# The Network Layer: Data Plane

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## 1 Consider the network below.

### 1.1 Show the forwarding table in router A, such that all traffic destined to host H3 is forwarded through interface 3.

Destination = H3
Link Interface = 3

### 1.2 Can you write down a forwarding table in router A, such that all traffic from H1 destined to host H3 is forwarded through interface 3, while all traffic from H2 destined to host H3 is forwarded through interface 4?

No. Unlike a general match-and-action table, a forwarding table only matches destination addresses.

## 2 Suppose two packets arrive to two different input ports of a router at exactly the same time. Also suppose there are no other packets anywhere in the router.

### 2.1 Suppose the two packets are to be forwarded to two different output ports. Is it possible to forward the two packets through the switch fabric at the same time when the fabric uses a shared bus?

No. A shared bus can only transfer one packet at a time.

### 2.2 Suppose two packets are to be forwarded to two different output ports. Is it possible to forward the two packets through the switch fabric at the same time when the fabric uses switching via memory?

No. Memory can only read/write one packet at a time.

### 2.3 Suppose the two packets are to be forwarded to the same output port. Is it possible to forward the two packets through the switch fabric at the same time when the fabric uses a crossbar?

No. The crossbar can transport more than one packet at a time, but only if they are going to different output ports.

## 3 We noted that the maximum queuing delay is $(n-1)D$ if the switching fabric is $n$ times faster than the input line rates. Suppose that all packets are of the same length, $n$ packets arrive at the same time to the $n$ input ports, and all $n$ packets want to be forwarded to different input ports. What is the maximum delay for a packet for each type of switching fabric?

In the first two cases, the maximum delay equals the delay experienced by the unlucky last packet, where $D$ equals the time to transfer a single packet through the switching fabric.

**Memory** $(n-1)D$

**Bus** $(n-1)D$

**Crossbar** 0

## 4 Consider the switch below. Suppose that all the datagrams have the same fixed length, that the switch operates in a slotted, synchronous manner, that in one time slot a datagram can be transferred from an input port to an output port, and that the switch fabric is a crossbar. What is the minimal number of time slots needed to transfer the packets shown from input ports to their output ports, assuming any input queue scheduling order you want (i.e. it need not have HOL blocking)? What is the largest number of slots needed, assuming the worst-case scheduling order you can devise, assuming that a non-empty input queue is never idle?

The minimum number of time slots is two. Since we can rearrange the input queues, the Z in the third queue can skip the line and be sent in the first slot, along with the X in the first and the Y in the second. In the next slot, only the X in the second queue and the Y in the third remain, which can be sent at the same time.

The worst case is five, if one packet is sent at a time.

## 5 Consider a datagram network with the following link interface forwarding scheme.

### 5.1 Provide a forwarding table that has five entries, uses longest prefix matching, and forwards packets to the correct link interfaces.

| | | |
|---|---|---|
| 11100000 00 | $\rightarrow$ | 0 |
| 11100000 01000000 | $\rightarrow$ | 1 |
| 11100000 | $\rightarrow$ | 2 |
| 11100001 0 | $\rightarrow$ | 2 |
| else | $\rightarrow$ | 3 |

### 5.2 Describe how your forwarding table determines the appropriate link interface for datagrams with destination addresses:

#### 5.2.1 11001000 10010001 01010001 01010101

This matches none of the entries, so it is sent to 3.

#### 5.2.2 11100001 01000000 11000011 00111100

This matches the fourth entry, so it is sent to 2.

#### 5.2.3 11100001 10000000 00010001 01110111

This matches none of the entries, so it is sent to 3.

