Link Layer:
CSMA/CD, MAC addresses, ARP

Smith College, CSC 249
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MAC Address

- 32-bit IP address:
  - *network-layer* address
  - used to get datagram to destination IP subnet
- MAC (or LAN, physical, Ethernet, hardware) address:
  - function: *get frame from one interface to another physically-connected interface (same network)*
  - 48 bit MAC address (for most LANs)
    - burned in NIC ROM
    - Written out as xx-xx-xx-xx-xx-xx in 'hexadecimal,' base 16, so each numeral represents 4 bits
    - *e.g., 45-3A-CD-28-5F-40*

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MAC Addresses in Hexadecimal

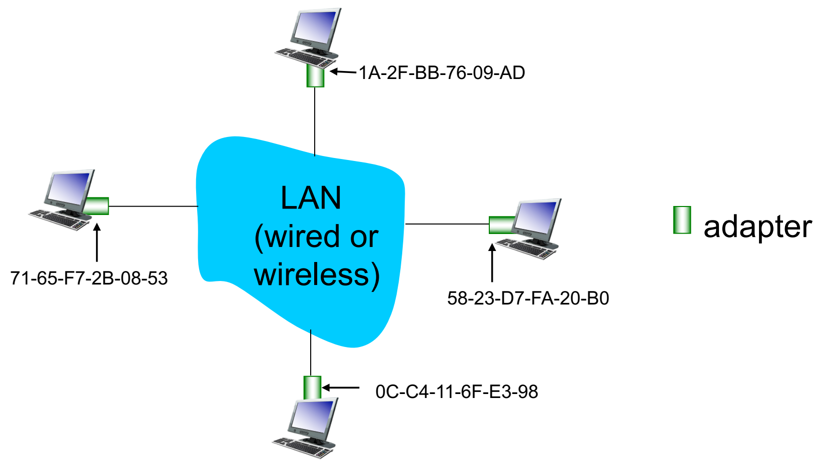
- 1001 1000 0110 1110 1011 1010 in base 2
- 9 8 6 14 __ __ in decimal for each nibble
- 9 8 6 E __ __ in hexadecimal

MAC v. IP Addresses

- MAC address allocation administered by IEEE
- Each manufacturer buys a portion of MAC address space (to assure uniqueness)
- MAC flat address ➜ portability
  - can move card from one LAN to another
  - no hierarchical structure to addresses
- Note: IP addresses are NOT portable
  - Hierarchical; and geographic significance
  - Depends on IP subnet to which node is attached

MAC addresses and ARP

each adapter on a LAN has unique *MAC* address



Delivering a datagram: Single Subnet

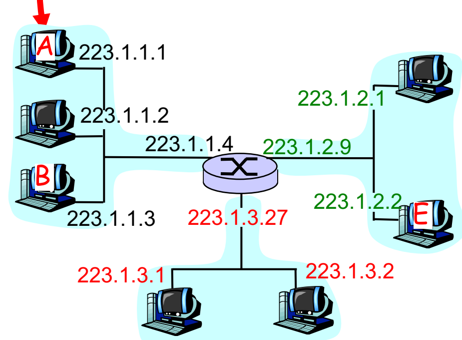
misc fields	223.1.1.1	223.1.1.3	data

Starting at A, given IP datagram addressed to B:

- Look up IP address of B
- Find B is on same subnet as A
- Link layer will send datagram directly to B inside link-layer frame
  - B and A are directly connected
- Remember definition of SUBNET?

routing table in A

Dest. Net.	next router	Nhops
223.1.1		1
223.1.2	223.1.1.4	2
223.1.3	223.1.1.4	2



Delivering a datagram: Different Subnet

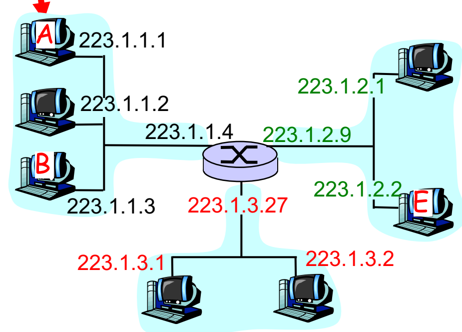
misc fields	223.1.1.1	223.1.2.2	data

Starting at A, dest. E:

