You are allowed 1 hour to complete this exam.
(i) This exam is closed book and closed notes. However, you may refer to a sheet of 8.5"x11" paper (single-sided) of your own design.
(ii) Write your solution directly onto this exam. Be sure to write your name and student ID clearly on the front of the exam.
(iii) Don’t panic! Be sure to start by reading the exam all the way through. Then answer the questions in whatever order you choose.
(iv) Show your reasoning clearly. If your reasoning is correct, but your final answer is wrong, you will receive most of the credit. If you just show the answer without reasoning, and your answer is wrong, you may receive no points at all.

The Stanford Honor Code
In accordance with both the letter and spirit of the Honor Code, I didn't cheat on this exam.

Signature: ____________________________________________
Short Multiple Choice Questions.

Instructions: in the following questions, check all listed assertions that appear to be correct. There is at least one correct assertion per question, but there may be more. Each correct assertion checked will earn you one point. For each incorrect assertion you check, you will lose one point. If you don’t know an answer, checking no assertion will neither earn you nor lose you any points.

1. **IP.** During normal IP packet forwarding by a router, which of the following packet fields are updated?
   (a.) IP header Source address
   (b.) IP header Destination address
   (c.) IP header TTL
   (d.) IP header checksum
   (e.) Destination UDP address
   (f.) Destination UDP port number

2. **IP addresses.** You are given the following network prefixes:
   171.64.121.0/24   171.64.180.0/24
   171.64.18.0/24    171.64.181.0/24
   171.64.19.0/24    171.64.187.0/24

   You are to aggregate the prefixes together into the smallest possible number of shorter prefixes. What is the smallest number of prefixes, and what are they?
   (a.) 1 prefix; 171.64.179.0/21
   (b.) 2 prefixes; 171.64.180.0/20, 171.64.18.0/21
   (c.) 4 prefixes; 171.64.180.0/23, 171.64.187.0/24, 171.64.121.0/24, 171.64.18.0/23
   (d.) 2 prefixes; 171.64.179.0/22, 171.64.183.0/24
   (e.) 3 prefixes 171.64.180.0/20, 171.64.187.0/24, 171.64.18.0/23

3. **Longest Prefix Match Lookups.** Which of the following are true:
   (a.) 171.64.128/16 cannot be a prefix because it is a Class B address.
   (b.) If a routing table contains prefixes 31.75/16 (for which packets are sent to port 1) and 31.75.93.128/25 (for which packets are sent to port 2) then an arriving packet with IP address 31.75.93.129 will be sent to port 2.
   (c.) A routing table can correctly contain the two prefixes 128.50.128/17 and 128.50.128/18 simultaneously.
   (d.) If a routing table is organized in order of increasing prefix length, then a routing decision may be performed by finding the last matching prefix.
4. **TCP.** Which of the following are true statements about TCP:
   (a.) A source’s retransmission timeout value (RTO) is always set equal to the measured RTT. Setting RTO < the measured RTT may lead to unnecessary retransmissions.
   (b.) A source’s retransmission timeout value is set to a value that increases with the variance in measured RTT values.
   (c.) RTO is picked randomly when a TCP connection starts, and remains fixed for the duration of the flow.

5. **Queues.** You notice that the packets you send to your friend always follow the same path and take a minimum of 100ms to reach her, with a variation in delay from 100-150ms, and an average of 125ms. You send an average of 100 new packets per second, and none of them are dropped. What is a good estimate of the average number of your packets buffered in routers along the path?
   (a.) 125
   (b.) 2.5
   (c.) 100
   (d.) 12.5
   (e.) There isn’t enough information in the question to make a good estimate.

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**Long Multiple Choice Questions.**

**Instructions:** in the following questions, check all listed assertions that appear to be correct. There is at least one correct assertion per question, but there may be more. Each correct assertion checked will earn you two points. **For each incorrect assertion you check, you will lose one point.** If you don’t know an answer, checking no assertion will neither earn you nor lose you any points.

