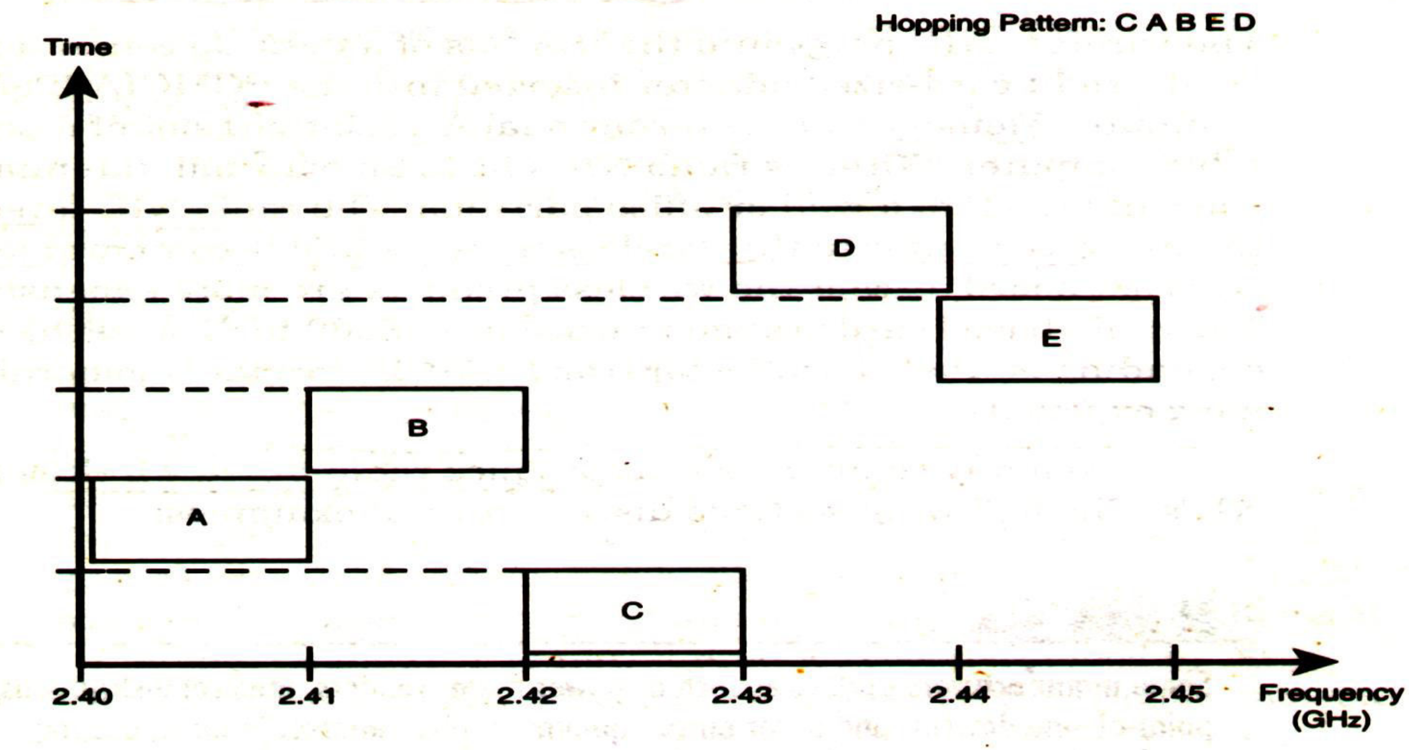


Figure 2.6
A frequency hopping spread spectrum.

FHSS (cont.)

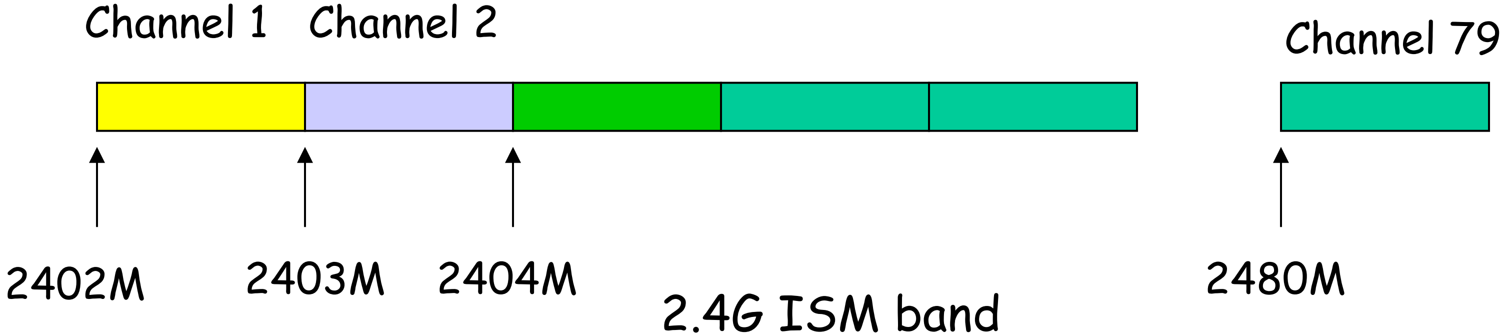
- Hopping Code: to determine the order of hopping frequencies
- The receiver must "listen" to incoming signals at the right time at the right frequency.
- FCC regulation: at least 75 frequencies, with max. dwell time 400ms.
- Adv.: very resilient to noise.
- Orthogonal hopping codes: a set of hopping codes that never use the same frequencies at the same time.

