CE443 – Computer Networks

Bootstrapping

DHCP, and ARP

Behnam Momeni
Computer Engineering Department
Sharif University of Technology

Acknowledgments: Lecture slides are from Computer networks course thought by Jennifer Rexford at Princeton University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Separating IP and MAC Addresses

- LANs are designed for arbitrary network protocols
  - Not just for IP (e.g., IPX, Appletalk, X.25, …)
    - Though now IP is the main game in town
  - Different LANs may have different addressing schemes
    - Though now Ethernet address is the main game in town
- A host may move to a new location
  - So, cannot simply assign a static IP address
    - Since IP addresses depend on host's position in topology
  - Instead, must reconfigure the adapter
    - To assign it an IP address based on its current location
- Must identify the adapter during bootstrap process
  - Need to talk to the adapter to assign it an IP address

Three Kinds of Identifiers

- **Host name** (e.g., www.cnn.com)
  - Mnemonic name appreciated *by humans*
  - Provides little (if any) information about location
  - Hierarchical, variable # of alpha-numeric characters
- **IP address** (e.g., 64.236.16.20)
  - Numerical address appreciated *by routers*
  - Related to host's current location in the topology
  - Hierarchical name space of 32 bits
- **MAC address** (e.g., 00-15-C5-49-04-A9)
  - Numerical address appreciated *within local area network*
  - Unique, hard-coded in the adapter when it is built
  - Flat name space of 48 bits

Three Hierarchical Assignment Processes

- **Host name:** www.cs.princeton.edu
  - Domain: registrar for each top-level domain (e.g., .edu)
  - Host name: local administrator assigns to each host
- **IP addresses:** 128.112.7.156
  - Prefixes: ICANN, regional Internet registries, and ISPs
  - Hosts: static configuration, or dynamic using DHCP
- **MAC addresses:** 00-15-C5-49-04-A9
  - Blocks: assigned to vendors by the IEEE
  - Adapters: assigned by the vendor from its block

Mapping Between Identifiers

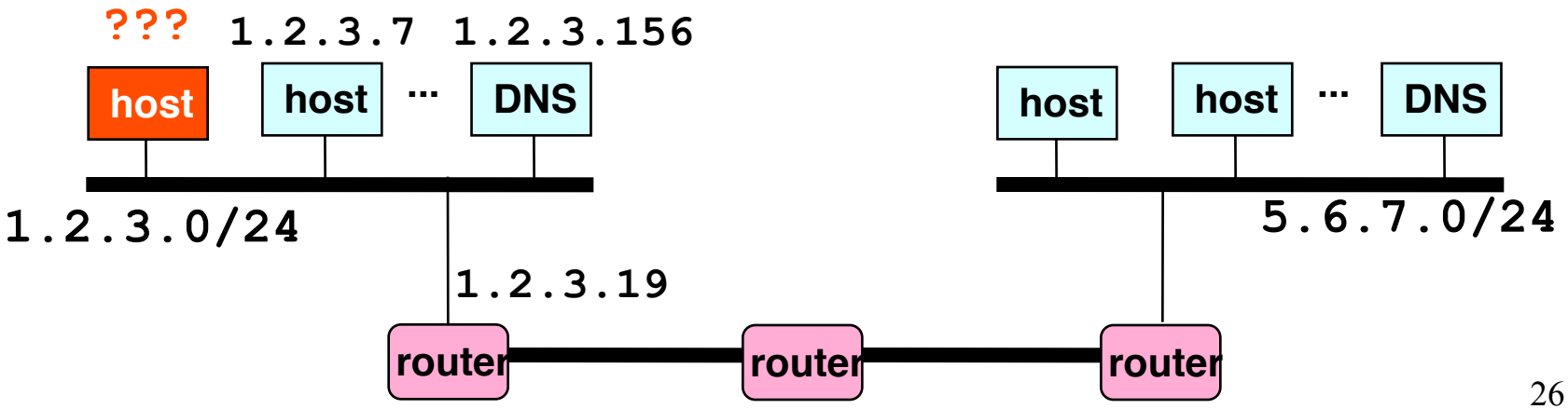
- Domain Name System (DNS)
  - Given a host name, provide the IP address
  - Given an IP address, provide the host name
- Dynamic Host Configuration Protocol (DHCP)
  - Given a MAC address, assign a unique IP address
  - … and tell host other stuff about the Local Area Network
  - To automate the boot-strapping process
- Address Resolution Protocol (ARP)
  - Given an IP address, provide the MAC address
  - To enable communication within the Local Area Network

Boot-Strapping an End Host

DHCP and ARP

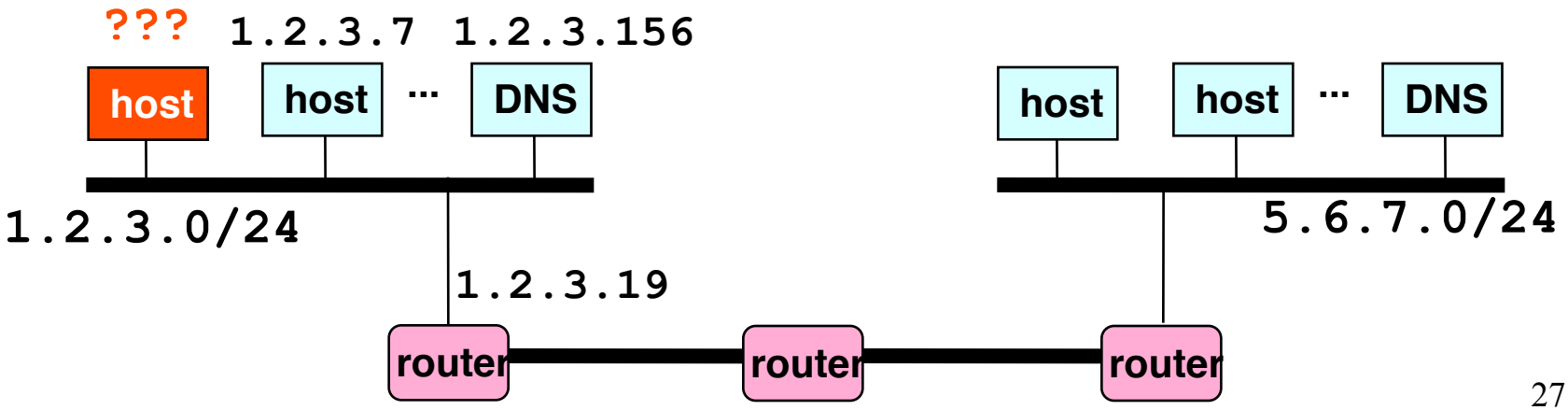
How To Bootstrap an End Host?

