Module M3

CPSC 317

October 2, 2020

(updated October 8, 2020)

Learning Goals

A. Link Layer

- Explain the purpose of the link layer, and the five type of services the link layer provides.
- Understand the basic types of mediums (point-to-point, broadcast) and what is meant by "access control"
- Explain why the link layer may use "error correction".
- Know three techniques for error detection: parity (1D and 2D), checksumming, CRC.
- Understand what errors can be detected and corrected in 2D parity checking.
- Advantages of CRC over parity checking and checksumming.
- Know the general structure of link layer "frames".
- Know the basic differences between a switch and a router.
- Understand link layer addressing, MAC addresses.

B. ARP

- What is the purpose of ARP
- Enumerate the steps to resolve an IP address on a LAN with ARP
- How is ARP implemented at Layer two.
- Describe the steps to send a datagram to one LAN to another LAN, assuming you need to resolve the IP addresses.
- Know how to perform a layer 2 broadcast.

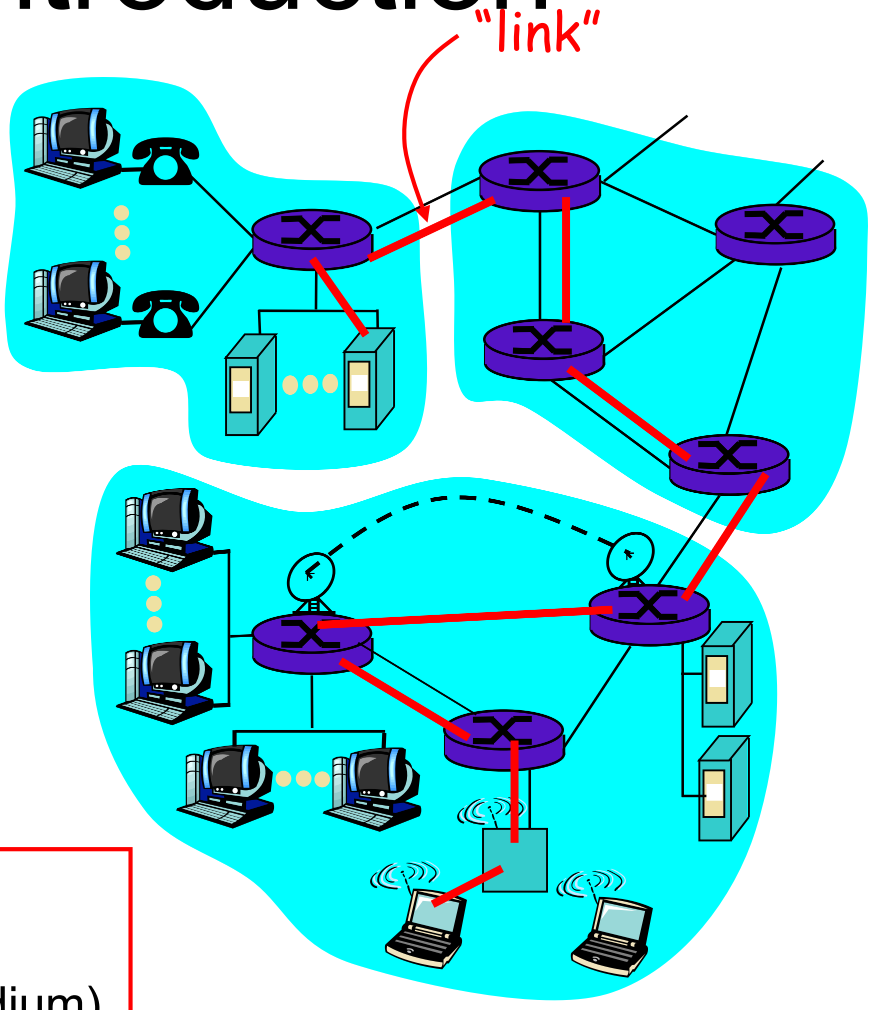
C. DHCP

- Describe the purpose of DHCP
- Trace the four steps to get an IP address for a particular interface on a LAN
- Know the configuration of DHCP on a LAN and the configuration information issued to support IP.
- Know the difference between a static and dynamic address, and the notion of leasing an IP.
- Understand the reason broadcast is needed.

Link Layer: Introduction

Some terminology:

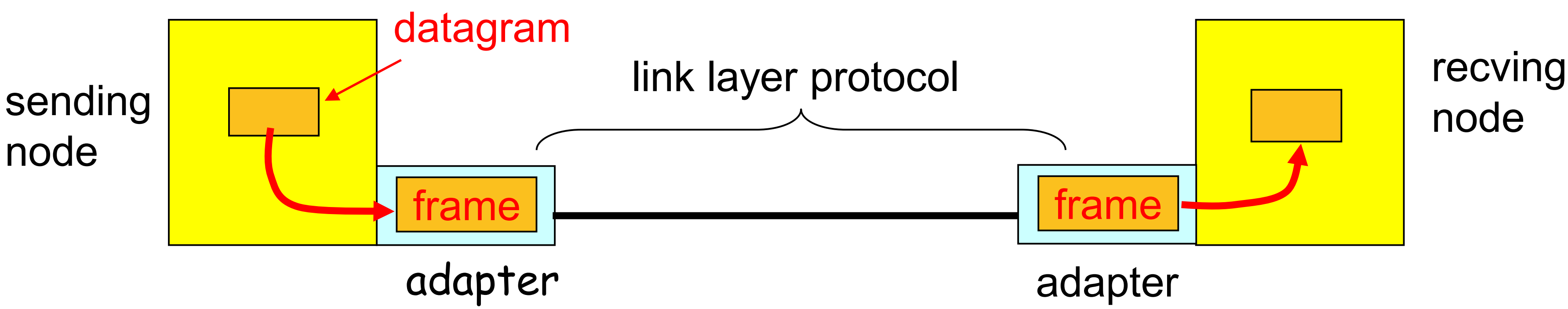
- hosts and routers are **nodes**
- communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
  - LANs
- layer-2 packet is a **frame**, encapsulates datagram



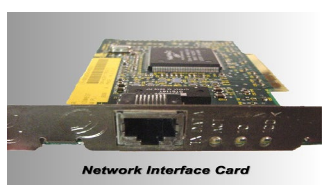
data-link layer has responsibility of transferring datagram from one node to adjacent node over a link (physical medium)

PHYSICAL PIECES

Adaptors Communicating



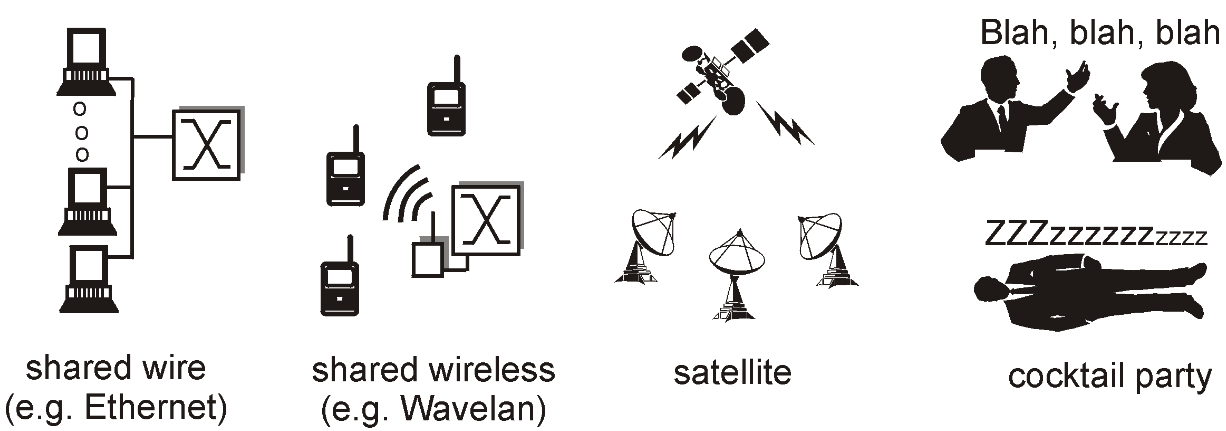
- link layer implemented in "adaptor" (aka NIC)
  - Ethernet card, PCMCI card, 802.11 card
- sending side
- receiving side
- adapter is semi-autonomous
- link & physical layers



Multiple Access Links and Protocols

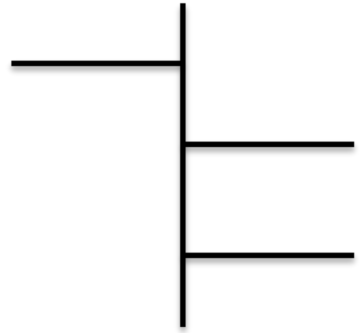
Two types of "links":

- point-to-point
  - PPP for dial-up access
  - point-to-point link between two routers
- broadcast (shared wire or medium)
  - traditional Ethernet
  - upstream HFC
  - 802.11 wireless LAN

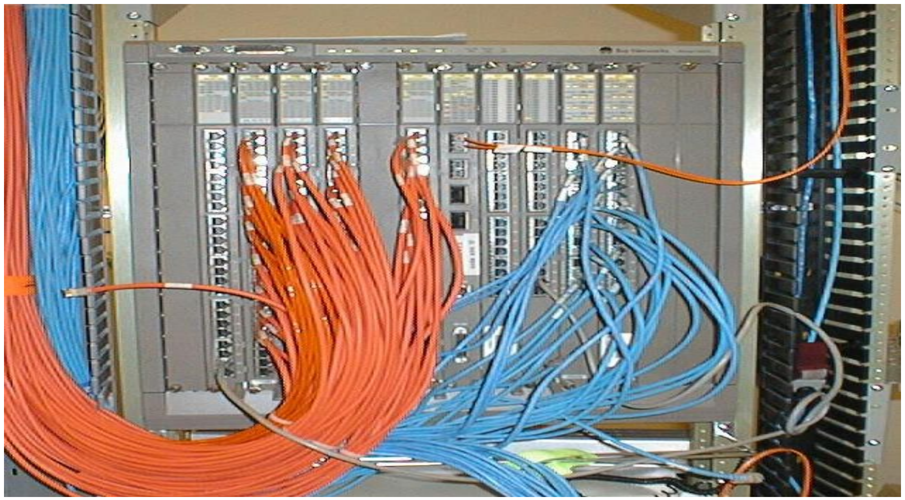


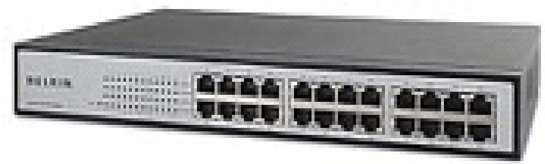
Switches (Layer 2, device)

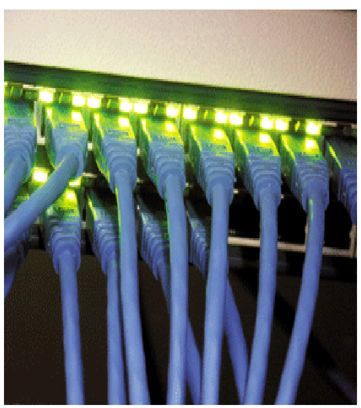
Single Broadcast Domain (link-layer or physical layer)



Network Router and Switches

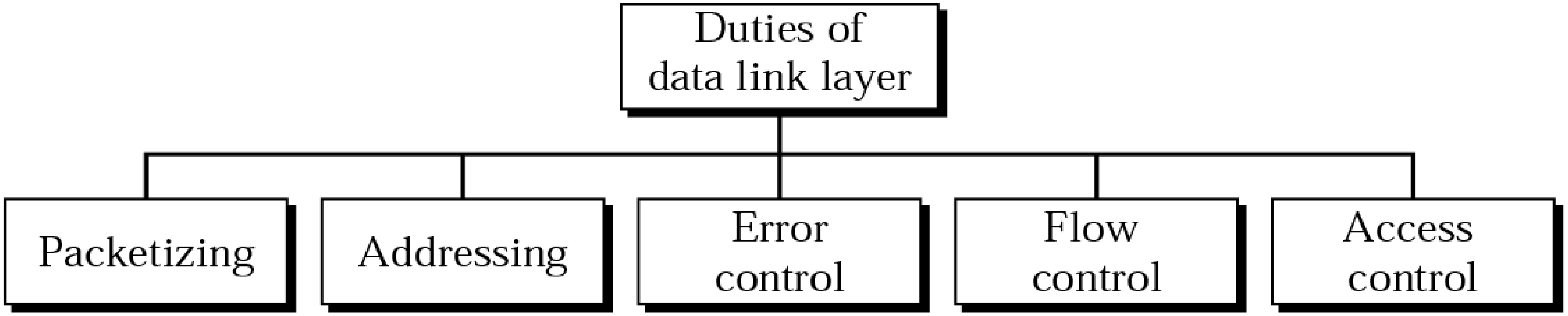






LINK LEVEL SERVICES

Link Layer Services



Link Layer Services

- Framing (or packetizing):
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
- *Addressing:* (media access control addresses)
  - "MAC" addresses used in frame headers to identify source, dest
    - different from IP address!
  - Broadcast medium (to who, from whom)
- Link access
  - MAC protocol (media access control)
  - with half duplex, nodes at both ends of link can transmit, but not at same time
- *Flow Control:*
  - pacing between adjacent sending and receiving nodes

Link Layer Services (more)

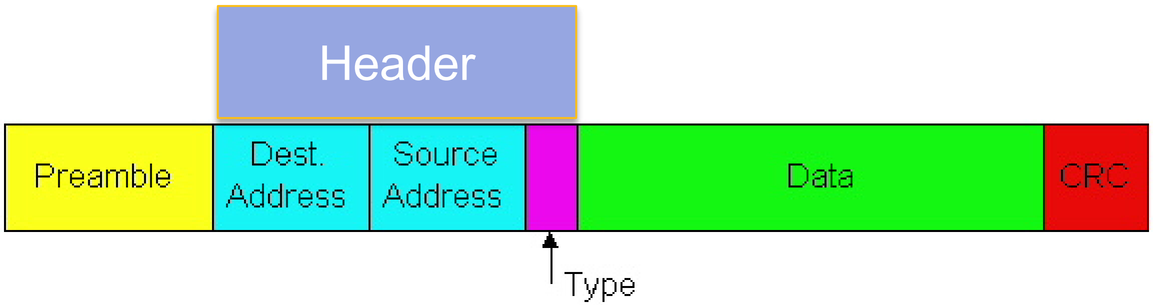
- More reliable delivery between adjacent nodes
  - seldom used on low bit error link (fiber, some twisted pair)
  - wireless links: high error rates
    - Q: why both link-level and end-end reliability?
- Error Detection:
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- Error Correction:
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission (Error correction/detection called ECD).

ADDRESS RESOLUTION PROTOCOL

Adapters and Frames

Frame on the wire (802.xxx)

Ethernet



Where do we send it?

