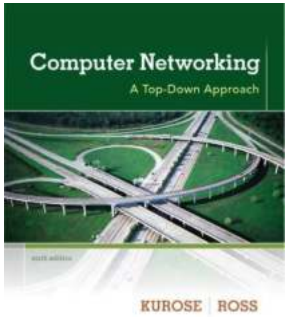
Taibah University
College of Computer Science and Engineering
Computer Engineering Department



Computer Networking: A Top Down Approach
6th edition
Addison-Wesley

Computer Networks

Ch5: Link layer

(Data Link Layer)

(V6)

*Chapter 5: Link layer

our goals:

- understand principles behind link layer services:
  - Error Detection, Error Correction
  - Multiple Access (MAC) protocols
    - channel partitioning:
      - FDMA, TDMA, CDMA
    - Random access protocols
      - ALOHA, Slotted ALOHA, CSMA, CSMA/CD, CSMA/CA
    - Controlled access protocols
  - MAC addresses and Address Resolution Protocol (ARP)
  - Examples of Link Layer Protocols: Local Area Networks (Ethernet (802.3))
    - Ethernet Frame Format
    - Ethernet switch
    - Switches vs. Routers

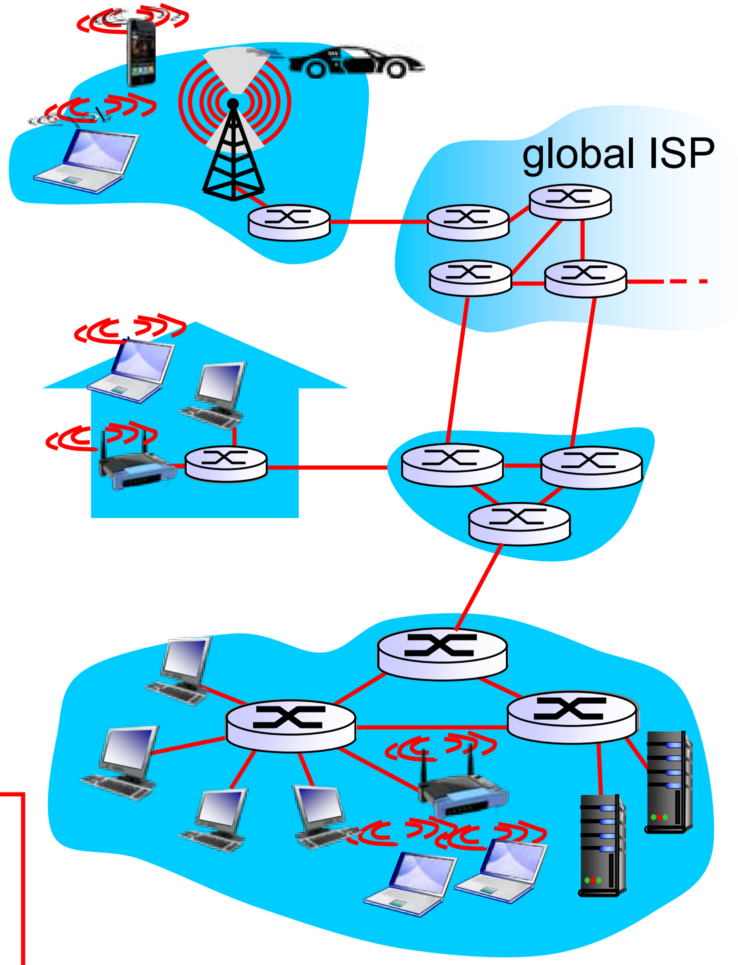
Link layer: introduction

terminology:

- hosts and routers: nodes
- communication channels that connect adjacent nodes along communication path: links
  - wired links
  - wireless links

- layer-2 packet: frame, encapsulates datagram

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



Link layer services

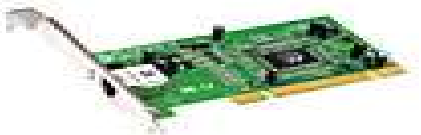
1. *framing:*
   - encapsulate datagram into frame, adding header, trailer
2. *Multiple Access Control (MAC)*
   - channel access if shared medium
   - "MAC" addresses used in frame headers to identify source, dest. MAC= Multiple Access Control
     - different from IP address!
3. *reliable delivery between adjacent nodes*
   - we learned how to do this already (chapter 3)!
   - seldom used on low bit-error link (fiber, some twisted pair)
   - wireless links: high error rates
     - *Q:* why both link-level and end-end reliability?

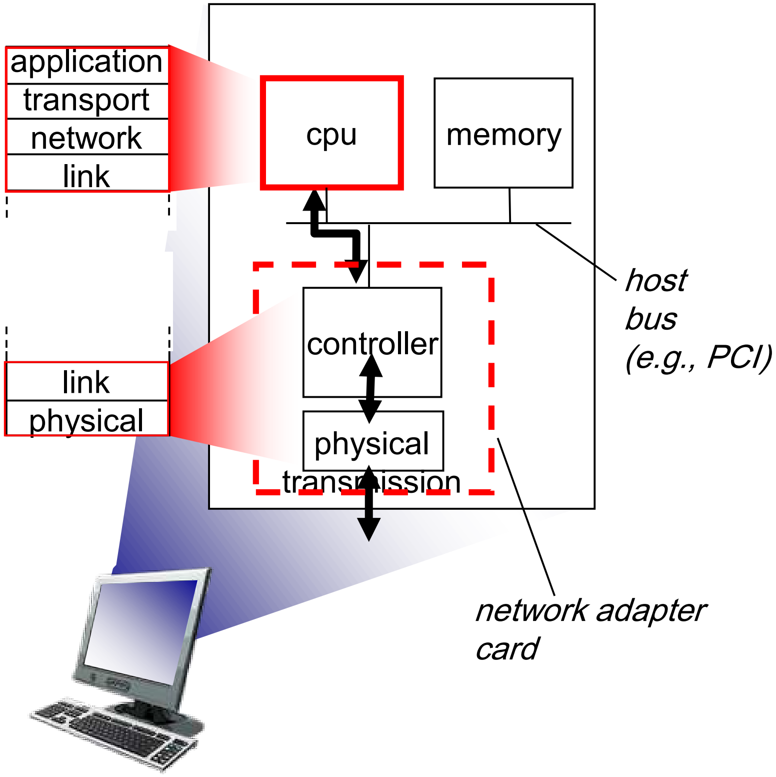
Link layer services (more)*

4. *flow control:*
   - pacing between adjacent sending and receiving nodes
5. *error detection* (ED):
   - errors caused by signal attenuation, noise.
   - receiver detects presence of errors:
     - signals sender for retransmission or drops frame
6. *error correction (EC):*
   - receiver identifies *and corrects* bit error(s) without resorting to retransmission (this type of EC is called Forwarded EC)
7. *half-duplex, full-duplex and Simplex*
   - **half duplex**, nodes at both ends of link can transmit, but not at same time: *(two directions but not at the same time)
   - * **full duplex:** nodes at both ends of link can transmit at same time. (two directions at the same time)
   - ***Simplex**: one node transmits only. (example: Radio, TV). (ONE direction ONLY)

