Lecture 8 - addressing, switching, and ARP

Acronyms

Acronym	Meaning
ARP	Address Resolution Protocol
BIA	Burned-In Address
CAM	Content-Addressable Memory
CIDR	Classless Inter-Domain Routing
CRC	Cyclic Redundancy Check
FCS	Frame Check Sequence
IFG	Interframe Gap
IP	Internet Protocol

Acronym	Meaning
LAN	Local Area Network
MAC	Medium Access Control
MLT	Multi-Level Transmission
MTU	Maximum Transmission Unit
NDP	Neighbor Discovery Protocol
NIC	Network Interface Card
OUI	Organizationally Unique Identifier
PAM	Pulse Amplitude Modulation
SFD	Start Frame Delimiter
STP	Spanning Tree Protocol
TTL	Time to Live
UTP	Unshielded Twisted Pair

Ethernet physical layer

Bits become signals through a line code → encoding scheme → converts binary into voltage

Line code must provide:

- Clock recovery → receiver must be able to stay synchronized with sender with a separate clock
- DC balance → no average voltage offset
  - Why? important that there is an even number of 0 and 1 so that there is no charge buildup
- Bandwidth efficiency: more bits per unit bandwidth = higher possible data rates

NRZ (non return to zero)--> 1 = high 0=low → simple but fails clock recovery

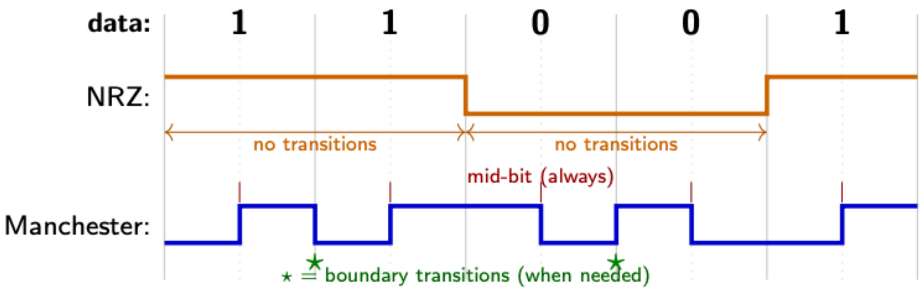
Ethernet line codes by generation

Generation	Line code	Notes
10 Mb/s (10BASE-T/5/2)	**Manchester**	Self-clocking; 2× bandwidth cost
100 Mb/s (100BASE-TX)	4B5B + MLT-3	4B5B maps 4 data bits → 5-bit code words; MLT-3 uses 3 voltage levels to cut bandwidth by 3×
1 Gb/s (1000BASE-T)	PAM-5	5-level amplitude modulation on all 4 wire pairs simultaneously
10+ Gb/s	PAM-4 / DSP	4-level PAM with digital signal processing and equalization

Manchester Encoding → 10 Mb.s Ethernet

Rule: every but period has a transition at its midpoint

- Bit 1 → low first half and high second half (rising edge at center)
- Bit 0 → high first half and low the second half (falling edge at the center)



Properties: guaranteed transition every bit period → clock recovery always possible
Cost: signal bandwidth = 2 x bit rate
Preamble connection: 10101010x7

<u>Ethernet frame structure</u>

Preamble+SFD	Dst MAC	Src MAC	Type	Payload	FCS
8 B	6 B	6 B	2 B	46–1500 B	4 B

Preamble(7B): 10101010x7 → clock sync for receiver PLL
SFD(1B): 10101011 → 2 final 1 bit marks “data starts now”
Dst/ Src MAC (6B each) → 48 bit link layer addresses
Type (2B): encapsulated protocol
Payload (46 - 1500 B) → pad to 46 B if shorter
FCS(4B) → CRC-32 → bad frames silently dropped/ not passed to higher layers

<u>Minimum and maximum frame size</u>
Maximum frame size: payload <= 1500 bytes → **1518 bytes total**
- This is where IP’s MTU of 1500 bytes come from