MEDIA ACCESS CONTROL ADDRESS

MAC address

48 bits --- 6 bytes

Given in hexadecimal

Locally administered address

88-B2-2F-54-1A-0F

MAC versus IP

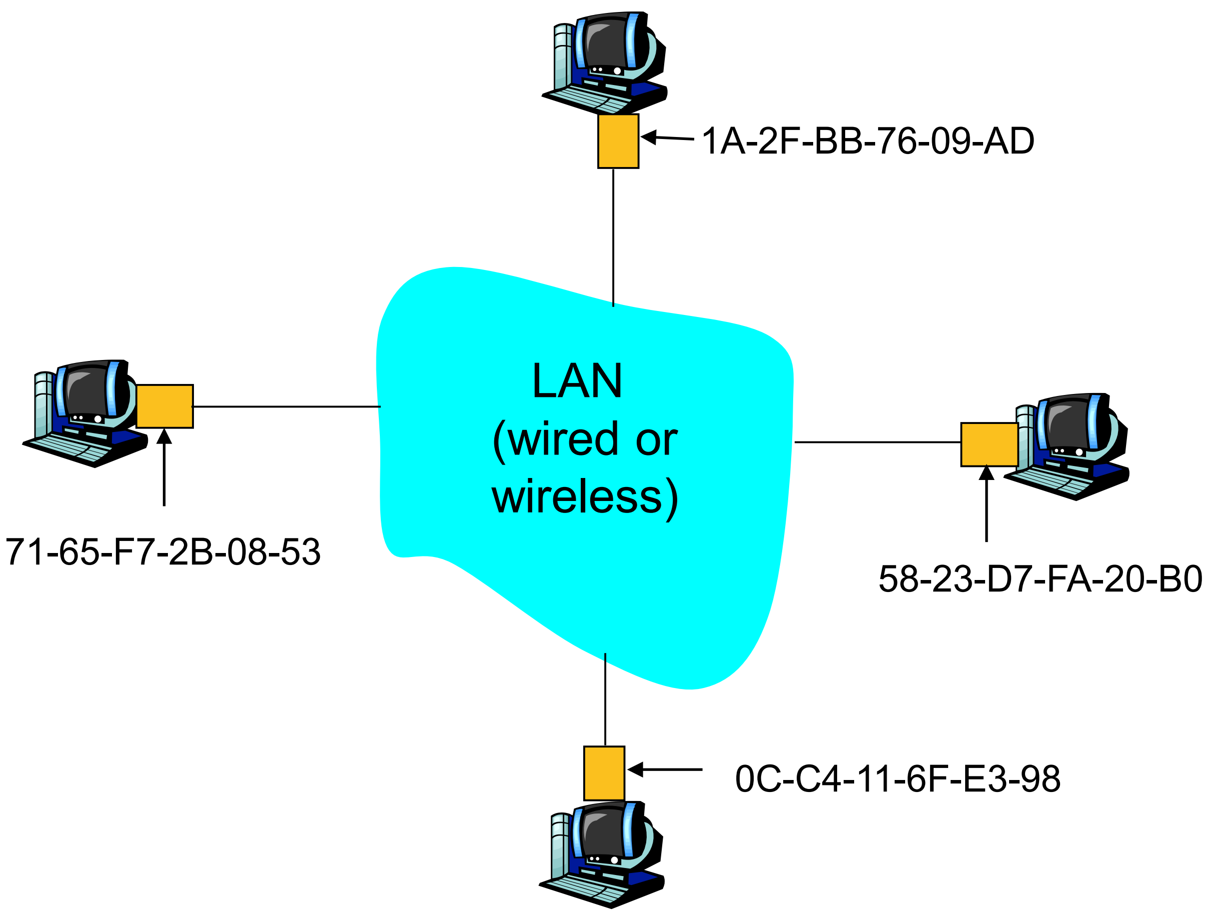
- 32-bit IP address:
  - *network-layer* address
  - used to get datagram to destination IP subnet
- 48-bit MAC (or LAN or physical or Ethernet) address:
  - used to get datagram from one interface to another physically-connected interface (same network)
  - MAC address (for most LANs) burned in the adapter ROM

LAN Address

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:
  - (a) MAC address: like Social Insurance number never changes, only has local meaning
  - (b) IP address: like postal address
- MAC flat address ➜ portability
  - can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - depends on IP subnet to which node is attached

LAN Addresses and ARP

Each adapter on LAN has unique LAN address



Broadcast address =
FF-FF-FF-FF-FF-FF

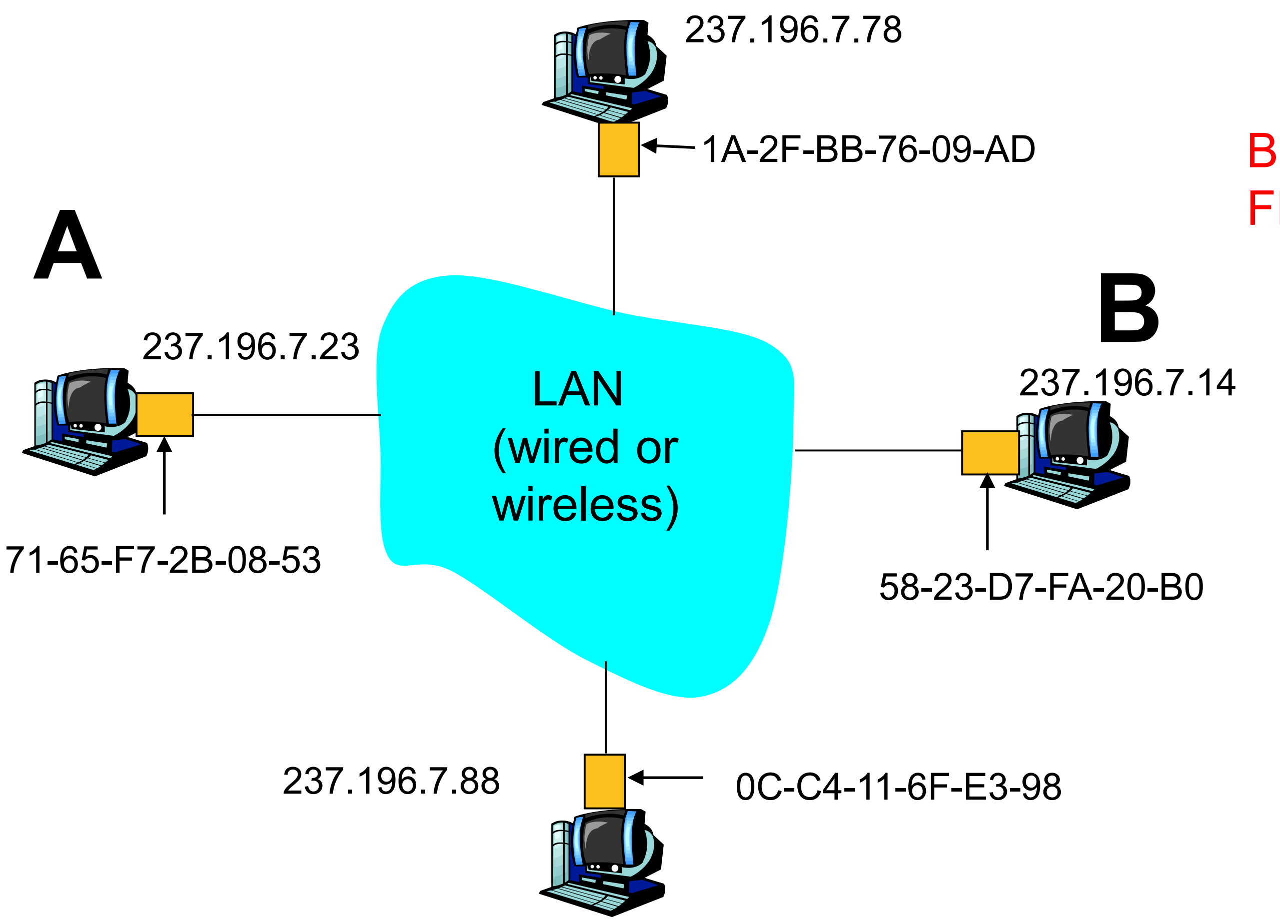
= adapter

Address Resolution Protocol

<table>
<tr><td colspan="2">Hardware type (16 bits)</td></tr>
<tr><td colspan="2">Protocol type (16 bits)</td></tr>
<tr><td>Length of the hardware address</td><td>Length of protocol address</td></tr>
<tr><td colspan="2">Operator (16 bits)</td></tr>
<tr><td colspan="2">Hardware address of the sender</td></tr>
<tr><td colspan="2">IP address of the sender</td></tr>
<tr><td colspan="2">Hardware address of the receiver</td></tr>
<tr><td colspan="2">IP address of the receiver</td></tr>
</table>

What do we do with it?

How to determine MAC address of B knowing B's IP address?



Broadcast address =
FF-FF-FF-FF-FF-FF

ARP Summary

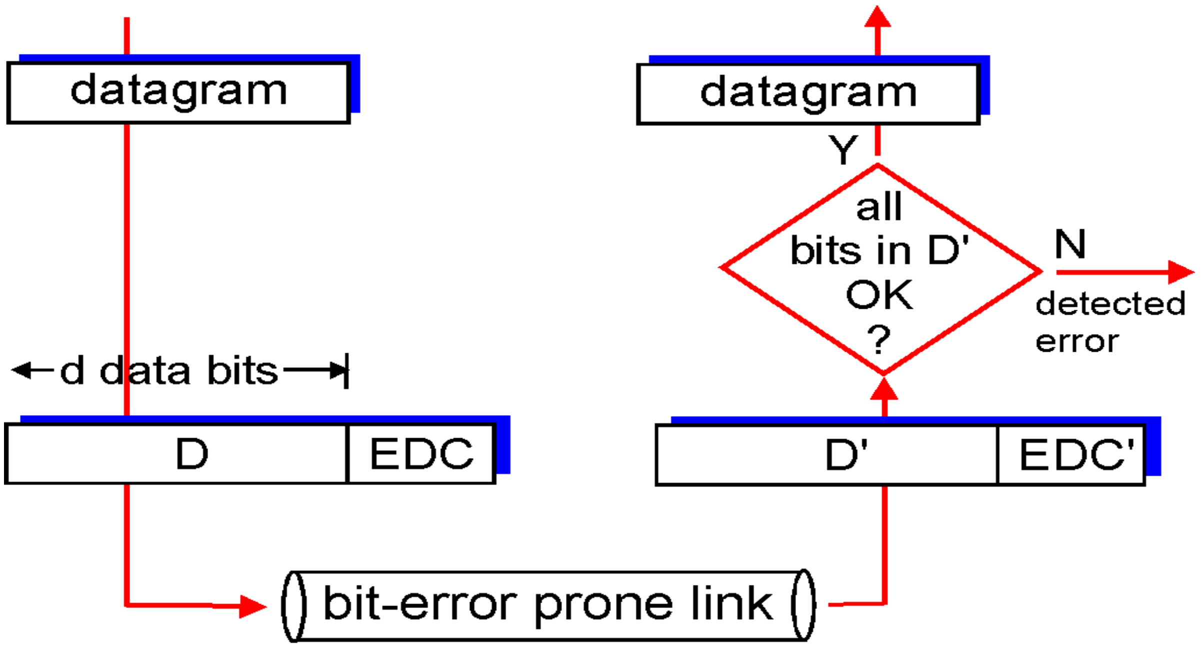
- A wants to send datagram to B, and B's MAC address not in A's ARP table.
- A broadcasts ARP query packet, containing B's IP address
  - Dest MAC address = FF-FF-FF-FF-FF-FF
  - all machines on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A's 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

ERROR DETECTION CORRECTION

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



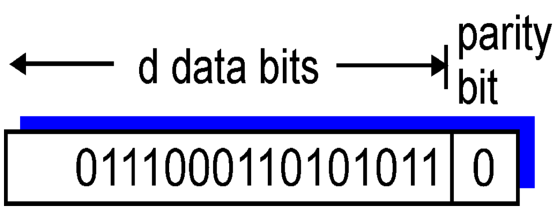
Single Bit Parity

1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 1 parity ?

1

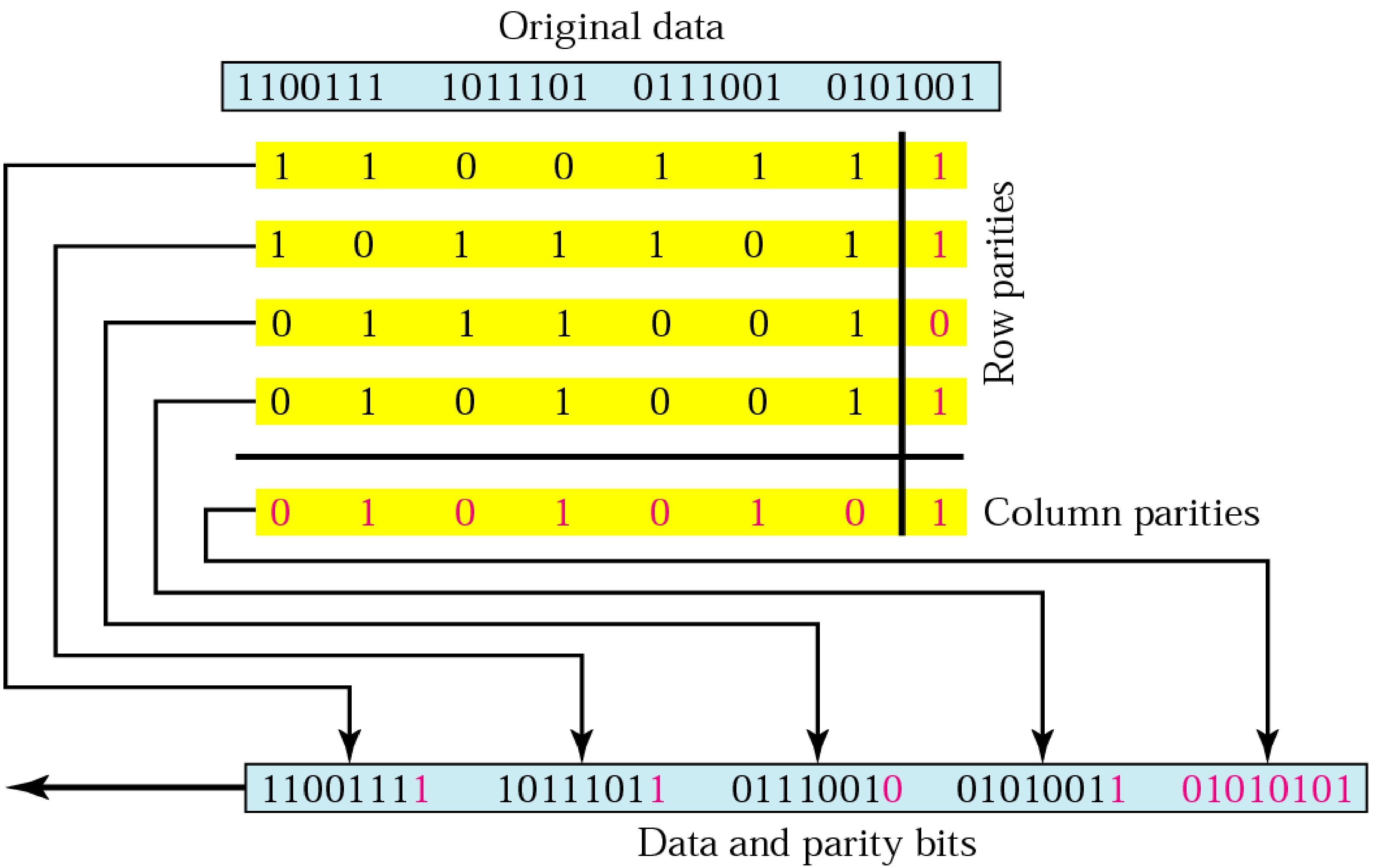
Even parity: add on a parity bit to make the parity even

Detect single bit errors



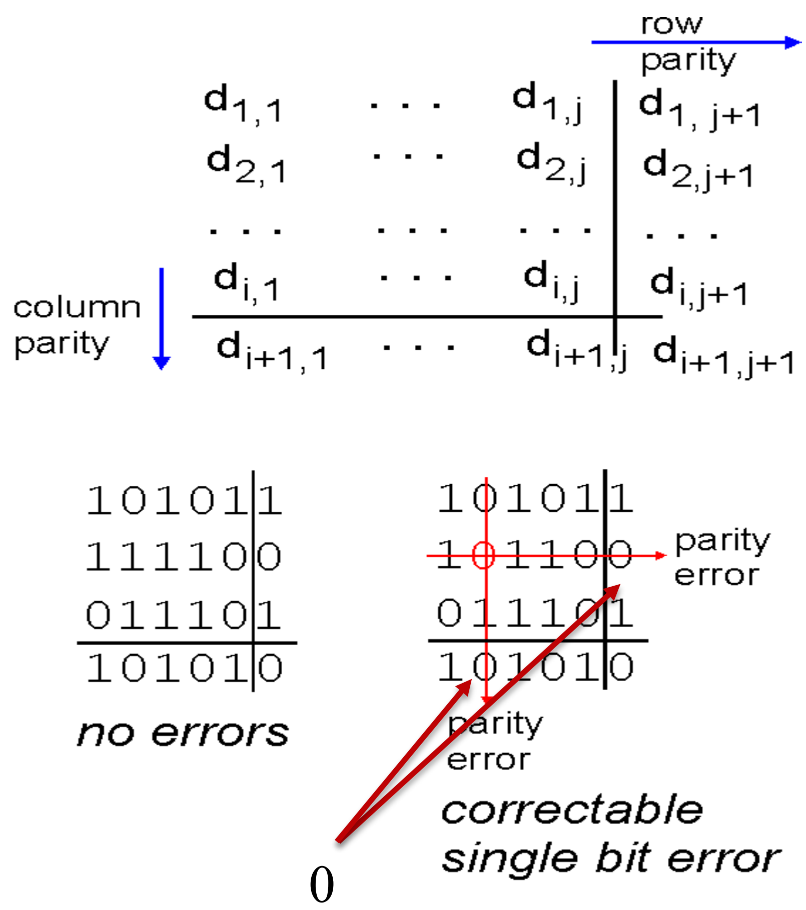
ERROR CORRECTION DETECTION

Two Dimensional Even Parity



Two Dimensional Parity Checking

Detect *and* *correct* single bit errors



2-D EDC

1. Data blocks are organized into table
2. Last column: check bits for rows
3. Last row: check bits for columns
4. Can **detect** and **correct single** bit error

Data

1	0	0	1	0	0
0	1	0	0	0	1
1	0	0	1	0	0
1	1	0	1	1	0
1	0	0	1	1	1

Parity bits

Can detect one, two, three errors,
But <u>NOT all four</u> errors.

