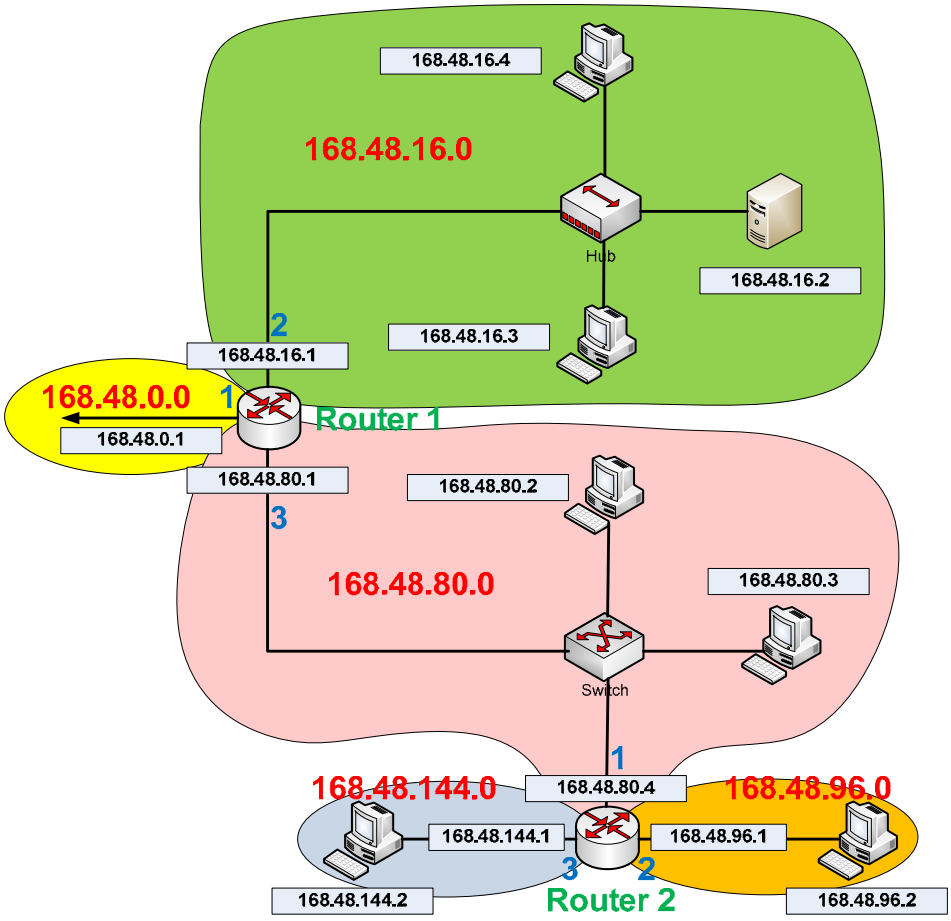
Lecture 14: TCP/IP

IP Routing

Routing is the process performed by routers to transfer packets from the source machine to the destination. Unlike switches, routers are configured by a network administrator. Routers share information about the different routes and the health of each router among themselves so that all of them can draw a picture of the whole network. Each router stores a table known as Routing table that contains information about the different routes that the router can send the packet through. Each machine on the network has some form of routing table. Routing tables in hosts (computer) usually have few entries (5 to 10 entries) depending on the number of network interface cards installed. Routing tables in Internet routers may have 100,000 different entries or possibly more.

Format of a Routing Table

Consider the following network (designed in the previous lecture). There are two routers (Router 1 and Router 2). Let us look at the format of the routing table in these routers.



Lecture 14: TCP/IP

A typical routing table may look something like the following:

Destination	Next Hop	Flags (H = 1 ➔ Destination is a Host) (H = 0 ➔ Destination is a Network) (G = 1 ➔ Next Hop is a Gateway/Router) (G = 0 ➔ Next Hop is not Gateway/Router)	Network Interface	Metric

- Destination: This lists the IP addresses of the possible destinations that the router knows how to route a packet to.
- Next Hop: This gives the next IP address that the packet will be transmitted over.
- Flags: These provide information about the devices that are connected to the router (gateway/router or not) and the type of destination (host or network).
- Network Interface: The port that the router will send the packet over.
- Metric: A measure of the quality of the link to help determine the most efficient link over which to send the packet.

