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COMPUTER NETWORKS HAND BOOK

SKILLUP / SKILLBRIDGE EXERCISES

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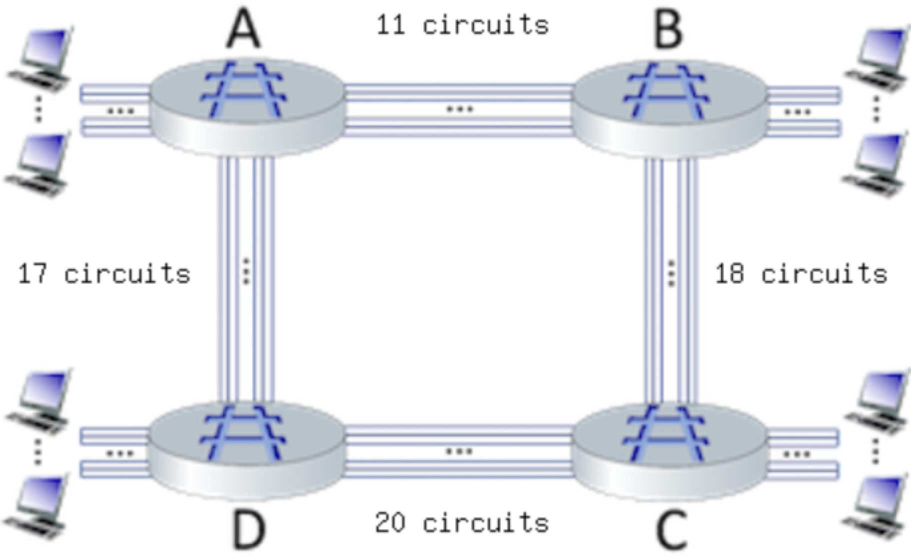
CHAPTER 1: INTRODUCTION

1.1 Circuit Switching

Consider the circuit-switched network shown in the figure below, with circuit switches A, B, C, and D. Suppose there are 13 circuits between A and B, 17 circuits between B and C, 10 circuits between C and D, and 15 circuits between D and A.



(1) What is the maximum number of connections that can be ongoing in the network at any one time?

Hint: The maximum number of connections is the sum of all links

(2) Suppose that these maximum numbers of connections are all ongoing. What happens when another call connection request arrives to the network, will it be accepted? Answer Yes or No

Hint: If all connections are full, the request will be blocked

(3) Suppose that every connection requires 2 consecutive hops, and calls are connected clockwise. For example, a connection can go from A to C, from B to D, from C to A, and from D to B. With these constraints, what is the is the maximum number of connections that can be ongoing in the network at any one time?

Hint: Find the max between the sum of the bottleneck links for cases A-¿C and B-¿D, but don't forget about bottleneck links

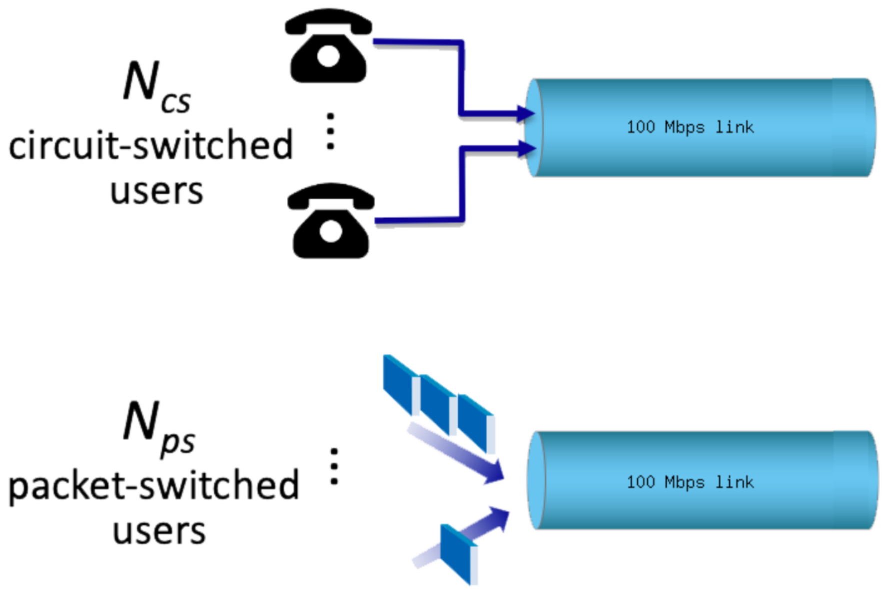
(4) Suppose that 15 connections are needed from A to C, and 16 connections are needed from B to D. Can we route these calls through the four links to accommodate all 31 connections? Answer Yes or No

Hint: Taking from the previous question, is the sum of the two connections greater than the value we calculated in question 3?

1.2 Quantitative Comparison of Packet Switching and Circuit Switching

This question requires a little bit of background in probability (but we'll try to help you though it in the solutions). Consider the two scenarios below:

- A circuit-switching scenario in which Ncs users, each requiring a bandwidth of 10 Mbps, must share a link of capacity 200 Mbps.
- A packet-switching scenario with Nps users sharing a 200 Mbps link, where each user again requires 10 Mbps when transmitting, but only needs to transmit 10 percent of the time.



Round your answer to two decimals after leading zeros

(1) When circuit switching is used, what is the maximum number of users that can be supported?

Hint: The Circuit users can't share bandwidth

(2) Suppose packet switching is used. If there are 39 packet-switching users, can this many users be supported under circuit-switching? Yes or No.

Hint: How much bandwidth does each user need? Is this less than the total bandwidth?

(3) Suppose packet switching is used. What is the probability that a given (specific) user is transmitting, and the remaining users are not transmitting?

Hint: Start with calculating the likelihood nobody is transmitting

(4) Suppose packet switching is used. What is the probability that one user (any one among the 39 users) is transmitting, and the remaining users are not transmitting?

Hint: The probability will be higher than the previous question

(5) When one user is transmitting, what fraction of the link capacity will be used by this user? Write your answer as a decimal.

Hint: The share is capacity / user's bandwidth

(6) What is the probability that any 22 users (of the total 39 users) are transmitting and the remaining users are not transmitting?

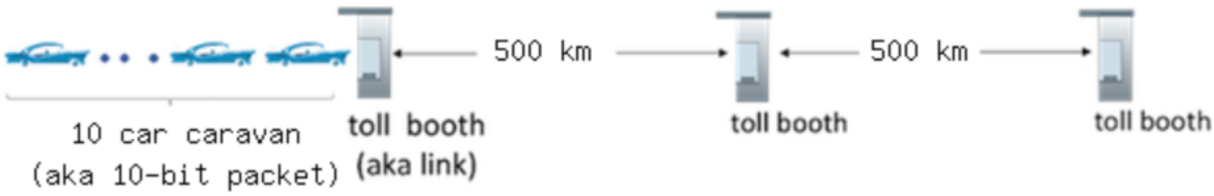
Hint: You will need to use a binomial distribution

(7) What is the probability that more than 20 users are transmitting?

Hint: Take the sum of all probabilities for x active users above 20

1.3 Car - Caravan Analogy

Consider the figure below, adapted from Figure 1.17 in the text, which draws the analogy between store-and-forward link transmission and propagation of bits in packet along a link, and cars in a caravan being serviced at a toll booth and then driving along a road to the next tollbooth.



Suppose the caravan has 10 cars, and that the tollbooth services (that is, transmits) a car at a rate of one car per 5 seconds. Once receiving serving a car proceeds to the next tool both, which is 400 kilometers away at a rate of 20 kilometers per second. Also assume that whenever the first car of the caravan arrives at a tollbooth, it must wait at the entrance to the tollbooth until all of the other cars in its caravan have arrived, and lined up behind it before being serviced at the toll booth. (That is, the entire caravan must be stored at the tollbooth before the first car in the caravan can pay its toll and begin driving towards the next tollbooth).

(1) Once a car enters service at the tollbooth, how long does it take until it leaves service?

Hint: This value is given in the prompt

(2) How long does it take for the entire caravan to receive service at the tollbooth (that is the time from when the first car enters service until the last car leaves the tollbooth)?

Hint: Try taking the time to service multiplied by number of cars

(3) Once the first car leaves the tollbooth, how long does it take until it arrives at the next tollbooth?

Hint: The time taken can be calculated by dividing the distance by the car's speed

(4) Once the last car leaves the tollbooth, how long does it take until it arrives at the next tollbooth?

Hint: The time taken can be calculated by dividing the distance by the car's speed

(5) Once the first car leaves the tollbooth, how long does it take until it enters service at the next tollbooth?

Hint: Take the time to service all cars but one, summed with the time it takes every car to reach the next toll booth

(6) Are there ever two cars in service at the same time, one at the first toll booth and one at the second toll booth? Answer Yes or No

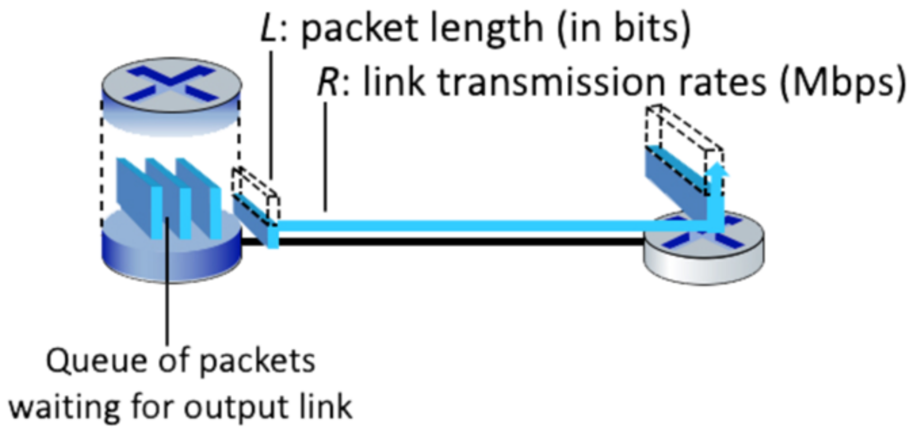
Hint: Cars can't get service at the next tollbooth until all cars have arrived

(7) Are there ever zero cars in service at the same time, i.e., the caravan of cars has finished at the first toll booth but not yet arrived at the second tollbooth? Answer Yes or No

Hint: There is a situation where the last car in the caravan, after being serviced but still travelling, will result in no cars being serviced until it arrives

1.4 One-hop Transmission Delay

Consider the figure below, in which a single router is transmitting packets, each of length L bits, over a single link with transmission rate R Mbps to another router at the other end of the link.



Suppose that the packet length is L= 8000 bits, and that the link transmission rate along the link to router on the right is R = 1 Mbps.

(1) What is the transmission delay?

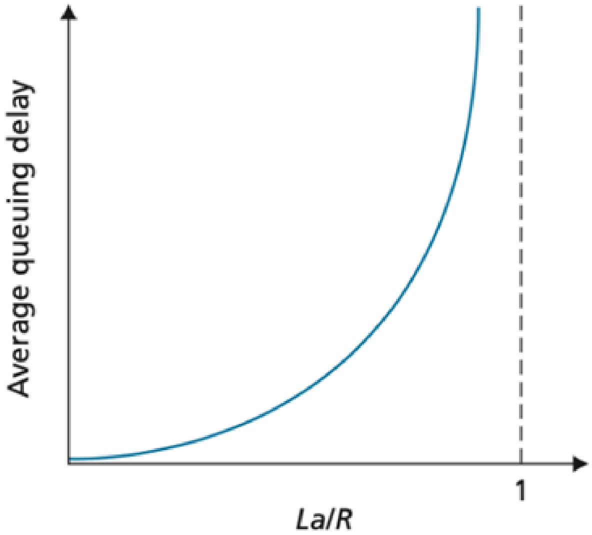
Hint: Transmission delay is calculated by L / R

(2) What is the maximum number of packets per second that can be transmitted by this link?

Hint: Use the rate and figure out how many packets can fit in that many bits

1.5 Queuing Delay

Consider the queuing delay in a router buffer, where the packet experiences a delay as it waits to be transmitted onto the link. The length of the queuing delay of a specific packet will depend on the number of earlier-arriving packets that are queued and waiting for transmission onto the link. If the queue is empty and no other packet is currently being transmitted, then our packet's queuing delay will be zero. On the other hand, if the traffic is heavy and many other packets are also waiting to be transmitted, the queuing delay will be long.



Assume a constant transmission rate of R = 700000 bps, a constant packet-length L = 5000 bits, and a is the average rate of packets/second. Traffic intensity I = La/R, and the queuing delay is calculated as I(L/R)(1 - I) for I ¡ 1.

(1) In practice, does the queuing delay tend to vary a lot? Answer with Yes or No

Hint: See section 1.4 in the text for more information on queuing delay

(2) Assuming that a = 32, what is the queuing delay? Give your answer in milliseconds (ms)

Hint: Use the formula given above to calculate the queuing delay

(3) Assuming that a = 89, what is the queuing delay? Give your answer in milliseconds (ms)

Hint: Use the formula given above to calculate the queuing delay

(4) Assuming the router's buffer is infinite, the queuing delay is 1.6542 ms, and 1344 packets arrive. How many packets will be in the buffer 1 second later?

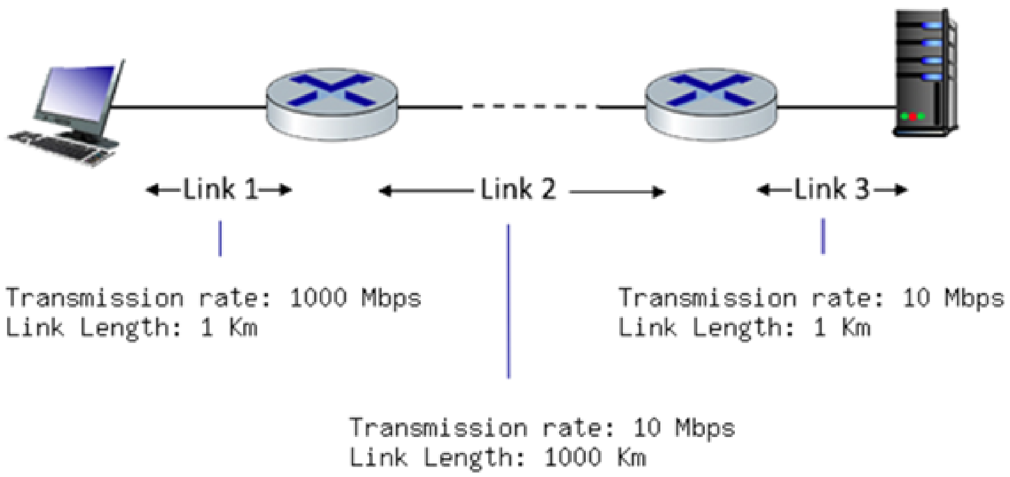
Hint: The number of packets left in the buffer after 1 second can be calculated with the formula: packets - (60/qdelay) rounded down

(5) If the buffer has a maximum size of 563 packets, how many of the 1344 packets would be dropped upon arrival from the previous question?

Hint: The number of packets dropped can be calculated with the formula: a - buffer size (if less than 0, then no packets are lost)

1.6 Computing End-End Delay (Transmission And Propagation Delay)

Consider the figure below, with three links, each with the specified transmission rate and link length.



Assume the length of a packet is 4000 bits. The speed of light propagation delay on each link is 3x10$\hat{8}$ m/sec

Round your answer to two decimals after leading zeros

(1) What is the transmission delay of link 1?

Hint: Transmission delay is L / R

(2) What is the propagation delay of link 1?

Hint: Propagation delay is d / s

(3) What is the total delay of link 1?

Hint: L1 delay is the sum of the transmission and propagation delay

(4) What is the transmission delay of link 2?

Hint: Transmission delay is L / R

(5) What is the propagation delay of link 2?

Hint: Propagation delay is d / s

(6) What is the total delay of link 2?

Hint: L2 delay is the sum of the transmission and propagation delay

(7) What is the transmission delay of link 3?

Hint: Transmission delay is L / R

(8) What is the propagation delay of link 3?

Hint: Propagation delay is d / s

(9) What is the total delay of link 3?

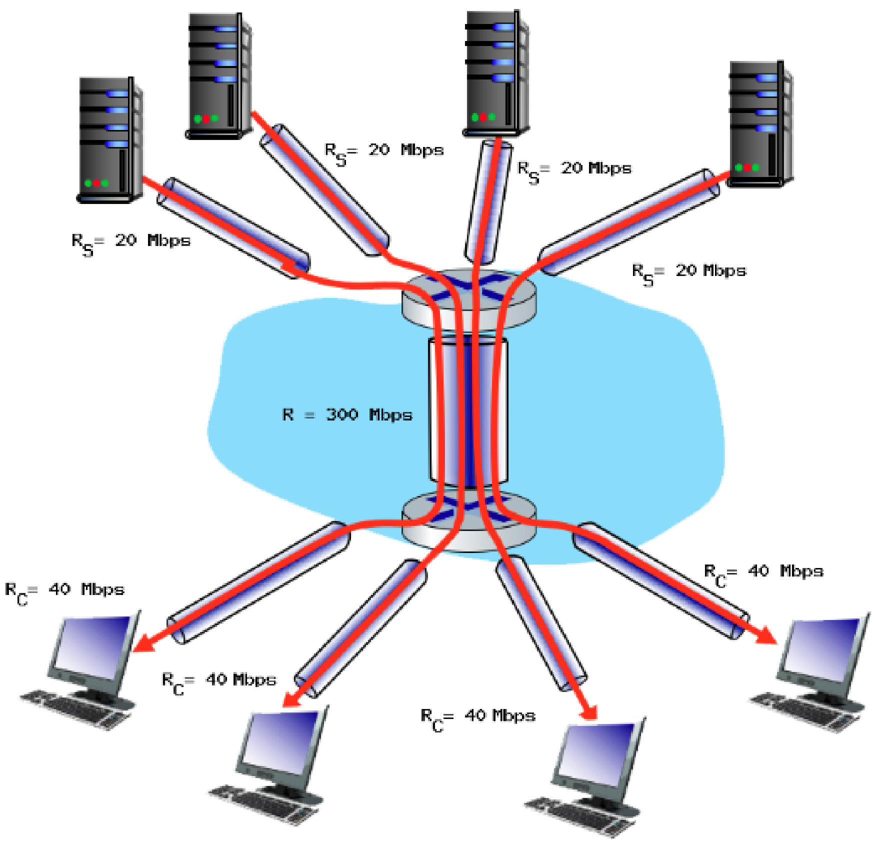
Hint: L3 delay is the sum of the transmission and propagation delay

(10) What is the total delay?

