Instructions

Record your answers in a file called hw2.pdf. Make sure to write your name and SID at the top of your assignment. For each problem, clearly indicate your final answer, bold and underlined. You do not need to explain your answer unless explicitly told to do so. Submit your answers via your instructional account using submit hw2.

Use the following in your calculations:

- 1B (byte) = 8b (bits)
- 1k = 10^3

Questions? Post on piazza, or email Andrew (andrewor at berkeley) or Steve (steve.wang at berkeley)!

Change Log

10/17

Q3: Added additional assumption - Receiver application buffers out-of-order packets
Q2: Clarify that only the path from A to B must satisfy the given property
Q5g: Change “after the 25th RTT” to “on the 26th RTT”

10/18

Q3a: Added additional assumption – Negligible ACK size
Q5b: Remove “AIMD” from the question, which directly conflicts with “congestion avoidance”
Q5g: Specify more precisely when the duplicate ACKs arrive
Q1 – IP Addressing and Forwarding (5pt)

A new era has dawned upon us. This is the age of intergalactic battles, and you are the chief network advisor to the Commander of Earth. But first, let’s look at some forwarding tables.

The following is the forwarding table of router R1 that is connected to other routers, R2 – R6. Assume the router does longest prefix match.

<table>
<thead>
<tr>
<th>Subnet Number</th>
<th>Next Hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.96.39.0/25</td>
<td>R2</td>
</tr>
<tr>
<td>128.96.39.0/27</td>
<td>R3</td>
</tr>
<tr>
<td>128.96.40.0/25</td>
<td>R4</td>
</tr>
<tr>
<td>192.4.153.0/26</td>
<td>R5</td>
</tr>
<tr>
<td>(default)</td>
<td>R6</td>
</tr>
</tbody>
</table>

How will the router handle packets addressed to each of the following destinations?

(a) 128.96.40.12
(b) 128.96.39.10
(c) 128.96.39.48
(d) 192.4.153.17
(e) 192.4.153.90
Q2 – RIP vs BGP Routing (10pt)

The Commander has assigned a new mission to you. You are tasked with designing the placement of routers grouped into autonomous systems (AS) that satisfy the following: The shortest path from router A to router B visits the same AS twice.

By visit the same AS twice, we mean the path includes a hop in a particular AS, leaves this particular AS, and returns to it later. By shortest path, we mean the path with the fewest number of hops (i.e. all link weights are 1).

Here is an example that doesn’t work:

In the topology above, the shortest path from A to B in terms of ASes is 1 → 2 → 3, which doesn’t visit the same AS twice. Instead, what we want is something like 1 → 3 → 2 → 3.

(a) (4pt) Draw a topology of routers grouped into ASes that satisfies the above property for the path from A to B. You may use no more than 10 routers and 5 ASes. Clearly indicate the shortest path, both in terms of routers (e.g. A → C → D → B) and ASes (e.g. 1 → 2 → 3).

(b) (3pt) In your topology from part (a), what path would RIP choose from A to B? Explain. (That is, if we were to run RIP over the complete router topology, ignoring AS boundaries.)

(c) (3pt) In your topology from part (a), what path would BGP choose from A to B? Explain.

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1 Note that in real networks RIP is used for intra-AS routing, rather than inter-AS routing. In this problem, we relax this assumption.
Q3 – Reliable Transport (10pt)

The Commander has spoken again. Earth has negotiated a new alliance with Alderaan, and is in need of a new reliable transport protocol to communicate with our new ally. You are tasked with designing this as a sliding-window protocol. The bandwidth of this link is 160kbps in both directions, the latency is 125ms, and the maximum packet size is 1kB.

A few additional assumptions:

- No re-ordering and processing delays
- Sender application always has data to send
- Receiver application always picks up data right away
- Receiver application buffers out-of-order packets (that result from packet drops)

(a) (3pt) What is the **minimum sender window size** (in packets) that will allow you to take full advantage of the bandwidth? For this part only, assume maximum packet size, no packet loss, and negligible ACK size. **Justify your answer.**

*A number of students treated ACKs the same size as the packet. We also accept this answer, as long as your assumptions are stated clearly.*

(b) (3pt) After deciding the sender window size $W_S$ in part (a), you and your colleagues are debating how large to set the receiver window size $W_R$.

- **Luke:** $W_R = 1$ If there is no re-ordering of packets, then there is no benefit to setting $W_R > 1$.
- **Leia:** $W_R = W_S$ This gives better performance than $W_R = 1$. However, setting $W_R > W_S$ offers no advantages over $W_R = W_S$.
- **Han:** $W_R >> W_S$ The larger $W_R$ is, the higher the throughput. Hence, $W_R$ should be as large as possible.

