University of Pittsburgh

ECE 1150: Computer Networks

Local Area Networks

Mai Abdelhakim, PhD

ECE Department

Swanson School of Engineering

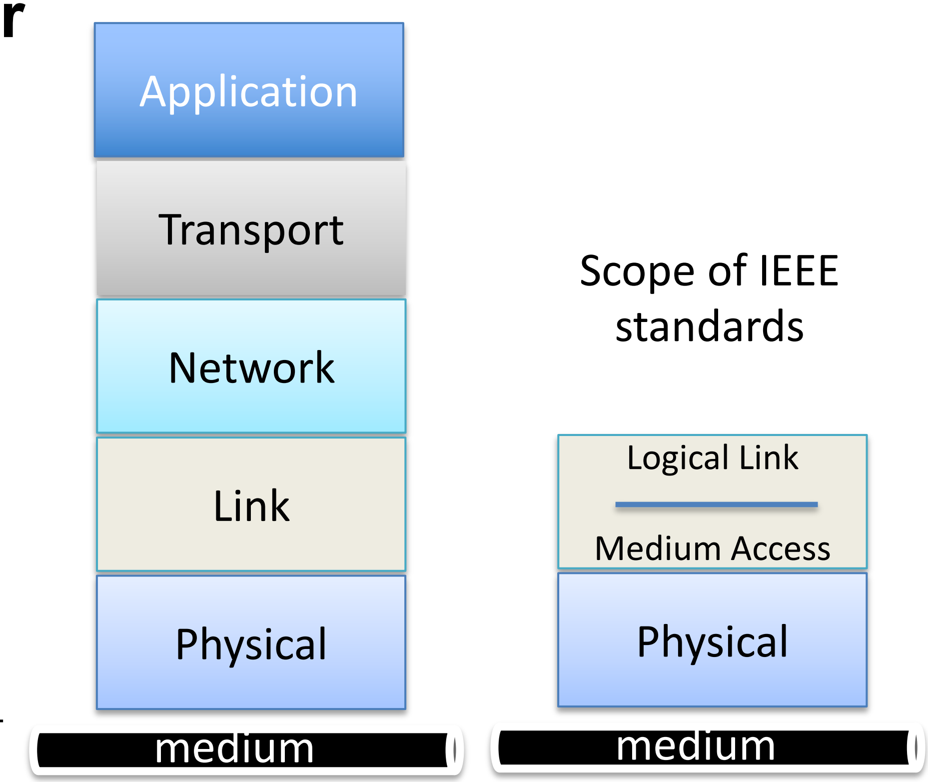
University of Pittsburgh

Objectives of This Unit

- Addressing at the Data Link Layer – MAC Address
- Framing
- Wired LAN – Ethernet
- Concept of virtual LANs
- Wireless LAN – Wi-Fi

Layer 2 Technology

- **Local Area Networks (LANs) considered Layer 2 technology**
- Dominant Technologies
  - Wired LAN: Ethernet, IEEE 802.3
  - Wireless LAN: Wi-Fi (also called Wireless Ethernet), IEEE 802.11
- Standardized by the **IEEE**

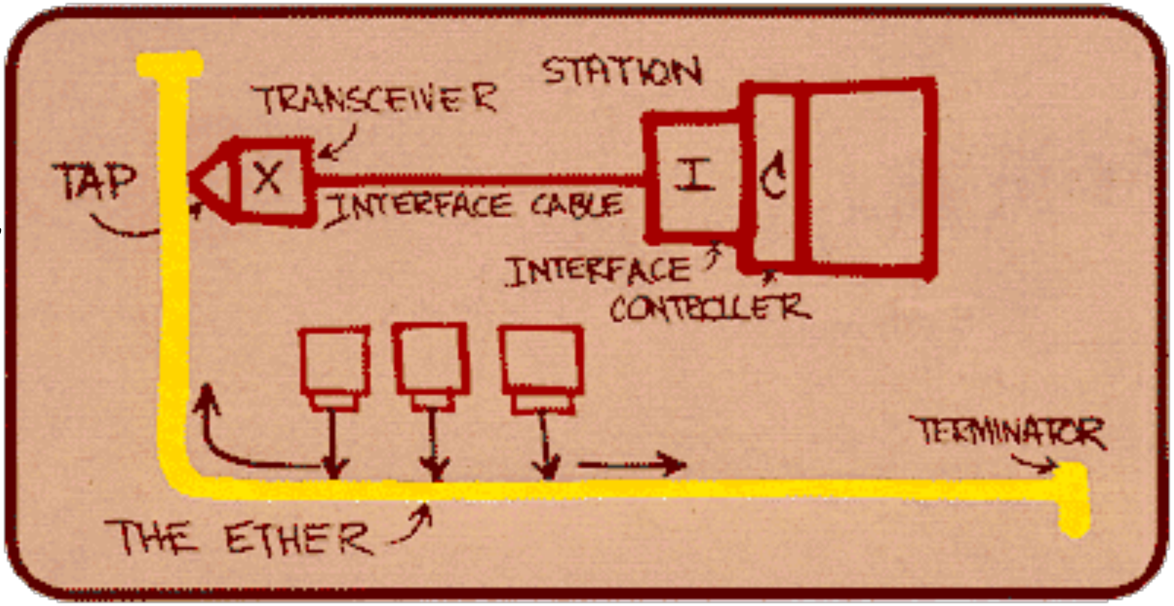


Wired LAN – Ethernet (IEEE 802.3)

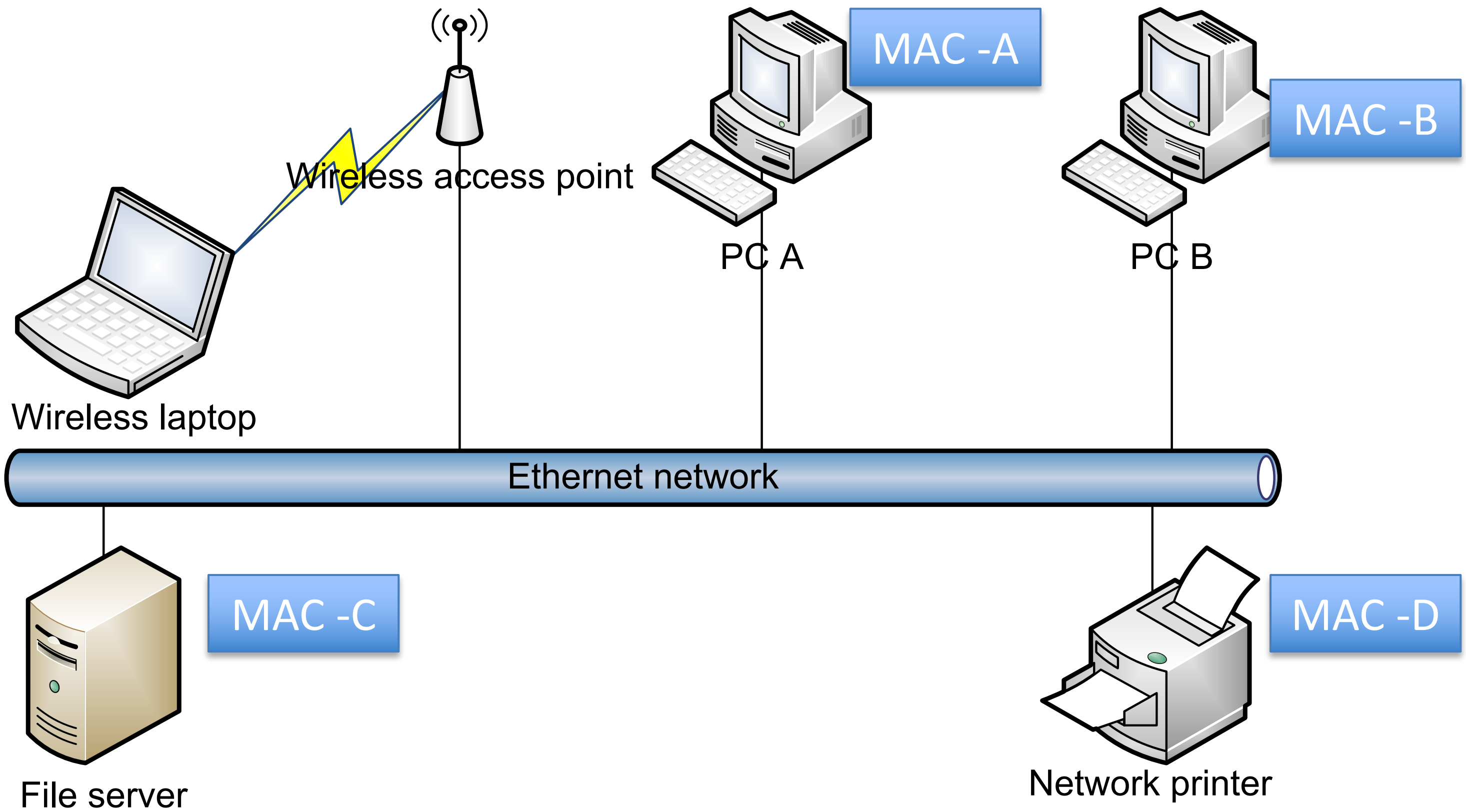
- IEEE 802.3 standards
  - Patented 1977
  - Standardized by IEEE 802.3 committee in 1983
    - Rates: 10Mbps, 100 Mbps, {1, 10, 100} Gbps options

