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22AIE204
COMPUTER NETWORKS

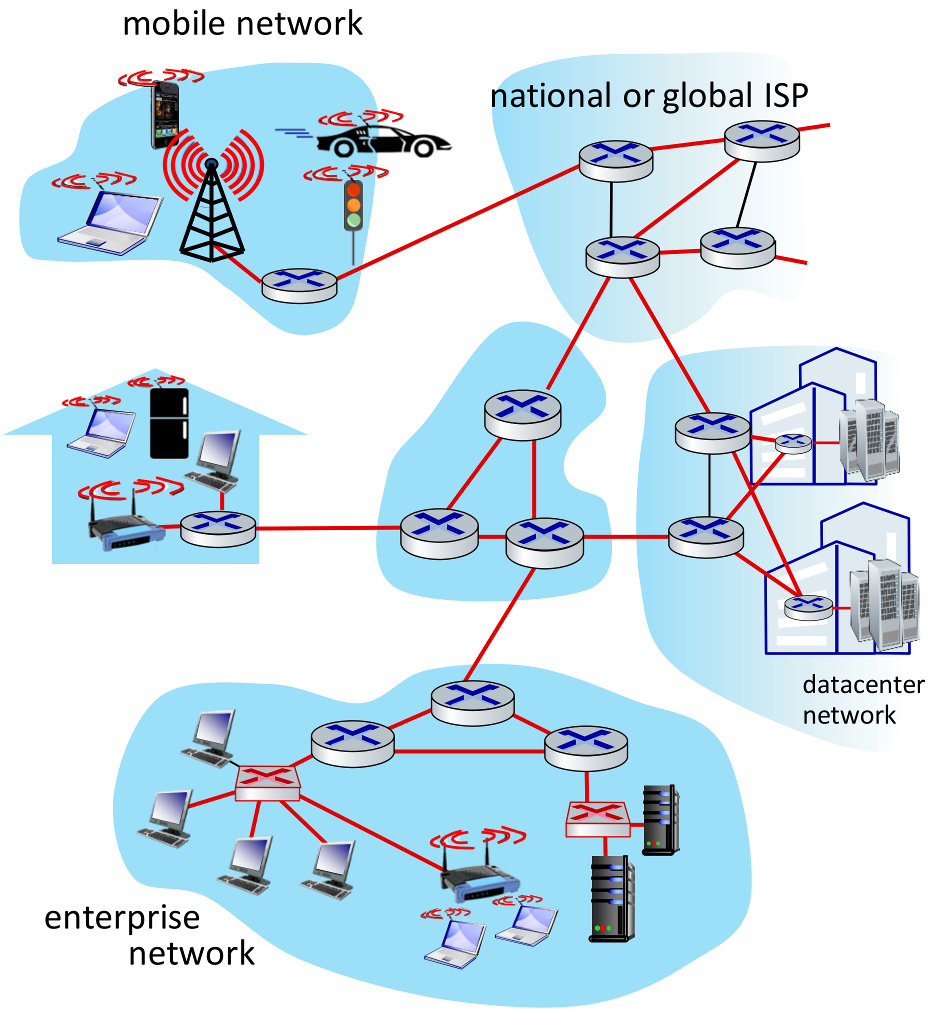
NETWORK ACCESS LAYER

- Data Link Layer
- Physical Layer

Link layer: introduction

terminology:

- hosts, routers: nodes
- communication channels that connect adjacent nodes along communication path: links
  - wired , wireless
  - LANs
- layer-2 packet: *frame*, encapsulates datagram



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

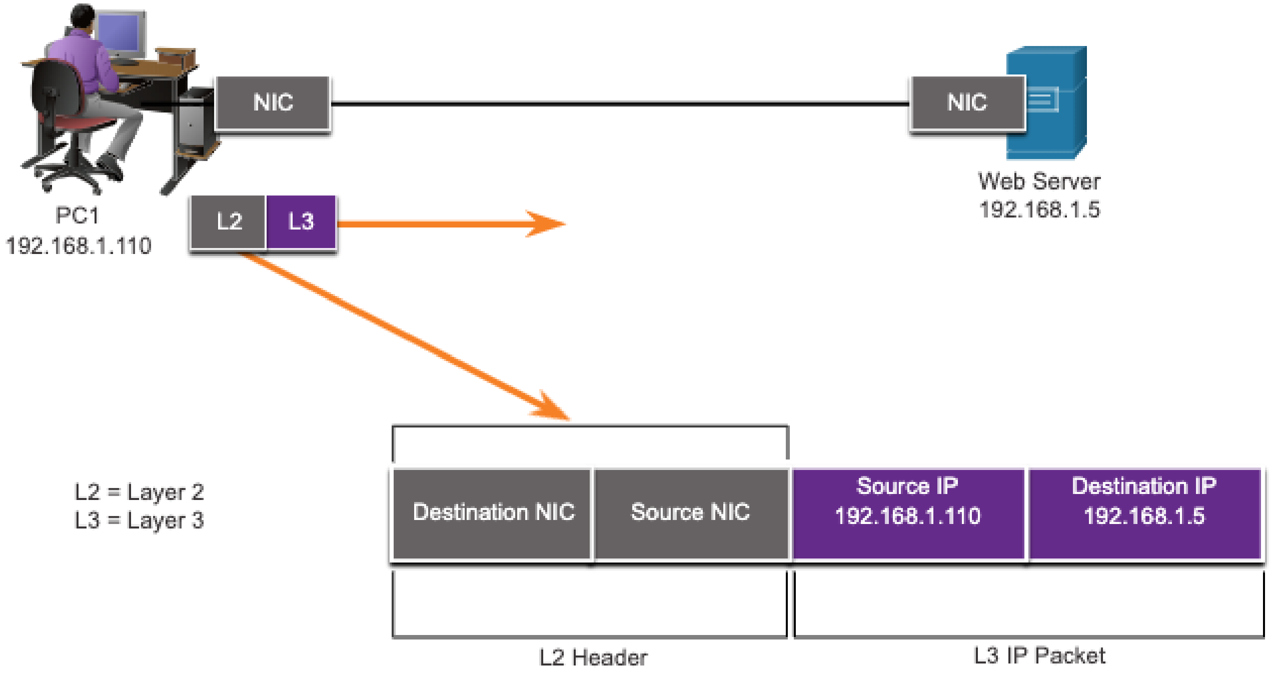
Purpose of Data Link Layer (Layer 2)

- Responsible for transferring data frame from one node to physically adjacent node over a link.
  - Node - hosts/end devices and routers
  - Link – Communication channels that connect the adjacent nodes

- Above layers of Data Link are Network Media independent
- Data Link Layer has both software and hardware portions and dependent on the type of network.
- Data Link Layer is Responsible for communications between nodes through network interface cards.
- Prepares network data for the physical network

Data Link Layer Services

- Framing/Link Access
  - The Protocol Data Unit (PDU) of Layer 2 is Frame and Layer3 is packet.
  - Encapsulates Layer 3 packets (IPv4 and IPv6) into Layer 2 Frames, adding header and trailer.
  - MAC address used in frame headers to identify source and destination in the link
  - MAC address keeps on changing in each hop/link, but IP addresses do not



Ref: Chapter 6, CCNA Introduction to Networks from Cisco Netacad

Data Link Layer Services

- Reliable delivery between adjacent nodes
  - Fiber, some twisted pair cables – low bit error link
  - Wireless links – high error rates
  - Flow control – pacing between adjacent sending and receiving nodes
- Error detection
  - Errors caused by signal attenuation and noise
  - Receiver detects presence of errors and drop frames.
  - Sender can retransmit
- Error correction – receiver identifies and correct bit errors without resorting to retransmission

Data Link Layer Services

- **Half-duplex communication**
  - Only allows one device to send or receive at a time on a shared medium.
  - Used on WLANs and legacy bus topologies with Ethernet hubs.

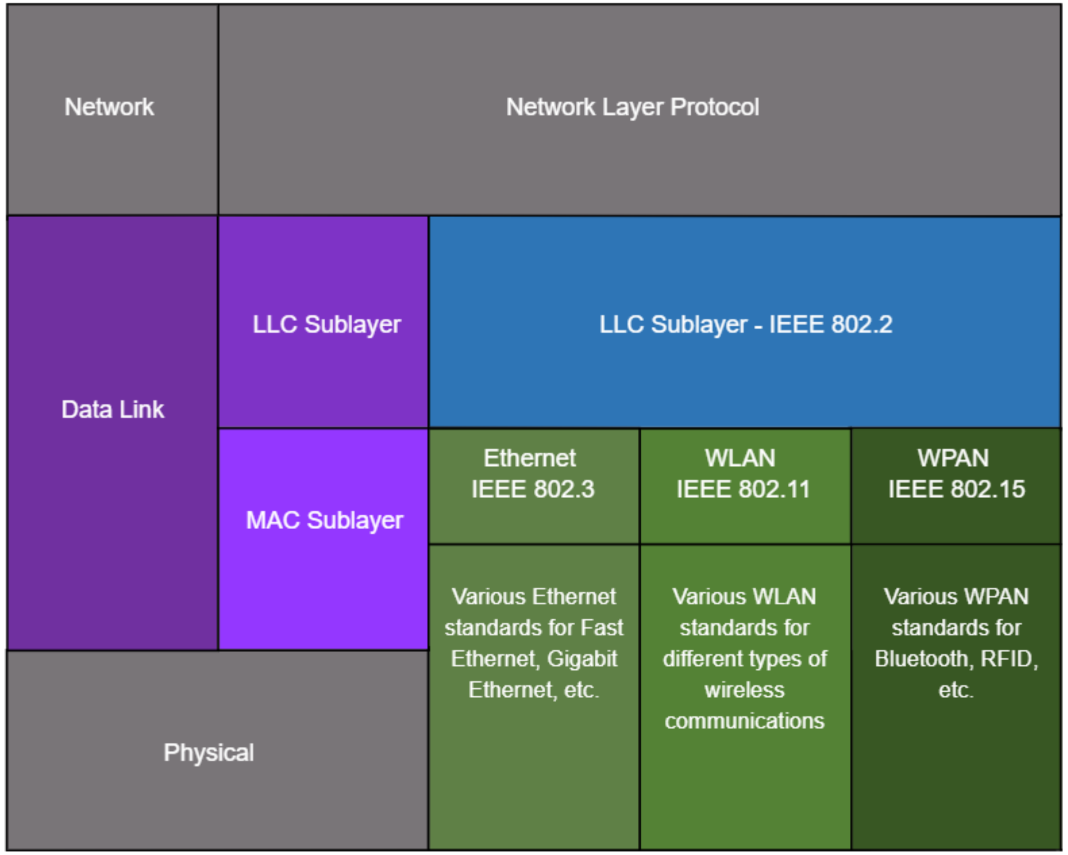
- **Full-duplex communication**
  - Allows both devices to simultaneously transmit and receive on a shared medium.
  - Ethernet switches operate in full-duplex mode.