- Look up network address of E
- E on *different* subnet
  - A, E not directly attached
- Routing table: next hop router to E is 223.1.1.4
- Link layer sends datagram to router 223.1.1.4 inside link-layer frame
- Datagram arrives at 223.1.1.4
- Process continues.....

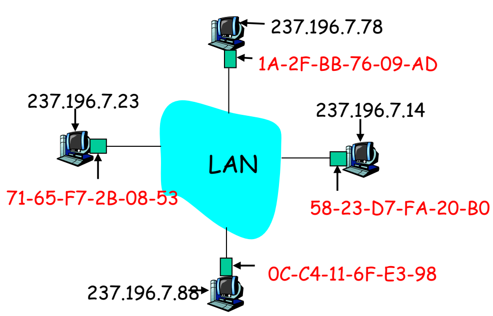
routing table in A

Dest. Net.	next router	Nhops
223.1.1		1
223.1.2	223.1.1.4	2
223.1.3	223.1.1.4	2



ARP: Address Resolution Protocol

Question: how to determine MAC address of receiver knowing receiver's IP address?



- Each node (Host, Router) on LAN maintains an ARP table
- ARP Table: IP/MAC address mappings for some LAN nodes

< IP address; MAC address; TTL>

  - TTL ~ 20 minutes
- Find more mappings via ARP query and response messages and by receiving frames

Slide Example: Creating an ARP Table

For the same LAN segment:

- 'A' wants to send datagram to 'B,' and 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 machines on LAN receive ARP query
  - ARP Packets contain IP & MAC address for source and destination
  - A caches (saves) IP-to-MAC address pair in its ARP table
- B receives ARP packet, responds to A with its (B's) MAC address
  - **Why does only 'B' respond?**
  - frame sent directly to A's MAC address (not broadcast)
- ARP is "plug-and-play":
  - nodes create their ARP tables *without intervention from net administrator*

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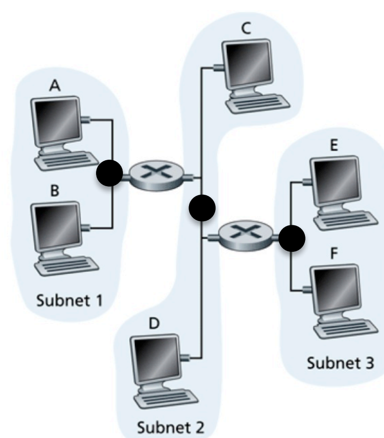
Question on Handout

- Provide MAC address and IP addresses for the interfaces at Host A, both routers, and Host F.
- Simplify the MAC addresses by writing them as all the same number (or letter) for all 6 bytes.
- For Subnet 1, use addresses of the form 192.168.1.xxx,
- For Subnet 2, 192.168.2.xxx
- For Subnet 3, 192.168.3.xxx.
- (The large dots are switches.) *… to be discussed*