FHSS-In Bluetooth

- 2.4Ghz ISM unlicensed band.
- Spread spectrum frequency hopping radio
  - Avoid interference
  - 79channels Hops every packet.
  - Nominally hops at 1600 times a second(1 slot packets).

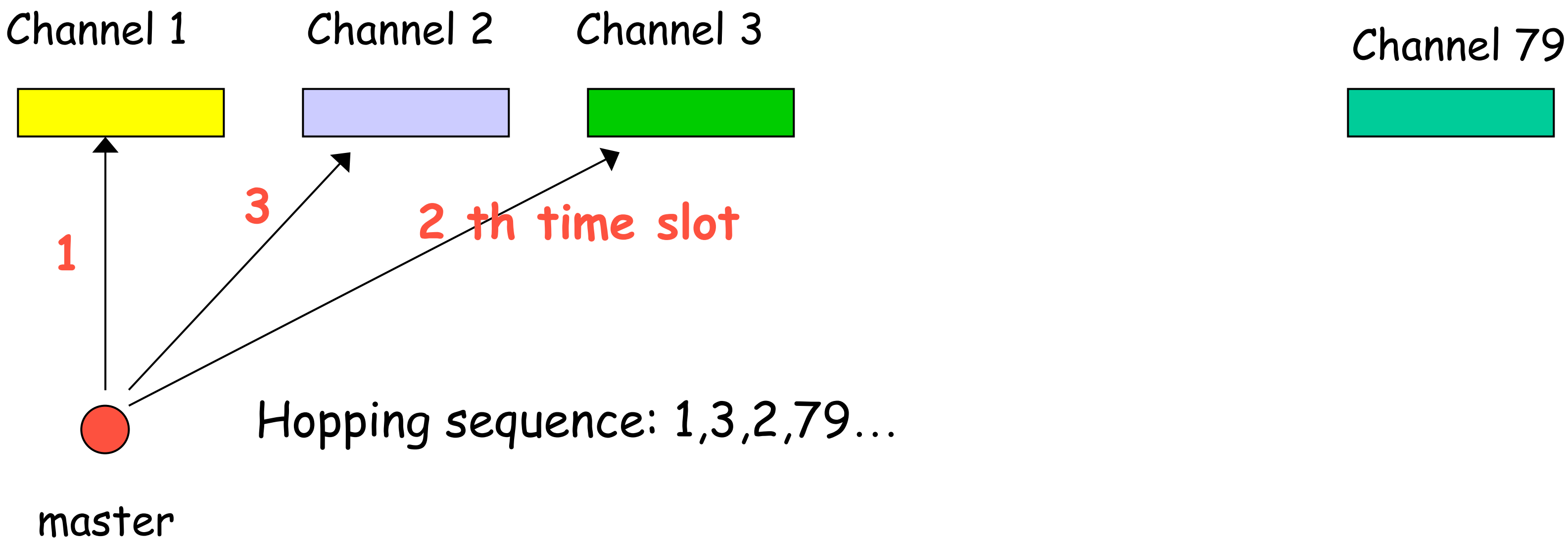
Bandwidth Management

- 2.4G ISM band
  - 2402-2480 M Hz
  - In total, 79 channels are scheduled
  - Each channel occupies 1M Hz
  - Bandwidth: 1M bps