Early diagram of Ethernet,

Cable called Ether.
Patented in 1977
Robert Metcalfe



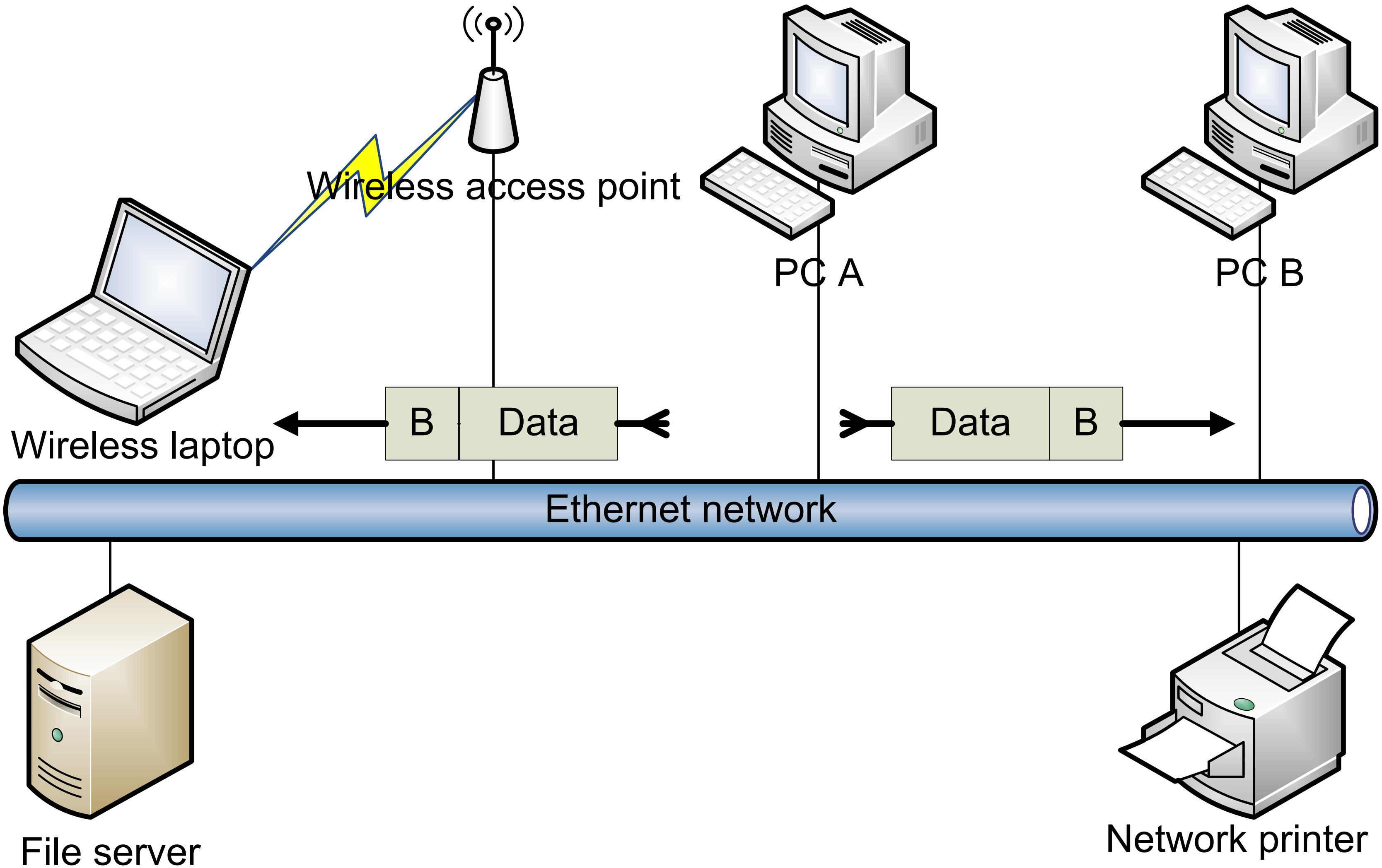
Classical Ethernet



- Traditional Ethernet: stations are connected to "bus'/wire (hub-based Ethernet)
  - Broadcast to all stations on the bus
- Each station is assigned a **unique address**

Packet on the Shared Medium

Packets must be addressed to a particular device



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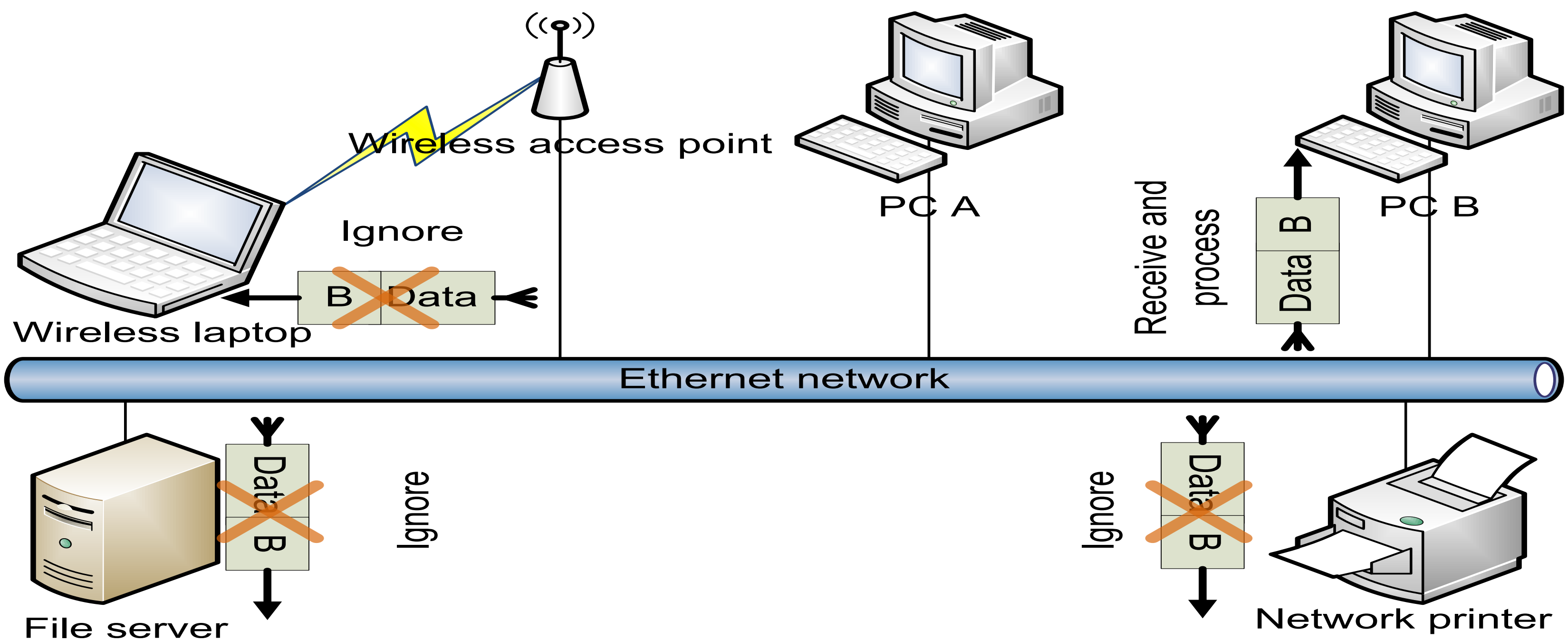
Broadcast in Ethernet