Red bits are errors

1 error

1	0	0	1	0	0	0
0	0	0	0	0	1	0
1	0	0	1	0	0	0
1	1	0	1	1	0	0
1	0	0	1	1	1	
1	1	0	1	1		0

2 errors

1	0	0	1	0	0	0
0	0	0	0	0	1	0
1	0	0	1	0	0	0
1	0	0	1	1	0	1
1	0	0	1	1	1	
1	0	0	1	1		0

3 errors

1	0	0	1	0	0	0
0	0	0	1	0	1	1
1	0	0	1	0	0	0
1	0	0	1	1	0	1
1	0	0	1	1	1	
1	0	0	0	1		0

4 errors

1	0	0	1	0	0
0	0	0	1	0	1
1	0	0	1	0	0
1	0	0	0	1	0
1	0	0	1	1	1

Internet checksum

Goal: detect "errors" (e.g., flipped bits) in transmitted segment (note: used at transport layer *only*)

Sender:

- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

Receiver:

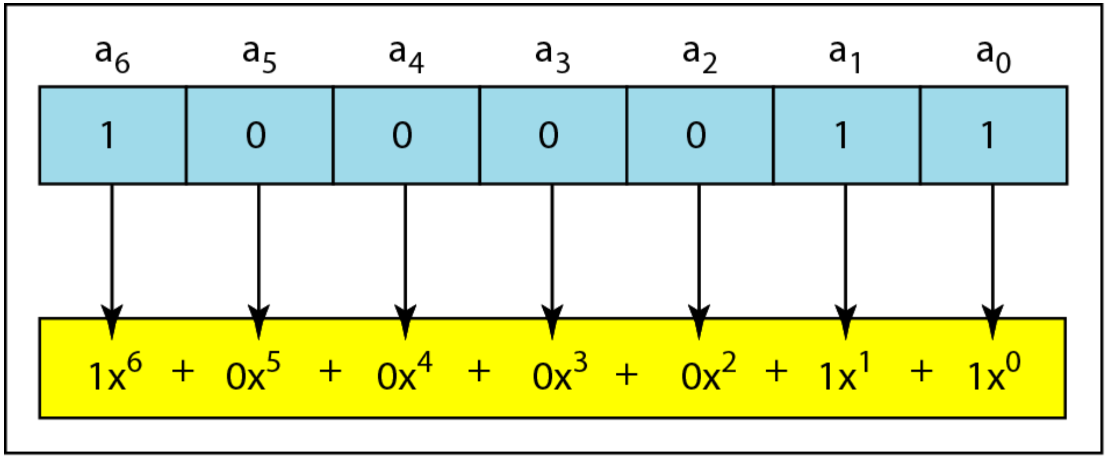
- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. *But maybe errors nonetheless?* More later ….

Checksum example

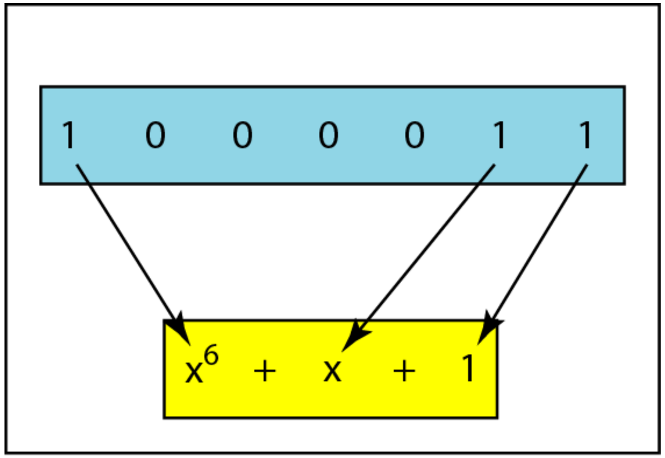
1	1	0	1	0
0	1	0	0	1
1	0	1	1	0
1	0	0	1	1

CYCLIC REDUNDANCY CHECK (CRC)

CRC -- Mod 2 Polynomials

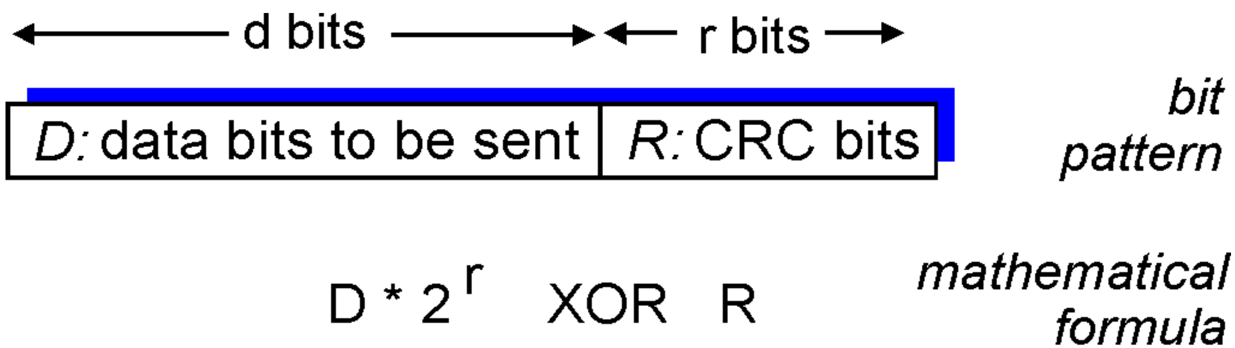


a. Binary pattern and polynomial



b. Short form

CRC



Generator:

Remainder:

CRC Sending

$$1*x^3 + 0*x^2 + 0*x^1 + 1*x^0$$

CRC Sending

$$1\ 0\ 0\ 1\ \overline{\big)\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 0}$$

CRC Sending

1 1 1 1 1 1 1 0 0 0

1 0 0 1

Cyclic Redundancy Check

- Choose r CRC bits, R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - can detect all burst errors less than r+1 bits, and burst errors greater that r+1 with probability 1-0.5^r
- Not good for authentication? Why?
- widely used in practice (ATM – Asynchronous Transfer Mode, HDCL – High Level Data Link Control)
- Easy to do in hardware

CRC Example

Want:

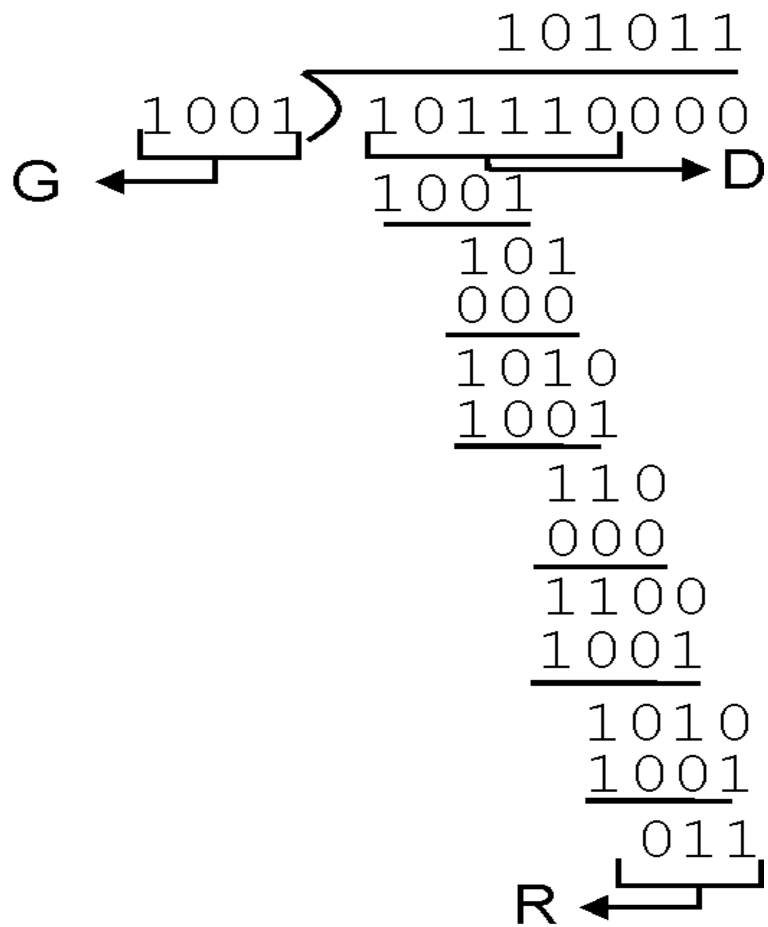
$$D \cdot 2^r \text{ XOR } R = nG$$

equivalently:

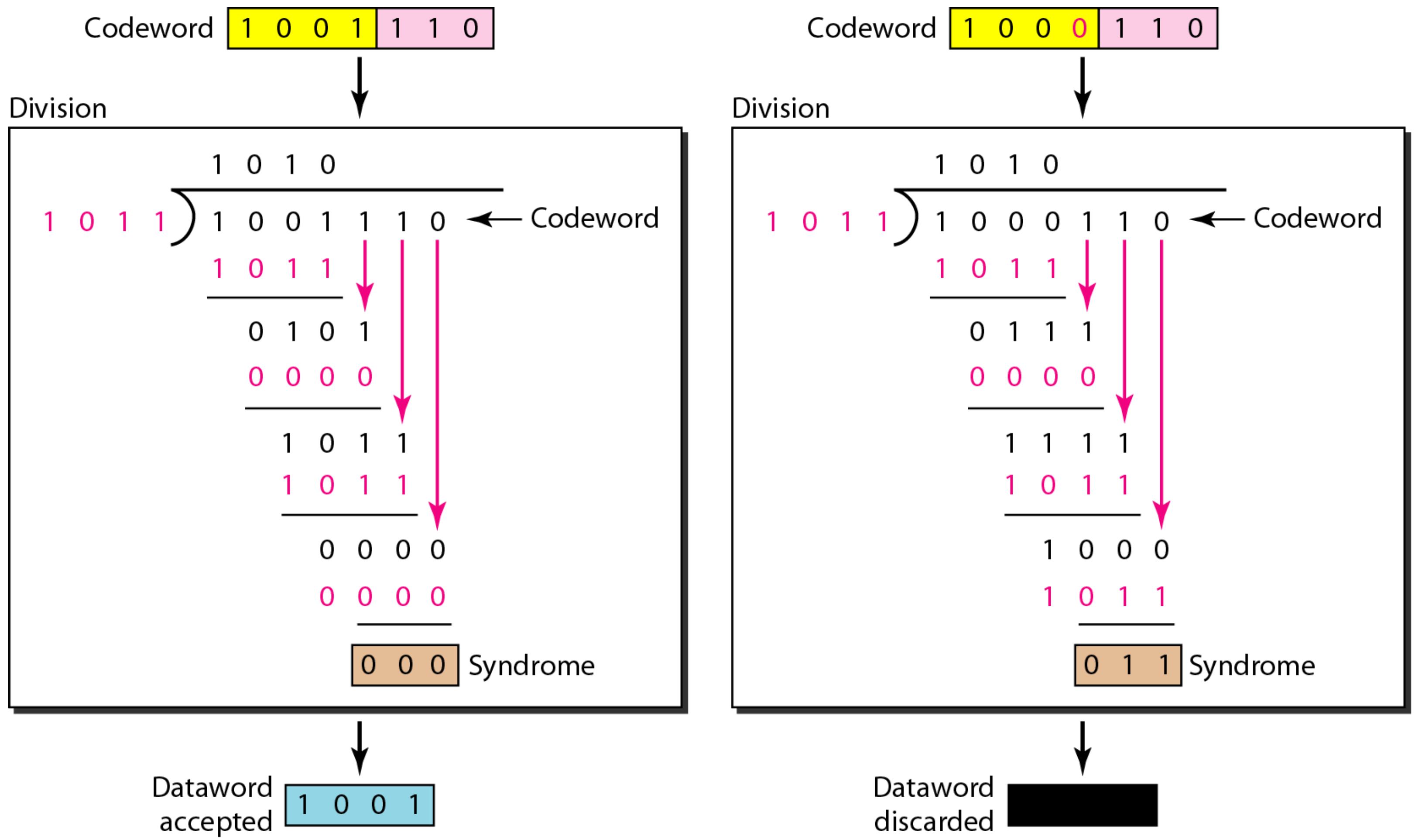
$$D \cdot 2^r = nG \text{ XOR } R$$

equivalently:

if we divide $D \cdot 2^r$ by G, want remainder R

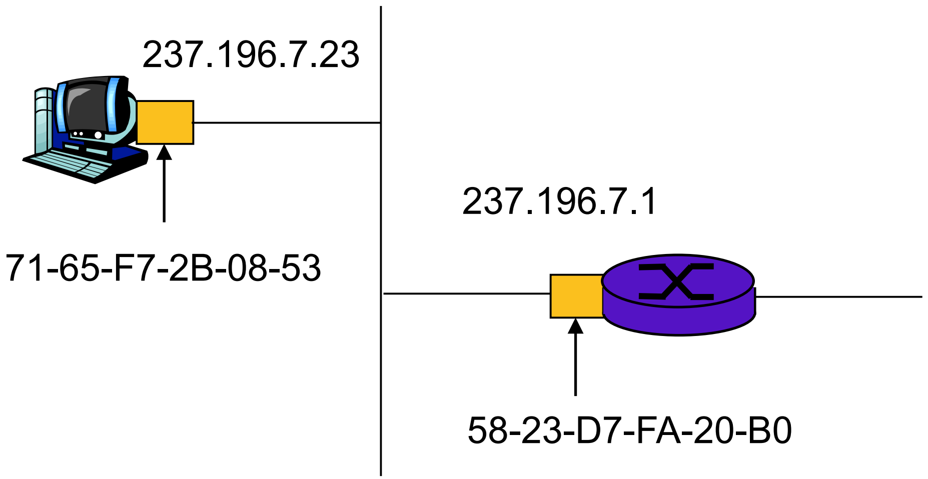


CRC sender-receiver

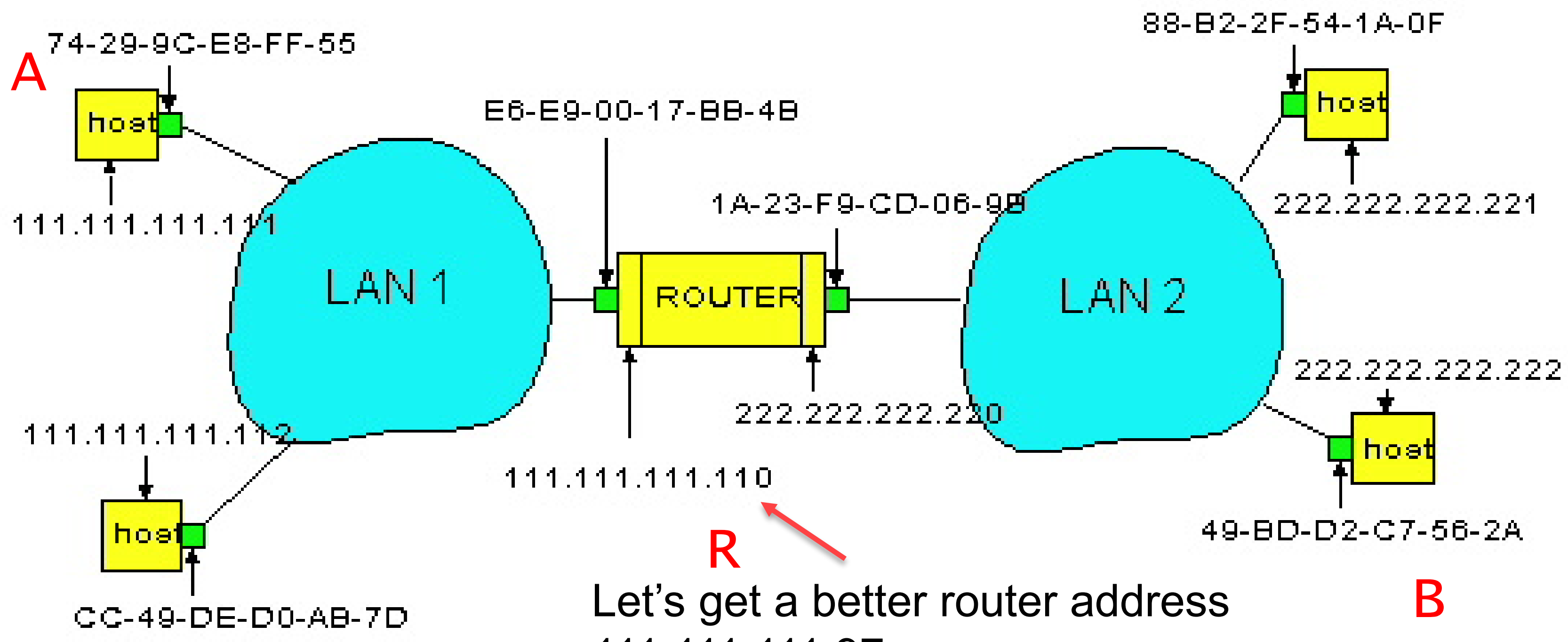


LAN to LAN

Default Router



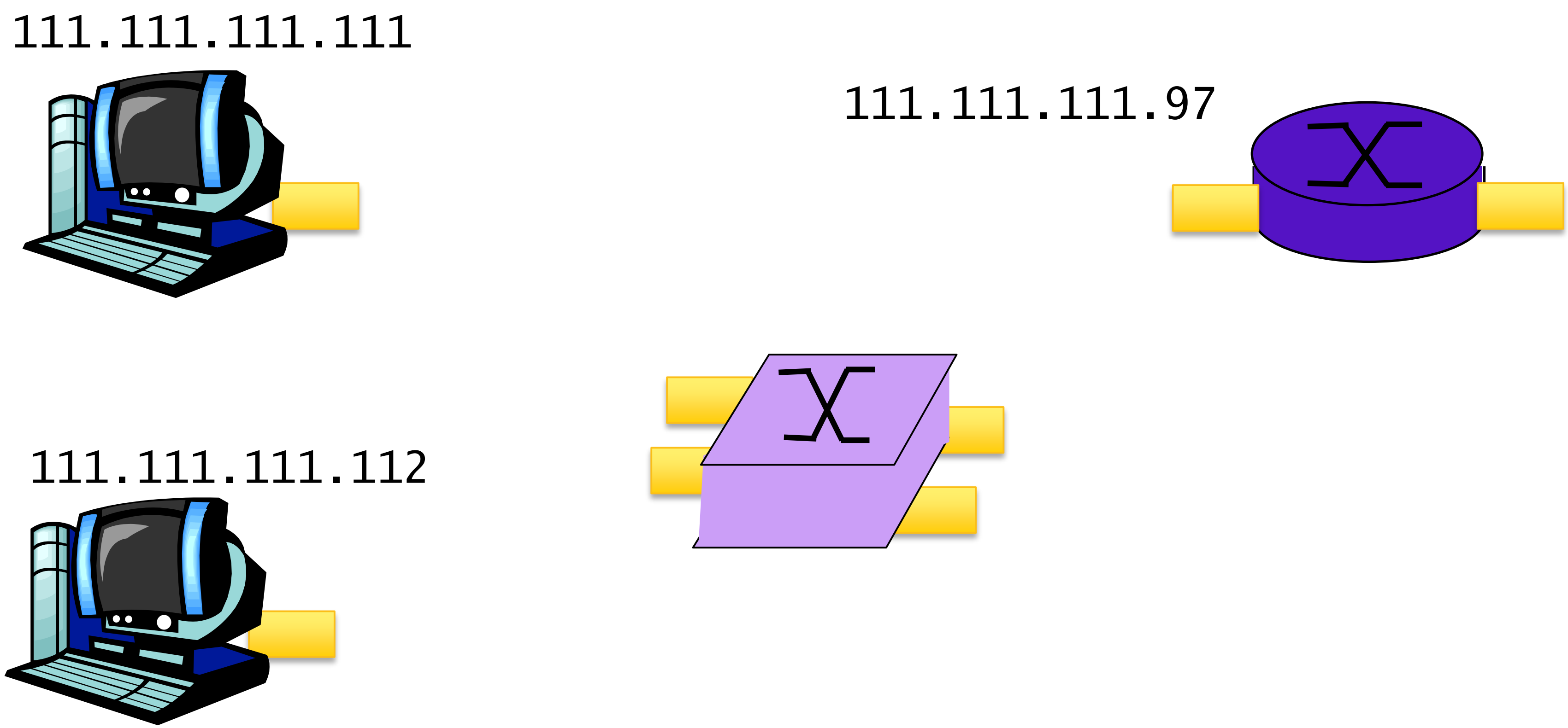
Send message A → B



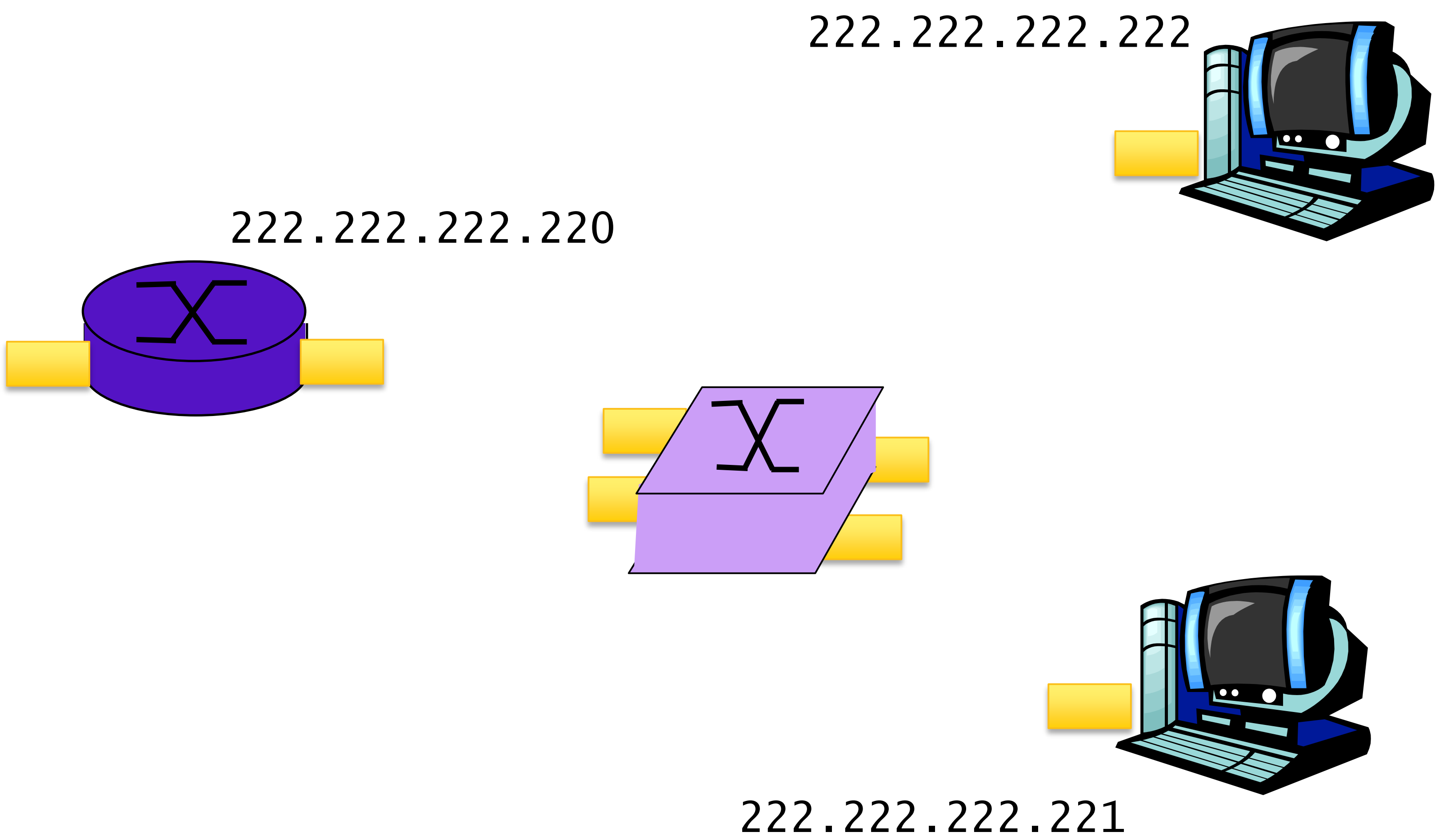
Let's get a better router address
111.111.111.97

Not given network prefix --- should be there --- will just need to make a reasonable guess at them