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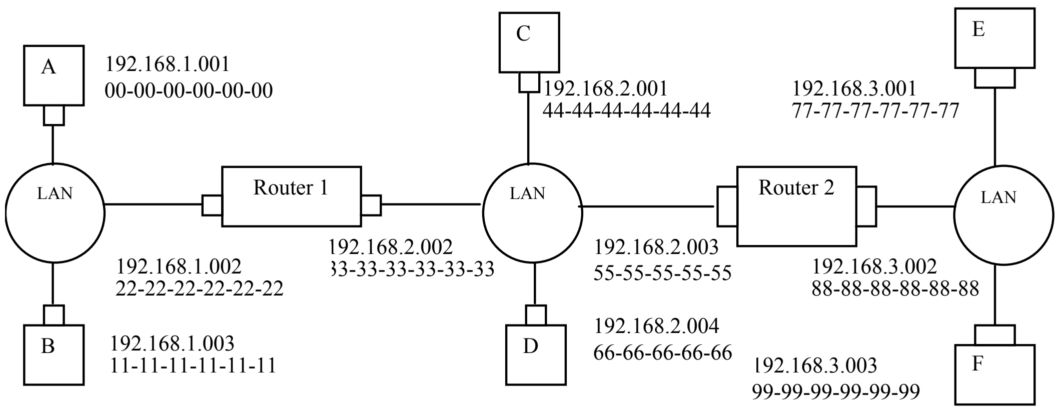
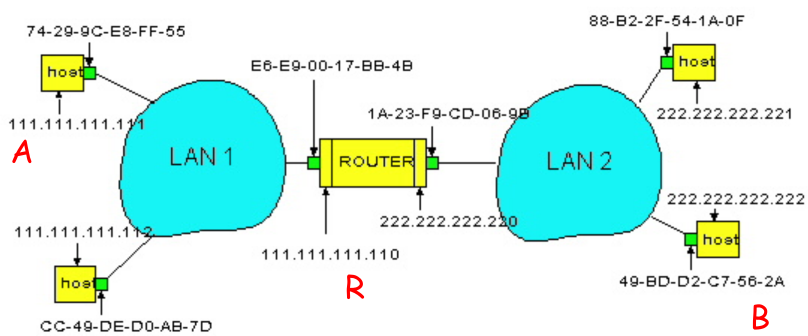
Question on Handout



Slide Example: Sending to another LAN

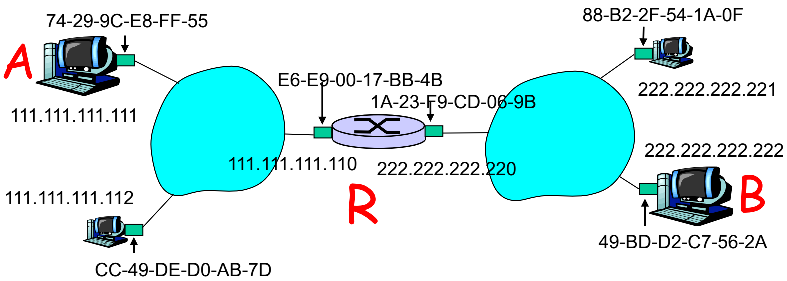
Send datagram from A to B via R

- assume A knows B's IP address



- Two ARP tables in router R, one for each IP network (LAN)

1) A creates IP datagram with source A, destination B
2) A uses ARP to get R's MAC address for 111.111.111.110
3) A creates link-layer frame with R's MAC address as destintaion, frame contains A-to-B IP datagram
4) A's adapter sends frame…
5) R's adapter receives frame…



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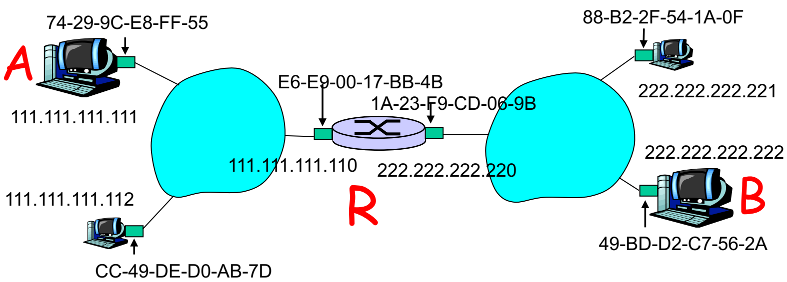
4) …A's adapter sends frame
5) …R's adapter receives frame
6) R removes IP datagram from Ethernet frame, sees it's destined to B
7) R uses ARP to get B's MAC address
8) R creates frame containing A-to-B IP datagram, and sends it to B