Types of Destinations:

Generally, there are 3 types of destinations that can be found in routing tables:

- Complete Destination IP Address: This represents the complete destination IP address in the packet.
- Destination Network ID: This represents the network ID of destination IP address of the packet.
- Default Gateway: This is where packets with destination IP addresses and Network IDs that are not found in the routing table will be sent.

Order of Searching the Routing Table

1. Destination column is searched to determine if the table contains an entry with the complete destination IP address ➔ If found, IP packet is forwarded along the next hop using the proper network interface

2. If the above was not found, the routing table is searched for the destination Net ID ➔ If found, IP packet is forwarded along the next hop using the proper network interface

Lecture 14: TCP/IP

3. If the above were not found, the routing table is searched for a default router entry ➔ If found, IP packet is forwarded to it using the proper network interface

4. If all the above were not found ➔ The packet is stated to be undeliverable and an ICMP message (host unreachable error) is sent back to the originating host.

Note: To see the routing table of a computer, try the DOS Command: " netstat –r "

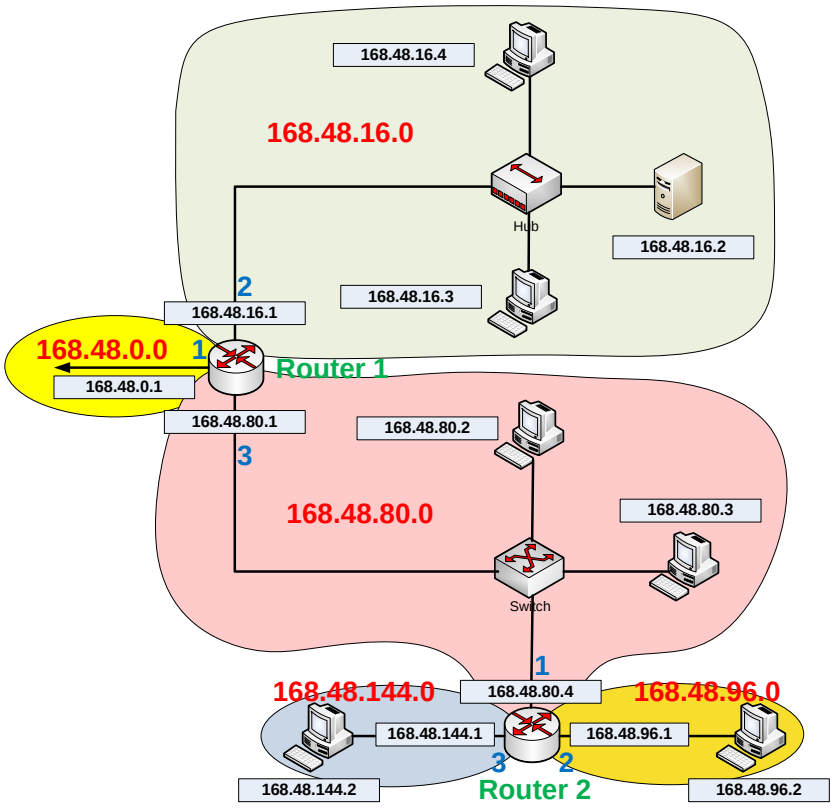
The following is an example of using **" netstat –r "**

```
C:\Documents and Settings\Wajih>netstat -r
Route Table
===========================================================================
Interface List
0x1 ........................... MS TCP Loopback interface
0x2  ...00  16  6f  70  11  9f  ......  Intel(R)  PRO/Wireless  2200BG  Network
Connection
- Packet Scheduler Miniport
0x3 ...00 15 60 ae 50 5e ...... Broadcom NetXtreme Gigabit Ethernet - Packet
Sch
eduler Miniport
===========================================================================
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0       10.59.0.64      10.59.8.50       20
        10.59.0.0    255.255.240.0       10.59.8.50      10.59.8.50       20
       10.59.8.50  255.255.255.255        127.0.0.1       127.0.0.1       20
   10.255.255.255  255.255.255.255       10.59.8.50      10.59.8.50       20
        127.0.0.0        255.0.0.0        127.0.0.1       127.0.0.1       1
        224.0.0.0        240.0.0.0       10.59.8.50      10.59.8.50       20
  255.255.255.255  255.255.255.255       10.59.8.50               2       1
  255.255.255.255  255.255.255.255       10.59.8.50      10.59.8.50       1
Default Gateway:        10.59.0.64
===========================================================================
Persistent Routes:
  None
```