- Signal is transmitted to all stations connected to bus
  - Traditional Ethernet operation is based on broadcast
  - Signal is transmitted to all stations connected to the wire
  - All computers on the network get the packet
  - But only intended destination opens it, others ignore



Addressing at Data Link Layer – MAC Addresses

- Address used in data link layer is: **MAC address**
  - Called a MAC address as it is associated with data link layer which is responsible for Medium Access Control
  - MAC Address is also called **Ethernet address, Physical address or Extended Unique Identifier (EUI-48)**.
- **MAC address is 48 bits in length**
  - **All 1's** address (48 One's) is pre-defined to be the **broadcast** address on the LAN

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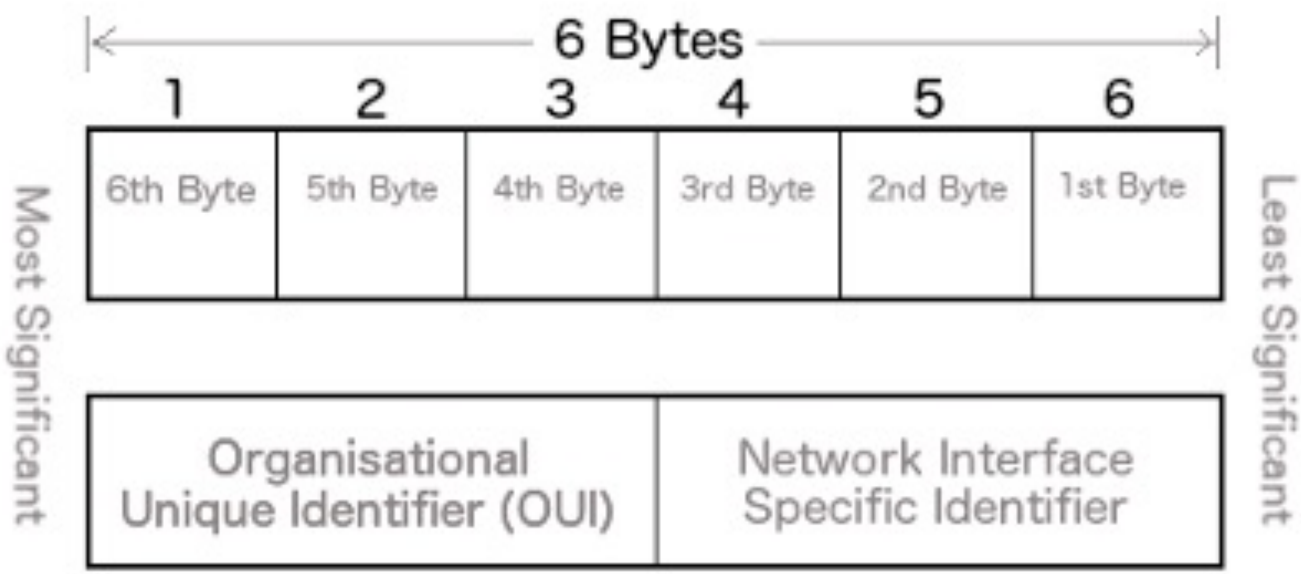
MAC Address

24 bits: Organizationally Unique Identifies (OUI) assigned by the IEEE

No two manufacturer have the same OUI.

http://standards-oui.ieee.org/oui.txt

24 bits: assigned by the manufacturer for each network interface card (NIC)



MAC Address Representation

- Hexadecimal notation
  - Address broken up into 12 blocks, each is 4-bits (12x4=48)
  - Each 4-bit block is represented as a hexadecimal digit 0-f

Bits	Hex	Bits	Hex	Bits	Hex	Bits	Hex
0000	0	0100	4	1000	8	1100	C
0001	1	0101	5	1001	9	1101	D
0010	2	0110	6	1010	A	1110	E
0011	3	0111	7	1011	B	1111	F

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MAC Address Representation

- Example

Note: Globally unique

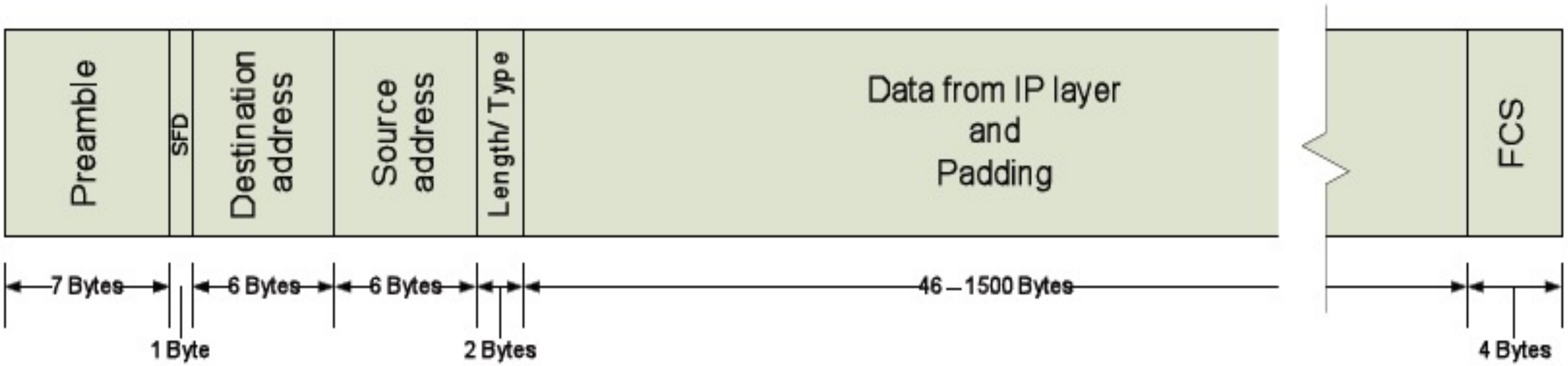
0000	0000	0001	0101	1100	0101	0101	0111	0001	1101	0001	1010
0	0	1	5	c	5	5	7	1	d	1	a

```
C:\Windows\system32\cmd.exe
Ethernet adapter Local Area Connection:

   Connection-specific DNS Suffix  . : home
   Description . . . . . . . . . . . : Broadcom NetXtreme 57xx Gigabit Controlle
r
   Physical Address. . . . . . . . . : 00-15-C5-57-1D-1A
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   Link-local IPv6 Address . . . . . : fe80::d848:beb0:fb44:4171%8(Preferred)
   IPv4 Address. . . . . . . . . . . : 192.168.1.5(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Lease Obtained. . . . . . . . . . : Thursday, April 08, 2010 9:53:44 AM
   Lease Expires . . . . . . . . . . : Tuesday, April 13, 2010 9:53:44 PM
   Default Gateway . . . . . . . . . : 192.168.1.1
   DHCP Server . . . . . . . . . . . : 192.168.1.1
   DHCPv6 IAID . . . . . . . . . . . : 201332875
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-0D-E4-D5-DA-00-18-8B-C9-24-6B

   DNS Servers . . . . . . . . . . . : 192.168.1.1
   NetBIOS over Tcpip. . . . . . . . : Enabled
```

View address:
Windows: **ipconfig**
Apple: **ifconfig**
(check en0, en1..)