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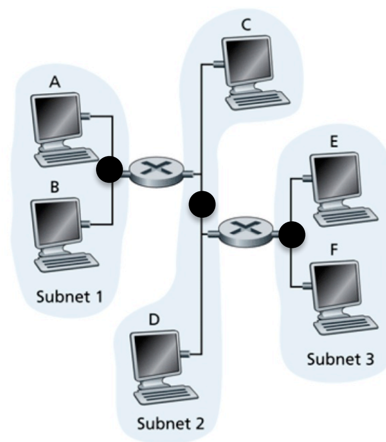
Problem 3 on Handout

- Suppose Host A sends a datagram to F.
- Give the source and destination MAC addresses in the frame encapsulating the IP datagram as the frame is transmitted
- from A to the left router,
- from the left router to the right router
- from the right router to F.
- Also give the source and destination IP addresses of the IP datagram encapsulated within the frame at each of these points in time.



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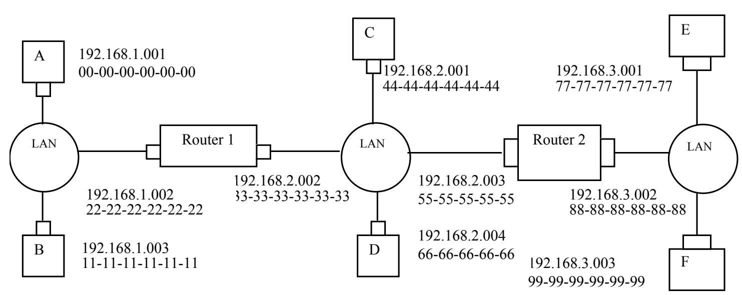
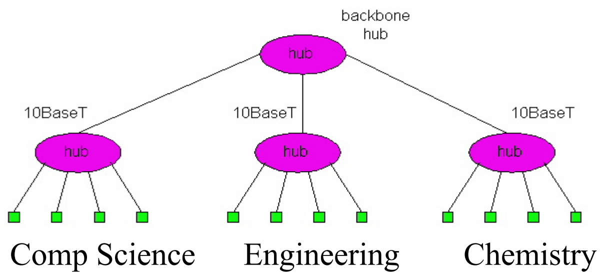
Problem 3 on Handout

- Host A sends a datagram to F.
- Give the source and destination MAC addresses
  - from A to the left router: S MAC____________________; D MAC ____________________
  - from the left router to the right router: S MAC_______________; D MAC ________________
  - from the right router to F: S MAC____________________; D MAC _____________________
- Also give the source and destination IP addresses of the IP datagram encapsulated within the frame at each of these points in time.