Hint: Total delay is the sum of L1, L2, and L3 delays

1.7 End To End Throughput And Bottleneck Links

Consider the scenario shown below, with four different servers connected to four different clients over four three-hop paths. The four pairs share a common middle hop with a transmission capacity of R = 300 Mbps. The four links from the servers to the shared link have a transmission capacity of R_S = 20 Mbps. Each of the four links from the shared middle link to a client has a transmission capacity of R_C = 40 Mbps.



(1) What is the maximum achievable end-end throughput (in Mbps) for each of four client-to-server pairs, assuming that the middle link is fairly shared (divides its transmission rate equally)?

Hint: What is the capacity of the smallest link?

(2) Which link is the bottleneck link? Format as R_C, R_S or R

Hint: What does it mean to be the bottleneck?

(3) Assuming that the servers are sending at the maximum rate possible, what are the link utilizations for the server links (R_S)? Answer as a decimal

Hint: If you know the bottleneck, how much does that use up of the server links' bandwidth?

(4) Assuming that the servers are sending at the maximum rate possible, what are the link utilizations for the client links (R_C)? Answer as a decimal

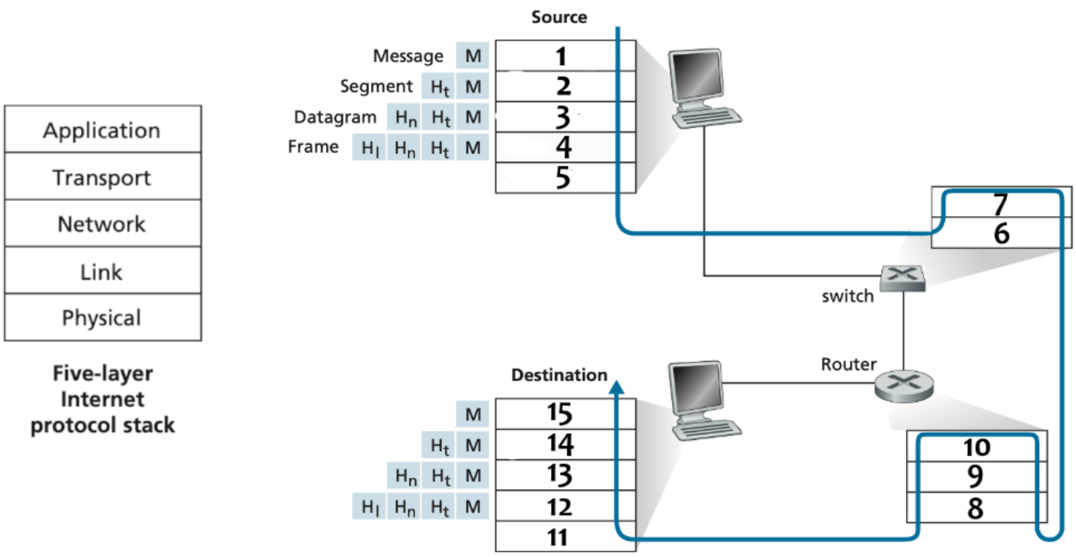
Hint: If you know the bottleneck, how much does that use up of the client links' bandwidth?

(5) Assuming that the servers are sending at the maximum rate possible, what is the link utilizations for the shared link (R)? Answer as a decimal

Hint: If you know the bottleneck, how much does that use up of the shared link's bandwidth?

1.8 The Ip Stack And Protocol Layering

In the scenario below, imagine that you're sending an http request to another machine somewhere on the network.



(1) What layer in the IP stack best corresponds to the phrase: 'passes frames from one node to another across some medium'

Hint: See section 1.5 in the text for information on the Internet Protocol Stack

(2) What layer in the IP stack best corresponds to the phrase: 'handles the delivery of segments from the application layer, may be reliable or unreliable'

Hint: See section 1.5 in the text for information on the Internet Protocol Stack

(3) What layer in the IP stack best corresponds to the phrase: 'bits live on the wire'

Hint: See section 1.5 in the text for information on the Internet Protocol Stack

(4) What layer in the IP stack best corresponds to the phrase: ’handles messages from a variety of network applications’

Hint: See section 1.5 in the text for information on the Internet Protocol Stack

(5) What layer in the IP stack best corresponds to the phrase: ’moves datagrams from the source host to the destination host’

Hint: See section 1.5 in the text for information on the Internet Protocol Stack

(6) What layer corresponds to box 1?

Hint: This will be the HTTP Message

(7) What layer corresponds to box 2?

Hint: This is the TCP Segment

(8) What layer corresponds to box 3?

Hint: The IP Datagram will be made here

(9) What layer corresponds to box 4?

Hint: A Frame is constructed in this box

(10) What layer corresponds to box 5?

Hint: Bits are live on the wire

(11) What layer corresponds to box 6?

Hint: Switches operate at the link layer and below

(12) What layer corresponds to box 7?

Hint: Switches operate at the link layer and below

(13) What layer corresponds to box 8?

Hint: Routers operate at the network layer and below

(14) What layer corresponds to box 9?

Hint: Routers operate at the network layer and below

(15) What layer corresponds to box 10?

Hint: Routers operate at the network layer and below

(16) What layer corresponds to box 11?

Hint: Live bits have arrived at the destination host

(17) What layer corresponds to box 12?

Hint: Frame is passed in this box

(18) What layer corresponds to box 13?

Hint: An IP Datagram is stripped from the frame at this point

(19) What layer corresponds to box 14?

Hint: The TCP Segment is stripped from the datagram

(20) What layer corresponds to box 15?

Hint: The HTTP Message is revealed after being extracted from the segment

CHAPTER 2: APPLICATION LAYER

2.1 DNS - Basics

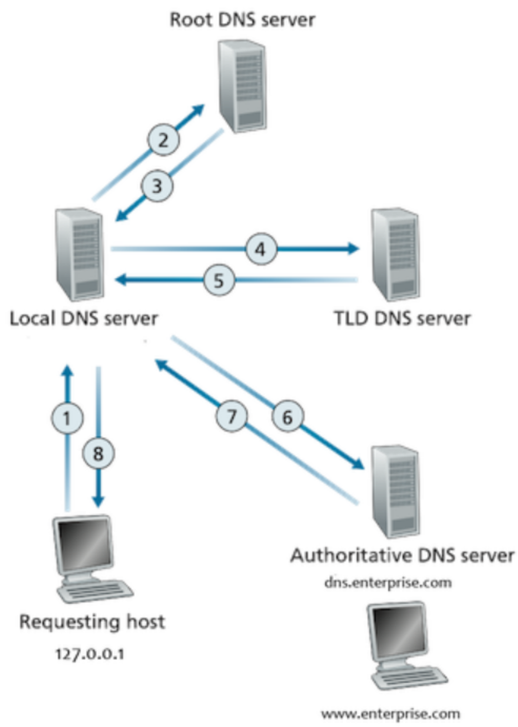
Imagine that you are trying to visit www.enterprise.com, but you don't remember the IP address the web-server is running on.

Assume the following records are on the TLD DNS server:

- (www.enterprise.com, dns.enterprise.com, NS)
- (dns.enterprise.com, 146.54.32.206, A)

Assume the following records are on the enterprise.com DNS server:

- (www.enterprise.com, east4.enterprise.com, CNAME)
- (east4.enterprise.com, 142.81.17.206, A)
- (enterprise.com, mail.enterprise.com, MX)
- (mail.enterprise.com, 247.29.179.11, A)



Assume your local DNS server only has the TLD DNS server cached.

(1) What transport protocol(s) does DNS use: TCP, UDP, or Both?

Hint: See section 2.4 in the text for more information on DNS

(2) What well-known port does DNS use?

Hint: See section 2.4 in the text for more information on DNS

(3) In the above example, how many unique type of Resource Records (RR) are there at the authoritative enterprise.com DNS server?

Hint: See section 2.4 in the text for more information on DNS

(4) Can you send multiple DNS questions and get multiple RR answers in one message? Answer with Yes or No

Hint: See section 2.4 in the text for more information on DNS

(5) To which DNS server does a host send their requests to? Answer with the full name

Hint: What is the first server the host contacts?

(6) Which type of DNS server holds a company's DNS records? Answer with the full name

Hint: The TLD and Root DNS servers won't hold that information

(7) In the example given in the problem, what is the name of the DNS server for enterprise.com?

Hint: See the diagram given in the problem

(8) When you make the request for www.enterprise.com, your local DNS requests the IP on your behalf. When it contacts the TLD server, how many answers (RR) are returned?

Hint: See section 2.4 in the text for more information on DNS

(9) In the previous question, there were two responses, one was a NS record and the other an A record. What was the content of the A record? Answer with the format: "name, value"

Hint: Use the records given and match to the requested information

(10) Assume that the enterprise.com website is actually hosted on east4.enterprise.com, what type of record is needed for this?

Hint: See section 2.4 in the text for more information on DNS

(11) Now imagine we are trying to send an email to admin@enterprise.com, and their mail server has the name mail.enterprise.com. What type of record will contain the name of the enterprise.com domain and the name of its mailserver(s)?

Hint: See section 2.4 in the text for more information on DNS

(12) In that MX record, what are the contents? Answer with the format: "name, value"

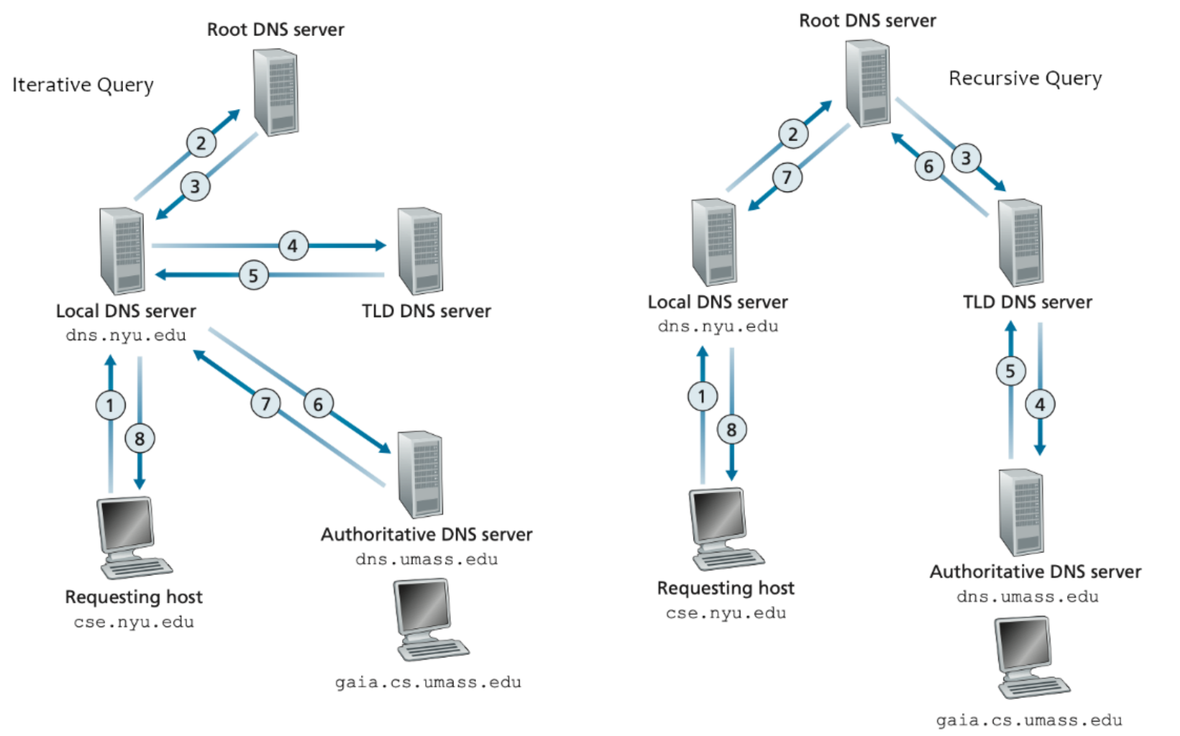
Hint: Use the records given and match to the requested information

(13) Does your local DNS server take advantage of caching similar to web requests? Answer with Yes or No

Hint: See section 2.4 in the text for more information on DNS

2.2 DNS - Iterative vs Recursive Query

Assume that a user is trying to visit gaia.cs.umass.edu, but his browser doesn't know the IP address of the website. In this example, examine the difference between an iterative and recursive DNS query.



(1) Between steps 1 and 2, where does the Local DNS server check first? Answer with 'User', 'DNS Local', 'DNS Root', 'DNS TLD', or 'DNS Authoritative'.

Hint: For more information on DNS, see section 2.4 in the text.

(2) Between steps 2 and 3, assuming the root DNS server doesn't have the IP we want, where does the response link? Answer with 'DNS Local', 'DNS Root', 'DNS TLD', or 'DNS Authoritative'.

Hint: For more information on DNS, see section 2.4 in the text.

(3) Between steps 4 and 5, assuming the TLD DNS server doesn't have the IP we want, where does the response link? Answer with 'DNS Local', 'DNS Root', 'DNS TLD', or 'DNS Authoritative'.

Hint: For more information on DNS, see section 2.4 in the text.

(4) Between steps 6 and 7, the authoritative DNS server responds with the IP we want. What type of DNS record is returned?

Hint: For more information on DNS, see section 2.4 in the text.

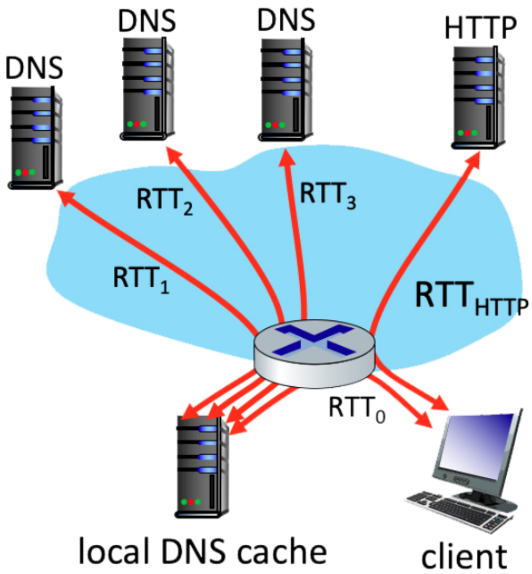
(5) Which type of query is considered best practice: iterative or recursive?

Hint: For more information on DNS, see section 2.4 in the text.

2.3 DNS and HTTP delays

Before doing this question, you might want to review sections 2.2.1 and 2.2.2 on HTTP (in particular the text surrounding Figure 2.7) and the operation of the DNS (in particular the text surrounding Figure 2.19).

Suppose within your Web browser you click on a link to obtain a Web page. The IP address for the associated URL is not cached in your local host, so a DNS lookup is necessary to obtain the IP address. Suppose that four DNS servers are visited before your host receives the IP address from DNS. The first DNS server visited is the local DNS cache, with an RTT delay of $RTT_0 = 3$ msecs. The second, third and fourth DNS servers contacted have RTT_s of 2, 25, and 17 msecs, respectively. Initially, let's suppose that the Web page associated with the link contains exactly one object, consisting of a small amount of HTML text. Suppose the RTT between the local host and the Web server containing the object is $RTT_{HTTP} = 26$ msecs.



(1) Assuming zero transmission time for the HTML object, how much time (in msec) elapses from when the client clicks on the link until the client receives the object?

Hint: Consider the DNS resolution time as well as the HTTP response time.

(2) Now suppose the HTML object references 7 very small objects on the same server. Neglecting transmission times, how much time (in msec) elapses from when the client clicks on the link until the base object and all 7 additional objects are received from web server at the client, assuming non-persistent HTTP and no parallel TCP connections?

Hint: Remember that once a DNS server has been queried, it doesn't need to be again for subsequent requests.

(3) Suppose the HTML object references 7 very small objects on the same server, but assume that the client is configured to support a maximum of 5 parallel TCP connections, with non-persistent HTTP.

Hint: For every 5 objects, it takes two RTT.

(4) Suppose the HTML object references 7 very small objects on the same server, but assume that the client is configured to support a maximum of 5 parallel TCP connections, with persistent HTTP.

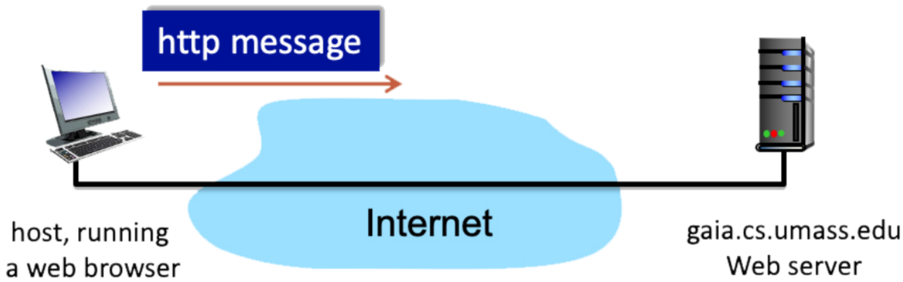
Hint: It only takes 1 RTT for every 5 objects after the base page.