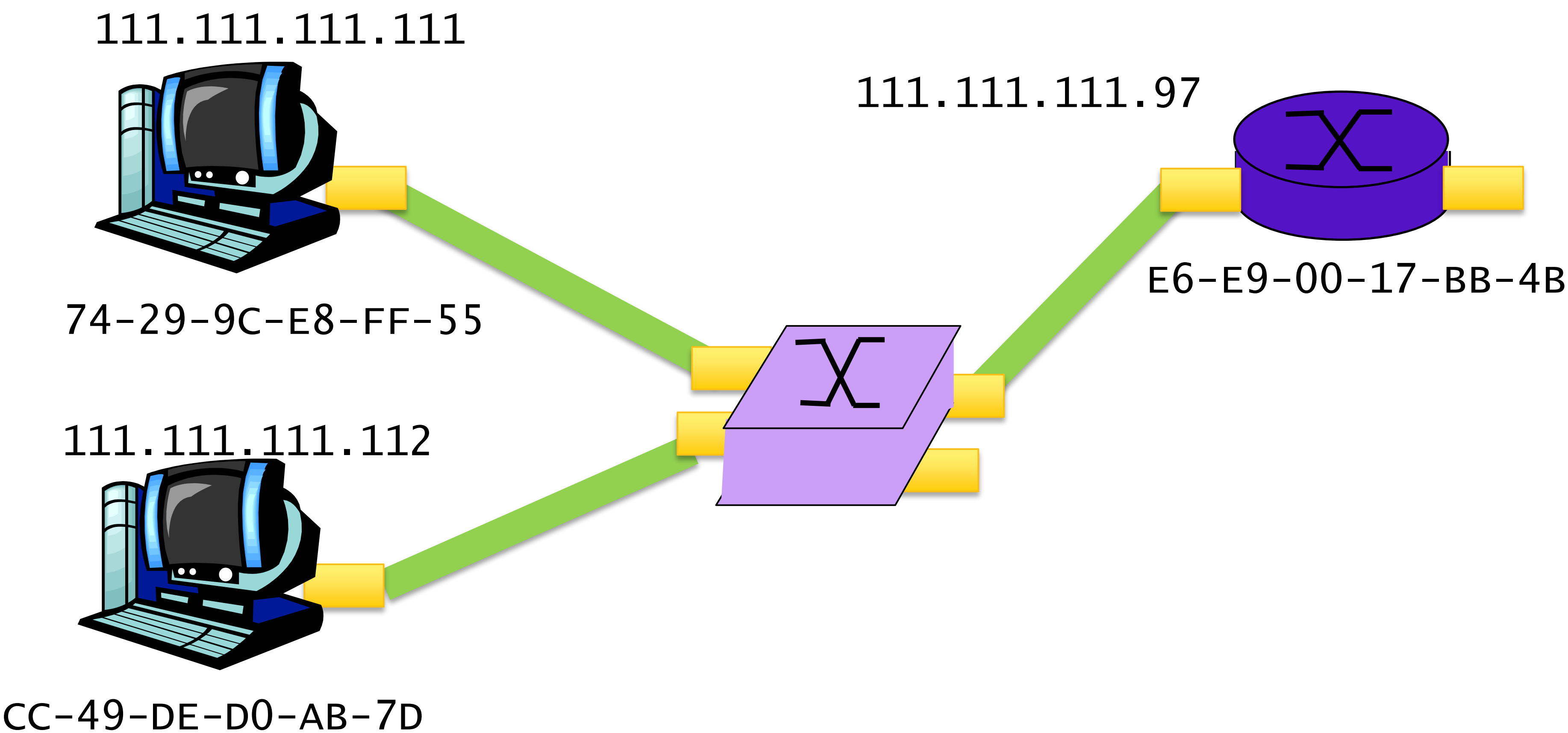
Local Area Network



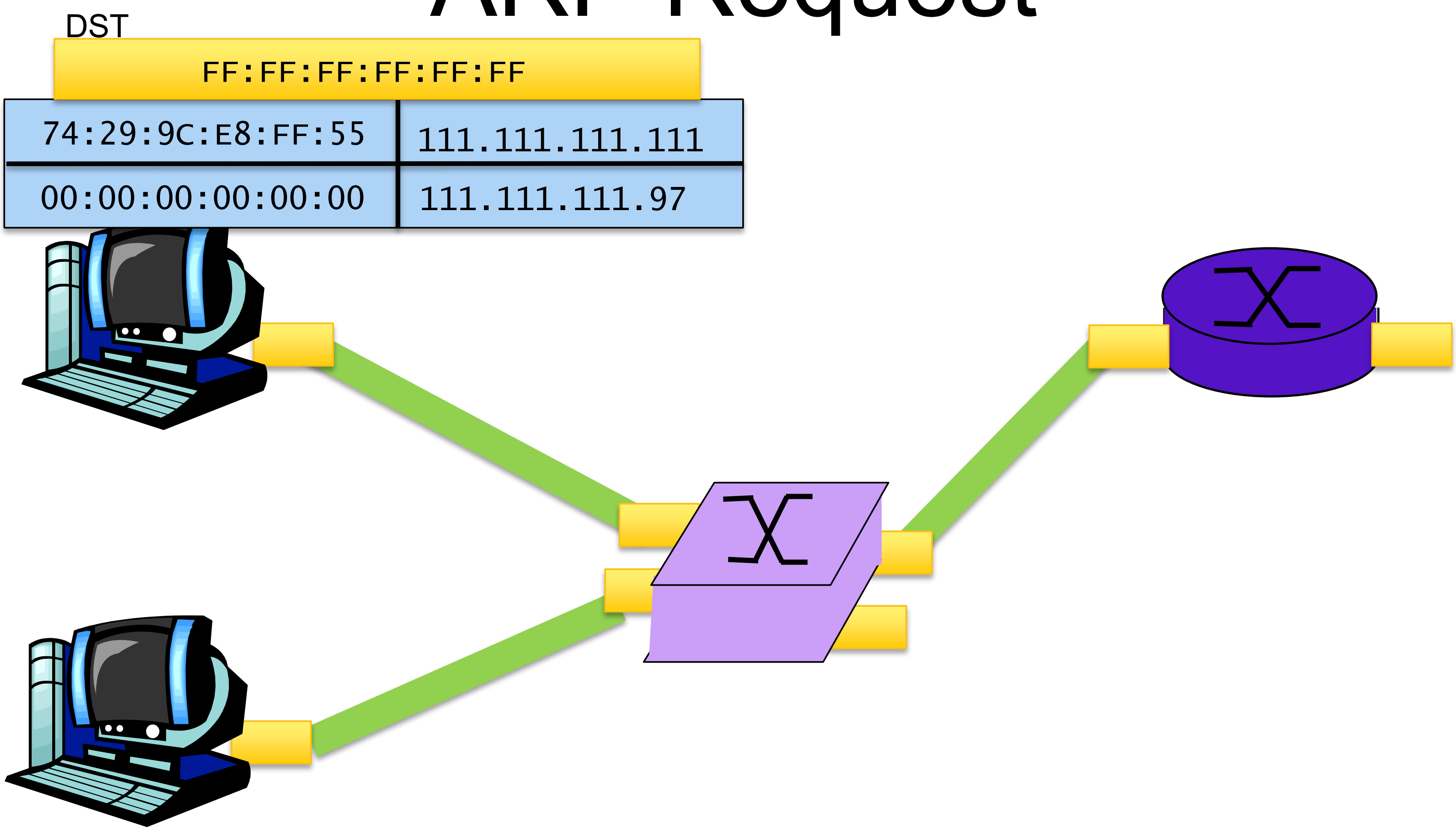
Local Area Network



111.111.111.97/27



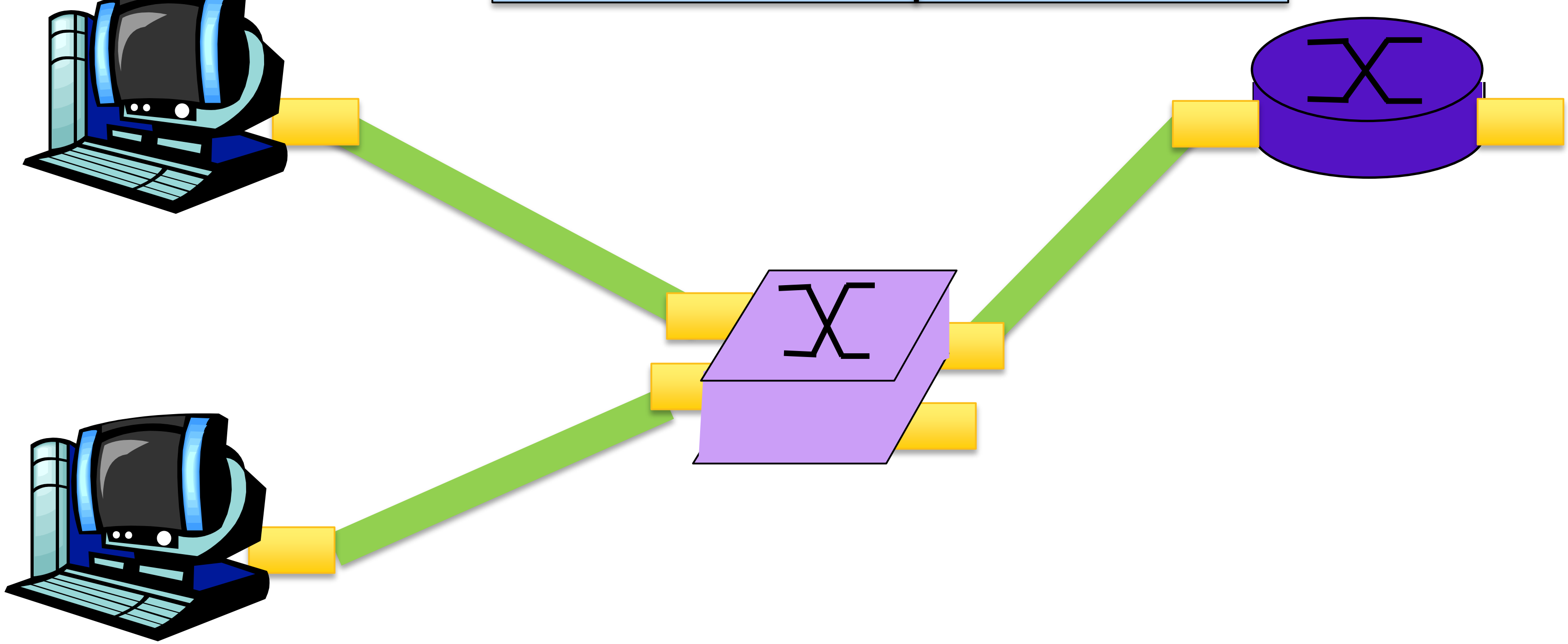
ARP Request


DST
FF:FF:FF:FF:FF:FF
74:29:9C:E8:FF:55
111.111.111.111
00:00:00:00:00:00
111.111.111.97

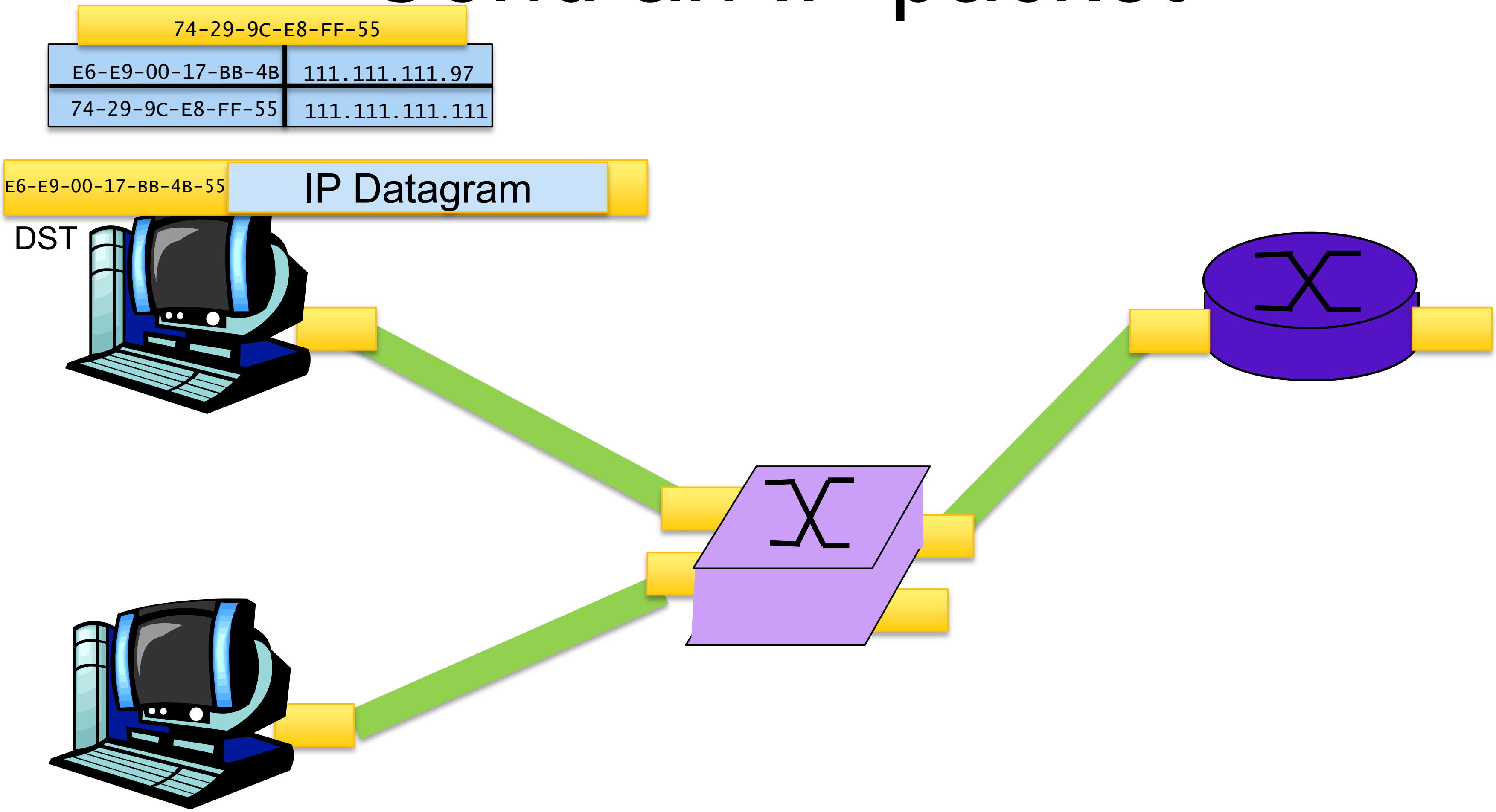
ARP Reply

DST 74-29-9C-E8-FF-55

E6-E9-00-17-BB-4B	111.111.111.97
74-29-9C-E8-FF-55	111.111.111.111

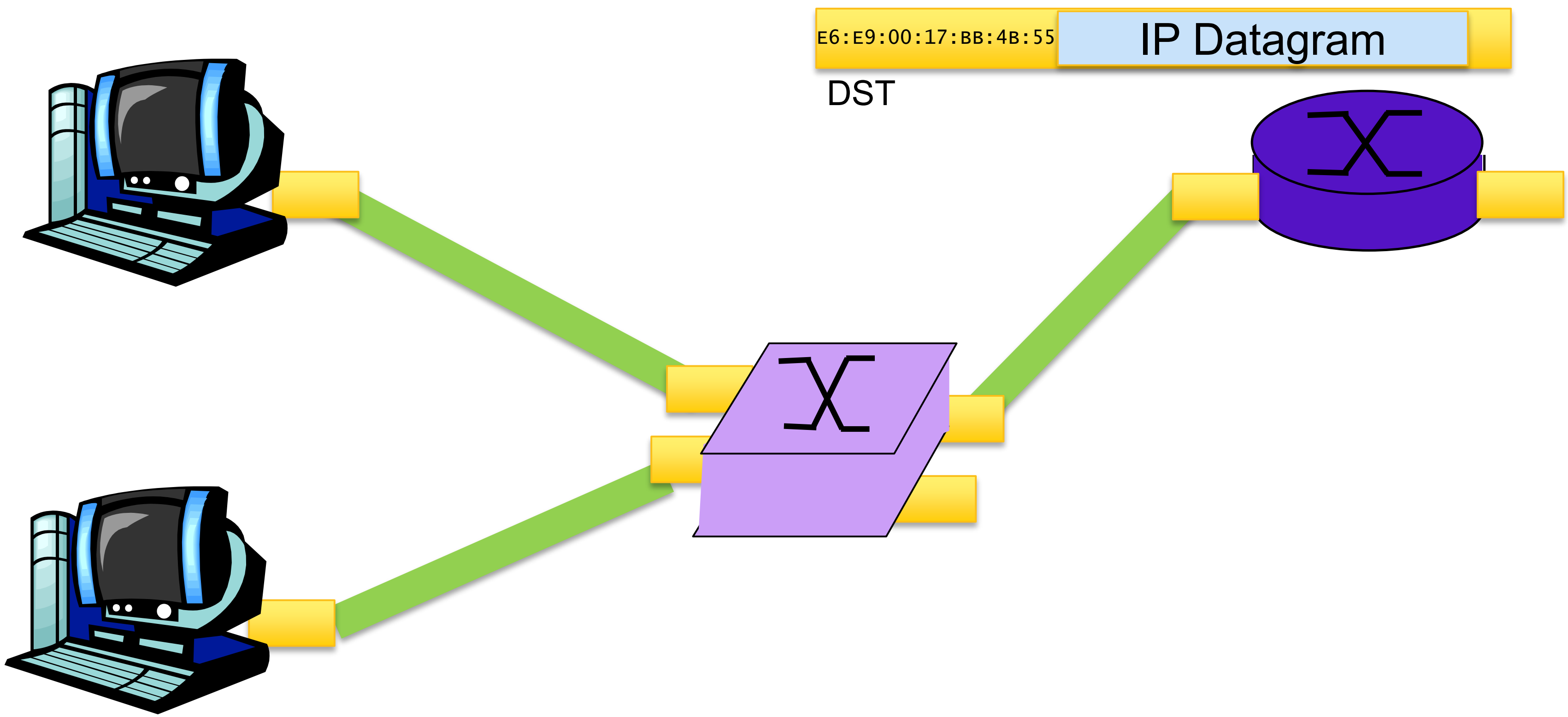


Send an IP packet

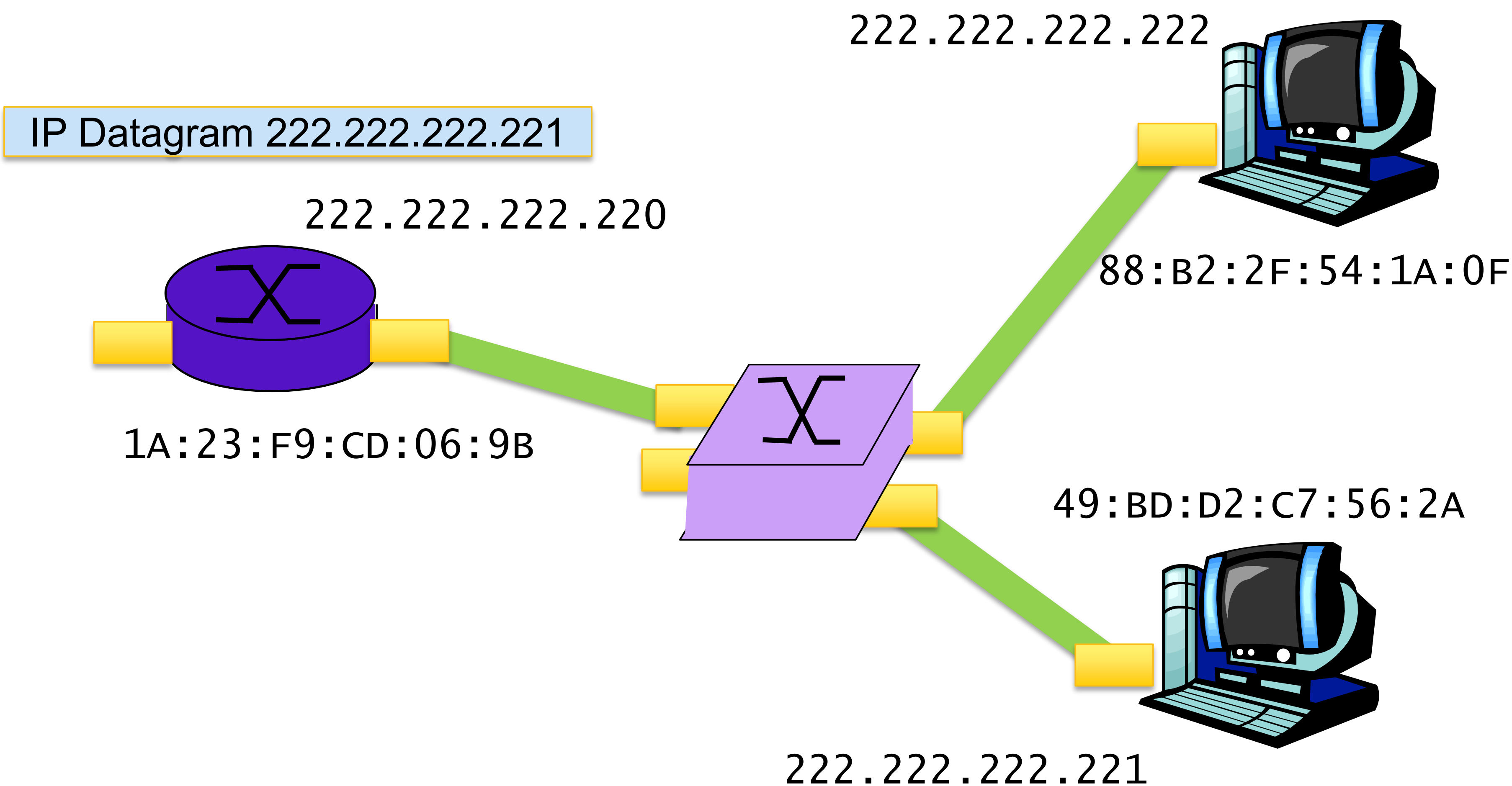


Send an IP packet

74:29:9C:E8:FF:55	
E6:E9:00:17:BB:4B	111.111.111.97
74:29:9C:E8:FF:55	111.111.111.111

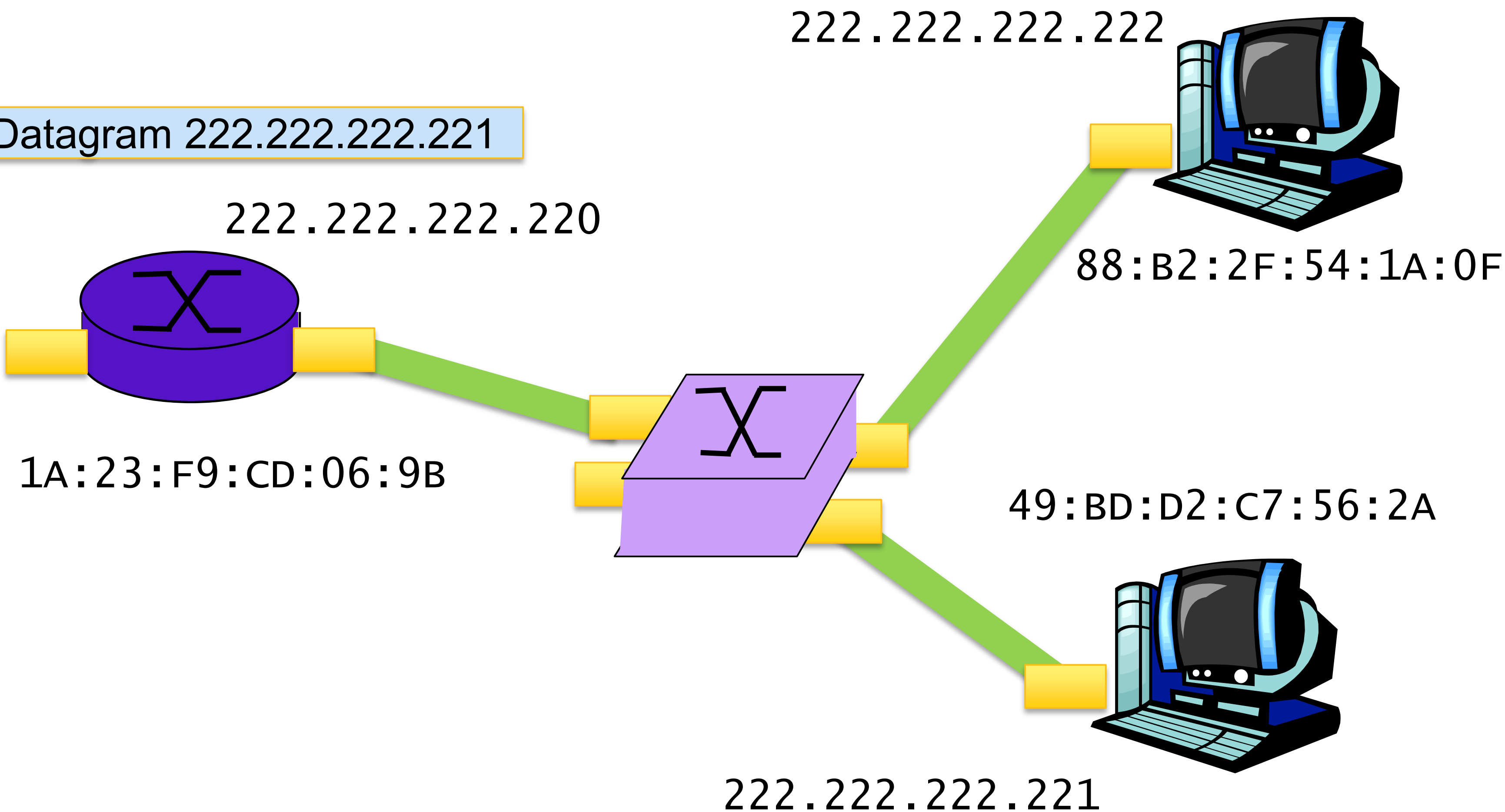


Local Area Network



Local Area Network

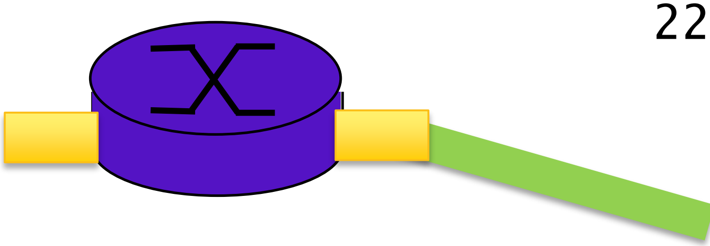
IP Datagram 222.222.222.221



Routing

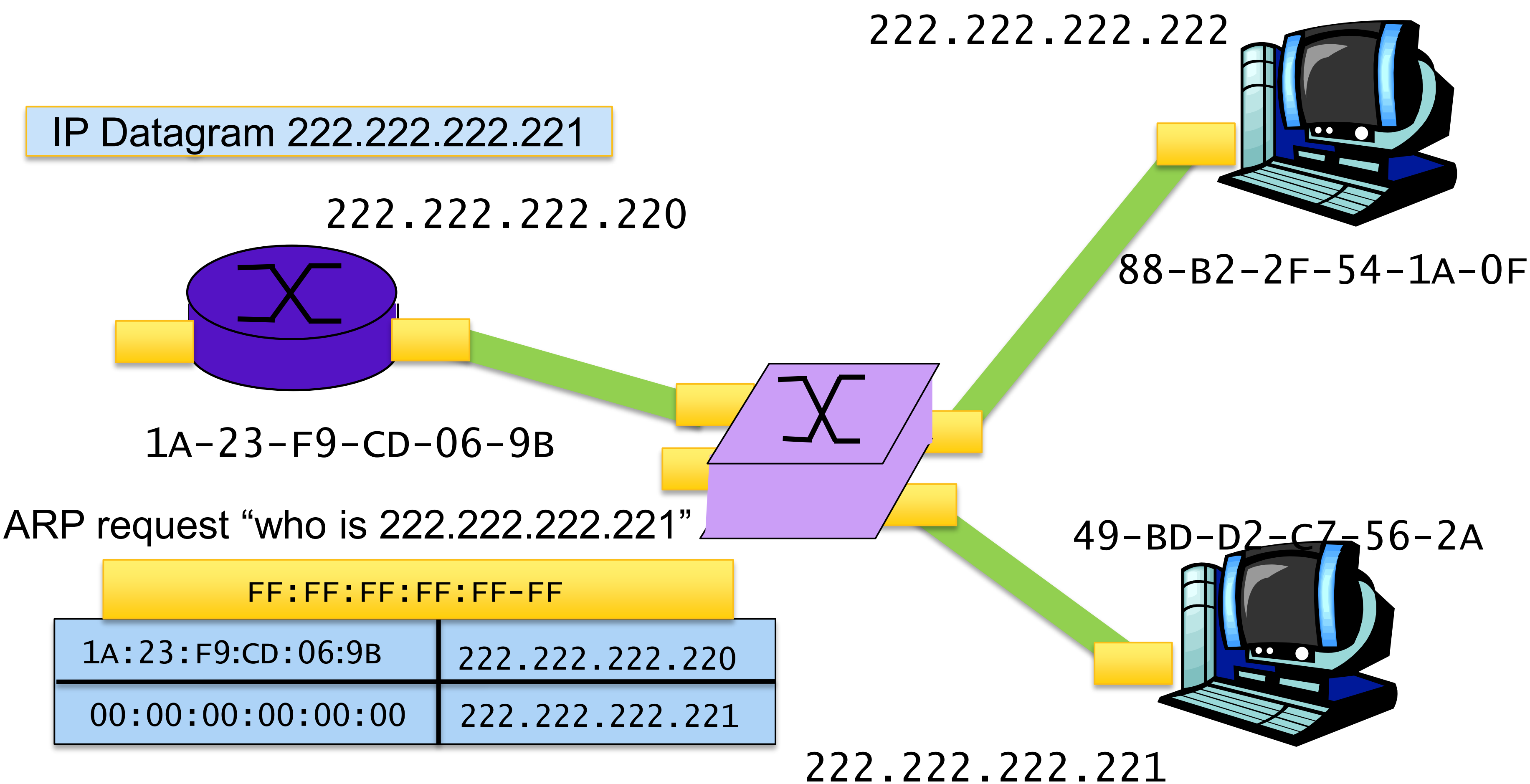
IP Datagram 222.222.222.221

222.222.222.220



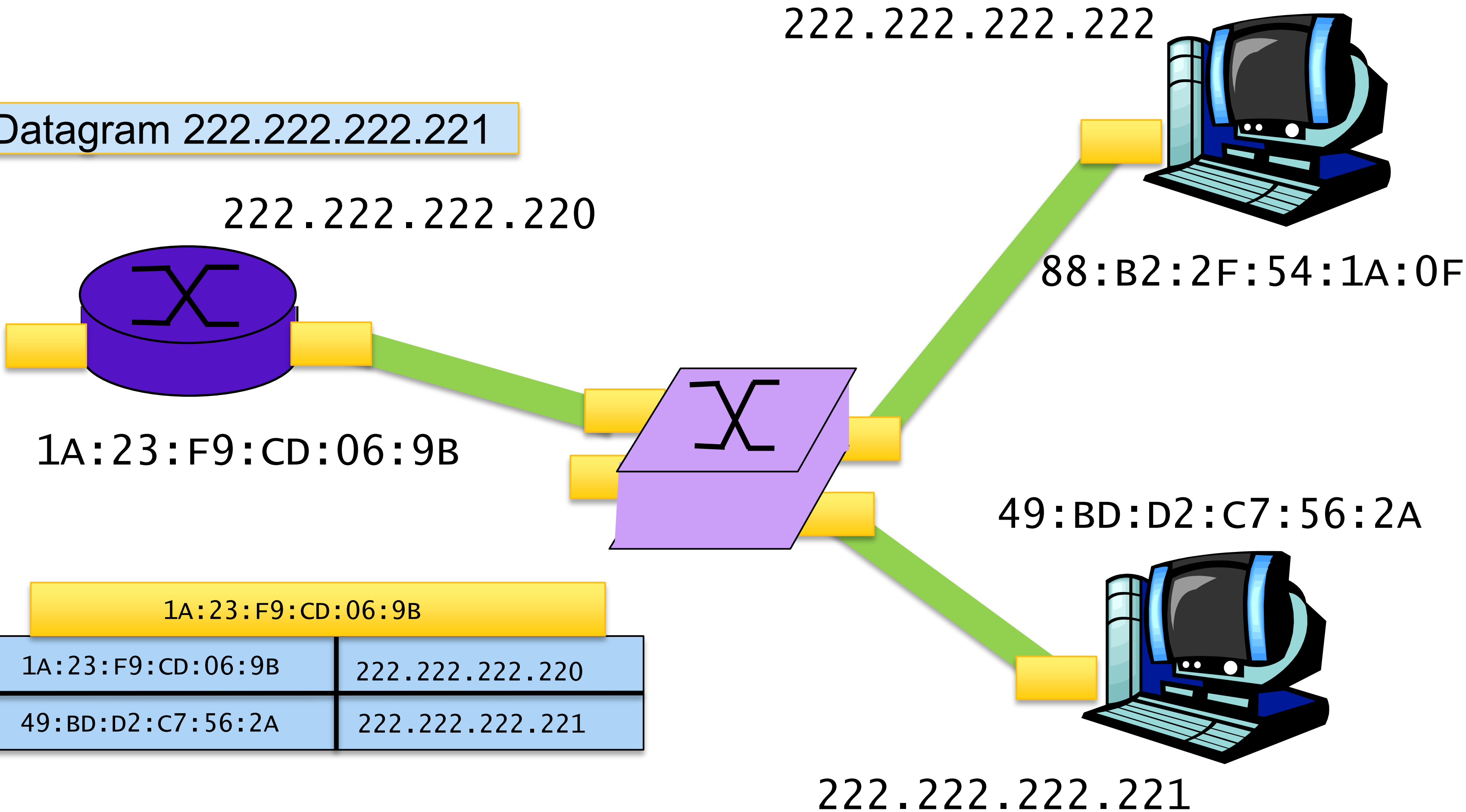
