Communications & Controls in IoT

Networking Basics-2

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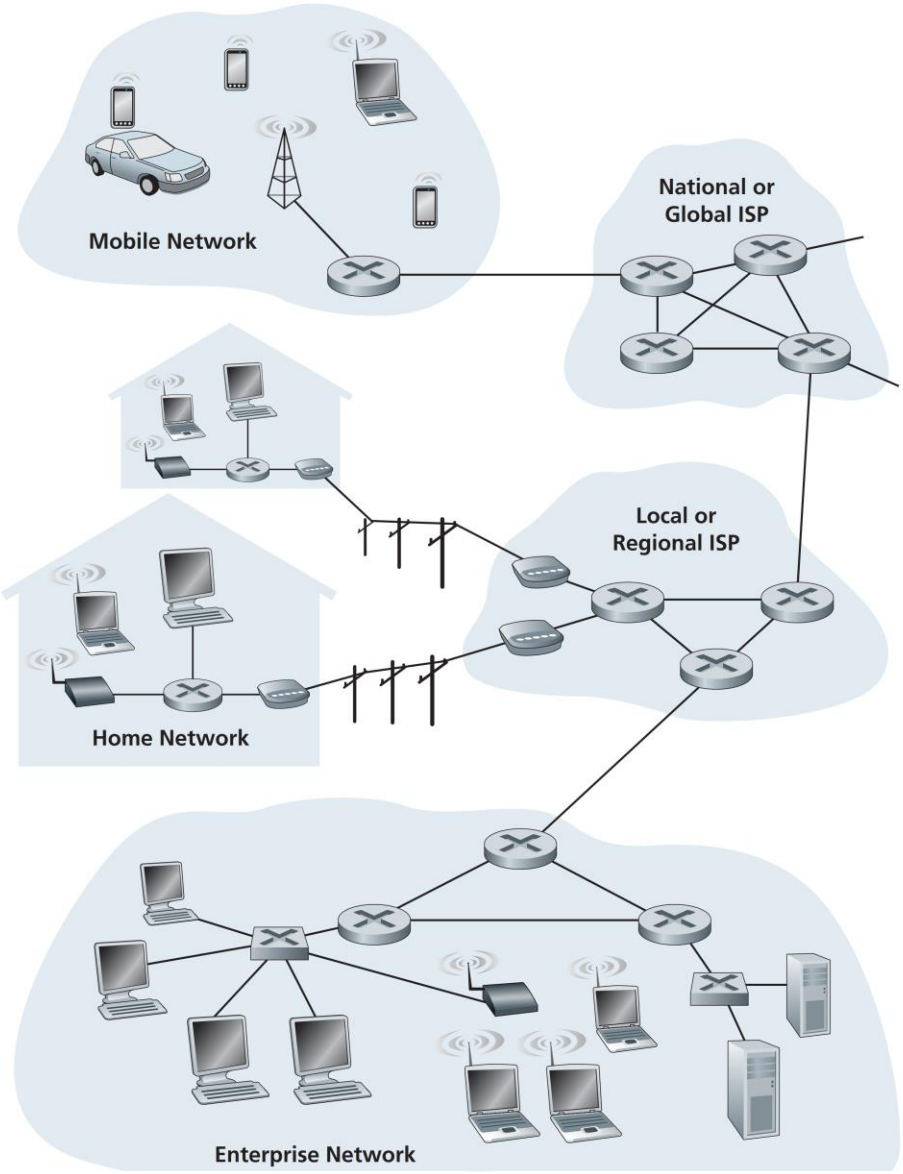
HYDERABAD

Main Reference

- [Kurose2012] J. Kurose and K. Ross, *Computer Networking*, Pearson, 2012.

Recap



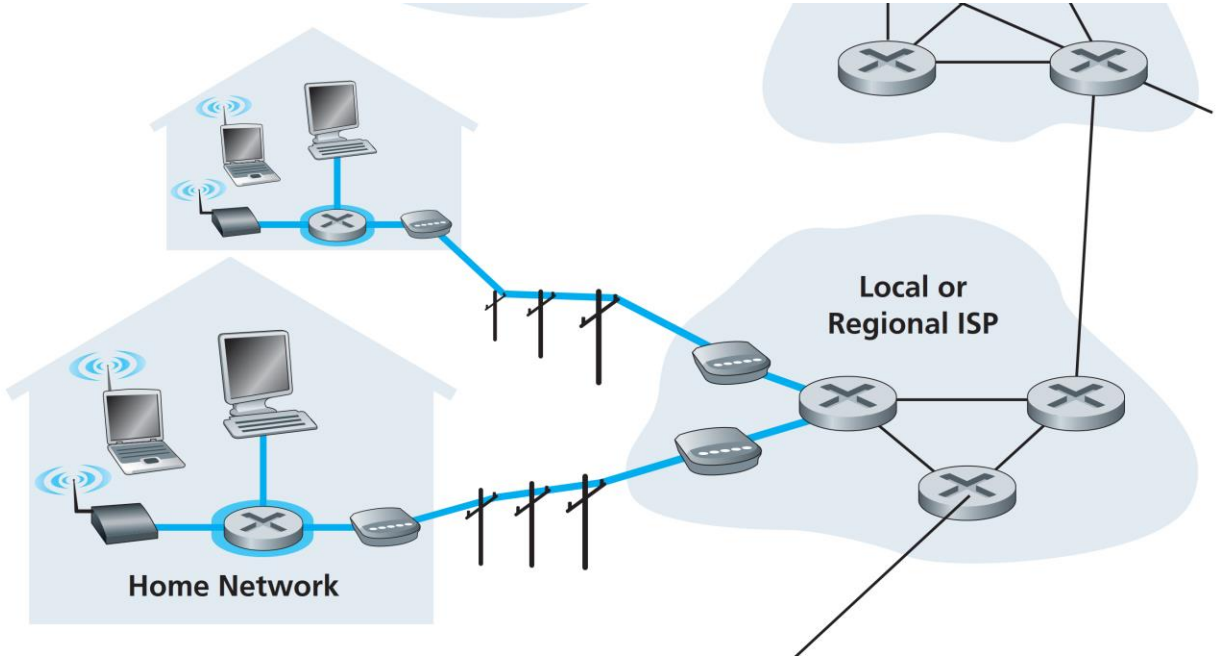
Some Pieces of Internet

The Internet is a computer network that interconnects hundreds of millions of computing devices throughout the world

Few Internet Terminologies

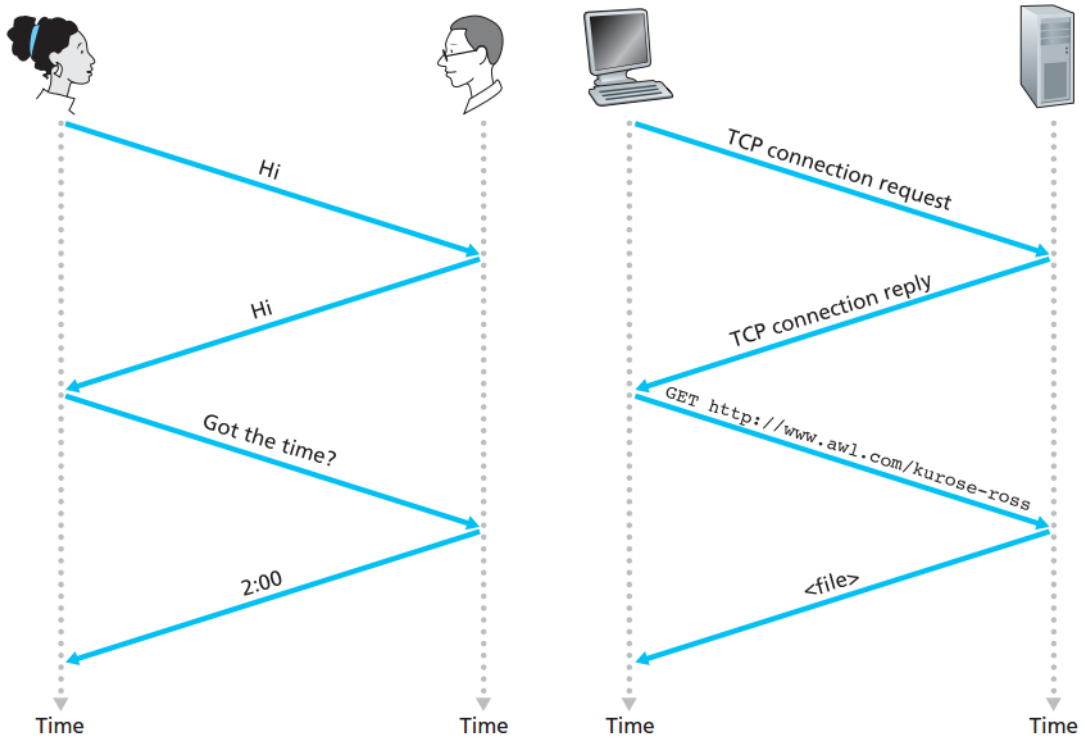
- Host or end-devices
  - computing devices connected to the internet
- Communication links
  - Connect the host in the network
- Packet switches
  - takes a packet arriving on one of its incoming communication links and forwards that packet on one of its outgoing communication links
  - Most prominent
    - Routers: Network core
    - Link-layer switches: access network
- Route or Path
  - The sequence of communication links and packet switches traversed by a packet from the sending end system to the receiving end system
- Internet service providers (ISPs)

Example of route



Protocol

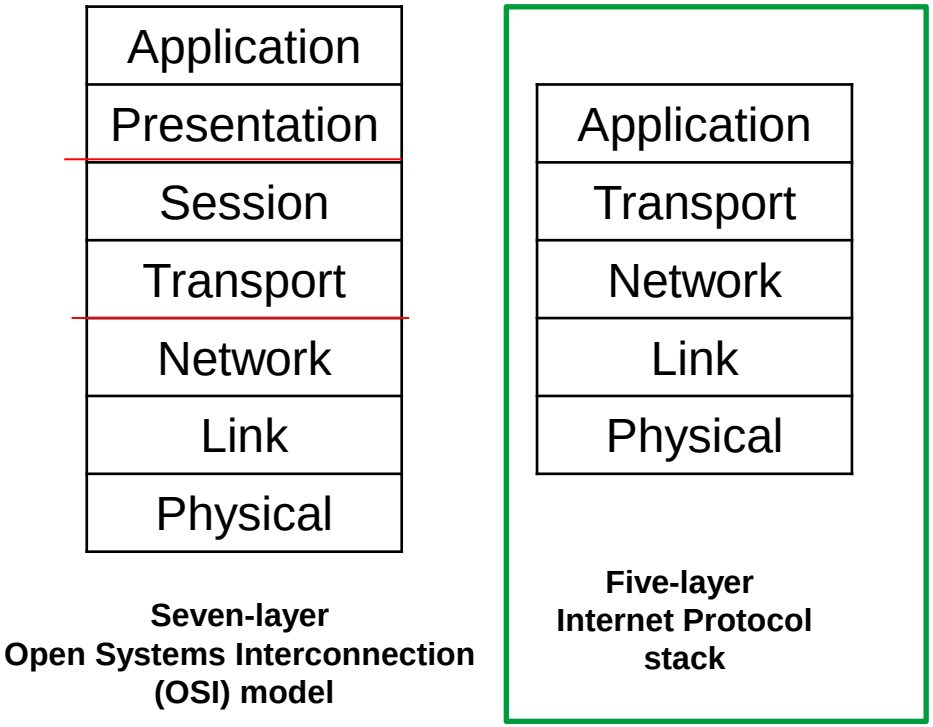
- A protocol defines the format and the order of messages exchanged between two or more communicating entities as well as the actions taken on the transmission and/or receipt of a message or other event. [Kurose2012]