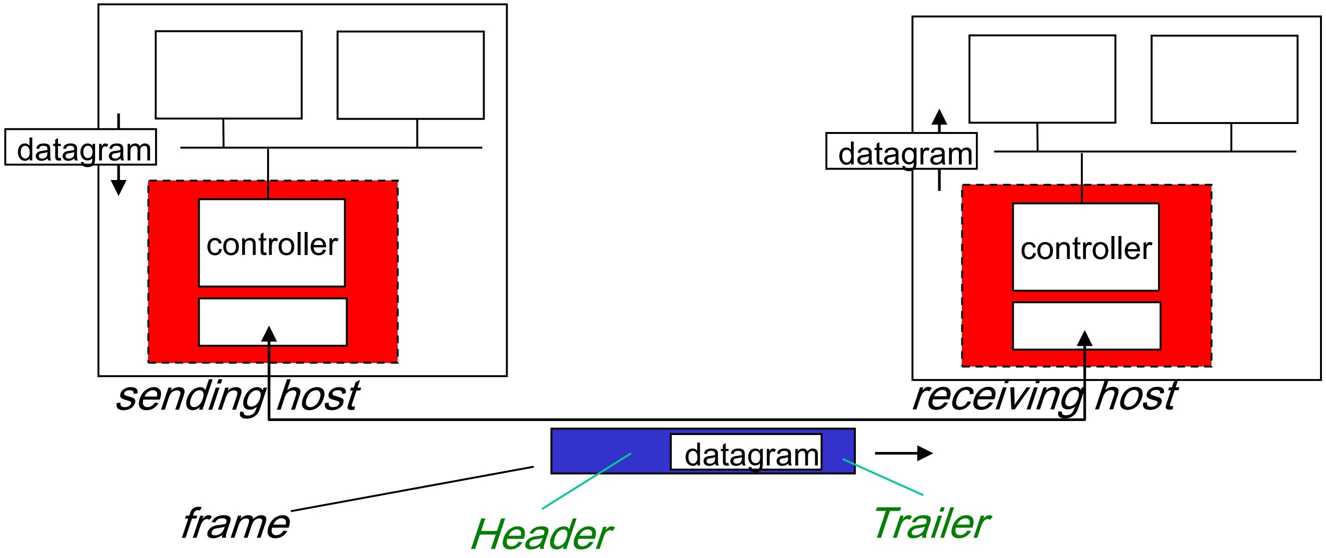
*Where is the link layer implemented?

- in each and every host
- link layer implemented in "adaptor" (aka *network interface card* NIC) or on a chip
  - 802.3 Ethernet card , 802.11 WIFI card; Ethernet chipset
  - implements link, physical layer
- attaches into host's system buses
- combination of hardware, software, firmware





Adaptors communicating

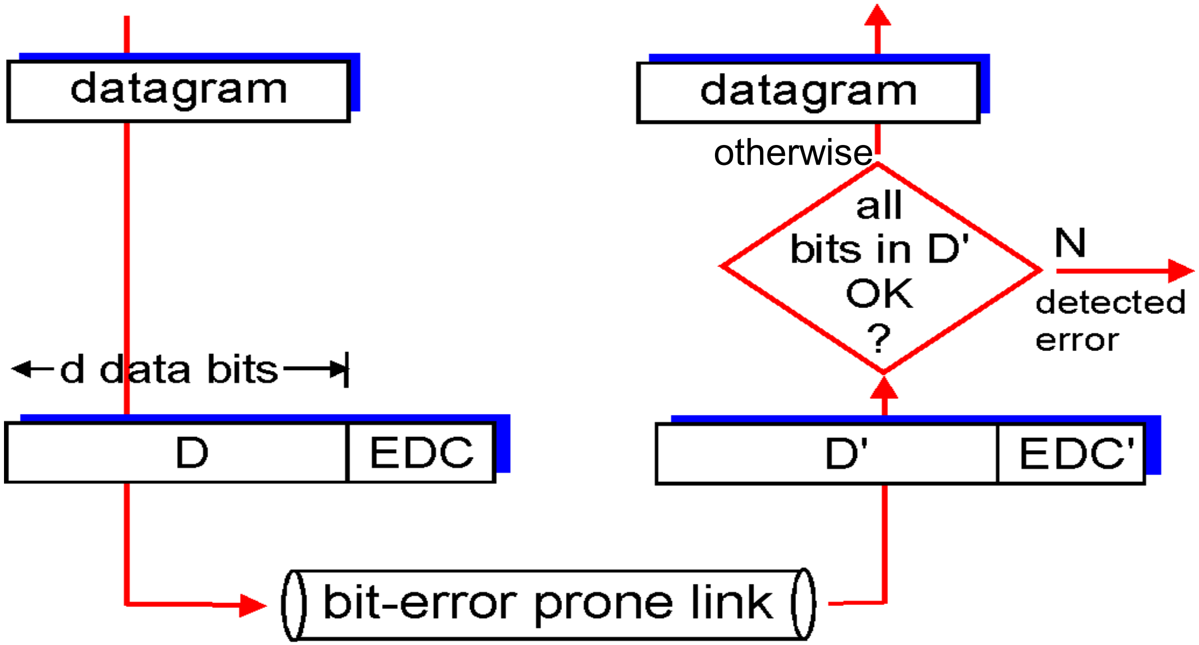


- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, rdt, flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc
  - extracts datagram, passes to upper layer at receiving side

Error detection

EDC= Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include header fields

- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction

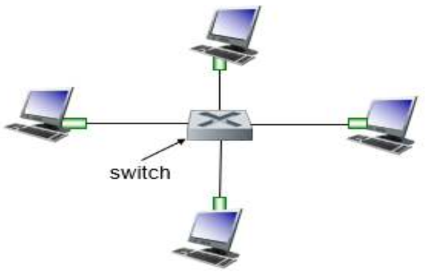


Multiple access links, protocols

~~///EA Mon 9 Nov~~

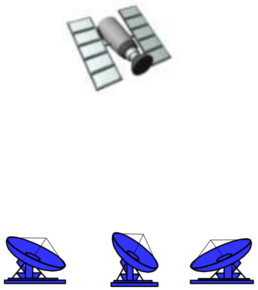
two types of "links":

- point-to-point protocol (PPP)
  - PPP for dial-up access
  - point-to-point link between Ethernet switch, host
- *broadcast (shared wire or medium)*
  - old-fashioned Ethernet
  - upstream HFC (Hybrid Fiber Coaxial)*
  - 802.3 Wired LAN   LAN: Local Area Network
  - 802.11 wireless LAN.



shared wire
(e.g., Wired LAN
802.3 Ethernet)

shared RF
(e.g., Wireless LAN
802.11 WiFi)



shared RF
(satellite)

humans at a
cocktail party
(shared air, acoustical)