Who is right? Circle the best answer, and **justify your choice.**
(c) **Han** now refines his argument. He suggests making $W_R$ as large as possible but using *selective acknowledgments* to avoid ever needing to retransmit a packet unnecessarily. Selective acknowledgments indicate any packets that have been successfully received after a lost packet. If, for instance, packets $P_1; P_2; P_4; P_5$ arrive, the receiver will acknowledge $P_2$, but in the acknowledgment indicate that $P_4$ and $P_5$ have also been received and do not need to be re-transmitted. Though the sender still cannot send packets beyond $P_2 + W_S$, it will know not to retransmit $P_4$ and $P_5$.

**Leia** then argues we can just use selective acknowledgement with $W_R=W_S$ for the same benefit.

**Luke** still thinks $W_R=1$ is sufficient.

Who is right? Circle the best answer, and *justify your choice*.

- **Luke**: $W_R = 1$  
  With selective acknowledgements and no re-ordering of packets, then there is no benefit to setting $W_R > 1$.

- **Leia**: $W_R = W_S$  
  This gives better performance than $W_R = 1$. However, setting $W_R > W_S$ offers no advantages over $W_R = W_S$ whether or not we use selective acknowledgements.

- **Han**: $W_R \gg W_S$  
  The use of selective acknowledgment allows us to use such larger windows because we continue to ack specific packets in the event of packet loss/corruption. The larger $W_R$ is, the higher the throughput. Hence, $W_R$ should be as large as possible.
Q4 – BGP Policy (5pt)

The Commander is devising an invasion strategy based on the enemy network’s communication patterns. You have mapped out the enemy’s network below, and in addition, you discover that they, just like Earth, also use standard BGP routing policies. In particular, they also follow the Gao-Rexford model, which includes valley-free routing.

Which paths are possible? *Circle ALL that are true.*

(a) x1 → X → Y → Z → z1
(b) x1 → X → U → W → Y → V → v1
(c) v1 → V → Y → Z → z1
(d) v1 → V → Y → Z → W → w1
(e) u1 → U → W → Y → y1
Q5 – TCP Congestion Control (8pt)

A new piece of intel has arrived. Your subordinates, putting their lives at risk, have retrieved the following graph from the enemy's base. Having recognized the shape of the graph instantly from EE122 many years ago, you conclude that the enemy is using TCP Reno (i.e. TCP with Fast Retransmit and Fast Recovery).

Assume that the TCP flow has been operating for some time, meaning the number of RTTs shown are with respect to when your subordinates started observing the flow's behavior.

a) (1pt) Identify the time periods when TCP slow start is operating.
b) (1pt) Identify the time periods when TCP congestion avoidance is operating.
c) (1pt) After the 14th RTT, is the segment loss detected by a triple duplicate ACK or by a timeout?
d) (1pt) What is the initial value of SSTHRESH, before the first congestion avoidance interval?
e) (2pt) What is the value of SSTHRESH at the 19th RTT?
f) (2pt) What is the value of SSTHRESH at the 24th RTT?
g) (Extra credit, 3pt) In the beginning of the 26th RTT (immediately after the CWND = 8), three duplicate ACKs were received. What will the values of the CWND and SSTHRESH after the third duplicate ACK?

A number of students treated the duplicate ACKs as occurring immediately before the end of the 26th RTT. We accept both answers, as long as your assumptions are stated clearly.
The Commander suspects that an enemy is spying on our communication with Alderaan. To find out, you decide to use traceroute, a program that traces the path (a sequence of routers) a packet follows to a destination.

(a) (2pt) In no more than two sentences, explain how traceroute works.

(b) (2pt) Use traceroute from a UCB machine to record the path taken to 216.81.59.173, the IP address of Alderaan’s planet gateway router. Attach a printout of the traceroute output.

If traceroute is not installed, try /usr/sbin/traceroute. Make sure to set the max hops to at least 64 using the –m option.

(c) (3pt) What are the ASes traversed, and in what order? For each AS, list the <AS Number, Organization Name>.

Hint: You may find the following commands useful
whois -h radb.ra.net [IP address]
whois -h whois.arin.net [AS number]

If OSX is available, use the –a option on traceroute; you won’t regret it.

(d) (3pt) What are the ISPs traversed, and in what order? Stop once you reach AS 21513.

Hint: Look at the router names and try to visit the corresponding website. The ISPs are often, but not always, identified by the router names. Just list as many as you can.

(e) (2pt) In your trace you encounter rows with three asterisks ***. What is going on? What might have caused it? (No star wars references!)