Data Link Layer Standards

- Data link layer protocols are defined by various organizations:
  - Institute for Electrical and Electronic Engineers (IEEE).
  - International Telecommunications Union (ITU).
  - International Organizations for Standardization (ISO).
  - American National Standards Institute (ANSI).
- IEEE 802 LAN/MAN standards are specific to the type of network (Ethernet, WLAN, WPAN, etc).

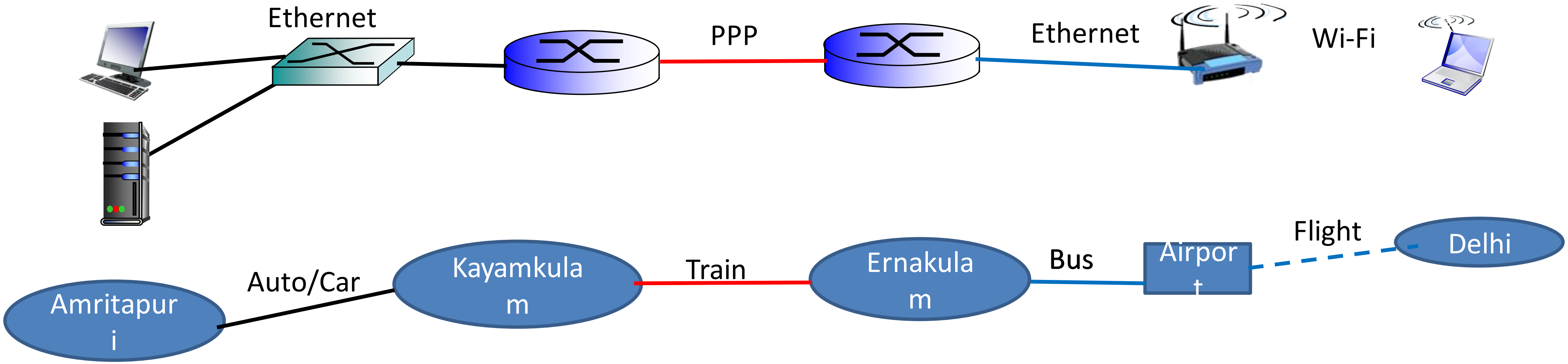
Data Link Layer Sublayers

- The Data Link Layer consists of two sublayers. **Logical Link Control (LLC)** and **Media Access Control (MAC).**
  - The LLC sublayer communicates between the networking software at the upper layers and the device hardware at the lower layers.
  - The MAC sublayer is responsible for data encapsulation and media access control.

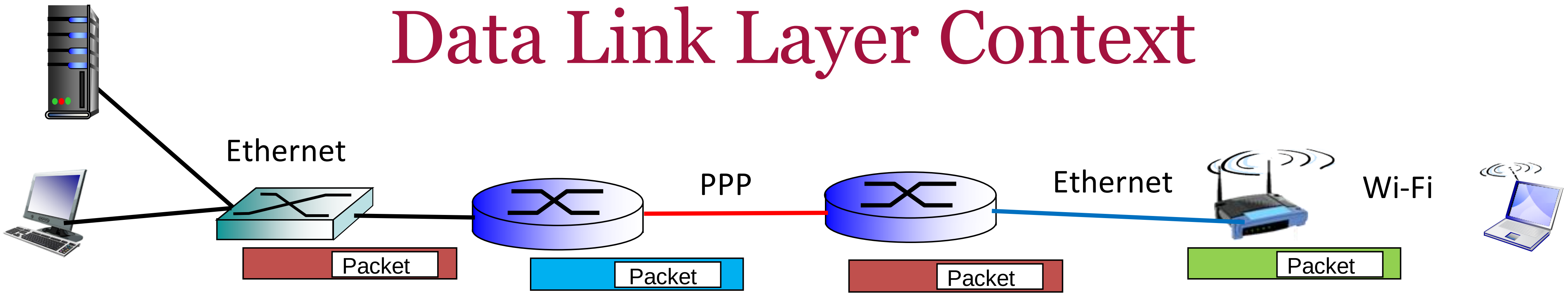


Data Link Layer Context

- Packets are transferred by different link protocols over different links
- Transportation segment = link, transportation mode = link protocol



Data Link Layer Context

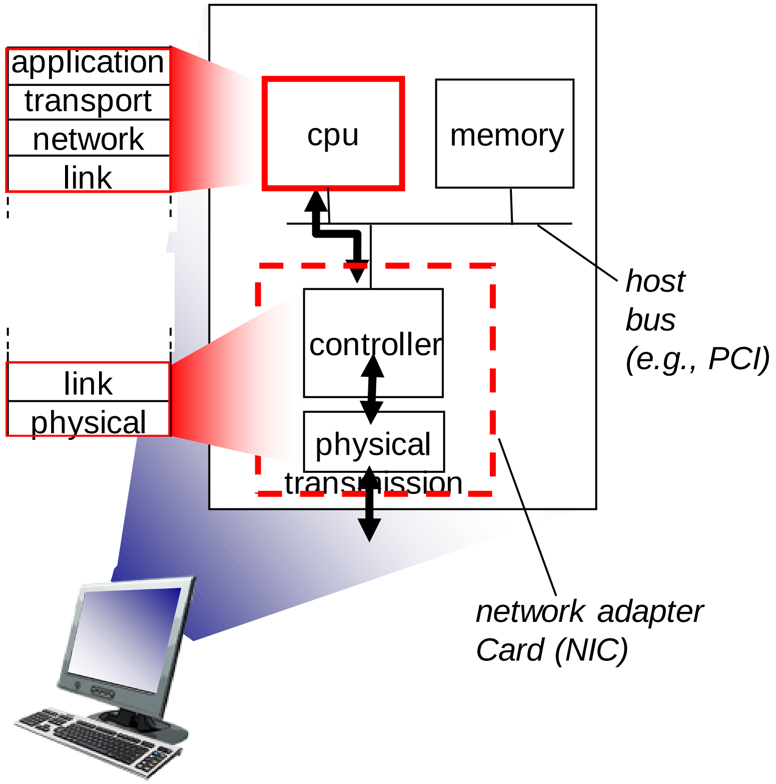


- Packets exchanged between nodes experience media transitions in different links
- At each hop along the path, a router performs four basic Layer 2 functions:
  - Accepts a frame from the network medium.
  - De-encapsulates the frame to expose the encapsulated packet.
  - Re-encapsulates the packet into a new frame.
  - Forwards the new frame on the medium of the next network segment.

Where is Link Layer Implemented?

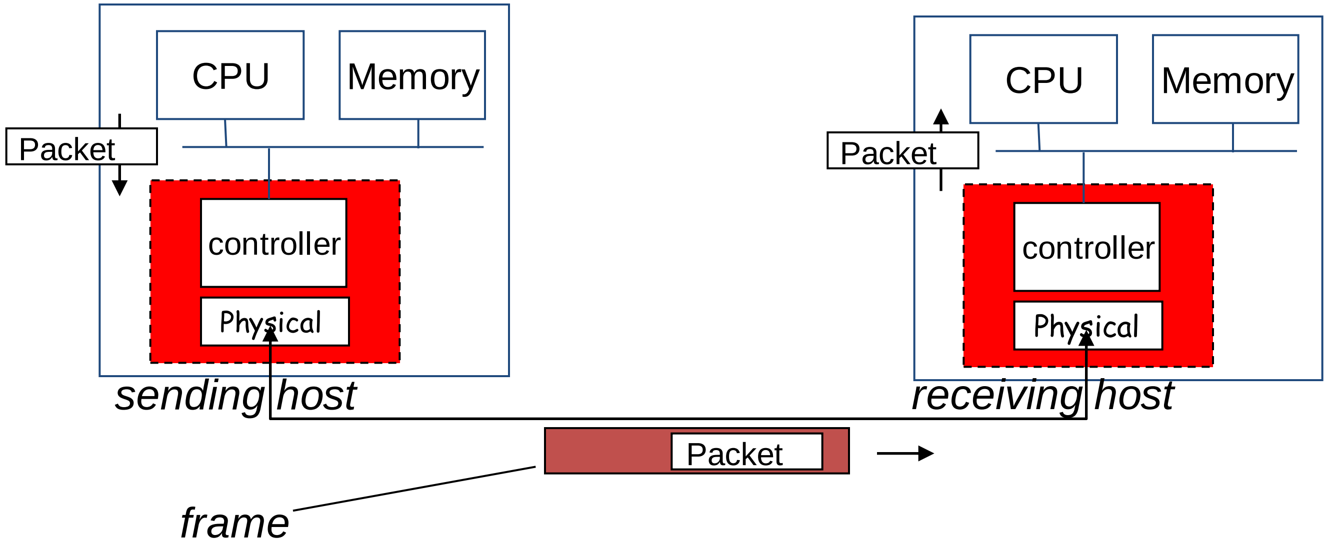
- In each host (routers & end devices)
- Implemented in adapter known as Network Interface card (NIC)
  - NIC interfaces software in data link layer and hardware in physical layer
  - Attaches into host’s system buses
  - Ex: Wireless NIC, Wired NIC etc


J. Kurose and K. Ross 2012, Computer Network,6th ed.



J. Kurose and K. Ross 2012, Computer Network,6th ed.

Adapter Role in Communication



- Sending side:
  - Encapsulates packet in frame
  - adds error checking bits, reliable data transfer, flow control, etc.
- Receiving side:
  - looks for errors, rdt, flow control, etc
  - Extracts packet, passes to upper layer at receiving side

Summary

- Data Link Layer Services
  - Framing, reliable delivery etc.
- Data Link Layer Sub layers
  - Logical Link Control layer
  - Media access control layer