[Kurose2012]

Analogy of human protocol and a computer network protocol

Internet protocol stack and OSI model



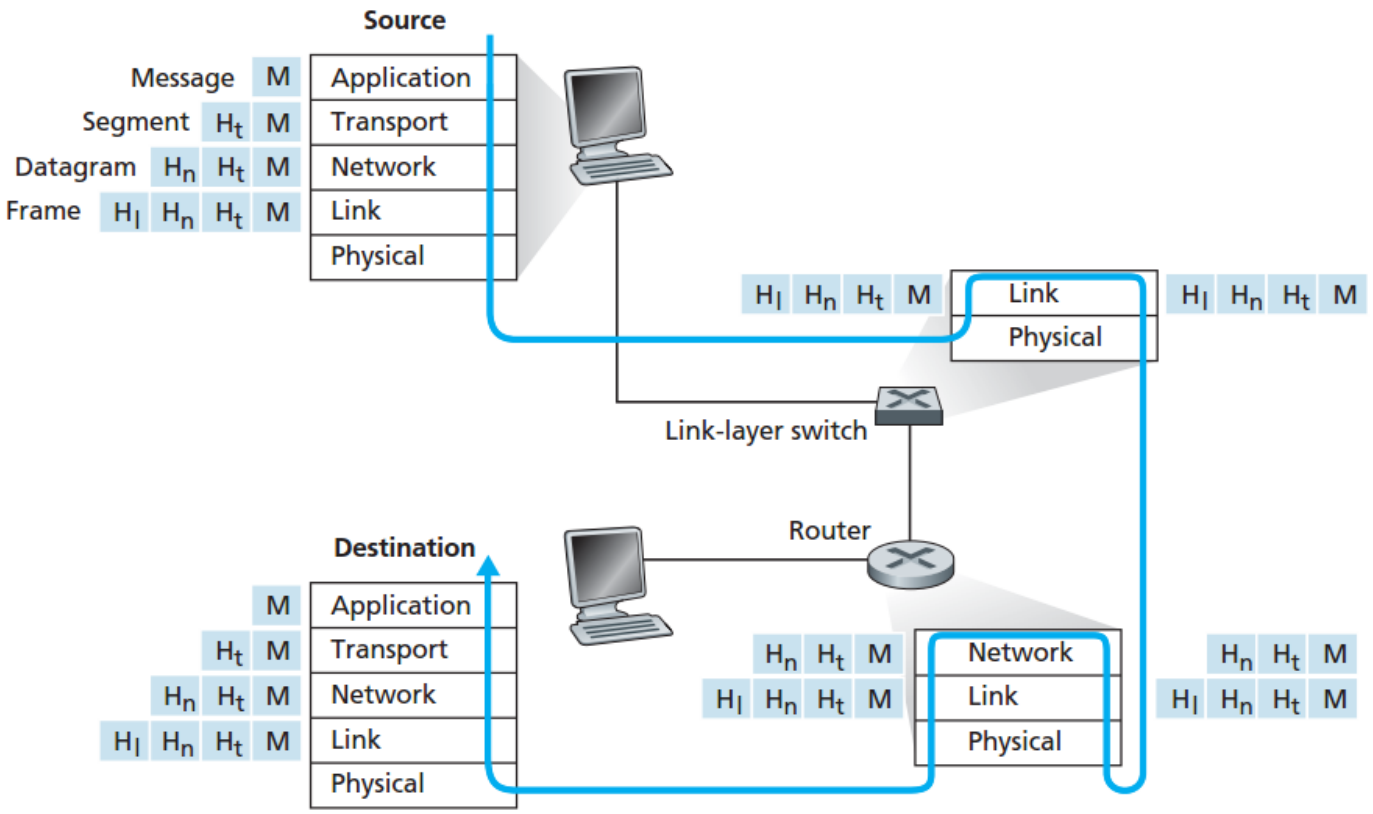
Protocols Layers and Their Service Models

- A layered architecture allows us to discuss a well-defined, specific part of a large and complex system.
- Provides modularity, making it much easier to change the implementation of the service provided by the layer.
- As long as the layer provides the same service to the layer above it and uses the same services from the layer below it, the remainder of the system remains unchanged when a layer's implementation is changed.

Internet protocol stack: Toy Example

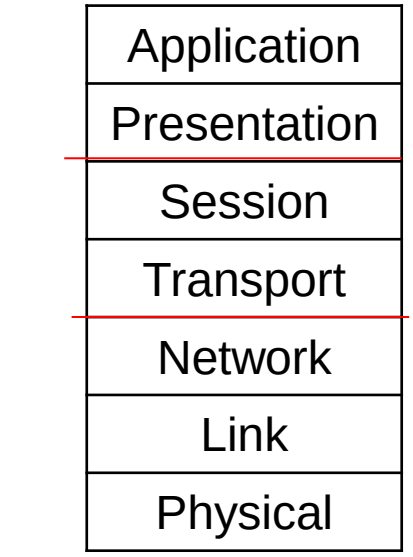
- Sending a courier from company branch in Hyderabad to company branch in New York
  - Application Layer: Individuals giving parcels
  - Transport Layer: office boy or admin assistant
  - Network Layer: Speed post/ Blue Dart (representative)
  - Link Layer: Different drivers (and vehicles)
  - Physical Layer: Road/Air/Water

Encapsulation of data across layers

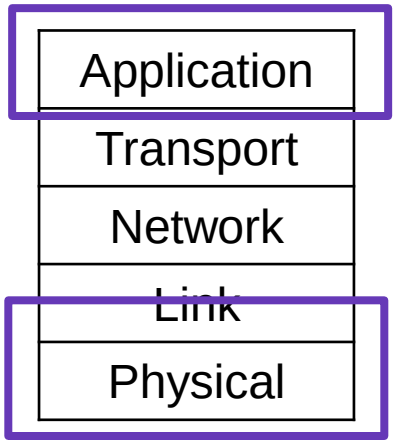


[Kurose2012]

Focus in this course



Seven-layer Open Systems Interconnection (OSI) model

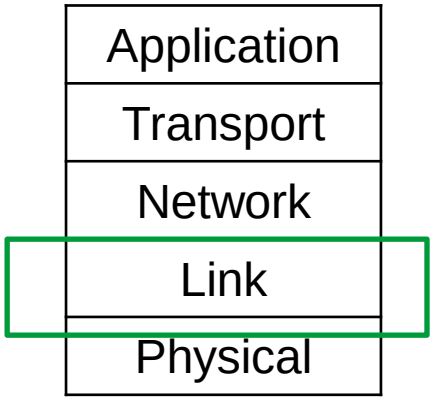


Five-layer Internet Protocol stack

Application
MAC and PHY

Today's Class

Internet protocol stack: *Link Layer*



Five-layer Internet Protocol stack

Internet Protocol Stack: *Link Layer*

- Also called Data Link Layer
- Responsible for moving data packets from one node to another across an individual link
- Implemented in network adapter or network interface card (NIC)
- Provides medium access control (MAC) for multiple nodes sharing a common medium
- Offer services like framing, reliable delivery, flow control, error detection and correction,
- Each NIC has 48 bit unique LAN/MAC/physical address
- Examples of link-layer protocols include Ethernet, WiFi, PPP

