

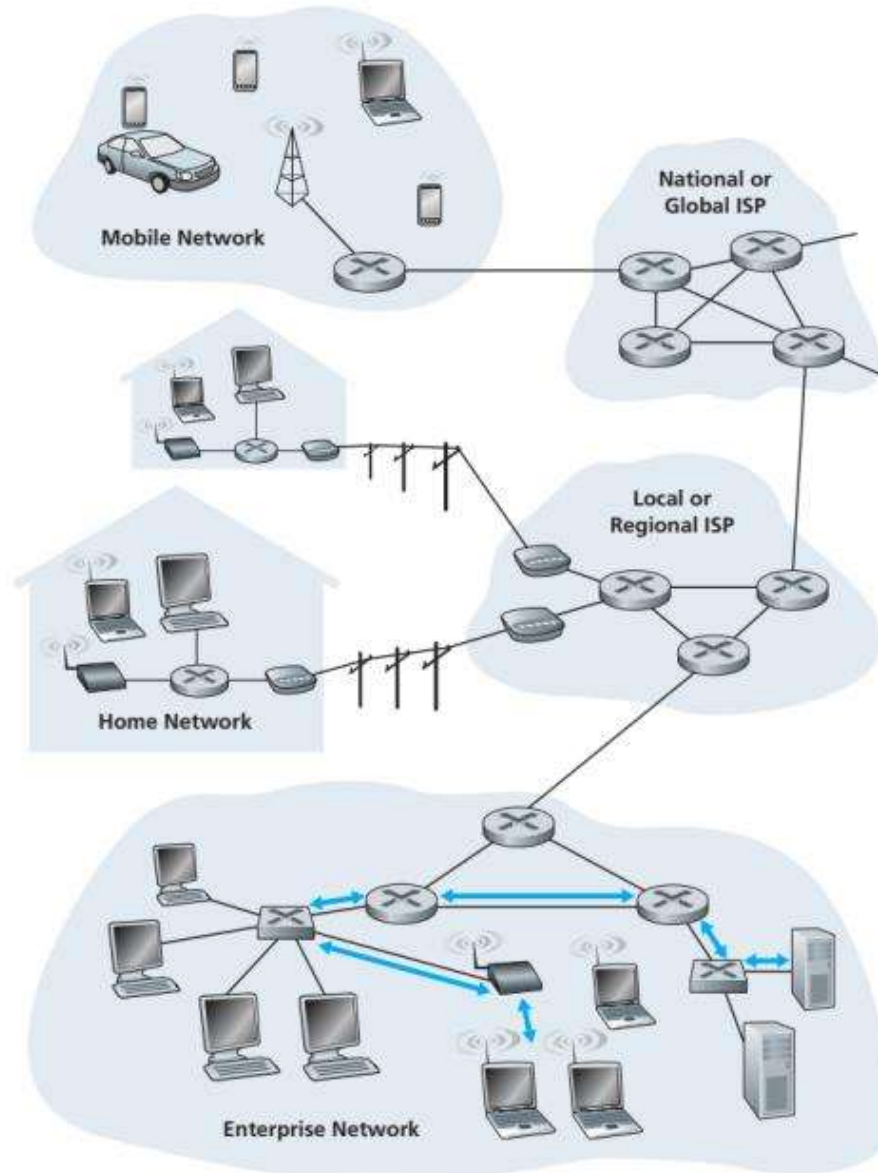
# Link Layer

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# Link Layer

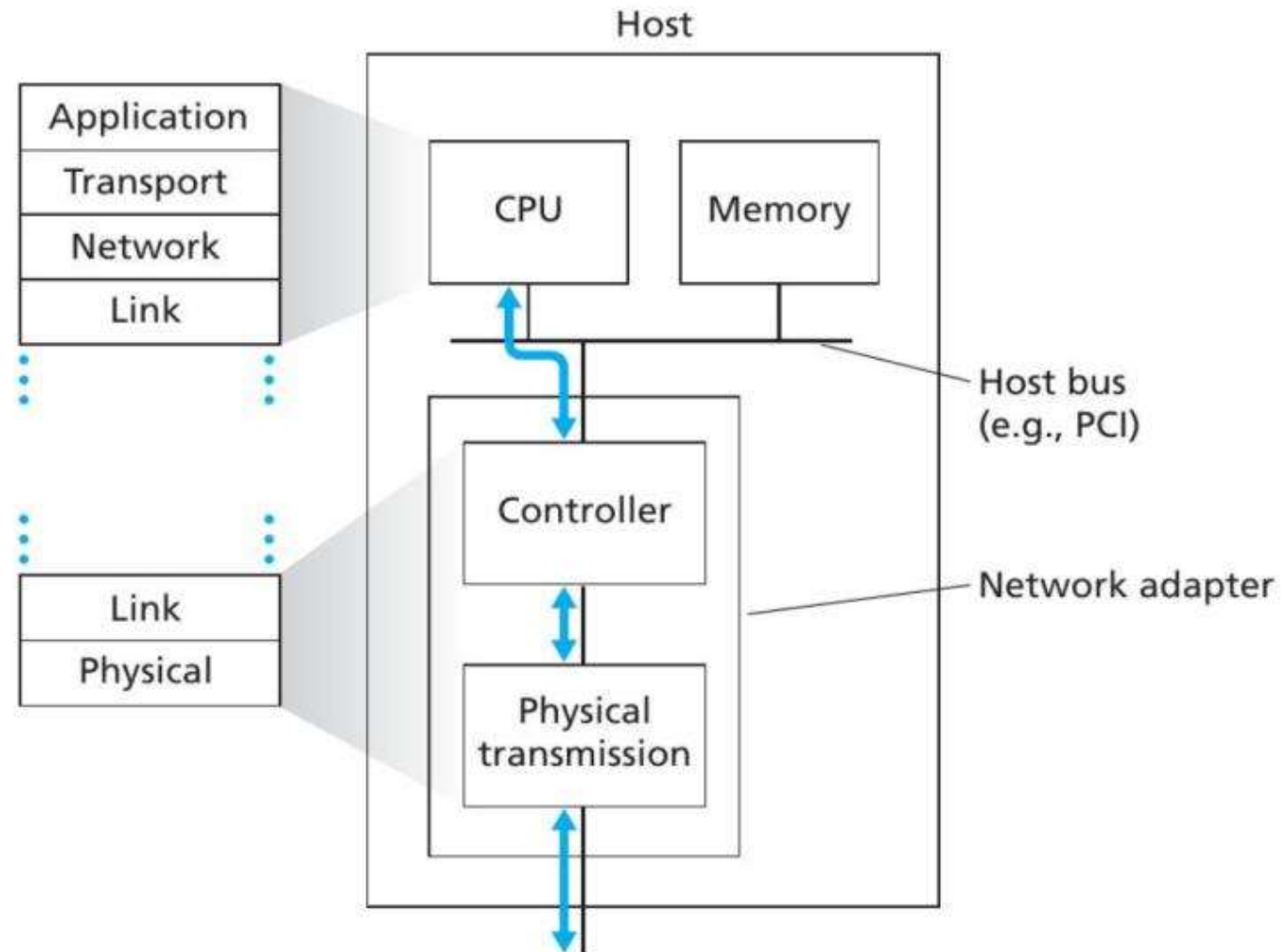
- Moves datagrams node-to-node
- Link layer protocols: Ethernet, IEEE 802.11 (Wireless LAN/Wifi), Token-ring, PPP
- Services
  - Framing
  - Link-access
  - Reliable-delivery
  - Flow Control
  - Error detection
  - Error correction
  - Half-duplex and Full-duplex

# Link Layer



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