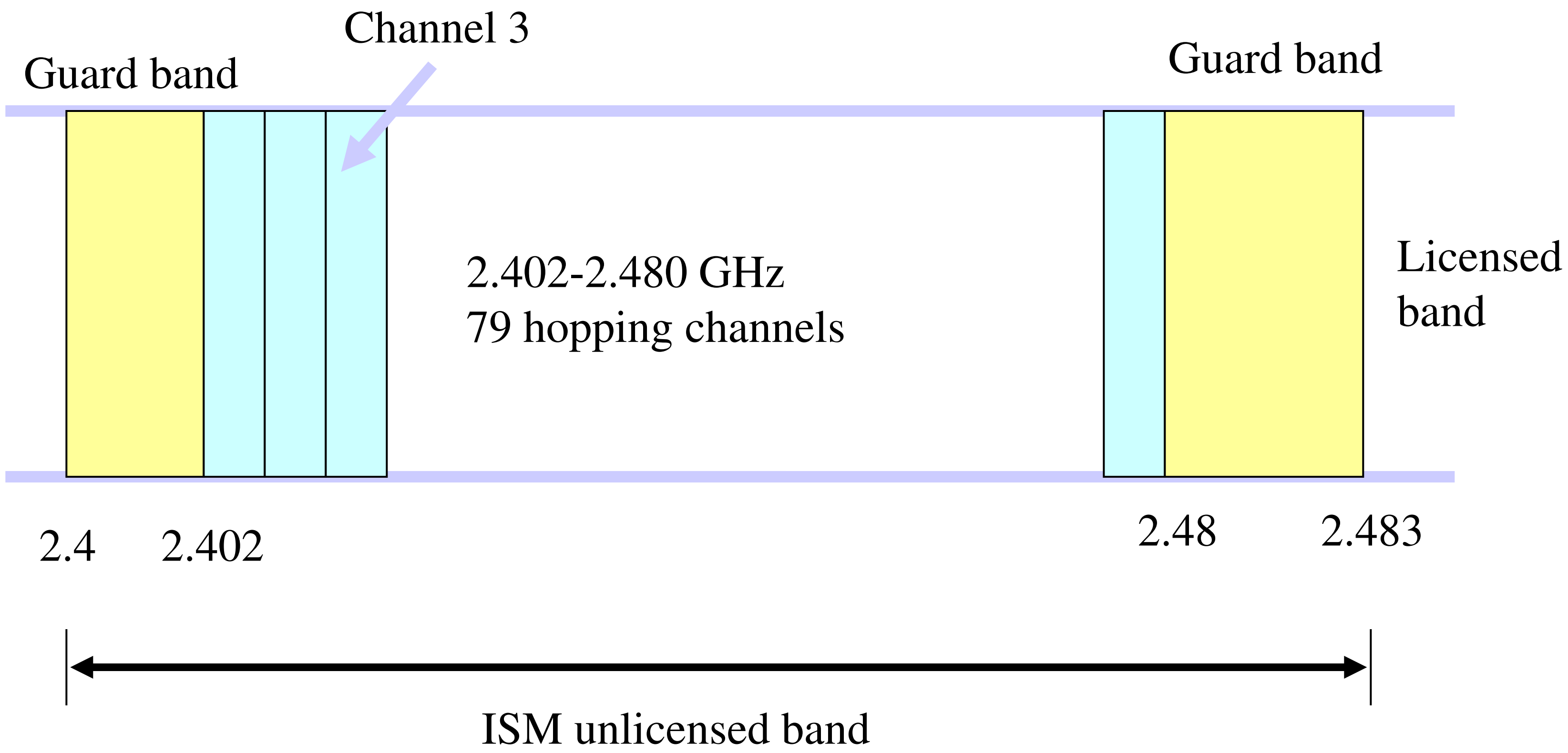


Frequency hopping

- Master hops 1600/s➔ 0.625ms/hop
- The master hops to another channel according to its hopping sequence



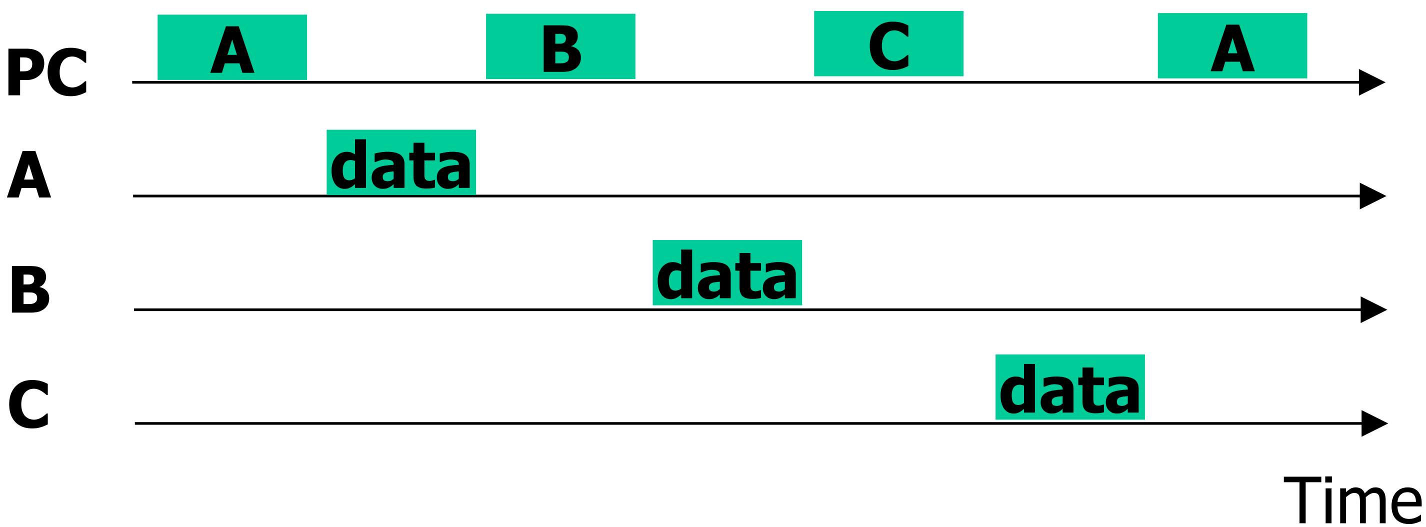
Frequency bands



"Taking Turns" MAC protocols

Polling:

- master node "invites" slave nodes to transmit in turn
- shortcomings:
  - polling overhead
  - latency
  - single point of failure (master)