Link Layer: *Various multiple access channels*

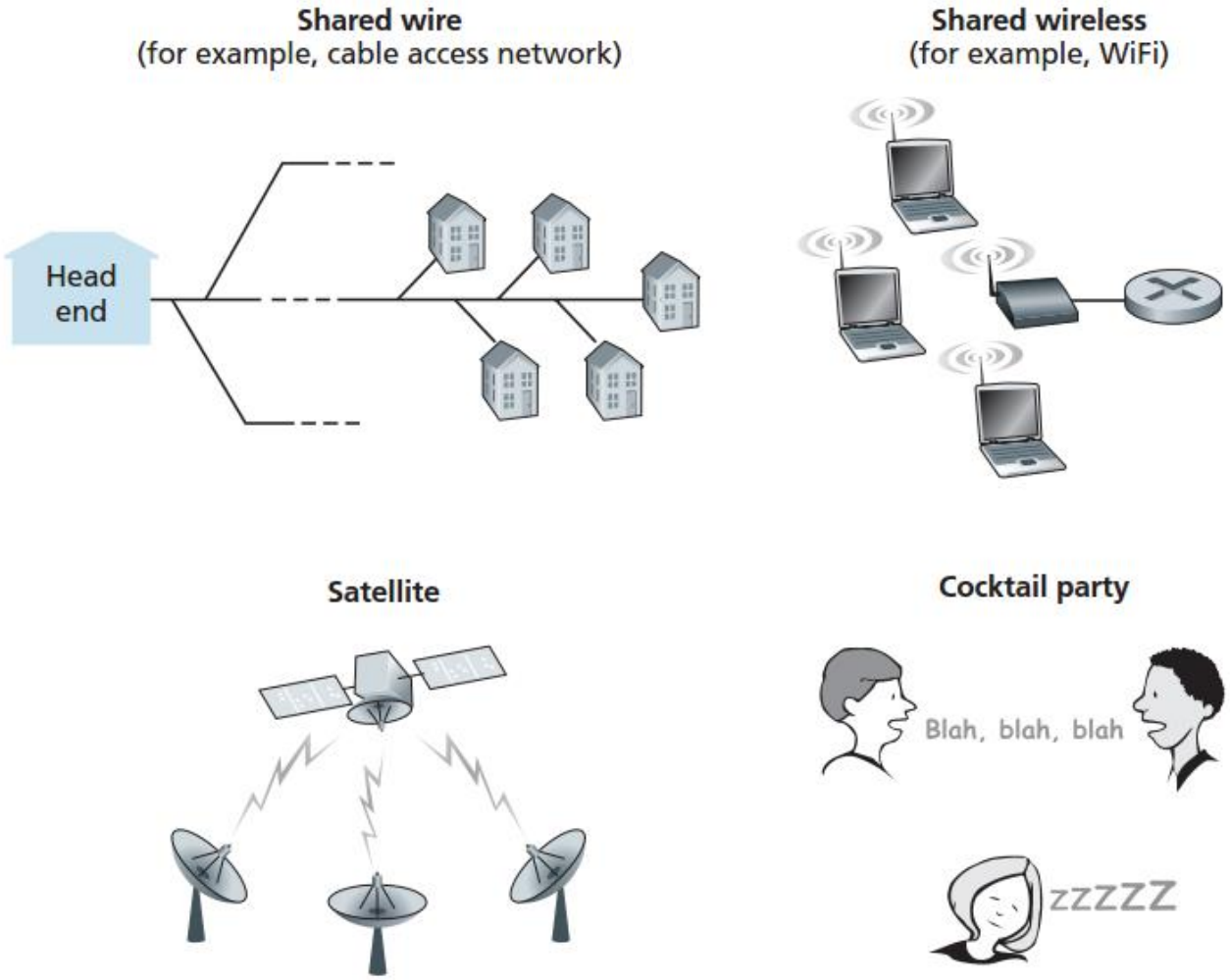


Figure 5.8 ♦ Various multiple access channels

Link Layer

- Different link layer protocols can be used over different links along a route
  - Trip from Hyderabad office to New York office

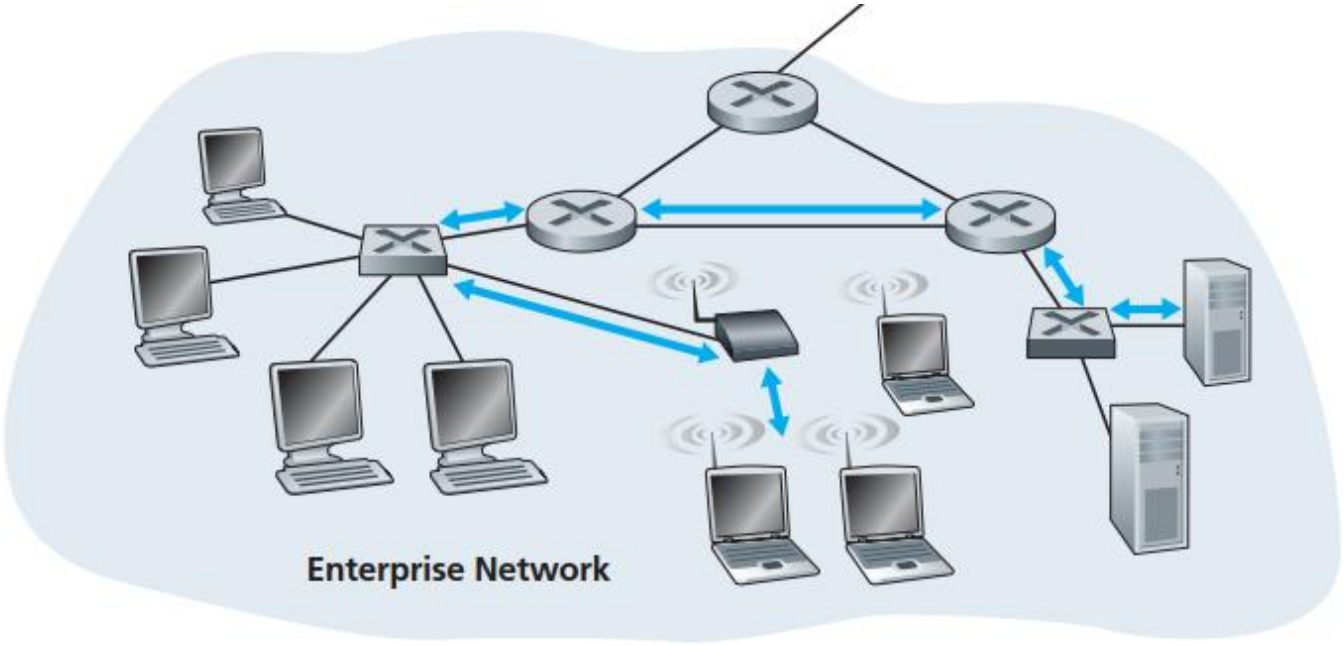
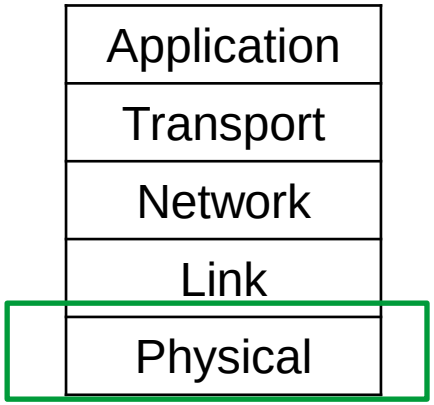


Figure 5.1 ♦ Six link-layer hops between wireless host and server

Link Layer: *MAC and IP addresses*

- MAC address is like social security number
- IP address is like house address
- Address resolution protocol to translate IP to MAC address and vice-versa

Internet protocol stack: *Physical Layer*

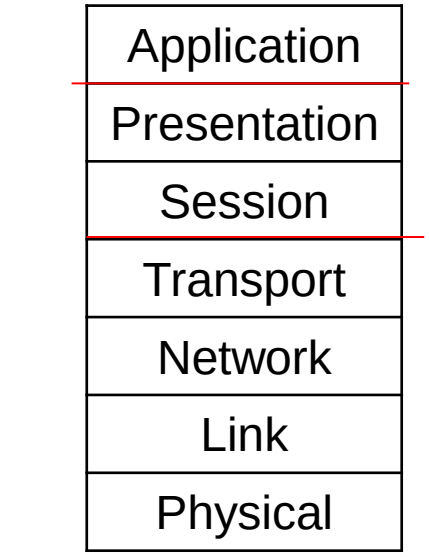


Five-layer Internet Protocol stack

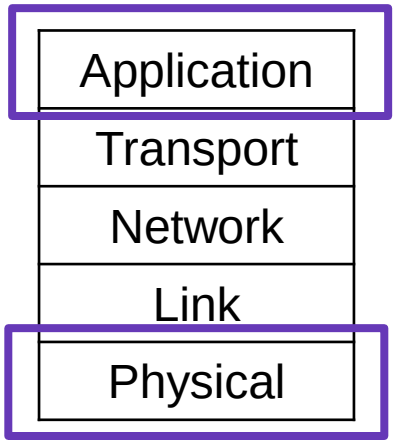
Internet Protocol Stack: *Physical Layer*

- Defines the means of transmitting raw bits rather than logical data packets over a physical link/medium connecting two nodes on the same network
- Provides interface (such as electrical, optical, and electromagnetic) to the transmission medium (such as twisted-pair copper wire, optical, air)
- Signal processing of bits and physical signals: Modulation, error correction and detection (Channel Coding), Bit Interleaving, Synchronization, Carrier sensing and collision detection, etc.
- Example: WLAN 802.11, LR-WPANs 802.15.4, Ethernet 802.3, Bluetooth 802.15.1

Focus in this course



Seven-layer Open Systems Interconnection (OSI) model

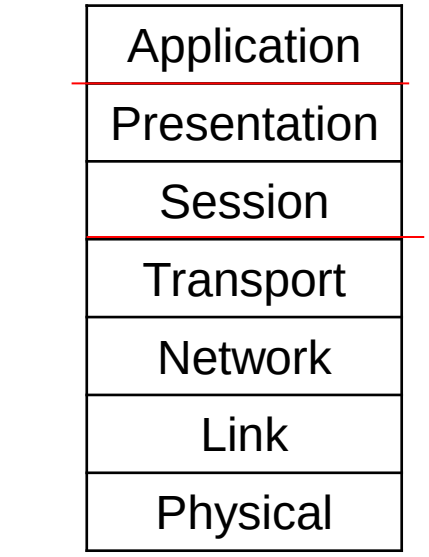


Five-layer Internet Protocol stack

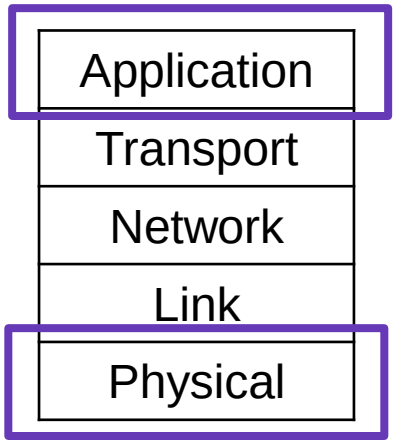
Application
MAC and PHY

Questions?

Focus in this course



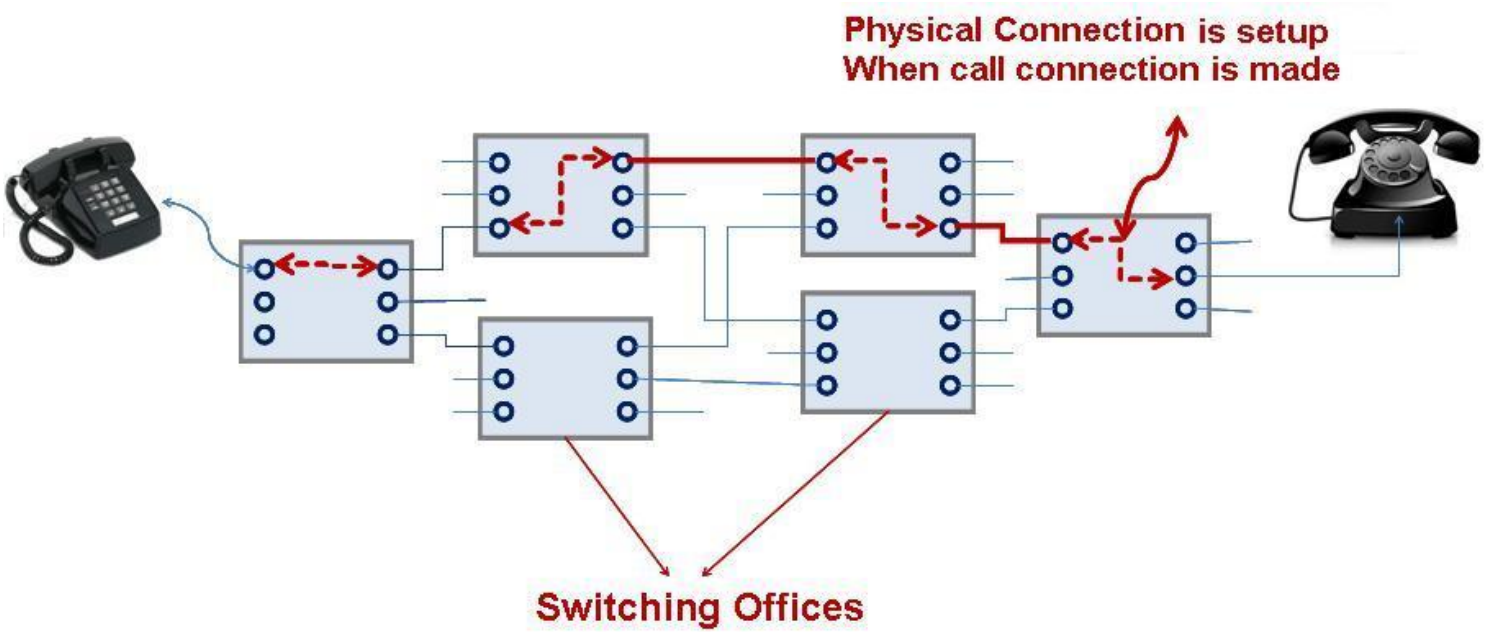
Seven-layer Open Systems Interconnection (OSI) model