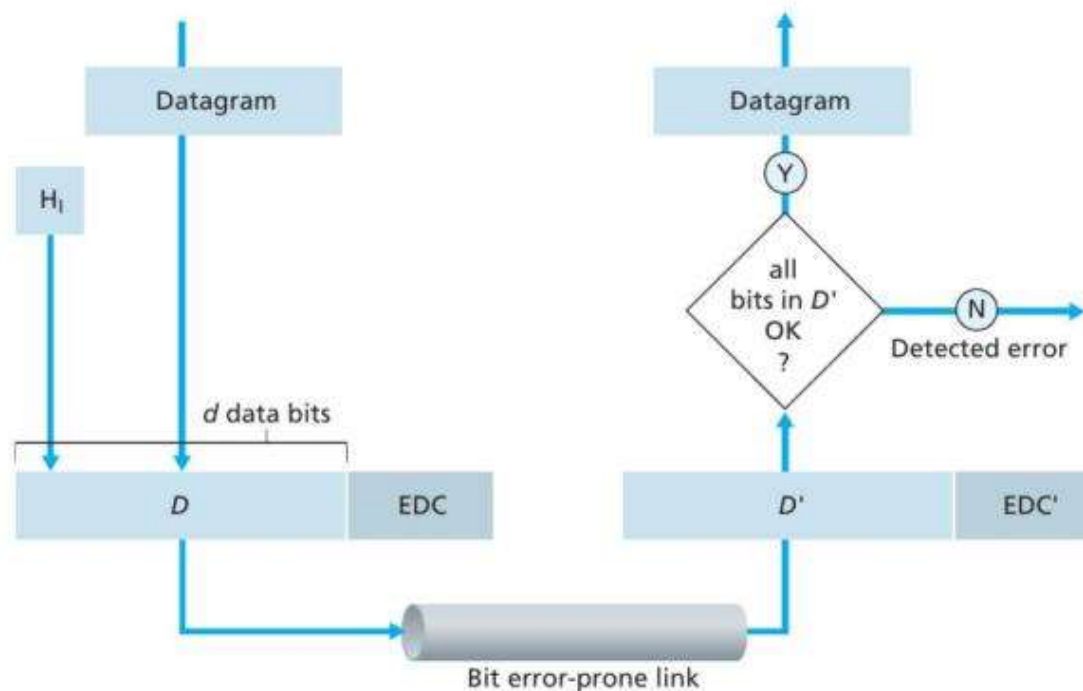
# Where is the Link layer implemented



# Link Layer Implementation

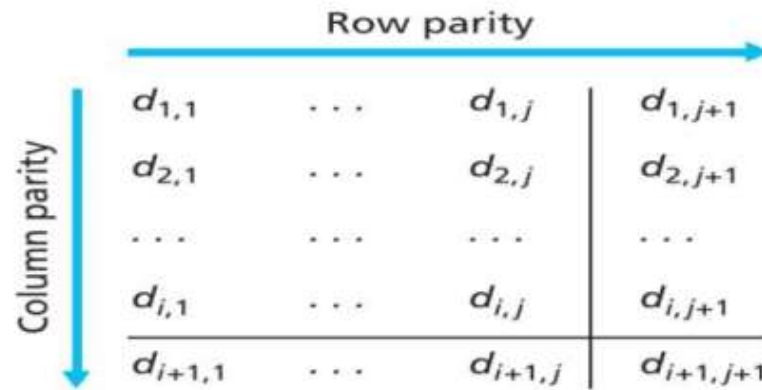
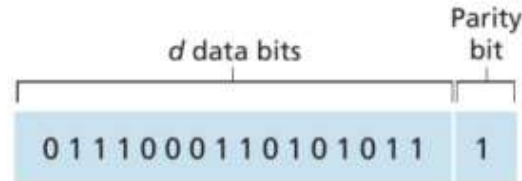
- Software components
  - receiving datagram from network layer
  - assembling link-layer addressing information
  - activating the controller hardware
- Hardware components
  - transfer frame from one adapter to another adapter
  - error detection and correction