- What local Domain Name System server to use?
- What IP address the host should use?
- How to send packets to remote destinations?
- How to ensure incoming packets arrive?



Avoiding Manual Configuration

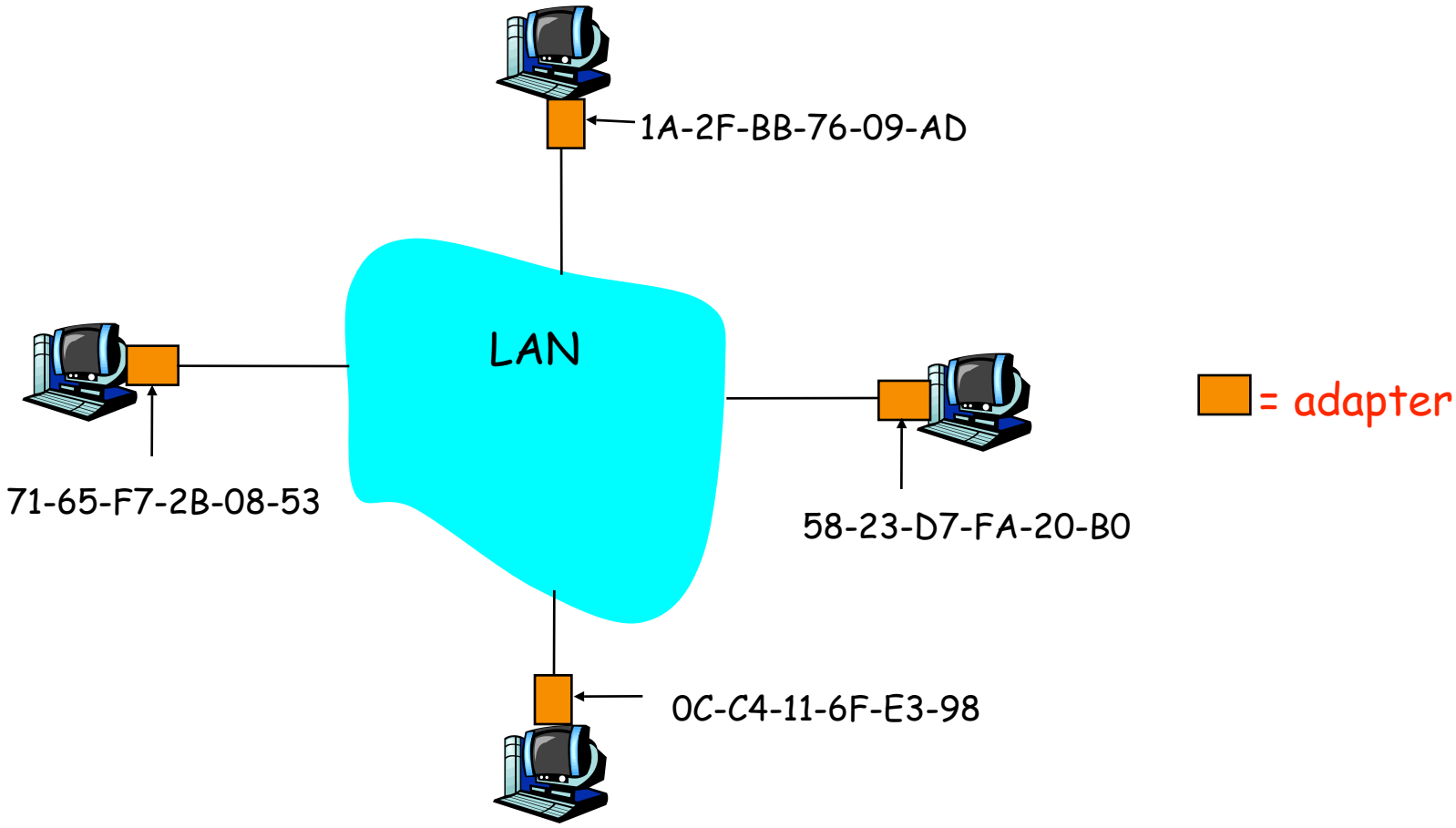
- Dynamic Host Configuration Protocol (DHCP)
  - End host learns how to send packets
  - Learn IP address, DNS servers, and gateway
- Address Resolution Protocol (ARP)
  - Others learn how to send packets to the end host
  - Learn mapping between IP address & interface address



Key Ideas in Both Protocols

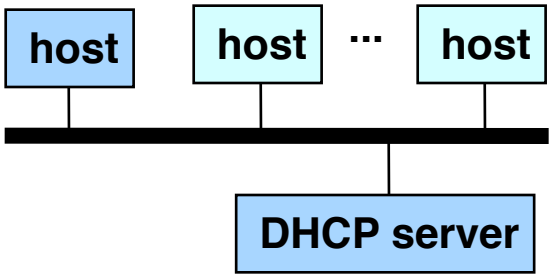
- **Broadcasting:** when in doubt, shout!
  - Broadcast query to all hosts in the local-area-network
  - … when you don't know how to identify the right one
- **Caching:** remember the past for a while
  - Store the information you learn to reduce overhead
  - Remember your own address & other host's addresses
- **Soft state:** … but eventually forget the past
  - Associate a time-to-live field with the information
  - … and either refresh or discard the information
  - Key for robustness in the face of unpredictable change

Media Access Control (MAC) Addresses



Bootstrapping Problem

- Host doesn't have an IP address yet
  - So, host doesn't know what source address to use
- Host doesn't know who to ask for an IP address
  - So, host doesn't know what destination address to use
- Solution: shout to discover a server who can help
  - Broadcast a DHCP server-discovery message
  - Server sends a DHCP "offer" offering an address



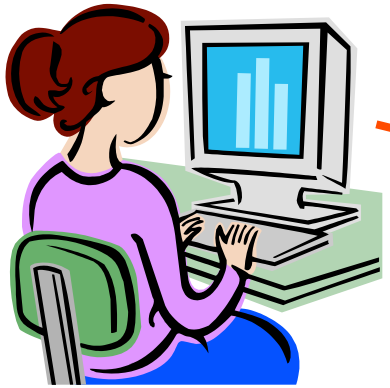
Broadcasting

- Broadcasting: sending to everyone
  - Special destination address: FF-FF-FF-FF-FF-FF
  - All adapters on the LAN receive the packet
- Delivering a broadcast packet
  - Easy on a “shared media”
  - Like shouting in a room – everyone can hear you