## 6 Consider a datagram network using 8-bit host addresses. Suppose a router uses longest prefix matching and has the following forwarding table. For each of the four interfaces, give the associated range of destination host addresses and the number of addresses in the range.

| | |
|---|---|
| 0: 0000 0000 to 0011 1111 | 64 addresses |
| 1: 0100 0000 to 0101 1111 | 32 addresses |
| 2: 0110 0000 to 1011 1111 | 96 addresses |
| 3: 1100 0000 to 1111 1111 | 64 addresses |

## 7 Consider a datagram network using 8-bit host addresses. Suppose a router uses longest prefix matching and has the following forwarding table. For each of the four interfaces, give the associated range of destination host addresses and the number of addresses in the range.

| | |
|---|---|
| 0: 1100 0000 to 1101 1111 | 32 addresses |
| 1: 1000 0000 to 1011 1111 | 64 addresses |
| 2: 1110 0000 to 1111 1111 | 32 addresses |
| 3: 0000 0000 to 0111 1111 | 128 addresses |

## 8 Consider a router that interconnects three subnets: Subnet 1, Subnet 2, and Subnet 3. Suppose all of the interfaces in each of these three subnets are required to have the prefix 223.1.17/24. Also suppose that Subnet 1 is required to support at least 60 interfaces, Subnet 2 is to support at least 90 interfaces, and Subnet 3 is to support at least 12 interfaces. Provide three network addresses (of the form a.b.c.d/x) that satisfy these requirements.

Subnet 1: 223.1.17.128/26
Subnet 2: 223.1.17.0/25
Subnet 3: 223.1.17.192/28

## 9 Rewrite the given forwarding table (using longest prefix matching) using the a.b.c.d/x notation instead of the binary string notation.

| | |
|---|---|
| 200.23.16.0/21 | 0 |
| 200.23.24.0/24 | 1 |
| 200.23.24.0/21 | 2 |
| Otherwise | 3 |

## 10 Rewrite the forwarding table from problem 5 using a.b.c.d/x notation instead of binary string notation.

224.0.0.0/10 $\to$ 0
224.64.0.0/16 $\to$ 1
224.0.0.0/8 $\to$ 2
225.0.0.0/9 $\to$ 2
else $\to$ 3

## 11 Consider a subnet with prefix 128.119.40.128/26.

### 11.1 Give an example of one IP address in dotted decimal notation that can be assigned to this network.

128.119.40.129

### 11.2 Suppose an ISP owns the block of addresses of the form 128.119.40.64/26. 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?

128.119.40.64/28
128.119.40.80/28
128.119.40.96/28
128.119.40.112/28

## 12 Consider the topology shown.

### 12.1 Assign network addresses to each of these six subnets, with the following constraints: All addresses must be allocated from 214.97.254/23; Subnet A should have enough addresses to support 250 interfaces; Subnets B and C should have enough to support 120 interfaces each.

A: 214.97.255.0/24
B: 214.97.254.12/30 - 214.97.254.0/25
C: 214.97.254.140/30 - 214.97.254.255/25
D: 214.97.254.0/30
E: 214.97.254.4/30
F: 214.97.254.8/30

### 12.2 Using the previous answers, provide the forwarding tables (using longest prefix matching) for each of the three routers.

Router 1

| | | |
|---|---|---|
| 11010110 1100001 11111111 | → | Subnet A |
| 11010110 1100001 11111110 000000 | → | Subnet D |
| 11010110 1100001 11111110 0 | → | Subnet D |
| 11010110 1100001 11111110 000010 | → | Subnet F |
| 11010110 1100001 11111110 1 | → | Subnet F |

Router 2

| | | |
|---|---|---|
| 11010110 1100001 11111110 1 | → | Subnet C |
| 11010110 1100001 11111110 000001 | → | Subnet E |
| 11010110 1100001 11111110 0 | → | Subnet E |
| 11010110 1100001 11111110 000010 | → | Subnet F |
| 11010110 1100001 11111111 | → | Subnet F |

Router 3

| | | |
|---|---|---|
| 11010110 1100001 11111110 0 | → | Subnet B |
| 11010110 1100001 11111110 000000 | → | Subnet D |
| 11010110 1100001 11111111 | → | Subnet D |
| 11010110 1100001 11111110 000001 | → | Subnet E |
| 11010110 1100001 11111110 1 | → | Subnet E |

## 13 Use the whois service at ARIN to determine the IP address blocks for three universities. Can the whois service be used to determine with certainty the geographical location of a specific IP address? Use maxmind.com to determine the locations of the web servers at each of these universities.