Ethernet Frame Structure

- Frame includes
  - source/destination MAC addresses (6 bytes each)
  - FCS: Frame check sequence (FCS) has the CRC bits
  - Preamble & SFD– alert receiver about packet arrival
  - frame length – inform receiver about packet end



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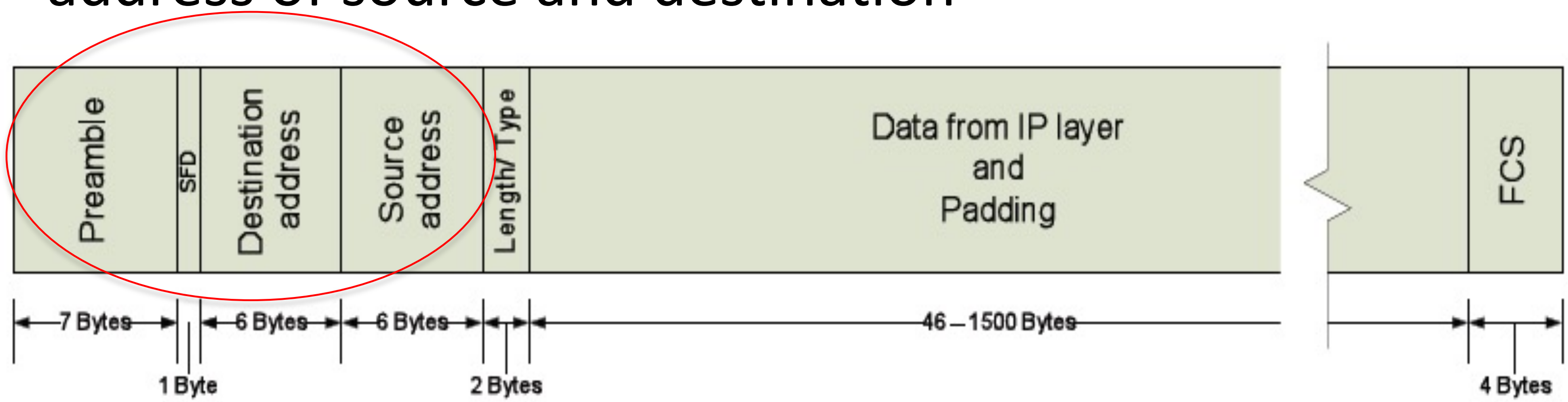
Ethernet Frame

- Preamble: Allows receiver to differentiate actual packet from noise, and synchronize with sender

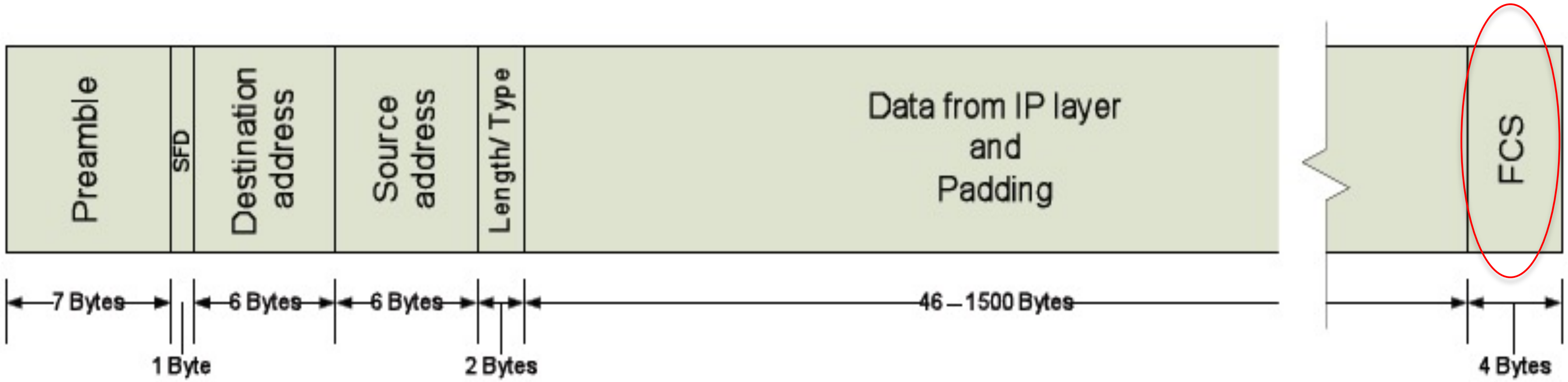
  10101010 10101010 10101010 10101010 10101010 10101010 10101010

  - Encoded by the physical layer using Manchester encoding
- Start Frame Delimiter (SFD): Indicates start of frame
  - 10101011
- Source and Destination Addresses: contain the MAC address of source and destination



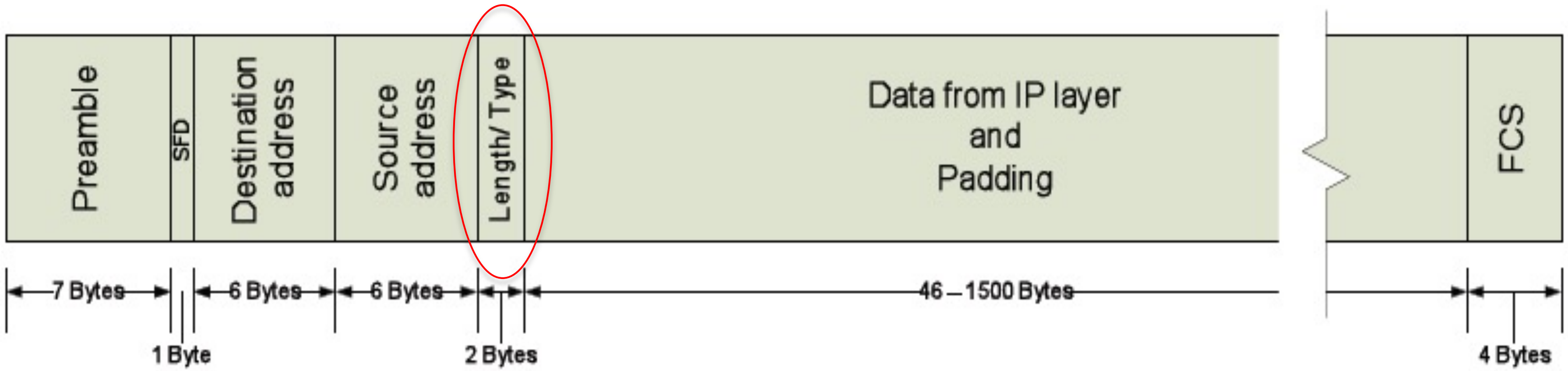
Ethernet Frame

- Data: Typically IP packet
- Frame check sequence (FCS)
  – 32 bit CRC value
  – Generator polynomial (divisor) specified as
    - CRC-32: 10000010 01100000 10001110 110110111