Response from the DHCP Server

- DHCP "offer message" from the server
  - Configuration parameters (proposed IP address, mask, gateway router, DNS server, ...)
  - Lease time (the time the information remains valid)
- Multiple servers may respond
  - Multiple servers on the same broadcast media
  - Each may respond with an offer
  - The client can decide which offer to accept
- Accepting one of the offers
  - Client sends a DHCP request echoing the parameters
  - The DHCP server responds with an ACK to confirm
  - … and the other servers see they were not chosen

Dynamic Host Configuration Protocol



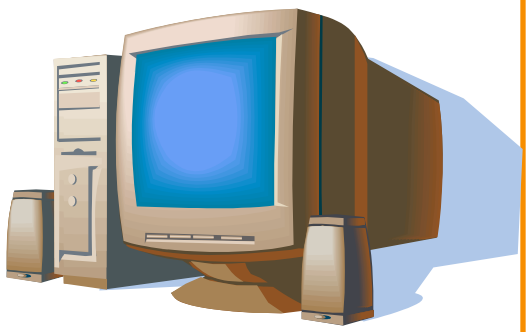
arriving client

DHCP discover (broadcast)

DHCP offer

DHCP request (broadcast)

DHCP ACK



DHCP server 233.1.2.5

Deciding What IP Address to Offer

- Server as centralized configuration database
  - All parameters are statically configured in the server
  - E.g., a dedicated IP address for each MAC address
  - Avoids complexity of configuring hosts directly
  - … while still having a permanent IP address per host
- Or, dynamic assignment of IP addresses
  - Server maintains a pool of available addresses
  - … and assigns them to hosts on demand
  - Leads to less configuration complexity
  - … and more efficient use of the pool of addresses
  - Though, it is harder to track the same host over time

Soft State: Refresh or Forget

- Why is a lease time necessary?
  - Client can release the IP address (DHCP RELEASE)
    - E.g., "ipconfig /release" at the DOS prompt
    - E.g., clean shutdown of the computer
  - But, the host might not release the address
    - E.g., the host crashes (blue screen of death!)
    - E.g., buggy client software
  - And you don't want the address to be allocated forever

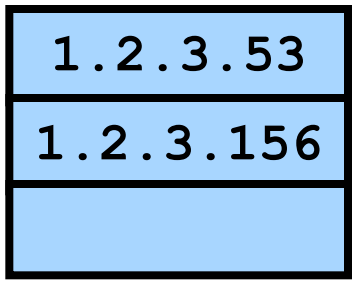
- Performance trade-offs
  - Short lease time: returns inactive addresses quickly
  - Long lease time: avoids overhead of frequent renewals

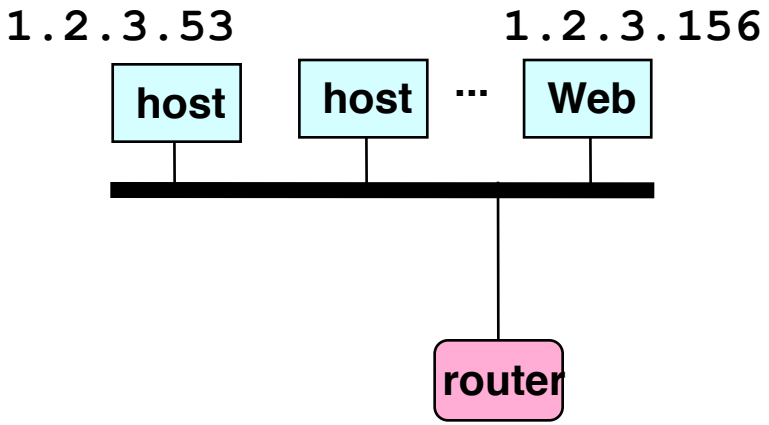
So, Now the Host Knows Things

- IP address
- Mask
- Gateway router
- DNS server
- …

- And can send packets to other IP addresses
  - But, how to learn the MAC address of the destination?

Sending Packets Over a Link





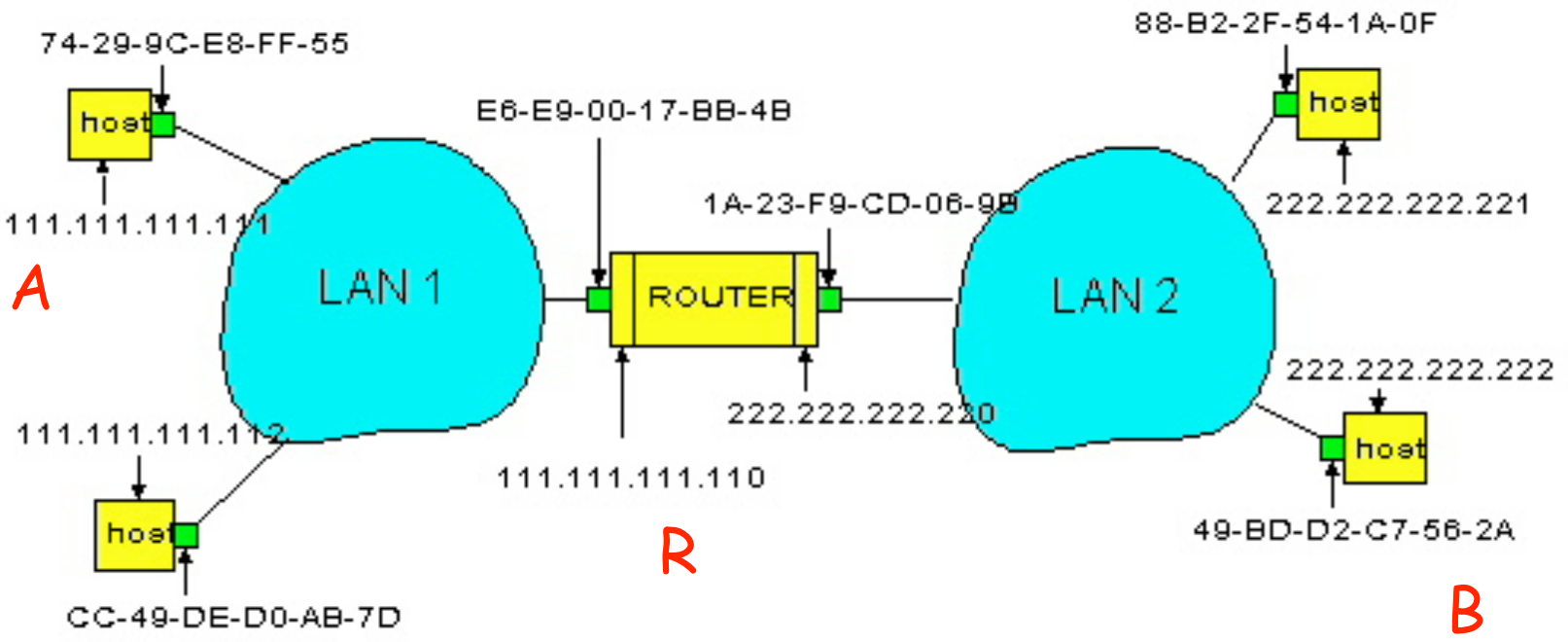
- Adapters only understand MAC addresses
  - Translate the destination IP address to MAC address
  - Encapsulate the IP packet inside a link-level frame