# Error Detection and Correction



- **EDC**: error detection and correction bits
- Parity checks
- Checksumming methods
- Cyclic redundancy checks (CRC)

# Parity Checks



**No errors**

1	0	1	0	1	1
1	1	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

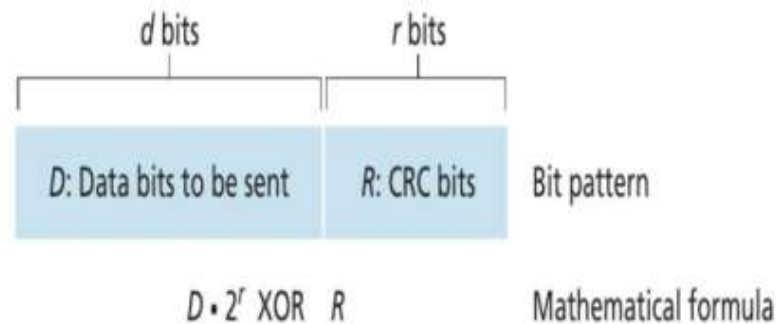
**Correctable single-bit error**

1	0	1	0	1	1
1	0	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

↓ Parity error

→ Parity error

# Cyclic Redundancy Check (CRC)



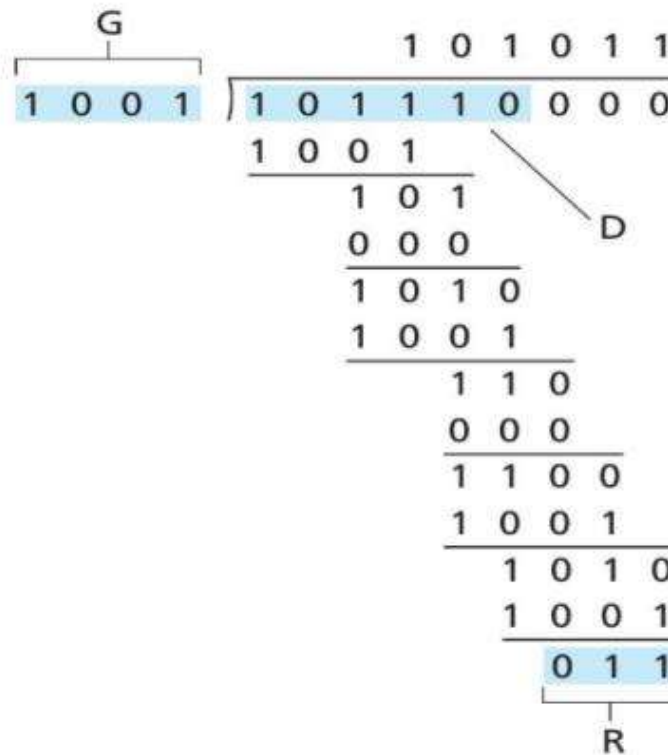
- Bit string can be viewed as a polynomial
- Sender and receiver **agree on**  $r + 1$  bit pattern known as **generator  $G$**
- Most significant bit of  $G$  should be **1**
- Given data  $D$ , sender will choose additional  $r$  bits,  $R$  and append them to  $D$
- The resulting  $d + r$  bit pattern should be **divisible** by  $G$ .
- CRC calculations are done in **modulo-2** arithmetic without carries and borrows (**XOR** operations)



- Find  $R$  such that there exists  $n$  that satisfies

$$D \cdot 2^r \text{ XOR } R = nG$$

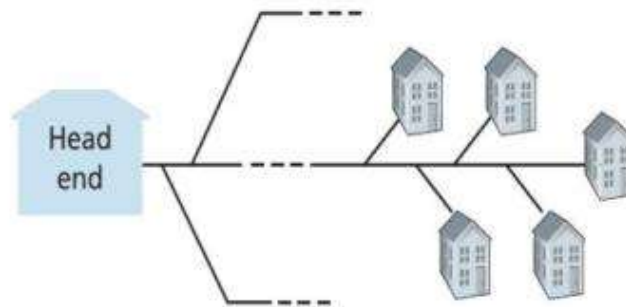
- $R = \text{remainder } \frac{D \cdot 2^r}{G}$
- Example:



- International standards define 8-, 16-, 24-, 32-bit generators.