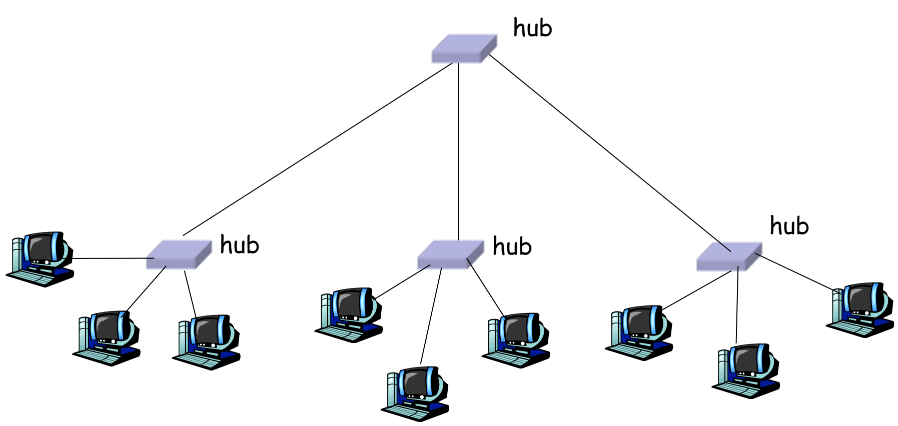


Ethernet Connections: Hubs

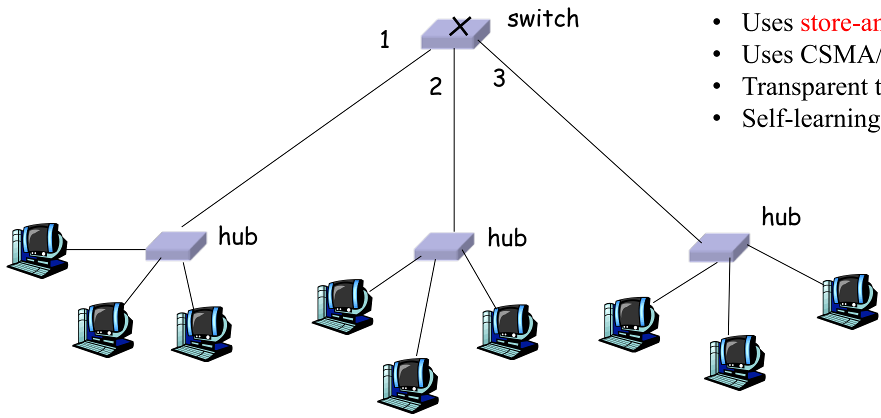
- Hubs repeat received bits on one interface to all other interfaces
  - …at the same rate
  - …no buffering (no store-and-forward)
  - …no CSMA/CD at hub
- A physical layer device – examines no headers
  - Extends max distance between nodes – **good**
  - Creates one large collision domain – **bad**
  - Cannot interconnect different physical media



Interconnecting with hubs



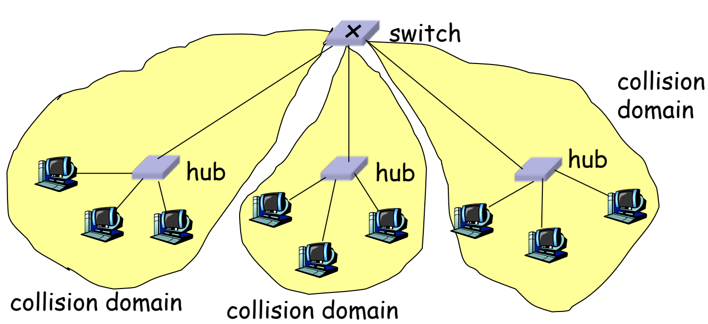
Interconnecting with switches



- Selectively forwards frames based on MAC destination address
- Uses store-and-forward
- Uses CSMA/CD
- Transparent to hosts, and so to IP
- Self-learning to build address table

Switch: traffic isolation

- …Switch installation breaks subnet into LAN segments
- Switch filters packets:
  - same-LAN-segment frames not usually forwarded onto other LAN segments
  - segments become separate collision domains

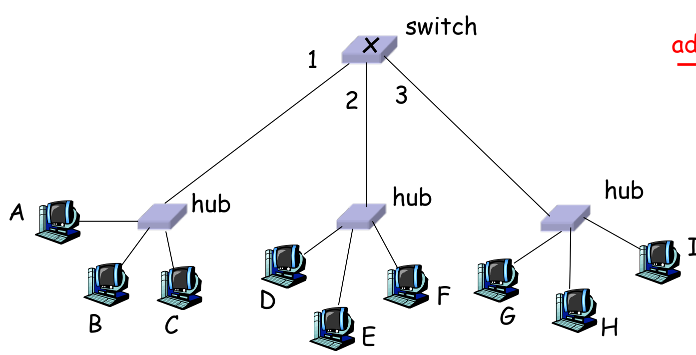


Switches: Self learning

- A switch has a switch table
- An entry in a switch table contains:
  - (MAC Address, Interface, Time Stamp)
  - stale entries in table dropped (TTL can be 60 min)
- 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