(5) What's the fastest method we've explored: Nonpersistent-serial, Nonpersistent-parallel, or Persistent-parallel?

Hint: What method had the lowest delay?

2.4 The HTTP Get Message

Consider the figure below, where a client is sending an HTTP GET message to a web server, gaia.cs.umass.edu



Suppose the client-to-server HTTP GET message is the following:

GET /kuros_ross_sandbox/interactive/quotation6.htm HTTP/1.0
Host: gaia.cs.umass.edu
If-Modified-Since: Tue, 14 Nov 2023 19:38:55 -0800

(1) What is the name of the file that is being retrieved in this GET message?

Hint: Look at what the GET request references

(2) What version of HTTP is the client running?

Hint: Look at the first line of the request

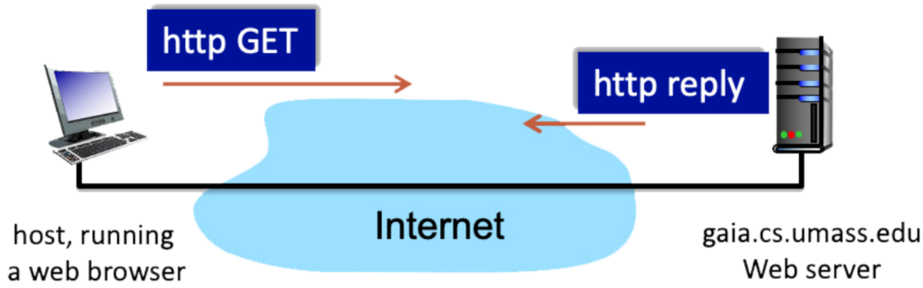
(3) True or False: The client already has a cached copy of the file

Hint: Look up the 'If-Modified-Since' field

2.5 The HTTP Response Message

Consider the figure below, where the server is sending a HTTP RESPONSE message back the client.
Suppose the server-to-client HTTP RESPONSE message is the following:

HTTP/1.0 404 Not Found
Date: Wed, 15 Nov 2023 03:54:26 +0000
Server: Apache/2.2.3 (CentOS)
Content-Length: 396
Connection: Close
Content-type: image/html



(1) Is the response message using HTTP 1.0 or HTTP 1.1?

Hint: Look at the first line of the response

(2) Was the server able to send the document successfully? Yes or No

Hint: Look up what the 404 Not Found response code does

(3) How big is the document in bytes?

Hint: Look at the

(4) Is the connection persistent or nonpersistent?

Hint: Look at the

(5) What is the type of file being sent by the server in response?

Hint: Look at the

(6) What is the name of the server and its version? Write your answer as server/x.y.z

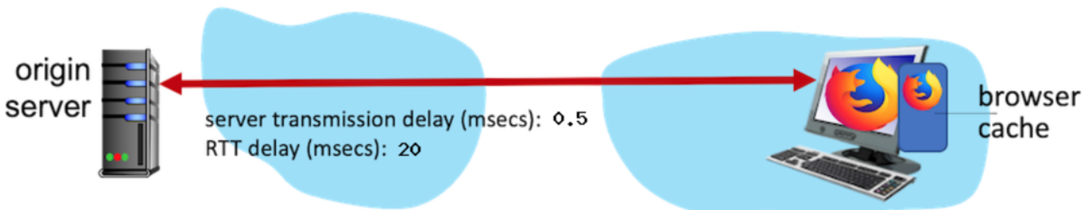
Hint: Look at the

(7) Will the ETag change if the resource content at this particular resource location changes? Yes or No

Hint: Look up what the function of the

2.6 Browser Caching

Consider an HTTP server and client as shown in the figure below. Suppose that the RTT delay between the client and server is 20 msecs; the time a server needs to transmit an object into its outgoing link is 0.5 msecs; and any other HTTP message not containing an object has a negligible (zero) transmission time. Suppose the client again makes 80 requests, one after the other, waiting for a reply to a request before sending the next request.



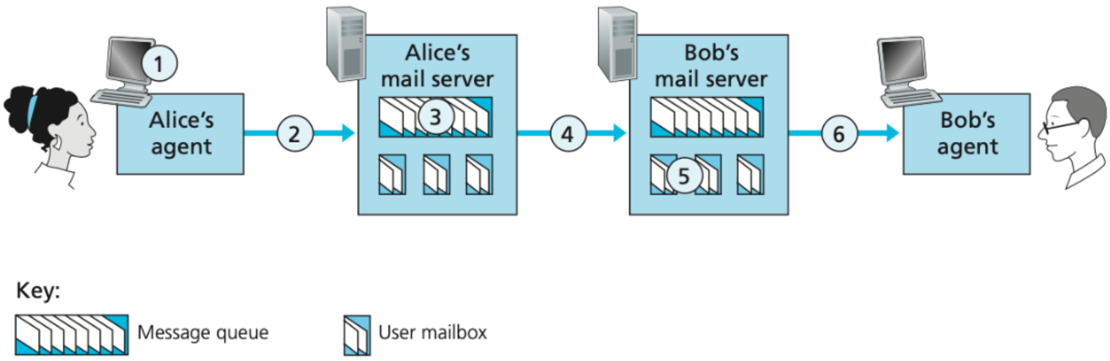
Assume the client is using HTTP 1.1 and the IF-MODIFIED-SINCE header line. Assume 50% of the objects requested have NOT changed since the client downloaded them (before these 80 downloads are performed)

(1) How much time elapses (in milliseconds) between the client transmitting the first request, and the completion of the last request?

Hint: If a request is cached, there's only the RTT time; otherwise, you also need to add the transmission time.

2.7 Electronic Mail and SMTP

Look at the scenario below, where Alice sends an email to Bob.



Alice sends a message to Bob

(1) At point 2 in the diagram, what protocol is being used?

Hint: SMTP is used when sending mail from client to server and from server to server

(2) At point 4 in the diagram, what protocol is being used?

Hint: SMTP is used when sending mail from client to server and from server to server

(3) At point 6 in the diagram, what protocol is being used?

Hint: SMTP isn't used when pulling emails from server to client

(4) Does SMTP use TCP or UDP?

Hint: SMTP uses a reliable connection to send data

(5) Is SMTP a 'push' or 'pull' protocol?

Hint: SMTP sends data from client to server, and from server to server

(6) Is POP3 a 'push' or 'pull' protocol?

Hint: This protocol takes data from server to client

(7) What port does SMTP use?

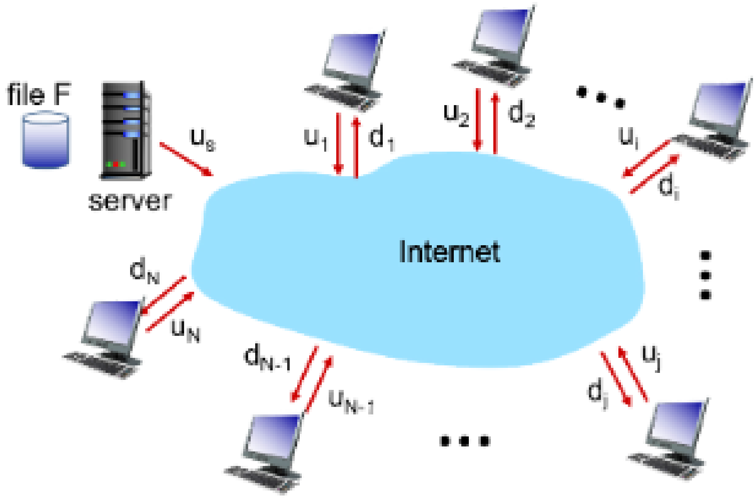
Hint: Look at section 2.3 in the text for more information

(8) What port does POP3 use?

Hint: Look at section 2.3 in the text for more information

2.8 A comparison of client-server and P2P file distribution delays

In this problem, you'll compare the time needed to distribute a file that is initially located at a server to clients via either client-server download or peer-to-peer download. Before beginning, you might want to first review Section 2.5 and the discussion surrounding Figure 2.22 in the text.



The problem is to distribute a file of size F = 10 Gbits to each of these 8 peers. Suppose the server has an upload rate of u = 100 Mbps.

The 8 peers have upload rates of: u_1 = 10 Mbps, u_2 = 14 Mbps, u_3 = 27 Mbps, u_4 = 26 Mbps, u_5 = 25 Mbps, u_6 = 25 Mbps, u_7 = 12 Mbps, and u_8 = 27 Mbps

The 8 peers have download rates of: d_1 = 34 Mbps, d_2 = 36 Mbps, d_3 = 36 Mbps, d_4 = 17 Mbps, d_5 = 28 Mbps, d_6 = 22 Mbps, d_7 = 17 Mbps, and d_8 = 30 Mbps

(1) What is the minimum time needed to distribute this file from the central server to the 8 peers using the client-server model?

Hint: See equation 2.1 in the text

(2) For the previous question, what is the root cause of this specific minimum time? Answer as 's' or 'ci' where 'i' is the client's number

Hint: Did the server or client result in the bottleneck?

(3) What is the minimum time needed to distribute this file using peer-to-peer download?

Hint: See equation 2.2 in the text

(4) For question 3, what is the root case of this specific minimum time: the server (s), client (c), or the combined upload of the clients and the server (cu)

Hint: What resulted in the bottleneck?

CHAPTER 3: TRANSPORT LAYER

3.1 Computing An Internet Checksum

Consider the two 16-bit words (shown in binary) below. Recall that to compute the Internet checksum of a set of 16-bit words, we compute the one's complement sum [1] of the two words. That is, we add the two numbers together, making sure that any carry into the 17th bit of this initial sum is added back into the 1's place of the resulting sum); we then take the one's complement of the result. Compute the Internet checksum value for these two 16-bit words:

11010110 01000100 — *this binary number is 54852 decimal (base 10)*
00110011 01011000 — *this binary number is 13144 decimal (base 10)*

(1) What is the sum of these two 16 bit numbers? Don't put any spaces in your answer

Hint: Remember to carry any overflow bits

(2) Using the sum from question 1, what is the checksum? Don't put any spaces in your answer

Hint: Take the one's complement of the sum

3.2 Reliable Data Transfer: rdt2.2

Consider the rdt2.2 protocol from the text (pages 209-212). The FSMs for the sender and receiver are shown below:

Suppose that the channel connecting the sender and receiver can corrupt but not lose or reorder packets. Now consider the figure below, which shows four data packets and three corresponding ACKs being exchanged between an rdt 2.2 sender and receiver. The actual corruption or successful transmission/reception of a packet is indicated by the corrupt and OK labels, respectively, shown above the packets in the figure below.

(1) At time t=0, what is the sender state?

Hint: Keep track of the sender FSM

(2) At time t=0, what is the receiver state?

Hint: Keep track of the receiver FSM

(3) At time t=0, what is the sequence/ack # of the packet?

Hint: The ACK number won't change until data is successfully received

(4) At time t=1, what is the sender state?

Hint: Keep track of the sender FSM

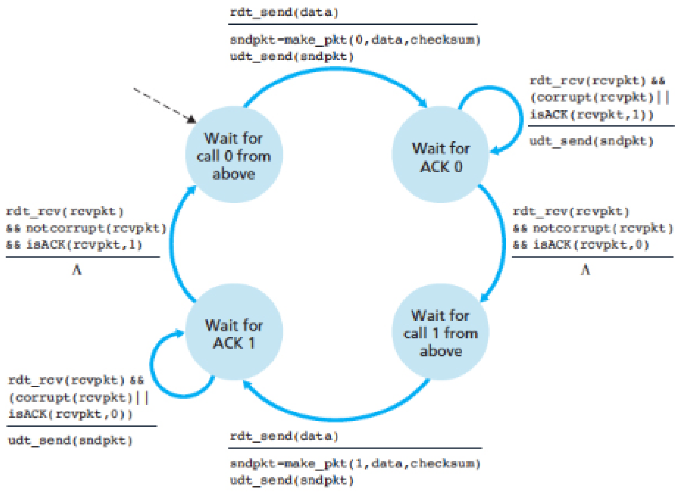


Figure 3.1: rdt2.2 Sender

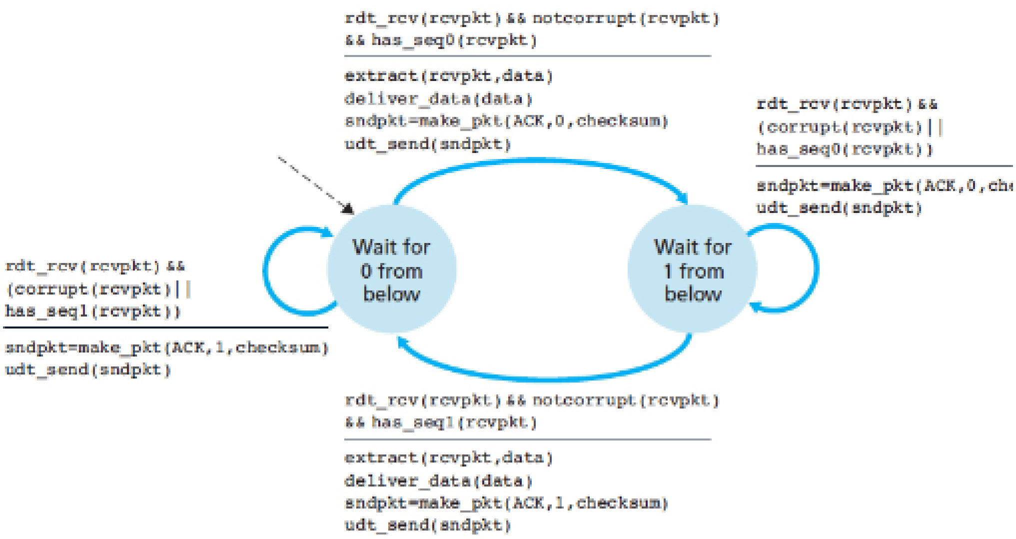


Figure 3.2: rdt2.2 Receiver

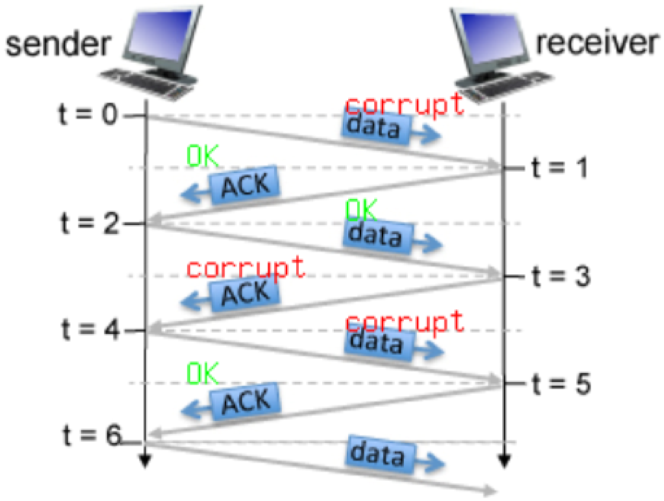


Figure 3.3: Data Exchange

(5) At time t=1, what is the receiver state?

Hint: Keep track of the receiver FSM

(6) At time t=1, what is the sequence/ack # of the packet?

Hint: The ACK number won't change until data is successfully received

(7) At time t=2, what is the sender state?

Hint: Keep track of the sender FSM

(8) At time t=2, what is the receiver state?

Hint: Keep track of the receiver FSM

(9) At time t=2, what is the sequence/ack # of the packet?

Hint: The ACK number won't change until data is successfully received

(10) At time t=3, what is the sender state?

Hint: Keep track of the sender FSM

(11) At time t=3, what is the receiver state?

Hint: Keep track of the receiver FSM

(12) At time t=3, what is the sequence/ack # of the packet?

Hint: The ACK number won't change until data is successfully received

(13) How many times is the payload of the received packet passed up to the higher layer?

Hint: The ACK number won't change until data is successfully received

3.3 Reliable Data Transfer: rdt30

Consider the RDT 3.0 protocol, for reliably communicating data from a sender to receiver over a channel that can lose or corrupt packets in either direction, and when the maximum delay from sender to receiver and back is not known. The FSMs for the sender and receiver are shown below, with their transitions labeled as SX and RY, respectively.

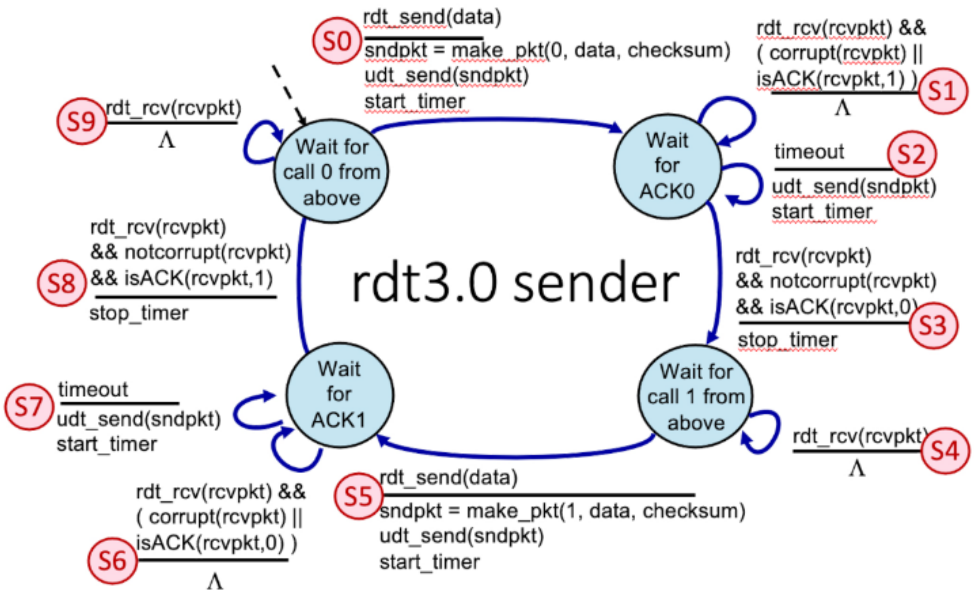


Figure 3.4: rdt3.0 sender

Now let's consider the sequence of sender and receiver transitions that would happen when one or more of the following complications occur: a packet (data or ACK) is lost, a timer times out (prematurely or not), or a message is corrupted. One or more of these events has occurred to produce the sequence of transitions below. In the sequence below, one transition has been omitted and replaced with a "*".

