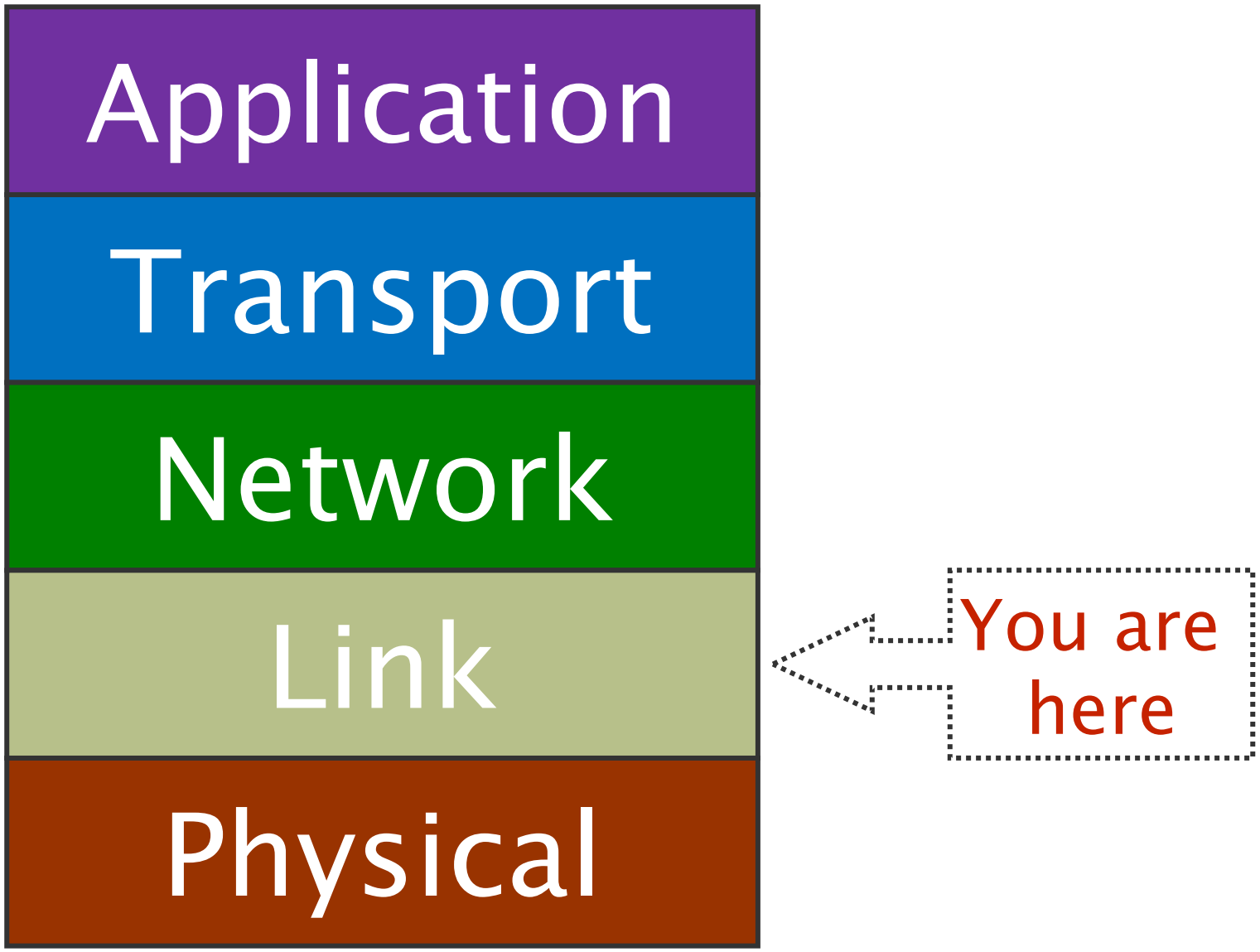
CS2105

An Awesome Introduction to Computer Networks

Lecture 9: The Link Layer, Part II

Department of Computer Science
School of Computing


Application
Transport
Network
Link
Physical
You are here

Lecture 9: The Link Layer

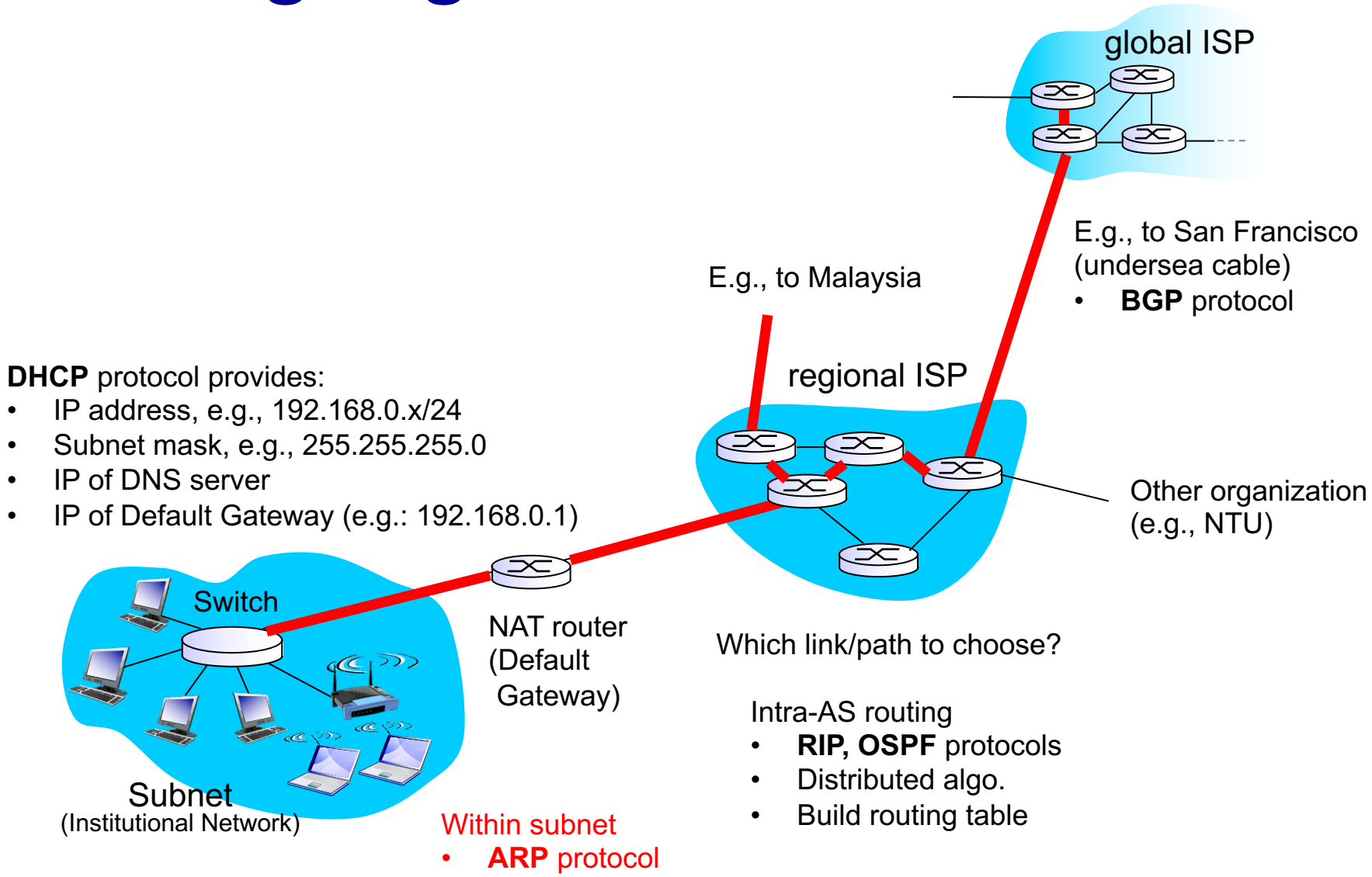
After this class, you are expected to understand:

- the role of link layer and the services it could provide.
- how parity and CRC scheme work.
- different methods for accessing shared medium.

L8

- how ARP allows a host to discover the MAC addresses of other nodes in the same subnet.
- the role of switches in interconnecting subnets in a LAN.

