CHAPTER 4: NETWORK LAYER: DATA PLANE

### Students to Discuss Solution: NAT (Week 7/8)

In some cases why may a NAT router need to change TCP sequence number of a packet? Can you provide an example?

Some applications (such as FTP) may include IP address or Port number in data part. The NAT box peeks in the data and changes the IP / Port number. This change may result in different data lengths (e.g., For FTP, IP addresses are encoded in ASCII in data) requiring the TCP sequence number to be changed as well.

### Students to Discuss Solution: IP Address Assignment (Week 7)

Suppose an ISP has a block of IP addresses starting with 144.4.64.0/19. It wants to create sub-blocks out of its available addresses such that it can meet the following requirements:

i. 32 blocks of 64 IP addresses

ii. 32 blocks of 32 IP addresses

iii. 64 blocks of 16 IP addresses

iv. 128 blocks of 8 IP addresses

v. 256 blocks of 4 IP addresses

Design the sub-blocks and give the slash notation for network address and the broadcast address for each sub-block. How many addresses are still available with the ISP after this allocation?

i. the first group needs 64 IP addresses for each block, 64 = 2^6, so the prefix is 26.

144.4.64.0/26 => 144.4.64.63/26

144.4.64.64/26 => 144.4.64.127/26

……

144.4.71.192/26=>144.4.71.255/26

ii. the second group needs 32 IP addresses for each block, 32 = 2^5, so the prefix is 27

144.4.72.0/27 => 144.4.72.31/27

144.4.72.32/27=>144.4.72.63/27

……

144.4.75.224/27=>144.4.75.255/27

iii. 16 IP addresses -> 2^4: 4 bits for host and (32-4) 28 bits for the network prefix.

The 64 blocks are as follows:

144.4.76.0/28 to 144.4.76.15/28

144.4.76.16/28 to 144.4.76.31/28

…

144.4.79.224/28 to 144.4.79.239/28

144.4.79.240/28 to 144.4.79.255/28

64 \* 16 = 1024 addresses

iv. 8 IP addresses -> 2^3: 3 bits for host and (32-3) 29 bits for the network prefix.

The 128 blocks are as follows:

144.4.80.0/29 to 144.4.80.7/29

144.4.80.8/29 to 144.4.80.15/29

…

144.4.83.240/29 to 144.4.83.247/29

144.4.83.248.29 to 144.4.83.255/29

128 \* 8 = 1024 addresses

v. 4 IP addresses >> 2^2: 2 bits for host and (32-2) 30 bits for the network prefix.

The 256 blocks are as follows:

144.4.84.0/30 to 144.4.84.3/30

144.4.84.4/30 to 144.4.84.7/30

…

144.4.87.248/30 to 144.4.87.251/30

144.4.87.252/30 to 144.4.87.255/30

256 \* 4 = 1024

Total used: 2048 + 4 \* 1024 = 6144

Remaining: 8192 -6144 = 2048

### Students to Discuss Solution: IP Fragmentation (Week 7)

An IP datagram that is 5540 bytes large is sent over a link with an MTU of 1500 bytes and therefore has to be fragmented. State the identifier, fragmentation offset and the value of the MF flag in the IP-header for the different fragments in the table below. You should assume that the IP-header is 20 bytes long and that the identifier field set to 2222.

Table

Description automatically generated

### LONGEST PREFIX MATCHING

Consider a datagram network using 8-bit host addresses.  
Suppose a router uses longest-prefix matching, and has the following forwarding table:

Table

Description automatically generated

### QUESTION LIST

1. Suppose a datagram arrives at the router, with destination address 00000101. To which interface will this datagram be forwarded using longest-prefix matching?  
2. Suppose a datagram arrives at the router, with destination address 10111010. To which interface will this datagram be forwarded using longest-prefix matching?  
3. Suppose a datagram arrives at the router, with destination address 01000001. To which interface will this datagram be forwarded using longest-prefix matching?

SOLUTION

1. Since the address is 00000101, it will go to interface 6.  
2. Since the address is 10111010, it will go to interface 5.  
3. Since the address is 01000001, it will go to interface 4.