Transition Sequence: S0, R3, S1, S2, R0, S1, *, R1, S1, S2, R1, S3, S5, R2, S6, S7, R3, S8

(1) What is the missing transition? To indicate the missing transition, enter S or R, followed by an index.

Hint: Follow the FSMs

3.4 TCP sequence and ACK numbers, with segment loss

Consider the figure below in which a TCP sender and receiver communicate over a connection in which the sender-¿receiver segments may be lost. The TCP sender sends an initial window of 4 segments. Suppose the initial value of the sender-¿receiver sequence number is 134 and the first 4 segments each contain 424 bytes. The delay between the sender and receiver is 7 time units, and so the first segment arrives at the receiver at t=8. As shown in the figure below, 1 of the 4 segment(s) are lost between the segment and receiver.

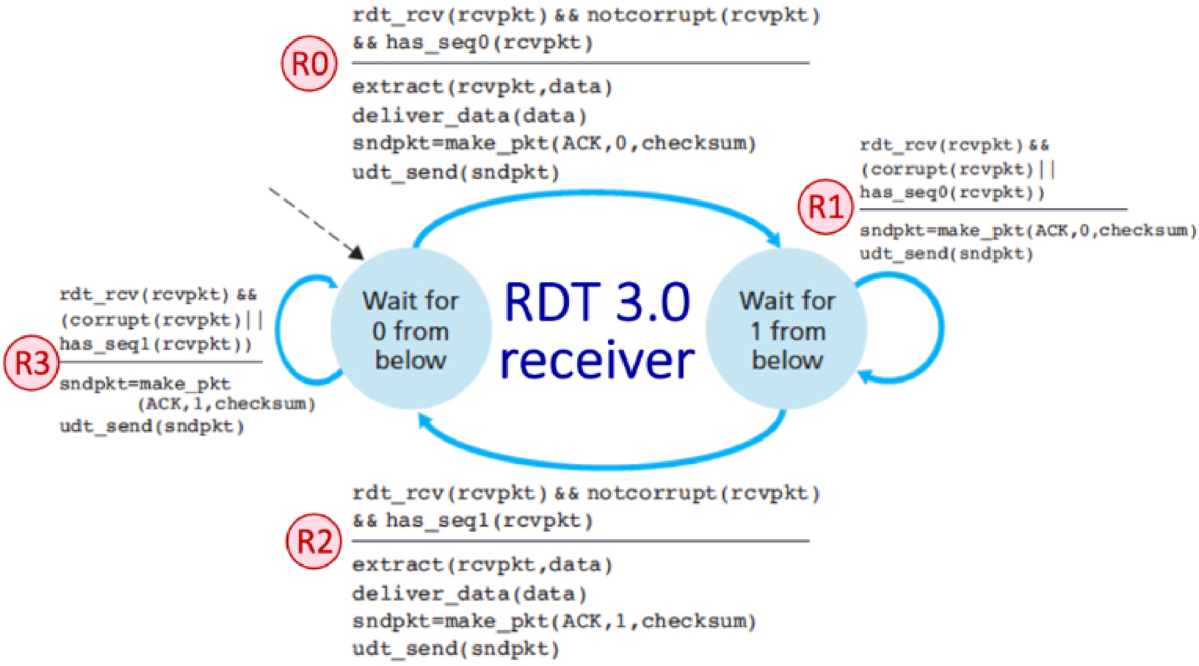


Figure 3.5: rdt3.0 receiver

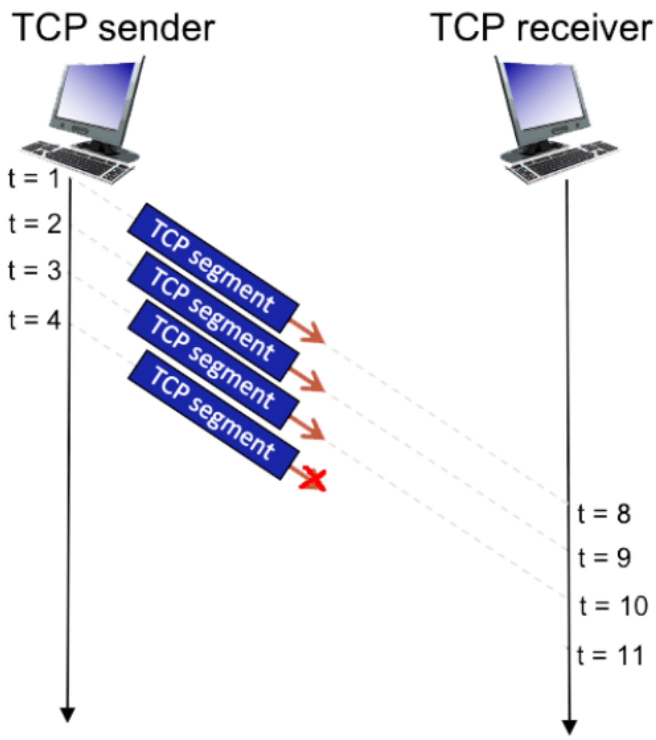


Figure 3.6: TCP Communication

(1) Give the sequence numbers associated with each of the 4 segments sent by the sender. Format your answer as: a,b,c,...

Hint: Sequence numbers are equal to the sum of the previous bytes sent and the old sequence number

(2) Give the ACK numbers the receiver sends in response to each of the segments. If a segment never arrives use 'x' to denote it, and format your answer as: a,b,c,...

Hint: ACKs cumulatively add the bytes received to the sequence number

3.5 Computing TCP's RTT and Timeout Values

Suppose that TCP's current estimated values for the round trip time (estimatedRTT) and deviation in the RTT (DevRTT) are 260 msec and 11 msec, respectively (see Section 3.5.3 for a discussion of these variables). Suppose that the next three measured values of the RTT are 270 msec, 400 msec, and 340 msec respectively.

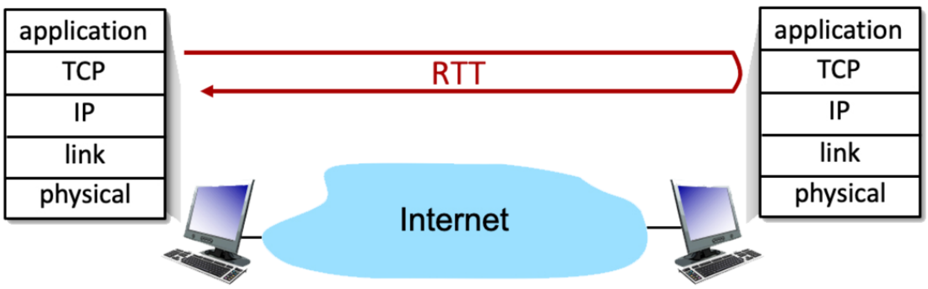


Figure 3.7: TCP's Round Trip Time

Compute TCP's new value of DevRTT, estimatedRTT, and the TCP timeout value after each of these three measured RTT values is obtained. Use the values of $\alpha = 0.125$, and $\beta = 0.25$. Round your answers to two decimal places after leading zeros.

(1) What is the estimatedRTT after the first RTT?

Hint: Calculate estimated RTT with: (1-α)*estimatedRTT + α*sampleRTT

(2) What is the RTT Deviation for the the first RTT?

Hint: Calculate RTT deviation with:(1-β)*DevRTT + β * |estimatedRTT -sampleRTT |

(3) What is the TCP timeout for the first RTT?

Hint: Calcualte TCP timeout with: estimatedRTT + (4*DevRTT)

(4) What is the estimatedRTT after the second RTT?

Hint: Calculate estimated RTT with: (1-α)*estimatedRTT + α*sampleRTT

(5) What is the RTT Deviation for the the second RTT?

Hint: Calculate RTT deviation with: (1-β)*DevRTT + β * |estimatedRTT - sampleRTT|

(6) What is the TCP timeout for the second RTT?

Hint: Calcualte TCP timeout with: estimatedRTT + (4*DevRTT)

(7) What is the estimatedRTT after the third RTT?

Hint: Calculate estimated RTT with: (1-α)*estimatedRTT + α*sampleRTT

(8) What is the RTT Deviation for the the third RTT?

Hint: Calculate RTT deviation with: (1-β)*DevRTT + β * |estimatedRTT - sampleRTT|

(9) What is the TCP timeout for the third RTT?

Hint: Calcualte TCP timeout with: estimatedRTT + (4*DevRTT)

3.6 TCP Congestion Window Evolution (TCP In Action: Slow Start, Congestion Avoidance, and Fast Retransmit)

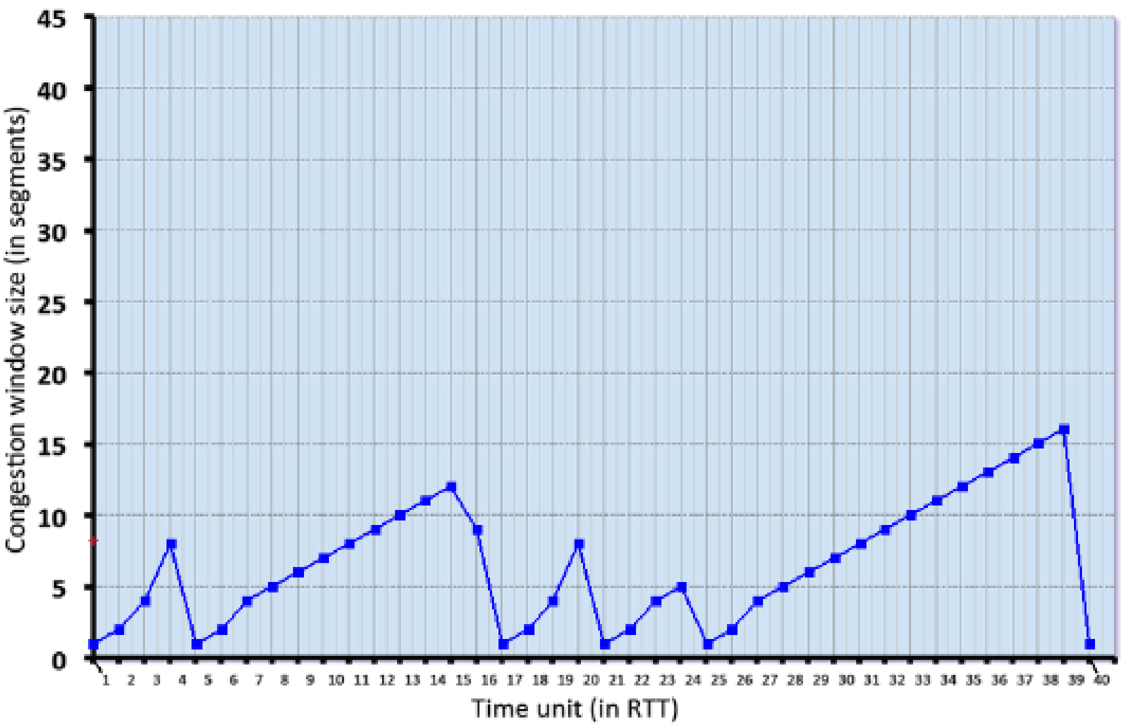
Consider the figure below, which plots the evolution of TCP's congestion window at the beginning of each time unit (where the unit of time is equal to the RTT); see Figure 3.53 in the text. In the abstract model for this problem, TCP sends a "flight" of packets of size cwnd at the beginning of each time unit. The result of sending that flight of packets is that either

(i) all packets are ACKed at the end of the time unit

(ii) there is a timeout for the first packet

(iii) there is a triple duplicate ACK for the first packet

In this problem, you are asked to reconstruct the sequence of events (ACKs, losses) that resulted in the evolution of TCP's *cwnd* shown below.



Consider the evolution of TCP's congestion window in the example above and answer the following questions. The initial value of *cwnd* is 1 and the initial value of *ssthresh* (shown as a red +) is 8.

(1) Give the times at which TCP is in slow start. Format your answer like: 1,3,5,9 (If none submit blank)

Hint: TCP is in slow start when starting or after a timeout, and below ssthresh

(2) Give the times at which TCP is in congestion avoidance. Format your answer like: 1,3,5,9 (If none submit blank)

Hint: TCP is in congestion avoidance when above ssthresh

(3) Give the times at which TCP is in fast recovery. Format your answer like: 1,3,5,9 (If none submit blank)

Hint: TCP is in fast recovery after a loss due to triple duplicate ACK and after the first time when below ssthresh

(4) Give the times at which packets are lost via timeout. Format your answer like: 1,3,5,9 (If none submit blank)

Hint: A timeout loss is characterized by a drop to cwnd=1

(5) Give the times at which packets are lost via triple ACK. Format your answer like: 1,3,5,9 (If none submit blank)

Hint: A triple duplicate ACK loss is characterized by a cut of cwnd ~ 1/2

(6) Give the times at which the value of ssthresh changes (if it changes between t=3 and t=4, use t=4 in your answer)

Hint: The ssthresh can change when there is a loss

3.7 TCP Retransmissions (Reliable Data Transmission with ACK Loss)

Consider the figure below in which a TCP sender and receiver communicate over a connection in which the segments can be lost. The TCP sender wants to send a total of 10 segments to the receiver and sends an initial window of 5 segments at t = 1, 2, 3, 4, and 5, respectively.

Suppose the initial value of the sequence number is 100 and every segment sent to the receiver each contains 489 bytes. The delay between the sender and receiver is 7 time units, and so the first segment arrives at the receiver at t = 8, and an ACK for this segment arrives at t = 15. As shown in the figure, 3 of the 5 segments is lost between the sender and the receiver, but none of the ACKs are lost. Assume there are no timeouts and any out of order segments received are thrown out.

(1) What is the sequence number of the segment sent at t=1?

Hint: The sequence number for the first segment is always the starting value

(2) What is the sequence number of the segment sent at t=2?

Hint: The sequence number is equal to the previous sequence number + the segment size

(3) What is the sequence number of the segment sent at t=3?

Hint: The sequence number is equal to the previous sequence number + the segment size

(4) What is the sequence number of the segment sent at t=4?

Hint: The sequence number is equal to the previous sequence number + the segment size

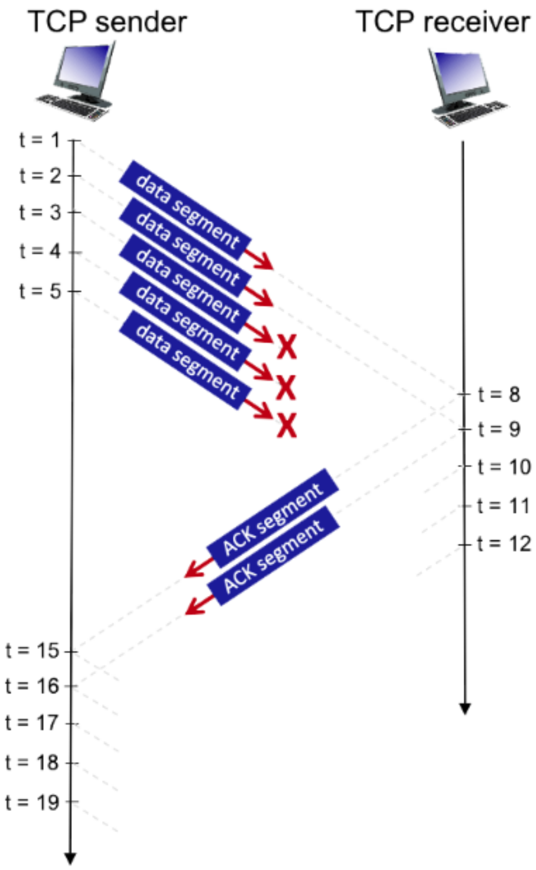


Figure 3.8: TCP Retransmissions

(5) What is the sequence number of the segment sent at t=5?