Routing: Big Picture



Lecture 8&9: Roadmap

6.1 Introduction to the Link Layer

6.2 Error Detection and Correction

6.3 Multiple Access Links and Protocols

6.4 Switched Local Area Networks

- 6.4.1 Link Layer Addressing & ARP
- 6.4.2 Ethernet
- 6.4.3 Link-layer Switches

MAC Address (1/2)

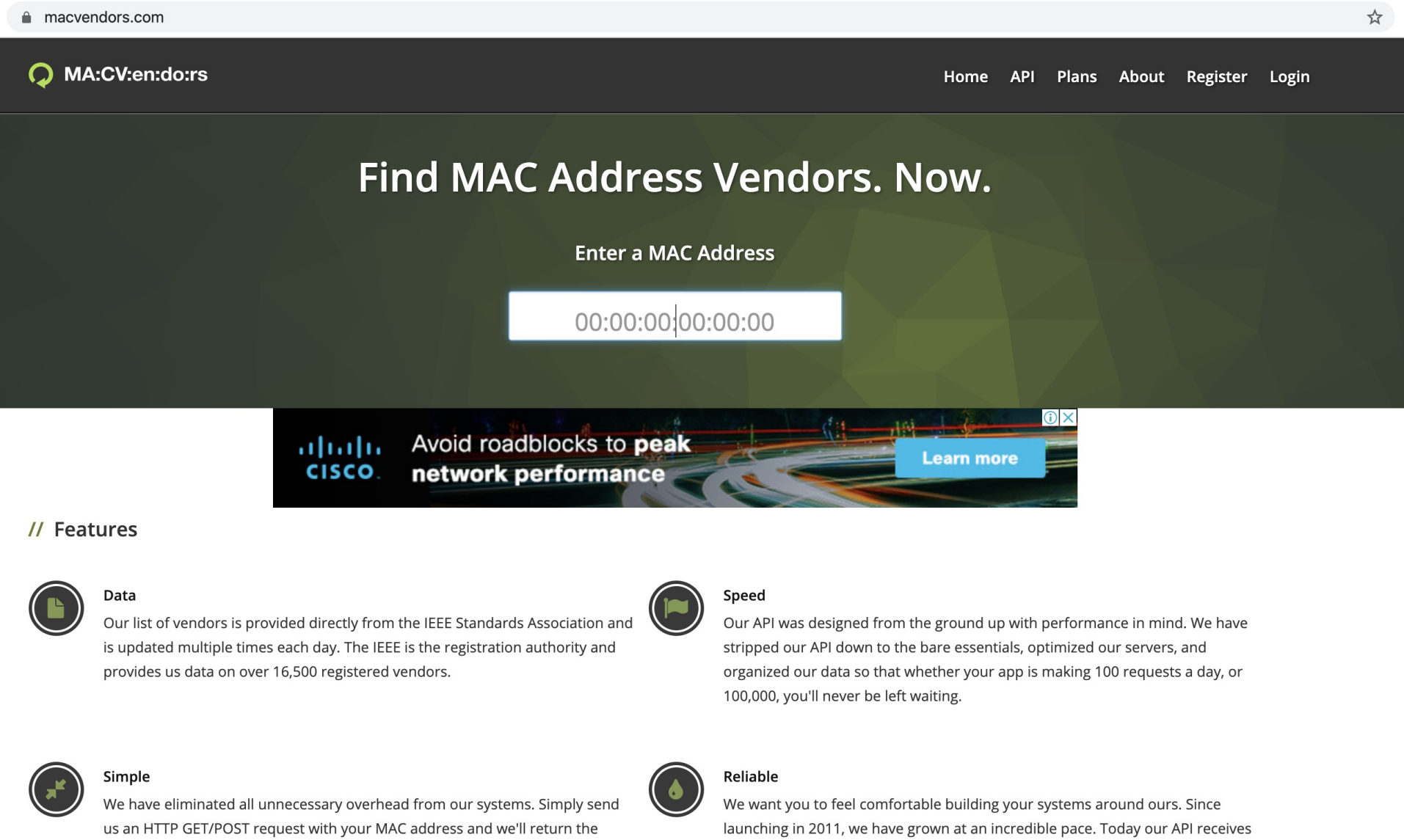
- Every adapter (NIC) has a MAC address (aka physical or LAN address).
  - Used to send and receive link layer frames.
  - When an adapter receives a frame, it checks if the destination MAC address of the frame matches its own MAC address.
    - If yes, adapter extracts the enclosed datagram and passes it to the protocol stack.
    - If no, adapter simply discards the frame without interrupting the host.

MAC Address (2/2)

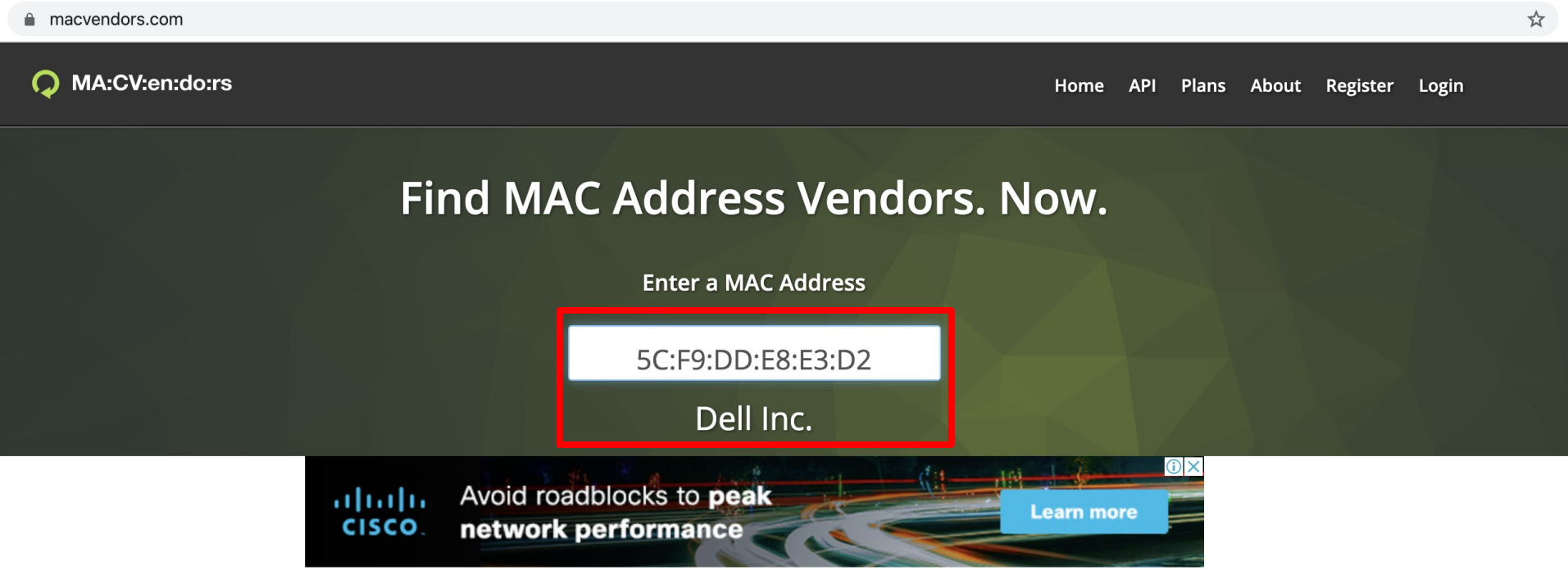
- MAC address is typically 48 bits, burned in NIC ROM (sometimes software settable).
  - Example: **5C-F9-DD-E8-E3-D2** — hexadecimal (base 16) notation
  - MAC address allocation is administered by IEEE.
    - The first three bytes identifies the vendor of an adapter.
  - Several websites allow us to check the vendor given a MAC address, e.g.:

    https://macvendors.com/

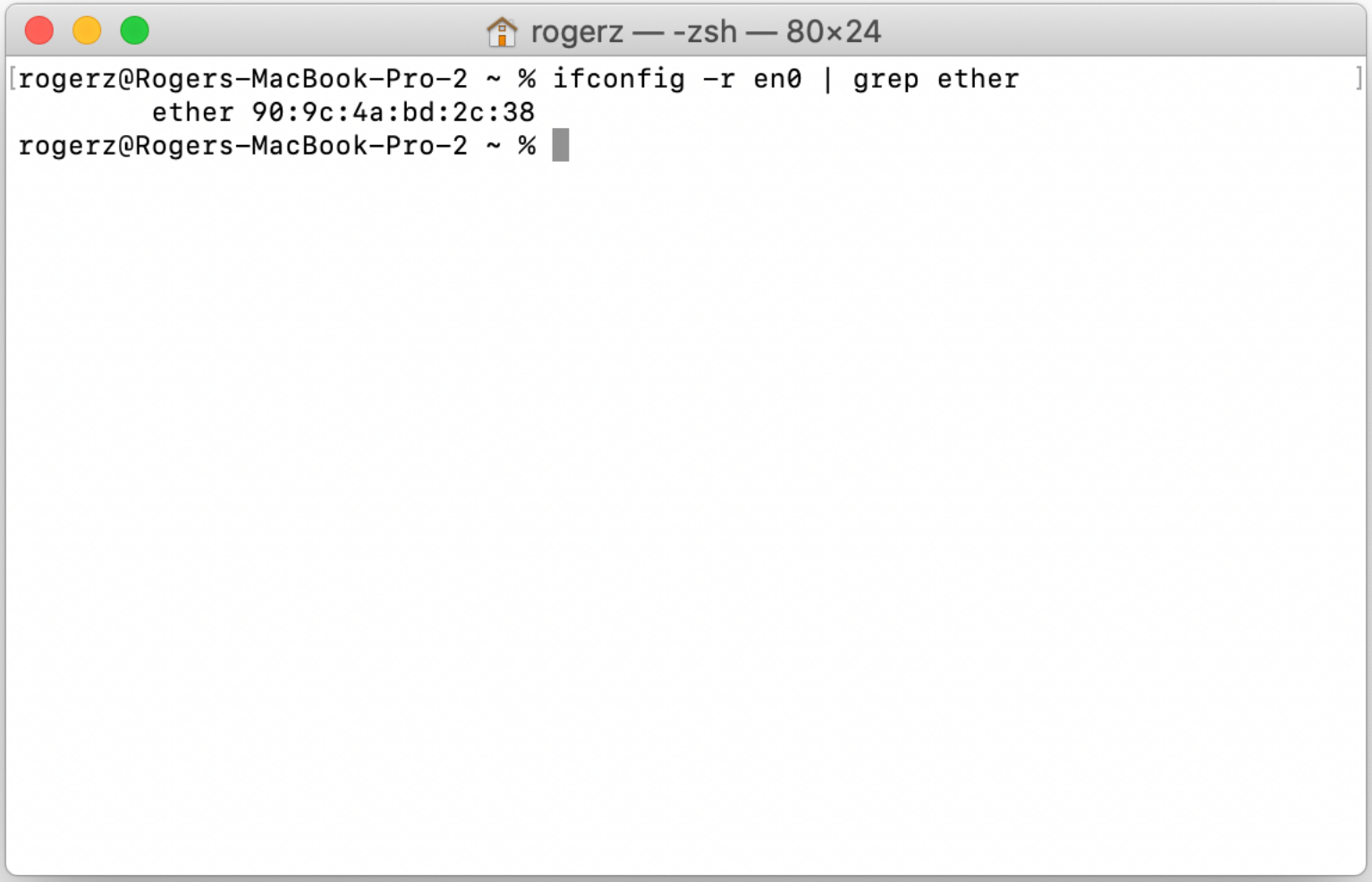
MAC Address (Ex: 1/3)



MAC Address (Ex: 2/3)



MAC Address (Ex: 3/3)



IP Address vs. MAC Address

- IP address
  - 32 bits in length
  - network-layer address used to move datagrams from source to dest.
  - Dynamically assigned; hierarchical (to facilitate routing)
  - Analogy: postal address
- MAC address
  - 48 bits in length
  - link-layer address used to move frames over every single link.
  - Permanent, to identify the hardware (adapter)
  - Analogy: NRIC number

ARP: Address Resolution Protocol

- Question: How to know the MAC address of a receiving host, knowing its IP address?
  - Use ARP [RFC 826]

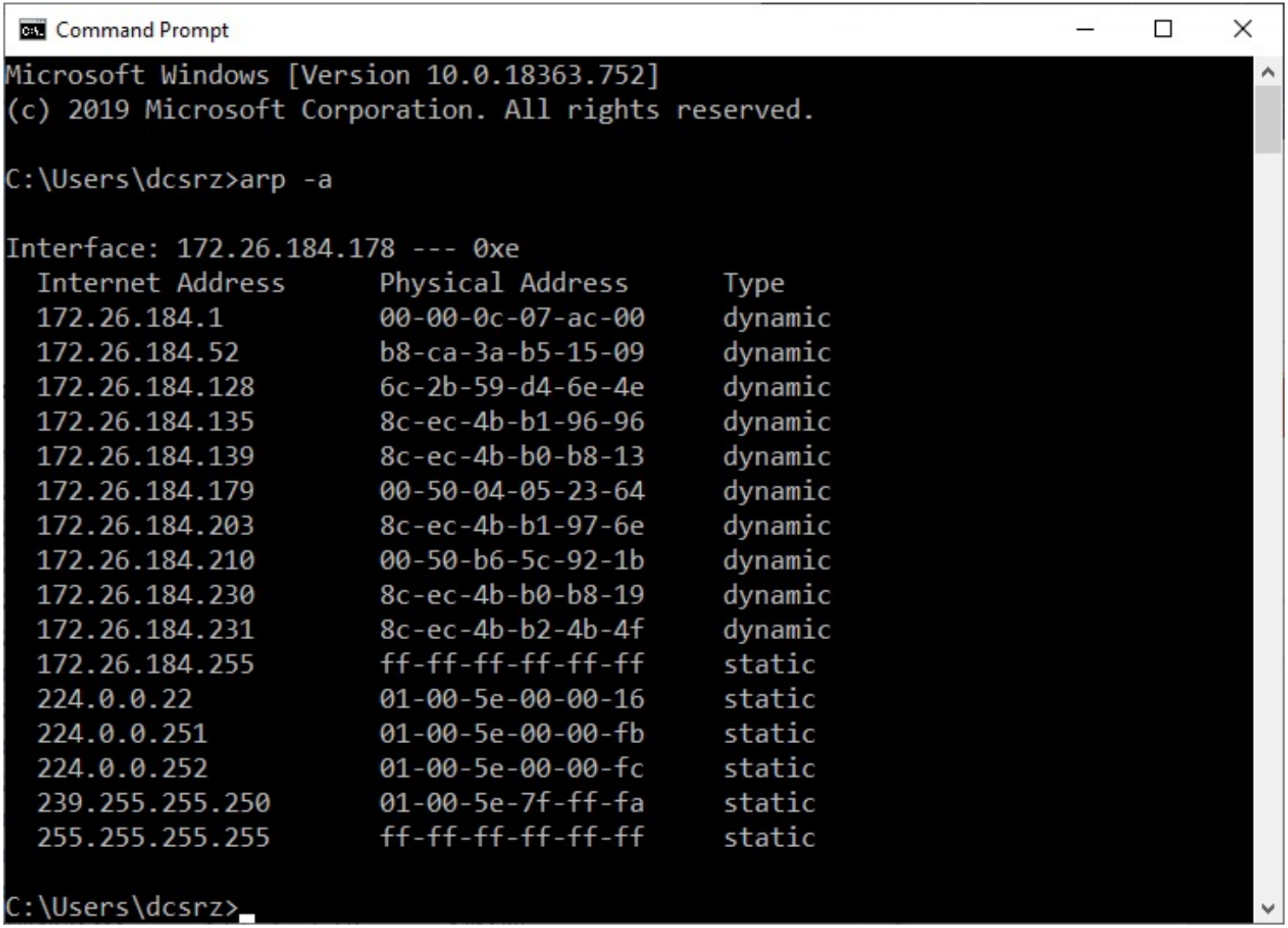
- Each IP node (host, router) has an ARP table.
  - Stores the mappings of IP address and MAC address of other nodes in the same subnet.

< IP address; MAC address; TTL >

time after which address mapping will be forgotten (typically a few minutes on Windows)

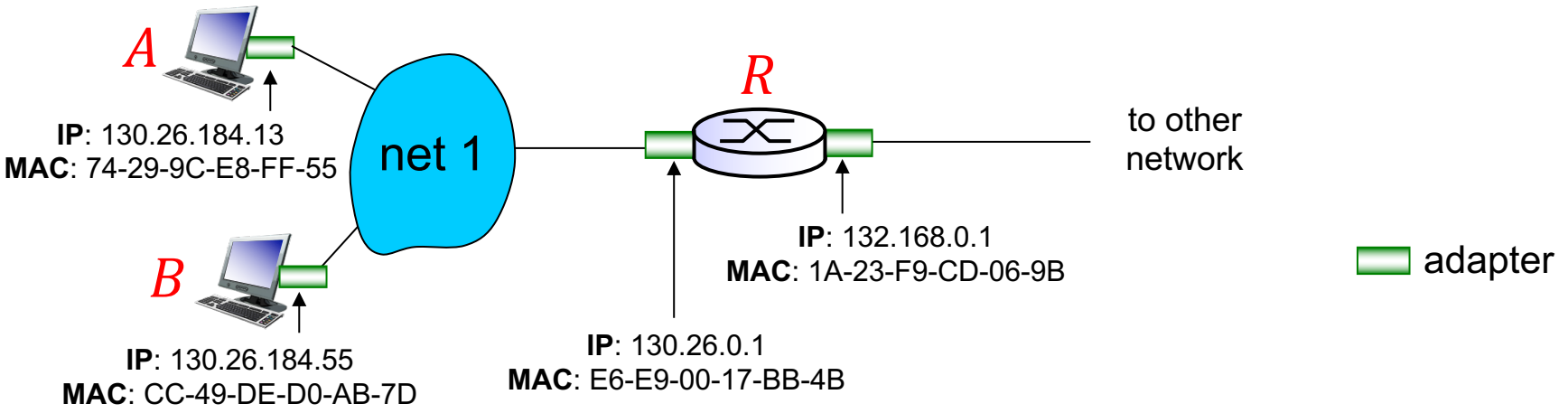
As *Maverick* (Top Gun) likes to say:

ARP Demo: Office Windows PC



Sending Frame in the Same Subnet

- Suppose A wants to send data to B. They are in the same subnet.
  1. If A knows B's MAC address from its ARP table
     - create a frame with B's MAC addresses and send it.
     - Only B will process this frame.
     - Other nodes may receive but will ignore this frame.
  2. What if A is not aware of B's MAC address?