Switch table example

Suppose C sends frame to B

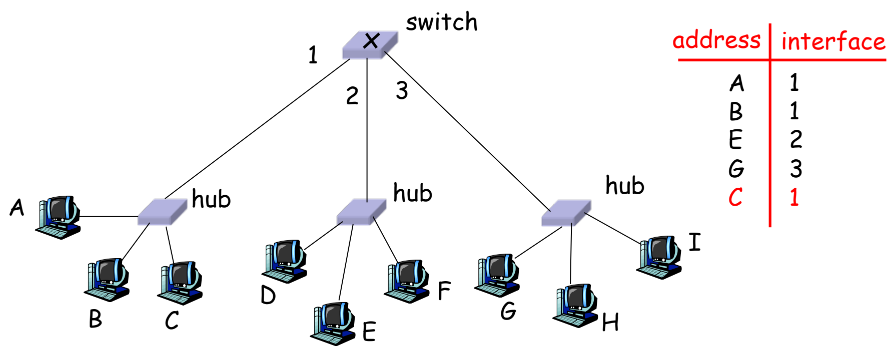


address	interface
A	1
B	1
E	2
G	3
C	1

- Switch receives frame from from C
  - Notes that B and C are in same segment
  - Switch does nothing

Switch example

Suppose C sends frame **to D**



- Switch receives frame from from C
  - Notes in 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; (but nothing is added to the table)

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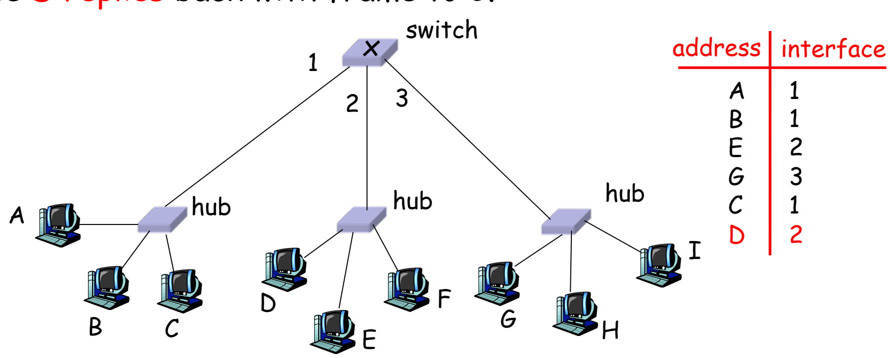
Switch example

Suppose D replies back with frame to C.



- Switch receives frame from from D
  - Notes in switch table that D is on interface 2
  - Because C is in table, switch forwards frame only to interface 1
- Frame received by C

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Problem 4 (on handout)

- Replace the router between subnets 1 and 2 with a switch S1, and label the router between 2 and 3 as R l.
- Consider sending an IP datagram from Host E to Host F. Will Host E ask router R l to help forward the datagram? Why? In the Ethernet frame containing the IP datagram, what are the source and destination IP and MAC addresses?
- Suppose E would like to send an IP datagram to B, and assume that E's ARP cache does not contain B's MAC address. Will B perform an ARP query to find B's MAC address? Why? In the Ethernet frame (containing the IP datagram destined to B) that is delivered to router R 1, what are the source and destination IP and MAC addresses'?