Lecture 14: TCP/IP

Examples

Consider the network shown below (same network that was designed in the previous lecture). Write 6 entries in the routing table of Router 2.



Solution

Destination	Next Hop	Flags (H = 1 ➔ Destination is a Host) (H = 0 ➔ Destination is a Network) (G = 1 ➔ Next Hop is a Gateway/Router) (G = 0 ➔ Next Hop is not Gateway/Router)	Network Interface	Metric (I selected random values here)
127.0.0.1	127.0.0.1	H = 1, G = 0	Port 0	1
168.48.80.0	168.48.80.4	H = 0, G = 0	Port 1	12
168.48.16.0	168.48.80.1	H = 0, G = 1	Port 1	15
168.48.144.2	168.48.144.2	H = 1, G = 0	Port 3	8
168.48.16.4	168.48.80.1	H = 1, G = 1	Port 1	13
Default	168.48.80.1	H = 0, G = 1	Port 1	15

Lecture 14: TCP/IP

Note on Routing Tables (see similar color of text in the table above):

- When the Destination = 127.0.0.1 ➔ Next hop = 127.0.0.1
- When the Destination is Network ID that is directly connected to the Router (so Host ID = 0) ➔ Next Hop = IP address of router port that is connected to the network.
- When the Destination is Network ID that is not connected to Router directly ➔ Next Hop = IP address of next Router that will bring the packet closer to the desired network
- When the Destination is a Host connected to the Router ➔ Next Hop = IP address of host
- When the Destination is a Host in a network that is not directly connected to the router ➔ Next Hop = IP address of next Router that will bring the packet closer to the desired network.
- When the Destination is Default ➔ Next Hop = IP address of next Router that will bring the packet closer to its destination (usually in this case it is the Internet)

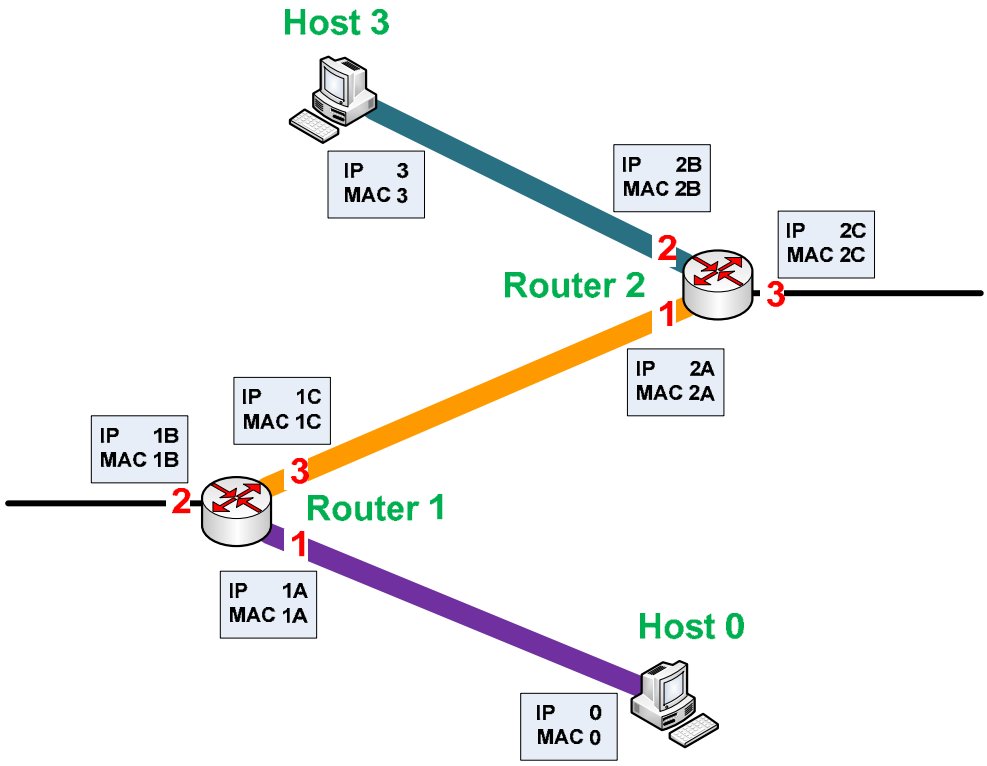
Note: How are MAC addresses and IP addresses used in the transmission of information over multiple networks?