Random Access MAC Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes

  -> *collisions*

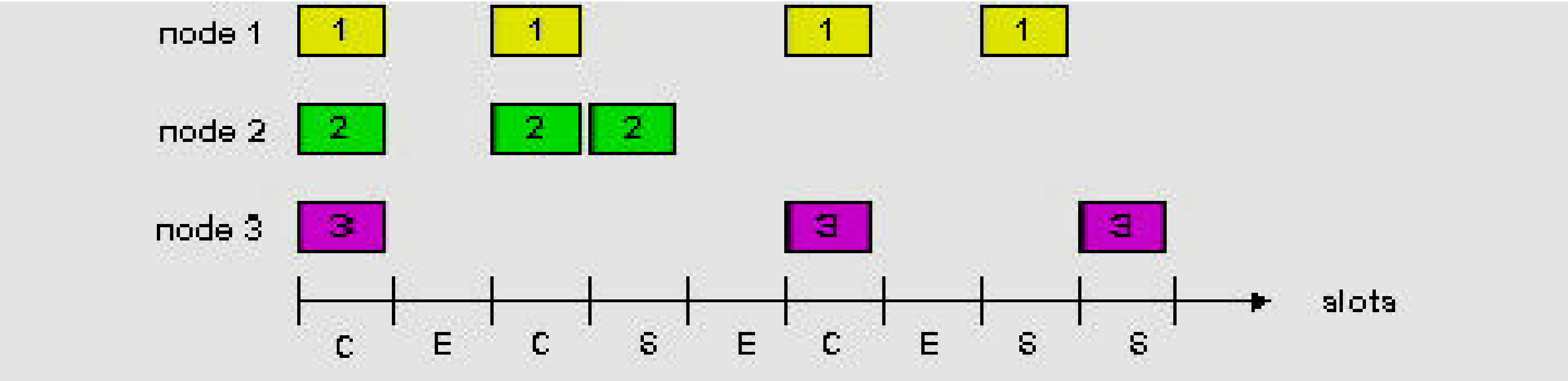
Random Access MAC Protocols

- random access protocol specifies:
  - how to detect collisions
  - how to solve the collisions (e.g., via delayed retransmissions)
- Examples:
  - ALOHA
  - slotted ALOHA
  - CSMA, CSMA/CD, CSMA/CA

Slotted ALOHA

Assumptions

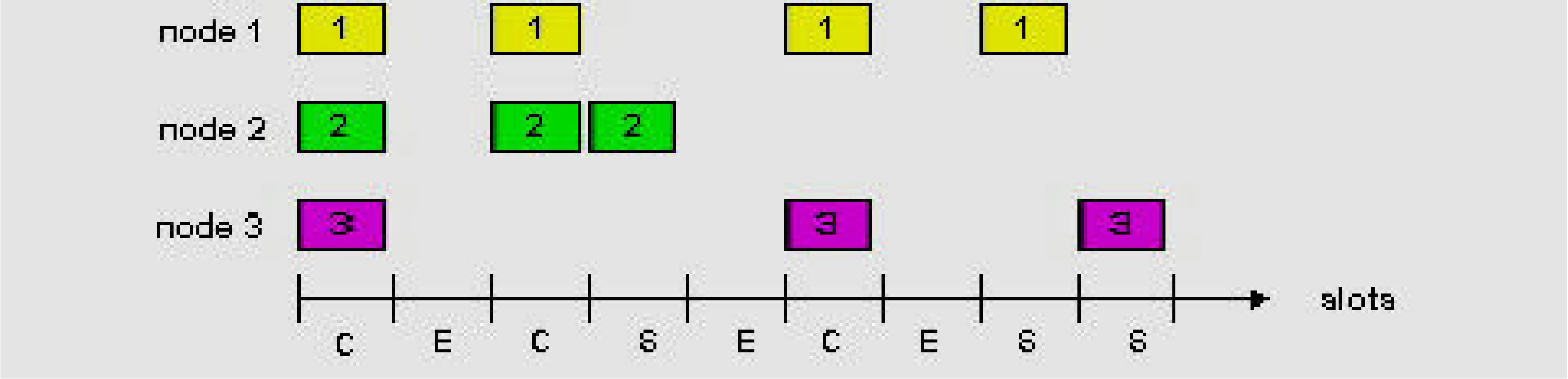
- all frames same size
- nodes are synchronized
- time is divided into equal size slots, time to transmit 1 frame
- nodes start to transmit frames only at beginning of slots
- if 2 or more nodes transmit in slot, all nodes detect collision



Slotted ALOHA

Operation

- when node has a to-be-transmitted frame, it transmits in next slot
- no collision, node can send new frame in next slot
- if collision, node retransmits frame in each subsequent slot with prob. p until success