- Transportation of data in different links
  - Use of adapters or NIC card

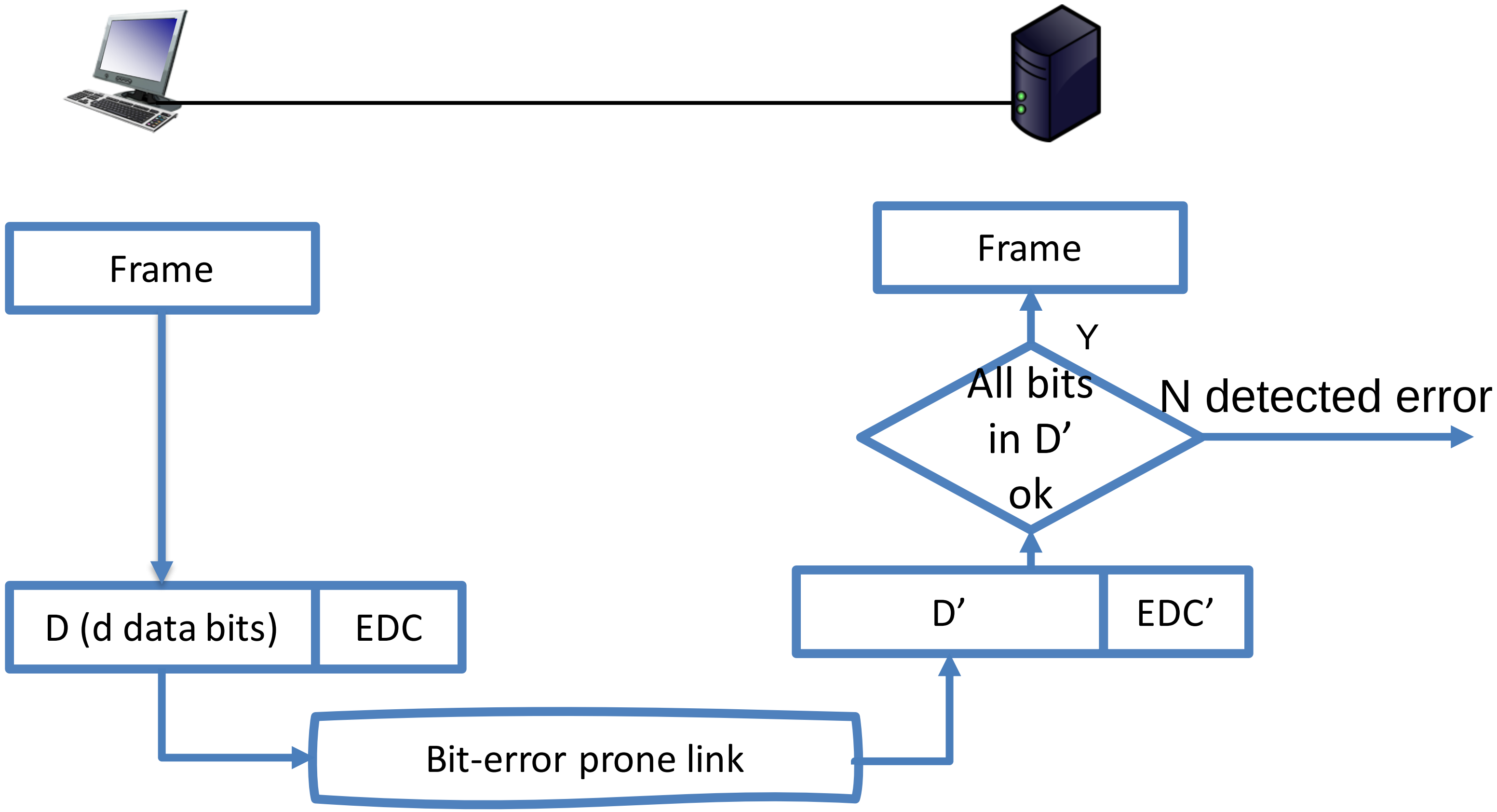
- Next we shall discuss on
  - Error detection and correction service of DLL

Objectives in Error Control

- Understand Error Detection Correction (EDC) process

- Examine various EDC methods:
  - Single bit error detection
  - Single bit error correction
  - Easier checksum method
  - Efficient & commonly used method to detect burst errors

Error Detection



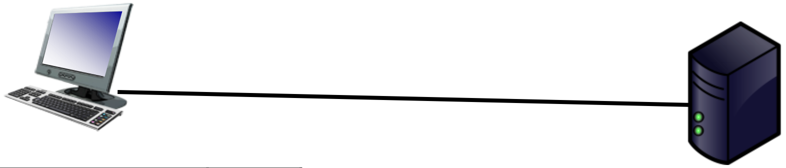
- Error detection or correction process
- EDC = Error detection Correction bits
- D = data bits
- Data protected by error checking include EDC bits in footer of the frame

- Error detection not 100% reliable!
  - Protocol may miss some errors
  - Larger EDC bits yield better detection and correction

Ref: J. Kurose and K. Ross 2012, Computer

Parity Checking

- Single bit parity for error detection
- Parity bit added in sender side
  - In case of even parity, if number of 1s is odd, the parity bit value is set to 1 in the sender side to have even number of 1s in the codeword (D+EDC).
- Detected for errors in the receiver side
  - At the receiver side, number of 1s are checked for even number of 1s in even parity. Even number of 1s are detected as error in this case



Sender		Receiver	
01110101	1	01110101	1

1 bit error detected

01100101	1

Odd number of bits error detected in even parity

2 bits error not detected

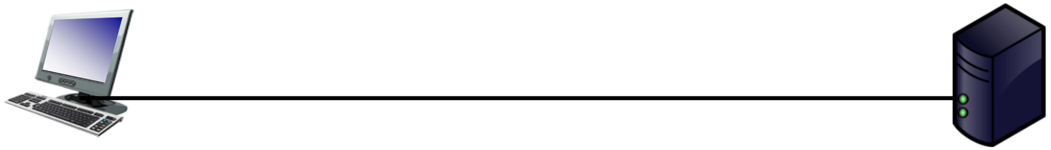
01000101	1

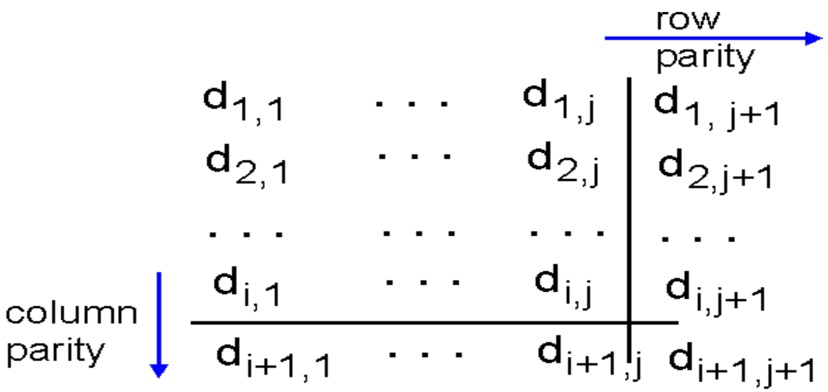
Even number of bits error not detected

Ref: J. Kurose and K. Ross 2012, Computer

Error correction using Two dimensional bit parity

- Example for detecting and correcting errors





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

1	0	1	1	0	**1**
1	0	0	1	0	**0**
1	1	1	0	1	**0**
1	**1**	**0**	**0**	**1**	**1**

1	0	1	1	0	**1**
1	0	0	1	0	**0**
1	1	1	0	1	**0**
1	**1**	**0**	**0**	**1**	**1**

1	0	1	1	0	**1**
1	1	0	1	0	**0**
1	1	1	0	1	**0**
1	**1**	**0**	**0**	**1**	**1**

Detecting the bit with error

1	0	1	1	0	**1**
1	1	0	1	0	**0**
1	1	1	0	1	**0**
1	**1**	**0**	**0**	**1**	**1**

Corrected bit from 1 to 0

1	0	1	1	0	**1**
1	**0**	0	1	0	**0**
1	1	1	0	1	**0**
1	**1**	**0**	**0**	**1**	**1**

Internet Checksum

- Sender side
- Compute Checksum – addition of segment contents (1's complement)
- Ex: 8-bit checksum computed on 2 data segments of 8 bits

- Receiver side
- Compute sum of data bits and checksum of received segment and do 1's complement of sum
- Zero result => no error detected

data

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

sum

1	1	1	0	0	0	1	0

Checksum (1's complement of sum)

0	0	0	1	1	1	0	1

Data received with checksum

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

Sum

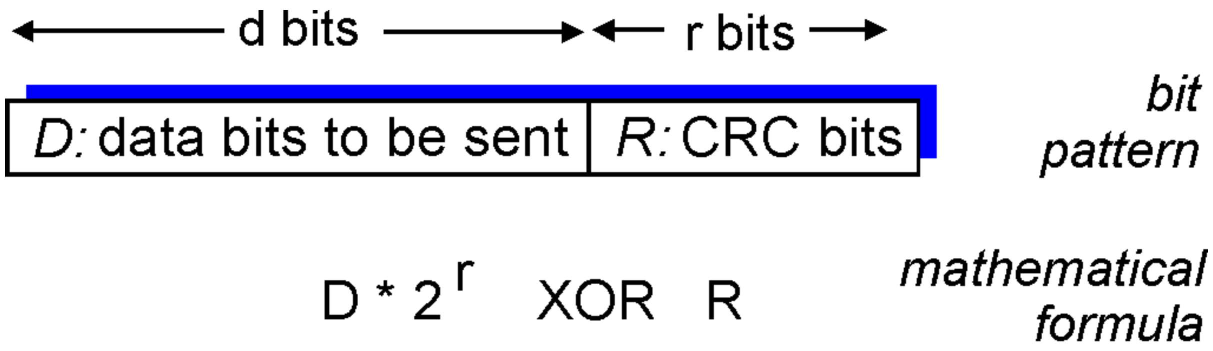
1	1	1	1	1	1	1	1

1's complement of checksum

0	0	0	0	0	0	0	0

Cyclic Redundancy Check

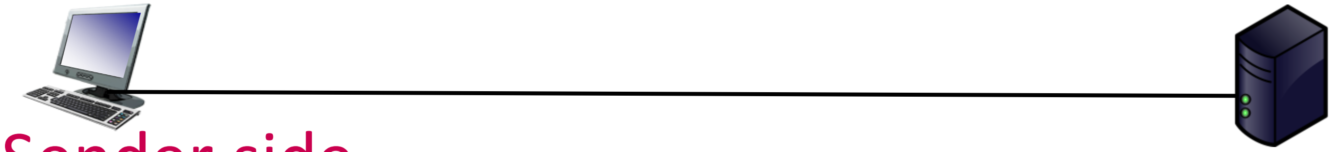
- Most powerful error detection coding



- Referring Data bits as D and Error Detection Correction bits as R
- Choose r +1 bit pattern (generator) G, known to sender & receiver
- Widely used in practice (Ethernet, 802.11, Wi-Fi, ATM)

Cyclic Redundancy Check

- Goal: choose r CRC bits R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - Receiver knows G, divides <D,R> by G
  - If there is non-zero remainder, error is detected
  - Can detect all burst errors less than r+1 bits

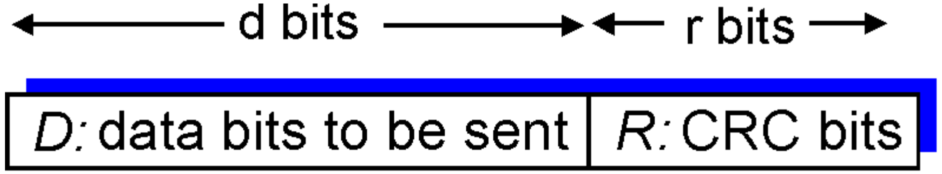


- Sender side
  - D=101110, r=3, G=1001
  - $D.2^r$ = 101110000
  - Remainder = $(D.2^r)/G$
  - Remainder = 011
  - Data sent =101110**011**