# Multiple Access Channels

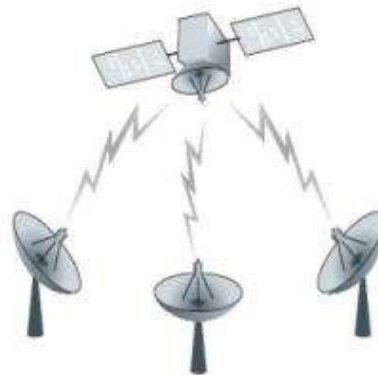
Shared wire  
(for example, cable access network)



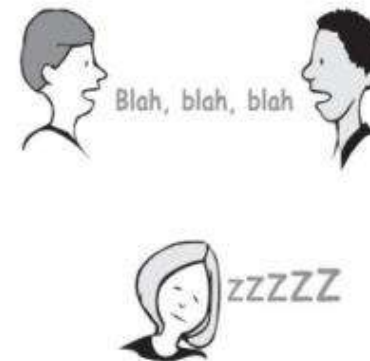
Shared wireless  
(for example, WiFi)



Satellite



Cocktail party



# Multiple Access Protocols

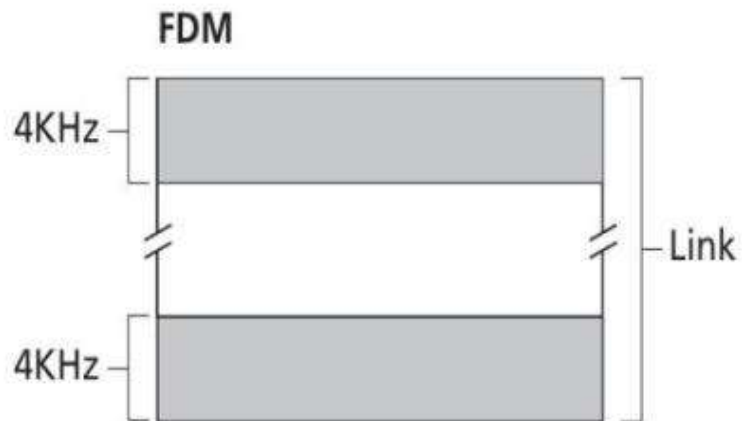
- If multiple nodes transmit frames at same time, packets **collide!**
- Channel partitioning protocols
  - TDM
  - FDM
- Random access protocols
  - Pure ALOHA
  - Slotted ALOHA
  - Carrier sense multiple access (CSMA), CSMA/CD
- Taking-turns Protocols
  - Polling protocol
  - Token-passing Protocol

# Multiple Access Protocols

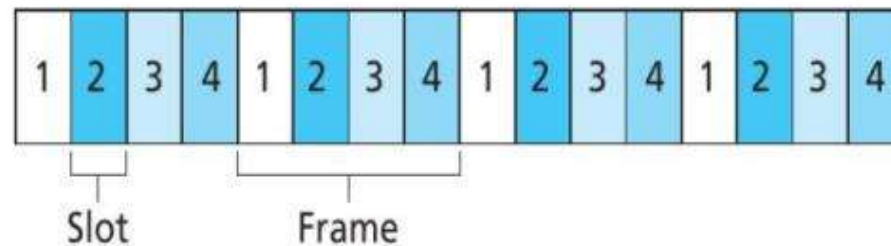
**Desirable characteristics** of MAC protocols on a broadcast channel of rate  $R$  bps:

- When only one node has frames to send, that node should have throughput of  $R$  bps
- When  $M$  nodes have frames to send, each node should have throughput of  $R/M$  bps
- Protocol is decentralized
- Protocol is simple and inexpensive to implement.

# Channel Partitioning Protocol



## TDM



Key:



# Drawbacks of TDM and FDM

- When only one node is active, it gets throughput of  $R/N$  bps.
- Node has to wait for its turn!
- Code division multiple access (CDMA)

# Slotted ALOHA

## Model and assumptions

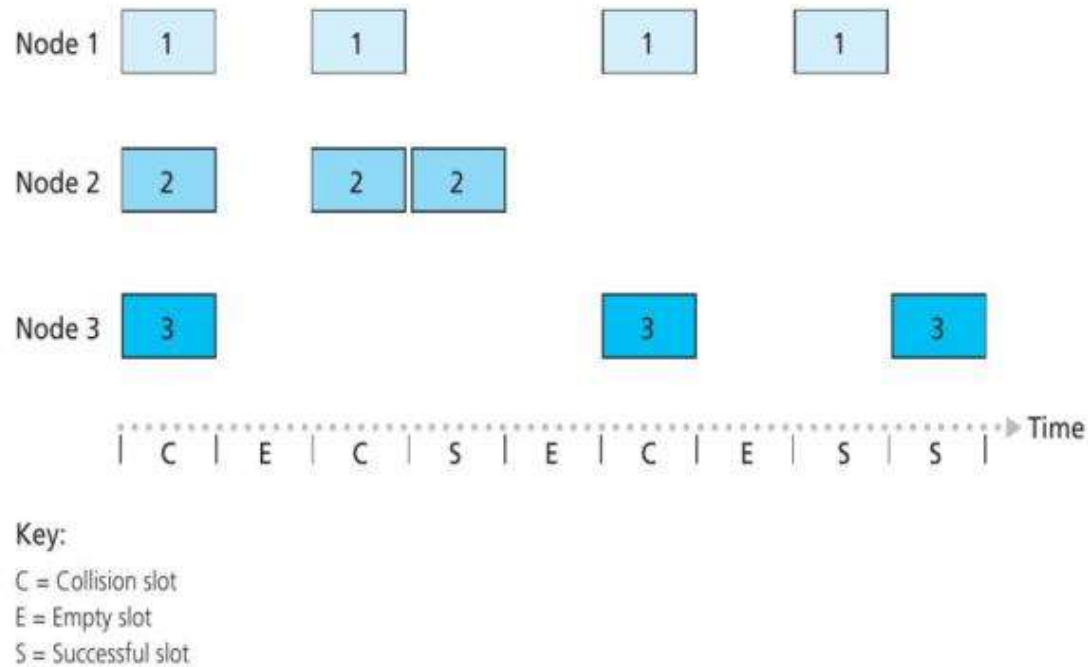
- All frame consists of exactly  $L$  bits
- Time is divided into slots of size  $L/R$  seconds
- Nodes start to transmit frames only at the beginning of slots
- Nodes are **synchronized**
- If two or more frames collide in a slot, then **all nodes can detect the collision before the slot ends**