Sending Frame in the Same Subnet

- What if B's MAC address is not in A's ARP table?

  ① A broadcasts an ARP query packet, containing B's IP address.
  - Dest MAC address set to FF-FF-FF-FF-FF-FF
  - All the other nodes in the same subnet will receive this ARP query packet, but only B will reply it.

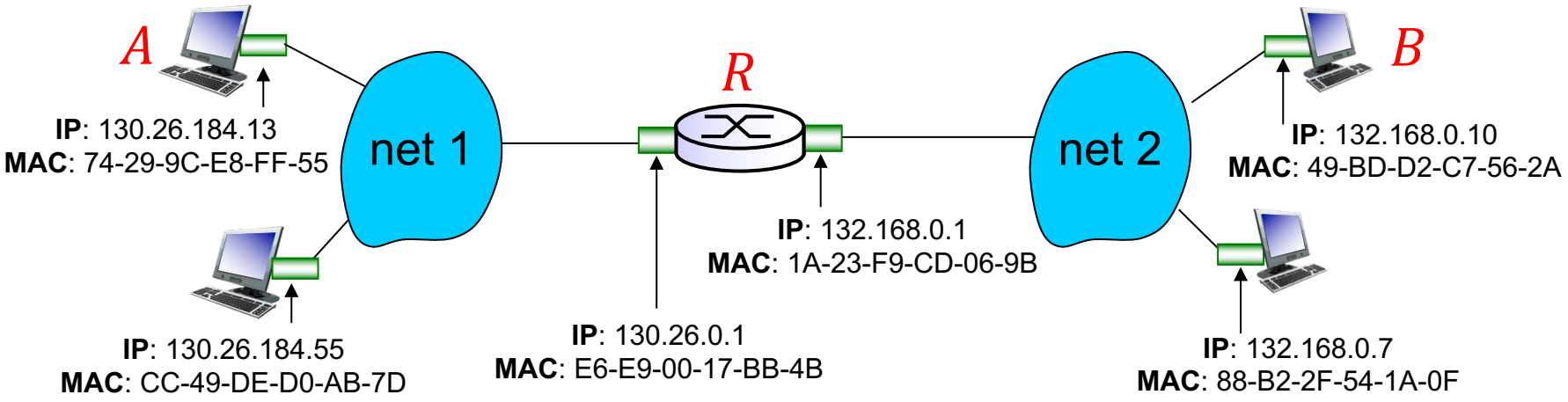
  ② B replies to A with its MAC address.
  - Reply frame is sent to A's MAC address.

  ③ A caches B's IP-to-MAC address mapping in its ARP table (until TTL expires).

Question: how to determine if B is in the same subnet?

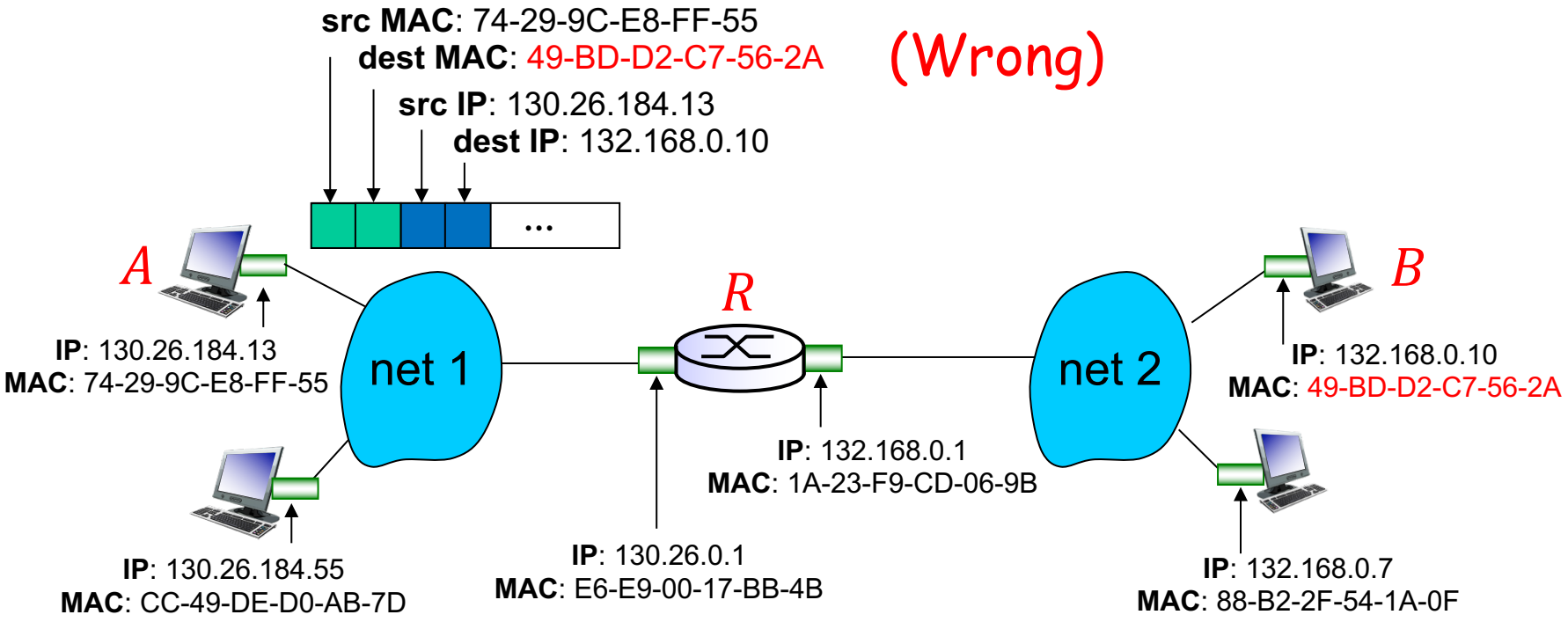
Sending Frame to Another Subnet

- Question: What if we send data to a host in another subnet?
  - For example, A sends datagram to B in another subnet.