Ethernet Frame

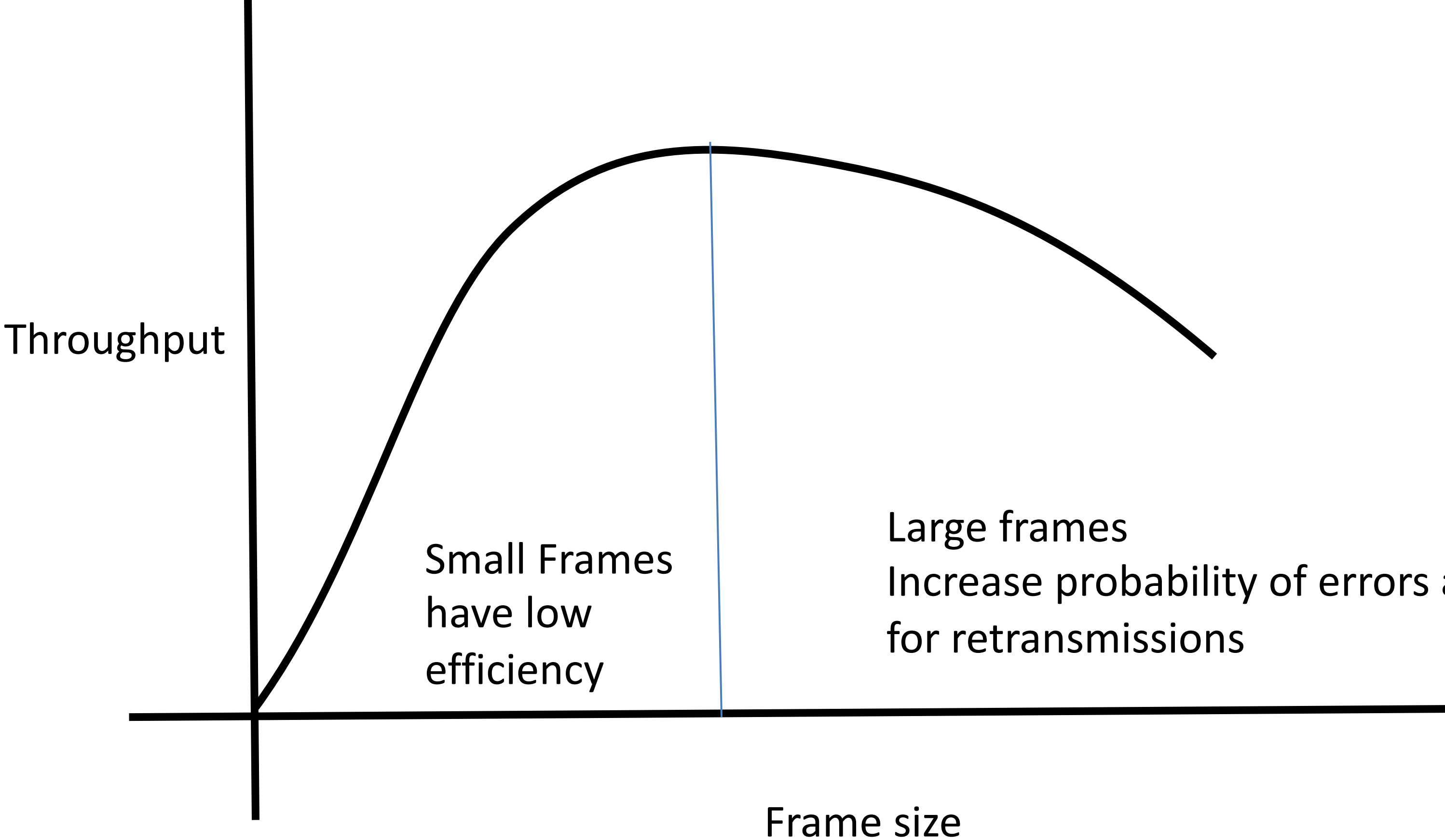
- Length
  - If less than 1,518 (max allowed packet length after the SFD)
    - Receiver knows how many bytes it gets after the SFD, then takes the last 4 bytes and checks the CRC
  - If greater than or equal to 1,518
    - Indicates type of packet (often used to indicate virtual LAN frame)



Required frame size large vs small?

Small frames, header and trailer introduces large overhead => low throughput

Large frames, probability of error in the frame can be large, packets may need to be retransmitted => low throughput



Medium Access Protocol in Ethernet IEEE 802.3: CSMA/CD with Exponential Backoff

1. Adapter receives data from network layer & creates frame

2. If adapter **senses** channel idle, it starts to transmit frame.

   If it senses channel **busy**,it **waits**

3. If adapter transmits entire frame without detecting another transmission, the adapter is done with frame !

4. If adapter detects another transmission while transmitting, it **aborts transmission**

5. After aborting, adapter enters **exponential backoff:** <u>**Waits for a random time**</u>, then sense the medium again to attempt retransmission

After the mth collision, adapter chooses a K at random from $\{0,1,2,\ldots,2^m-1\}$.

Adapter waits K x 512 bit times and returns to **Step 2**

max m = 10

Ethernet CSMA/CD Algorithm with Exponential Backoff

- Binary Exponential Backoff
  - If a frame experiences m collisions, a node choose value k at random from the set: **$\{0, 1, 2, 3, \ldots 2^m - 1\}$**
    - That means that as frame experience more collisions the larger the interval from which K is chosen
  - The actual time is then: K . 512 bit times (K times the time needed to send 512 bits on Ethernet)
    - This is the slot time of the classical ethernet, designed to be larger than round trip propagation delay
    - For 10Mbps Ethernet: 1 bit duration is **0.1 µsec,**
      - Backoff slot =512 bits times = 512 x 0.1=51.2 µsec
        - » Greater than worst case round trip delay
        - » 512 is min frame size (without preamble)

Example: CSMA/CD in Ethernet

- After the first collision (m=1), a node randomly choose k from set {0,1}
  - If it choose k=0, then it immediately senses the medium again and transmits if it is idle
  - If it chooses k=1, then it waits 512 bit times then sense the channel
- If second collision occurs (m=2) to the frame, it chooses K from the set : { 0, 1, 2, 3}
  - Since $2^m - 1 = 3$
- If 10 collisions (m=10) happen, then device randomly choose k from set: {0,1,..1023}
- Note that The **size of the set grows exponentially with collisions, hence the name exponential backoff**!

Question

- What is the average number of backoff slots after M collisions?

Tophat

Q_Backoff

What is the average number of backoff slots after 2 collisions (m=2)?

A	1
B	1.5
C	2
D	none of the above

Wired LAN – Ethernet (IEEE 802.3) Physical Layer

- Wide variety of physical media and signaling supported
- Signaling: Classic Ethernet used Manchester signaling
- Cabling: coaxial cable, later on UTP, recently fiber

Wired LAN – Ethernet (IEEE 802.3) Physical Layer

Name	Type	Maximum Data Rate	Used by
Category 3	UTP	10 Mbps	10BASE-T
Category 5	UTP/STP	100 Mbps	100BASE-T
Category 5e	UTP/STP	1 Gbps	1000BASE-T
Category 6/6a	UTP/STP	10Gbps	10GBASE-T
OM1 (62.5/125 µm)	Fiber	1-10 Gbps*	1000BASE-SX
OM3 (50/125 µm)	Fiber	10-100 Gbps*	10GBASE-SR

* Speed depends on circuit length

SR multimode fiber
S: short range multimode
OM: optical mode
R/W type of fiber, X type of coding

Ethernet - Hubs vs. switches

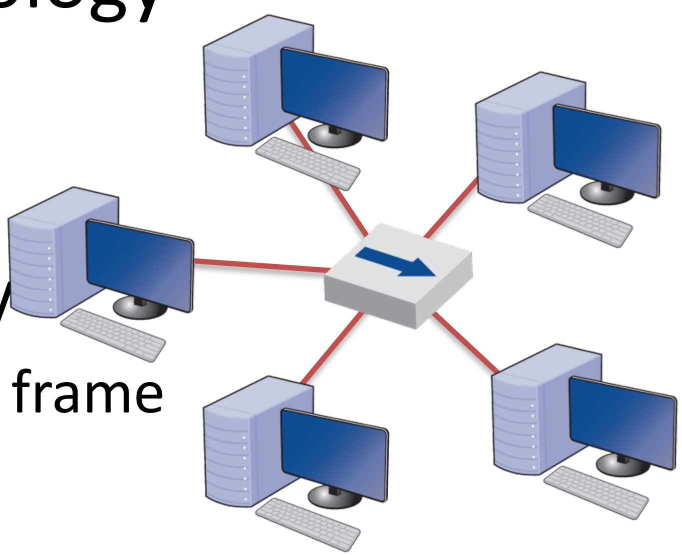
- Hubs vs. switches
  - Hubs send data out to all computers
    - Old technology, but useful for network diagnostics

- Switches try to send data to the intended destination only
    - This speeds up the network, at extremely low cost

– Topology?