# Slotted ALOHA

- When a node has **fresh frame** to send, it waits for beginning of the next slot and transmits the frame in the slot
- If there is no collision, the node has successfully transmitted the packet and no need to retransmit
- If there is a collision, the node detects it before end of the slot. The node **retransmits the frame in each subsequent slot with probability  $p$**  until the frame is transmitted without a collision



# Slotted ALOHA: Drawbacks



- Collisions
- Empty spaces
- Efficiency: fraction of successful slots

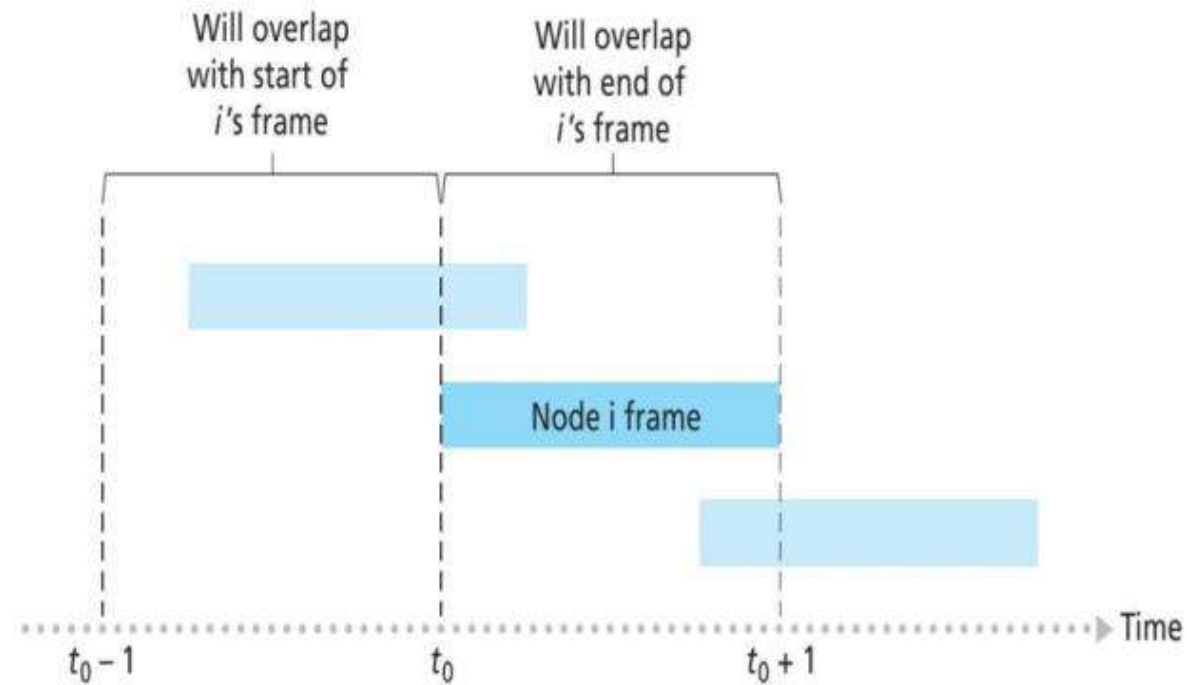
# Efficiency of Slotted ALOHA

- Assume that each node always has a frame to send
- Probability that only one node (out of  $N$ ) transmits
- $Np(1 - p)^{N-1}$
- Efficiency =  $Np(1 - p)^{N-1}$
- Find  $p$  that maximizes efficiency, let it be  $p^*$
- As  $N \rightarrow \infty$ , Efficiency  $\rightarrow \frac{1}{e}$
- Only 37% of slots are used for successful transmission! a similar analysis show that 37% slots are empty and remaining slots have collisions.

# Pure ALOHA

- Unslotted time axis
- Transmit a frame as soon as it arrives
- If there is a collision, node retransmits the frame immediately with probability  $p$ . Otherwise, wait for frame transmission time.
- After this wait, it then retransmits the frame with probability  $p$  or waits for another frame time with probability  $1 - p$ .