Slotted ALOHA

Pros

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision

Slotted Aloha efficiency

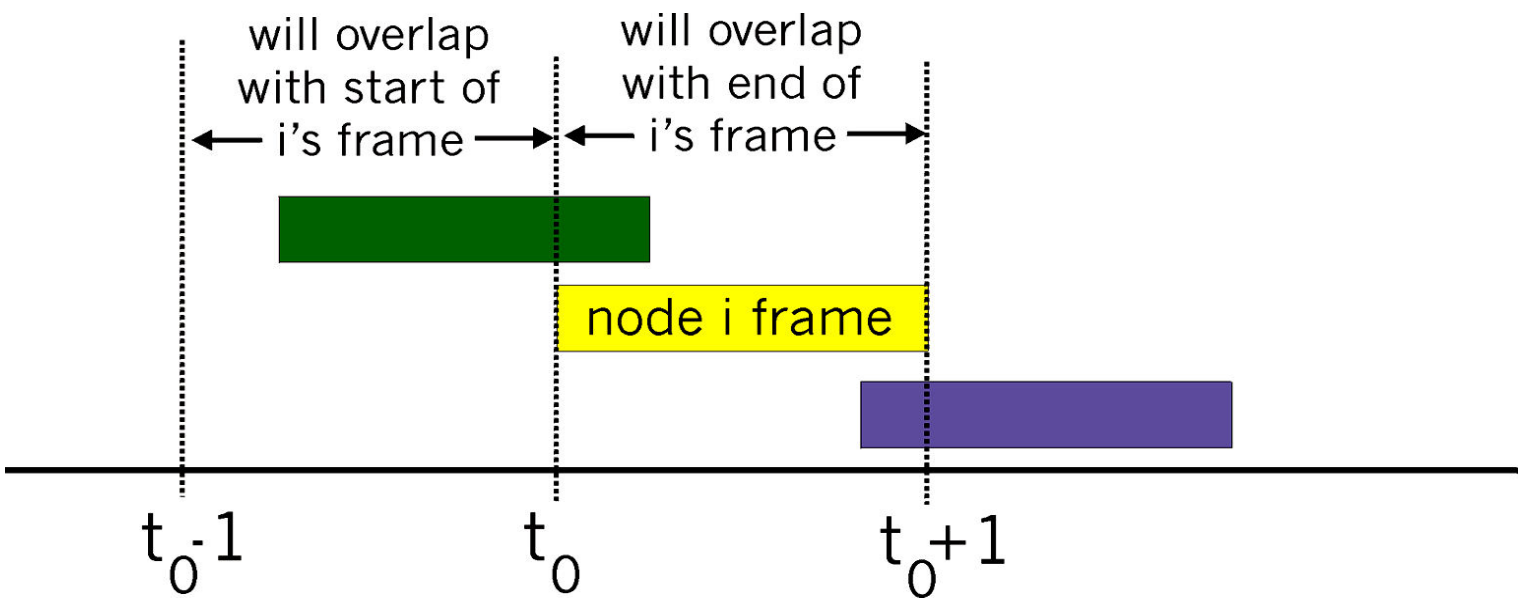
Efficiency is the long-run fraction of successful slots when there's many nodes, each with many frames to send

- N nodes with many frames to send, each transmits in slot with probability p
- Prob. that 1st node has success in a slot = $p(1-p)^{N-1}$
- prob that any node has a success = $Np(1-p)^{N-1}$
- For max efficiency with N nodes, find p^* that maximizes $Np(1-p)^{N-1}$
- For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives $1/e = .37$

At best: channel used for useful transmissions **37%** of time!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure Aloha efficiency

P(success by given node) = P(node transmits) ·

P(no other node transmits in $[t_0-1,t_0]$ ·

P(no other node transmits in $[t_0,t_0+1]$

$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$

$= p \cdot (1-p)^{2(N-1)}$

… choosing optimum p and then letting n -> infty ...

Even worse ! $= 1/(2e) = .18$

CSMA
(Carrier Sense Multiple Access)

CSMA: listen before transmit:

- If channel sensed idle: transmit entire frame
- If channel sensed busy, defer transmission

- Human analogy: don't interrupt others!

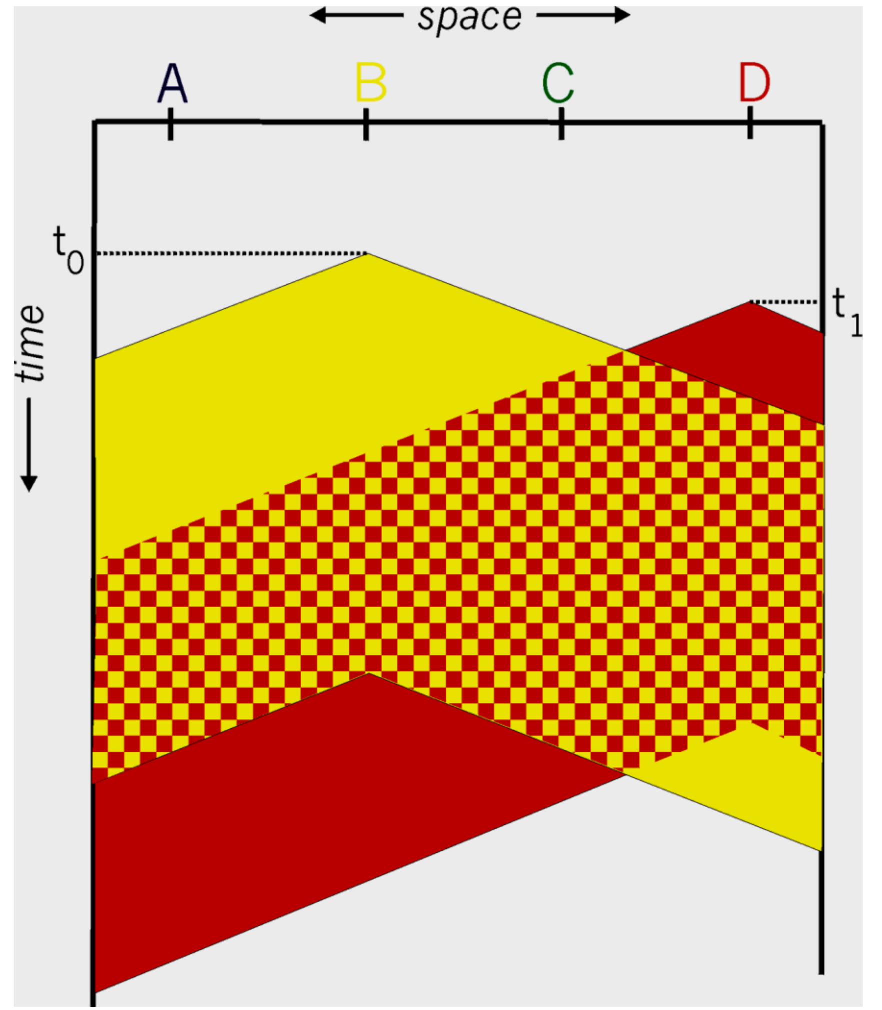
CSMA collisions

collisions *can* still occur:
propagation delay means two nodes may not hear each other's transmission