- Receiver side
  - Data received =101110011
  - This divided by G=1001
  - Since Remainder =0
  - There is No error

Cyclic Redundancy Check

- Required: $D.2^r$ XOR R = nG
- Equivalently, D. 2^r = nG XOR R
- Similar to, if we divide D.2r by G,



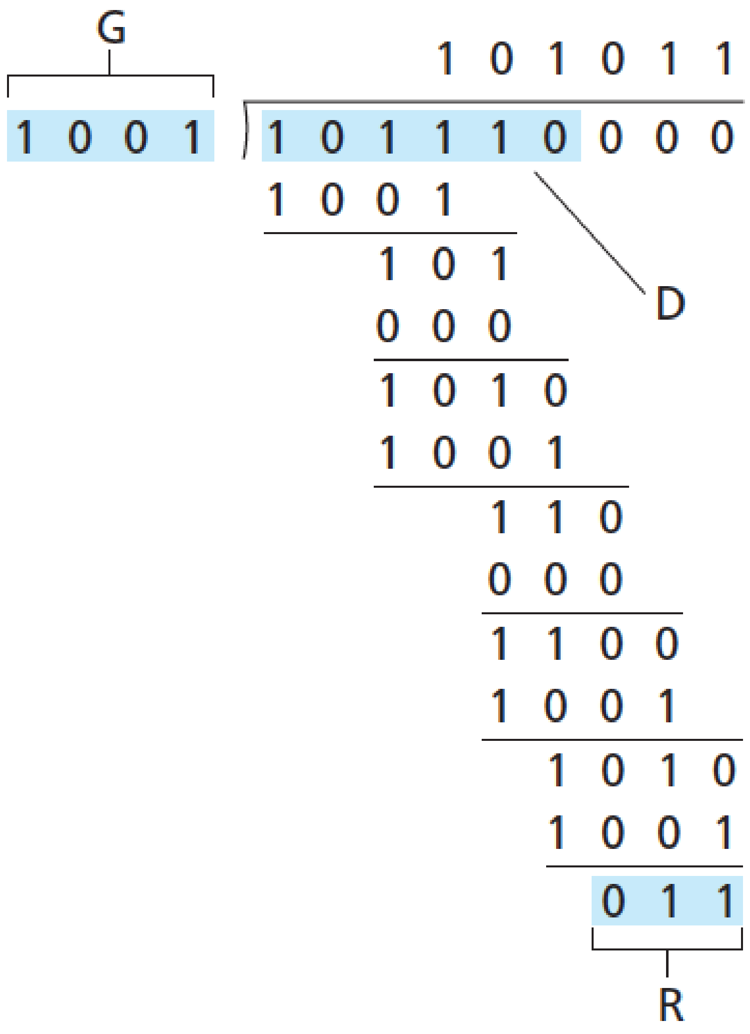
bit pattern

$D * 2^r$ XOR R

mathematical formula

- Want remainder R to satisfy

$$R = \text{remainder}\left[\frac{D \cdot 2^r}{G}\right]$$



Summary

- Algorithm for Error detection and correction

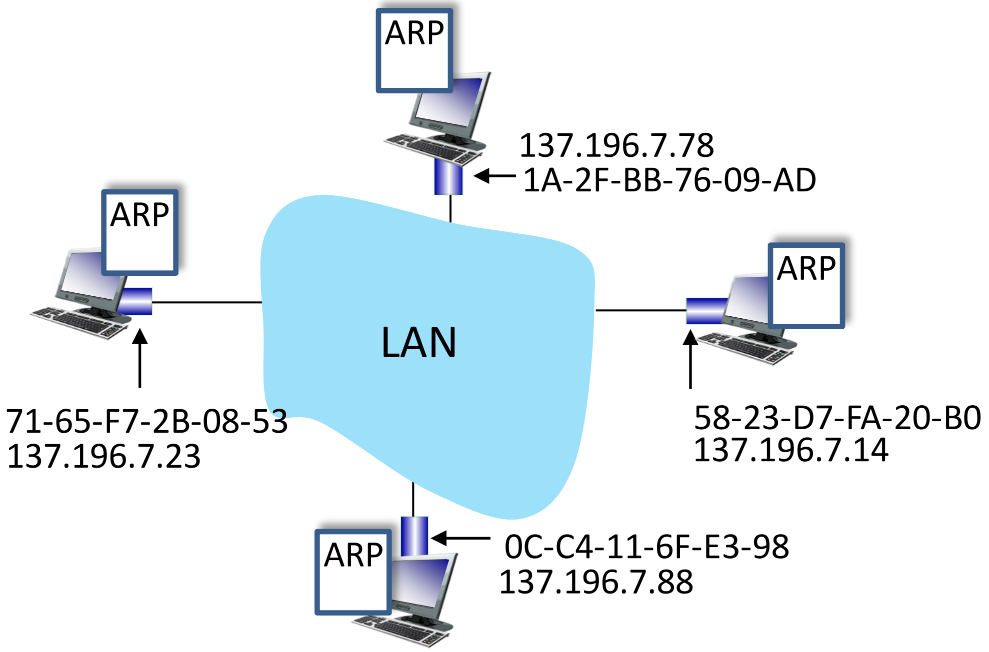
- Error detection using parity
- Error correction using two-dimensional bit parity

- Analyzed Error detection method using Checksum

- Evaluated Cyclic redundancy check (CRC) method

ARP: address resolution protocol

Question: how to determine interface's MAC address, knowing its IP address?



ARP table: each IP node (host, router) on LAN has table

- IP/MAC address mappings for some LAN nodes:

  < IP address; MAC address; TTL>
- TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

ARP protocol in action

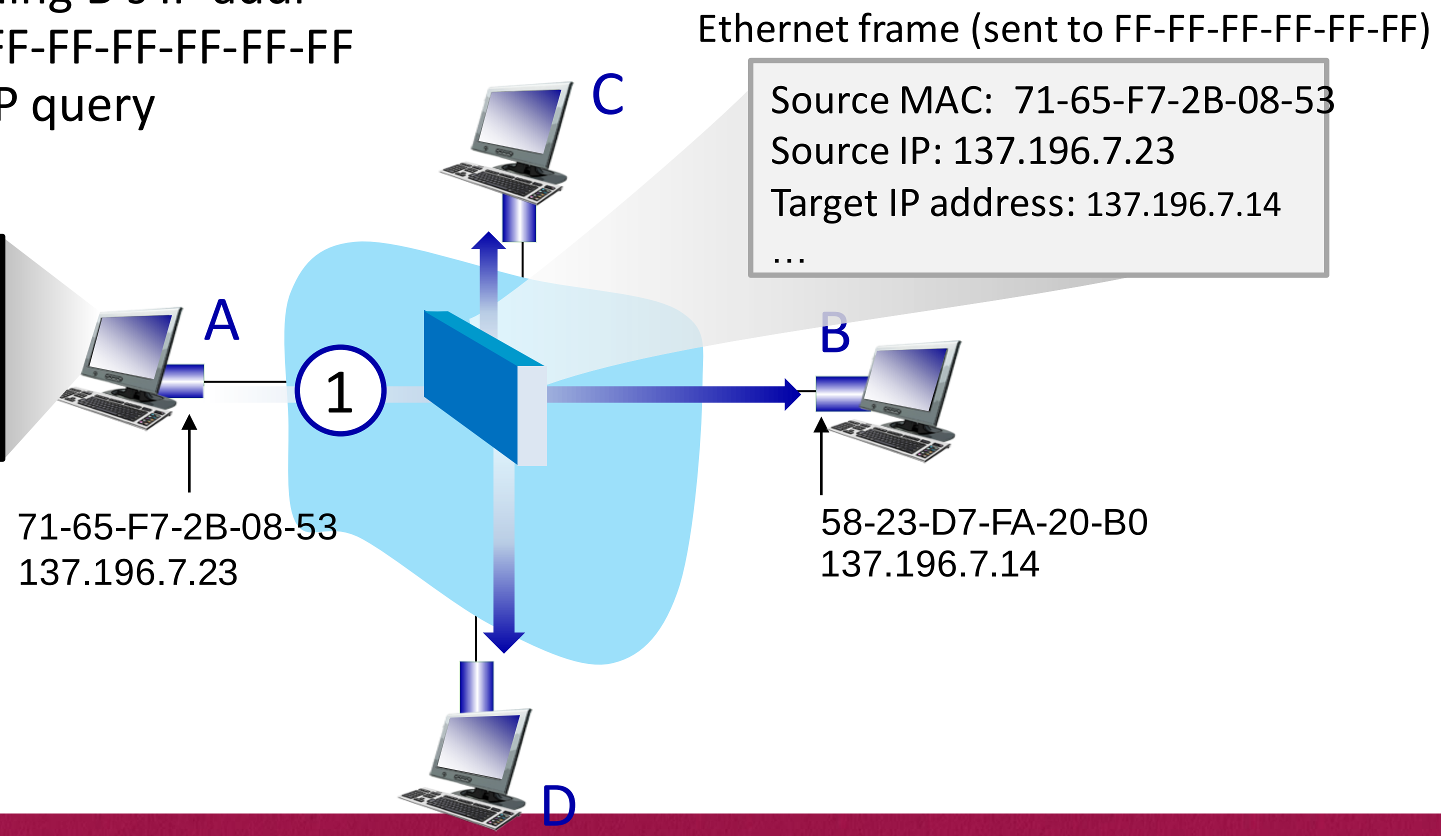
example: A wants to send datagram to B

- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

1 A broadcasts ARP query, containing B's IP addr
- destination MAC address = FF-FF-FF-FF-FF-FF
- all nodes on LAN receive ARP query