Multiple ACcess (MAC*) protocols ~~///C8A 15Nov~~

- Single-shared broadcast channel
- Two or more simultaneous transmissions by nodes: interference
  - *collision* if node receives two or more signals at the same time

multiple access (MAC) protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

*MAC: Multiple Access , Media Access

An ideal multiple access (MAC*) protocol*

given: broadcast channel of rate R bps

Desiderata (Plan):

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

*MAC: Multiple Access , Media Access

** MAC protocols: taxonomy

three broad classes:

- *channel partitioning:* *FDMA, TDMA, CDMA*
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use

**TDMA: Time Division Multiple Access*
FDMA: Frequency Division Multiple Access
CDMA: Code Division Multiple Access

- *Random Access:* slotted ALOHA, ALOHA, CSMA, CSMA/CD, CSMA/CA
  - channel not divided, allow collisions
  - "recover" from collisions

CSMA: Carrier Sense Multiple Access,
CSMA/CD: -------------------------------, with Collision Detection
CSMA/CA: -------------------------------, with Collision Avoidance

- *Controlled Access: "taking turns "*
  - nodes take turns, but nodes with more to send can take longer turns

Random Access protocols*

- when node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- If two or more transmitting nodes at the same time ➜ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
  - Also called "Contention" access.
- examples of random access MAC protocols:
  - ALOHA
  - Slotted ALOHA
  - CSMA, CSMA/CD, CSMA/CA

**CSMA: Carrier Sense Multiple Access,*
CSMA/CD: ------------------------------, with Collision Detection
CSMA/CA: ------------------------------, with Collision Avoidance

*CSMA (Carrier Sense Multiple Access)

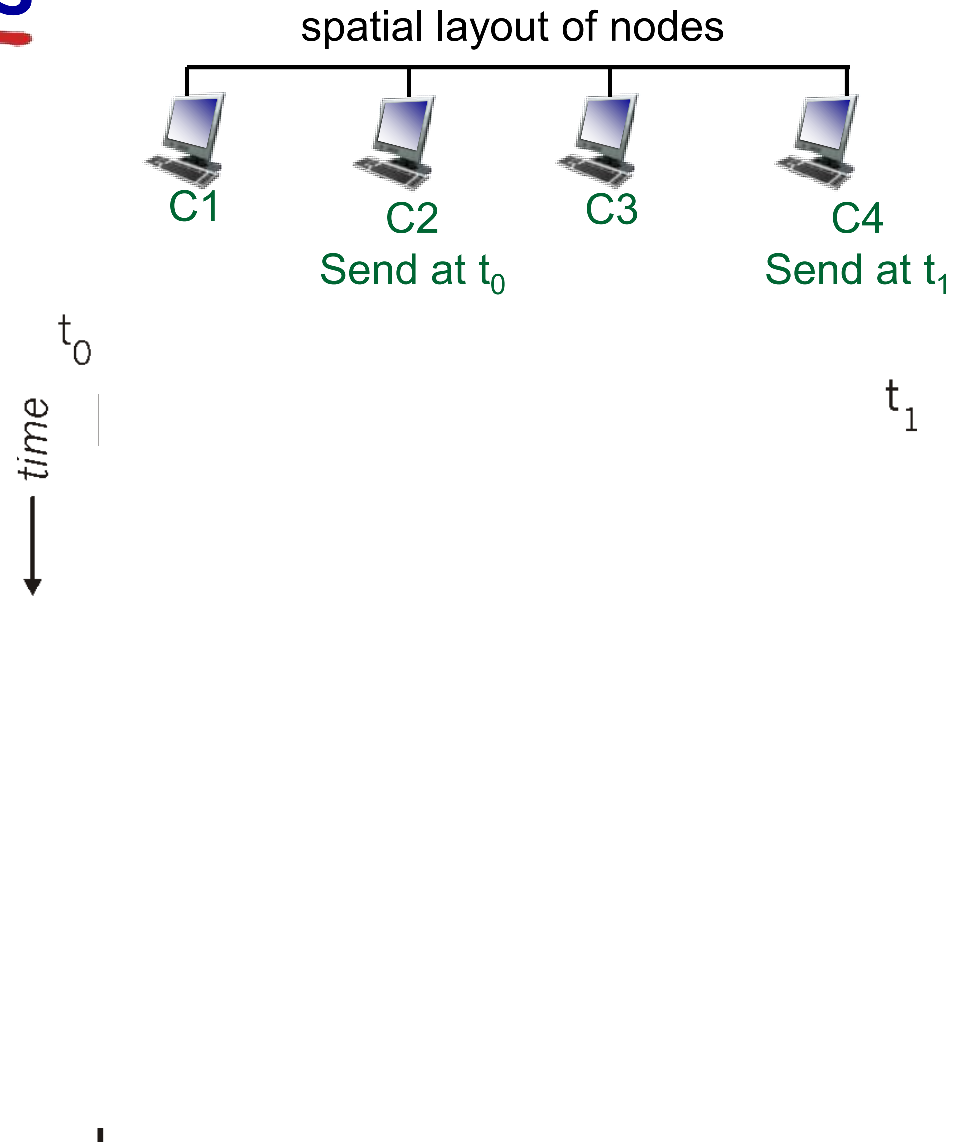
CSMA: listen before transmit:

- if channel sensed idle (free, not busy): transmit entire frame
- if channel sensed busy, defer (delay) transmission

- human analogy: don' t interrupt others!

CSMA collisions

- collisions *can* still occur: because of propagation delay, two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted
  - distance & propagation delay play role in in determining collision probability



spatial layout of nodes

C1

C2
Send at t_0

C3

C4
Send at t_1

t_0

time

t_1

More (++)

**Figure 5.12 page 455*

*CSMA/CD (collision detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted (ended), reducing channel wastage

- collision detection:
  - easy in wired LANs: How? measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength
- human analogy: the polite conversationalist

* MAC addresses and ARP** ~~///CA14&M Wed 11 Nov~~

- From Ch 4:
  - IP address: 32-bit for IPv4, and 128 bits for IPv6
    - *network-layer* address for interface
    - used for layer 3 (network layer) forwarding
- MAC (or LAN or physical or Ethernet) address:
  - function: *used 'locally" to get frame from one interface to another physically-connected interface (same network, in IP-addressing sense)*
  - 48 bit MAC address (for most LANs) burned in NIC ROM, also sometimes software settable
  - e.g.: 1A-2F-BB-76-09-AD
  - MAC address on NIC: next slide)