As we know, there are two addresses that are used in networking (Network layer address called IP address, and Data Link layer address called MAC address). How are these addresses used as information is being transmitted over the network? The answer is that IP addresses are used for the source to destination transmission while MAC addresses are used for single hop transmission. As we now know, each port of a router or of a host on the network has its own network interface card (each of these has a MAC address and an IP address. This is illustrated in the following figure where we have two host machines and two routers that connect them together. Assume that:

Lower **Host 0** machine has:	IP 0	MAC 0	
Router 1 has 3 ports with:	IP 1A	MAC 1A	(Port 1)
	IP 1B	MAC 1B	(Port 2)
	IP 1C	MAC 1C	(Port 3)
Router 2 has 3 ports with:	IP 2A	MAC 2A	(Port 1)
	IP 2B	MAC 2B	(Port 2)
	IP 2C	MAC 2C	(Port 3)
Upper **Host 3** machine has:	IP 3	MAC 3	

From the structure of the network, if the lower machine (Host 0) wants to send a packet to the upper machine (Host 3), the packet will have to leave Host 0 going to Router 1 through port 1, which will have

to make a determination that port 3 is the port through which this packet will have to be transmitted. This packet will then reaches Router 2 through port 1, which will have to make a determination that port 2 is the necessary port for transmitting the packet that will send it to its final destination of Host 3.



Let us know look at what are the IP addresses that are in the packets as they are being transmitted over the different links and also the MAC addresses of the frames that carry these packets as they are being transmitted.

Link between Host 0 and Router 1

Packet Header: Source IP Address = IP 0
Destination IP Address = IP 3

Frame Header: Source MAC Address = MAC 0
Destination MAC Address = MAC 1A

Link between Router 1 and Router 2

Packet Header: Source IP Address = IP 0
Destination IP Address = IP 3

Frame Header: Source MAC Address = MAC 1C
Destination MAC Address = MAC 2A

Lecture 14: TCP/IP

Link between Router 2 and Host 3

Packet Header: Source IP Address = IP 0
Destination IP Address = IP 3

Frame Header: Source MAC Address = MAC 2B
Destination MAC Address = MAC 3

Conclusion: The IP addresses in a packet do not change as it travels over a network but the MAC addresses change depending on the links they are traveling over.

Address Resolution Protocol (ARP)

This protocol is used in networks such as Ethernet. To transmit frames in Ethernets, MAC addresses are used which have the format (xx:xx:xx:xx:xx:xx) where each (x) is a hexadecimal number. MAC addresses are unique to each computer in the world since these addresses are linked to the Network Interface Cards (NIC). So, a computer that would like to send a packet to another with a specific IP address on the network would broadcast an ARP packet on network asking all computers a question that looks like "To the machine with IP address x.x.x.x, please inform me (where my MAC address is xx:xx:xx:xx:xx:xx) about your MAC address". The computer with the particular IP address x.x.x.x will respond only to the requesting computer with its MAC address.

Reverse Address Resolution Protocol (RARP)

In specific cases, a host on the network may know the MAC address but not the IP address. In this situation, a reverse process to that done in the ARP is used to get the IP address assigned to the machine. So, a host may use the RARP protocol to ask the question that looks like "Machine with MAC address xx:xx:xx:xx:xx:xx, please inform me of the corresponding IP address".