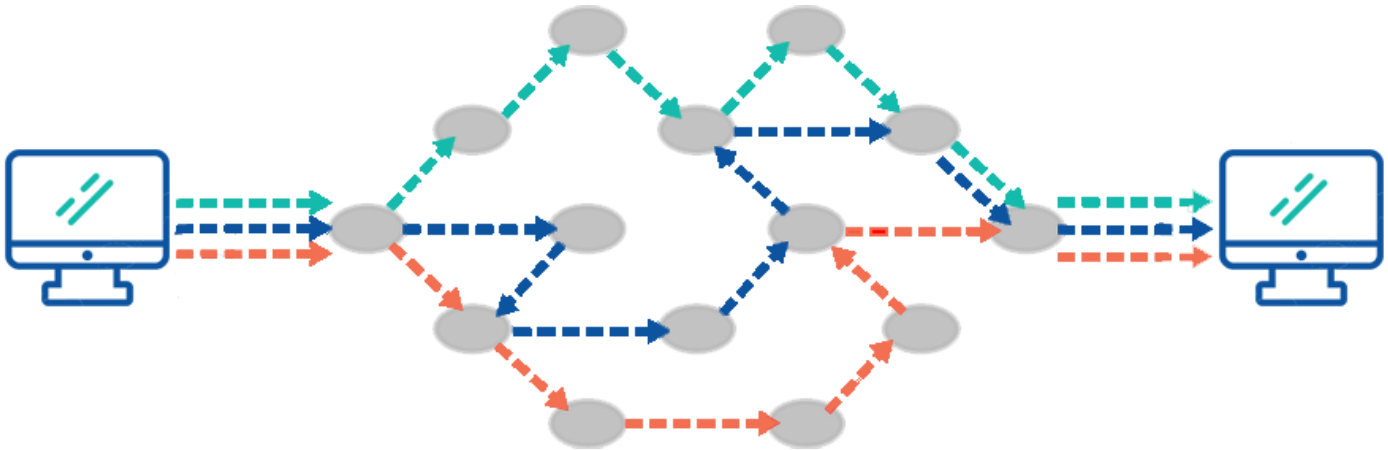


Five-layer Internet Protocol stack

Application
MAC and PHY

Circuit Switched vs Packet Switched





https://www.apposite-tech.com/blog/packet-switching-vs-circuit-switching/

Statistical Multiplexing

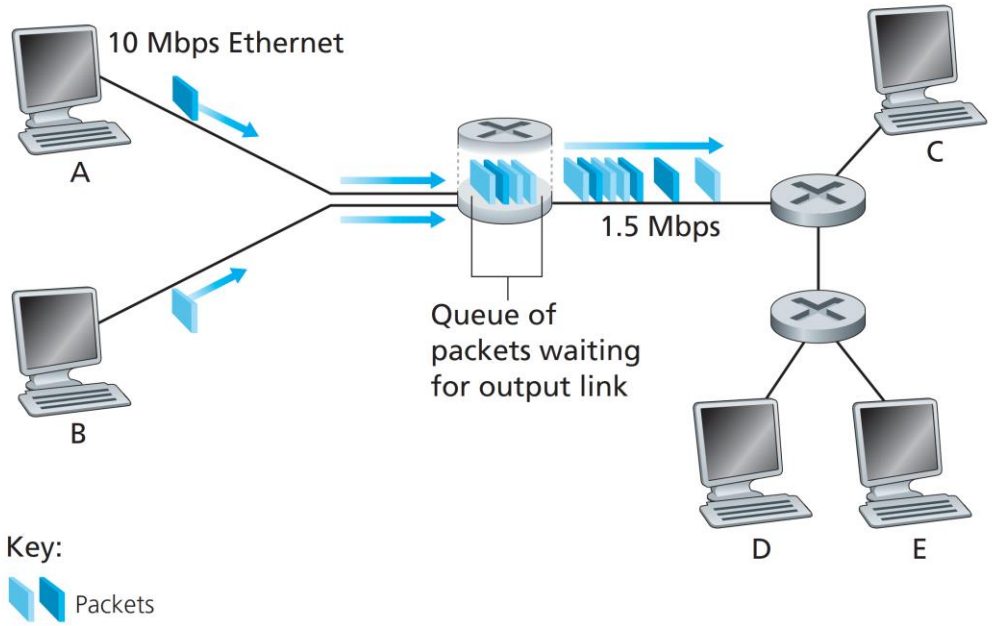
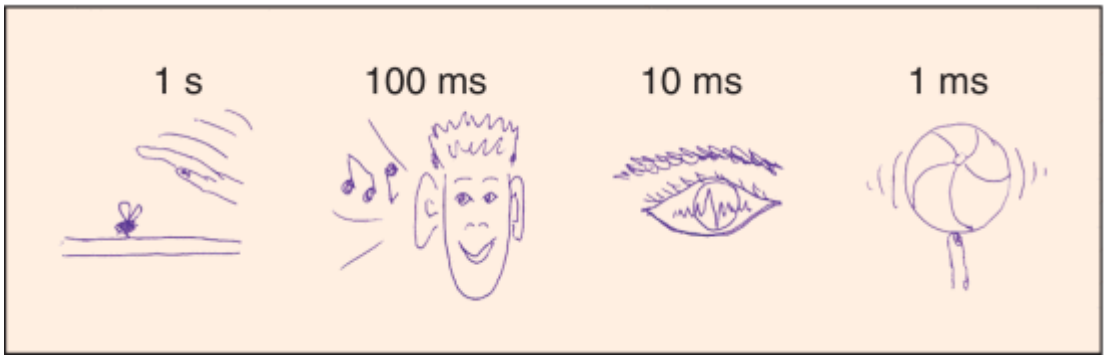


Figure 1.12 ♦ Packet switching

- Number of users = 35
- Ten slots in TDM
- Probability of user being active = p = 0.1
- For this case, probability of outage is 0.0004

Statistical Multiplexing: An example

- Frame duration generally ranges from 1ms to 10ms



Human reaction and interaction times (coarse)

Image Credit: G. P. Fettweis, "A 5G wireless communications vision", *Microwave J.*, pp. 24-36, Dec. 2012..

Circuit Switched vs Packet Switched

Circuit Switching	Packet Switching
Physical path between source and destination	No physical path
All packets use same path	Packets travel independently
Reserve the entire bandwidth in advance	Does not reserve
Bandwidth Wastage	No Bandwidth wastage
No store and forward transmission	Supports store and forward transmission

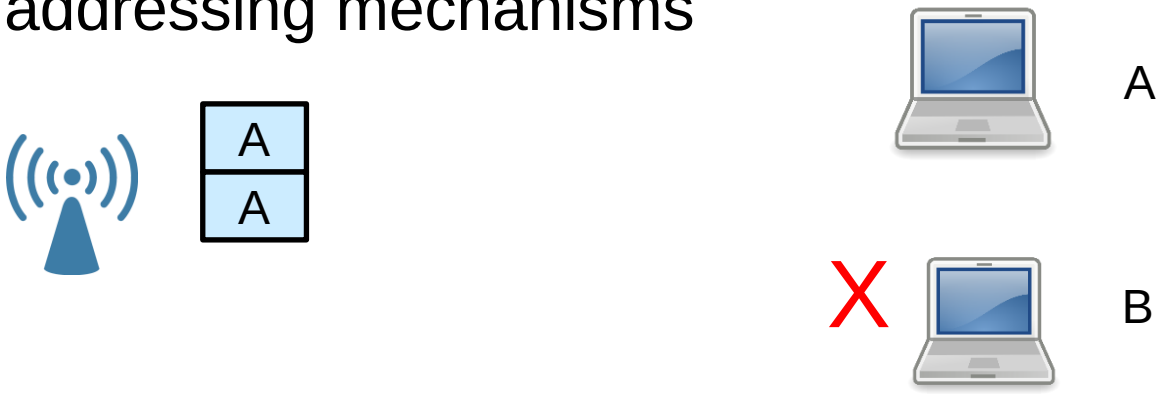
https://www.apposite-tech.com/blog/packet-switching-vs-circuit-switching/

Medium Access Control (MAC) protocols

Medium Access Control (MAC)

- One of the two sublayers of data link layer
- Acts as an interface between the logical link control (LLC) and the network's physical layer
- Provides channel access control mechanisms across a shared physical medium