Forwarding Table

Local Area Network



Local Area Network

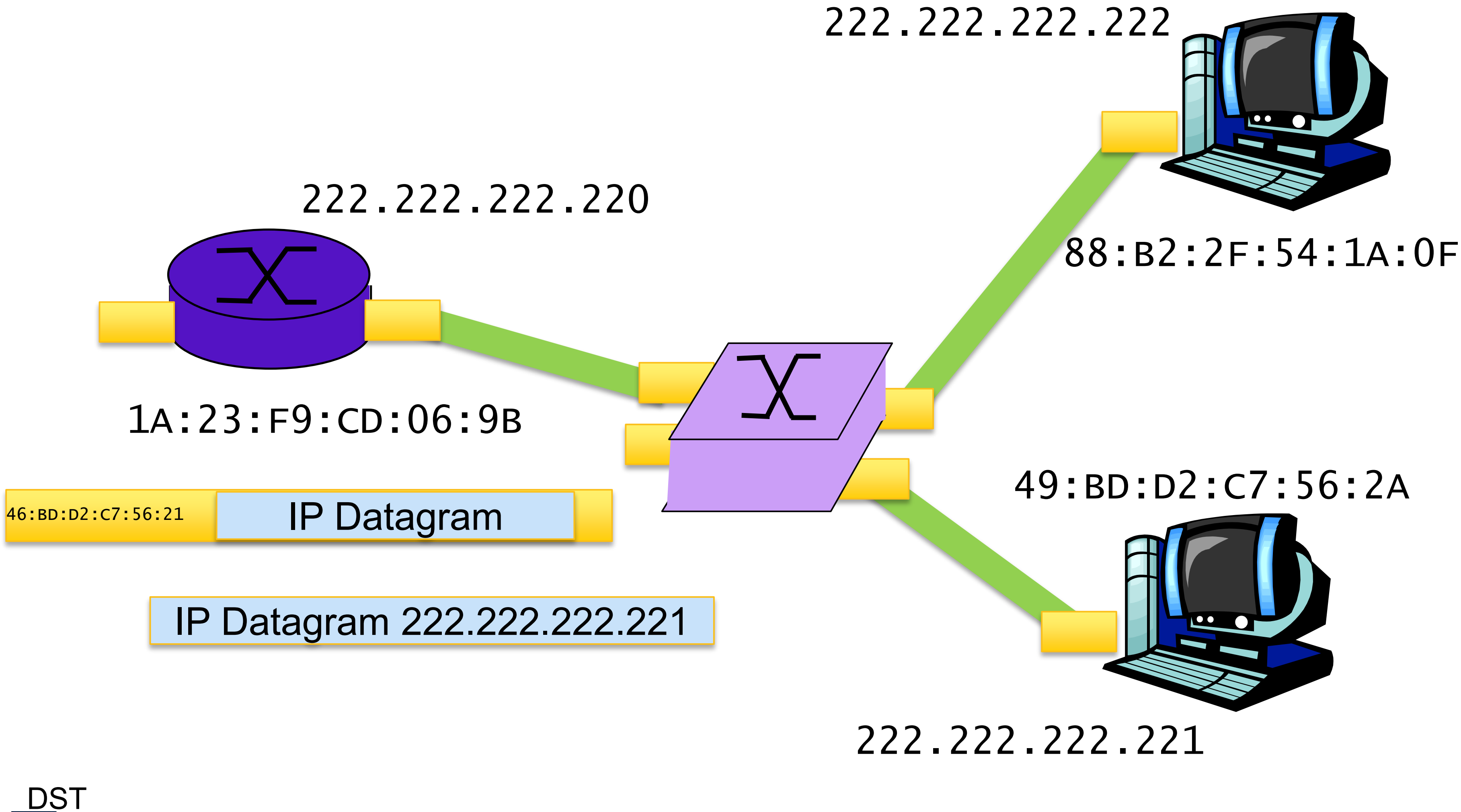
IP Datagram 222.222.222.221



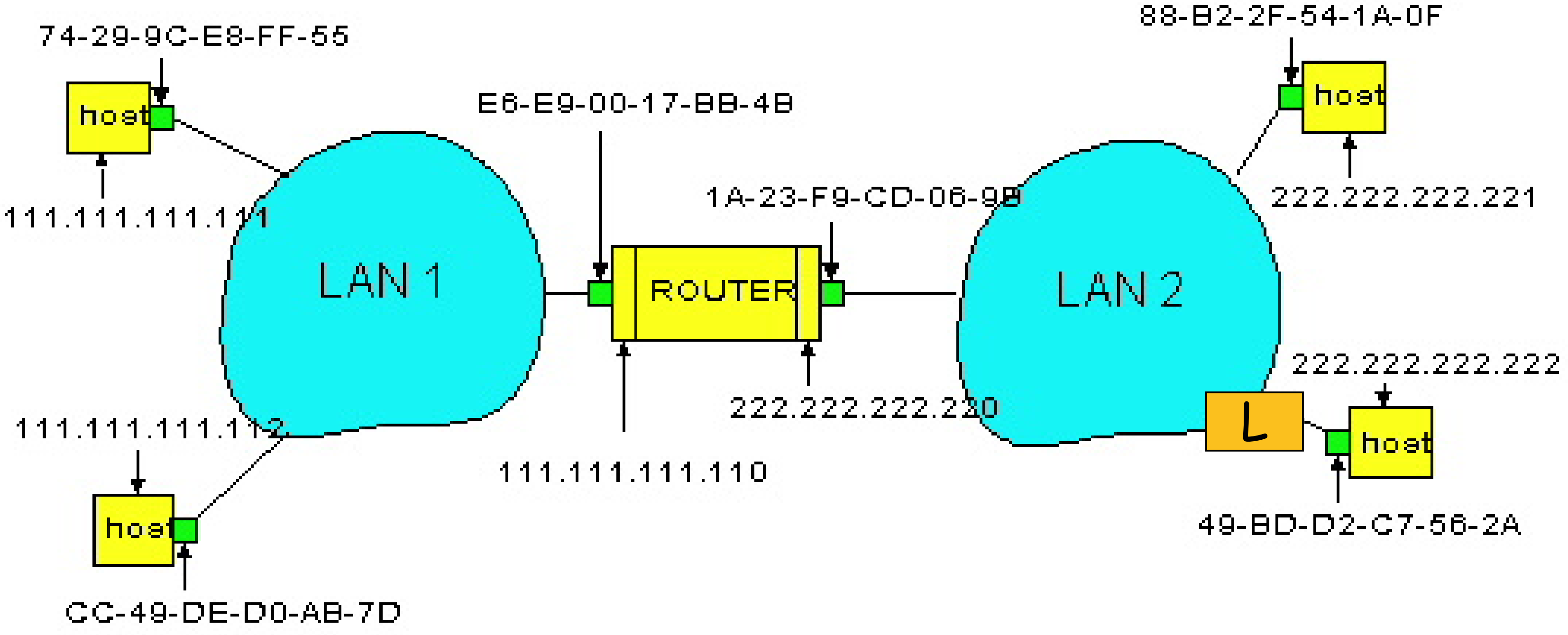
1A:23:F9:CD:06:9B

1A:23:F9:CD:06:9B	222.222.222.220
49:BD:D2:C7:56:2A	222.222.222.221

Local Area Network



What if B replies to A



Fun Facts about ARP

- ARP is stateless, always read a response even if it didn't make a request
- ARP is not authenticated, anyone can ARP
- Can you spoof ARP?
- ARP is in a single "broadcast domain"
- Reverse-ARP used to be used to get an IP address (obsolete) --- DHCP

DYNAMIC HOST CONFIGURATION PROTOCOL

DHCP: Dynamic Host Configuration Protocol

goal: allow host to *dynamically* obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/"on")
- support for mobile users who want to join network (more shortly)

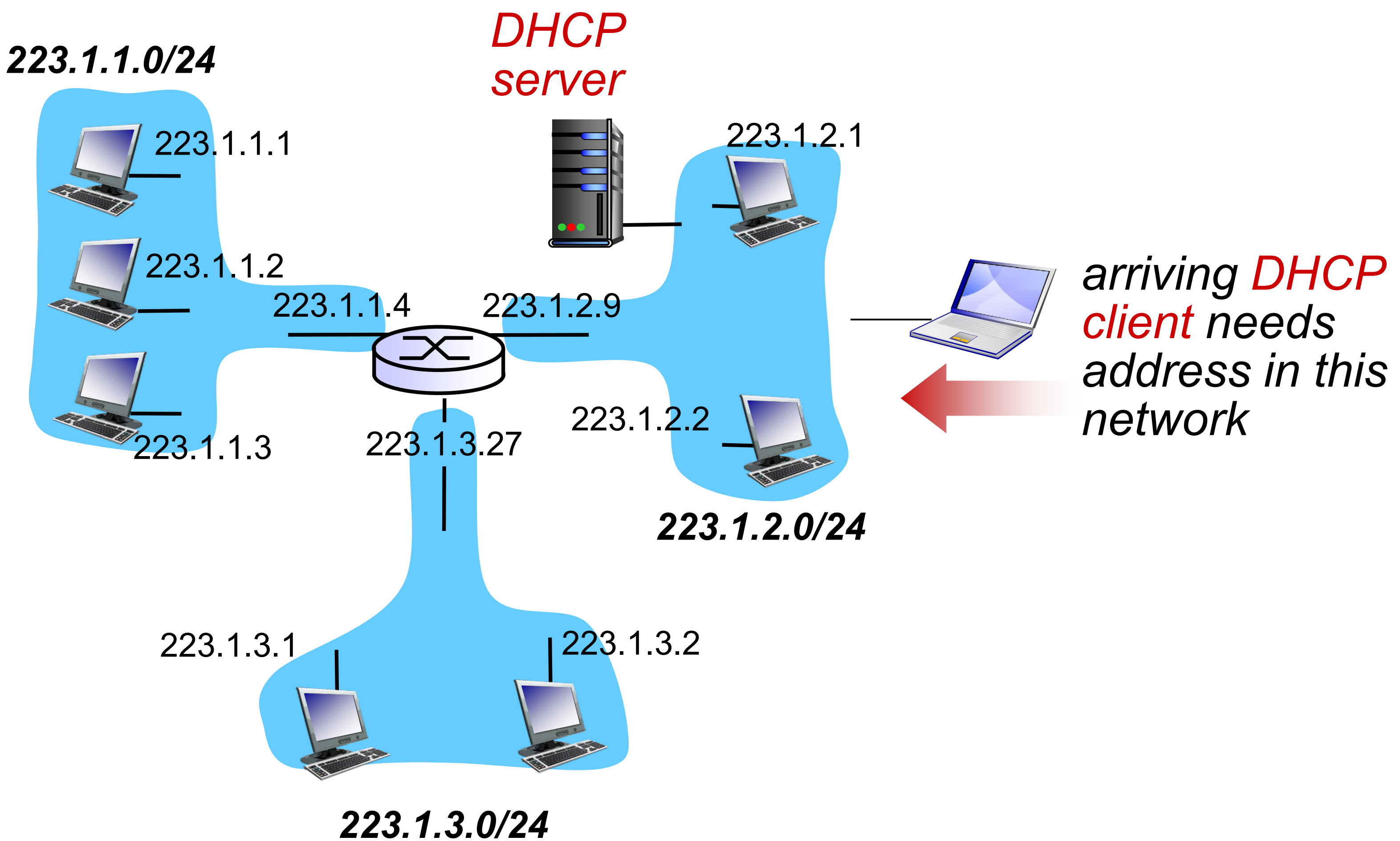
DHCP overview:

- DHCP is built on a client-server model