No, the geographical location cannot be determined with certainty.

Stanford:
IP: 171.67.215.200
Net Range: 171.64.0.0 - 171.67.255.255
CIDR: 171.64.0.0/14
Location: Newark, California

Harvard:
IP: 23.185.0.1
Net Range: 23.185.0.0 - 23.185.0.255
CIDR: 23.185.0.0/24
Location: United States

Harvey Mudd:
IP: 134.173.32.22
Net Range: 134.173.0.0 - 134.173.255.255
CIDR: 134.173.0.0/16
Location: Rancho Cucamonga, California

## 14 Consider sending a 2400-byte datagram into a link that has an MTU of 700 bytes. Suppose the original datagram is stamped with the identification number 422. How many fragments are generated? What are the values in the various fields in the IP datagram(s) generated related to fragmentation?

Fragment 1
Bytes of data: 680
Identification: 422
Flag: 1
Fragmentation offset: 0

Fragment 2
Bytes of data: 680
Identification: 422
Flag: 1
Fragmentation offset: 85

Fragment 3
Bytes of data: 680
Identification: 422
Flag: 1
Fragmentation offset: 170

Fragment 4
Bytes of data: 340
Identification 422
Flag: 0
Fragmentation offset: 255

## 15 Suppose datagrams are limited to 1,500 bytes (including header) between source Host A and destination Host B. Assuming a 20-byte IP header, how many datagrams would be required to send an MP3 consisting of 5 million bytes? Explain.

Since each datagram needs a 20 byte IP header as well as a 20 byte TCP header, each will have at most 1460 bytes of data. 5,000,000/1460=3424.7 $\rightarrow$ 3425 datagrams.

## 16 Consider the network setup in figure 4.25. Suppose that the ISP instead assigns the router the address 24.34.112.235 and that the network address of the home network is 192.168.1/24.

### 16.1 Assign addresses to all interfaces in the home network.

192.168.1.1
192.168.1.2
192.168.1.3
192.168.1.4

### 16.2 Suppose each host has two ongoing TCP connections, all to port 80 at host 128.119.40.86. Provide the six corresponding entries in the NAT translation table.

| WAN | LAN |
|---|---|
| 23.34.112.235, 5002 | 192.168.1.1, 3002 |
| 23.34.112.235, 5003 | 192.168.1.1, 3003 |
| 23.34.112.235, 5004 | 192.168.1.2, 3004 |
| 23.34.112.235, 5005 | 192.168.1.2, 3005 |
| 23.34.112.235, 5006 | 192.168.1.3, 3006 |
| 23.34.112.235, 5007 | 192.168.1.3, 3007 |

## 17 Suppose you are interested in detecting the number of hosts behind a NAT. You observe that the IP layer stamps an identification number sequentially on each IP packet. The identification number of the first IP packet generated by a host is a random number, and the identification numbers of the subsequent IP packets are sequentially assigned. Assume all IP packets generated by hosts behind the NAT are sent to the outside world.

### 17.1 Based on this observation, and assuming you can sniff all packets sent by the NAT to the outside, can you outline a simple technique that detects the number of unique hosts behind a NAT? Justify your answer.

Yes, if all of the hosts are actively transmitting. You would observe several interleaved streams of sequential identification numbers, one stream per host. The number of streams corresponds to the number of active hosts.

### 17.2 If the identification numbers are not sequentially assigned but randomly assigned, would your technique work? Justify your answer.

No. The streams would not be distinguishable.