Wired LAN – Ethernet (IEEE 802.3) Network Topology

- Topology: Basic geographic layout of a network
- Types
  - **Logical**: How the network works conceptually
  - **Physical**: How the network is physically installed
- Ethernet: Physical star topology
  - Hub: Logical bus topology
    - Frame received by all devices
  - Switch: Logical star topology
    - Only destination receives the frame



Ethernet Switch - Self Learning

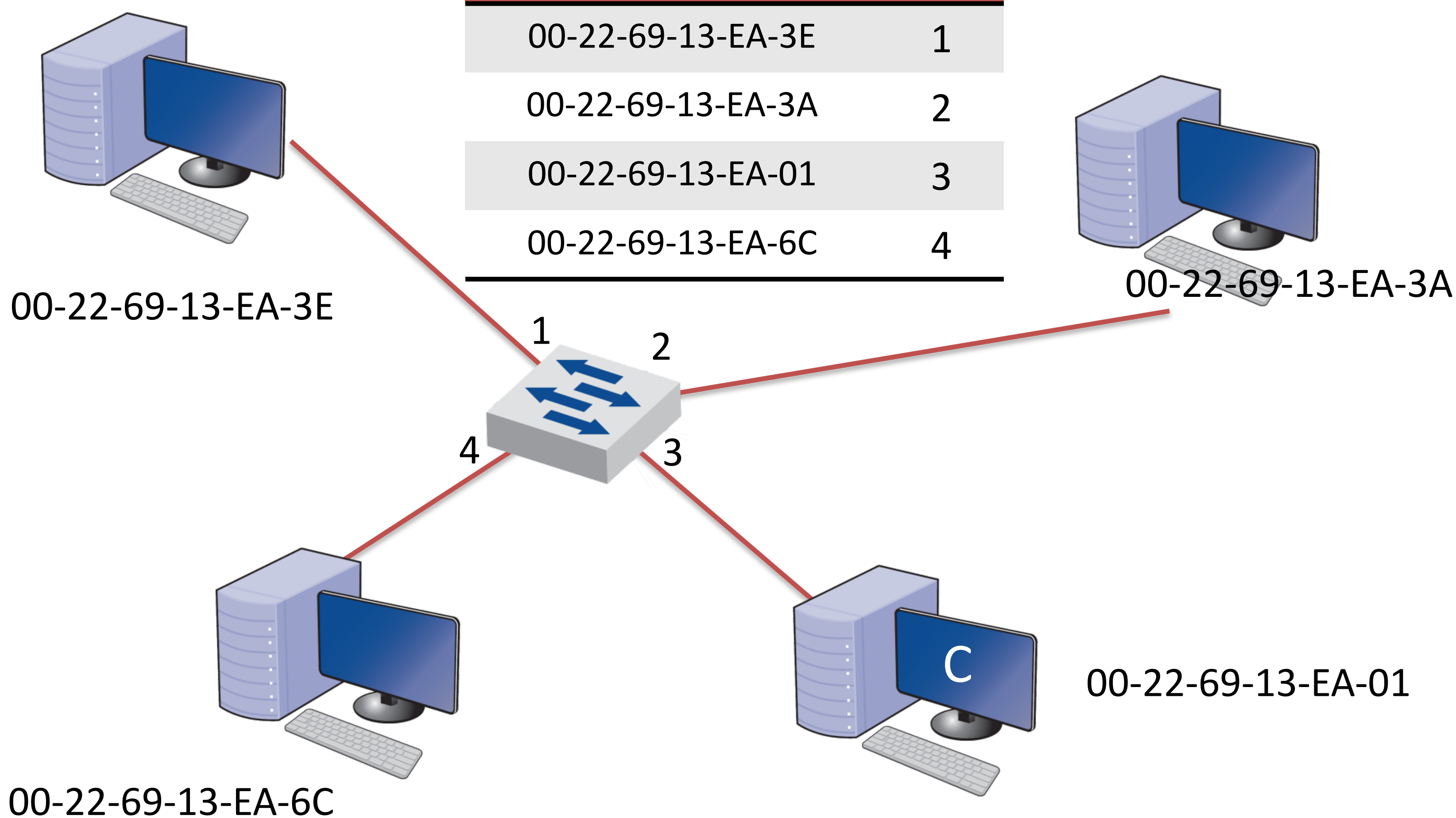
- Switch operation
  - Switch creates **switch table**
    - Also called forwarding table
    - The table is initially empty
  - Switches <u>learn</u> which **MAC** address associated with which **interface** (physical **port**) by <u>reading the source</u> address in a frame

Ethernet – Switch Table

- Switch-based Ethernet

Switch Forwarding Table

MAC	Port
00-22-69-13-EA-3E	1
00-22-69-13-EA-3A	2
00-22-69-13-EA-01	3
00-22-69-13-EA-6C	4

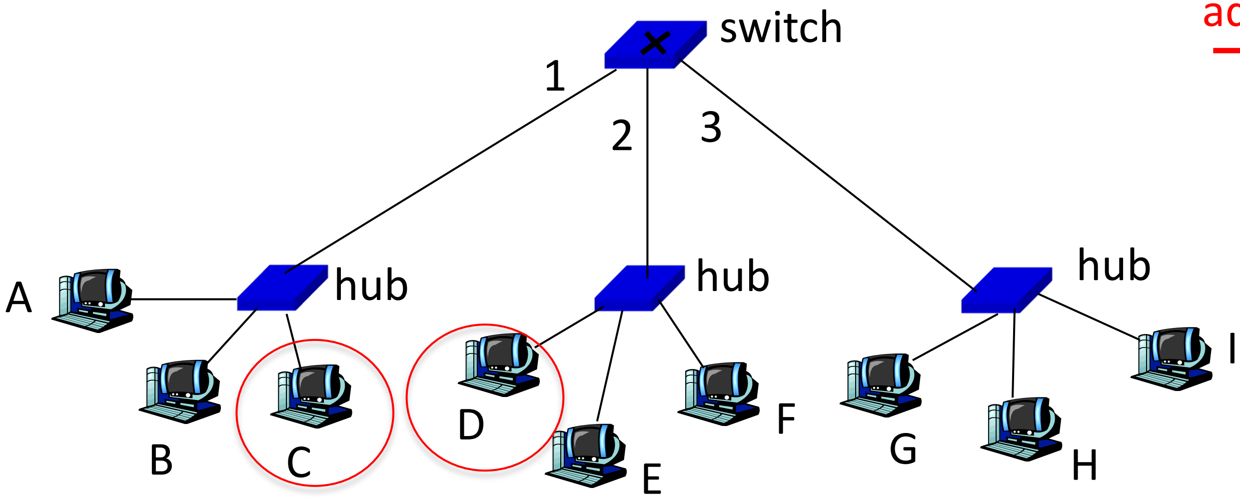


Switch

- When a new frame is received at the switch:
  - Saves the **source MAC address** and corresponding interface in table (if not there)
  - The switch reads the destination MAC address
  - Looks up destination address in the switch table
    - If found, forwards frame to the corresponding interface
    - If not found, broadcasts frame to all devices (like a hub)
- Entry of tables are updated

Switch Example

- Suppose C sends frame to D
- Switch receives frame from from C
  - Add to switch table that C is on interface 1
  - Because D is not in table, switch forwards frame into interfaces 2 and 3
- Frame received by D