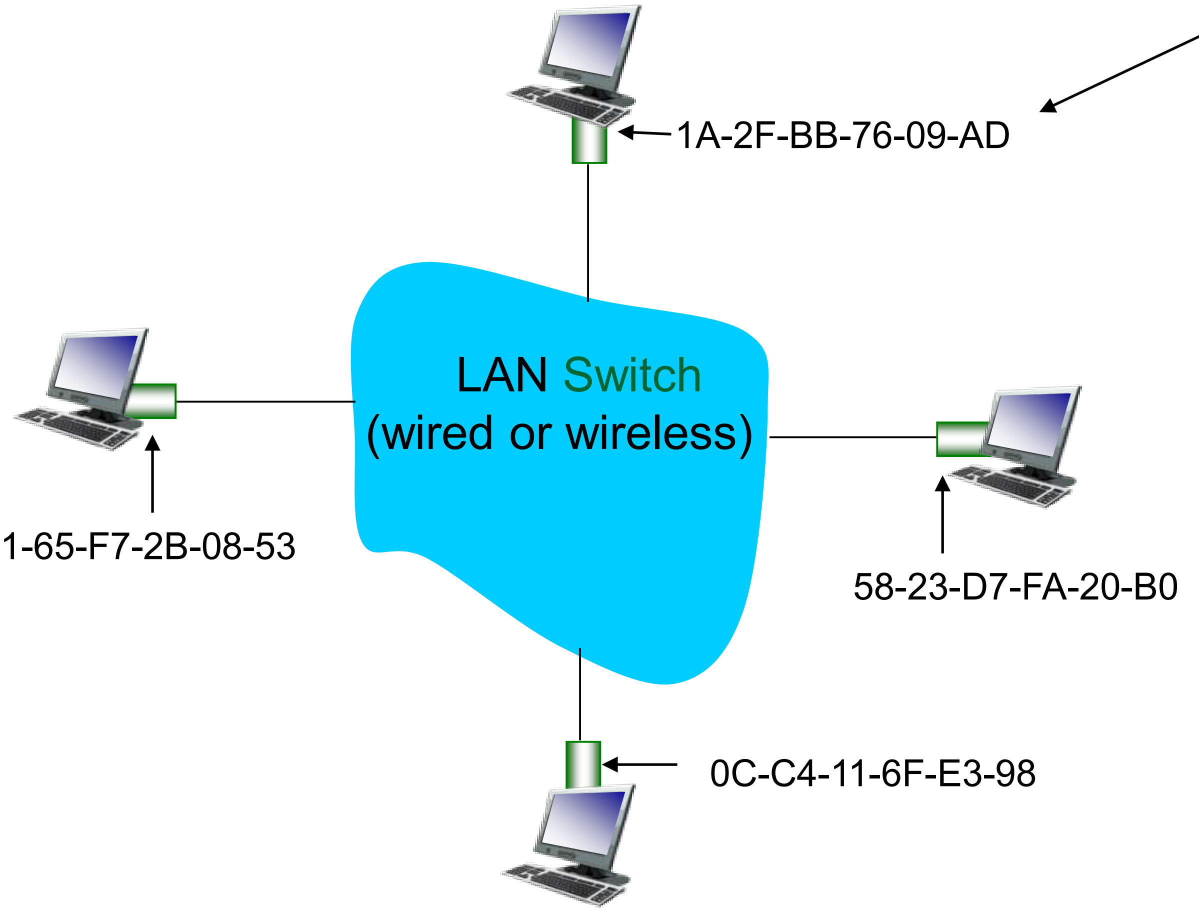
hexadecimal (base 16) notation (each "number" represents 4 bits)

**ARP: Address Resolution Protocol*

More (++)

LAN addresses and ARP

Each adapter (NIC) on LAN has unique *LAN* address called MAC address



MAC Address
12 Hexadecimal Digits
(48 bits) binary

🟩 adapter

NIC
Network Interface Card

**ARP: Address resolution protocol*

LAN addresses (more)

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- analogy:
  - MAC address: like Social Security Number
  - IP address: like postal address
- MAC flat address ➜ portability
  - can move LAN card from one LAN to another
- IP hierarchical address *not* portable
  - address depends on IP subnet to which node is attached

*ARP: Address Resolution Protocol

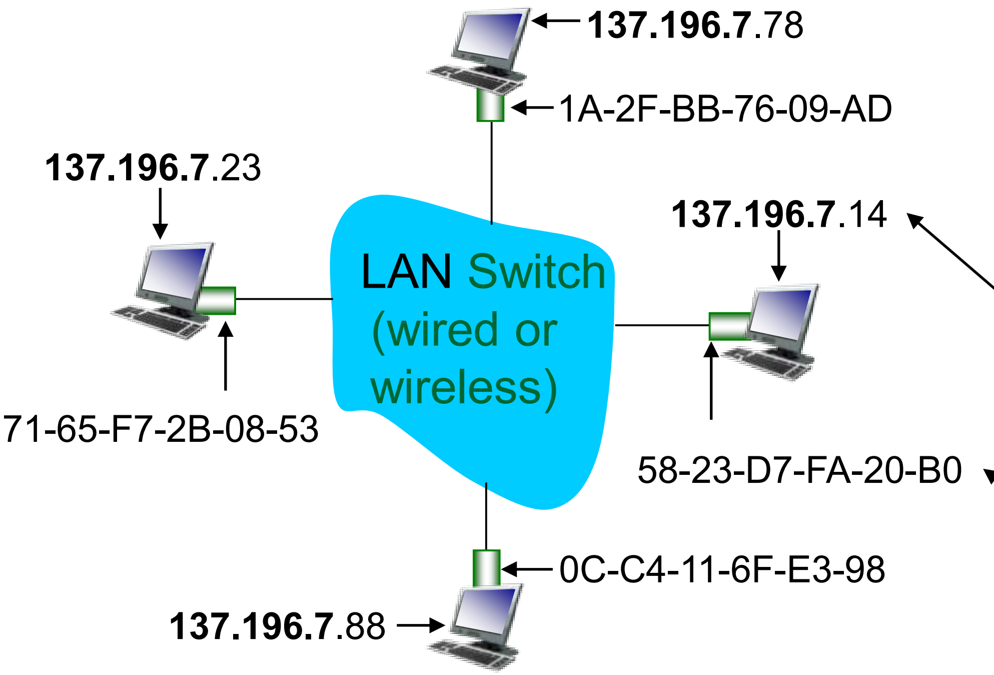
Question: how to determine interface's MAC address, knowing its IP address?

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)



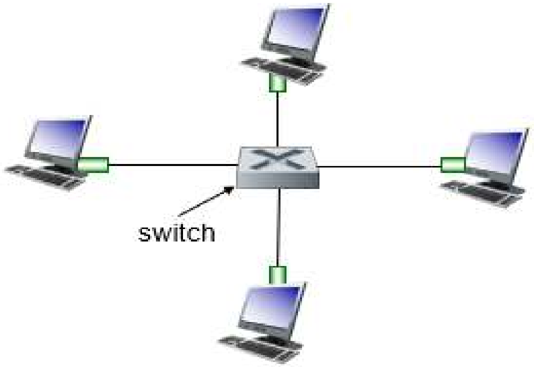
IPv4 Address
32 bits
4 Decimal Numbers

MAC Address
12 Hexadecimal Digits
(48 bits) binary

NNNH
Subnet Mask: 255.255.255.0, OR: 137.196.7.0/24
NID: 137.196.7.0, Broad cast add: 137.196.7.255,
Valid Host Addressing Range: 1-254.