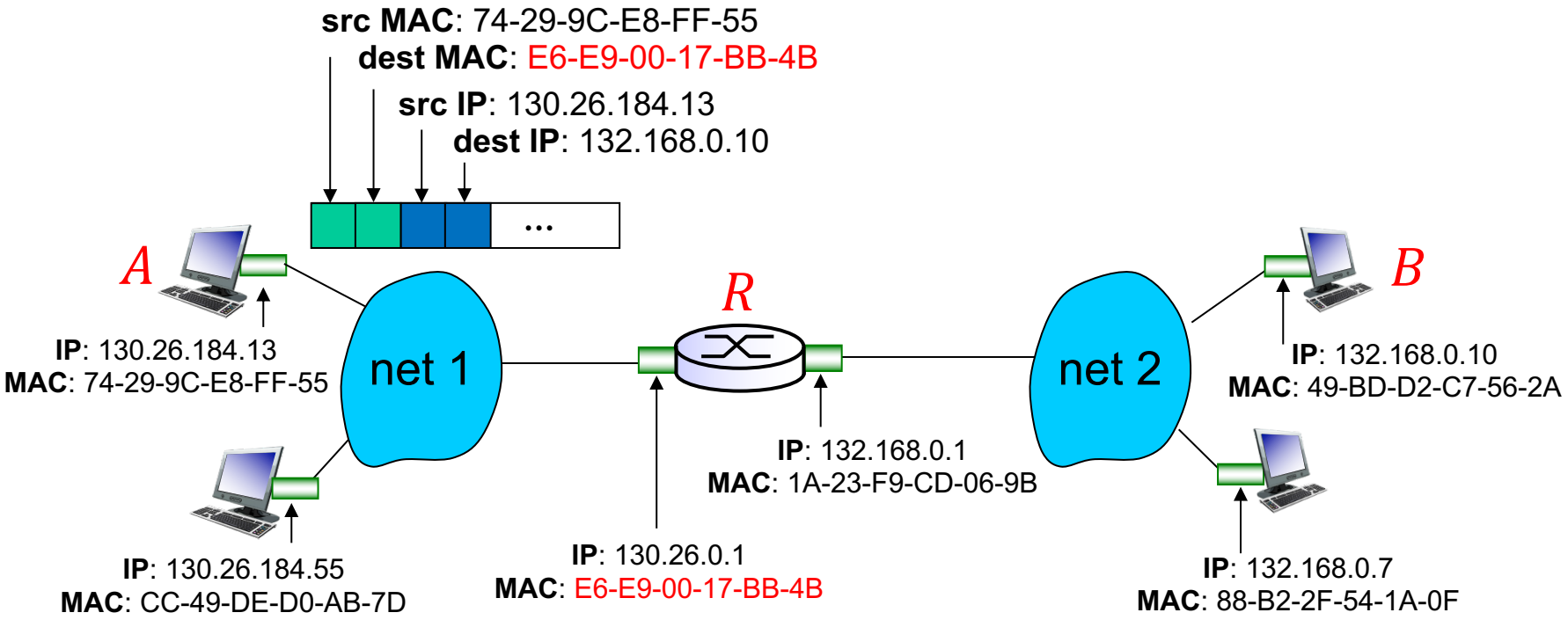
Sending Frame to Another Subnet

- A sends datagram to B in another subnet.
  - Can A create a frame as follows?
    - No. all adapters in net 1 will ignore this frame because of the mismatch of destination MAC address.



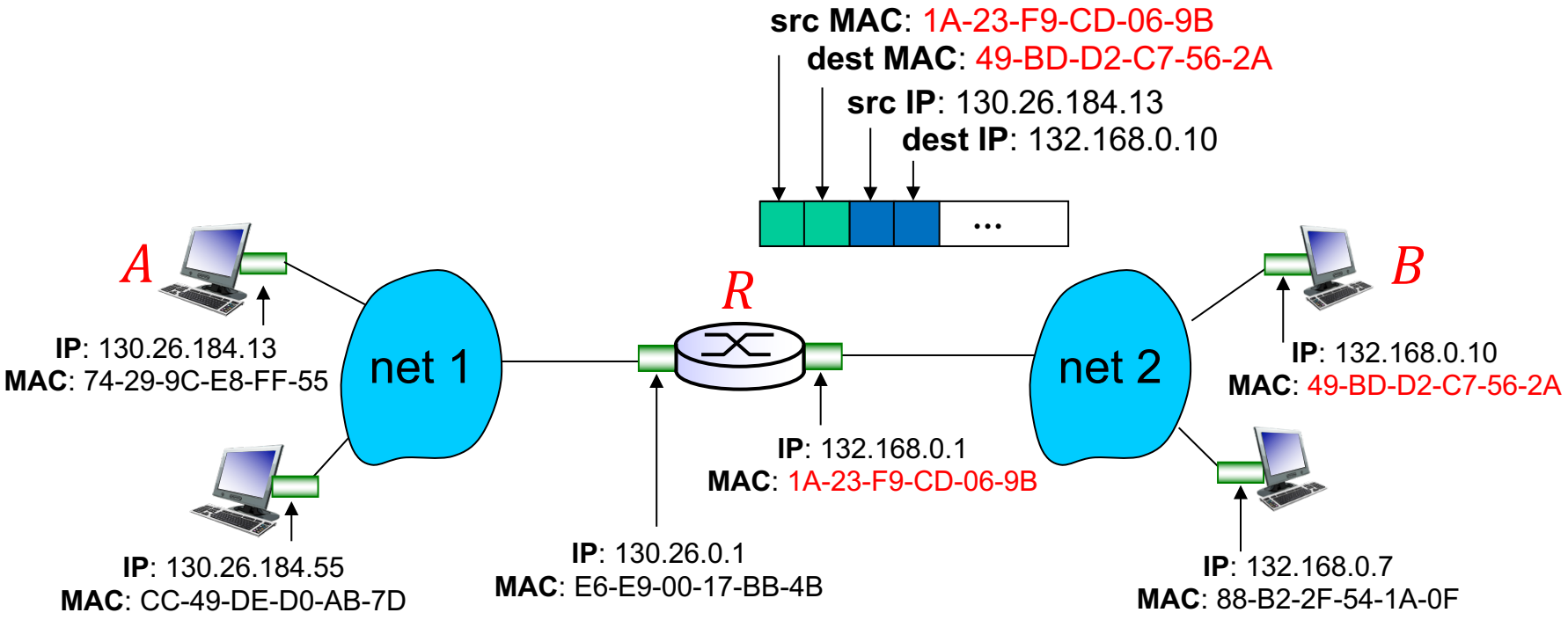
Sending Frame to Another Subnet

- A sends datagram to B in another subnet.
  - A should create a link-layer frame with (1) R's MAC address (2) B's IP address as destination.



Sending Frame to Another Subnet

- A sends datagram to B in another subnet.
  - R will move datagram to outgoing link and construct a new frame with B's MAC address.



Lectures 8&9: Roadmap

6.1 Introduction to the Link Layer

6.2 Error Detection and Correction

6.3 Multiple Access Links and Protocols

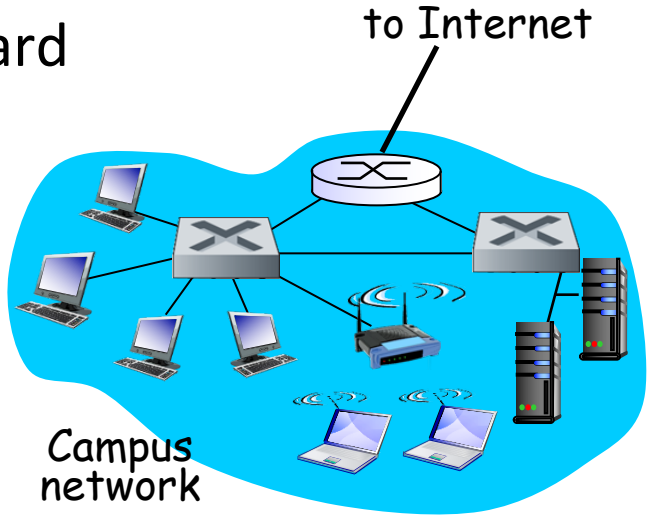
6.4 Switched Local Area Networks

- 6.4.1 Link Layer Addressing & ARP
- 6.4.2 Ethernet
- 6.4.3 Link-layer Switches

Local Area Network (LAN)

- LAN is a computer network that interconnects computers within a geographical area such as office building or university campus.

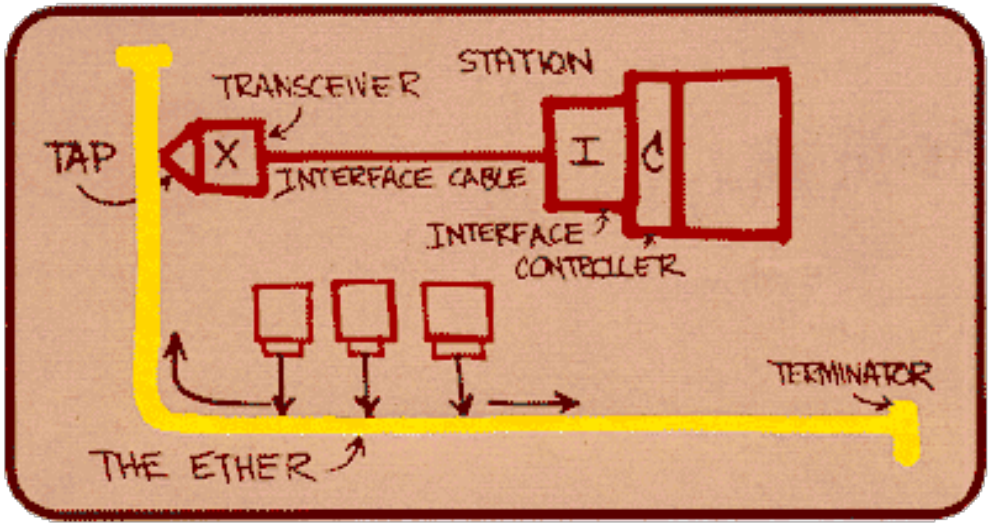
- LAN technologies:
  - IBM Token Ring: IEEE 802.5 standard
  - Ethernet: IEEE 802.3 standard
  - Wi-Fi: IEEE 802.11 standard
  - Others



Ethernet

- "Dominant" wired LAN technology:
  - Developed in mid 1970s
  - Standardized by Xerox, DEC, and Intel in 1978
  - Simpler and cheaper than token ring and ATM