ARP table in A

IP addr	MAC addr	TTL



ARP protocol in action

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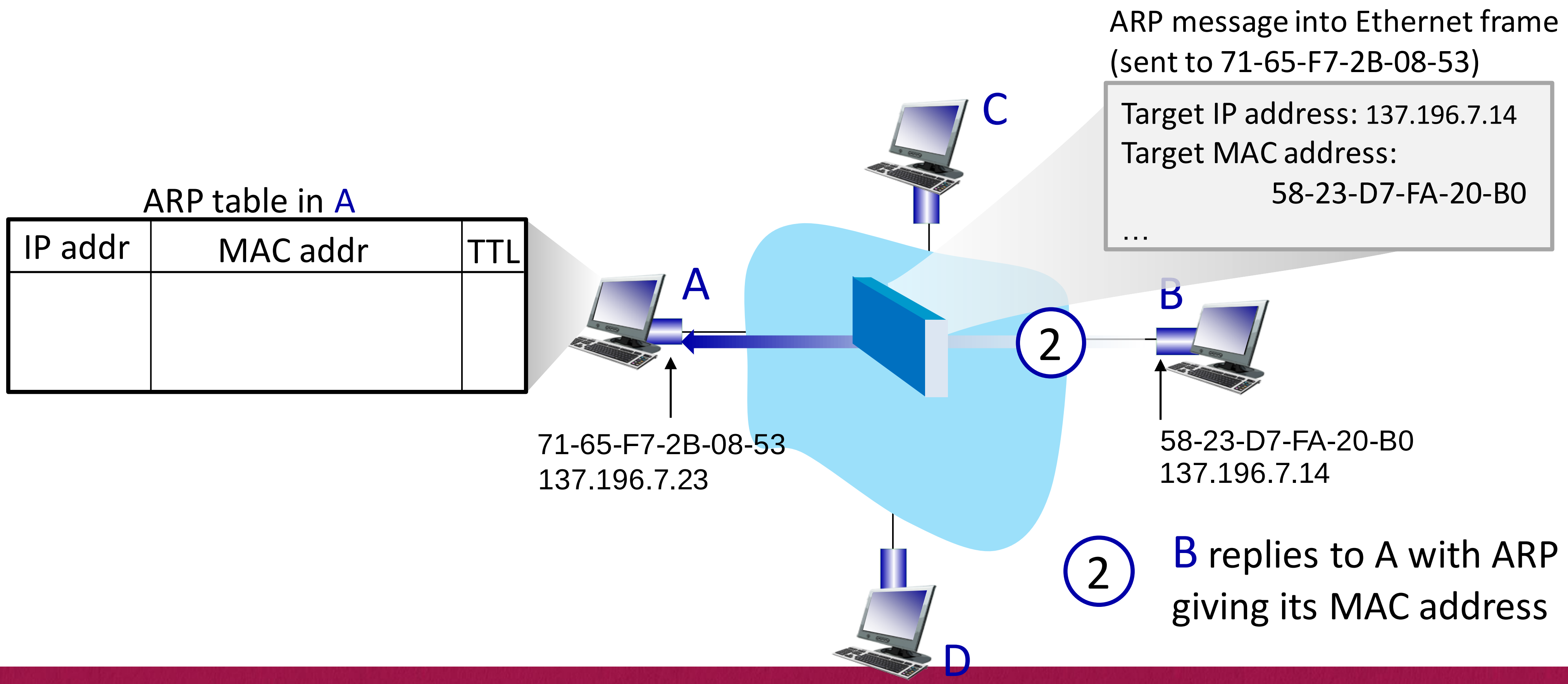


2 B replies to A with ARP response, giving its MAC address

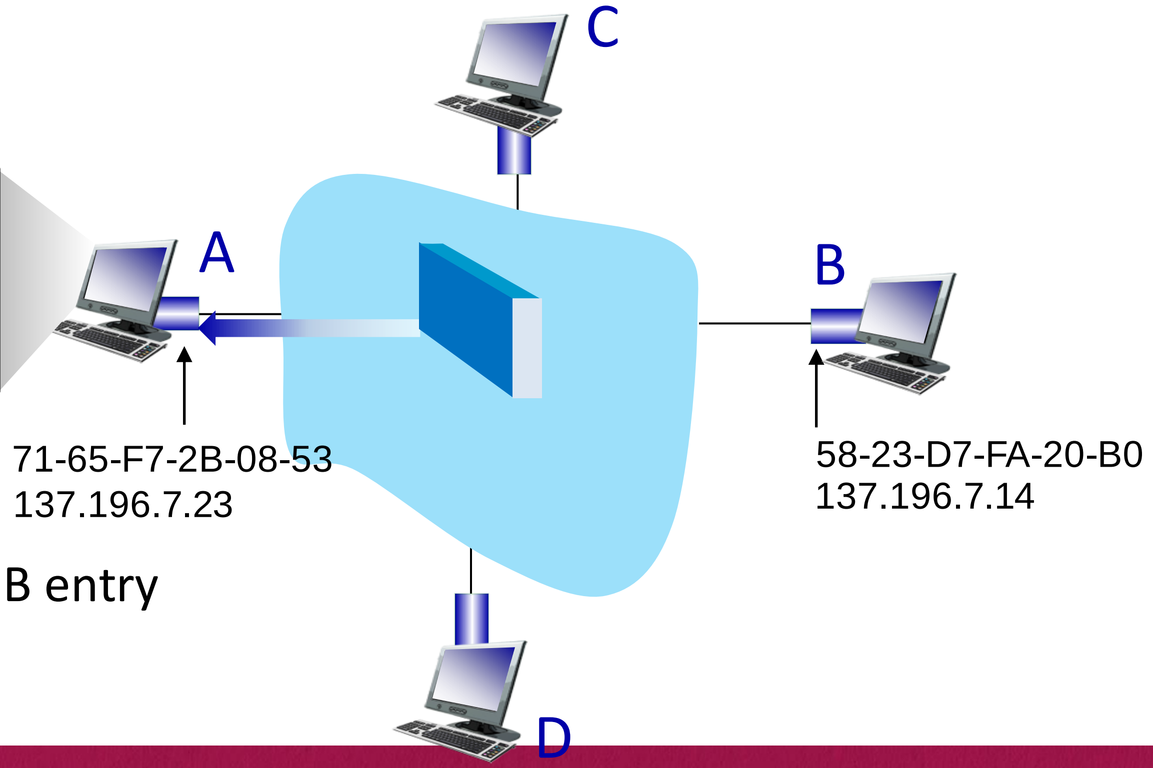
ARP protocol in action

example: A wants to send datagram to B

- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

ARP table in A

IP addr	MAC addr	TTL
137.196.7.14	58-23-D7-FA-20-B0	500

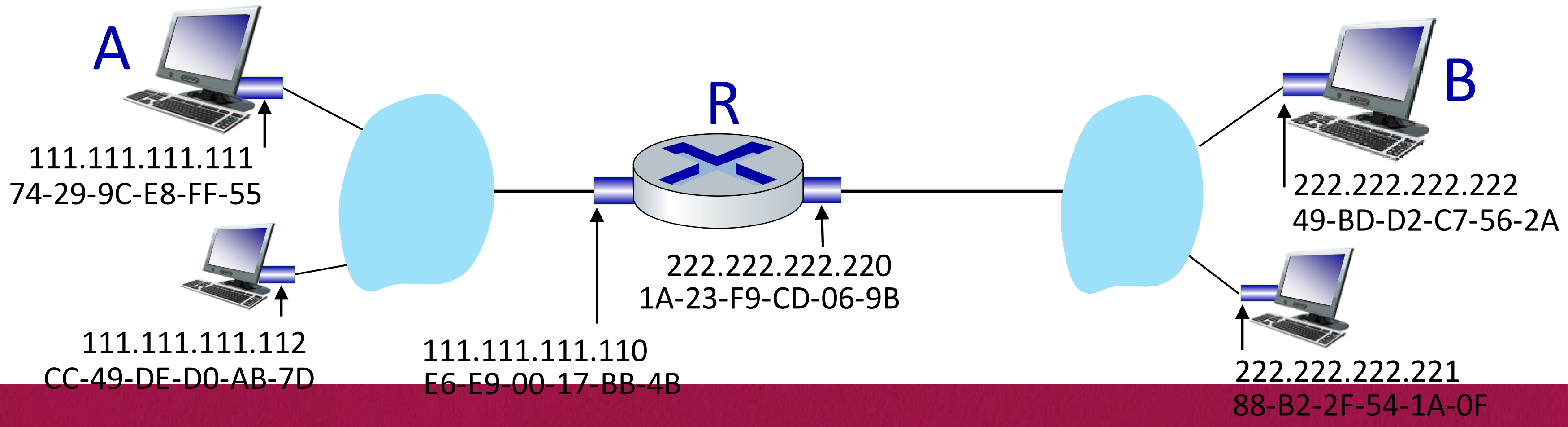


3 A receives B's reply, adds B entry into its local ARP table

Routing to another subnet: addressing

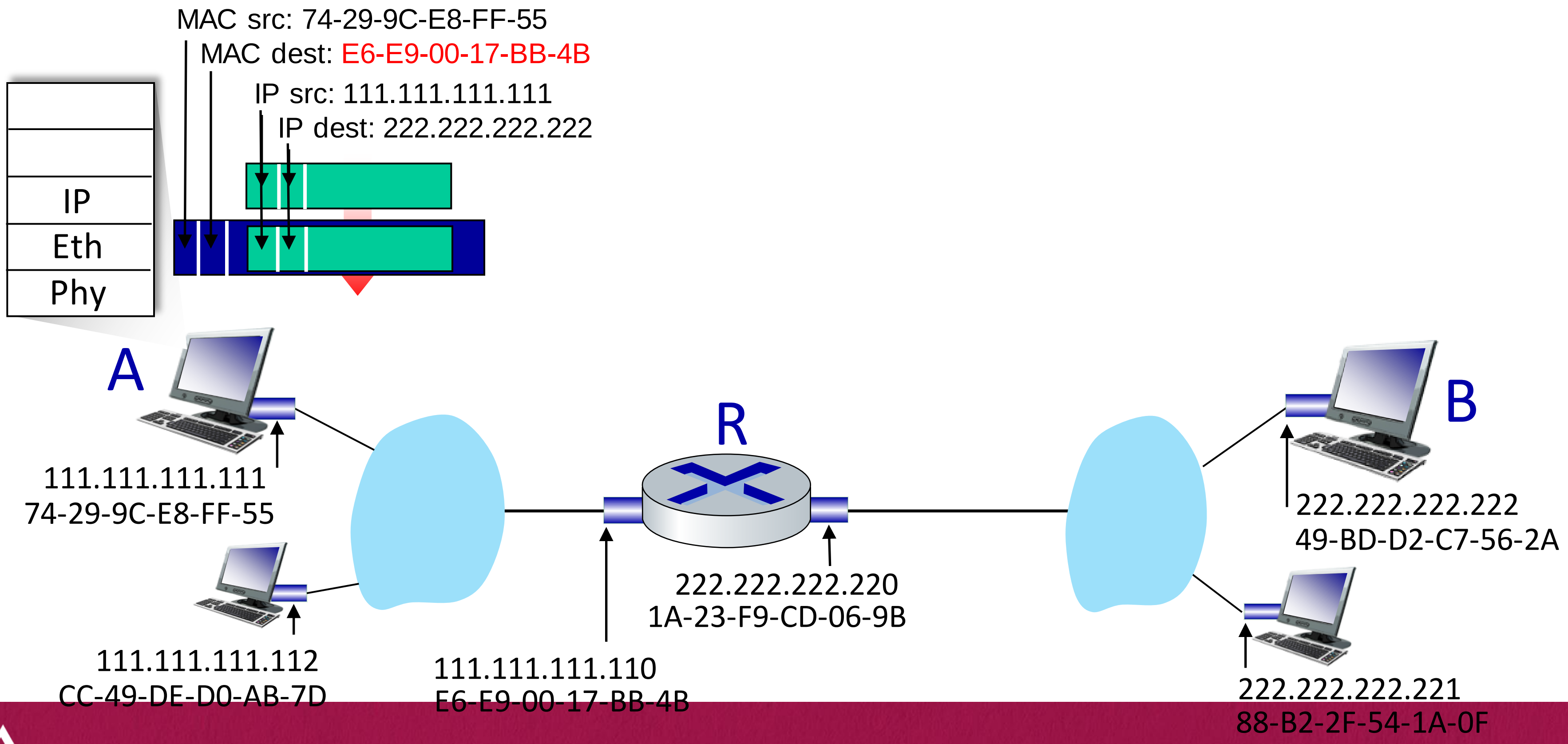
walkthrough: sending a datagram from *A* to *B* via *R*

- focus on addressing – at IP (datagram) and MAC layer (frame) levels
- assume that:
  - A knows B's IP address
  - A knows IP address of first hop router, R (how?)
  - A knows R's MAC address (how?)