## 18 Suppose a peer with username Arnold discovers through querying that a peer with username Bernard has a file it wants to download. Also suppose that Bernard and Arnold are both behind a NAT. Try to devise a technique that would allow Arnold to establish a TCP connection with Bernard without application-specific NAT configuration. If you have difficulty devising such a technique, discuss why.

If Arnold and Bernard are within the same local network, Arnold would be able to discover Bernard's LAN side address and establish a connection directly. If they were in different local networks, it would be impossible, since he would only be able to discover the router's address, not the one for Bernard's host.

## 19 Consider the SDN OpenFlow network shown in figure 4.30. Specify the flow table entries in s2 that implement the given forwarding behavior.

| Match | Action |
|---|---|
| Ingress Port = 1; IP Src = 10.3.*; IP Dst = 10.1.* | Forward(2) |
| Ingress Port = 2; IP Src = 10.1.*; IP Dst = 10.3.* | Forward(1) |
| Ingress Port = 1; IP Dst = 10.2.0.3 | Forward(3) |
| Ingress Port = 2; IP Dst = 10.2.0.3 | Forward(3) |
| Ingress Port = 1; IP Dst = 10.2.0.4 | Forward(4) |
| Ingress Port = 2; IP Dst = 10.2.0.4 | Forward(4) |
| Ingress Port = 4; IP Dst = 10.2.0.3 | Forward(3) |
| Ingress Port = 3; IP Dst = 10.2.0.4 | Forward(4) |

# 20 Repeat the previous problem for the given forwarding behavior.

| Match | Action |
|---|---|
| Ingress Port(3); IP Dst = 10.1.* | Forward(2) |
| Ingress Port(3); IP Dst = 10.3.* | Forward(2) |
| Ingress Port(4); IP Dst = 10.1.* | Forward(1) |
| Ingress Port(4); IP Dst = 10.3.* | Forward(1) |

# 21 Repeat the previous problem. Give the flow table entries at packet switches s1 and s3 such that any arriving datagrams with a source address of h3 or h4 are routed to the destination hosts specified in the destination address field in the IP datagram.

S1

| Match | Action |
|---|---|
| IP Src = 10.2.*; IP Dst = 10.1.0.1 | Forward(2) |
| IP Src = 10.2.*; IP Dst = 10.1.0.2 | Forward(3) |
| IP Src = 10.2.*; IP Dst = 10.3.* | Forward(1) |

S3

| Match | Action |
|---|---|
| IP Src = 10.2.*; IP Dst = 10.1.* | Forward(3) |
| IP Src = 10.2.*; IP Dst = 10.3.0.6 | Forward(1) |
| IP Src = 10.2.*; IP Dst = 10.3.0.5 | Forward(2) |

# 22 Repeat the previous problem for each of the following sets of firewall behaviors at s2, ignoring traffic forwarded to other routers.

## 22.1 Only traffic arriving from hosts h1 and h6 should be delivered to hosts h3 or h4.

| Match | Action |
|---|---|
| IP Src = 10.1.0.1; IP Dst = 10.2.0.4 | Forward(4) |
| IP Src = 10.1.0.1; IP Dst = 10.2.0.3 | Forward(3) |
| IP Src = 10.3.0.6; IP Dst = 10.2.0.4 | Forward(4) |
| IP Src = 10.3.0.6; IP Dst = 10.2.0.3 | Forward(3) |

## 22.2 Only TCP traffic is allowed to be delivered to hosts h3 or h4.

| Match | Action |
|---|---|
| IP Dst = 10.2.0.3; IP proto = 6 | Forward(3) |
| IP Dst = 10.2.0.4; IP proto = 6 | Forward(4) |

## 22.3 Only traffic destined to h3 is to be delivered.

| Match | Action |
|---|---|
| IP Dst = 10.2.0.3 | Forward(3) |

## 22.4 Only UDP traffic from h1 and destined to h3 is to be delivered.

| Match | Action |
|---|---|
| IP Src = 10.1.0.1; IP Dst = 10.2.0.3; IP proto = 17 | Forward(3) |