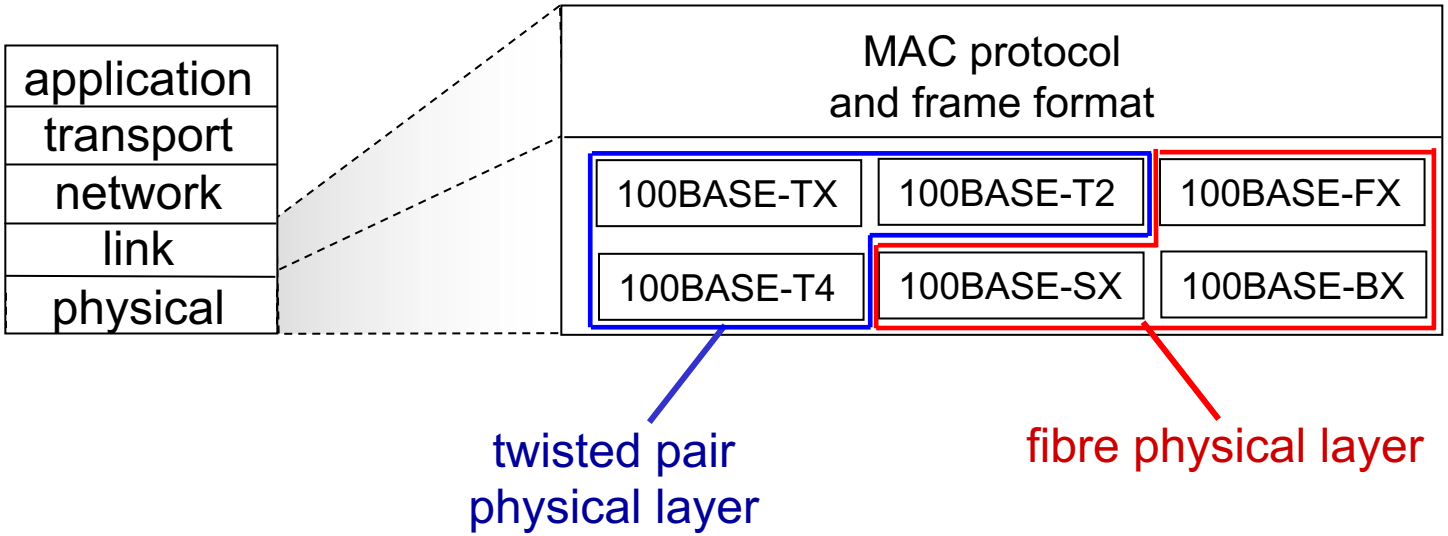
Ethernet connection
(Source: Wikipedia)



Metcalfe's Ethernet sketch

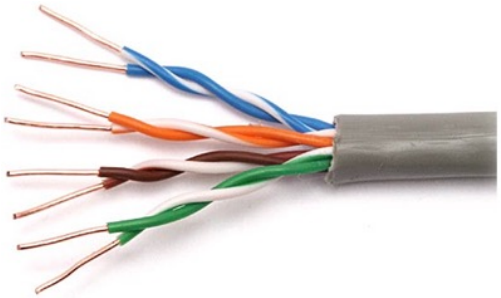
802.3 Ethernet Standards (1/2)

- A series of Ethernet standards have been developed over the years.
  - Different speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps, 100 Gbps
  - Different physical layer media: cable, fiber optics
  - MAC protocol and frame format remain unchanged



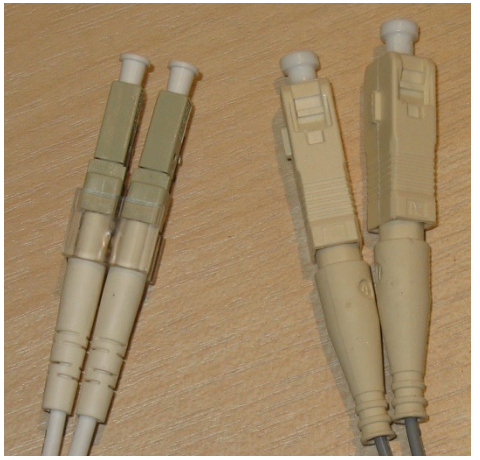
802.3 Ethernet Standards (2/2)

- Twisted Pair Copper Connectors:
  - RJ45
  - CAT 6
    - Max. speed: 10 Gbps
    - Max. length: 100m



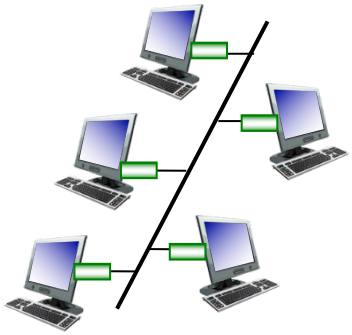
Source: Wikipedia

- Optical Fibre Connectors:
  - Left: LC/PC connectors
    Right: SC/PC connectors
  - Single-mode fibre
    - Max. speed: 10 or 40 Gbps
    - Max. length: > 80 km

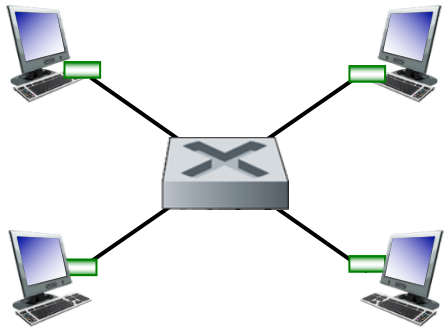


Ethernet: Physical Topology

- Bus topology: popular in mid 90s
  - all nodes can collide with each other
- Star topology: prevails today
  - switch in center
  - nodes do not collide with each other



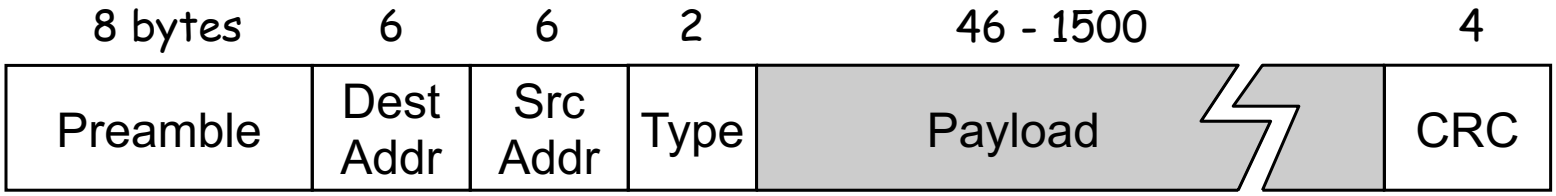
Ethernet with bus topology



Ethernet with star topology

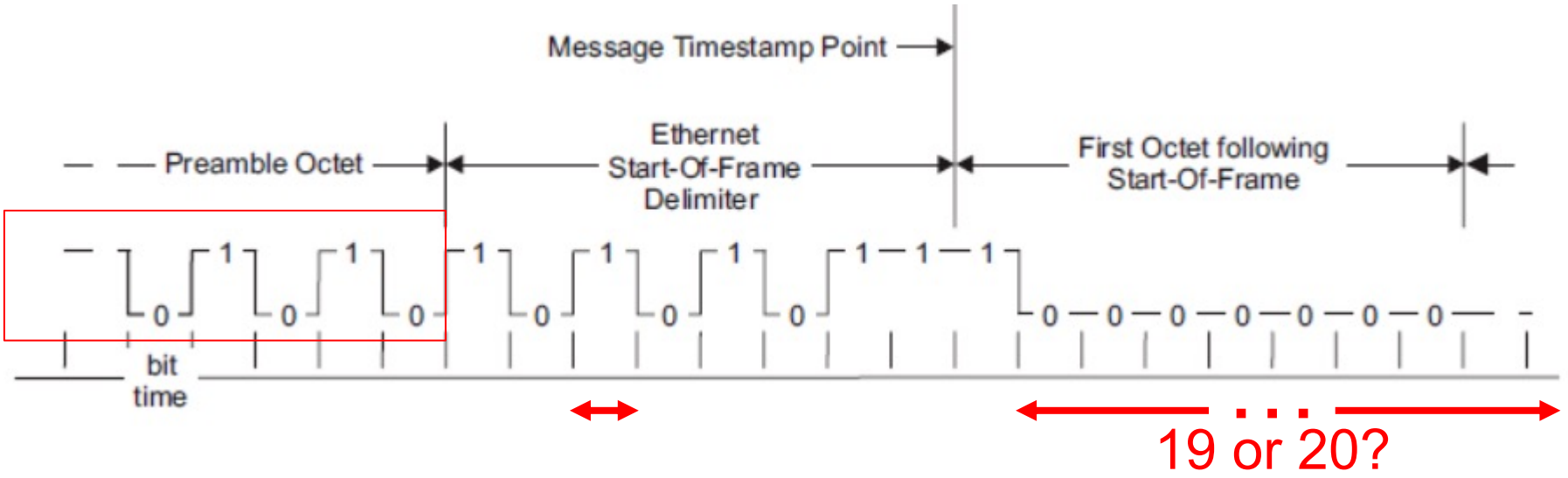
Ethernet Frame Structure (1/3)

- Sending NIC (adapter) encapsulates IP datagram in Ethernet frame.