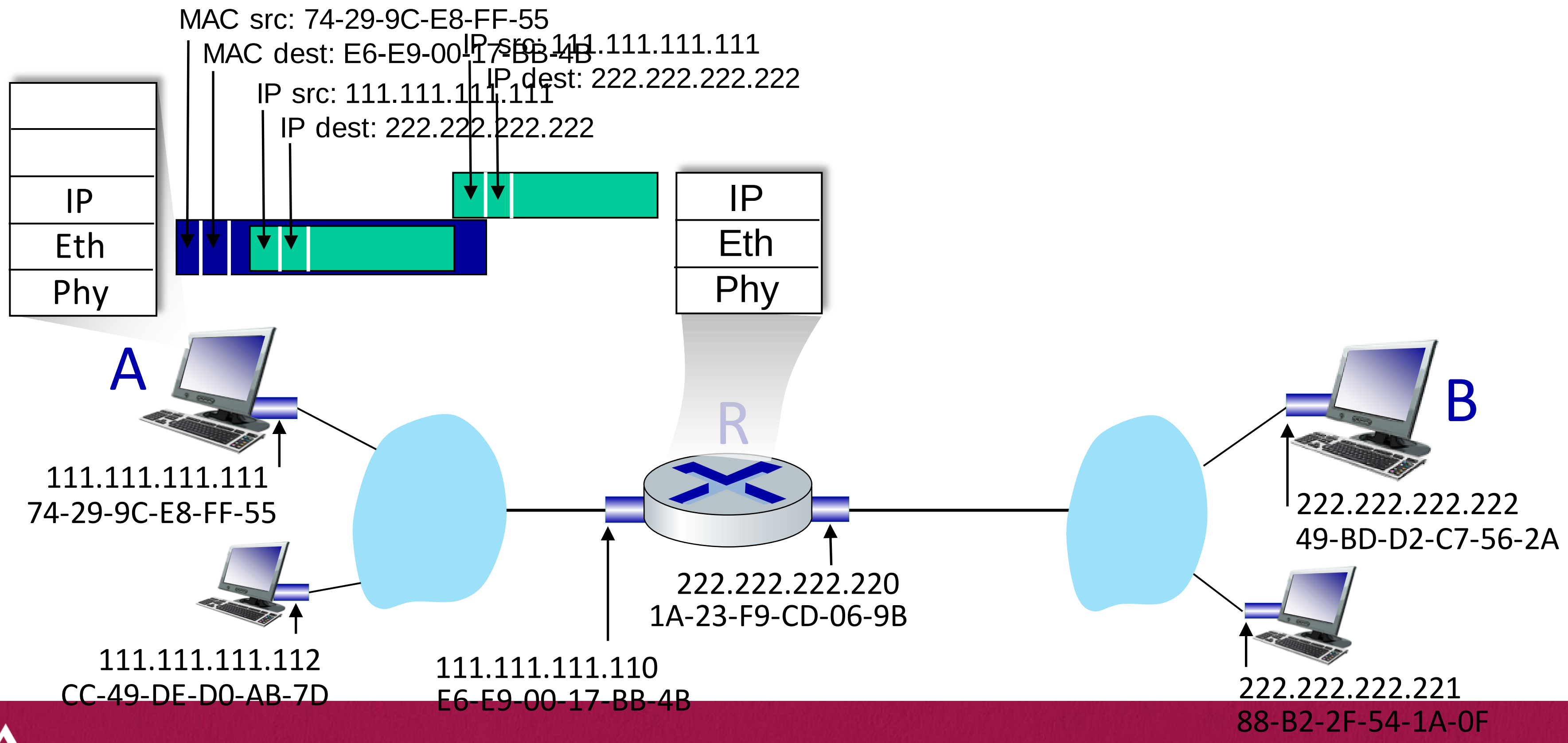
Routing to another subnet: addressing

- A creates IP datagram with IP source A, destination B
- A creates link-layer frame containing A-to-B IP datagram
  - R's MAC address is frame's destination



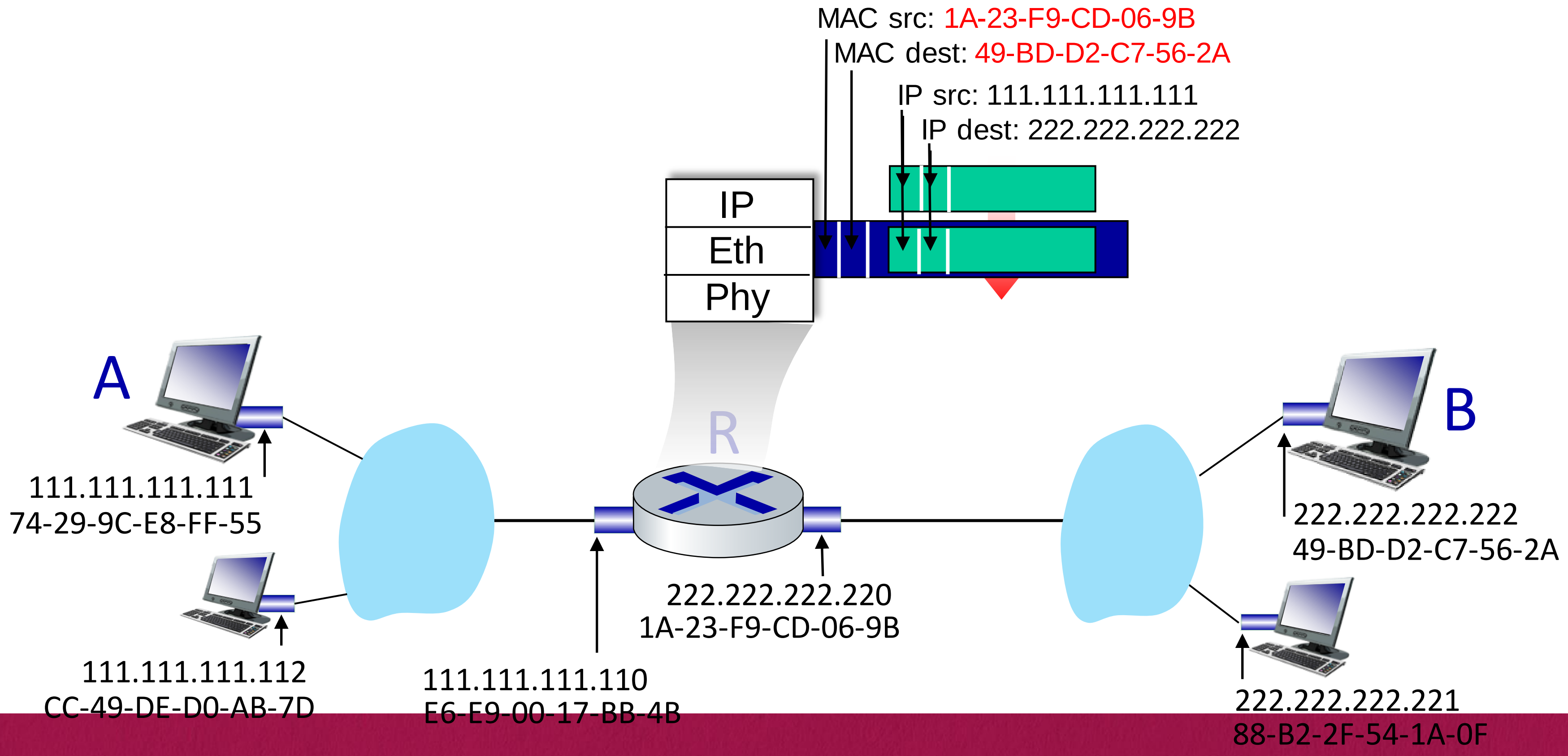
Routing to another subnet: addressing

- frame sent from A to R
- frame received at R, datagram removed, passed up to IP