*ARP protocol: same LAN

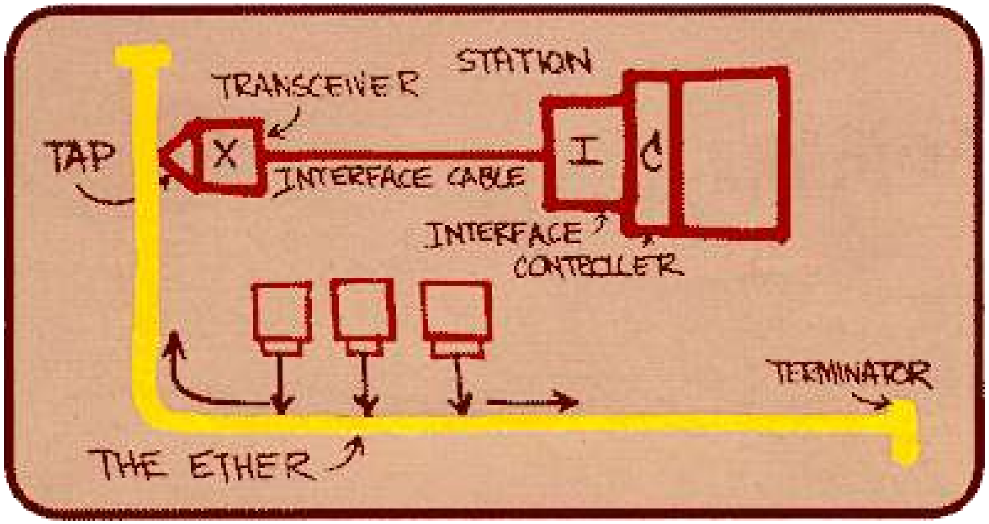
- A wants to send datagram to B
  - A knows the IP address for B
  - B' s MAC address not in A' s ARP table.
- A **broadcasts** ARP query packet, containing B's IP address
  - dest MAC address
    - = FF-FF-FF-FF-FF-FF
  - all nodes on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A' s MAC address (**unicast**)
- A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)
  - soft state: information that times out (goes away) unless refreshed
- ARP is "plug-and-play":
  - nodes create their ARP tables *without intervention from net administrator*



Examples of Link Layer Protocols: Ethernet (802.3) ///EA Wed 11 Nov

"dominant" wired LAN technology:

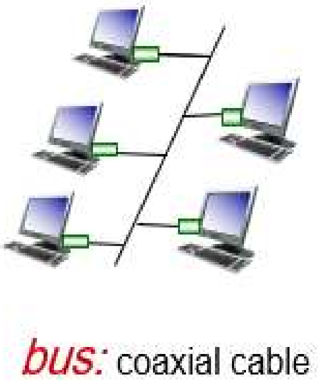
- cheap $20 for NIC
- first widely used LAN technology
- simpler, cheaper than token LANs and ATM
- kept up with speed race: 10 Mbps – 10 Gbps

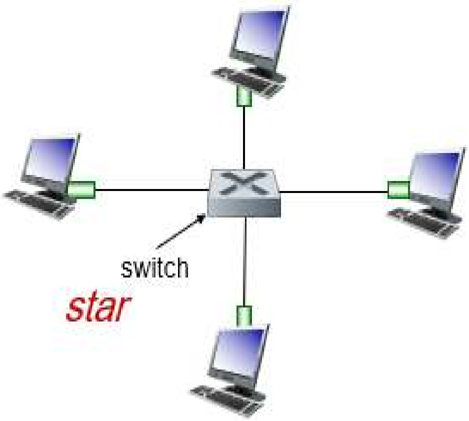


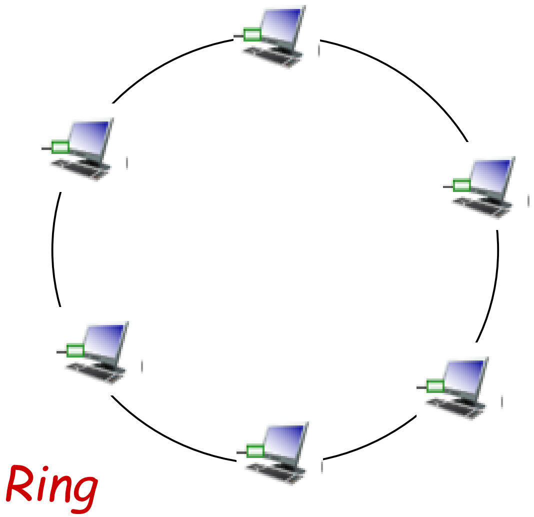
Metcalfe's Ethernet sketch

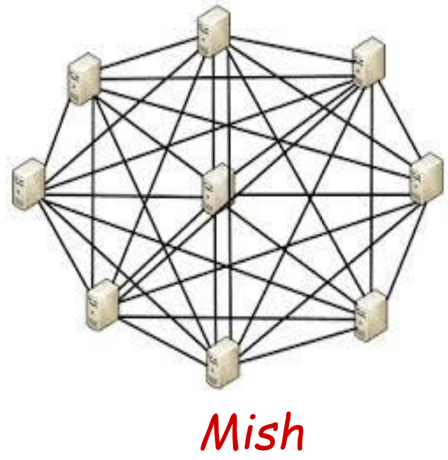
*Ethernet: physical topology

- *bus: old.* popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
- Ring: old
- *star:* popular today
  - active *switch* in center
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)



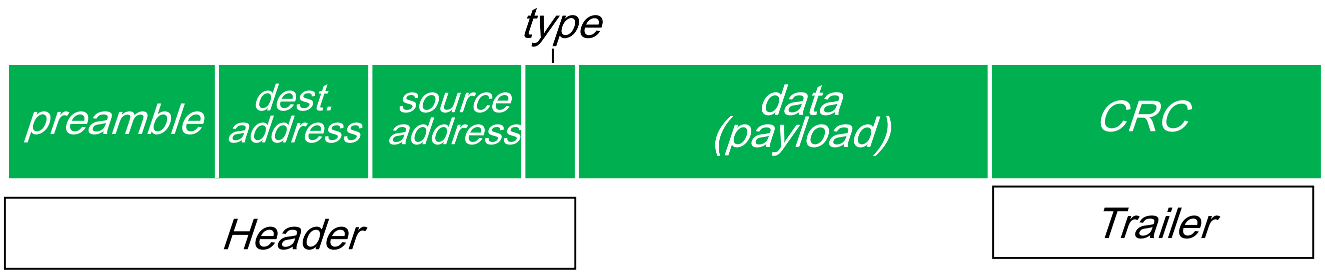






*Ethernet frame structure

sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

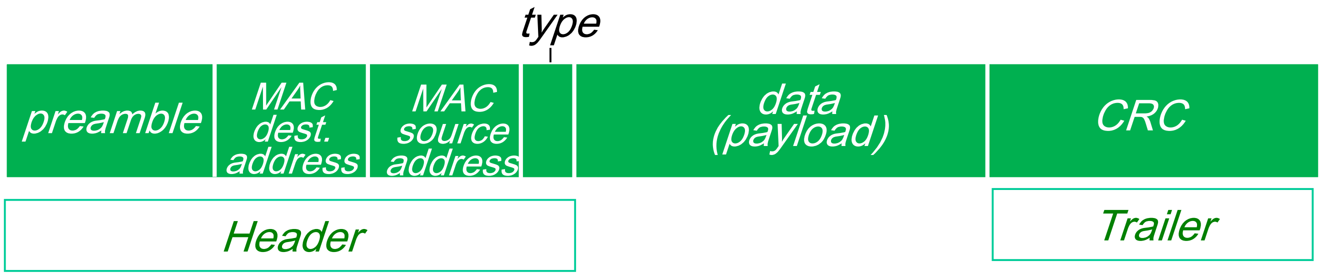


preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
  - = 10101010 10101010 10101010 10101010 10101010 10101010 10101010 // 10101011
- used to synchronize receiver, sender clock rates