# Pure ALOHA

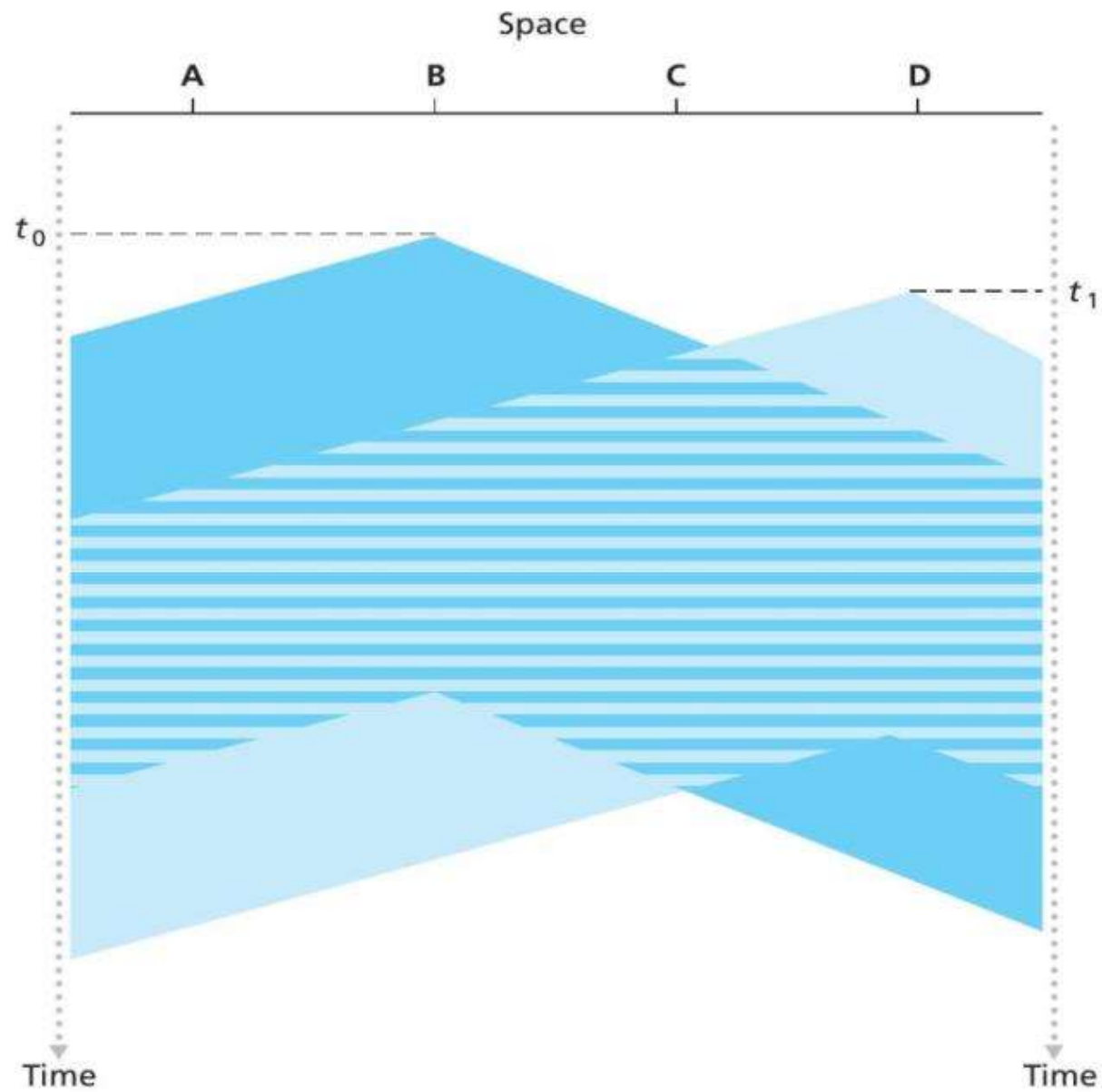


- Efficiency :  $\frac{1}{2e}$

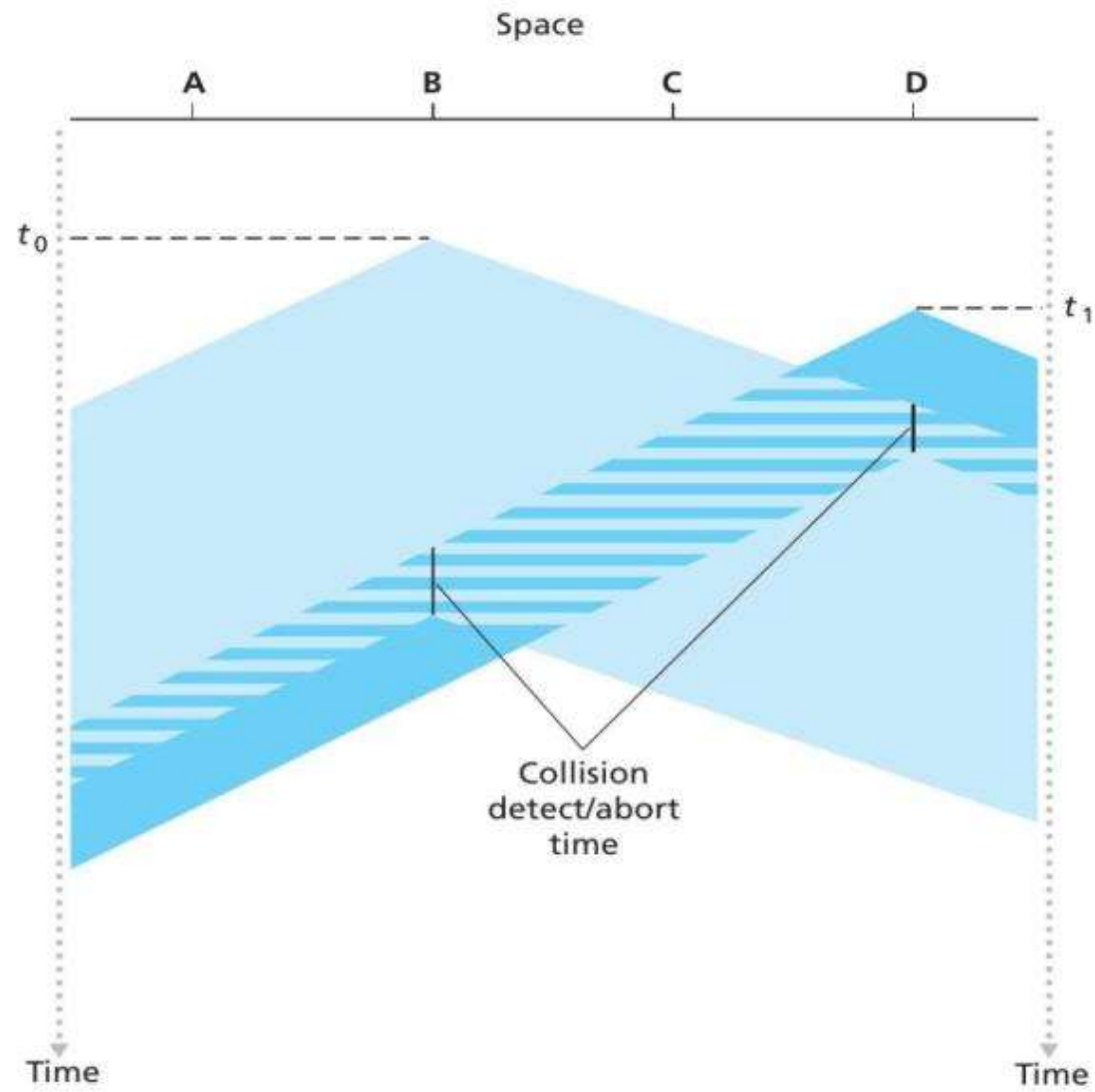
# Carrier Sense Multiple Access

- Listen before speaking: carrier sensing
- If channel is busy, nodes 'backs off' a random amount of time and then senses again.
- If the channel is idle, node transmits the frame
- collision detection: If someone else begins talking at the same time, stop talking