Hint: The sequence number is equal to the previous sequence number + the segment size

(6) What is the value of the ACK sent at t=8? (If segment lost, write 'x')

Hint: The ACK value is 'x' if the segment never arrives, or is equal to the next expected sequence number

(7) What is the value of the ACK sent at t=9? (If segment lost, write 'x')

Hint: The ACK value is 'x' if the segment never arrives, or is equal to the next expected sequence number

(8) What is the value of the ACK sent at t=10? (If segment lost, write 'x')

Hint: The ACK value is 'x' if the segment never arrives, or is equal to the next expected sequence number

(9) What is the value of the ACK sent at t=11? (If segment lost, write 'x')

Hint: The ACK value is 'x' if the segment never arrives, or is equal to the next expected sequence number

(10) What is the value of the ACK sent at t=12? (If segment lost, write 'x')

Hint: The ACK value is 'x' if the segment never arrives, or is equal to the next expected sequence number

(11) What is the sequence number of the segment sent at t = 15? (If ACK never arrives, write 'x')

Hint: If the sender doesn't send a segment, write 'x'; otherwise, the sequence number is equal to the previous sequence number + the segment size

(12) What is the sequence number of the segment sent at t = 16? (If ACK never arrives, write 'x')

Hint: If the sender doesn't send a segment, write 'x'; otherwise, the sequence number is equal to the previous sequence number + the segment size

(13) What is the sequence number of the segment sent at t = 17? (If ACK never arrives, write 'x')

Hint: If the sender doesn't send a segment, write 'x'; otherwise, the sequence number is equal to the previous sequence number + the segment size

(14) What is the sequence number of the segment sent at t = 18? (If ACK never arrives, write 'x')

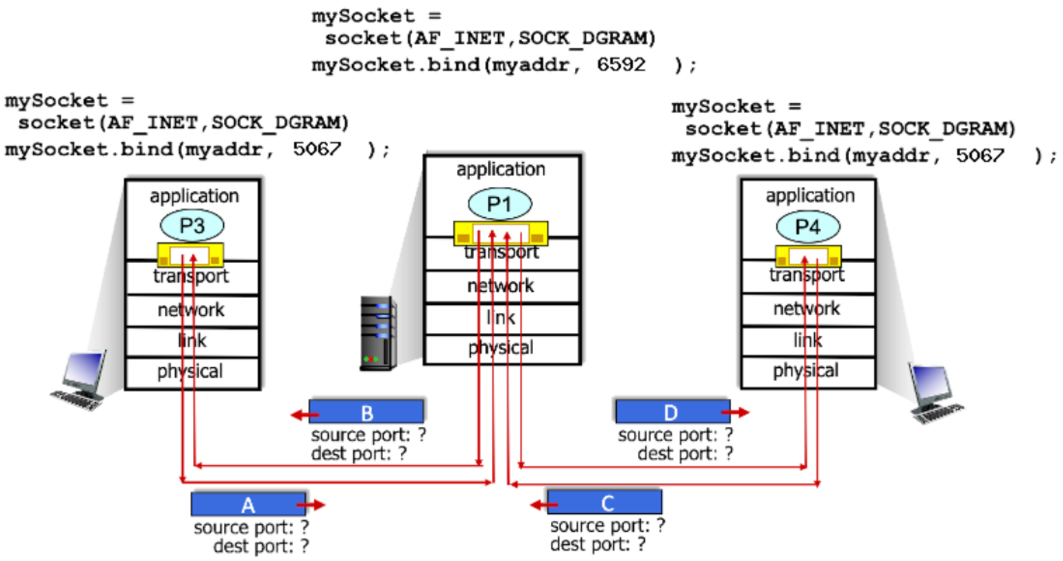
Hint: If the sender doesn't send a segment, write 'x'; otherwise, the sequence number is equal to the previous sequence number + the segment size

(15) What is the sequence number of the segment sent at t = 19? (If ACK never arrives, write 'x')

Hint: If the sender doesn't send a segment, write 'x'; otherwise, the sequence number is equal to the previous sequence number + the segment size

3.8 UDP Multiplexing and Demultiplexing

In the scenario below, the left and right clients communicate with a server using UDP sockets. The same socket at the server is used to communicate with both clients. The Python code used to create the sockets is shown in the figure. Consider the four transport-layer packets – A, B, C and D – shown in the figure below.



(1) What is the source port # for packet D?

Hint: The source port is the port # of the machine where the packet starts

(2) What is the destination port # for packet A?

Hint: The destination port is the port # of the machine where the packet ends

(3) What is the source port # for packet D?

Hint: The source port is the port # of the machine where the packet starts

(4) What is the destination port # for packet D?

Hint: The destination port is the port # of the machine where the packet ends

(5) What is the source port # for packet C?

Hint: The source port is the port # of the machine where the packet starts

(6) What is the destination port # for packet C?

Hint: The destination port is the port # of the machine where the packet ends

(7) What is the source port # for packet B?

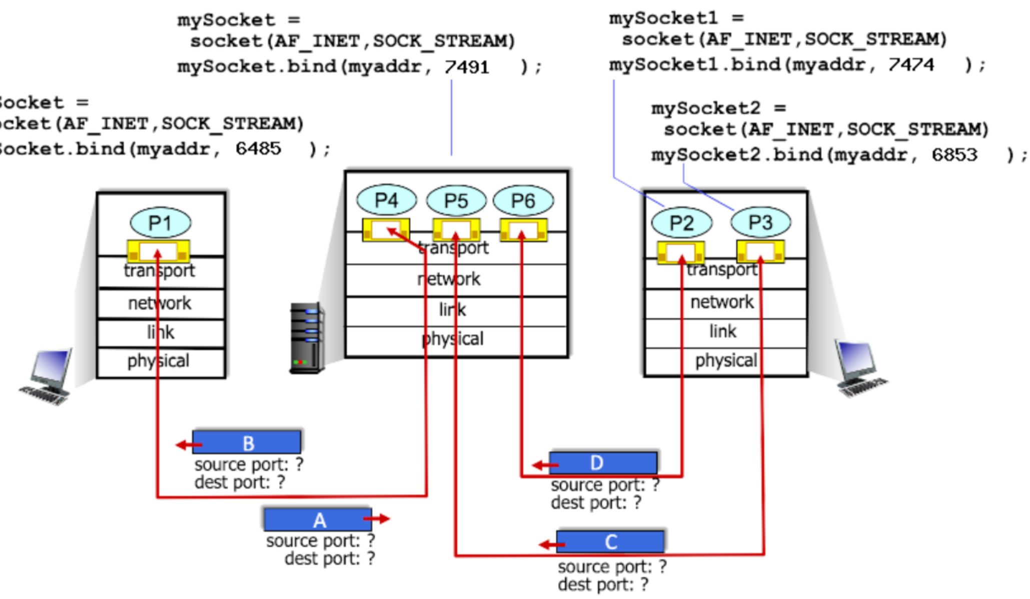
Hint: The source port is the port # of the machine where the packet starts

(8) What is the destination port # for packet B?

Hint: The destination port is the port # of the machine where the packet ends

3.9 TCP Multiplexing and Demultiplexing

In the scenario below, the left and right TCP clients communicate with a TCP server using TCP sockets. The Python code used to create a single welcoming socket in the server is shown in the figure (the welcoming socket itself is not shown graphically); code is also shown for the client sockets as well. The three sockets shown in server were created as a result of the server accepting connection requests on this welcoming socket from the two clients (one connection from the client on the left, and two connections from the client on the right).



(1) What is the source port # for packet B?

Hint: The source port is the port # of the machine where the packet starts

(2) What is the destination port # for packet B?

Hint: The destination port is the port # of the machine where the packet ends

(3) What is the source port # for packet A?

Hint: The source port is the port # of the machine where the packet starts

(4) What is the destination port # for packet A?

Hint: The destination port is the port # of the machine where the packet ends

(5) What is the source port # for packet D?

Hint: The source port is the port # of the machine where the packet starts

(6) What is the destination port # for packet D?

Hint: The destination port is the port # of the machine where the packet ends

(7) What is the source port # for packet C?

Hint: The source port is the port # of the machine where the packet starts

(8) What is the destination port # for packet C?

Hint: The destination port is the port # of the machine where the packet ends

CHAPTER 4: NETWORK LAYER: DATA PLANE

4.1 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:

Prefix Match	Interface
11	1
10	2
110	3
101	4
011	5
otherwise	6

(1) Suppose a datagram arrives at the router, with destination address 00101111. To which interface will this datagram be forwarded using longest-prefix matching?

Hint: Use the information given in the table

(2) Suppose a datagram arrives at the router, with destination address 10100101. To which interface will this datagram be forwarded using longest-prefix matching?

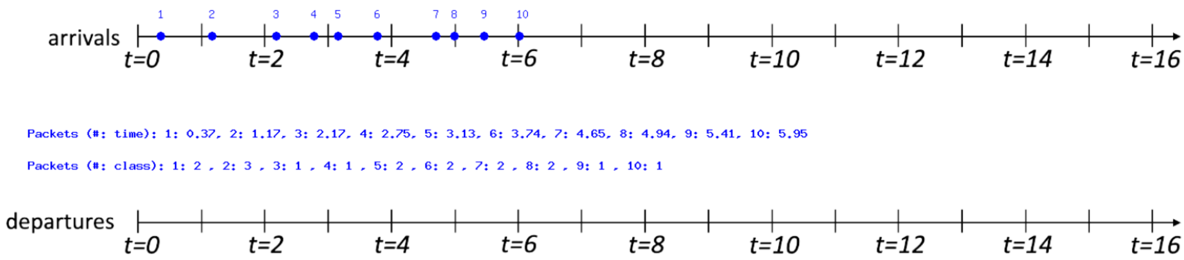
Hint: Use the information given in the table

(3) Suppose a datagram arrives at the router, with destination address 10110100. To which interface will this datagram be forwarded using longest-prefix matching?

Hint: Use the information given in the table

4.2 Packet Scheduling

Consider the arrival of 10 packets to an output link at a router in the interval of time [0, 5], as indicated by the figure below. We'll consider time to be "slotted", with a slot beginning at t = 0, 1, 2, 3, etc. Packets can arrive at any time during a slot, and multiple packets can arrive during a slot. At the beginning of each time slot, the packet scheduler will choose one packet, among those queued (if any), for transmission according to the packet scheduling discipline (that you will select below). Each packet requires exactly one slot time to transmit, and so a packet selected for transmission at time t, will complete its transmission at t+1, at which time another packet will be selected for transmission, among those queued. You might want to review section 4.2.5 in the 8th edition of our textbook, on packet scheduling.



In the case of Priority, RR, and WFQ there will be three classes of traffic (1, 2, 3), with lower class numbers having higher priority in the case of priority schedule, or beginning earlier in the case of RR and WFQ. In the case of WFQ, scheduling weights are 0.5, 0.3, and 0.2.

4.2.1 Packet Scheduling Discipline - FIFO

(1) At t=1, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(2) At t=2, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(3) At t=3, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(4) At t=4, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(5) At t=5, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(6) At t=6, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(7) At t=7, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(8) At t=8, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(9) At t=9, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(10) At t=10, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(11) At t=11, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(12) At t=12, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(13) At t=13, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

(14) At t=14, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out in the order they're received

4.2.2 Packet Scheduling Discipline - Priority

(1) At t=1, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(2) At t=2, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(3) At t=3, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(4) At t=4, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(5) At t=5, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(6) At t=6, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(7) At t=7, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(8) At t=8, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(9) At t=9, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(10) At t=10, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(11) At t=11, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(12) At t=12, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(13) At t=13, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

(14) At t=14, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Packets are sent out based on priority (lower = sooner), and in the order they're received

4.2.3 Packet Scheduling Discipline - RoundRobin

(1) At t=1, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(2) At t=2, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(3) At t=3, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(4) At t=4, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(5) At t=5, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(6) At t=6, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(7) At t=7, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(8) At t=8, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(9) At t=9, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(10) At t=10, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(11) At t=11, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(12) At t=12, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(13) At t=13, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(14) At t=14, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

4.2.4 Packet Scheduling Discipline - WFQ

(1) At t=1, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(2) At t=2, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(3) At t=3, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(4) At t=4, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(5) At t=5, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(6) At t=6, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(7) At t=7, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(8) At t=8, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(9) At t=9, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(10) At t=10, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(11) At t=11, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(12) At t=12, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(13) At t=13, which packet is sent out? Give the packet # or 'n/a' if applicable

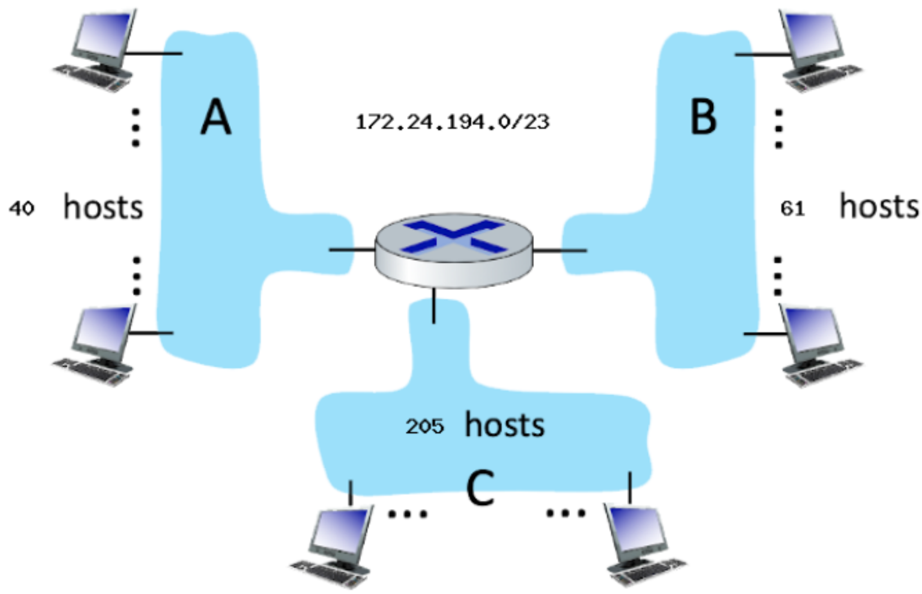
Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

(14) At t=14, which packet is sent out? Give the packet # or 'n/a' if applicable

Hint: Every iteration (starting at 1) the router sends out a packet with that class (assuming the total # of packets in that class is less than their share) and iterates (eg: class 1 to class 2); if there is no packet in that class the router sends out the next available class.

4.3 Subnet Addressing

Consider the router and the three attached subnets below (A, B, and C). The number of hosts is also shown below. The subnets share the 23 high-order bits of the address space: 172.24.194.0/23



Assign subnet addresses to each of the subnets (A, B, and C) 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.

(1) Is the address space public or private?

Hint: Private IP addresses are in a specific range depending on the class

(2) How many hosts can there be in this address space?

Hint: Take $2^x - 2$, where x is the number of host bits

(3) What is the subnet address of subnet A? (CIDR notation)

Hint: The next subnet address will be 1 bigger than the broadcast address of the previous subnet

(4) What is the broadcast address of subnet A?

Hint: The broadcast address is the last IP in the range

(5) What is the starting address of subnet A?

Hint: The first IP can be calculated by taking the subnet address and adding 1 to the last octet

(6) What is the ending address of subnet A?

Hint: The last IP can be found by taking the broadcast IP and subtracting 1 from the last octet

(7) What is the subnet address of subnet B? (CIDR notation)

Hint: The next subnet address will be 1 bigger than the broadcast address of the previous subnet

(8) What is the broadcast address of subnet B?

Hint: The broadcast address is the last IP in the range

(9) What is the starting address of subnet B?

Hint: The first IP can be calculated by taking the subnet address and adding 1 to the last octet

(10) What is the ending address of subnet B?

Hint: The last IP can be found by taking the broadcast IP and subtracting 1 from the last octet

(11) What is the subnet address of subnet C? (CIDR notation)

Hint: The next subnet address will be 1 bigger than the broadcast address of the previous subnet

(12) What is the broadcast address of subnet C?

Hint: The broadcast address is the last IP in the range

(13) What is the starting address of subnet C?

Hint: The first IP can be calculated by taking the subnet address and adding 1 to the last octet

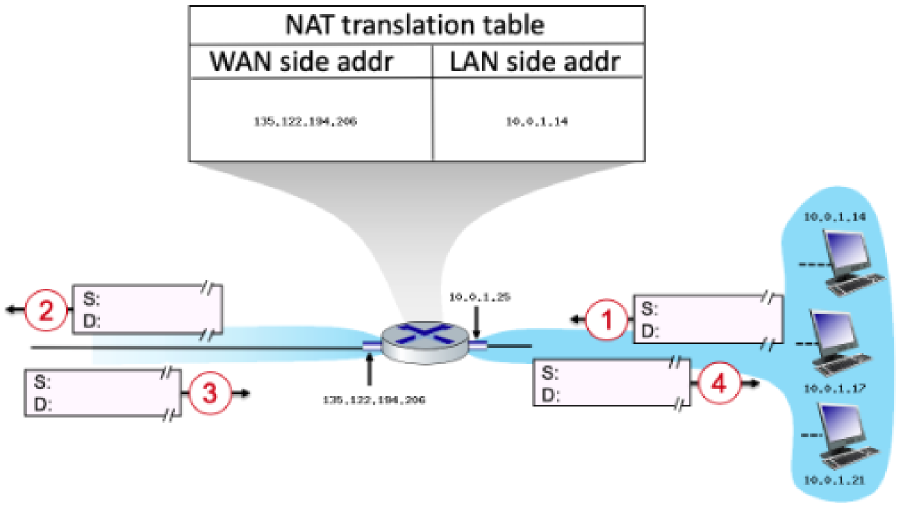
(14) What is the ending address of subnet C?

Hint: The last IP can be found by taking the broadcast IP and subtracting 1 from the last octet

4.4 Network Address Translation

Consider the scenario below in which three hosts, with private IP addresses 10.0.1.14, 10.0.1.17, 10.0.1.21 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 135.122.194.206

Before doing this problem, you might want to reread the section on the NAT protocol in section 4.3.4 in the text.



Suppose that the host with IP address 10.0.1.14 sends an IP datagram destined to host 128.119.178.186. The source port is 3478, and the destination port is 80.

(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?

Hint: So far the packet hasn't been modified

(2) At step 1, what is the destination IP address?

Hint: So far the packet hasn't been modified

(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?

Hint: The NAT will change the source address at this point

(4) At step 2, what is the destination IP address for this datagram?