Address Resolution Protocol Table

- Every node maintains an ARP table
  - (IP address, MAC address) pair
- Consult the table when sending a packet
  - Map destination IP address to destination MAC address
  - Encapsulate and transmit the data packet
- But, what if the IP address is not in the table?
  - Sender broadcasts: “Who has IP address 1.2.3.156?”
  - Receiver responds: “MAC address 58-23-D7-FA-20-B0”
  - Sender caches the result in its ARP table
- No need for network administrator to get involved

Example: A Sending a Packet to B

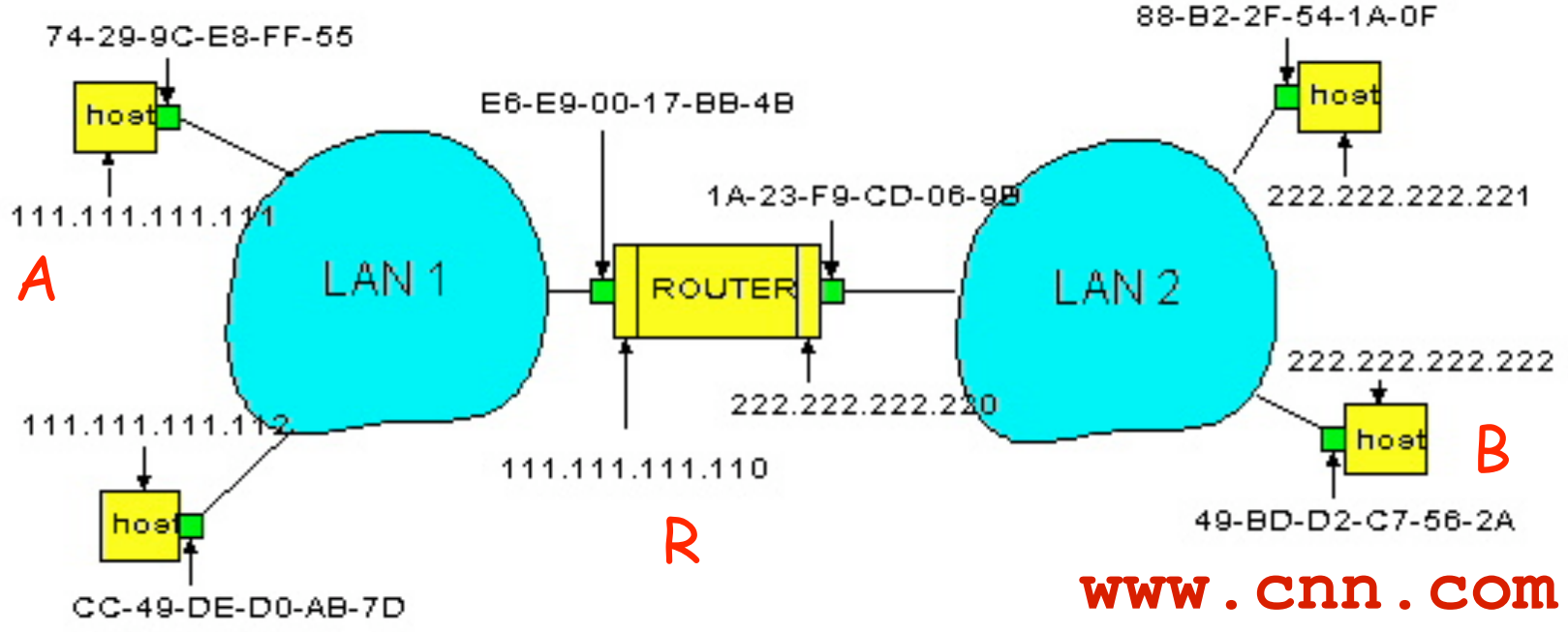
How does host A send an IP packet to B (www.cnn.com)?



A sends packet to R, and R sends packet to B.