- DHCP supports several modes of IP-Address allocation

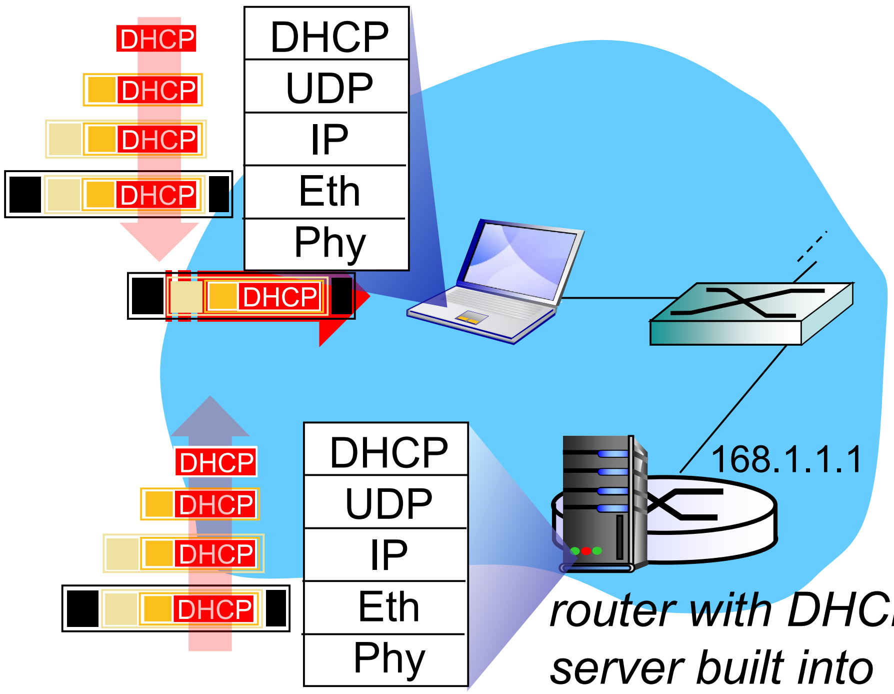
DHCP basic messages:

- host broadcasts "DHCP discover" msg
- DHCP server responds with "DHCP offer" msg
- host requests IP address: "DHCP request" msg
- DHCP server sends address: "DHCP ack" msg

DHCP client-server scenario



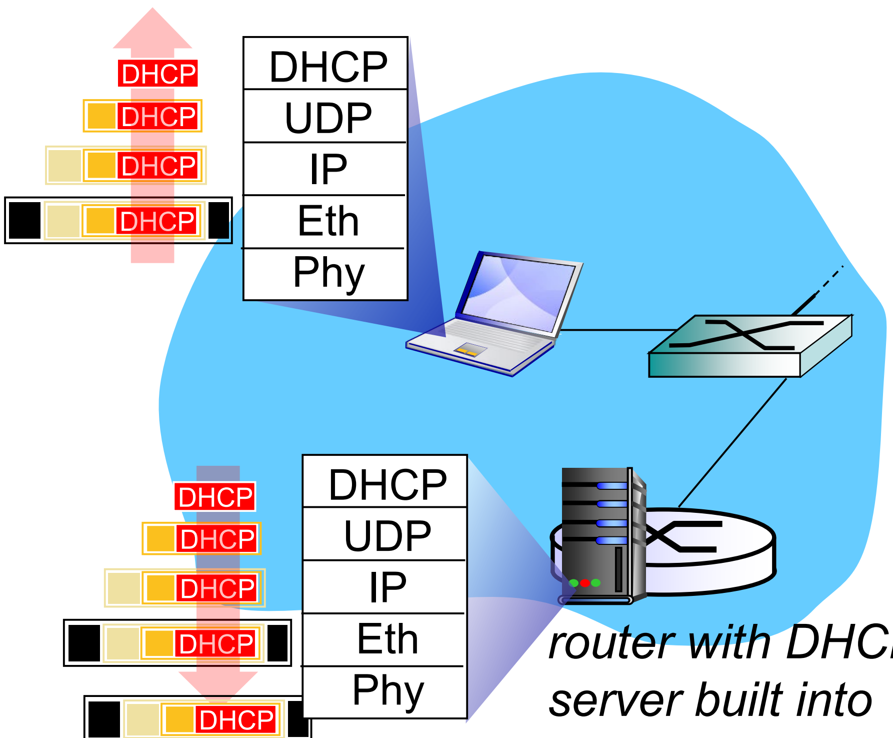
DHCP packet to server



router with DHCP server built into router

- connecting laptop needs its IP address, address of first-hop router, network prefix, address of DNS server
- DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.3 Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet de-muxed to IP de-muxed, UDP de-muxed to DHCP

DHCP message from server

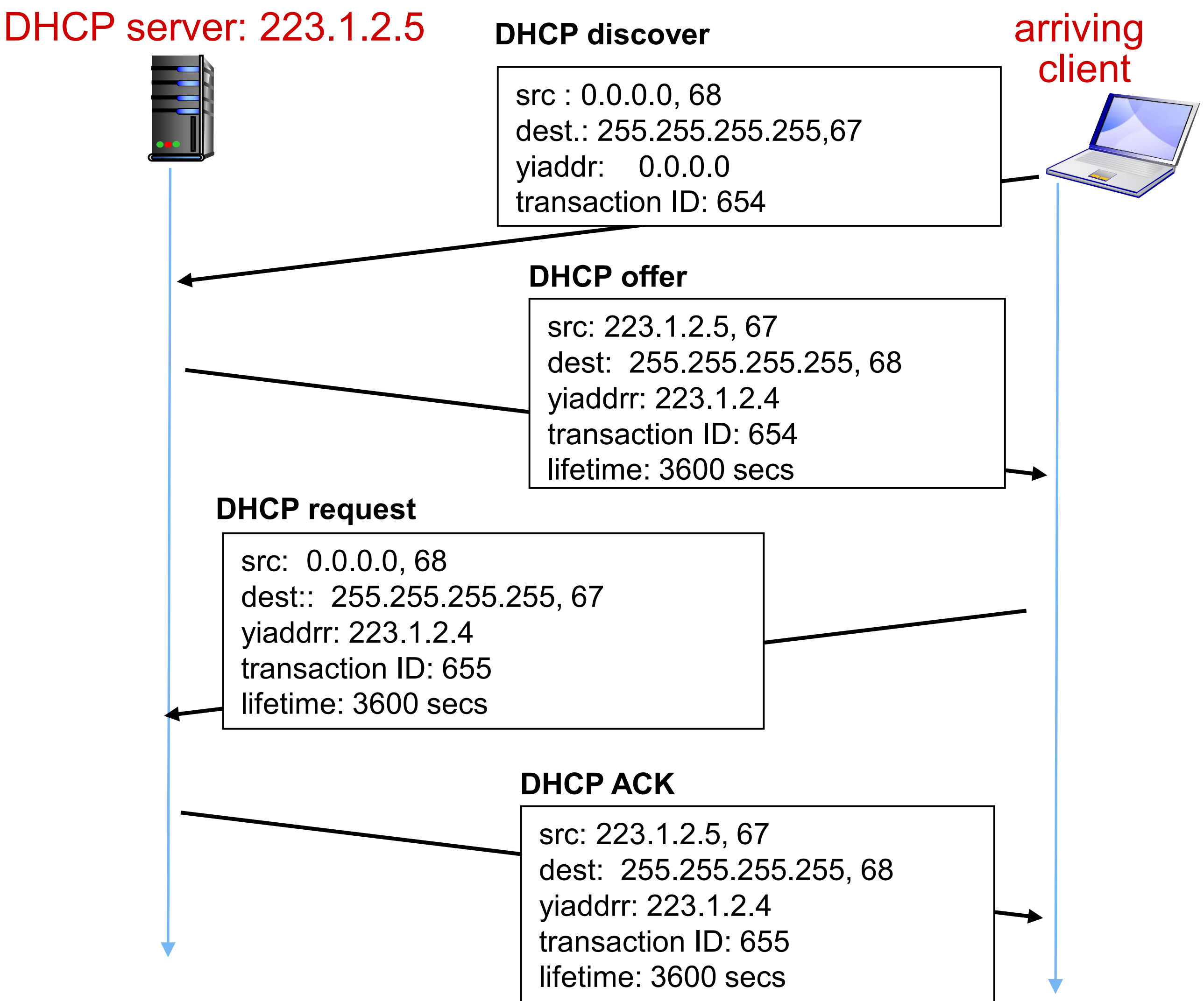


router with DHCP server built into router

- DCP server formulates DHCP ACK containing client' s IP address, IP address of first-hop router for client, name & IP address of DNS server