# CSMA



# CSMA/CD



# Taking-Turns Protocol

- Polling Protocol

- Master node polls each of the nodes in a **round-robin** fashion
- Polling delay
- Master node may fail!

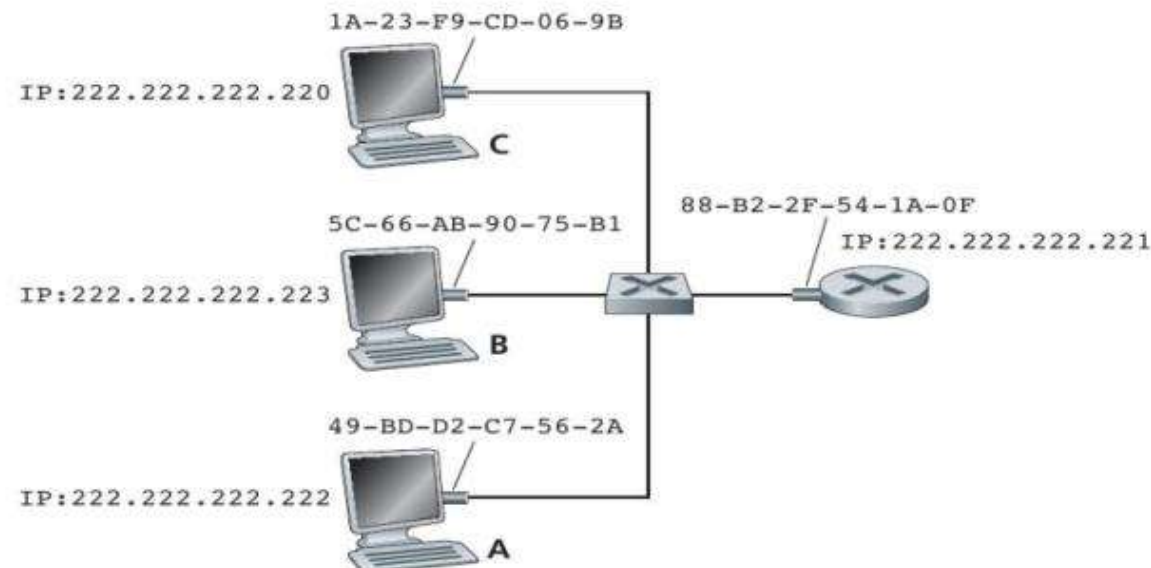
- Token-passing Protocol

- A special-purpose frame known as a **token** is exchanged among the nodes
- A node with token can transmit a maximum number of frames and send the token to next node
- A node holds token only if it has frames to transmit
- Very efficient.