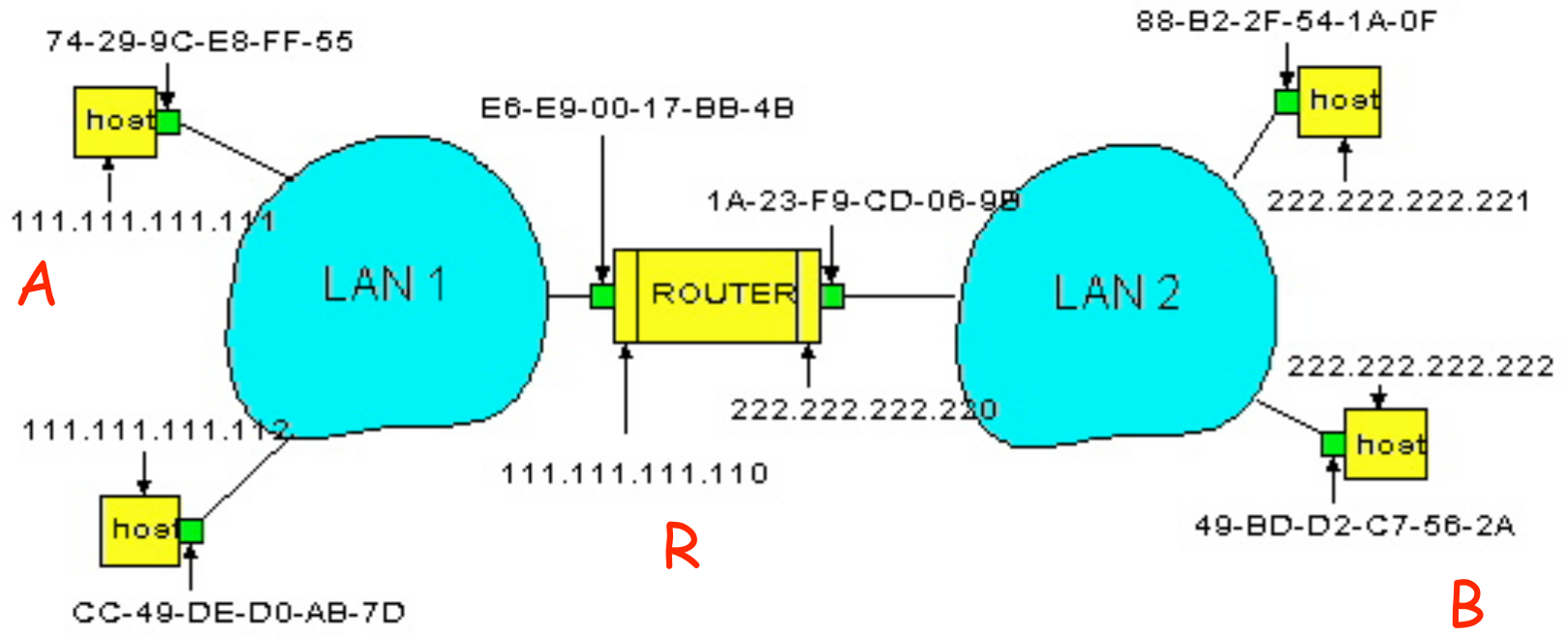
Basic Steps

- Host A must learn the IP address of B via DNS
- Host A uses gateway R to reach external hosts
- Host A sends the frame to R's MAC address
- Router R forwards IP packet to outgoing interface
- Router R learns B's MAC address and forwards frame



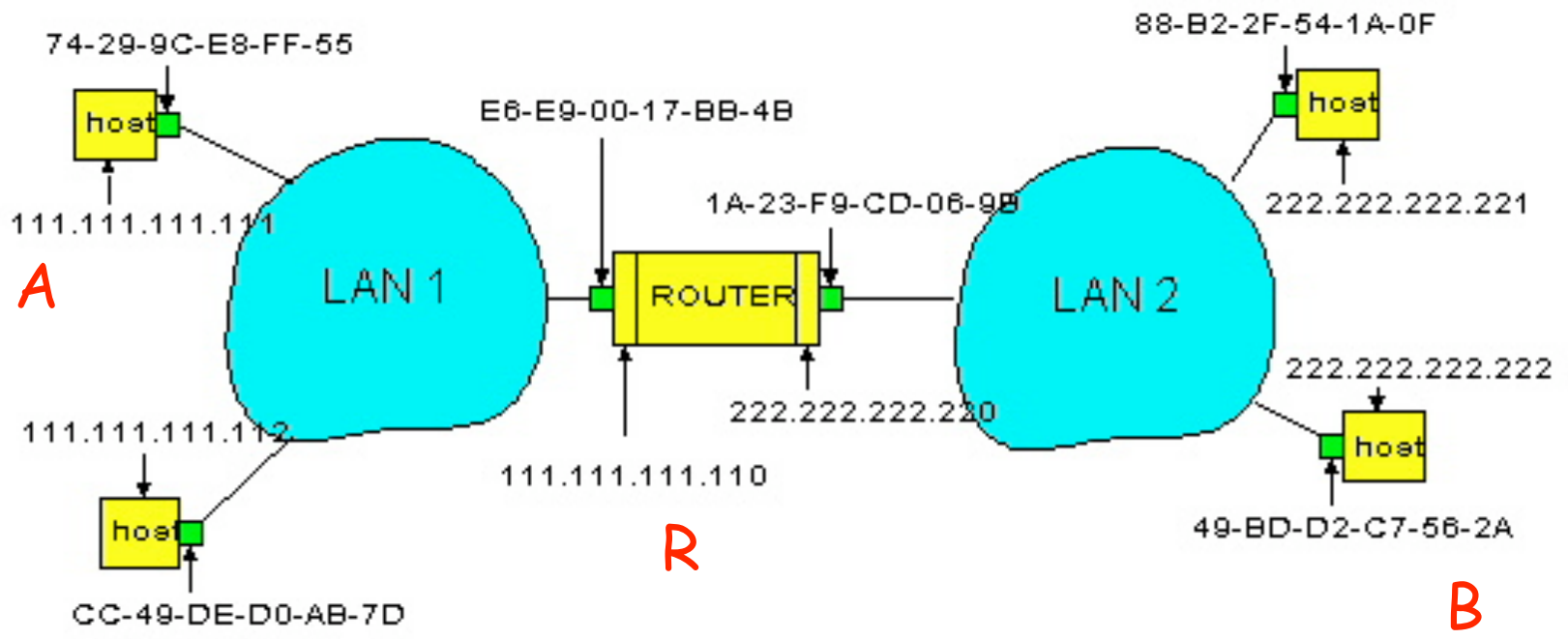
Host A Learns the IP Address of B

- Host A does a DNS query to learn B's address
  - Suppose gethostbyname() returns 222.222.222.222
- Host A constructs an IP packet to send to B
  - Source 111.111.111.111, destination 222.222.222.222