Minimum frame size: payload >= 46 bytes → **64 total bytes**
- required for CSMA/CD: sender must still be transmission when the collision echo arrives
- At 10Mb/s max cable length gives round trip delay → **t=51.2 ms**
    - Lmin =2tR = 64 bytes
- In modern full duplex switched ethernet, collisions cant occur → 64 bytes minimum is a legacy constraint
- If payload < 46 bytes, the sender adds pad bytes to reach the minimum
- IFG (interframe GAP): 96 bit silence after each frame → this is how the receiver knows the frame has ended

<u>MAC addresses</u>
MAC address (which is also called a hardware address or burned in address, **BIA**) is a 48 bit identifier for a network interface, written in hex → A4:C3:F0:85:AC:2D

Structure:

- Bytes 1-3 → OUI (organizationally unique identifier) → assigned to manufactures by IEEE
- Bytes 4-6: device specific → assigned by manufacturers

Special bits in byte 1:

- Bit 0 (I/G)→ 0=unit cast , 1=multicast
- Bit 1 (U/L)--> 0=globally administered, 1=locally administered

Broadcast: FF:FF:FF:FF:FF:FF → all devices on LAN receive it

NOTE: mac addresses are flat → no topological structure unlike IP

- IP addresses have structure and help to get from one to another and have meaning
- MAC is constant and assigned by manufacturer

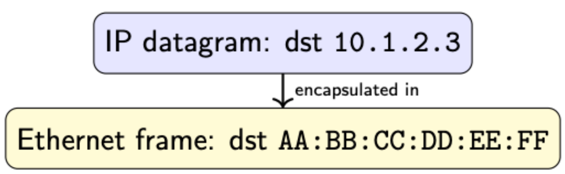
<u>Flat vs Hierarchical Addressing</u>

MAC(flat) → changes at each hop

- Identifies the hardware
- No location information
- Does not change as a device moves (physically)
- Used by switching for local frame delivery

IP(hierarchial) → address stays the same from end to end

- Encodes network topology in the prefix
- Changes when a device moves between subnets
- Used by routers for global routing



<u>ARP: the problem</u>

Host A knows it needs to reach 192.168.1.20 on the same subnet.

To send an Ethernet frame, it needs the **destination MAC address**. Where does it come from?

ARP (Address Resolution Protocol): "Who has IP 192.168.1.20? Tell me your MAC."

[Wikipedia: Address Resolution Protocol]

<u>ARP exchange</u>

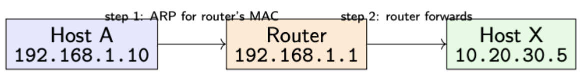
1. ARP request (broadcast)
   a. Ethernet dst: FF:FF:FF:FF:FF:FF → everyone on LAN receives
   b. Content: "I'm 192.168.1.10 (AA:AA:AA:AA:AA:AA). Who has 192.168.1.20?"

2. ARP reply (unicast)
    a. Ethernet dst: AA:AA:AA:AA:AA:AA → back to hist A only
    b. Content: ”I’m 192.168.1.20; my MAC is BB:BB:BB:BB:BB:BB.”
3. Host A sends a datagram
    a. Ethernet frame dst: BB:BB:BB:BB:BB:BB

ARP table (cache): Host A stores the Ip → MAC mapping with a TTL → no time no ARP needed
Host can also learn from ARP request they overhear

<u>ARP for off-subnet destinations</u>

Host A (`192.168.1.10`) wants to reach Host X (`10.20.30.5`) — different subnet.



1. Host A sees that `10.20.30.5` is **not on the local subnet**
2. Host A consults its routing table → next hop is default gateway `192.168.1.1`
3. Host A ARPs for the **gateway's** MAC address
4. Frame is sent to router's MAC; IP datagram inside still has dst `10.20.30.5`

ARP operates within one subnet (broadcast domain) only.