collision:
entire packet transmission time wasted

note:
role of distance & propagation delay in determining collision probability

spatial layout of nodes

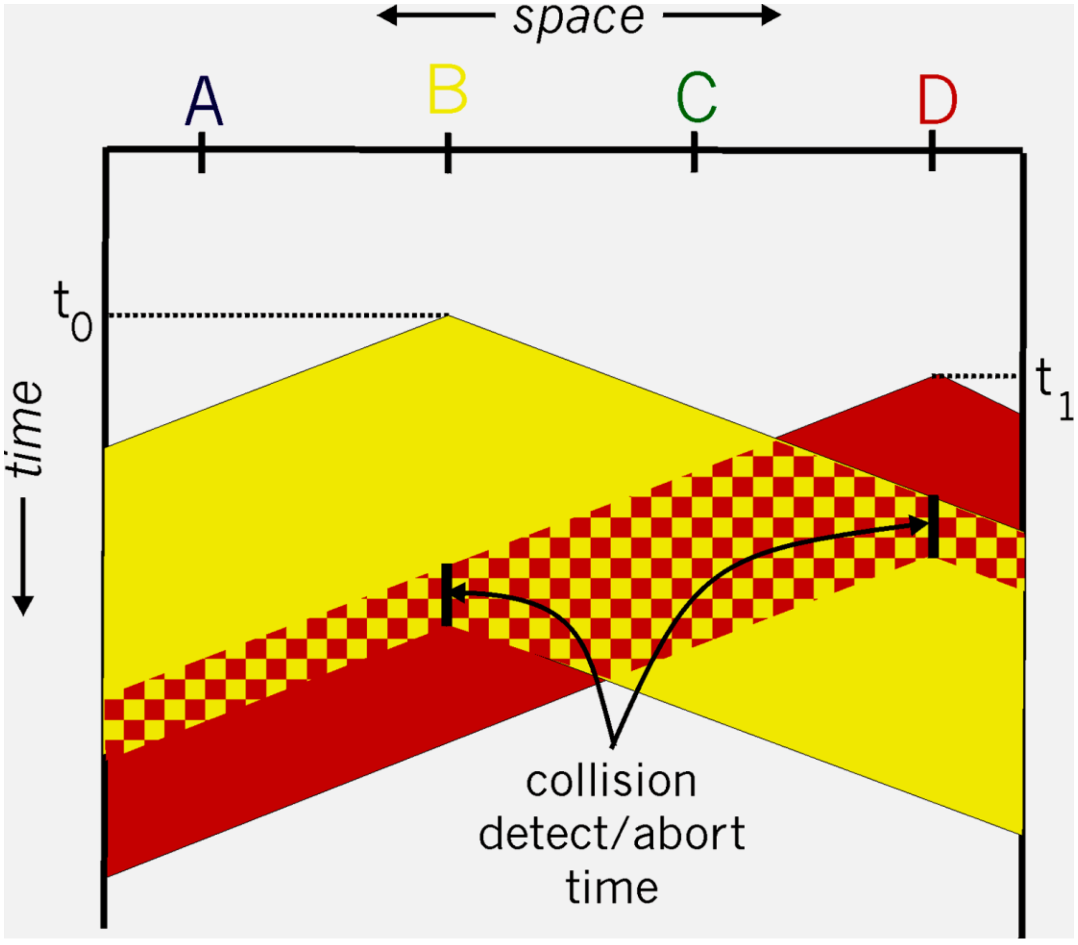


CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA
- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in *wired* LANs: measure signal strengths, compare transmitted, received signals
  - difficult in *wireless* LANs: receiver shut off while transmitting
- human analogy: the polite conversationalist

CSMA/CD collision detection



Random Multiple Access for Wireless Networks

- ALOHA
- CSMA
- MACA
- FAMA
- CSMA/CA

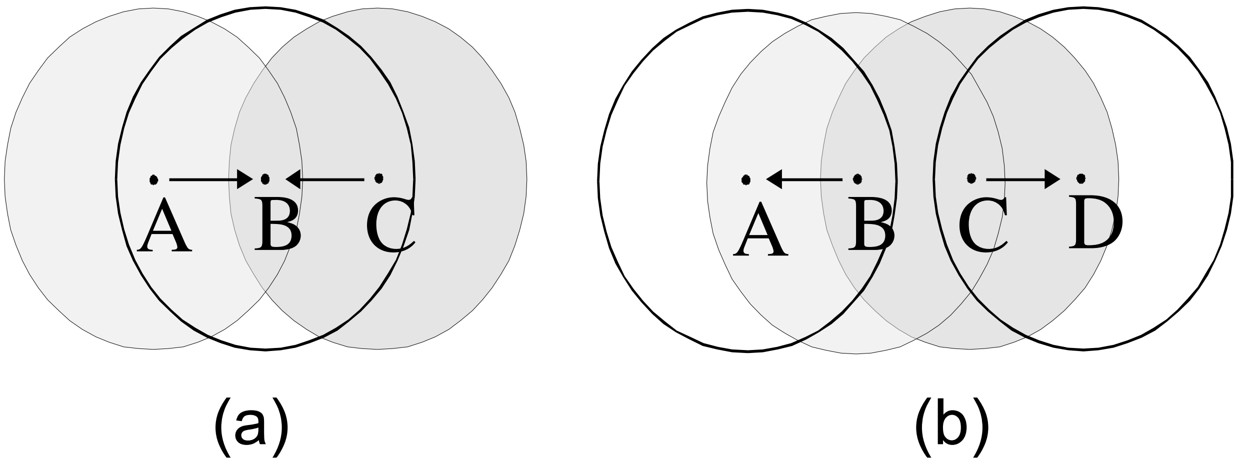


Fig. 1: (a) the hidden terminal problem,
(b) the exposed terminal problem

CSMA/CA (Collision Avoidance)