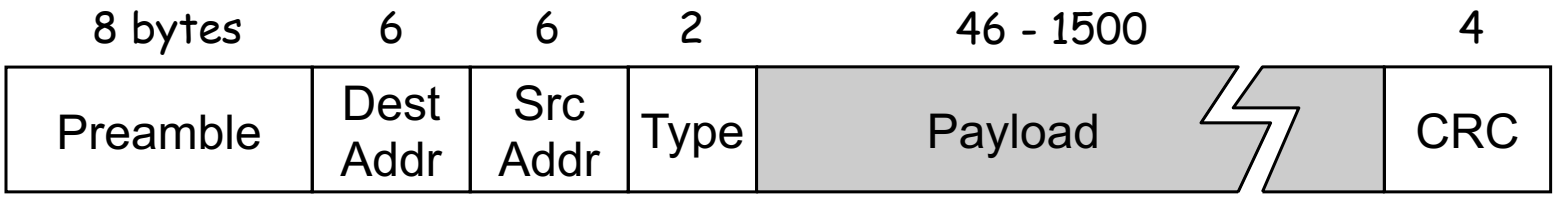
- *Preamble:*
  - 7 bytes with pattern **10101010** (AA_{Hex}) followed by 1 byte with pattern **10101011** (AB_{Hex}).
  - used to synchronize receiver and sender clock rates.

Ethernet Frame Structure (2/3)



- The premable provides a “square wave” pattern that tells the receiver the sender’s clock rate;
- and it tells the receiver the width of a bit;
- which is important if there is a long string of bits of the same value, e.g., 19 or 20 zeros.

Ethernet Frame Structure (3/3)



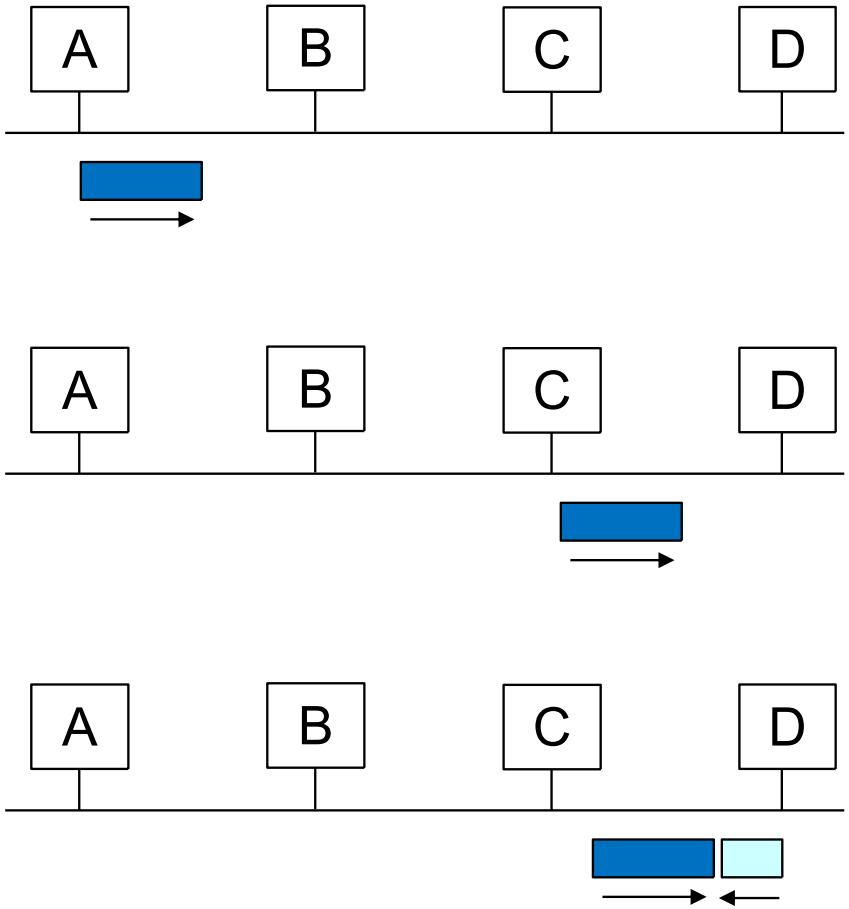
- *Source and dest MAC address:*
  - If NIC receives a frame with matching destination address, or with broadcast address, it passes data in the frame to network layer protocol.
  - Otherwise, NIC discards frame.
- *Type:* Indicates higher layer protocol (mostly IP).
- *CRC:* corrupted frame will be dropped.

Ethernet Data Delivery Service

- Connectionless: no handshaking between sending and receiving NICs.
- Unreliable: receiving NIC doesn't send ACK or NAK to sending NIC.
  - data in dropped frames will be recovered only if initial sender uses higher layer rdt (e.g. TCP); otherwise dropped data is lost.
- Ethernet's multiple access protocol: CSMA/CD with binary (exponential) backoff.

Collisions in Bus Topology Ethernet

- Collision may happen in Ethernet of bus topology.
- For example:
  - A sends a frame at time t.
  - A's frame reaches D at time $t + d$.
  - D begins transmission at time $t + d - 1$ and collides with A's frame.



Ethernet CSMA/CD Algorithm

1. NIC receives datagram from network layer, creates frame.
2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame!
4. If NIC detects another transmission while transmitting, aborts and sends jam signal.
5. After aborting, NIC enters binary back-off:
   - after m^{th} collision, NIC chooses K at random from {0, 1, 2, …, 2^m-1}.
   - NIC waits K*512 bit times, returns to Step 2.

Ethernet CSMA/CD Algorithm

Exponential backoff:

- After 1st collision: choose K at random from {0, 1}; wait K * 512 bit transmission times before retransmission.
- After 2nd collision: choose K from {0, 1,…, 2^2-1}.

  …
- After m^{th} collision, choose K at random from {0, 1, …, 2^m-1}

- *Goal*: adapt retransmission attempts to estimated current load
  - More collisions implies heavier load.
  - longer back-off interval with more collisions.

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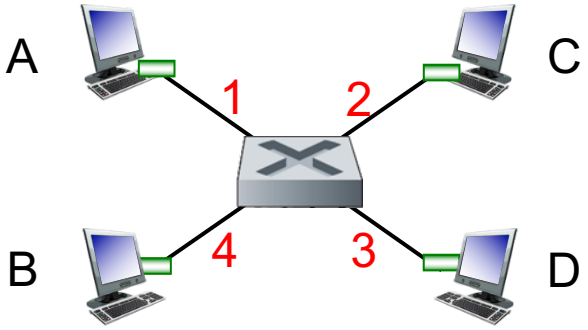
Ethernet Switch

- A link-layer device used in LAN
  - Store and forward Ethernet frames
  - Examine incoming frame's MAC address, selectively forward frame to one-or-more outgoing links.
- Transparent to hosts
  - No IP address
  - Hosts are unaware of the presence of switches

a 50-port Ethernet switch
(Source: Wikipedia)

Ethernet Switch

- In Ethernet of star topology, hosts have dedicated connection to switch.

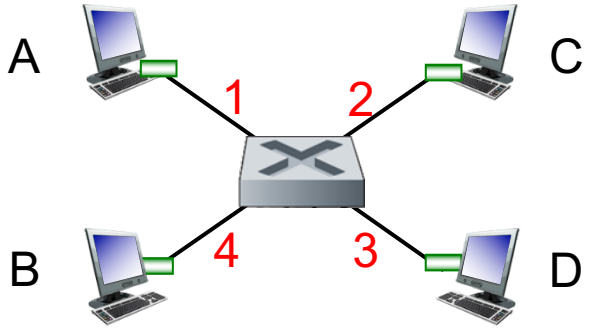


A switch with 4 interfaces (1, 2, 3, 4)

- Switch buffers frames and is full duplex.
  - A and D can send frames to each other simultaneously.
- Ethernet protocol is used on each link, but no collisions!