Ethernet frame structure (cont.)*

- *MAC addresses:* 6 byte source, destination MAC addresses
  - if adapter receives frame with matching destination address, or with broadcast address (e.g. ARP packet), it passes data in frame to network layer protocol
  - otherwise, adapter discards frame
- *type:* indicates higher layer protocol (mostly IP but others possible, e.g., Novell IPX, AppleTalk)
- *CRC:* cyclic redundancy check at receiver
  - error detected: frame is dropped
- *Payload*: 46-1500 Byte.

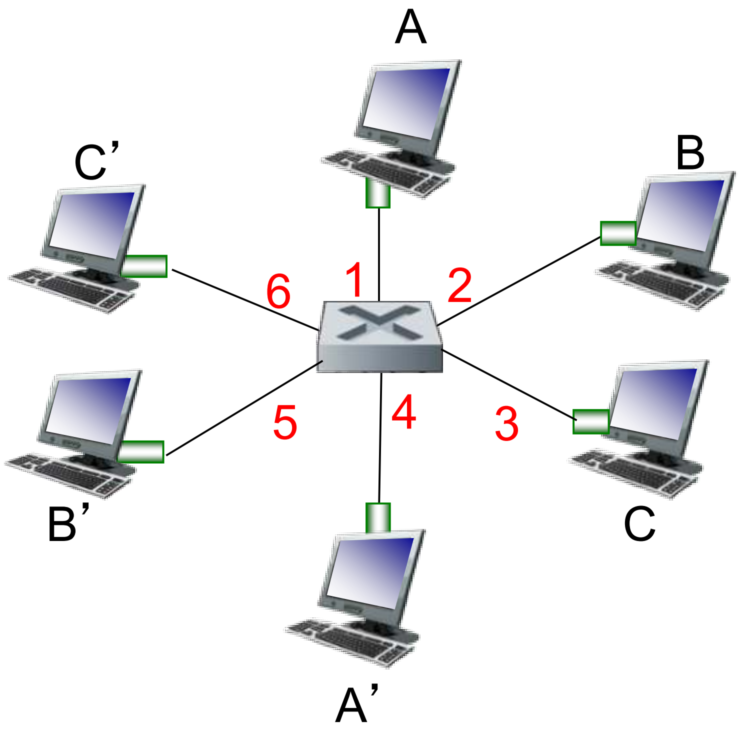


Ethernet switch

- link-layer device: takes an *active* role
  - store, forward Ethernet frames
  - examine incoming frame' s MAC address, selectively forward frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- *transparent*
  - hosts are unaware of presence of switches
- *plug-and-play, self-learning*
  - switches do not need to be configured

Switch: *multiple* simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, but no collisions; full duplex
  - each link is its own collision domain
- *switching:* A-to-A' and B-to-B' can transmit simultaneously, without collisions



switch with six interfaces (1,2,3,4,5,6)

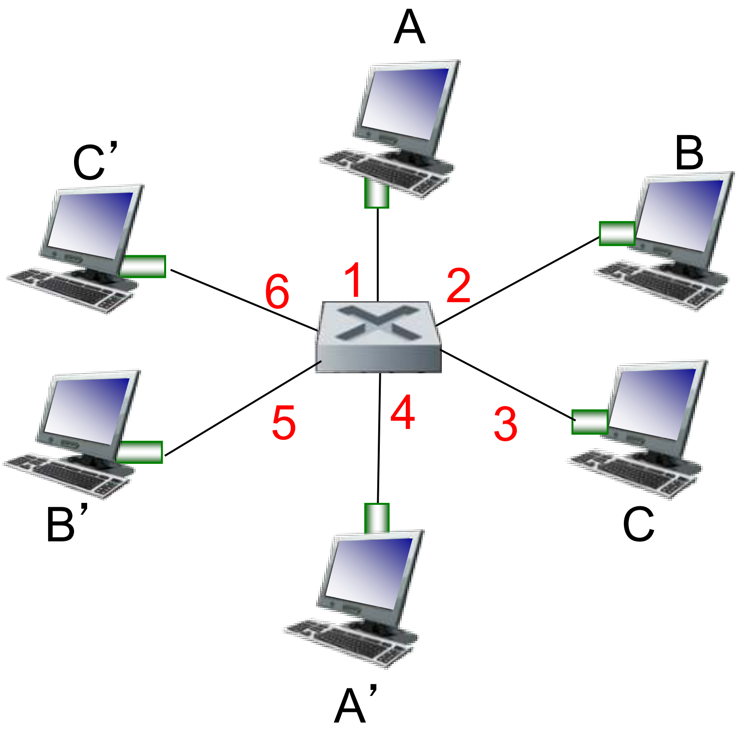
Switch forwarding table

Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

- A: *each switch has a switch table, each entry:*
  - *(MAC address of host, interface to reach host, time stamp)*
  - *looks like a routing table!*

Q: how are entries created, maintained in switch table?

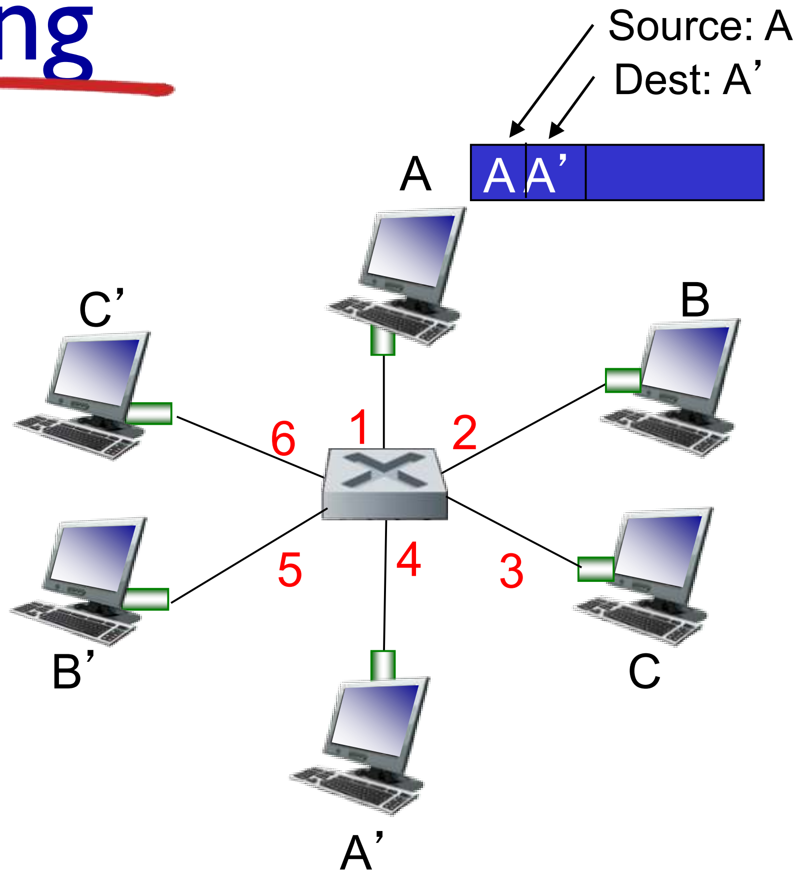
- *something like a routing protocol?*



switch with six interfaces (1,2,3,4,5,6)