Hint: NAT wouldn't change the destination address for outgoing datagrams

(5) Will the source port have changed? Yes or No.

Hint: The NAT will change the port, but is it the source or destination port?

(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?

Hint: When a packet makes the return trip, the source and destination addresses are swapped

(7) At step 3, what is the destination IP address for this datagram?

Hint: When a packet makes the return trip, the source and destination addresses are swapped

(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?

Hint: The NAT won't change the source IP for incoming datagrams

(9) At step 4, what is the destination IP address for this datagram

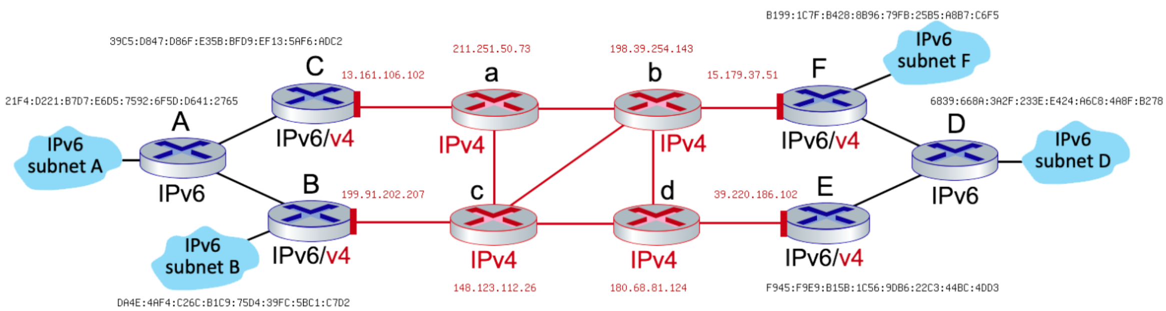
Hint: The NAT will change the destination IP for the incoming datagrams

(10) Has a new entry been made in the router's NAT table? Yes or No.

Hint: NAT entries are only made by outgoing requests

4.5 IPv6 Tunneling and Encapsulation

Consider the network shown below which contains four IPv6 subnets, connected by a mix of IPv6-only routers(shaded blue), IPv4-only routers (shaded red) and dual-capable IPv6/IPv4 routers (shaded blue with red interfaces to IPv4 routers). You might want to review Section 4.3.4 in the textbook before doing this problem.



Suppose that a host of subnet F wants to send an IPv6 datagram to a host on subnet A. Assume that the forwarding between these two hosts goes along the path: $F --> b --> d --> c --> B --> A$

(1) Is the datagram being forwarded from F to b an IPv4 or IPv6 datagram?

Hint: If both routers support IPv6, the datagram will be IPv6; otherwise, the datagram will be IPv4

(2) What is the source address of this F to b datagram?

Hint: The source address will either be where the datagram starts, or where the IPv6 packet is encapsulated

(3) What is the destination address of this F to b datagram?

Hint: The destination address will either be where the datagram ends, or where the IPv6 packet is decapsulated

(4) Is this F to b datagram encapsulating another datagram? Yes or No.

Hint: If the packet is entering, inside of, or exiting the IPv4 routers, the IPv6 packet is currently encapsulated by the IPv4 datagram

(5) What is the source address of this encapsulated datagram?

Hint: The source address is where the datagram originates from

(6) What is the destination address of this encapsulated datagram?

Hint: The destination address is the datagrams goal endpoint

(7) Is the datagram being forwarded from b to d an IPv4 or IPv6 datagram?

Hint: If both routers support IPv6, the datagram will be IPv6; otherwise, the datagram will be IPv4

(8) What is the source address of this b to d datagram?

Hint: The source address will either be where the datagram starts, or where the IPv6 packet is encapsulated

(9) What is the destination address of this b to d datagram?

Hint: The destination address will either be where the datagram ends, or where the IPv6 packet is decapsulated

(10) Is this b to d datagram encapsulating another datagram? Yes or No.

Hint: If the packet is entering, inside of, or exiting the IPv4 routers, the IPv6 packet is currently encapsulated by the IPv4 datagram

(11) What is the source address of this encapsulated datagram?

Hint: The source address is where the datagram originates from

(12) What is the destination address of this encapsulated datagram?

Hint: The destination address is the datagrams goal endpoint

(13) Is the datagram being forwarded from d to c an IPv4 or IPv6 datagram?

Hint: If both routers support IPv6, the datagram will be IPv6; otherwise, the datagram will be IPv4

(14) What is the source address of this d to c datagram?

Hint: The source address will either be where the datagram starts, or where the IPv6 packet is encapsulated

(15) What is the destination address of this d to c datagram?

Hint: The destination address will either be where the datagram ends, or where the IPv6 packet is decapsulated

(16) Is this d to c datagram encapsulating another datagram? Yes or No.

Hint: If the packet is entering, inside of, or exiting the IPv4 routers, the IPv6 packet is currently encapsulated by the IPv4 datagram

(17) What is the source address of this encapsulated datagram?

Hint: The source address is where the datagram originates from

(18) What is the destination address of this encapsulated datagram?

Hint: The destination address is the datagrams goal endpoint

(19) Is the datagram being forwarded from c to B an IPv4 or IPv6 datagram?

Hint: If both routers support IPv6, the datagram will be IPv6; otherwise, the datagram will be IPv4

(20) What is the source address of this c to B datagram?

Hint: The source address will either be where the datagram starts, or where the IPv6 packet is encapsulated

(21) What is the destination address of this c to B datagram?

Hint: The destination address will either be where the datagram ends, or where the IPv6 packet is decapsulated

(22) Is this c to B datagram encapsulating another datagram? Yes or No.

Hint: If the packet is entering, inside of, or exiting the IPv4 routers, the IPv6 packet is currently encapsulated by the IPv4 datagram

(23) What is the source address of this encapsulated datagram?

Hint: The source address is where the datagram originates from

(24) What is the destination address of this encapsulated datagram?

Hint: The destination address is the datagrams goal endpoint

(25) Is the datagram being forwarded from B to A an IPv4 or IPv6 datagram?

Hint: If both routers support IPv6, the datagram will be IPv6; otherwise, the datagram will be IPv4

(26) What is the source address of this B to A datagram?

Hint: The source address will either be where the datagram starts, or where the IPv6 packet is encapsulated

(27) What is the destination address of this B to A datagram?

Hint: The destination address will either be where the datagram ends, or where the IPv6 packet is decapsulated

(28) Is this B to A datagram encapsulating another datagram? Yes or No.

Hint: If the packet is entering, inside of, or exiting the IPv4 routers, the IPv6 packet is currently encapsulated by the IPv4 datagram

(29) What router is the 'tunnel entrance'? Give the router's letter

Hint: The tunnel entrance is the router which encapsulates the IPv6 datagram

(30) What router is the 'tunnel exit'? Give the router's letter

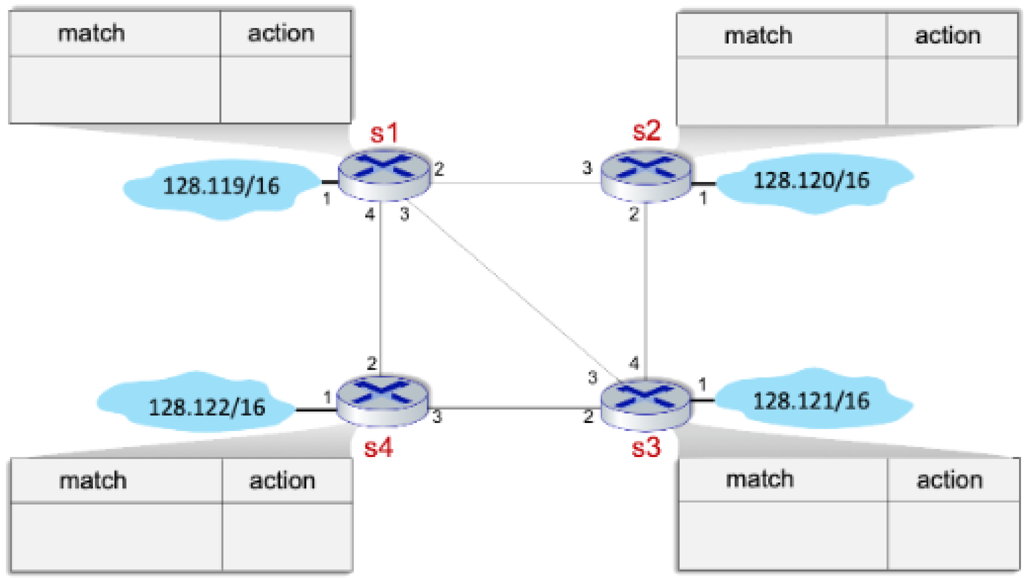
Hint: The tunnel exit is the router which decapsulates the IPv6 datagram

(31) Which protocol encapsulates the other, IPv4 or IPv6?

Hint: In order to maintain compatibility with existing IPv4 infrastructure, IPv6 datagrams are put in the payload of an IPv4 datagram

4.6 Openflow Flow Tables

Consider the 4-router network shown below, where packet forwarding is controlled by flow tables (e.g., configured via OpenFlow in an SDN controller), rather than by a forwarding table computed by a routing algorithm. The addresses of networks attached to each of the router is also shown. The interfaces at each of the routers are also as indicated.



Suppose we want the following forwarding behavior of packets to be implemented:

- TCP packets coming from the source network attached to s3 and destined to the network attached to s1 should be forwarded along the path: $s3- > s1$. UDP packets coming from the source network attached to s3 and destined to the network attached to s1 should be forwarded along the different path: $s3- > s2- > s1$

Complete the match-plus-action tables in each of the routers, s1, s2, s3, and s4, that implement these forwarding behaviors. Your rules should be as strict as possible (should only allow these behaviors, and no other forwarding behaviors). You can assume that any packet arriving at a router that does not match a rule in that table will be dropped.

(1) For router s1, what should the value of the 'IP Src' be? Pick either a specific address (including CIDR), any, or none

Hint: The source will be the subnet of where the packet originated

(2) For router s1, what should the value of the 'IP Dst' be? Pick either a specific address (including CIDR), any, or none

Hint: The destination will be the subnet of where the packet is going, which doesn't change as the packet travels

(3) For router s1, what should the value of the 'Src Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from entering based on content, the src port will be 'any'

(4) For router s1, what should the value of the ’Dst Port’ be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from exiting based on content, the dst port will be ’any’

(5) For router s1, what should the value of the ’IP Proto’ be? Pick either TCP, UDP, or any

Hint: Depending on if this router is regulating content entering or exiting, this will be the protocol associated with the content or ’any’

(6) For router s1, what should the action of the rule be? Some examples include forward, allow, deny, etc

Hint: Since the default behavior of a router is to drop an unmatched packet, the action for this rule will be ’forward’

(7) For router s1, what interface should the packets be forwarded to?

Hint: The interface will be the one attached to the next router in the packet’s path

(8) For router s1, what should the value of the ’IP Src’ be? Pick either a specific address (including CIDR), any, or none

Hint: The source will be the subnet of where the packet originated

(9) For router s1, what should the value of the ’IP Dst’ be? Pick either a specific address (including CIDR), any, or none

Hint: The destination will be the subnet of where the packet is going, which doesn’t change as the packet travels

(10) For router s1, what should the value of the ’Src Port’ be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from entering based on content, the src port will be ’any’

(11) For router s1, what should the value of the ’Dst Port’ be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from exiting based on content, the dst port will be ’any’

(12) For router s1, what should the value of the ’IP Proto’ be? Pick either TCP, UDP, or any

Hint: Depending on if this router is regulating content entering or exiting, this will be the protocol associated with the content or ’any’

(13) For router s1, what should the action of the rule be? Some examples include forward, allow, deny, etc

Hint: Since the default behavior of a router is to drop an unmatched packet, the action for this rule will be ’forward’

(14) For router s1, what interface should the packets be forwarded to?

Hint: The interface will be the one attached to the next router in the packet’s path

(15) For router s2, what should the value of the ’IP Src’ be? Pick either a specific address (including CIDR), any, or none

Hint: The source will be the subnet of where the packet originated

(16) For router s2, what should the value of the 'IP Dst' be? Pick either a specific address (including CIDR), any, or none

Hint: The destination will be the subnet of where the packet is going, which doesn't change as the packet travels

(17) For router s2, what should the value of the 'Src Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from entering based on content, the src port will be 'any'

(18) For router s2, what should the value of the 'Dst Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from exiting based on content, the dst port will be 'any'

(19) For router s2, what should the value of the 'IP Proto' be? Pick either TCP, UDP, or any

Hint: Depending on if this router is regulating content entering or exiting, this will be the protocol associated with the content or 'any'

(20) For router s2, what should the action of the rule be? Some examples include forward, allow, deny, etc

Hint: Since the default behavior of a router is to drop an unmatched packet, the action for this rule will be 'forward'

(21) For router s2, what interface should the packets be forwarded to?

Hint: The interface will be the one attached to the next router in the packet's path

(22) For router s3, what should the value of the 'IP Src' be? Pick either a specific address (including CIDR), any, or none

Hint: The source will be the subnet of where the packet originated

(23) For router s3, what should the value of the 'IP Dst' be? Pick either a specific address (including CIDR), any, or none

Hint: The destination will be the subnet of where the packet is going, which doesn't change as the packet travels

(24) For router s3, what should the value of the 'Src Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from entering based on content, the src port will be 'any'

(25) For router s3, what should the value of the 'Dst Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from exiting based on content, the dst port will be 'any'

(26) For router s3, what should the value of the 'IP Proto' be? Pick either TCP, UDP, or any

Hint: Depending on if this router is regulating content entering or exiting, this will be the protocol associated with the content or 'any'

(27) For router s3, what should the action of the rule be? Some examples include forward, allow, deny, etc

Hint: Since the default behavior of a router is to drop an unmatched packet, the action for this rule will be 'forward'

(28) For router s3, what interface should the packets be forwarded to?

Hint: The interface will be the one attached to the next router in the packet's path

(29) For router s3, what should the value of the 'IP Src' be? Pick either a specific address (including CIDR), any, or none

Hint: The source will be the subnet of where the packet originated

(30) For router s3, what should the value of the 'IP Dst' be? Pick either a specific address (including CIDR), any, or none

Hint: The destination will be the subnet of where the packet is going, which doesn't change as the packet travels

(31) For router s3, what should the value of the 'Src Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from entering based on content, the src port will be 'any'

(32) For router s3, what should the value of the 'Dst Port' be? Pick either a specific port, or any

Hint: Unless the router needs to block packets from exiting based on content, the dst port will be 'any'

(33) For router s3, what should the value of the 'IP Proto' be? Pick either TCP, UDP, or any

Hint: Depending on if this router is regulating content entering or exiting, this will be the protocol associated with the content or 'any'

(34) For router s3, what should the action of the rule be? Some examples include forward, allow, deny, etc

Hint: Since the default behavior of a router is to drop an unmatched packet, the action for this rule will be 'forward'

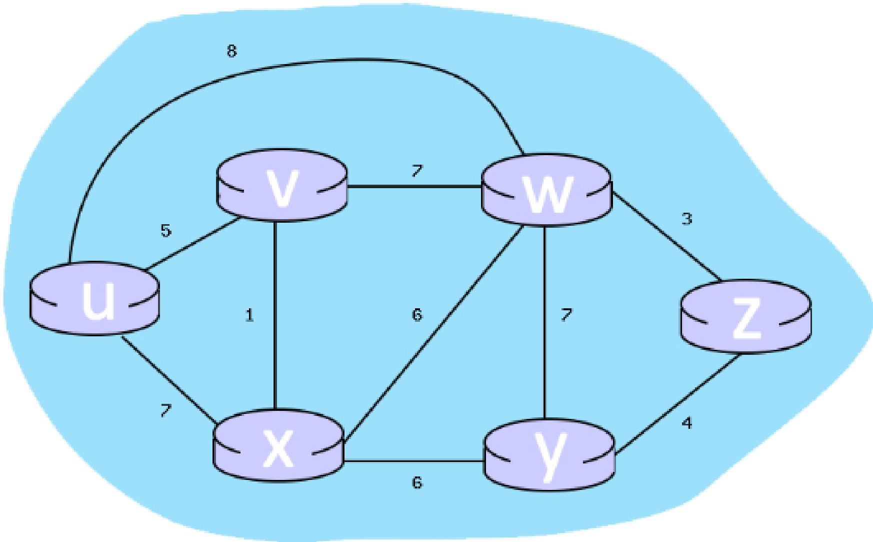
(35) For router s3, what interface should the packets be forwarded to?

Hint: The interface will be the one attached to the next router in the packet's path

CHAPTER 5: NETWORK LAYER: CONTROL PLANE

5.1 Dijkstra's Link State Algorithm

Consider the 6-node network shown below, with the given link costs.