Switch Forwarding Table

- Q: how does switch know A is reachable via interface 1, B is reachable via interface 4?
- A: each switch has a switch table.
  - Format of entry:



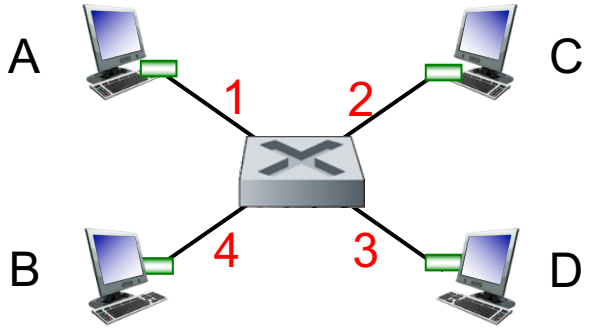
A switch with 4 interfaces (1, 2, 3, 4)

< MAC address of host, interface to reach host, TTL >

- Q: how are entries created and maintained in a switch table?

Switch: Self-learning

- Switch *learns* which hosts can be reached through which interfaces.
  - When receiving a frame from A, note down the location of A in switch table.
  - If destination B is found in the table, forward the frame onto that link.
  - If destination B is unknown, broadcast the frame to all outgoing links.



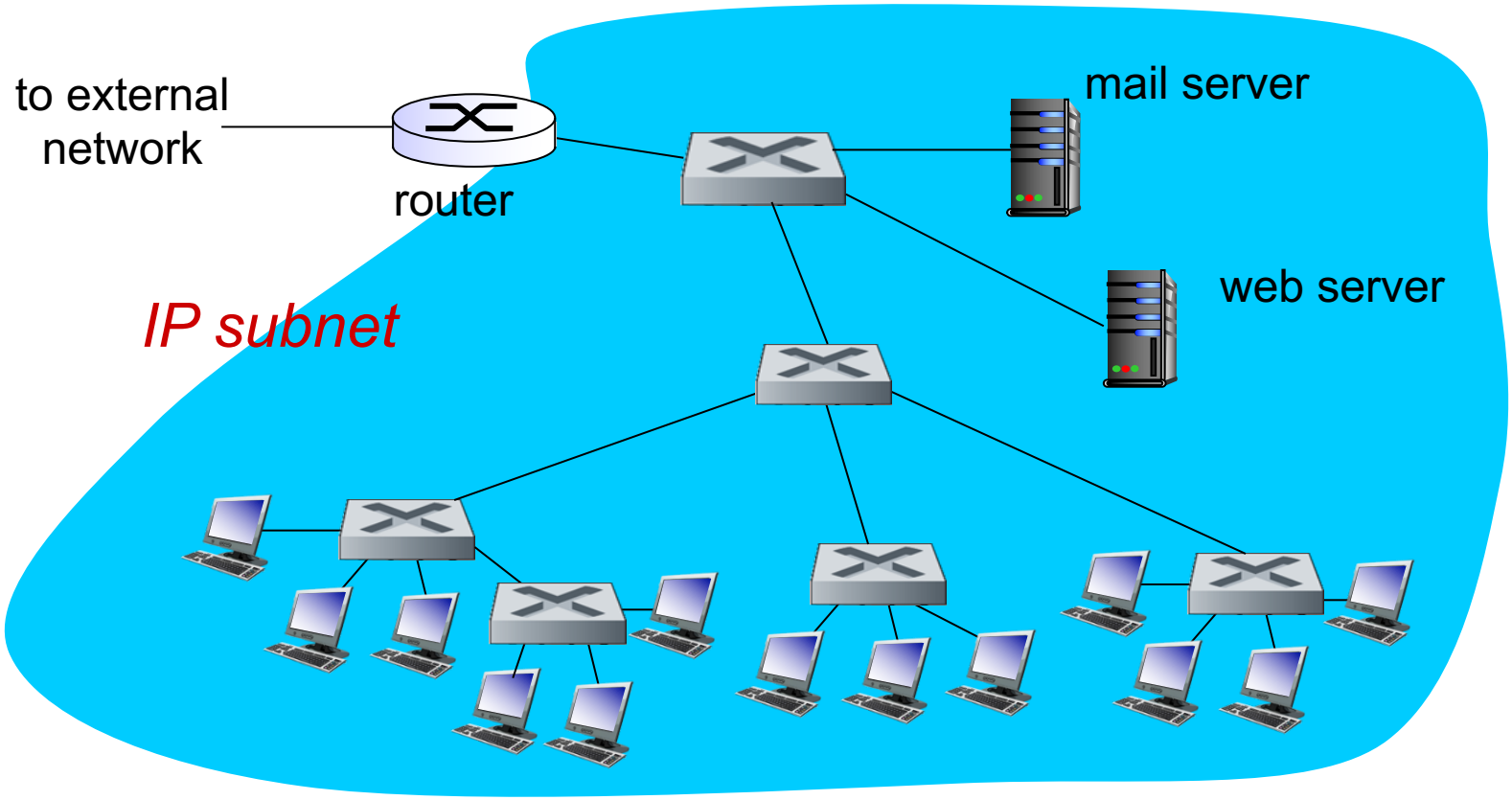
A switch with 4 interfaces (1, 2, 3, 4)

MAC addr	Interface	TTL
A	1	60

Switch table (initially empty)

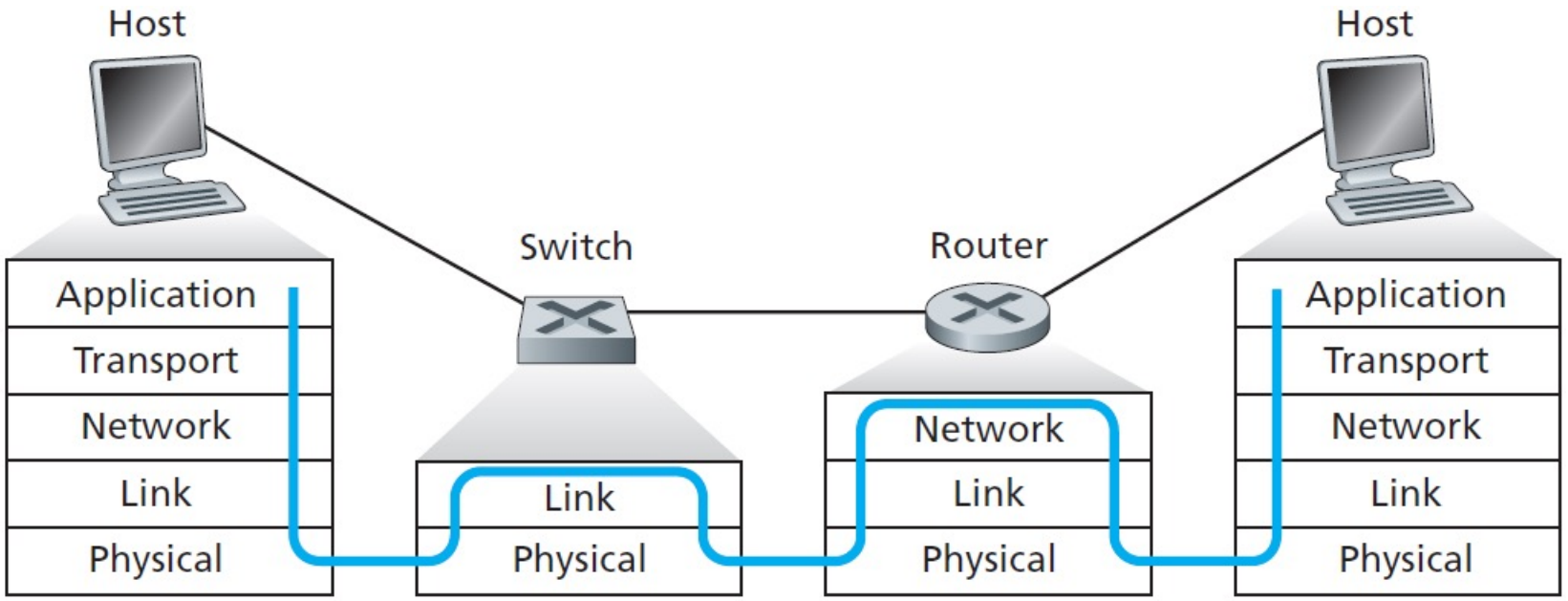
Interconnecting Switches

- Switches can be connected in hierarchy.



Switches vs. Routers

- Routers
  - Check IP address
  - Store-and-forward
  - Compute routes to destination
- Switches
  - Check MAC address
  - Store-and-forward
  - Forward frame to outgoing link or broadcast



Lecture 9: Summary

- ARP [RFC 826] resolves the mapping from network layer (IP) address to link layer (MAC) address.

- Instantiation and implementation of link layer technologies.
  - Ethernet
  - CSMA/CD protocol with binary back-off
  - Ethernet switches and switch tables