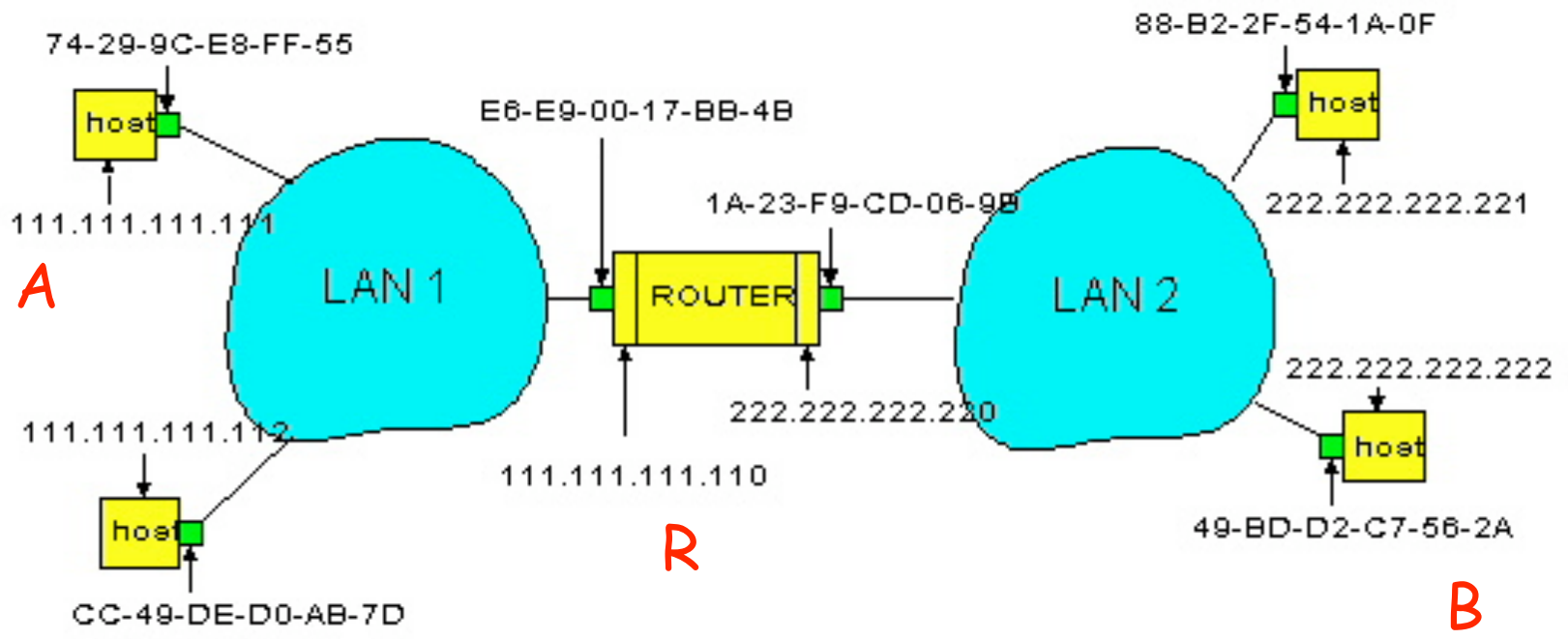
Host A Learns the IP Address of B

- IP header
  - From A: 111.111.111.111
  - To B: 222.222.222.222
- Ethernet frame
  - From A: 74-29-9C-E8-FF-55
  - To gateway: ????



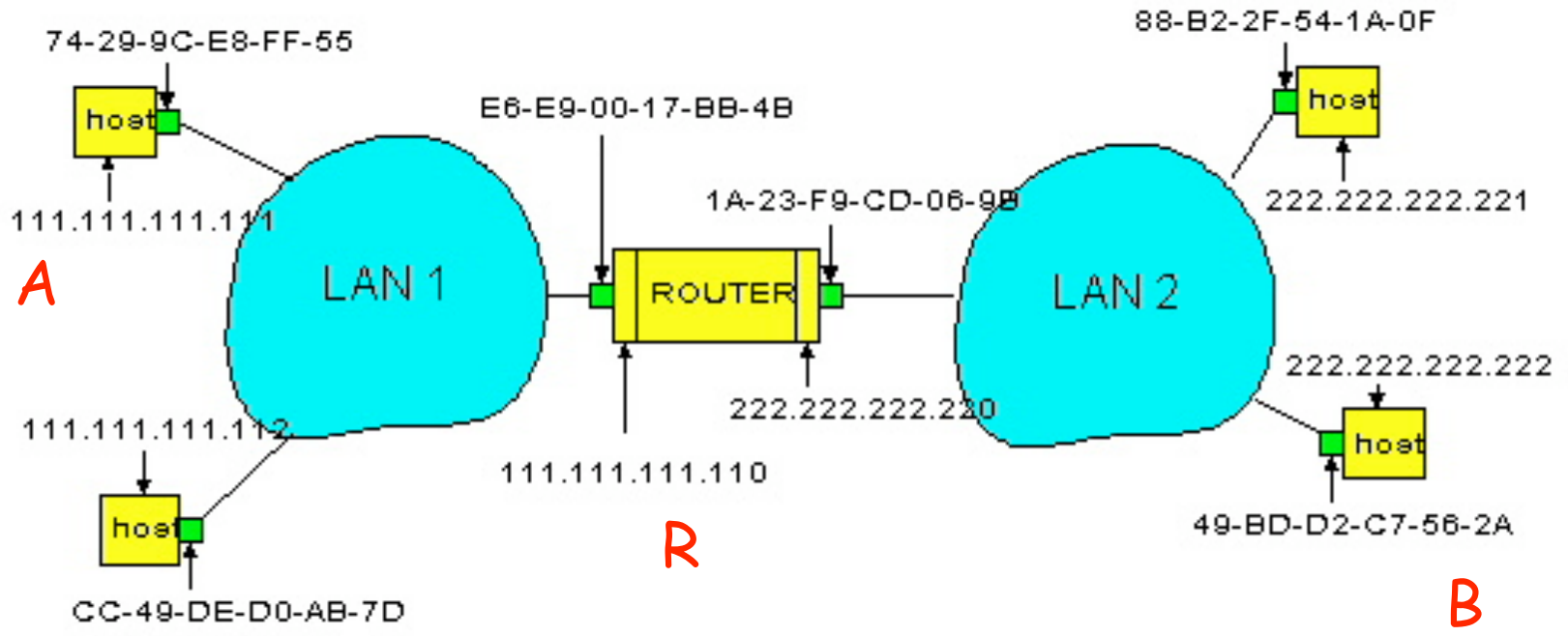
Host A Decides to Send Through R

- Host A has a gateway router R
  - Used to reach destinations outside of 111.111.111.0/24
  - Address 111.111.111.110 for R learned via DHCP
- But, what is the MAC address of the gateway?