Using Dijkstra's algorithm, find the least cost path from source node U to all other destinations and answer the following questions

(1) What is the shortest distance to node y and what node is its predecessor? Write your answer as n,p

Hint: See section 5.2.1 in the text if you have trouble understanding Dijkstra

(2) What is the shortest distance to node v and what node is its predecessor? Write your answer as n,p

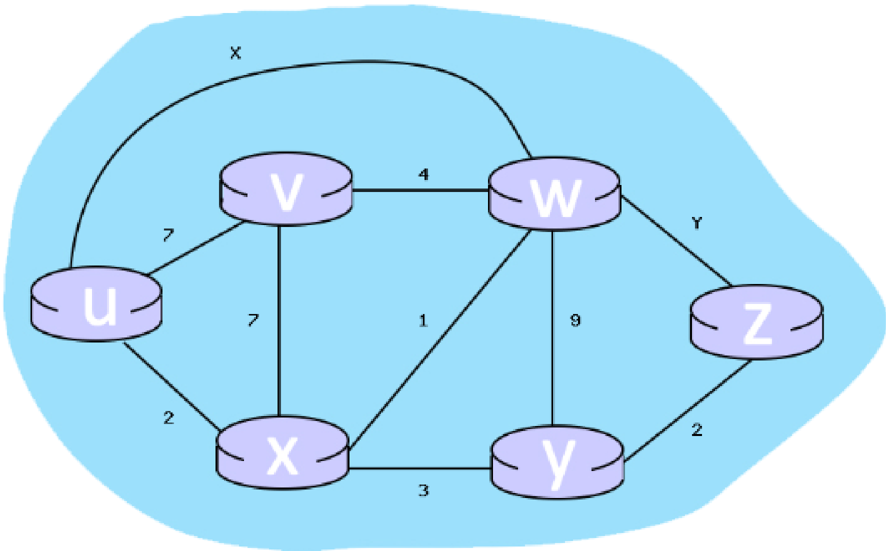
Hint: See section 5.2.1 in the text if you have trouble understanding Dijkstra

(3) What is the shortest distance to node z and what node is its predecessor? Write your answer as n,p

Hint: See section 5.2.1 in the text if you have trouble understanding Dijkstra

5.2 Dijkstra's Link State Algorithm - Advanced

Consider the incomplete 6-node network shown below, with the given link costs.



Consider the completed table below, which calculates the shortest distance to all nodes from Z:

Node	Shortest distance from Z	Previous Node
Z	0	n/a
W	1	Z
X	2	W
Y	2	Z
U	4	X
V	5	W

(1) For link X, what is the cost associated with this link? If the answer can't be determined given the information, respond with 'n/a'

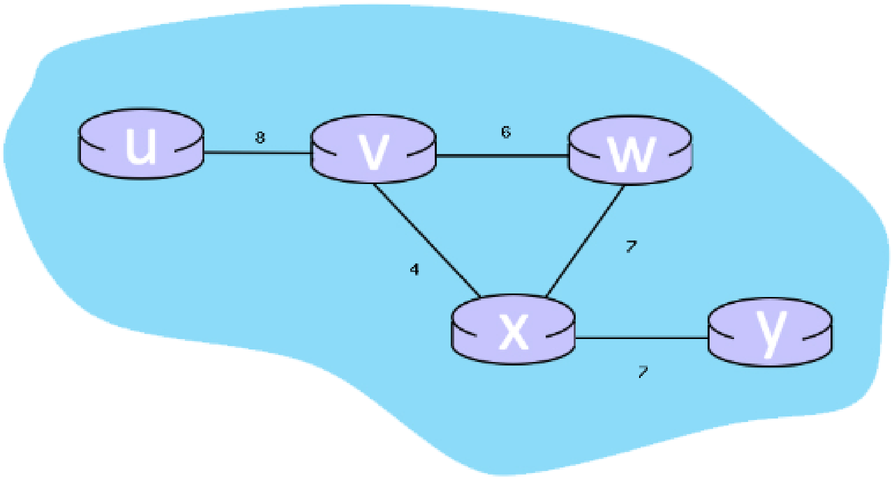
Hint: Looking at the completed table, find a node (let's call that the 'final' node) connected to a link with an unknown cost. Now consider the node on the other end of that link. If this other node is the 'Previous node' on the least cost path to the final node, and if that least cost path to the other node is known, then you can figure out the cost of that link - it's the difference in cost to the final node minus the cost to the other node.

(2) For link Y, what is the cost associated with this link? If the answer can't be determined given the information, respond with 'n/a'

Hint: Looking at the completed table, find a node (let's call that the 'final' node) connected to a link with an unknown cost. Now consider the node on the other end of that link. If this other node is the 'Previous node' on the least cost path to the final node, and if that least cost path to the other node is known, then you can figure out the cost of that link - it's the difference in cost to the final node minus the cost to the other node.

5.3 Bellman Ford Distance Vector algorithm (for computing least cost paths)

Consider the 6-node network shown below, with the given link costs:



(a) When the algorithm converges, what are the distance vectors from router 'X' to all routers? Write your answer as u,v,w,x,y

Hint: See Section 5.2.2 in the text

(b) What are the initial distance vectors for router 'U'? Write your answer as u,v,w,x,y and if a distance is ∞, write 'x'

Hint: See Section 5.2.2 in the text

(c) The phrase 'Good news travels fast' is very applicable to distance vector routing when link costs decrease; what is the name of the problem that can occur when link costs increase?

Hint: See Section 5.2.2 in the text

CHAPTER 6: LINK LAYER

6.1 Error Detection and Correction: Two Dimensional Parity

Suppose that a packet's payload consists of 10 eight-bit values (e.g., representing ten ASCII-encoded characters) shown below. (Here, we have arranged the ten eight-bit values as five sixteen-bit values):

10100110 01010010

11110001 11100011

01000000 11100011

10111110 11000110

00101101 00100111

Figure 6.1: Ten eight-bit values as five sixteen-bit values

Both the payload and parity bits are shown. One of these bits is flipped.

00100101 00010110 0

01011110 10101011 0

10011001 00101001 0

11011000 00011010 1

00010010 00001111 0

00101000 10000101 1

Figure 6.2: One of these bits is flipped

Both the payload and parity bits are shown; Either one or two of the bits have been flipped.

01001111 10100111 0

10000010 10111111 0

11001101 11101001 0

00111111 11011111 1

11101100 10101101 0

11110011 10000011 1

Figure 6.3: Either one or two of the bits have been flipped

(1) For figure 6.1, compute the two-dimensional parity bits for the 16 columns. Combine the bits into one string

Hint: See figure 6.5 in the text

(2) For figure 1, compute the two-dimensional parity bits for the 5 rows (starting from the top). Combine the bits into one string

Hint: See figure 6.5 in the text

(3) For figure 1, compute the parity bit for the parity bit row from question 1. Assume that the result should be even.

Hint: Use your answer from question 1 and calculate the parity of it.

(4) For figure 2, indicate the row and column with the flipped bit (format as: x,y), assuming the top-left bit is 0,0

Hint: See figure 6.5 in the text

(5) For figure 3, is it possible to detect and correct the bit flips? Yes or No

Hint: You can detect the bit flips, but can you find the exact location? Read section 6.2.1 in the text.

6.2 Error Detection and Correction: Cyclic Redundancy Check

Consider the Cyclic Redundancy Check (CRC) algorithm discussed in Section 6.2.3 of the text. Suppose that the 4-bit generator (G) is 1001, that the data payload (D) is 10011000 and that r = 3.

(1) What are the CRC bits (R) associated with the data payload D, given that r = 3?

Hint: Recall from the text that in calculating the CRC bits, all CRC calculations are done in modulo-2 arithmetic without carries in addition or borrows in subtraction. This means that addition and subtraction are identical and both equal to the bitwise exclusive-OR (XOR) of the operands.

6.3 Random Access Protocols: Aloha

Assume that there are 2 active nodes, each of which has an infinite supply of frames they want to transmit, and these frames have a constant size of L bits. If two or more frames collide, then all nodes will detect the collision.

There are two versions of the Aloha protocol: Slotted and Pure. In this problem we will be looking at the efficiency of these two variations. In the case of Slotted Aloha, frames will be sent only at the beginning of a time slot, frames take an entire time slot to send, and the clocks of all nodes are synchronized.

Please round all answers to 2 decimal places.

Aloha protocol: Pure

(1) Given a probability of transmission p = 0.37, what is the maximum efficiency?

Hint: See section 6.3.2 in the text for more information on how to calculate the efficiency of the aloha protocol

(2) Given a probability of transmission p = 0.72, what is the maximum efficiency?

Hint: See section 6.3.2 in the text for more information on how to calculate the efficiency of the aloha protocol

Aloha protocol: Slotted

(1) Given a probability of transmission p = 0.37, what is the maximum efficiency?

Hint: See section 6.3.2 in the text for more information on how to calculate the efficiency of the aloha protocol

(2) Given a probability of transmission p = 0.72, what is the maximum efficiency?

Hint: See section 6.3.2 in the text for more information on how to calculate the efficiency of the aloha protocol

6.4 Random Access Protocols: Collisions

Consider the figure below, which shows the arrival of 8 messages for transmission at different multiple access wireless nodes at times $t = < 0.2, 0.4, 1.2, 2.6, 2.7, 3.2, 3.6, 4.2 >$ and each transmission requires exactly one time unit.

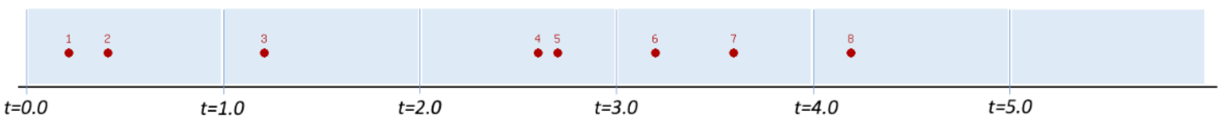


Figure 6.4: The arrival of 8 messages for transmission

Protocol: Aloha

(1) Suppose all nodes are implementing the Aloha protocol. For each message, indicate the time at which each transmission begins. Separate each value with a comma and no spaces.

Hint: For more information on the Aloha protocol(s), see chapter 6.3.2 in the text.

(2) Which messages transmit successfully? Write your answer as a comma seperated list with no spaces using the messages' numbers

Hint: For more information on the Aloha protocol(s), see chapter 6.3.2 in the text.

Protocol: Slotted-Aloha

(1) Suppose all nodes are implementing the Slotted Aloha protocol. For each message, indicate the time at which each transmission begins. Separate each value with a comma and no spaces.

Hint: For more information on the Aloha protocol(s), see chapter 6.3.2 in the text.

(2) Which messages transmit successfully? Write your answer as a comma seperated list with no spaces using the messages' numbers

Hint: For more information on the Aloha protocol(s), see chapter 6.3.2 in the text.

Protocol: CSMA

(1) Suppose all nodes are implementing Carrier Sense Multiple Access (CSMA), but without collision detection. Suppose that the time from when a message transmission begins until it is beginning to be received at other nodes is 0.4 time units. (Thus if a node begins transmitting a message at t=2.0 and transmits that message until t=3.0, then any node performing carrier sensing in the interval [2.4, 3.4] will sense the channel busy.) For each message, indicate the time at which each message transmission begins, or indicate that message transmission does not begin due to a channel that is sensed busy when that message arrives. Separate each value with a comma and no spaces, and if the channel is sensed busy, substitute it with 's'

Hint: For more information on the CSMA(/CD) protocol, see chapter 6.3.2 in the text.

(2) Which messages transmitted successfully? Write your answer as a comma seperated list with no spaces using the messages' numbers

Hint: For more information on the CSMA(/CD) protocol, see chapter 6.3.2 in the text.

Protocol: CSMA-CD

(1) Suppose all nodes are implementing Carrier Sense Multiple Access (CSMA), with collision detection (CSMA/CD). Suppose that the time from when a message transmission begins until it is beginning to be received at other nodes is 0.4 time units, and assume that a node can stop transmission instantaneously when a message collision is detected. (Thus if a node begins transmitting a message at t=2.0 and transmits that message until t=3.0, then any node performing carrier sensing in the interval [2.4, 3.4] will sense the channel busy.) For each message, indicate the time at which each message transmission begins, or indicate that message transmission does not begin due to a channel that is sensed busy when that message arrives. Separate each value with a comma and no spaces, and if the channel is sensed busy, substitute it with 's'

Hint: For more information on the CSMA(/CD) protocol, see chapter 6.3.2 in the text.

(2) Which messages transmitted successfully? Write your answer as a comma seperated list with no spaces using the messages' numbers

Hint: For more information on the CSMA(/CD) protocol, see chapter 6.3.2 in the text.

(3) At what time did each message stop transmitting due to a collision. Write your answer as a comma seperated list with no spaces using the messages' numbers in order, and if a message didn't stop, write 'x' for that message

Hint: For more information on the CSMA(/CD) protocol, see chapter 6.3.2 in the text.

6.5 Link Layer (and network layer) addressing, forwarding

Consider the figure below. The IP and MAC addresses are shown for nodes A, B, C and D, as well as for the router's interfaces.

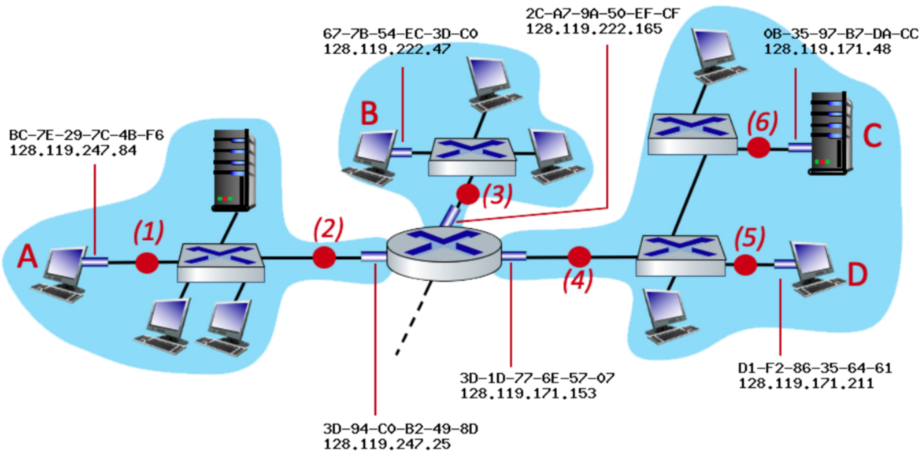


Figure 6.5: The IP and MAC addresses

Consider an IP datagram being sent from node C to node A.

(1) What is the source mac address at point 6?

Hint: Use the diagram to find the mac address of the source

(2) What is the destination mac address at point 6?

Hint: Use the diagram to find the mac address of the router's relevant link

(3) What is the source IP address at point 6?

Hint: Use the diagram to find the IP address of the source

(4) What is the destination IP address at point 6?

Hint: Use the diagram to find the IP address of the destination

(5) Do the source and destinaton mac addresses change at point 4? Answer with yes or no.

Hint: Datagrams can be sent to any host on the same subnet via the link layer

(6) Do the source and destinaton mac addresses change at point 2? Answer with yes or no.

Hint: Datagrams can be sent to any host on the same subnet via the link layer

(7) What is the source mac address at point 2?

Hint: Use the diagram to find the mac address of the router's relevant link

(8) What is the destination mac address at point 2?

Hint: Use the diagram to find the mac address of the destination

(9) Do the source and destinaton mac addresses change at point 1? Answer with yes or no.

Hint: Datagrams can be sent to any host on the same subnet via the link layer

6.6 Learning Switches - Basic

Consider the LAN below consisting of 10 computers connected by two self-learning Ethernet switches. (You may want to re-read section 6.4.3 in the 8th edition textbook). At t=0 the switch table entries for both switches are empty. At t = 1, 2, 3, and 4, a source node sends to a destination node as shown below, and the destination replies immediately (well before the next time step).

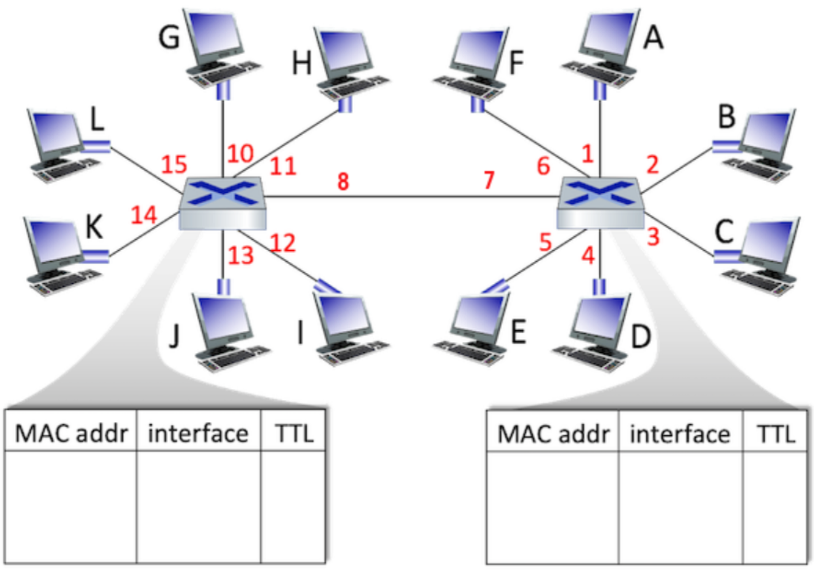


Figure 6.6: LAN connected by two self-learning Ethernet switches.

Assume that the following transmissions occur (the transmissions in reply occur but are not shown in the list below):

$t = 1 : I- > F$
$t = 2 : J- > H$
$t = 3 : L- > I$
$t = 4 : L- > H$

Fill out the two switch tables and answer the questions below.

(1) At t=1, what is the source entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(2) At t=1, what is the destination entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(3) At t=1, what is the source entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(4) At t=1, what is the destination entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(5) At t=2, what is the source entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(6) At t=2, what is the destination entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(7) At t=2, what is the source entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(8) At t=2, what is the destination entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(9) At t=3, what is the source entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(10) At t=3, what is the destination entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(11) At t=3, what is the source entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(12) At t=3, what is the destination entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(13) At t=4, what is the source entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(14) At t=4, what is the destination entry for switch 1? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 1, then use the value in the picture, otherwise the interface will be '7'.

(15) At t=4, what is the source entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

(16) At t=4, what is the destination entry for switch 2? Format your answer as letter,number or 'n/a'

Hint: If the host is on switch 2, then use the value in the picture, otherwise the interface will be '8'.