<u>HUB vs switch</u>

HUB (repeater):

- Receives on one port, retransmits on all others
- All ports share one collision domain
- Half duplex – CSMA/CD required
- Every host sees every frame

Switch

- Forwards frames selectively by MAC address
- Each port is its own collision domain
- Full duplex → no collisions possible
- Frames go only where they need to

Why switches replaced this:

- Performance: multiple simultaneous transmission (A→ B and C→ D at the same time)
- Privacy: hosts don't receive frames not addressed to them
- Full duplex: no CSMA/ CD needed→ full link bandwidth in both directions

<u>Switch forwarding and self learning</u>

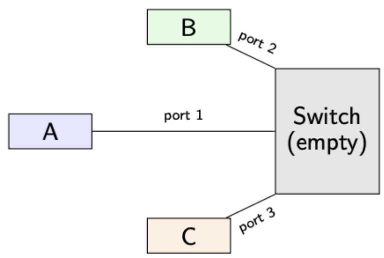
Forwarding table:

MAC Address	Port	TTL
AA:AA:AA:AA:AA:AA	1	4:58
BB:BB:BB:BB:BB:BB	3	4:45
CC:CC:CC:CC:CC:CC	2	4:12

Self learning: when a frame arrives on port P from source MAC X , record (X→P)

Forwarding rule:
1. Look up destination MAC in table
2. If found → forward to that port only
3. If not found → flood (all ports except ingress)
4. Broadcast/multicast → flood always

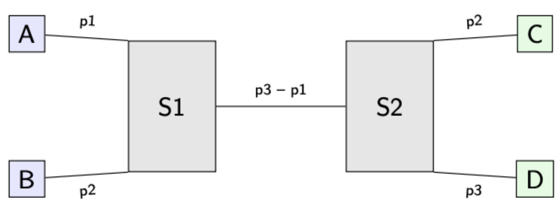
<u>Self learning example</u>



Frame	Switch action	Table after
A → B (dst unknown)	Learn A→port 1; **flood** ports 2, 3	A→1
B → A (dst known!)	Learn B→port 2; **forward** to port 1	A→1, B→2
C → A (dst known!)	Learn C→port 3; **forward** to port 1	A→1, B→2, C→3

After a few exchanges, the switch has **learned all host locations** and forwards efficiently.

<u>Multi switch LAN</u>



Scenario: A sends to D (tables empty)

1. S1: learns A→p1; D unknown → flood p2 (to B) and p3 (toward S2)
2. S2: learns A→p1 (via S1); D unknown → flood p2 (C) and p3 (D)
3. D receives; B and C discard

D replies to A (S2 now knows A; S1 now knows D)

1. S2: D→p3 learned; A known at p1 → **forward** only to S1
2. S1: A known at p1 → **forward** only to A

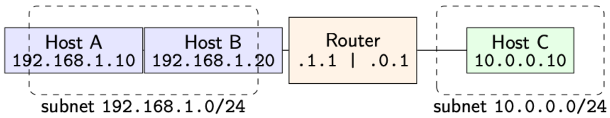
Switches are **transparent** to end hosts.

<u>Subnets</u>

Subnet → a set of interfaces sharing the same IP prefix → reachable at the link layer without a router

CIDR notation 192.168.1.0/24

→ first 24 bits are the network prefix; last 8 bits identity hosts (0-255)



- ARP operates within a subnet
- Cross subnet traffic goes through a router
- Each router interface belongs to a different subnet

<u>Power over ethernet and auto negotiation</u>

Power over ethernet (PoE)

- Delivers DC power over the same UTP cable as data
- 802.3af: 15.4 W per port 802.3at: 30 W 802.3bt: up to 90 W
- Used for: IP phones, wireless access points, IP cameras, IoT sensors

Auto-negotiation:

- Interfaces advertise their capabilities; both ends select highest common mode
- 1000BASE-T interfaces can fall back to 100 or 10 Mb/s if needed

Duplex mismatch (common misconfiguration):

- One end full-duplex, other end half-duplex
- Full-duplex end never backs off; half-duplex end sees constant collisions
- Symptom: poor throughput, high CRC error counts