### SUBNET ADDRESSING

Consider the router and the two attached subnets below (A and B). The number of hosts is also shown below. The subnets share the 23 high-order bits of the address space: 192.168.106.0/23

A picture containing text

Description automatically generated

Assign subnet addresses to each of the subnets (A and B) so that the amount of address space assigned is minimal, and at the same time leaving the largest possible contiguous address space available for assignment if a new subnet were to be added. Then answer the questions below.

### QUESTION LIST

1. Is the address space public or private?  
It is private address space  
2. How many hosts can there be in this address space?  
/23. So, 32 – 23 = 9, the total number of hosts can be hosted in this address range is 2^9 – 2 (two addresses are broadcasting addresses)  
3. What is the subnet address of subnet A? (CIDR notation)  
  
4. What is the broadcast address of subnet A?  
  
5. What is the starting address of subnet A?  
  
6. What is the ending address of subnet A?  
  
7. What is the subnet address of subnet B? (CIDR notation)  
  
8. What is the broadcast address of subnet B?  
  
9. What is the starting address of subnet B?  
  
10. What is the ending address of subnet B?

SOLUTION

1. The address 192.168.106.0/23 is private.  
  
2. Maximum number of hosts = 2^x - 2 = 2^9 - 2 = 510. The reason we have to subtract 2 from the final number is because there are always 2 addresses allocated for each address block: the subnet ID (the first address) and the broadcast address (the last address); for example, if you have 5 bits for hosts, you can have 30 hosts, because 2 of the addresses are for the subnet ID and the broadcast address which when added equals 32, which is 2^5.  
  
3. Subnet A has 18 hosts, so it will need at least 20 addresses (for the subnet ID and broadcast address). The least number of bits that satisfy this is 5 bits. Knowing that, we take the prior subnet and add 32, the result of which is 192.168.106.32/27  
  
4. The broadcast address of subnet A (192.168.106.32/27) is 192.168.106.63, because it is the last address in the IP range.  
  
5. The first IP address of subnet A (192.168.106.32/27) is 192.168.106.33, found by adding 1 to the subnet address.  
  
6. The last IP address of subnet A (192.168.106.32/27) is 192.168.106.62, found by subtracting 1 from the broadcast address (192.168.106.63).  
  
7. Similar to the prior subnet, subnet B has 25 hosts, so it will need at least 27 addresses (for the subnet ID and broadcast address). The least number of bits that satisfy this is 5 bits. Knowing that, we take the prior subnet and add 32, the result of which is 192.168.106.0/27  
  
8. The broadcast address of subnet B (192.168.106.0/27) is 192.168.106.31, because it is the last address in the IP range.  
  
9. The first IP address of subnet B (192.168.106.0/27) is 192.168.106.1, found by adding 1 to the subnet address.  
  
10. The last IP address of subnet B (192.168.106.0/27) is 192.168.106.30, found by subtracting 1 from the broadcast address (192.168.106.31).

### NETWORK ADDRESS TRANSLATION

Consider the scenario below in which three hosts, with private IP addresses 10.0.1.13, 10.0.1.15, 10.0.1.18 are in a local network behind a NAT'd router that sits between these three hosts and the larger Internet. IP datagrams being sent from, or destined to, these three hosts must pass through this NAT router. The router’s interface on the LAN side has IP address 10.0.1.25, while the router’s address on the Internet side has IP address 135.122.191.211  
  
Before doing this problem, you might want to reread the section on the NAT protocol in section 4.3.4 in the text.

Diagram

Description automatically generated with medium confidence

Suppose that the host with IP address 10.0.1.15 sends an IP datagram destined to host 128.119.177.182. The source port is 3362, and the destination port is 8

### QUESTION LIST

1. Consider the datagram at step 1, after it has been sent by the host but before it has reached the router. What is the source IP address for this datagram?  
  
2. At step 1, what is the destination IP address?  
  
3. Now consider the datagram at step 2, after it has been transmitted by the router. What is the source IP address for this datagram?  
  
4. At step 2, what is the destination IP address for this datagram?  
  
5. Will the source port have changed? Yes or No.  
  
6. Now consider the datagram at step 3, just before it is received by the router. What is the source IP address for this datagram?  
  
7. At step 3, what is the destination IP address for this datagram?  
  
8. Last, consider the datagram at step 4, after it has been transmitted by the router but before it has been received by the host. What is the source IP address for this datagram?  
  