- CSMA/CA: carrier sense multiple access with collision avoidance
  - a station wishing to send must sense the medium
  - collision avoidance: a random backoff after the medium is sensed idle
  - collision detection will not function properly because the STA may not be able to detect the collision while transmitting.

Summary of MAC protocols

Fixed Multiple Access MAC protocols:

- share channel efficiently and fairly at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols:

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

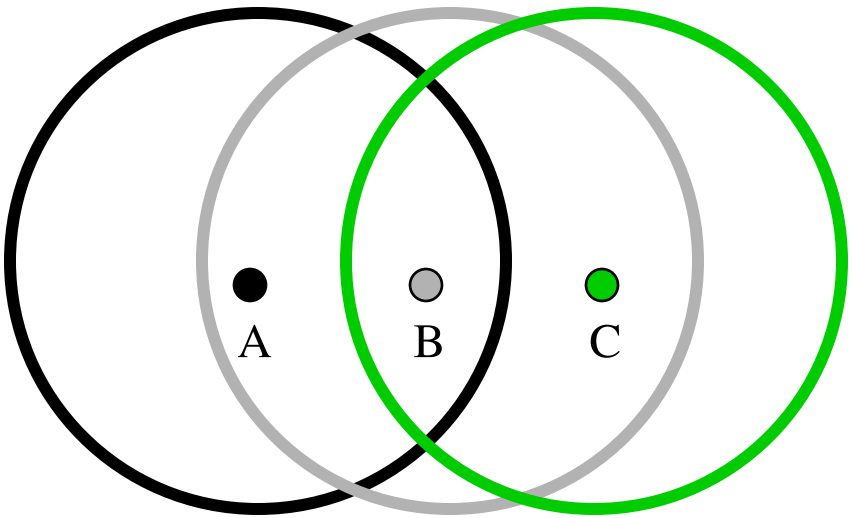
Summary of MAC protocols

- What do you do with a shared media?
  - Channel Partitioning, by time, frequency or code
    - Time Division,Code Division, Frequency Division
  - Random accessing (dynamic),
    - ALOHA, S-ALOHA, CSMA, CSMA/CD, CSMA/CA
    - carrier sensing: easy in some technologies (wire), hard in others (wireless)
    - collision detection: easy in *wired* LANs, difficult in *wireless* LANs
    - CSMA/CD used in Ethernet
    - CSMA/CA used in Wireless LAN

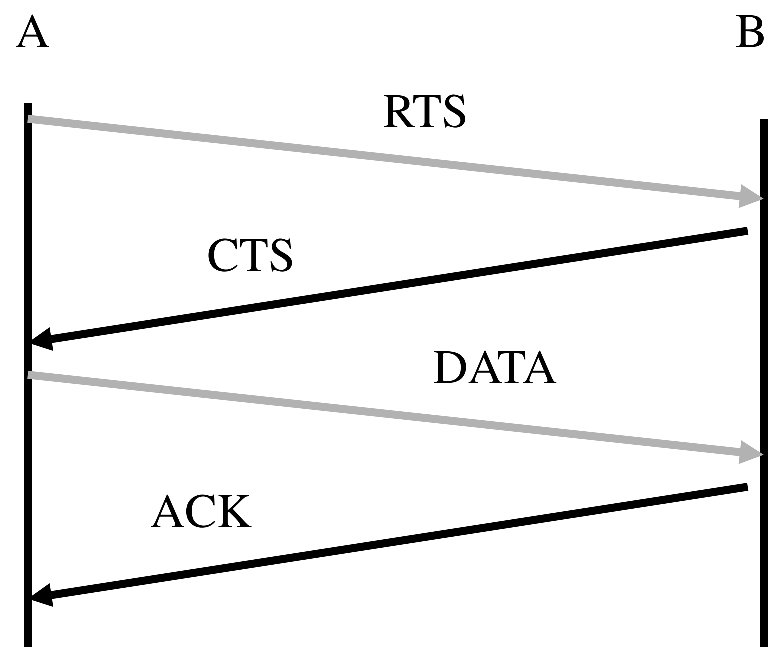
Wireless LAN 802.11

- CSMA/CA (Collision Avoidance)
  - Node A first sends Request To Send(RTS) packet indicating when and how much data it would like to send
  - Node B sends back a Clear To Send (CTS) packet with the amount of data and the time of transmission back to node A
  - Expose Terminal Problem