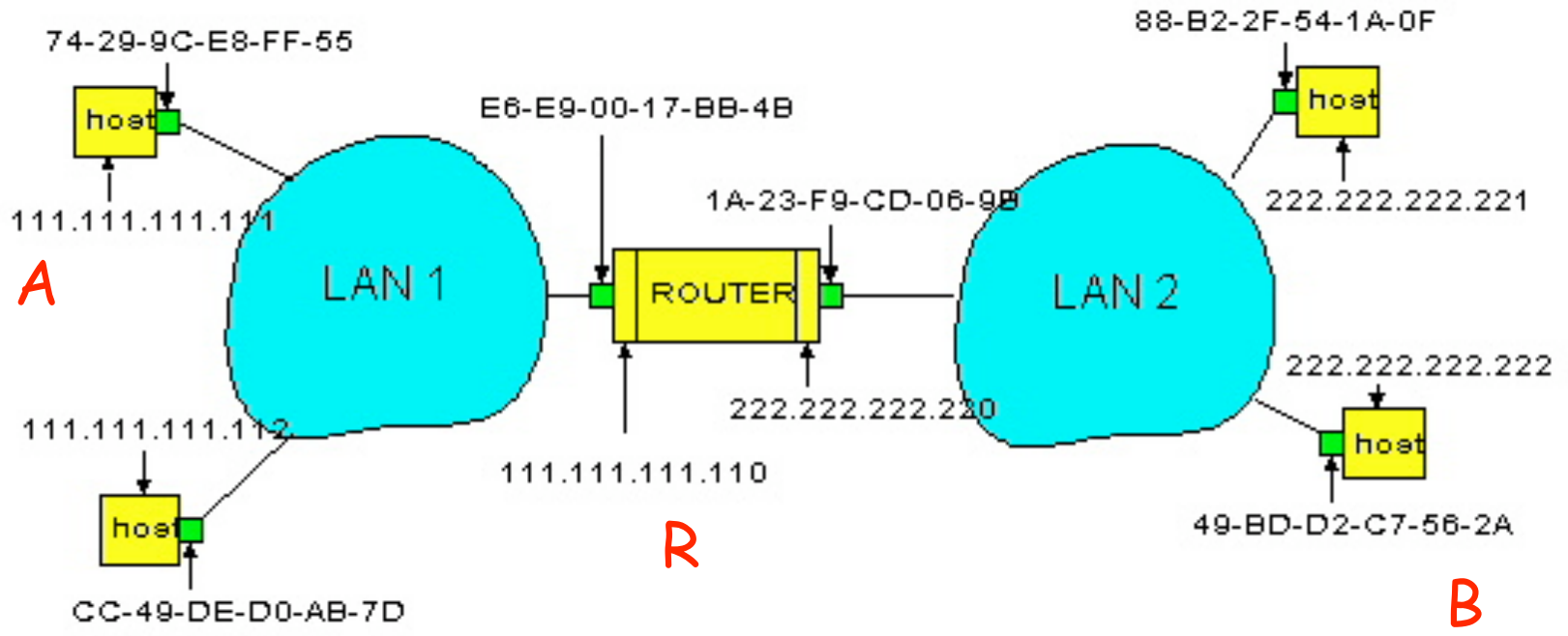
Host A Sends Packet Through R

- Host A learns the MAC address of R's interface
  - ARP request: broadcast request for 111.111.111.110
  - ARP response: R responds with E6-E9-00-17-BB-4B
- Host A encapsulates the packet and sends to R



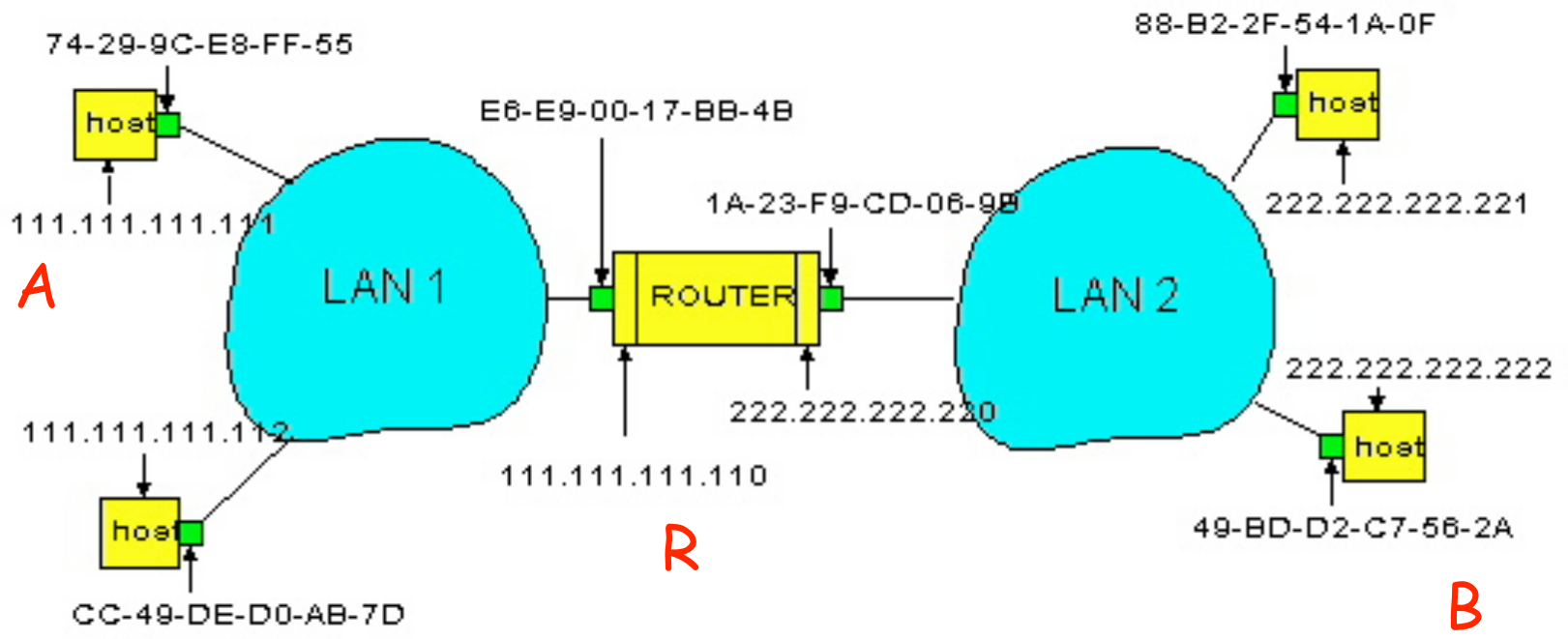
Host A Sends Packet Through R

- IP header
  - From A: 111.111.111.111
  - To B: 222.222.222.222
- Ethernet frame
  - From A: 74-29-9C-E8-FF-55
  - To R: E6-E9-00-17-BB-4B