9. At step 4, what is the destination IP address for this datagram

### SOLUTION

1. The source address will be the local host's IP, which is 10.0.1.15  
  
2. The destination address will be the remote machine's IP, which is 128.119.177.182  
  
3. The source address will be the router's public IP, which is 135.122.191.211  
  
4. The destination address will be the remote machine's IP, which is 128.119.177.182  
  
5. Yes, the NAT will change the source port.  
  
6. The source address will be the remote machine's IP, which is 128.119.177.182  
  
7. The destination address will be the router's public IP, which is 135.122.191.211  
  
8. The source address will be the remote machine's IP, which is 128.119.177.182  
  
9. The destination address will be the local host's IP, which is 10.0.1.15  
  
10. No, an entry is made when there's an outbound request, which only happens between step 1 and step 2.

Diagram

Description automatically generated

# Quiz

**Q1**. A router performs routing when a data packet arrives. True or **False**?

**Q2**. When a packet arrives, a router performs forwarding. **True**or False?

A physical router can only perform forwarding

**Q3**. To perform forwarding, a router needs to perform routing first. **True**or False?

**Q4**. To perform forwarding, a router must inspect the source address in the arriving packet's header. True or **False?**

**Q5**. IP packet fragmentation:

A. helps speed up data delivery in the Internet

B. cannot be avoided

**C. can be avoided by controlling TCP segment size based on path MTU discovery**

D. can be avoided by configuring the maximum transfer unit (MTU) of the underlying link layer.

**Q6**. Each network interface of a host must be configured with an IP address. **True**or False?

**Q7**. Two hosts connected to the same subnet can reach each other without the help of a router. **True**or False?

**Q8**. In the original "classful" addressing scheme, the network address part of the 32-bit IP address could have a maximum of:

A. 8 bits

B. 10 bits

C. 16 bits

**D. 24 bits**

Graphical user interface, application

Description automatically generated with medium confidence

**Q9**. In today's CIDR addressing scheme, the subnet part of the 32-bit IP address:

A. can only have 24 bits

B. must be at least 8 bits long

C. can have maximum length of 28 bits

**D. can have any arbitrary length (<= 32 bit)**

Timeline

Description automatically generated with low confidence

**Q10**. CIDR addressing scheme could work without the help of subnet masks. True or **False?**

**Q11**. How many IP addresses belong to the subnet 128.119.254.0/26?

A.16

B. 32

**C. 64**

D. 128

**Q12**. What are the IP addresses at the two end-points of the subnet 128.119.254.0/26 ?

**A. 128.119.254.0 and 128.119.254.63**

B. 128.119.254.0 and 128.119.254.128

C. 128.119.254.63 and 128.119.254.128

D. 128.119.254.0 and 128.119.254.64

**Q13**. Without DHCP, a host cannot be configured with an IP address. True or **False**?

hard-coded by system admin in a file – Windows: control-panel->network->configuration->tcp/ip- >properties – UNIX: /etc/rc.config

**Q14**. From IP address, one can guess the geographic location of the device. **True**or False?

**Q15**. The two subnets 128.119.245.128/25 and 128.119.245.0/26 have overlapping IP addresses. True or **False**?

**Q16**. One of the advantages of NAT is that the organisation can change the addresses of the devices within its local network without notifying the outside world. **True**or False?

**Q17**. NAT violates the layering principle. **True**or False?

NAT violates the architectural model of IP, which states that every IP address uniquely identifies a single machine worldwide. The whole software structure of the Internet is built on this fact. With NAT, thousands of machines may (and do) use address 10.0.0.1.