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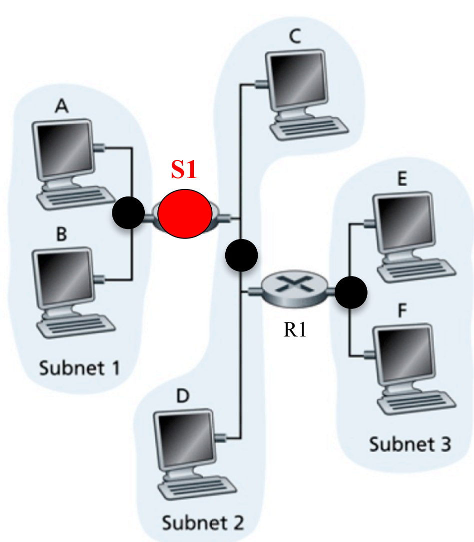
Figure for Question



- From Host E to Host F. Will Host E ask router R l to help? What are the source and destination IP and MAC addresses?
- Host E to Host B, and assume that E's ARP cache does not contain B's MAC address. Will B perform an ARP query? In the Ethernet frame (withthe IP datagram to B) that is delivered to router R 1, what are the source and destination IP and MAC addresses'?

Problem 4 (on handout)

- Suppose Host A would like to send an IP datagram to Host B, and neither A's ARP cache contains B's MAC address nor does B's ARP cache contain A's MAC address. Further suppose that the switch S1's forwarding table contains entries for Host B and router R l only. Thus, A will broadcast an ARP request message.
  - What actions will switch S1 perform once it receives the ARP request message?
  - Will router R1 also receive this ARP request message?
  - If so, will R1 forward the message to Subnet 3?
  - Once Host B receives this ARP request message, it will send back to Host A an ARP response message. But will it send an ARP query message to ask for A's MAC address? Why?
  - What will switch S1 do once it receives an ARP response message from Host B?

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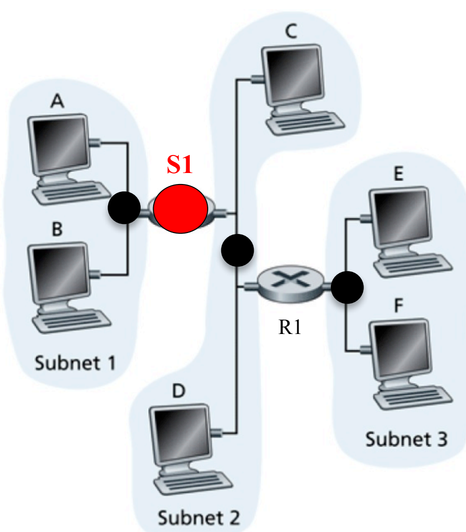
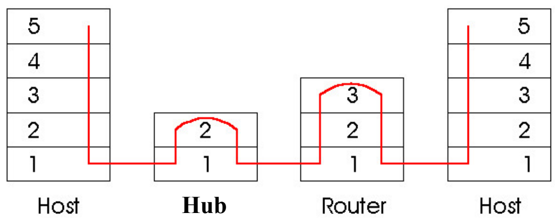
Figure for Question



- Host A to Host B. A's ARP cache does not contain B's MAC address. B's ARP cache does not contain A's MAC address. Assume switch S1's forwarding table contains entries for Host B and router R l only. Thus, A will broadcast an ARP request message.
  - What actions will switch S1 perform once it receives the ARP request message?
  - Will router R1 also receive this ARP request message?
  - If so, will R1 forward the message to Subnet 3?
  - Once Host B receives this ARP request message, it will send back to Host A an ARP response message. But will it send an ARP query message to ask for A's MAC address? Why?
  - What will switch S1 do once it receives an ARP response message from Host B?

Switches vs. Routers

- both store-and-forward devices
  - Routers are network layer devices
  - Switches are link layer devices
  - Hubs are physical layer repeaters
- Routers maintain routing tables, implement routing algorithms
- Switches maintain switch tables, implement filtering, learning algorithms



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Summary comparison

- Hub
  -
  -
- Switch
  -
  -
- Router
  -
  -

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Chapter 6: Summary

- Data link layer services:
  - error detection and correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
  - Plug-and-play for ARP and switch table learning
- Link layer technologies
  - Ethernet
  - switched LANS (switches v. hubs)

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