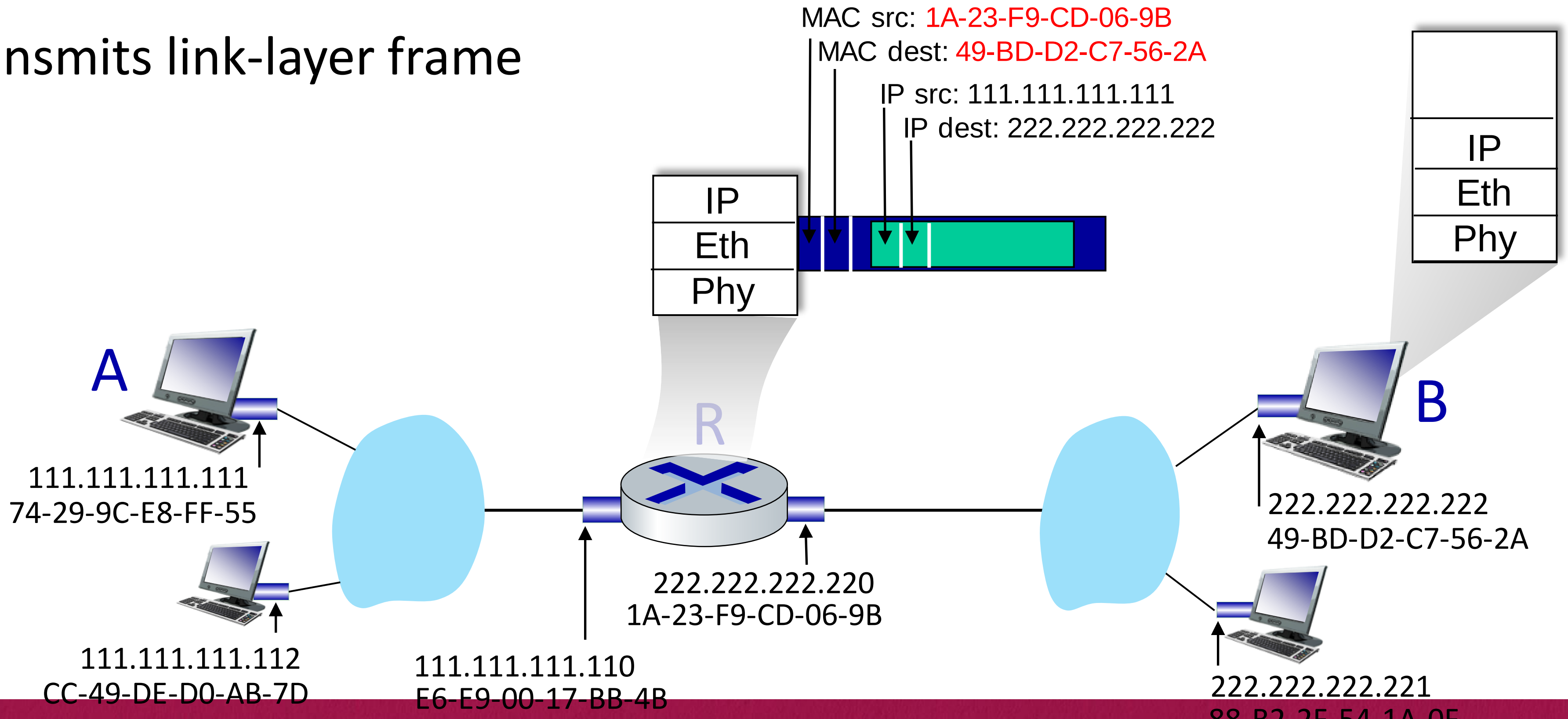
Routing to another subnet: addressing

- R determines outgoing interface, passes datagram with IP source A, destination B to link layer
- R creates link-layer frame containing A-to-B IP datagram. Frame destination address: B's MAC address



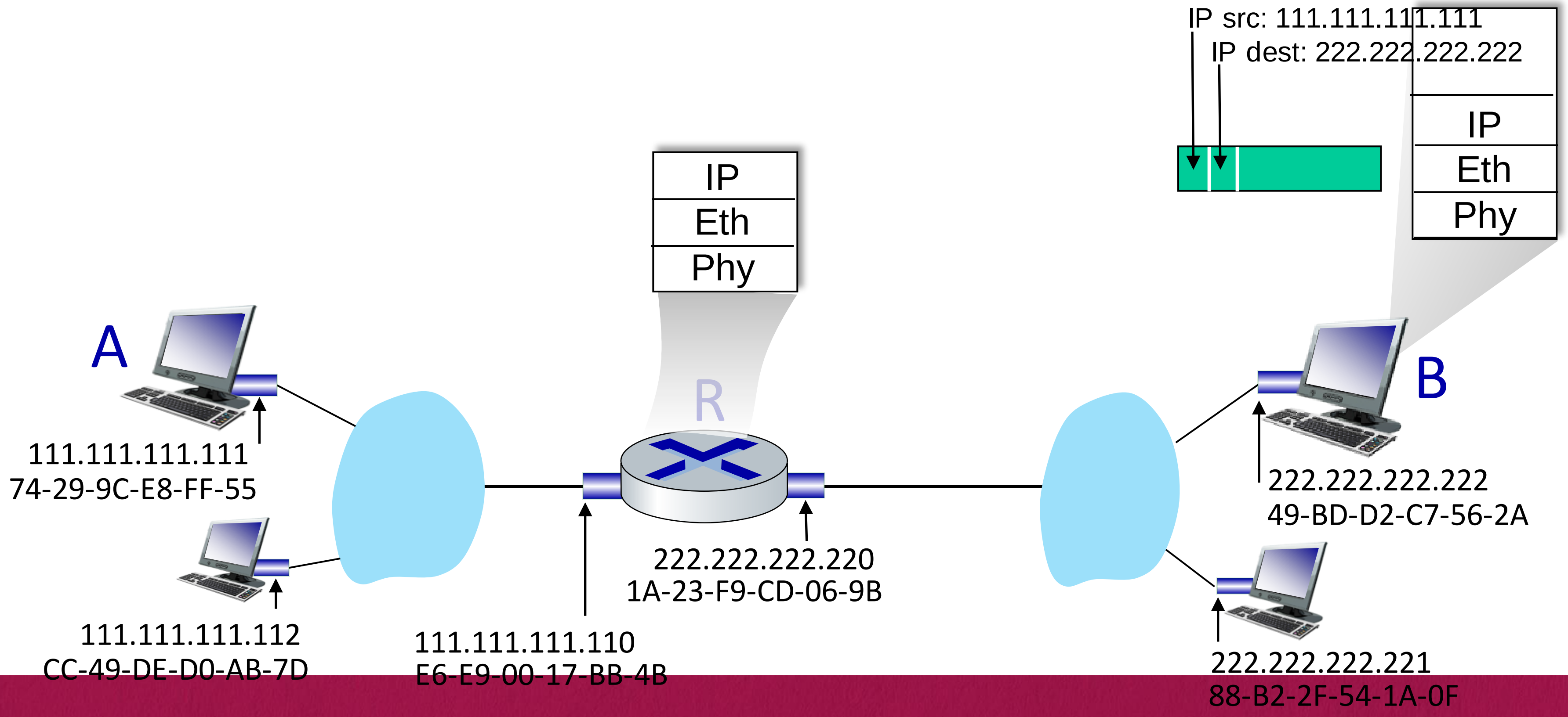
Routing to another subnet: addressing

- R determines outgoing interface, passes datagram with IP source A, destination B to link layer
- R creates link-layer frame containing A-to-B IP datagram. Frame destination address: B's MAC address
- transmits link-layer frame



Routing to another subnet: addressing

- B receives frame, extracts IP datagram destination B
- B passes datagram up protocol stack to IP



Objectives in Physical Layer Basics

- Examine the purpose of Physical Layer
- Understand physical layer characteristics & functions
  - Components
  - Encoding
  - Signaling
- Explore Bandwidth terms

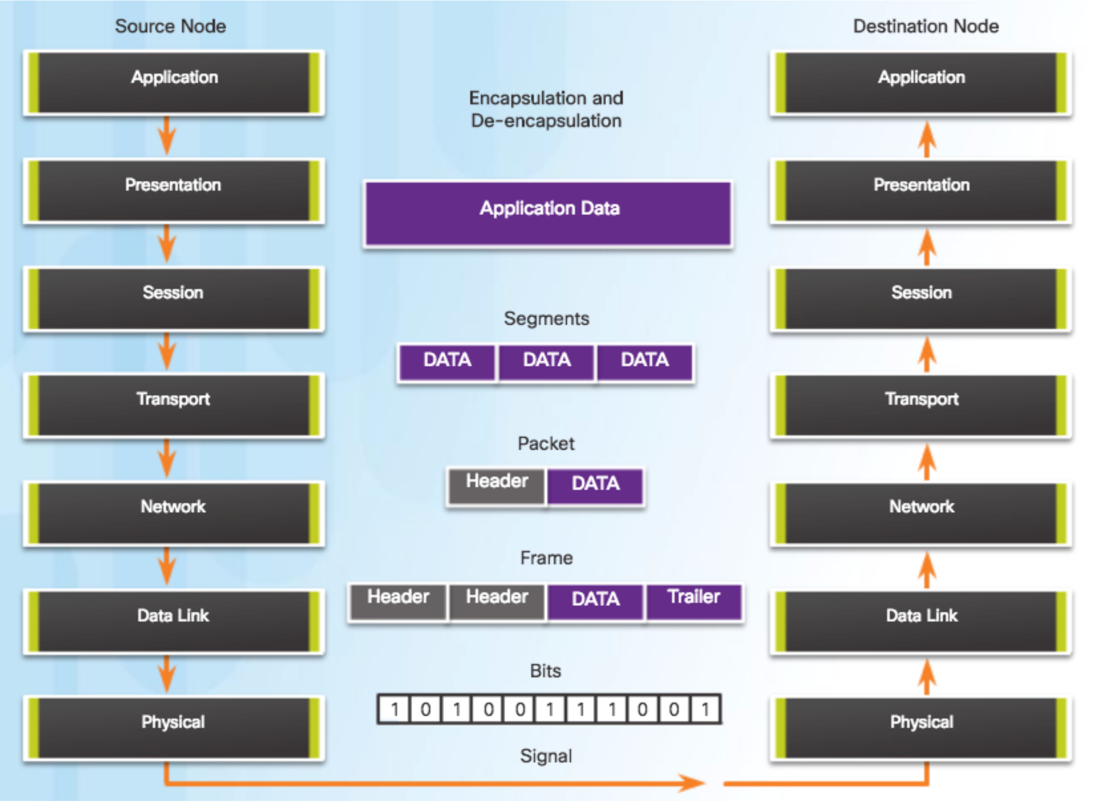
Purpose of Physical Layer

- Before any network communications can occur, a physical connection to a local network must be established.
- This connection could be wired or wireless, depending on the setup of the network.
- A Network Interface Card (NIC) connects a device to the network.
- Some devices may have just one NIC, while others may have multiple NICs (Wired and/or Wireless, for example).
- Not all physical connections offer the same level of performance.
- Only through this physical connection, actual data as bits are sent.