**Q18**. For NAT to work, we need at least two public IP addresses. True or **False**?

Diagram

Description automatically generated

Destination network Next Router # of hops Interface

Top Router

223.1.1.0/24 Direct 0 223.1.1.3

223.1.4.0/24 Direct 0 223.1.4.1

223.1.9.0/24 Direct 0 223.1.9.2

223.1.7.0/24 223.1.9.1 1 223.1.9.2

223.1.2.0/24 223.1.9.1 1 223.1.9.2

22.1.3.0/24 223.1.9.1 2 223.1.9.2

Left Router

223.1.2.0/24 Direct 0 223.1.2.6

223.1.7.0/24 Direct 0 223.1.7.1

223.1.9.0/24 Direct 0 223.1.9.1

223.1.3.0/24 223.1.7.2 1 223.1.7.1

223.1.1.0/24 223.1.9.2 1 223.1.9.1

223.1.4.0/24 223.1.9.2 1 223.1.9.1

Right Router

223.1.3.0/24 Direct 0 223.1.3.27

223.1.7.0/24 Direct 0 223.1.7.2

223.1.2.0/24 223.1.7.1 1 223.1.7.2

223.1.9.0/24 223.1.7.1 1 223.1.7.2

223.1.4.0/24 223.1.7.1 2 223.1.7.2

223.1.1.0/24 223.1.7.1 2 223.1.7.2

**Q1** The only entries in a certain route table are (128.59.28.0/22, port 0), (128.59.28.0/23, port 1) and (128.59.28.0/24, port 2). These entries indicate CIDR network number, the prefix and the corresponding port to which a packet should be forwarded. If a packet arrives with a destination IP address equal to 128.59.29.18, which port will this router forward the packet to?

Answer: The address of the IP packet matches 128.59.28.0 in the first 23 bits. The 24th bit is different. Since we use the longest prefix match, the router will use the port corresponding to 128.59.28.0/23 in its route table and forward the packet to port 1.

**Q2**. A Router R1 has received a datagram with destination IP = 199.20.30.30.

The current routing table at R1 has got four entries as follows:

* 199.20.30.0/28 Interface 1
* 199.20.30.16/29 Interface 2
* 199.20.30.24/30 Interface 3
* Default Interface 4

Which interface would be selected by R1 to forward this packet? Show your working.

Answer: Network ranges 199.20.30.0/28 to 199.20.30.15/28 199.20.30.16/29 to 199.20.30.23/29 199.20.30.24/30 to 199.20.30.27/30 R1 would forward to interface 4.

**Q3**. Suppose an ISP owns the block of addresses of the form 101.101.128/17. Suppose it wants to create four subnets from this block, with each block having the same number of IP addresses. What are the prefixes (of form a.b.c.d/x) for the four subnets?

* 101.101.128/19
* 101.101.160/19
* 101.101.192/19
* 101.101.224/19

**Q4**. Suppose a peer with username Arnold discovers through querying that a peer with user name Bernard has a file it wants to download. Also suppose that Bernard is behind a NAT whereas Arnold isn’t. Let 138.76.29.7 be the WAN-side address of the NAT and let 10.0.0.1 be the internal IP address for Bernard. Assume that the NAT is not specifically configured for the P2P application.

(a) Discuss why Arnold’s peer cannot initiate a TCP connection to Bernard’s peer, even if Arnold knows the WAN-side address of the NAT, 138.76.29.7.

NAT will not have an entry for a connection initiated from the WAN side, hence will drop incoming packets from Arnold.

(b) Now, suppose that Bernard has established an ongoing TCP connection to another peer, Cindy who is not behind a NAT. Also suppose that Arnold learned from Cindy that Bernard has the desired file and that Arnold can establish (or already has established) a TCP connection with Cindy. Describe how Arnold can use these two TCP connections (one from Bernard to Cindy and the other from Arnold to Cindy) to instruct Bernard to initiate a direct TCP connection (that is, not passing through Cindy) back to Arnold. This technique is sometimes called connection reversal. Note that even though Bernard is behind a NAT, Arnold can use this direct TCP connection to request the file, and Bernard can use the connection to deliver the file.

Bernard can know the IP address of Arnold through Cindy. Then, the p2p application can initiate a connection through NAT to Arnold and upload the file.

**Q5**. Suppose you purchase a wireless router/ADSL modem and connect it to your telephone socket. Also suppose that your ISP dynamically assigns one IP address to your connecting device (i.e. your router/modem). Also suppose that you have five PCs at home that use 802.11 to wirelessly connect to your wireless router. How are IP addresses assigned to five PCs? Does the wireless router use NAT? Why or why not?

Answer: Typically, the wireless router includes a DHCP server. DHCP is used to assign IP addresses to the 5 PCs and to the router interface. Yes, the wireless router also uses NAT as it obtains only one IP address from the ISP.

**Q6**. List all the changes a NAPT box makes in TCP and IP headers when it receives a packet from inside node (private IP address) destined to a global IP address say 8.8.8.8.

The changes the following fields in IP header:

* Source IP address
* IP header Checksum

In TCP Header:

* Source Port No
* TCP Checksum