Switch: self-learning

- switch *learns* which hosts can be reached through which interfaces
  - when frame received, switch "learns" location of sender: incoming LAN segment
  - records sender/location pair in switch table

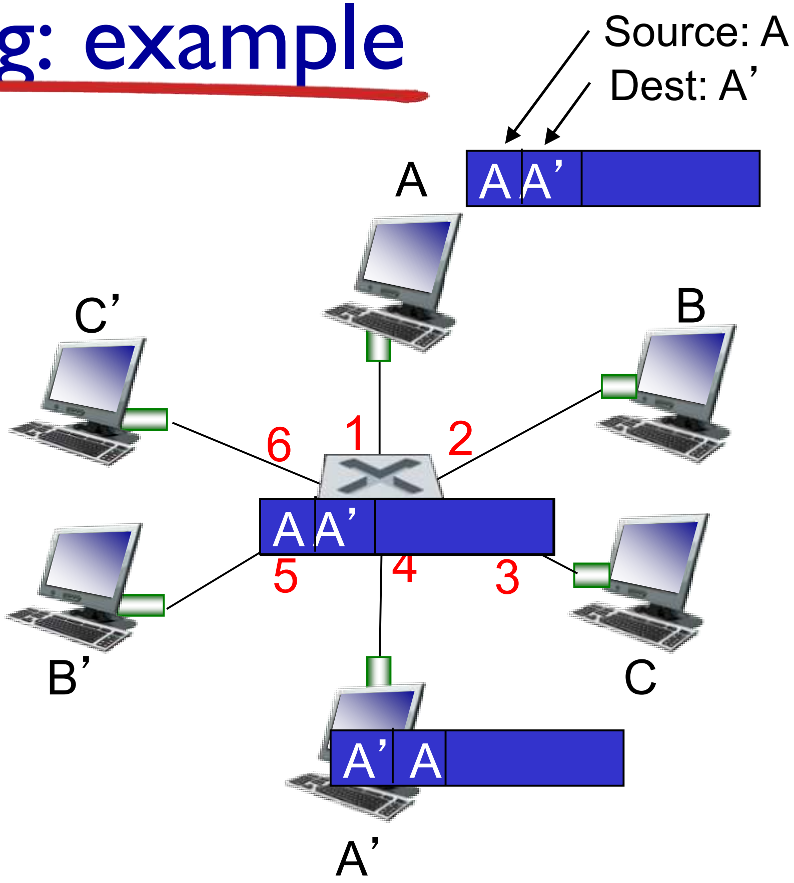


MAC addr	interface	TTL
A	*1*	*60*

Switch table (initially empty)

Self-learning, forwarding: example

- frame destination, A', locaton unknown: *flood*
- destination A location known: *selectively send on just one link*

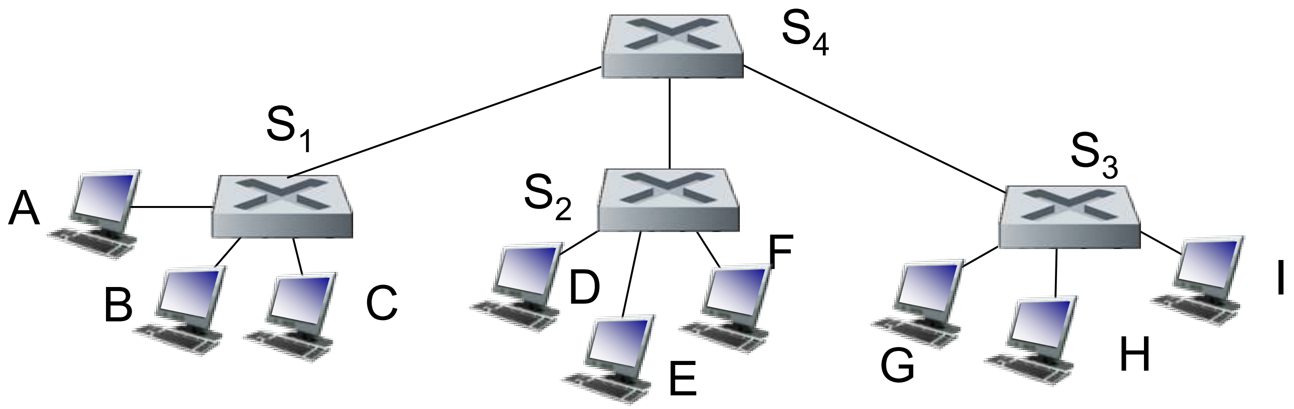


MAC addr	interface	TTL
A	*1*	*60*
A'	*4*	*60*

switch table (initially empty)

