###### *CSE 473 – Introduction to Computer Networks Roch Guérin*

Midterm Exam

##### *Your Name: 10/23/2017*

**Five (5) Problems for a total of 100 points**

1. **[25 points]** A New York hospital has deployed a system that allows doctors to view patient records and X-rays remotely using a web browser. Patient records and X-Rays are stored in an off-site data center reachable from the hospital over a dedicated 1 Gbps (109 bits/sec) link with a roundtrip propagation of 2ms (0.002 sec). Because connectivity is over a dedicated link, the hospital and the data center have configured their TCP stacks to bypass slow-start entirely and start immediately with a full *cwnd*.
   1. **[5 points]** Assuming that both *cwnd* and *rcvWindow* are set to 128 kbytes (217 bytes), *i.e.,* they are scaled by a factor 2, what is the maximum achievable sustained transfer rate over a TCP connection between the hospital and the data center? Explain your answer.

* 1. **[5 points]**  Assume next as well as in subsequent questions that *cwnd* and *rcvWindow* have instead been scaled by a factor 8 and have, therefore, a maximum value of 512 kbytes (219 bytes). What is now the maximum transfer rate of a TCP connection? Explain your answer.

* 1. **[10 points]** Access to patient records is done over http 1.0, *i.e.,* non-persistent http, but download of objects (X-rays) embedded in a patient’s record is done using parallel TCP connections, one per object. Consider a patient record that is 256 kbytes (218 bytes) with two (2) embedded X-rays, each 2 Mbytes (221 bytes) in size. How long will it take for a physician to download the patient record and its two (2) X-rays? Explain your answer.

* 1. **[5 points]** How would the answer change if the hospital and its data center had instead used http 1.1, *i.e.,* persistent http? Explain your answer.

1. **[20 points]**. Private network A uses the 10.1.0.0/16 private address space and connects to the Internet using a PAT/NAT router (Ra) with public IP address 65.5.4.15. Private network B also uses the 10.1.0.0/16 private address space and connects to the Internet using a PAT/NAT router (Rb) with public IP address 142.3.7.45. Assume a host with address 10.1.1.1 in private network A has four parallel TCP connections to port 80 on a host with the same private address 10.1.1.1 in private network B. The four connections have source port numbers 50551 to 50554.
2. **[3 points]** What is the IP address carried in the destination address field of packets leaving host 10.1.1.1 in private network A on those 4 connections, and similarly what is this destination address when those packets leave router Ra? Justify your answer.

1. **[5 points]** Describe possible entries present in Ra and Rb as a result of those four connections, and state explicitly how many entries there are in each router.

1. **[5 points]** Using notation consistent with your answer in the previous question and focusing on the connection with source port number 50551 from host 10.1.1.1 in private network A, give the source and destination addresses and port numbers for packets that (i) leave host 10.1.1.1 in private network A, (ii) leave router Ra, (iii) reach host 10.1.1.1 in private network B; and conversely for packets in the reverse direction from host 10.1.1.1 in private network B to host 10.1.1.1 in private network A (for a total of six (6) distinct packet headers). Use the format <destAddr, destPort; srcAddr, srcPort> in your answer.

1. **[2 points]** Assume next that host 10.1.1.2 in private network A also opens four connections to port 80 on host 10.1.1.1 in private network B. What is the IP address carried in the destination address field of packets arriving at router Rb on those four connections? Justify your answer.

1. **[5 points]** How many new entries, if any, would these four connections create on Ra and Rb? Justify your answer.
2. **[25 points]** Consider a circular DHT with 1024 nodes/servers and hash values in the range [0,2128–1]. A key with hash value *h* is assigned to the node whose ID is *closest* to *h*, where closest is defined as “immediate successor” under modulo operation. Assume that the first node to join the DHT is assigned ID 0, and initially owns the entire range of hash values. Subsequent nodes that join are assigned the lower half of the hash range of the node they contact to join the DHT, with their ID being the upper bound of that range. For example, if the DHT had only two nodes with IDs 0 and 2127, respectively, the node with ID 0 would be the owner of any key with hash values in the range [2127+1, 2128 = 0], and node 2127 would own [1, 2127].
3. **[10 points]** Consider the first four nodes to join after node 0, and assume that they all join by contacting node 0. What are the IDs and hash value ranges for those four nodes after they have joined, and what is the remaining hash value range for node 0 after the four nodes have joined?

1. **[10 points]** Assume next that the 1024 (210) nodes of the DHT have been added so that they are evenly distributed across the range of hash values, *i.e.,* they each have a range of 2128/210 = 2118 hash values, with corresponding IDs of 0, 2118, 2x2118, 3x2118 … Each node is configured with one shortcut that connects them to the node furthest away from them on the ring, *e.g.,* node 0 has a shortcut to node with ID 512x2118 = 29x2118 = 2127. Consider now that node 0 receives a request for a key with hash value 2126+2125. Through how many nodes will the request goes through before the answer is sent back to node 0? Justify your answer.

1. **[5 points]** Nodes maintain caches to previous answers so that on average a node can answer a query for a key it does not own with a 10% probability. Consider a request that arrives at node 0 for a key that is owned by node 5x2118. What is the expected number of hops the query will go through? Justify your answer

1. **[10 points]** Two audio clients, A and B, are using 16 kbps codecs, and are connected over a packet network as shown below, *i.e.,* four routers R1 to R4 connected by 10 Gbps links and access links that run at 10 Mbps. The end-to-end one way propagation delay is 15ms.

R1

R2

R3

R4

10Mbps

10Gbps

10Gbps

10Gbps

10Mbps

Assuming that packets travelling from either A to B or B to A see on average queue sizes of about *512* kBytes (a kBytes = 1024 bytes) at each router, and that the audio application they use tolerates a one way average delay of approximately 100ms, what is the maximum packet payload size that the codecs can use? (Ignore the transmission times of the audio packet itself).

1. **[20 points]** Consider two TCP connections that share a common bottleneck link of speed 100 Mbps. Both use TCP Reno with a standard *rcvWindow* size of 64 kBytes and have disabled delayed ACKs. The MSS on both paths is such that the maximum payload size of a TCP packet is 1 kBytes, *i.e.,* 1024 bytes. Connection 1 has an RTT value of 5ms, while connection 2 has an RTT of 10ms.
   1. **[10 points]** Assume that connection 1 was initially the only one active and that it had reached a *cwnd* value of 64 kbytes, which therefore saturates the bottleneck link capacity. Explain why this is the case **[5 points],** and consequently how much data is approximately stored in the router’s buffer **[5 points]**. Justify your answer. (Ignore the impact of IP and TCP headers).

* 1. **[5 points]** Assume next that connection 2 becomes active and that it starts with a value of *ssthresh* = 32kbytes, and that both connection 1 and connection 2 experience a loss right after connection 2 enters the congestion avoidance phase. What are the values of *cwnd1* and *cwnd2* after their respective connections exit the fast recovery phase following the loss and re-enter congestion avoidance? Justify your answer.
  2. **[5 points]** Once connection 1 and connection 2 reach steady state, what will approximately be their respective average transfer rates? Justify your answer.