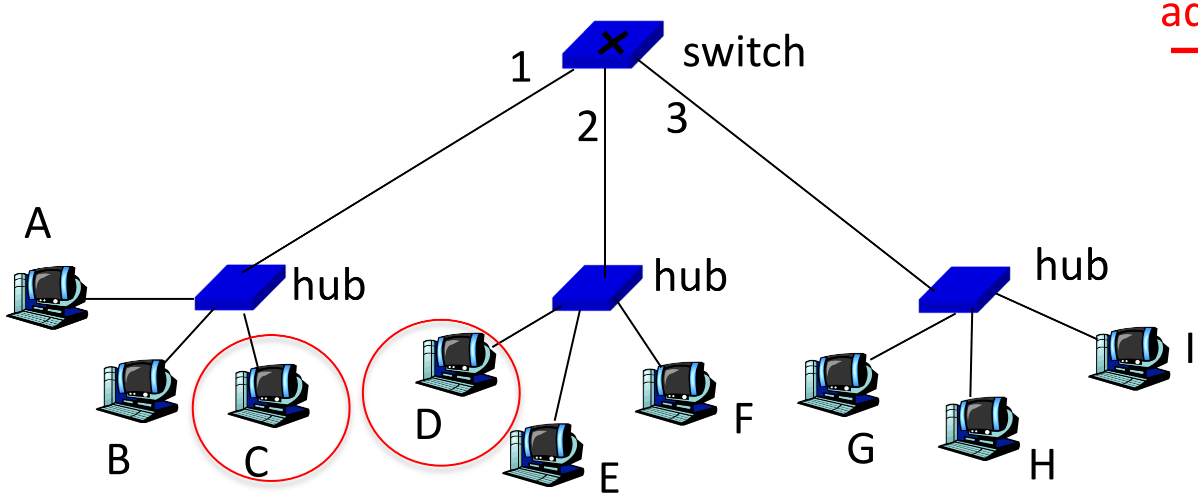


Switch table before C send data to D

address	interface
A	1
B	1
E	2
G	3

Switch Example (Continued)

- Suppose D replies back with frame to C.
- Switch receives frame from from D
  - Add to switch table that D is on interface 2
  - Because C is in table, switch forwards frame only to interface 1
- Frame received by C



address	interface
A	1
B	1
E	2
G	3
C	1

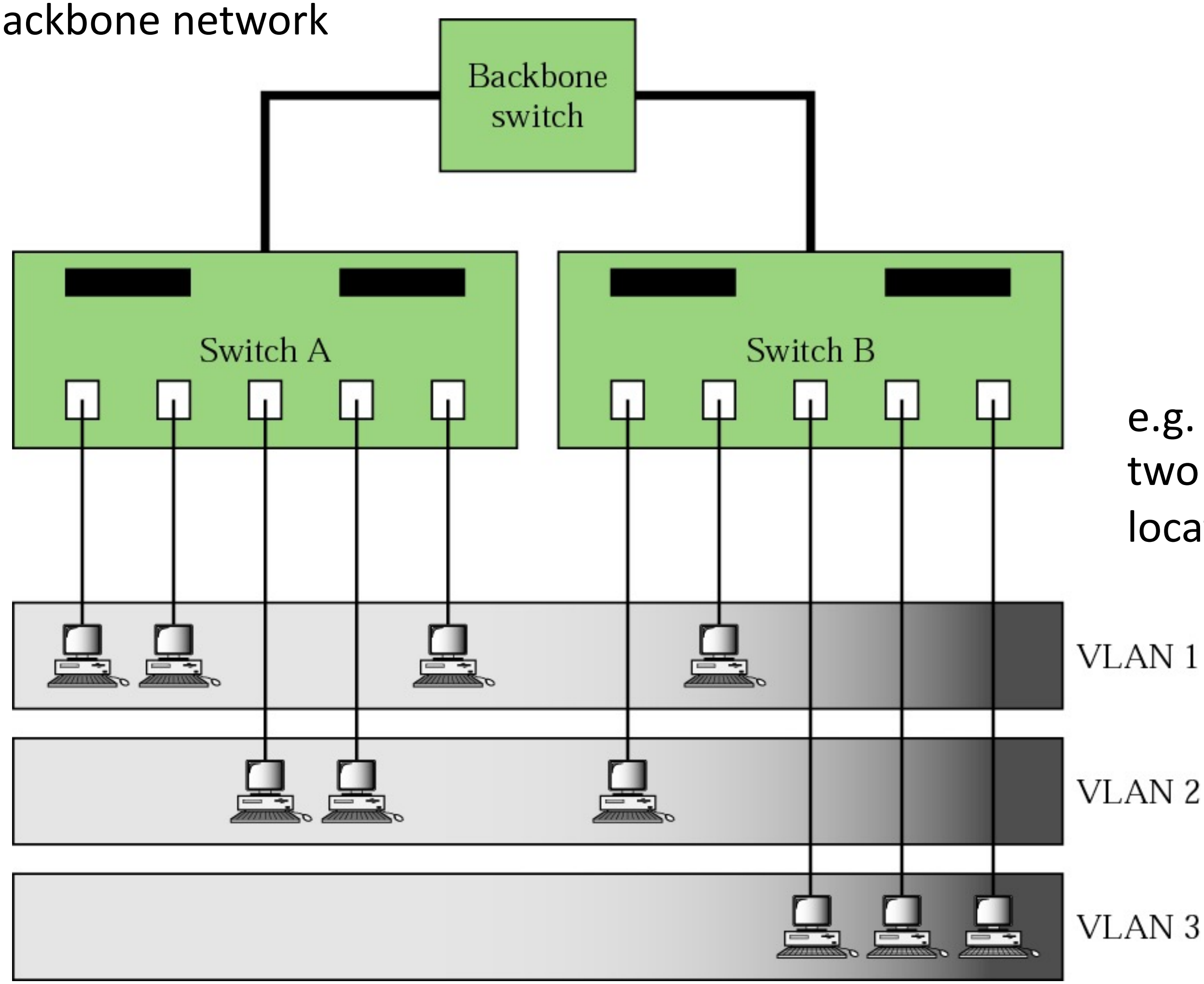
Virtual LANs (VLANs)

- May be located on different physical LAN segments
- LAN's based on LOGICAL instead of PHYSCIAL connections
- Configured by **software**, not hardware
- Broadcast goes to members of the VLAN

Preamble	Dest. Address	Source Address	VLAN Tag	Type	Body	FCS

Extended VLANs

Can be used in backbone network



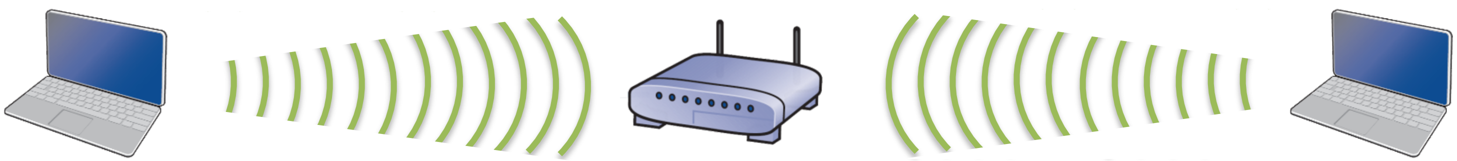
e.g. 3 dept. in two office locations

IEEE 802.11: Wireless Ethernet – Wi-Fi

- Commonly called Wi-Fi
- A family of standards developed by IEEE formally called **IEEE 802.11**
- Uses radio frequencies to transmit signals **through the air** (instead of cables)
- Wi-Fi has many benefits
  - Provides network connections where **cabling** is impossible or undesirable
  - Allows device and user **mobility**

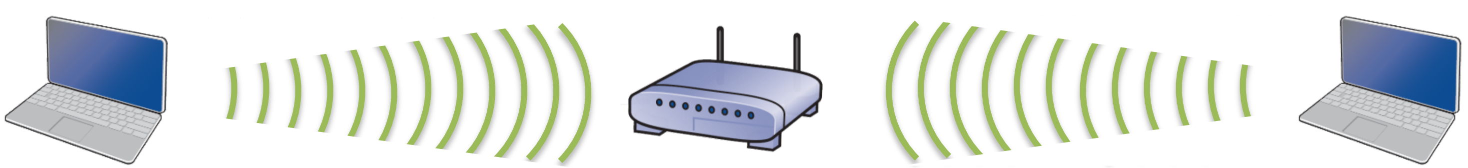
IEEE 802.11: Wireless LAN

- Components
  - Wirelesscess points (APs)
    - AP sends **periodic beacon signals**
  - Wireless NICs
- Topology: Physical **star**
- Common frequencies
  - 2.4 GHz range
  - 5 GHz range