# Link-Layer Addressing

- Are IP addresses really unique?
- Node's adapter has a link-layer address
- Also known as **LAN address** or **Physical address** or **MAC address**
- MAC address
  - Managed by IEEE
  - Flat structure
  - Broadcast address : **FF-FF-FF-FF-FF-FF**



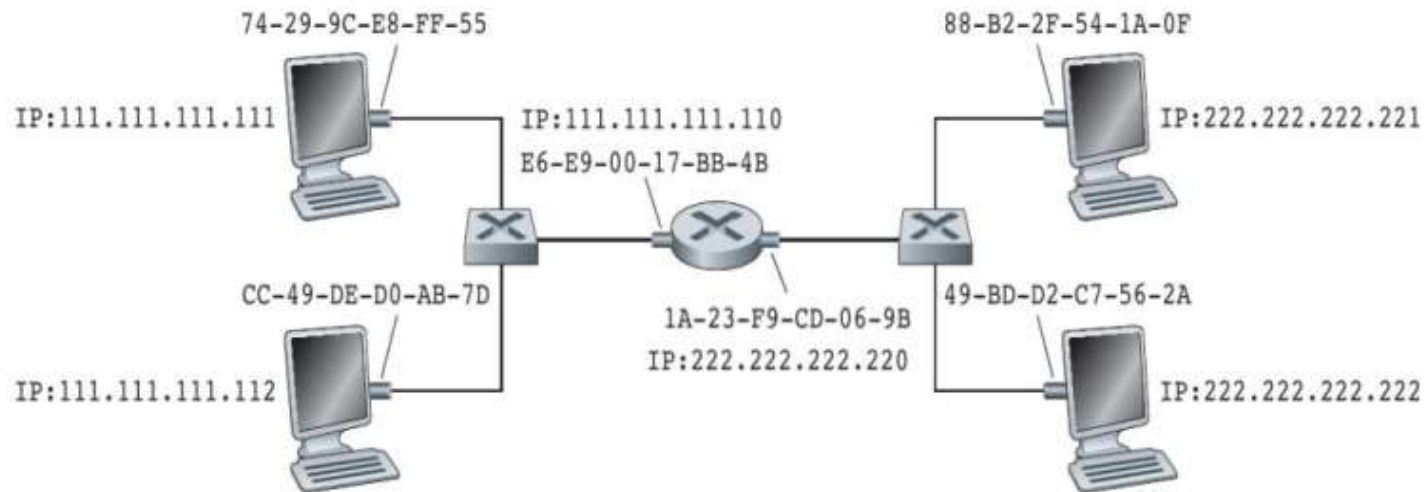
# Address Resolution Protocol

- Sending node has to provide it's link layer not only IP address of destination but also **destination's MAC address**
- How does the source node determines the MAC address of it's destination?
- **Address Resolution Protocol (ARP)**
- Analogous to DNS

IP Address	MAC Address	TTL
222.222.222.221	88-B2-2F-54-1A-0F	13:45:00
222.222.222.223	5C-66-AB-90-75-B1	13:52:00

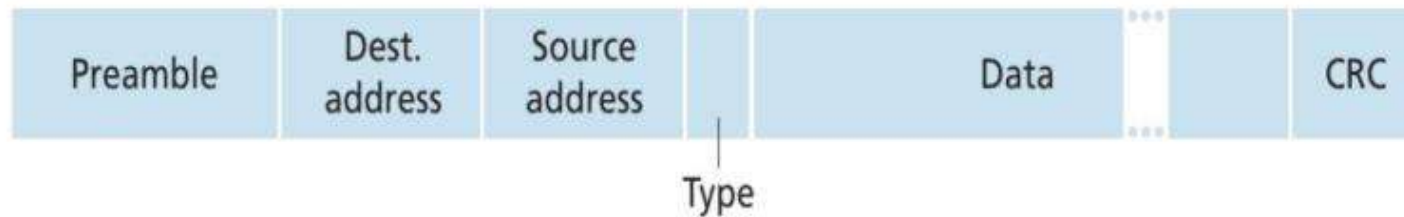
- Suppose node 222.222.222.220 wants to send a datagram to 222.222.222.222
- If ARP does not have an entry about the destination, it first constructs an ARP **query** packet.
- Query:
  - IP addresses of sender and receiver
  - sender's MAC address
  - Broadcast MAC address
- Encapsulated in a link-layer frame and sent in to the subnet
- Each node checks to see if its IP address matches with the destination address
- The one node with a match sends a ARP **response** packet with desired mapping

# Sending a Datagram Off the Subnet



- Destination MAC address should be that of **router's MAC** on subnet 1
- The router determines the correct interface based on destination IP address
- After processing, router encapsulates the datagram in a frame with **destination MAC address**.

# Ethernet



- Popular wired LAN technology
- Data field: **minimum length** is 46 bytes and **maximum length** is 1500 bytes
- Type field: specifies the protocol at network layer
- **Preamble:**
  - 8-bytes
  - first byte has value **10101010**
  - last byte has value **10101011**
  - to synchronize the clocks



# Ethernet's MAC Protocol: CSMA/CD

- The adapter takes datagram from network layer and prepares Ethernet frame and keeps in adapter's buffer
- If the channel is idle for **96 bit times**, it starts to transmit the frame
- If the channel is busy, it waits until it senses no signal energy plus 96 bit times and then starts to transmit the frame
- If the adapter transmits the entire frame without detecting collision, the adapter is finished with the frame
- If the adapter detects a collision, it stops transmitting its frame and instead transmits a **48-bit jam signal**

# Ethernet's MAC Protocol: CSMA/CD

- After transmitting the jam signal, the adapter enters an **exponential backoff** phase.
- Exponential Backoff: After experiencing  $n$ th collision in a row for a frame, the adapter chooses a value for  $K$  at random from  $\{0, 1, 2, \dots, 2^m - 1\}$  for  $m = \min(n, 10)$ . The adapter then waits  $K \cdot 512$  bit times and then returns to step 2.
- $d_{prop}$  is maximum time it takes signal energy to propagate between any two adapters
- $d_{trans}$  is the time to transmit a maximum size Ethernet frame.
- Efficiency =  $\frac{1}{1 + 5d_{prop}/d_{trans}}$