Wireless LAN 802.11

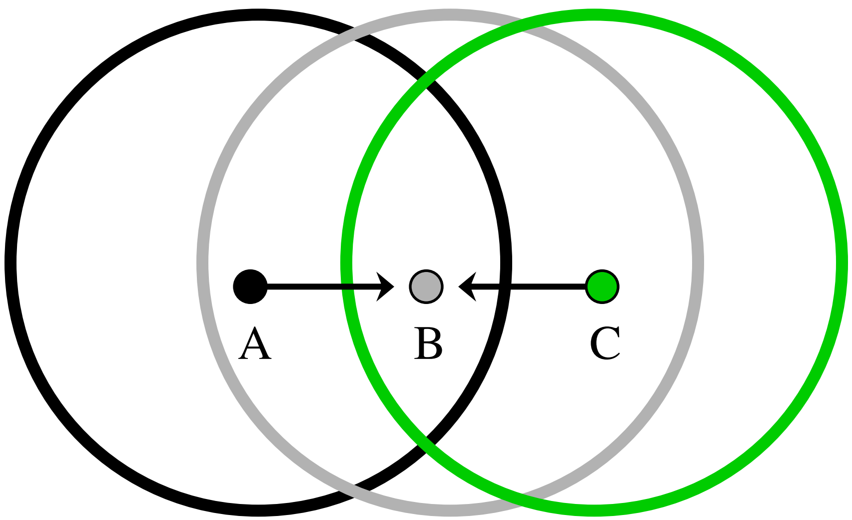


CSMA/CA

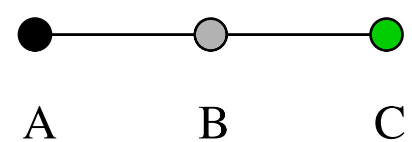


Wireless LAN 802.11

- CSMA
  - Carrier sense Medium Access
  - Hidden Terminal Problem

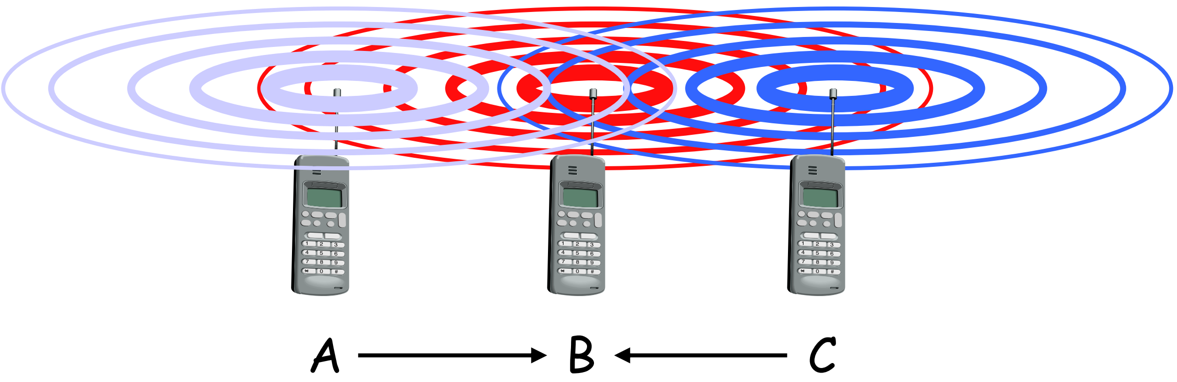


A hears B
C hears B
B hears A and C



Hidden Terminal Problem

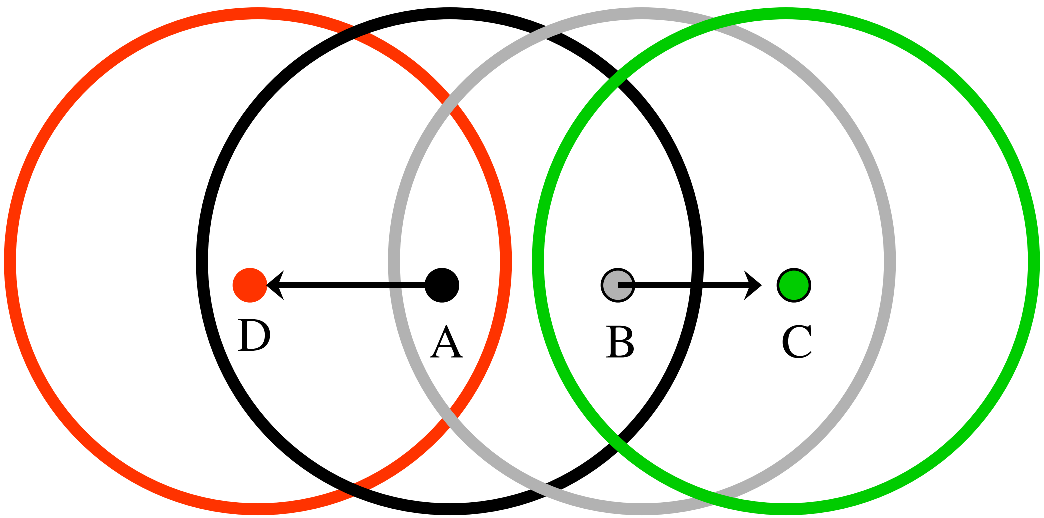
- A sends to B, C cannot receive A
- C wants to send to B, C senses a “free” medium (CS fails)
- collision at B, A cannot receive the collision (CD fails)
- A is “hidden” for C



Wireless LAN 802.11

❒ Exposed Terminal Problem

- **Exposed terminal problem** occurs when a node is prevented from sending packets to other nodes due to a neighboring transmitter.



Exposed Terminal Problem

- B sends to A, C wants to send to D
- C has to wait, CS signals a medium in use
- since A is outside the radio range of C waiting is not necessary
- C is "exposed" to B