- Provides addressing mechanisms



Link Layer: *Various multiple access channels*

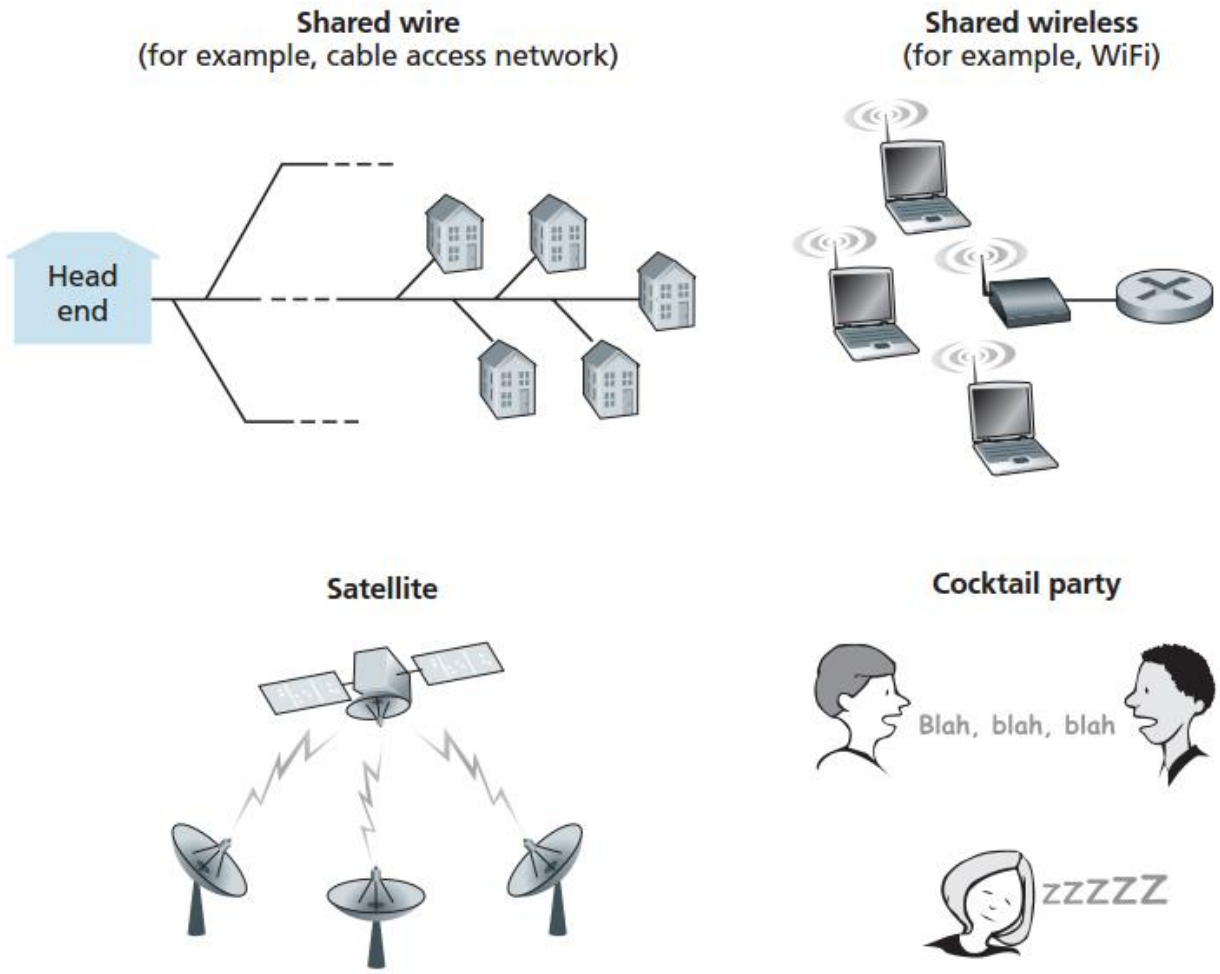


Figure 5.8 ♦ Various multiple access channels

Another Analogy: Roads

https://www.freepik.com/vectors/travel

Conversation Etiquettes

- Meeting
  - Give everyone a chance to speak
  - Don’t monopolize the conversation
- Class
  - Don’t speak until you are spoken to
- General
  - Don’t interrupt when someone is speaking
  - Don’t fall asleep when someone is speaking
    - What happens if somebody sleeps?

Desirable Properties of MAC protocols

A MAC protocol for a broadcast channel of rate *R* bps should have following desirable properties

- When only one node has to send data, that node has throughput of *R* bps
- When *M* nodes have to send data, each of the nodes should have average rate of *R/M* bps
- The protocol is decentralized so that there is no master node with single point of failure
- The protocol is simple so that it is inexpensive to implement

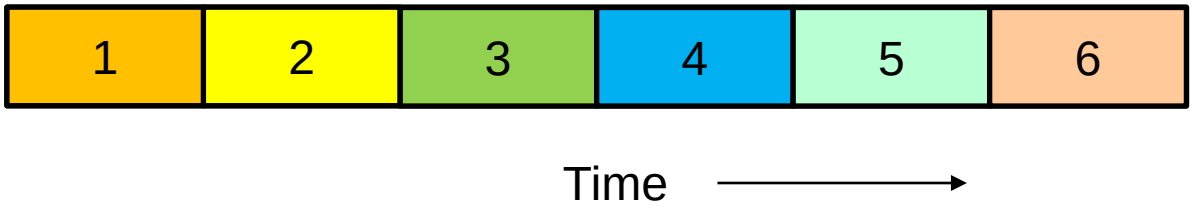
Types of MAC protocols

- Channel Partitioning Protocols (or Fixed Assignment Protocols)
  - TDMA, FDMA, CDMA, SDMA
- Random Access Protocols
  - Aloha, Slotted Aloha, CSMA/CA
- Taking Turn Protocols (or Demand Assignment Protocols)
  - Token Ring
  - Polling

Channel Partitioning Protocols

Time Division Multiple Access (TDMA)

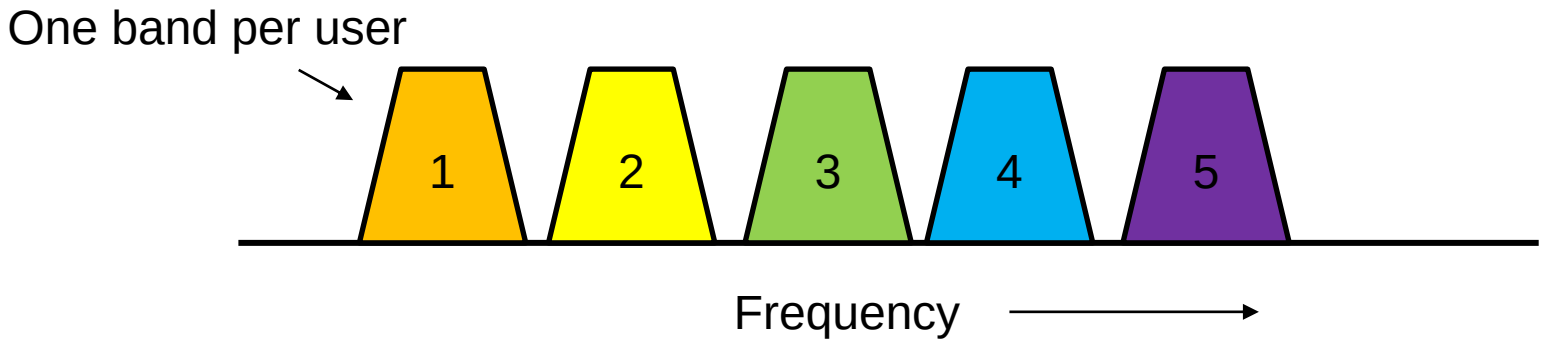
- Time Division Multiple Access
  - TDMA is a digital technique that divides a single channel or band into time slots
  - Examples: T1 carrier systems (digital transmission of multiplexed telephone calls), 2G cellular system GSM



- Advantages
  - No Collision
  - Fair usage
- Disadvantages
  - Wastage of resources
  - Delay
  - Need Synchronization

Frequency Division Multiple Access (FDMA)

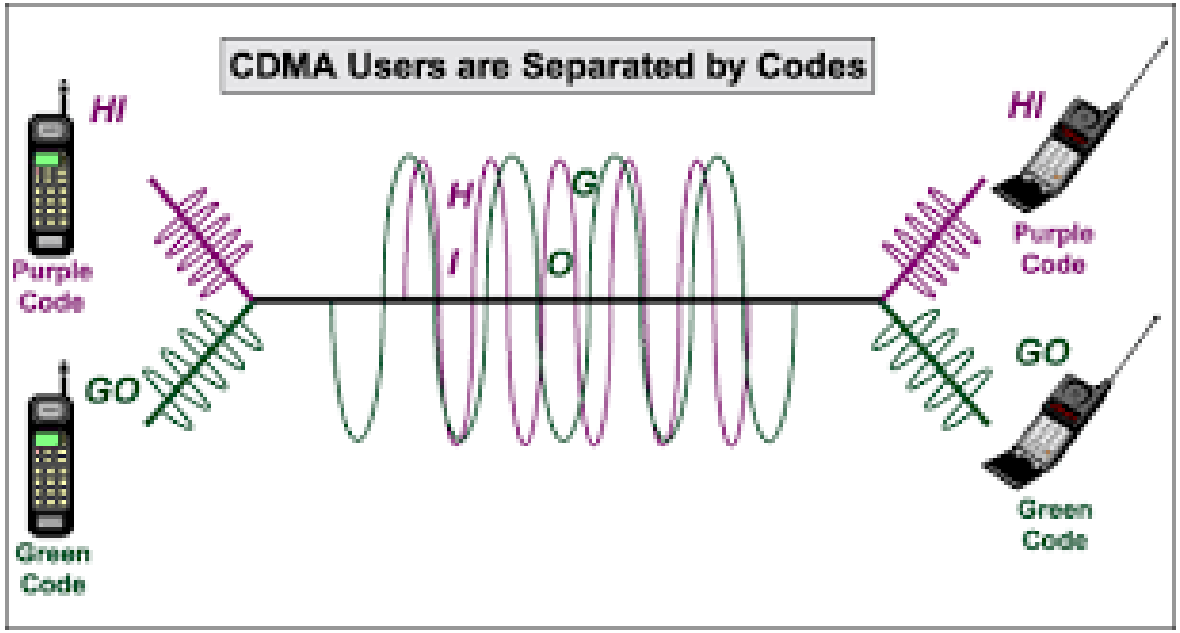
- FDMA divides the shared medium bandwidth into individual channels
- Examples: Cable television system, FM stations



- Advantages
  - No Collision
  - Fair usage
- Disadvantages
  - Wastage of resources
  - Need synchronization

Code Division Multiple Access (CDMA)