Interconnecting switches

- switches can be connected together



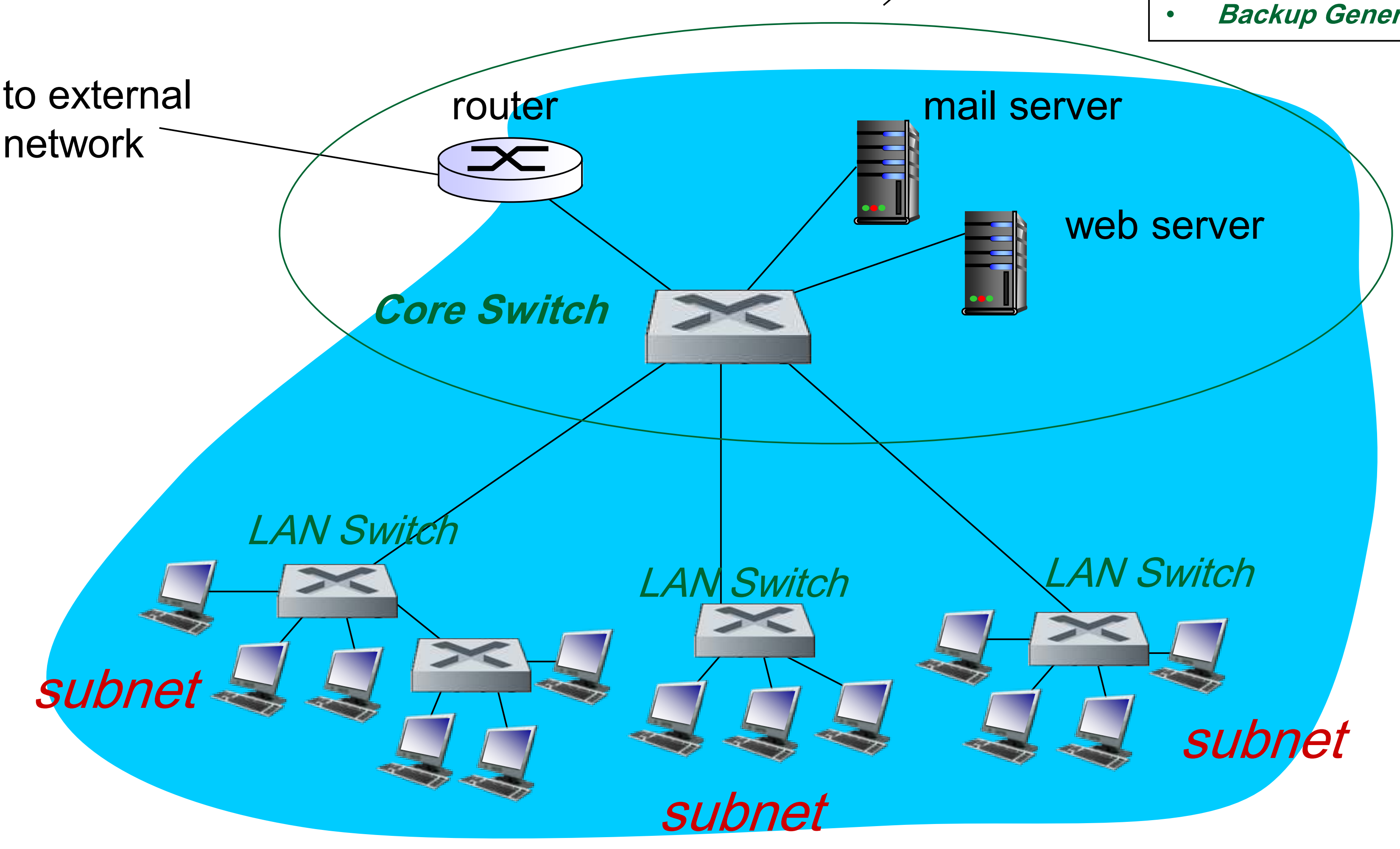
Q: sending from A to G - how does S$_1$ know to forward frame destined to F via S$_4$ and S$_3$?

- *A:* self learning! (works *exactly* the same as in single-switch case!)

*Institutional network

Data Center

- *Special room*
- *High Access security*
- *Anti-Fire GAS system*
- *Low Temp all the time*
- *Water Leakage detectors*
- *Backup Batteries*
- *Backup Generator*



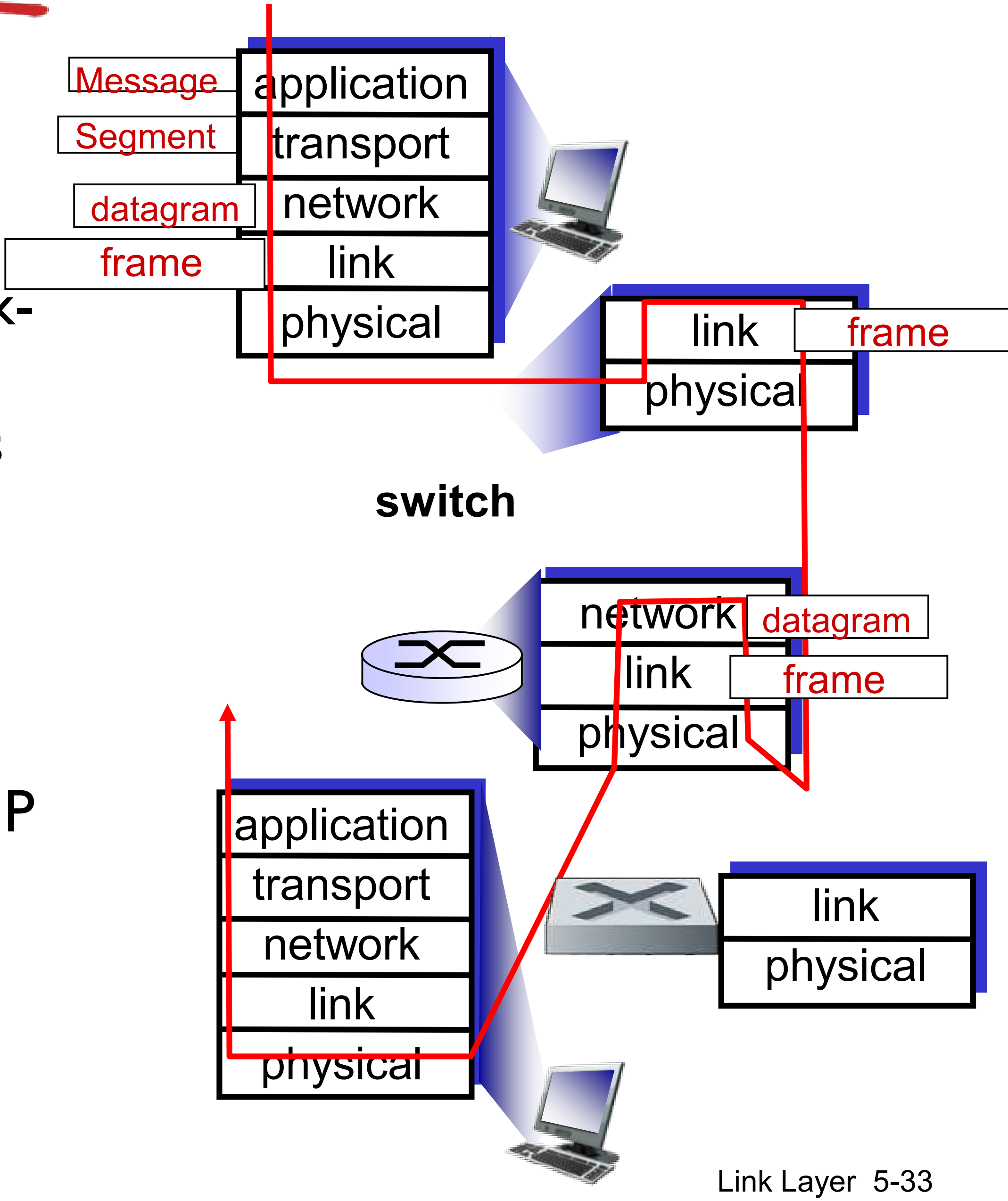
Switches vs. routers

both are store-and-forward:

- *routers:* network-layer devices (examine network-layer headers)
- *switches*: link-layer devices (examine link-layer headers)

both have forwarding tables:

- *routers:* compute tables using routing algorithms, IP addresses
- *switches:* learn forwarding table using flooding, learning, MAC addresses



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