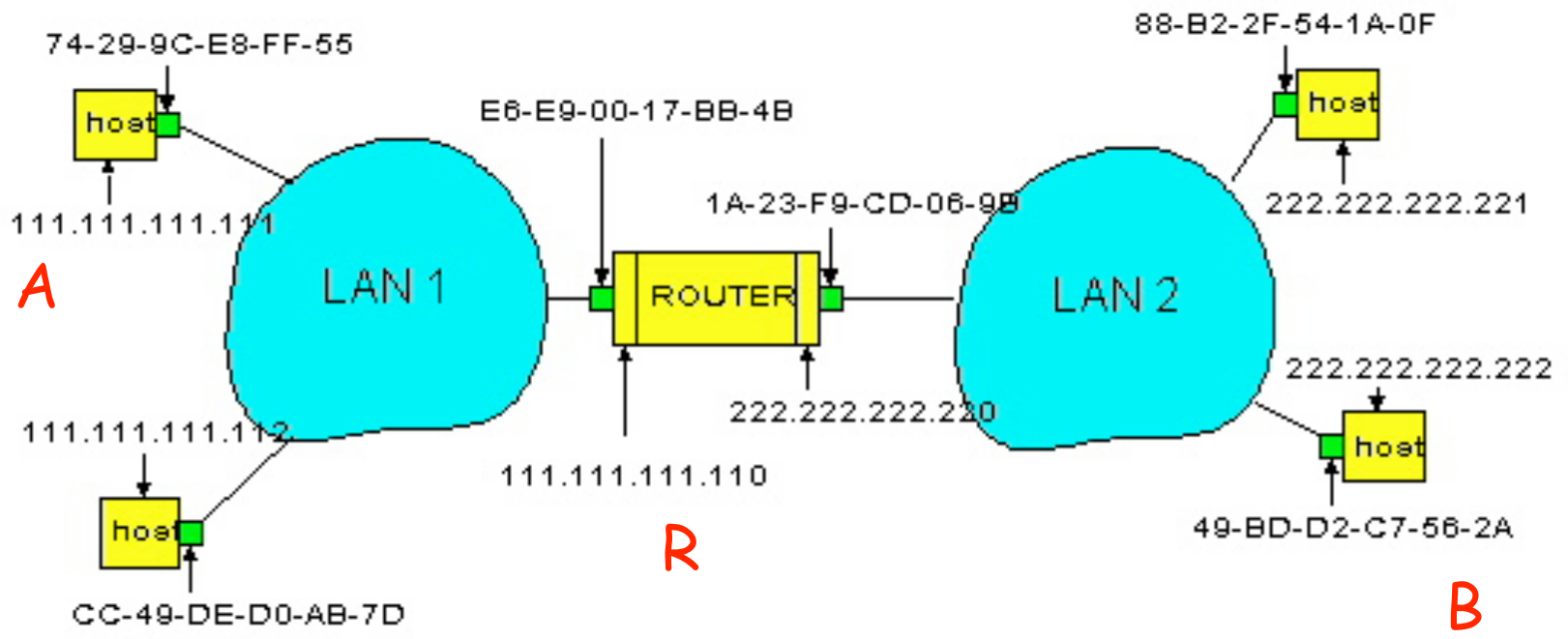
R Decides how to Forward Packet

- Router R's adapter receives the packet
  - R extracts the IP packet from the Ethernet frame
  - R sees the IP packet is destined to 222.222.222.222
- Router R consults its forwarding table
  - Packet matches 222.222.222.0/24 via other adapter



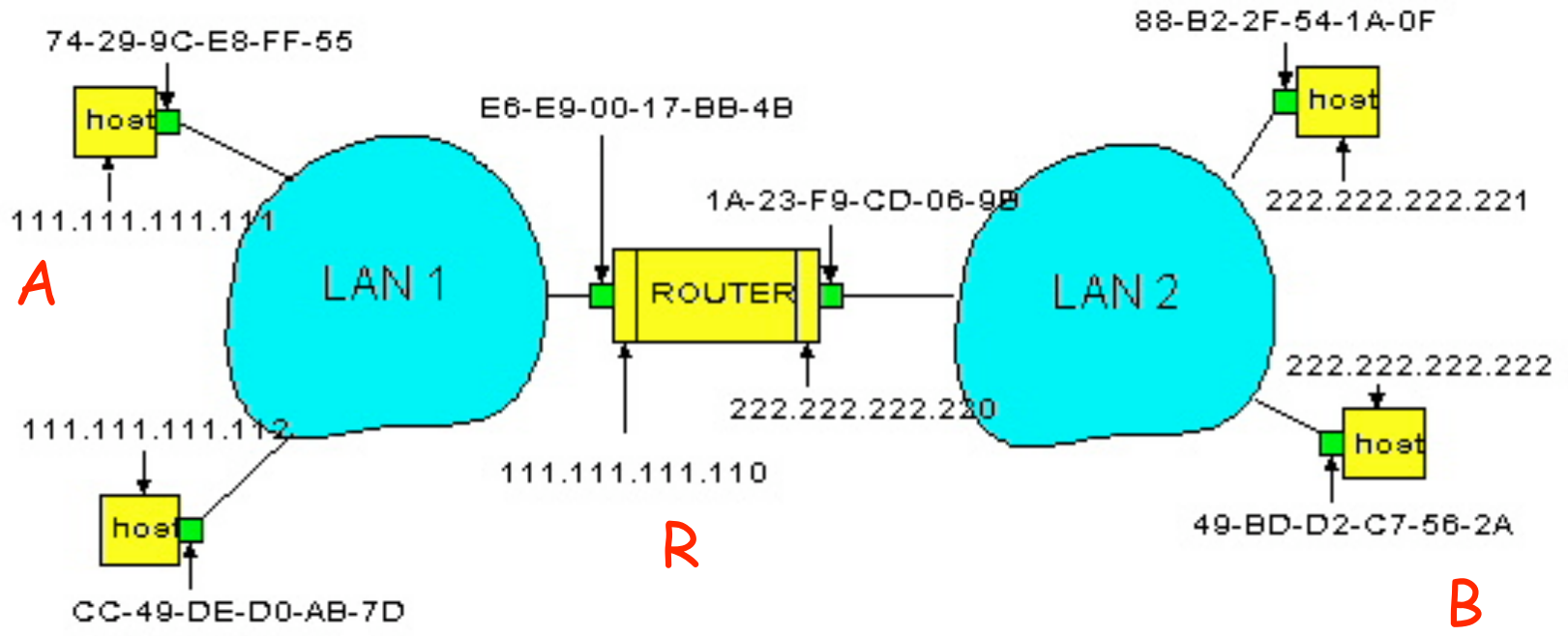
Router R Wants to Forward Packet

- IP header
  - From A: 111.111.111.111
  - To B: 222.222.222.222
- Ethernet frame
  - From R: 1A-23-F9-CD-06-9B
  - To B: ???



R Sends Packet to B

- Router R's learns the MAC address of host B
  - ARP request: broadcast request for 222.222.222.222
  - ARP response: B responds with 49-BD-D2-C7-56-2A
- Router R encapsulates the packet and sends to B



Router R Wants to Forward Packet

- IP header
  - From A: 111.111.111.111
  - To B: 222.222.222.222
- Ethernet frame
  - From R: 1A-23-F9-CD-06-9B
  - To B: 49-BD-D2-C7-56-2A