Ref: Chapter3, CCNA Introduction to Networks from Cisco Netacad

Physical Layer

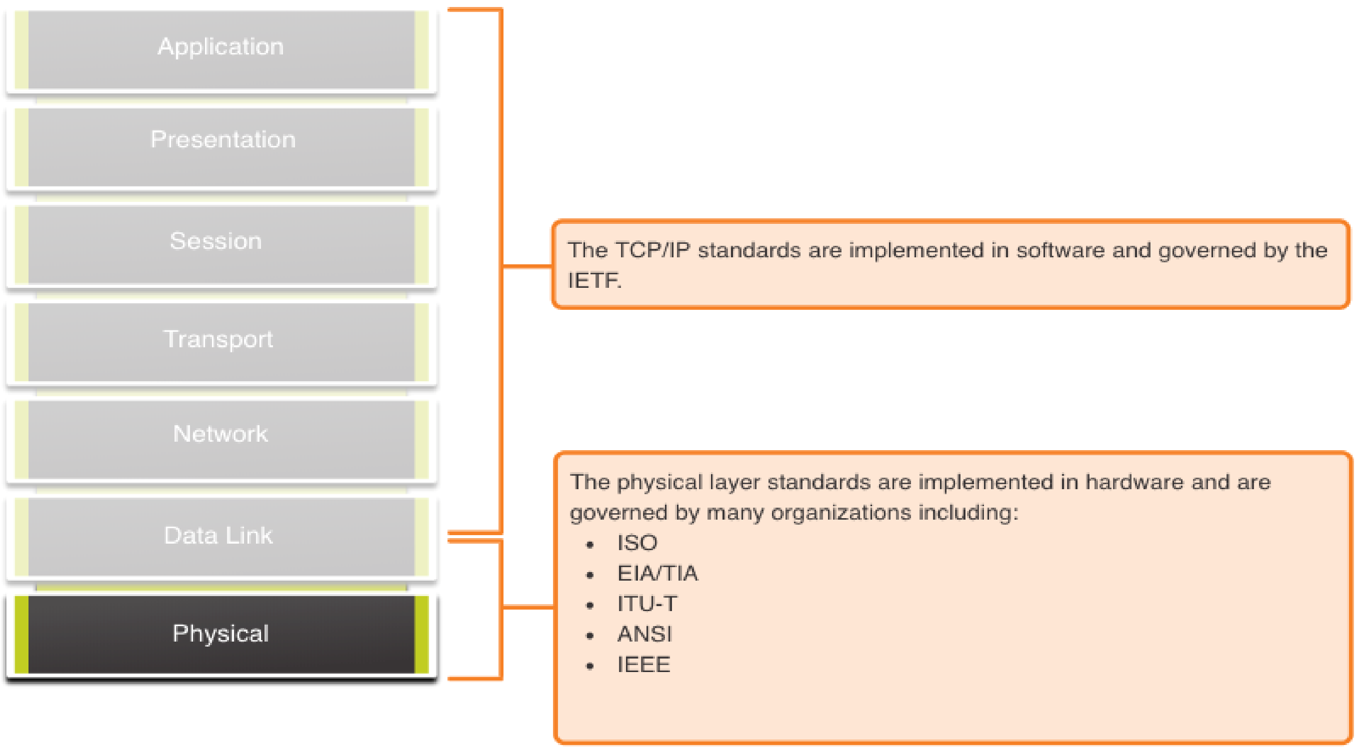
- Transports bits across the network media
- Accepts a complete frame from the Data Link Layer and encodes it as a series of signals that are transmitted to the local media
- This is the last step in the encapsulation process.
- The next device in the path to the destination receives the bits and re-encapsulates frame



Ref: CCNA Introduction to Networks from Cisco Netacad

Physical Layer Standards

- Implemented in hardware
- Govern by ISO, IEEE etc
- Address 3 functional areas
    - Physical Components
    - Encoding
    - Signaling



Physical Components

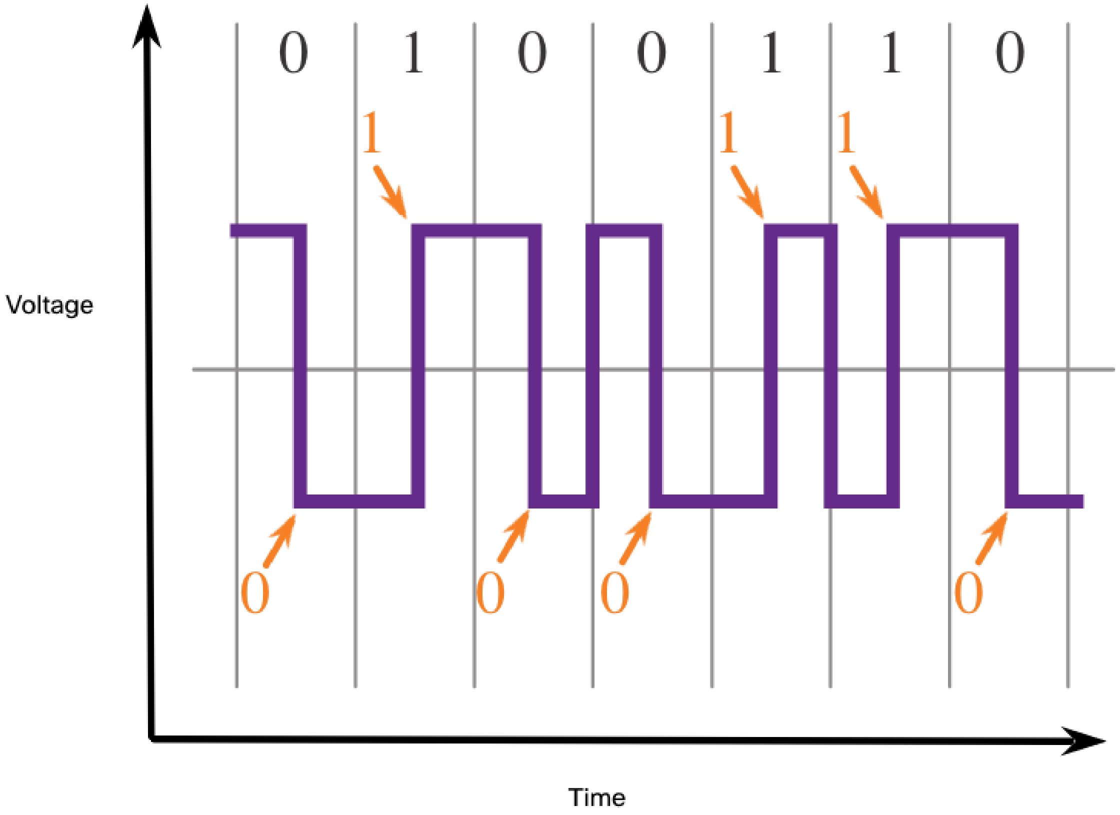
- Hardware devices, media and other connectors that transmit bits as signals

- Hardware components like NICs,
- interfaces and connectors, cable materials, and
- cable designs are all specified in standards associated with the physical layer.

Ref: CCNA Introduction to Networks from Cisco Netacad

Encoding

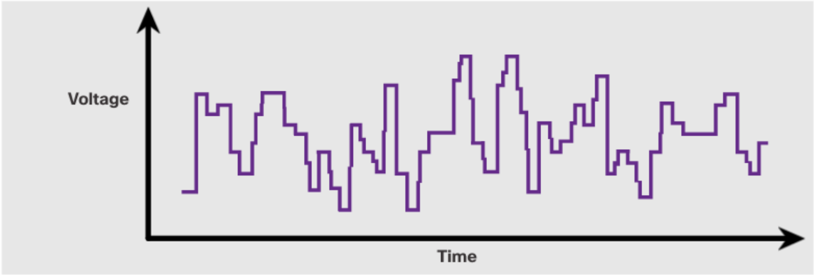
- Method of converting a stream of data bits into a predefined "code”.
- ‘coding’ provides predictable patterns that can be recognized by the next networking device.
- Examples of encoding methods include Manchester (shown), 4B/5B, 8B/10B etc
- Manchester – Transition occurs at the middle of each bit period



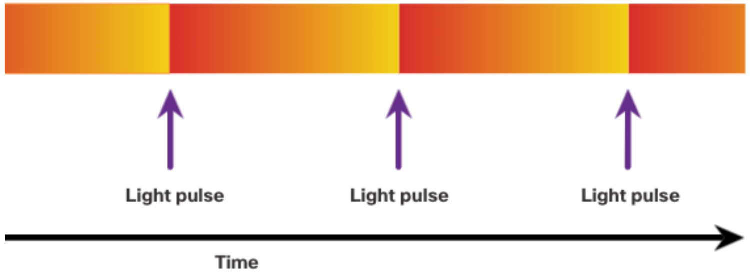
Ref: CCNA Introduction to Networks from Cisco Netacad

Signaling

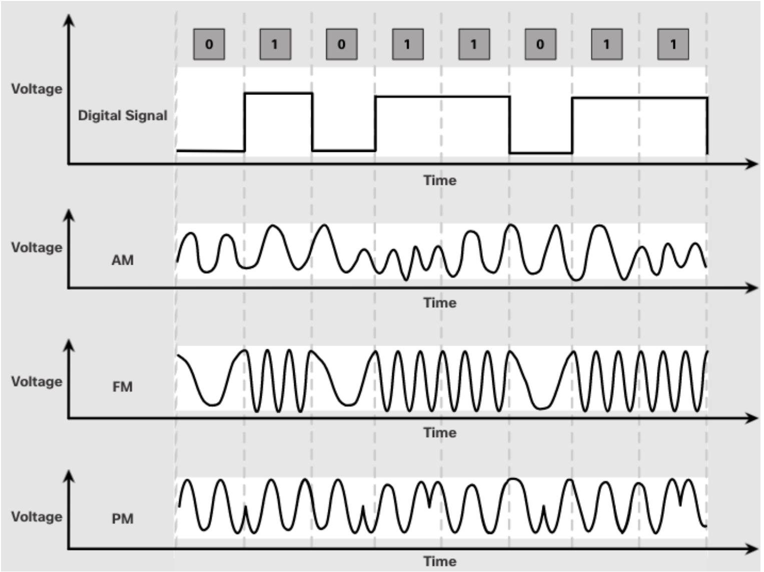
- Method of representing the bit “1” and “0” on the physical medium
- Signaling method varies based on the type of physical medium being used
- Three types of media:
    - Copper,
    - Fiber optic
    - Wireless



Electrical Signals Over Copper Cable



Light Pulses Over Fiber-Optic Cable



Microwave Signals Over Wireless

Ref: CCNA Introduction to Networks from Cisco

Physical Layer Characteristics

- Physical layer is responsible for speed of data transfer in controlling bits for transmission.
- Bandwidth is the capacity at which a medium can carry data.
- Measures the amount of data flow in bps
- Physical media properties, current technologies, and the laws of physics play a role in determining available bandwidth.

Unit of Bandwidth	Abbreviation	Equivalence
Bits per second	bps	1 bps = fundamental unit of bandwidth
Kilobits per second	Kbps	1 Kbps = 1,000 bps = 10^3 bps
Megabits per second	Mbps	1 Mbps = 1,000,000 bps = 10^6 bps
Gigabits per second	Gbps	1 Gbps – 1,000,000,000 bps = 10^9 bps
Terabits per second	Tbps	1 Tbps = 1,000,000,000,000 bps = 10^{12} bps

Ref: CCNA Introduction to Networks from Cisco Netacad

Bandwidth terminology

- Terms used to measure the quality of bandwidth include:
  - Latency, Throughput & Goodput

- Latency = Amount of time, including delays, for the data to travel from one device to the another
- Throughput = The measure of the transfer of bits across the media over a given period

- Goodput = The measure of usable data transferred over a given period
- *Goodput = Throughput - traffic overhead*

Summary

- Purpose of Physical Layer – bits transferred in hardware
- Physical layer characteristics
  - Components
  - Encoding
  - Signaling
  - Bandwidth

Namah Shivaya