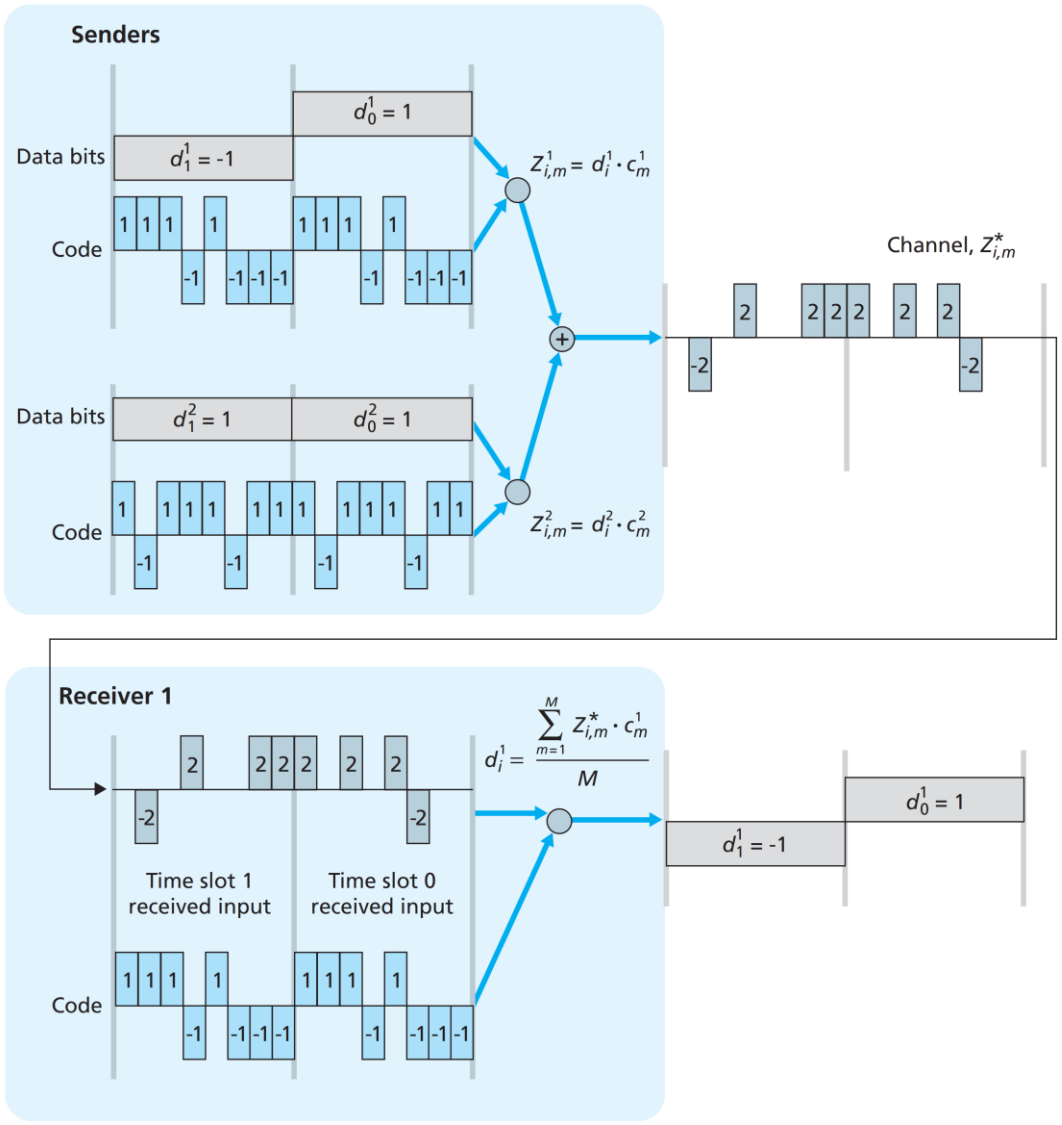
- It is also known as spread spectrum because it takes the digitized version of an analog signal and spreads it out over a wider bandwidth at a lower power level.
- Example: 2G IS-95, 3G (WCDMA)



Source: http://www.electronicdesign.com/communications/fundamentals-communications-access-technologies-fdma-tdma-cdma-ofdma-and-sdma

CDMA

- Use of higher rate PN sequences
- Low auto and cross correlation

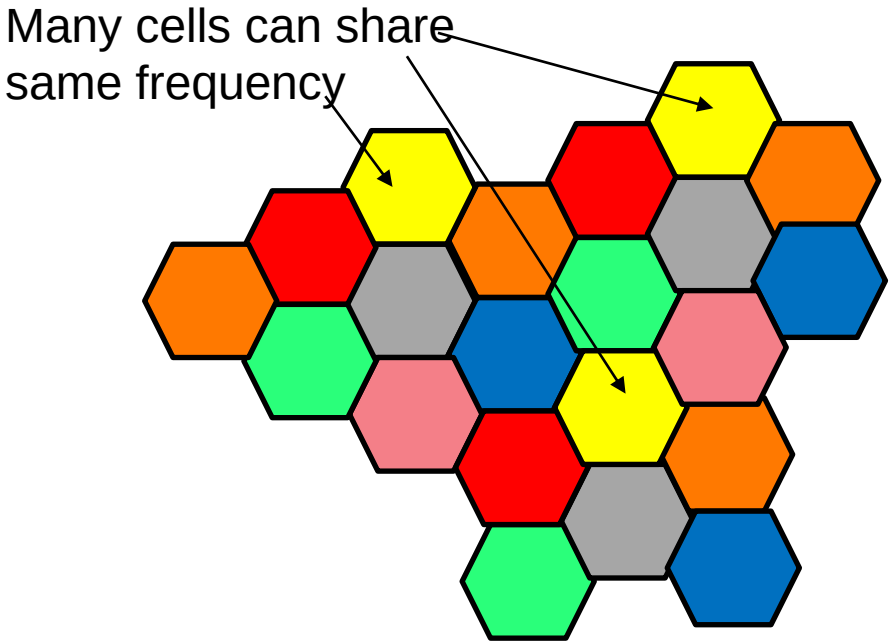


CDMA

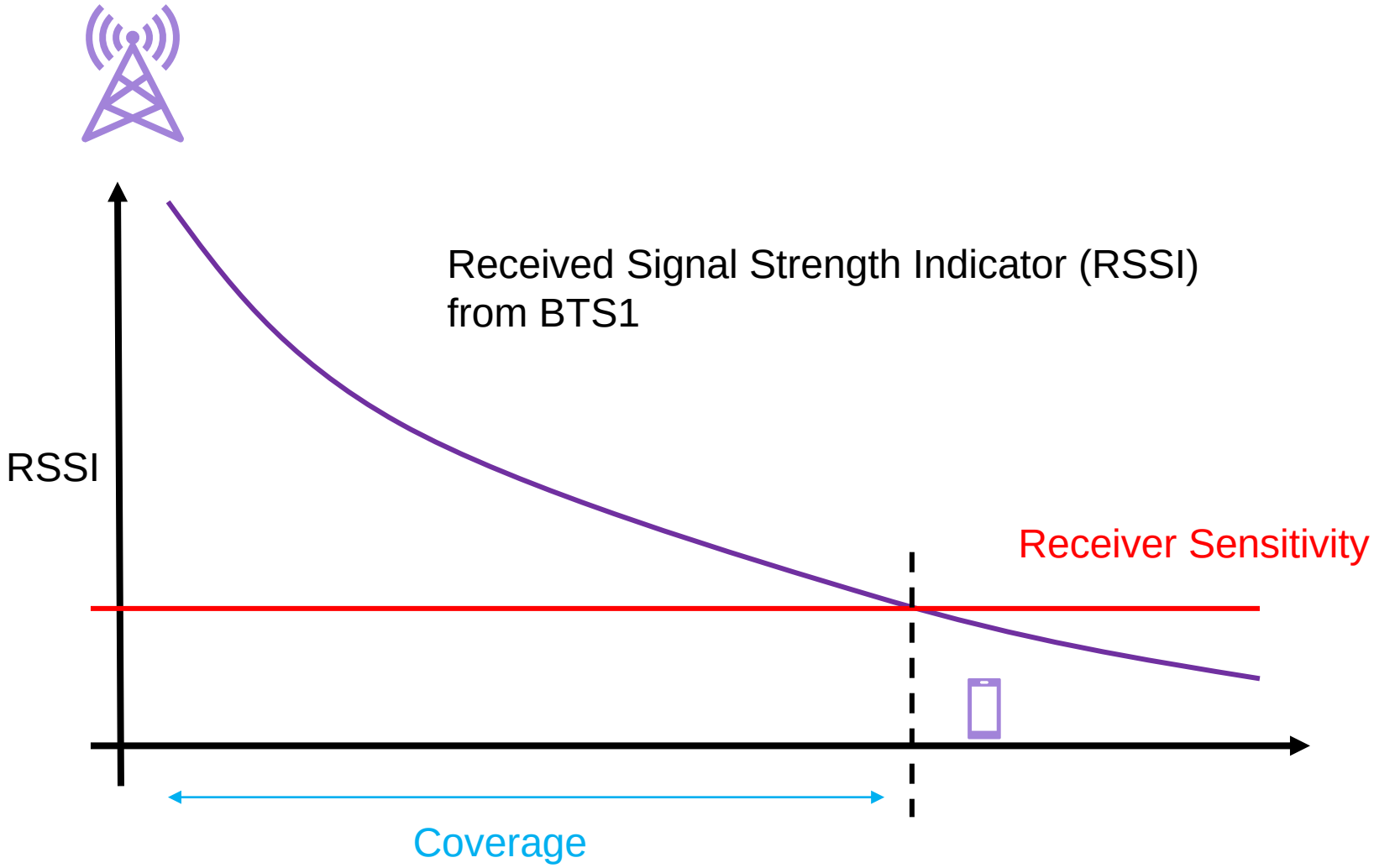
- Advantages
  - No collisions
  - Asynchronous CDMA possible
  - Better efficiency than TDMA and FDMA
- Disadvantages
    - Need extra processing
    - Power control is needed

Space Division Multiple Access (SDMA)