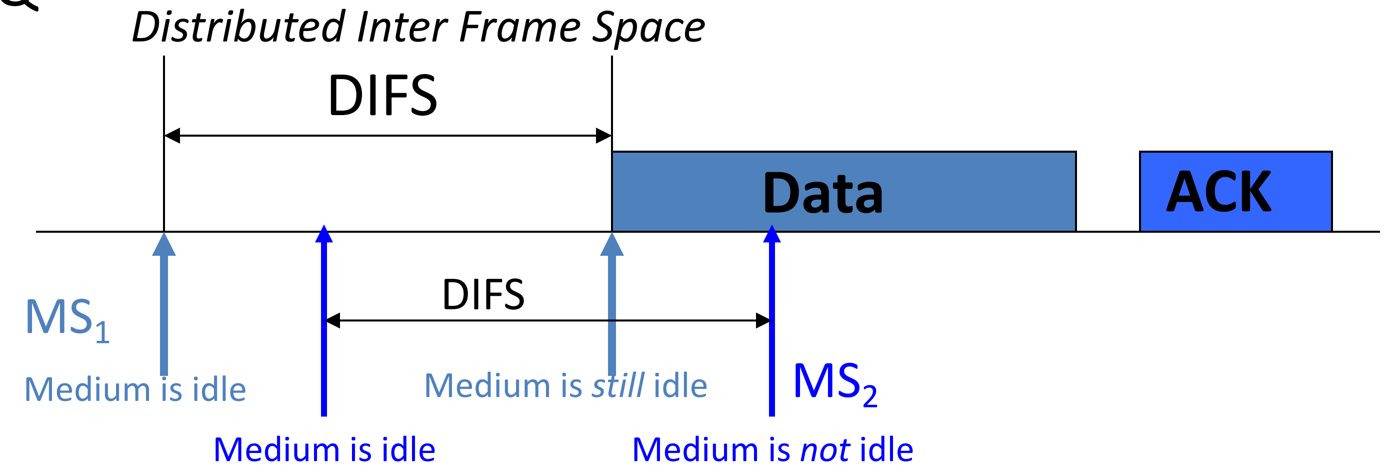
IEEE 802.11: Medium Access Control

- Uses **CSMA/CA** (CSMA with **collision avoidance**)
  - Collision avoidance is similar to CSMA/CD in Ethernet
  - More challenging in wireless
  - **Hidden node problem**



CSMA/CA – DCF

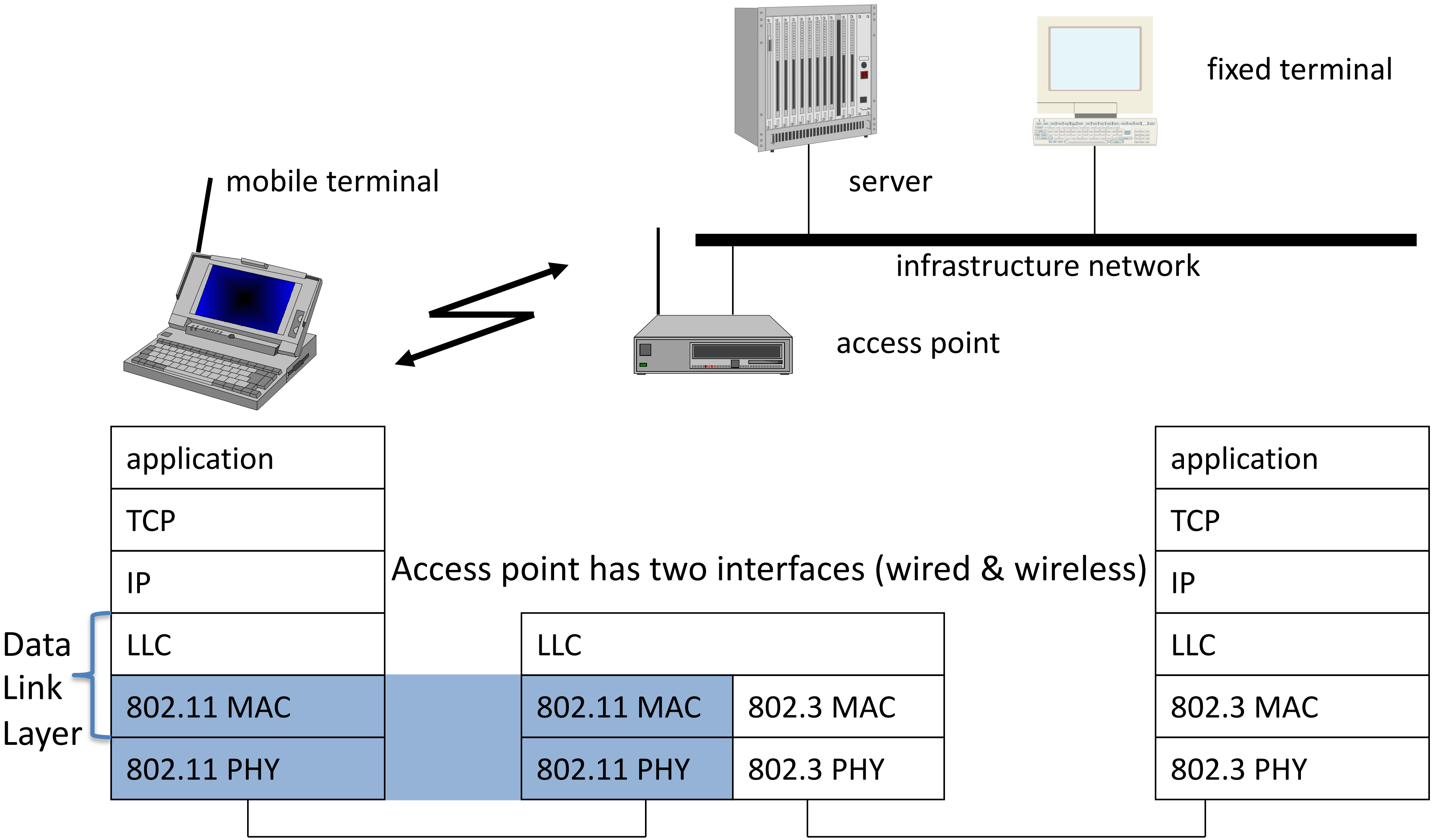
- Distributed Coordination Function (DCF)
  - Wait for a period of time (called DIFS), transmit if channel is still idle, then wait for ACK .. Similar to stop-and-wait ARQ



CSMA/CA – PCF

- Point coordination function (PCF)
  - Device wishing to transmit first sends **Request to Send (RTS)** to the AP, specifying the duration of the requested transmission
  - If no other device is transmitting, the AP replies with **Clear to Send (CTS)** specifying the **duration** …
    - All devices hear the CTS and will not transmit.

IEEE 802.11 & IEEE 802.3



LLC: Logical Link Control (get Network layer data)

Key Takeaways

- Addressing and framing at Data Link Layer
    - MAC address is used in LANs
    - CRC used for error detection in Ethernet and Wi-Fi
    - Data link frame includes MAC addresses, CRC and other information (length, start of the frame…) along with data from network layer.
- Wired Ethernet (IEEE 802.3) is based on CSMA/CD with exponential backoff to minimize collisions
- Switch vs Hubs operation
- Wireless LAN – Wi-Fi uses CSMA with collision avoidance (CSMA/CA)
- VLANs divides devices based on logical function instead of physical connections