6.7 Learning Switches - Advanced

Consider the LAN below consisting of 10 computers connected by two self-learning Ethernet switches. (You may want to re-read section 6.4.3 in the text). At t=0 the switch table entries for both switches are empty. At t = 1, 2, 3, 4, 5, 6, 7, 8, and 9, a source sends to a destination as shown below, and the destination replies immediately (well before the next time step).

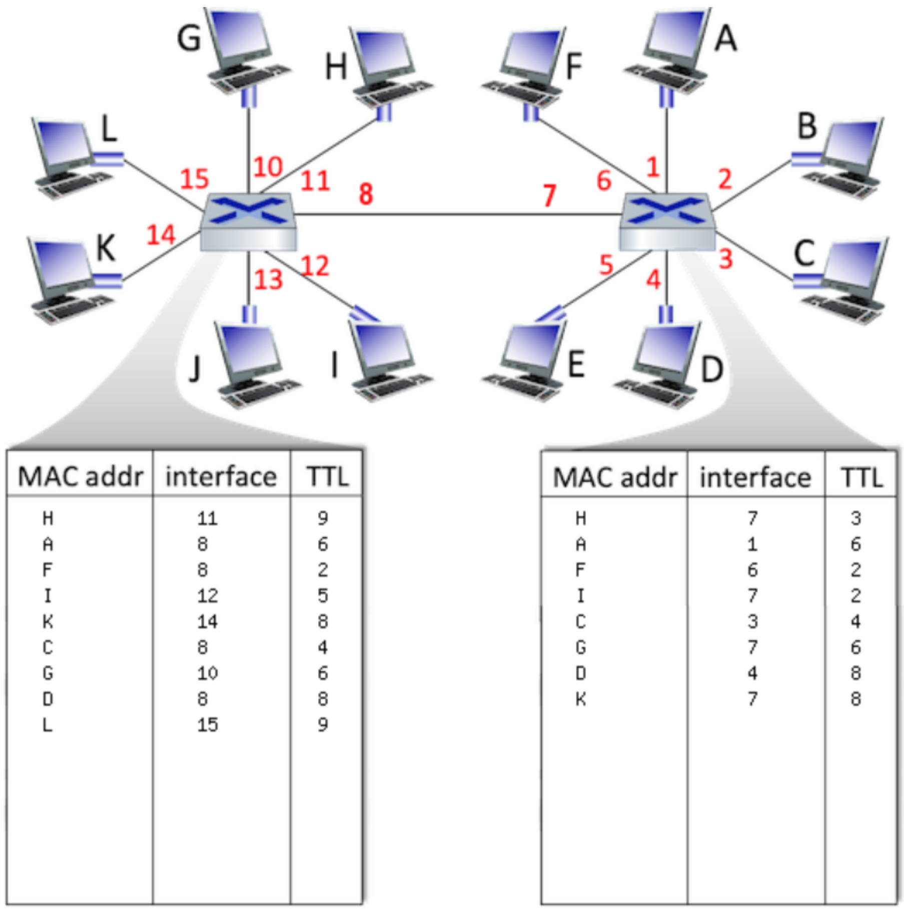


Figure 6.7: LAN connected by two self-learning Ethernet switches

(1) At t=1, what two nodes communicated? Write your answer in alphabetical order as x,y (If there is only enough information for 1 node, write that, and if there's no information, write 'n/a')

Hint: Look at the 'TTL' value between the two switch tables and correlate the two nodes that communicated

(2) At t=2, what two nodes communicated? Write your answer in alphabetical order as x,y (If there is only enough information for 1 node, write that, and if there's no information, write 'n/a')

Hint: Look at the 'TTL' value between the two switch tables and correlate the two nodes that communicated

(3) At t=4, what two nodes communicated? Write your answer in alphabetical order as x,y (If there is only enough information for 1 node, write that, and if there's no information, write 'n/a')

Hint: Look at the 'TTL' value between the two switch tables and correlate the two nodes that communicated

(4) At t=3, what two nodes communicated? Write your answer in alphabetical order as x,y (If there is only enough information for 1 node, write that, and if there's no information, write 'n/a')

Hint: Look at the 'TTL' value between the two switch tables and correlate the two nodes that communicated

CHAPTER 7: WIRELESS AND MOBILE NETWORKS

7.1 CDMA - Basic

Imagine a scenario where a sender and receiver using CDMA (Section 7.2.1 from the text) are exchanging data. Assume both the sender and receiver use a CDMA code of size 7, where M = 1, -1, 1, 1, 1, 1, 1.

(1) Given the CDMA code above and the bit d=1, what is the encoded output? Separate each value with a comma and no spaces

Hint: To calculate the output string, multiply each bit of the CDMA code by the input bit.

(2) Given the CDMA code above and the output string: -1,1,-1,-1,-1,-1,-1, what is the decoded bit value?

Hint: To calculate the original bit value, multiply each input bit by the respective CDMA code bit, sum these values and divide by the size of the CDMA code.

7.2 CDMA - Advanced

This time, assume there are 3 senders whom interfere with eachother and that the interfering transmitted bit signals are additive. The value received at a receiver, however, is now the sum of the transmitted bits from all senders.

Assume that sender 1 has a CDMA code of (-1, 1, 1, 1, -1, 1, 1, -1, -1), sender 2 has a CDMA code of (1, 1, 1, 1, 1, -1, -1, -1, -1), and sender 3 has a CDMA code of (-1, 1, -1, 1, 1, 1, -1, -1, 1) and their combined output is: (1, -3, -1, -3, -1, -1, 1, 3, 1)

(1) Assuming you are receiver 1, what is the decoded bit? If it can't be done, answer with 'n/a'

Hint: Assuming the CDMA code was chosen 'well', follow the same steps as normal to decode the bit value. If it isn't chosen well, then you'll end up with a non-integer

(2) Assuming you are receiver 2, what is the decoded bit? If it can't be done, answer with 'n/a'

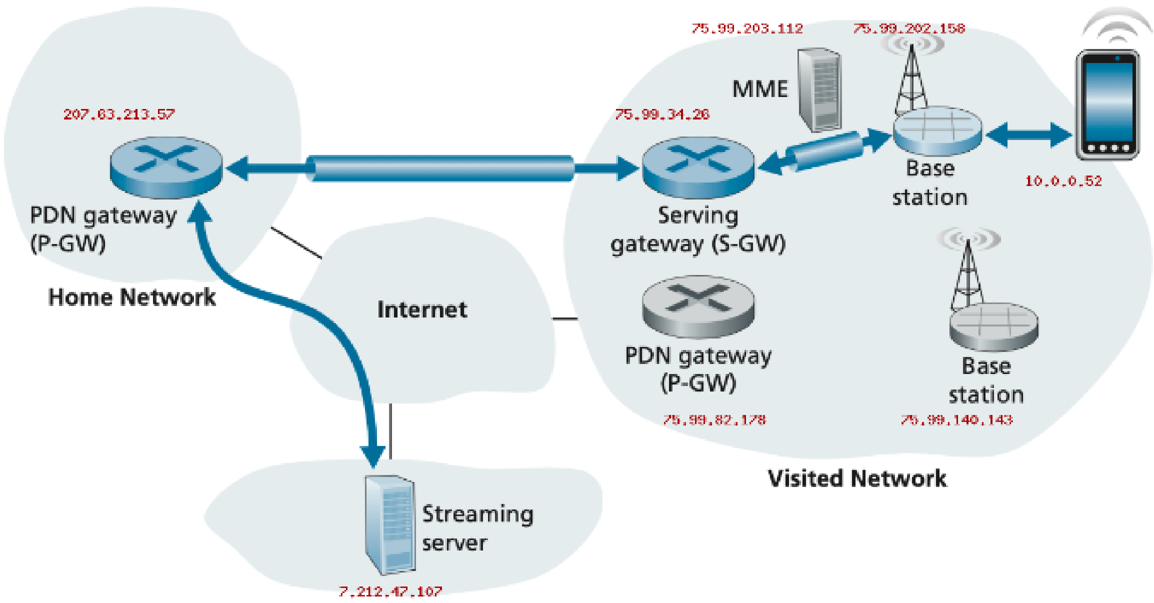
Hint: Assuming the CDMA code was chosen 'well', follow the same steps as normal to decode the bit value. If it isn't chosen well, then you'll end up with a non-integer

(3) Assuming you are receiver 3, what is the decoded bit? If it can't be done, answer with 'n/a'

Hint: Assuming the CDMA code was chosen 'well', follow the same steps as normal to decode the bit value. If it isn't chosen well, then you'll end up with a non-integer

7.3 4G Wireless Tunneling

In the graphic below, a mobile phone has a TCP connection with the streaming server using wireless 4G. Assume that both the mobile phone and the server use TCP port 9980 and any intermediary nodes that tunnel the datagrams use port 6734.



(1) What is the source IP address of the datagram sent from the mobile phone to the base station?

Hint: The source address will be where the datagram originates, unless there's a tunnel, then it's the tunnel's origin.

(2) What is the destination IP address of the datagram sent from the mobile phone to the base station?

Hint: The destination address will be where the datagram is going (not an intermediate mode), unless there's a tunnel, then it's the tunnel's exit.

(3) What is the transport-layer port number in the datagram sent from the mobile phone to the base station?

Hint: If not encapsulated, the datagram will have the streaming port; otherwise, it will be the tunneling port.

(4) What transport-layer protocol is indicated in the datagram sent from the mobile phone to the base station?

Hint: The mobile phone is using TCP to stream, but 4G tunnels use UDP

(5) Is there an encapsulated datagram within the datagram sent from the mobile phone to the base station? Answer Yes or No

Hint: If tunneling, there is an encapsulated datagram

(6) What is the source IP address of the datagram sent from the base station to the serving gateway?

Hint: The source address will be where the datagram originates, unless there's a tunnel, then it's the tunnel's origin.

(7) What is the destination IP address of the datagram sent from the base station to the serving gateway?

Hint: The destination address will be where the datagram is going (not an intermediate mode), unless there's a tunnel, then it's the tunnel's exit.

(8) What is the transport-layer port number in the datagram sent from the base station to the serving gateway?

Hint: If not encapsulated, the datagram will have the streaming port; otherwise, it will be the tunneling port.

(9) What transport-layer protocol is indicated in the datagram sent from the base station to the serving gateway?

Hint: The mobile phone is using TCP to stream, but 4G tunnels use UDP

(10) Is there an encapsulated datagram within the datagram sent from the base station to the serving gateway? Answer Yes or No

Hint: If tunneling, there is an encapsulated datagram

(11) What is the source IP address of the encapsulated datagram?

Hint: The source address will be where the datagram originates.

(12) What is the destination IP address of the encapsulated datagram?

Hint: The destination address will be where the datagram is going (not an intermediate mode).

(13) What is the transport-layer port number in the encapsulated datagram?

Hint: The datagram will have the streaming port.

(14) What transport-layer protocol is indicated in the encapsulated datagram?

Hint: The mobile phone is using TCP to stream.

(15) What is the source IP address of the datagram sent from the serving gateway to the PDN gateway?

Hint: The source address will be where the datagram originates, unless there's a tunnel, then it's the tunnel's origin.

(16) What is the destination IP address of the datagram sent from the serving gateway to the PDN gateway?

Hint: The destination address will be where the datagram is going (not an intermediate mode), unless there's a tunnel, then it's the tunnel's exit.

(17) What is the transport-layer port number in the datagram sent from the serving gateway to the PDN gateway?

Hint: If not encapsulated, the datagram will have the streaming port; otherwise, it will be the tunneling port.

(18) What transport-layer protocol is indicated in the datagram sent from the serving gateway to the PDN gateway?

Hint: The mobile phone is using TCP to stream, but 4G tunnels use UDP

(19) Is there an encapsulated datagram within the datagram sent from the serving gateway to the PDN gateway? Answer Yes or No

Hint: If tunneling, there is an encapsulated datagram

(20) What is the source IP address of the encapsulated datagram?

Hint: The source address will be where the datagram originates.

(21) What is the destination IP address of the encapsulated datagram?

Hint: The destination address will be where the datagram is going (not an intermediate mode).

(22) What is the transport-layer port number in the encapsulated datagram?

Hint: The datagram will have the streaming port.

(23) What transport-layer protocol is indicated in the encapsulated datagram?

Hint: The mobile phone is using TCP to stream.

(24) What is the source IP address of the datagram sent from the PDN gateway to the server?

Hint: The source address will be where the datagram originates, unless there's a tunnel, then it's the tunnel's origin.

(25) What is the destination IP address of the datagram sent from the PDN gateway to the server?

Hint: The destination address will be where the datagram is going (not an intermediate mode), unless there's a tunnel, then it's the tunnel's exit.

(26) What is the transport-layer port number in the datagram sent from the PDN gateway to the server?

Hint: If not encapsulated, the datagram will have the streaming port; otherwise, it will be the tunneling port.

(27) What transport-layer protocol is indicated in the datagram sent from the PDN gateway to the server?

Hint: The mobile phone is using TCP to stream, but 4G tunnels use UDP

(28) Is there an encapsulated datagram within the datagram sent from the PDN gateway to the server? Answer Yes or No

Hint: If tunneling, there is an encapsulated datagram

(29) Is data encrypted between the mobile phone and the base station? Answer Yes or No

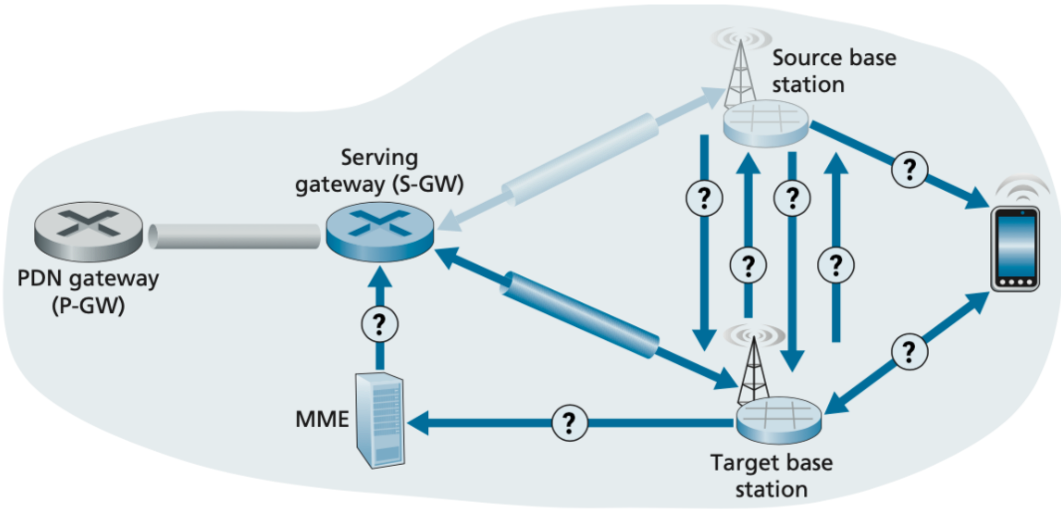
Hint: Base stations and mobile phones encrypt data sent between them.

(30) Does the server know about any of the wireless tunneling? Answer Yes or No

Hint: The destination only knows about the PDN gateway.

7.4 4G Wireless Handover

Consider the scenario, where a mobile phone connected to a base station (source) is streaming a video from the internet, and the mobile phone is going to switch to a closer base station (target) without interrupting their video stream. This process (called a handover) is shown in the diagram below.



Take a look at the statements below and put them in the correct order.

(A) The current (source) base station selects the target base station, and sends a Handover Request message to the target base station.

(B) The target base station informs the MME that it (the target base station) will be the new base station servicing the mobile device. The MME, in turn, signals to the Serving Gateway and the target base station to reconfigure the Serving- Gateway-to-base-station tunnel to terminate at the target base station, rather than at the source base station.

(C) At this point, the target base station can also begin delivering datagrams to the mobile device, including datagrams forwarded to the target base station by the source base station during handover, as well as datagrams newly arriving on the reconfigured tunnel from the Serving Gateway. It can also forward outgo- ing datagrams received from the mobile device into the tunnel to the Serving Gateway.

(D) The source base station will also stop forwarding datagrams to the mobile device and instead forward any tunneled datagrams it receives to the target base station, which will later forward these datagrams to the mobile device.

(E) The target base station checks whether it has the resources to support the mobile device and its quality of service requirements. If so, it pre-allocates channel resources (e.g., time slots) on its radio access network and other resources for that device. This pre-allocation of resources frees the mobile device from having to go through the time-consuming base-station association protocol discussed earlier, allowing handover to be executed as fast as possible. The target base station replies to the source base station with a Handover Request Acknowledge message, containing all the information at the target base station that the mobile device will need to associate with the new base station.

(F) The source base station receives the Handover Request Acknowledgement message and informs the mobile device of the target base station's identity and channel access information. At this point, the mobile device can begin send- ing/receiving datagrams to/from the new target base station. From the mobile device's point of view, handover is now complete! However, there is still a bit of work to be done within the network.

(G) The target base station confirms back to the source base station that the tunnel has been reconfigured, allowing the source base station to release resources associated with that mobile device.

Answer the following:

(1) Which lettered step (A-G) above corresponds to the first step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.

(2) Which lettered step (A-G) above corresponds to the second step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.

(3) Which lettered step (A-G) above corresponds to the third step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.

(4) Which lettered step (A-G) above corresponds to the fourth step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.

(5) Which lettered step (A-G) above corresponds to the fifth step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.

(6) Which lettered step (A-G) above corresponds to the sixth step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.

(7) Which lettered step (A-G) above corresponds to the seventh and final step in the handover process?

Hint: Take a look at section 7.6.1 in the text for information on 4G handovers.