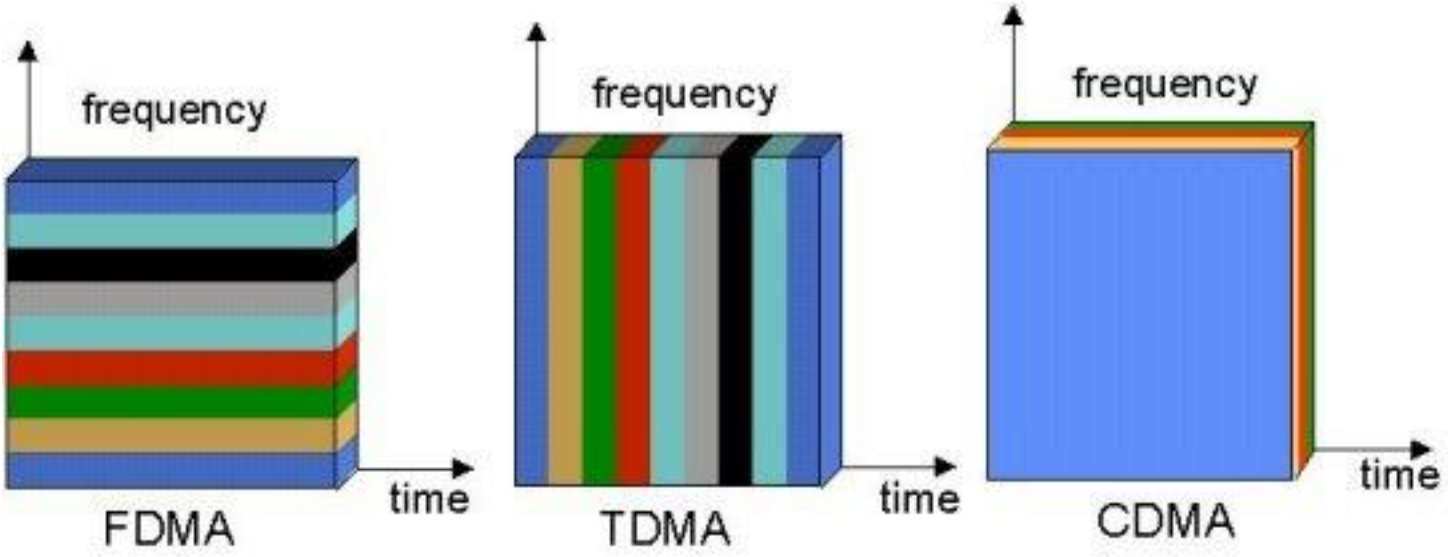
- Space Division Multiple Access
  - SDMA uses physical separation methods that permit the sharing of wireless channels. For instance, a single channel may be used simultaneously if the users are spaced far enough from one another to avoid interference. Known as frequency reuse, the method is widely used in cellular radio systems. Cell sites are spaced from one another to minimize interference.



Coverage in Free-Space



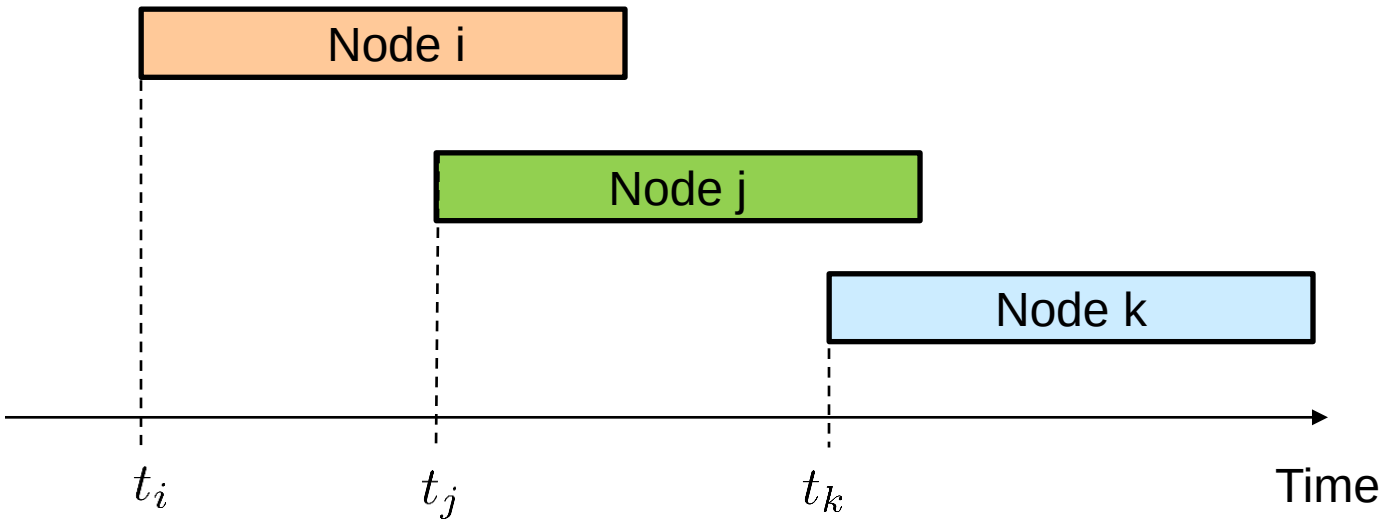
Difference between different TDMA/FDMA/CDMA



Random Access Protocols

Aloha

- When you have data, send it
- If data doesn't go through, resend it after random delay
  - Send with probability *p* or wait for one transmission frame with probability *1-p*

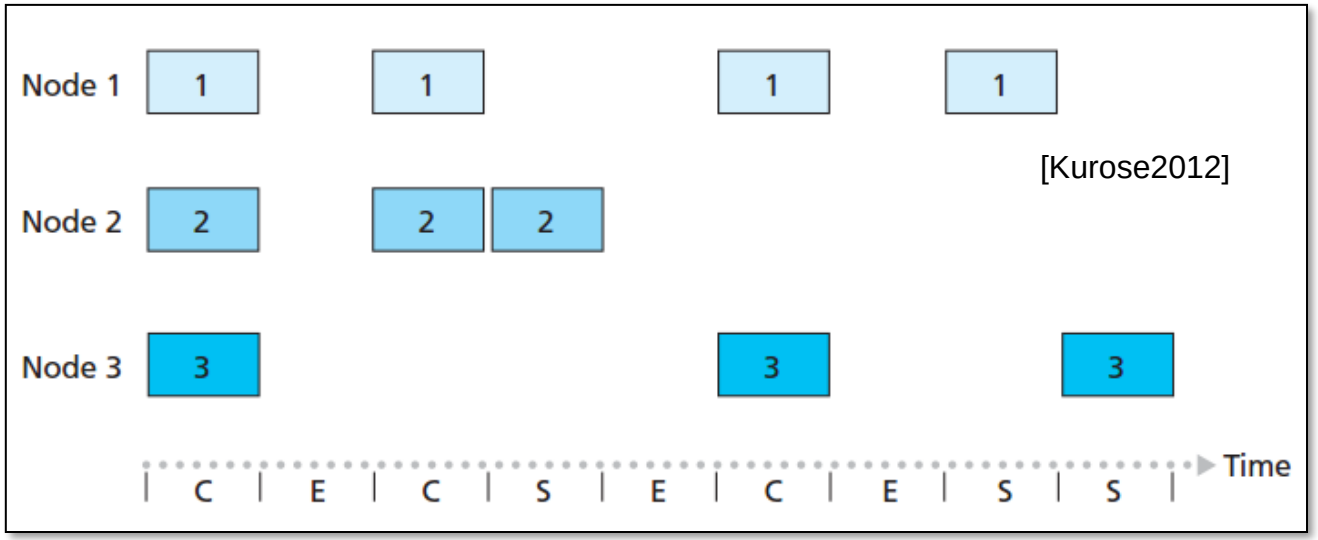


Aloha

- Advantages
  - Full instantaneous rate
  - Fully decentralized
- Disadvantages
  - Low efficiency:
    - Probability of success is $p(1-p)^{2(N-1)}$
    - 18.5% for large *N*
  - Suitable only for light loaded network
  - Unstable for certain channel conditions
    - Avalanche of retransmission attempts
    - Nice animation
      - http://www.wirelesscommunication.nl/reference/chaptr06/aloha/alohplay.htm

Slotted Aloha

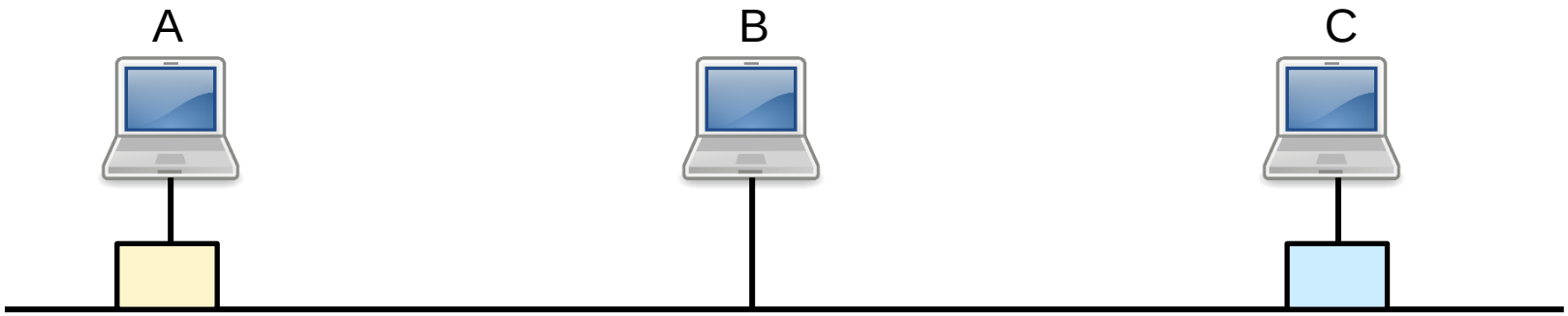
- Time is divided into equal time slots
- Sensor node can send data only at the beginning of a slot
- If have data to send, send at the start of slot. If collision, send in the next slot with probability *p* and do not transmit with probability *1-p*
- Requires time synchronization between nodes
- Better than Aloha but still low
  - Probability of success is $Np(1-p)^{N-1}$
  - Asymptotic numbers: Efficiency: 37%; Wastage: 37%; Collisions: 26%



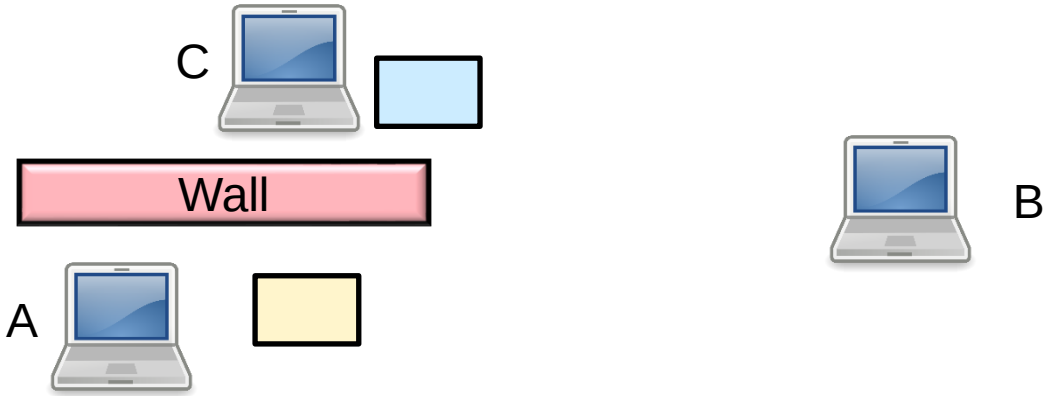
[Kurose2012]