- encapsulation of DHCP server, frame forwarded to client, demuxing up to DHCP at client
- client now knows its IP address, name and IP address of DSN server, IP address of its first-hop router

DHCP client-server scenario



DHCP: more than IP addresses

DHCP can return more than just allocated IP address on network:

- address of first-hop router for client
- name and IP address of DNS server
- network mask (indicating network versus host portion of address, network prefix)

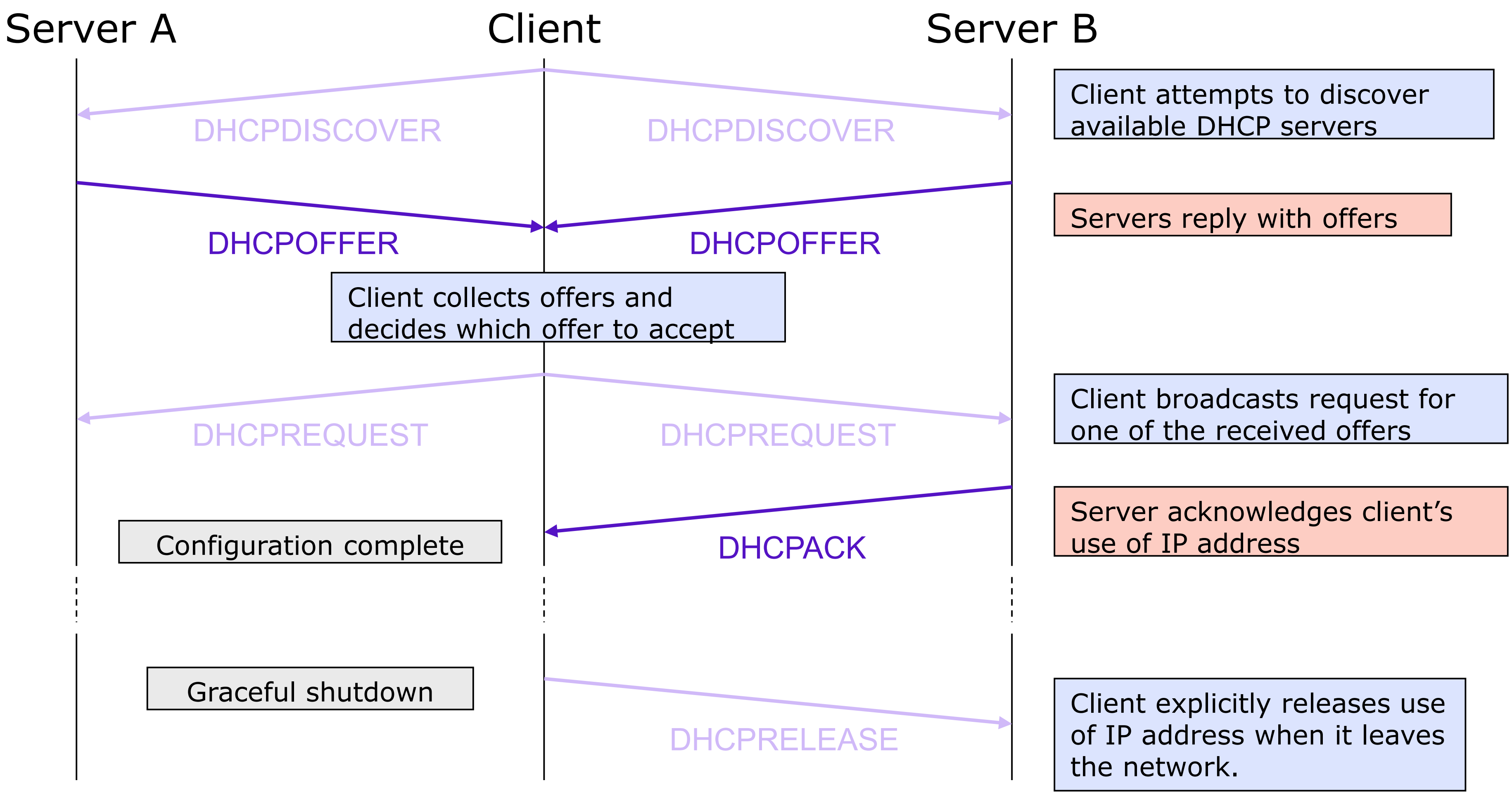
Why

- Why use leases?

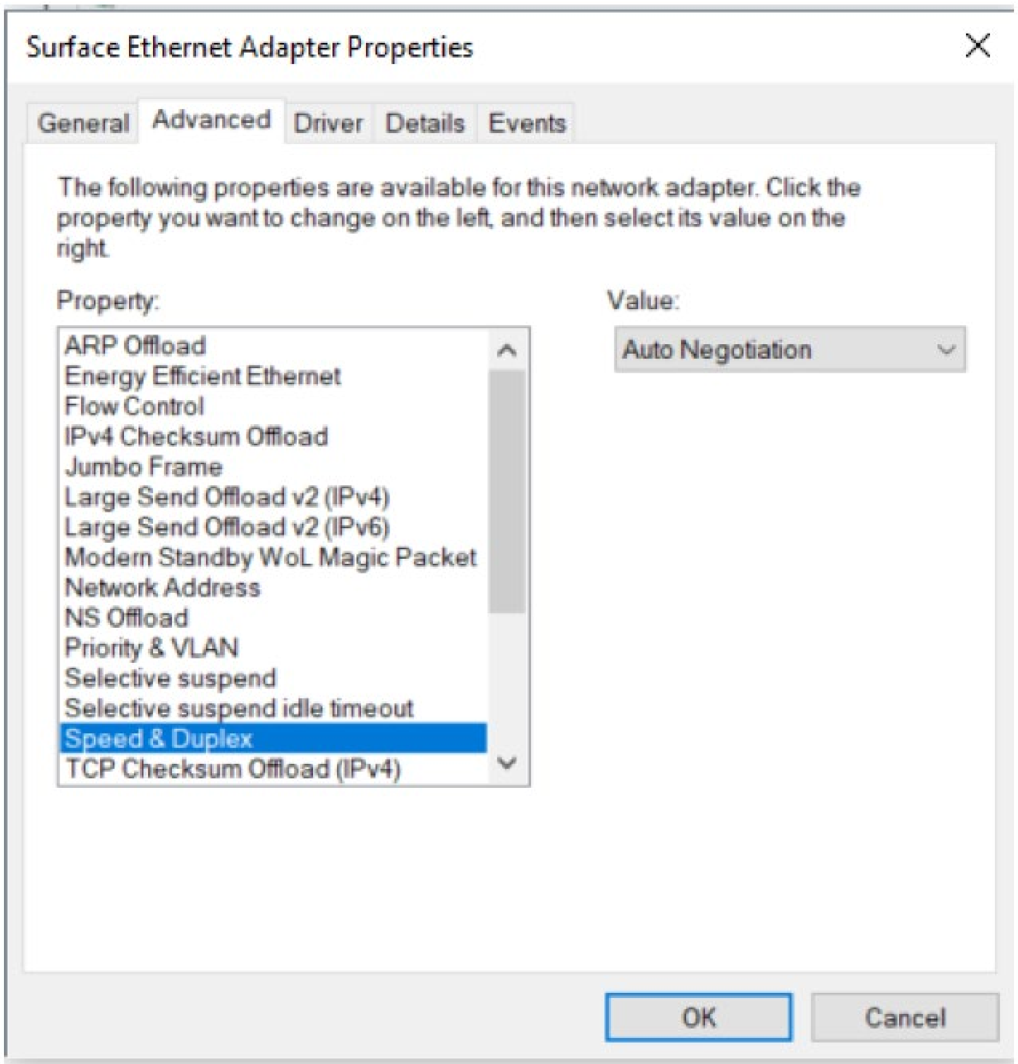
- What if two machines request an IP at the same time?

- What if there are more than one servers?

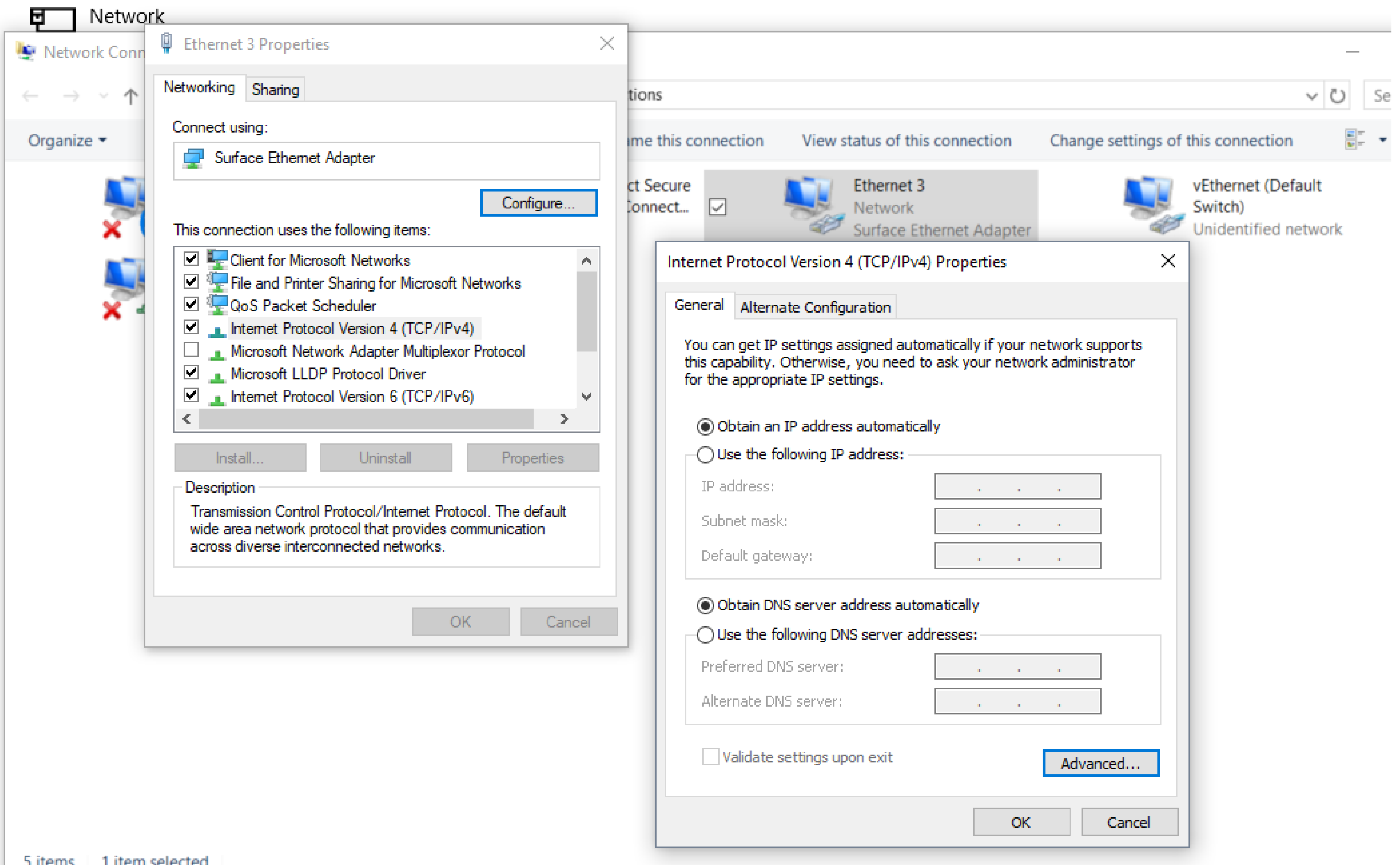
DHCP Conversation (two servers)



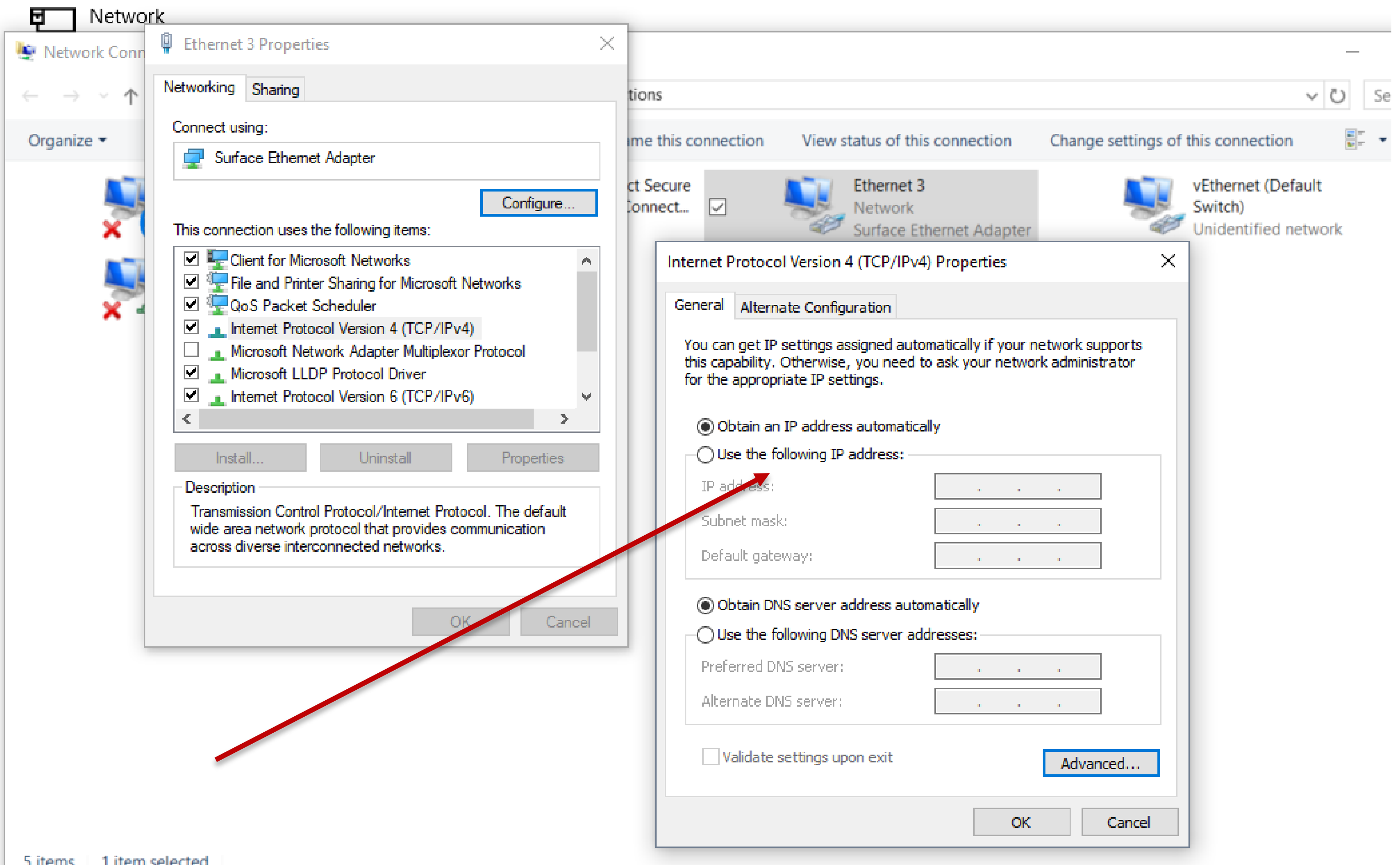
Configuring the Adapter



Configuring the Host



Configuring the Host



Plug and Play