Carrier Sense Multiple Access (CSMA)

- Listen before sending
- Send only if channel is idle
- Collisions can still happen (Hidden Node Problem)
- If collision, back-off for random delay and transmit again

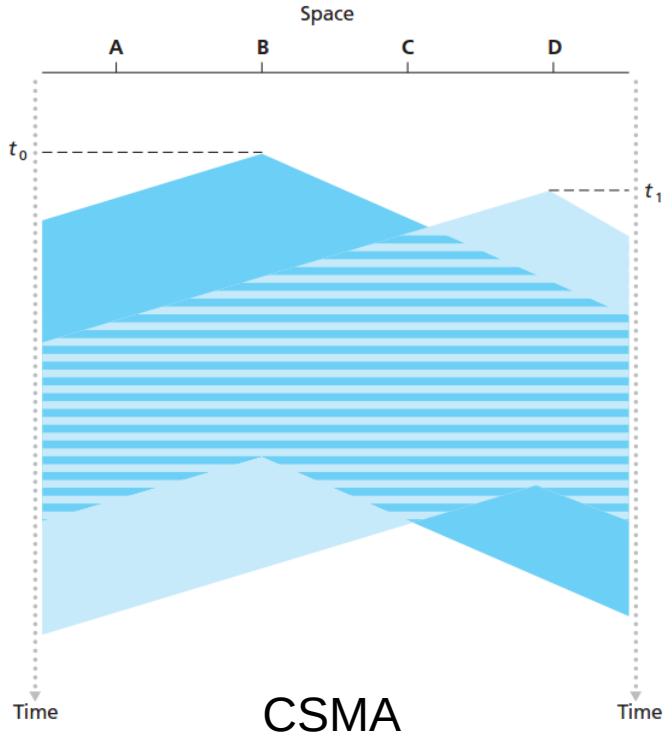


- Hidden Node Problem in Wireless Networks



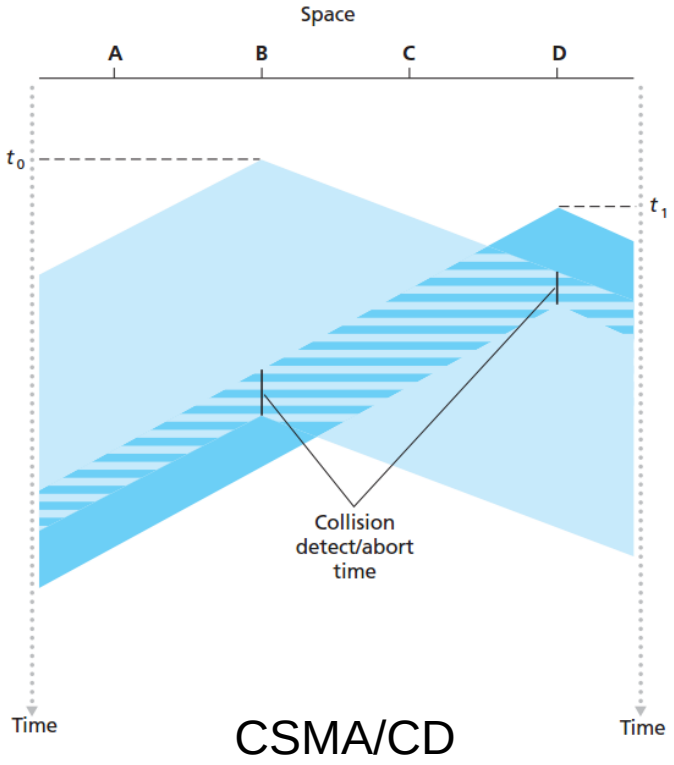
CSMA with collision detection (CD)

- Listen while transmitting!
- Stop transmitting as soon as collision is detected
- Wait for random duration before retry (binary exponential backoff)
- Improves CSMA performance at the cost of complexity
- Used in original Ethernet (wired LAN technology IEEE 802.3)



CSMA

[Kurose2012]



CSMA/CD

Binary Exponential Backoff

- A node, which has already observed *n* collisions for a packet, chooses value *K* at random from $\{0,1,\ldots,2^n-1\}$
- For ethernet, node *K*512* bit times

- Why exponential backoff?
  - Large backoff time and small number of nodes
    - long wait times and channel idle
  - Small backoff time and large number of nodes
    - large number of collisions

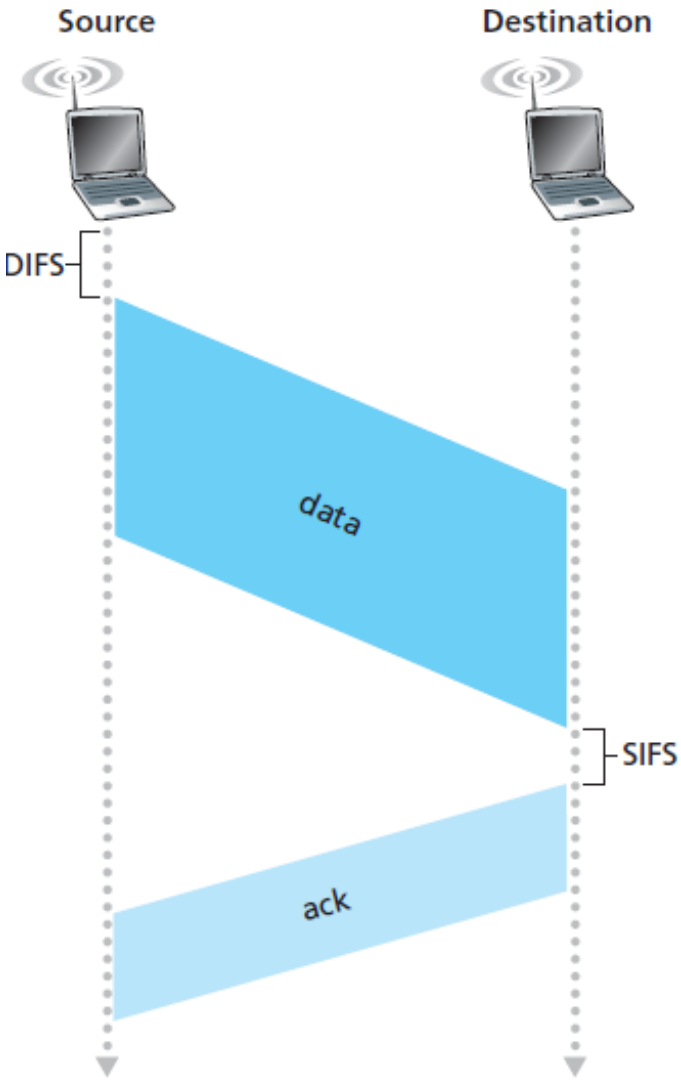
- What happens if a new user wants to transmit when there are several users already in contention?

CSMC/CD

- Advantages
  - Saves resources
- Disadvantages
  - Needs extra hardware and processing
  - Possible only in wired

CSMA/CA (Collision Avoidance)

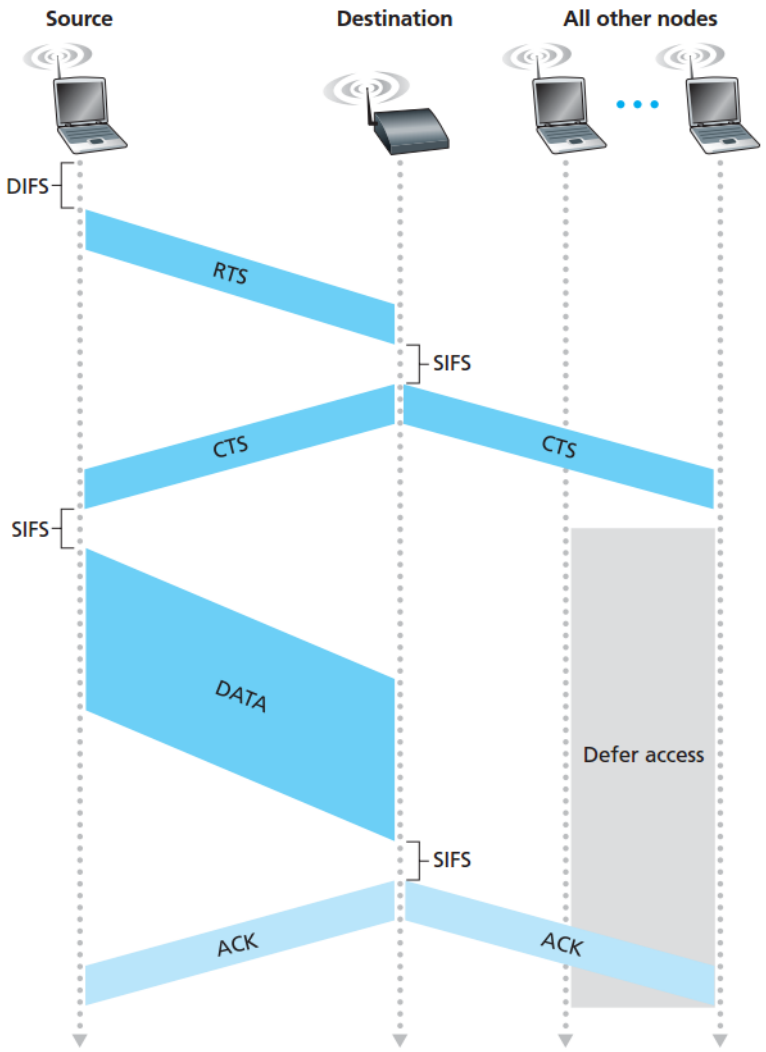
- Listens for an idle channel
- Once channel is detected
  - idle waits for Distributed Inter Frame Spacing (DIFS)
  - Performs exponential random backoff
  - Counter is frozen if the channel is busy
- Once the counter hits zero, sends the complete frame and waits for an ack
  - If ack, repeat the procedure for next packet
  - If no ack, repeat with a longer window
- Suitable for wireless networks
- Used in most of the 802.11 (WLAN) technologies



[Kurose2012]

CSMA/CA with RTS and CTS

- Three-way handshake :
  - RTS-CTS-Data
- CSMA and use of ready to send (RTS) and clear to send (CTS)
  - In RTS/CTS access mode, prior to the data transmission the sending node will send a RTS packet to announce the upcoming transmission
  - When the destination node receives the RTS it will send a CTS packet after a short inter-frame space (SIFS) interval
  - Both the RTS and CTS packets are short control packets
- Removes hidden node issues



[Kurose2012]