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**For questions 6-14.** The National Security Agency wants to monitor all of the Internet traffic passing through a big routing center in Denver, Colorado. The routing center has 14 bidirectional links connecting it to neighboring routing centers around the nation (**Hint:** Be sure to remember that there are 14 links when answering the questions below!). All of the links have a data-rate of 10Gb/s and we will assume that they are 50% loaded; in other words, they operate at an effective data rate of 5Gb/s. We will assume that each flow has an average of 14 packets and the average packet size is 250bytes. We will further assume that the client for each flow is connected to the Internet via a 1Mb/s DSL link, that each client is sending or receiving at-most one flow at a time, and that the flows keep the DSL link 90% busy, on average, for the duration of the transfer. You can assume that flows start instantly, and operate at the same rate for the duration of the flow (i.e. you can ignore the congestion control and window-size mechanism of TCP).
6. On average, how many packets arrive per second to the routing center?
   (a.) 35M  
   (b.) 38,000  
   (c.) 2.5M  
   (d.) 333,330

7. When measured at the routing center, what is the duration of a flow, on average, in seconds?
   (a.) 43ms  
   (b.) 31ms  
   (c.) 28ms  
   (d.) 528 microseconds

8. How many flows, on average, are in progress at the routing center at a time?
   (a.) 5556  
   (b.) 2885  
   (c.) 77,784  
   (d.) 177,488

9. How often does a new flow start, on average?
   (a.) 400ns  
   (b.) 200ms  
   (c.) 1.8ms  
   (d.) We don’t have enough information to know

10. If it takes 100 CPU instructions, on average, to process each 32-bit word of data, (and one instruction is executed per cycle), how fast (in GHz) must the CPU run in order to process and examine every packet?
    (a.) About 2GHz  
    (b.) About 20GHz  
    (c.) About 200GHz  
    (d.) About 2000 GHz  
    (e.) We don’t have enough information to know.

11. If it was possible to perfectly load-balance the traffic over multiple computers, how many 3GHz computers would be needed?
    (a.) About 1000  
    (b.) Just 1  
    (c.) About 75  
    (d.) We don’t have enough information to know.

12. If the computer was to capture and store every packet header on a disk drive, how many Terabytes would it accumulate per day? Assume that a packet header (including a timestamp that is written to disc with the packet) is 64 bytes long.
    (a.) 190 Tbytes per day  
    (b.) 1.9 Gbytes per day  
    (c.) 190 Gbytes per day  
    (d.) 68 Gbytes per day

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13. How fast would the computer need to write to the disk drive (in Megabytes per second)?
   (a.) 2,200 kbytes per second
   (b.) 2,400 Gbytes per second
   (c.) 2,240 Mbytes per second
   (d.) 64 Gbytes per second

14. If the packet headers were written to multiple disk-drives in parallel, how many
    50Mbyte/second disk drives would be needed?
   (a.) 45
   (b.) 220
   (c.) 1
   (d.) 24
   (e.) 1466

**Longer questions**

15. **Routing.** Use Dijkstra’s shortest path first algorithm to find the shortest path from computer A to
    every other computer in the network below. At each stage of the algorithm, clearly show the
    “candidate set” and the “shortest path” set. Assume all the links are bidirectional and symmetric
    (i.e. the cost of using a link is the same in both directions).
16. **Security.** A network attacker from Berkeley is trying to break into an ongoing TCP connection between two well-behaved researchers at Stanford (web client machine S1 and http-server S2). Fortunately, TCP makes it quite hard to break in, because both ends pick a random initial sequence number for data they send over the connection.

   (a.) The attacker sends an IP datagram to host S2 with spoofed source address S1. She creates a TCP packet with the correct destination port (dport) and guesses the correct source port (sport) number to use.

      (i.) What is the probability that she will guess the right value? (TCP port numbers are 16-bits long).

      (ii.) If she guesses the value incorrectly, what will happen to the packet?
(b.) Given that sequence numbers are 32 bits, what is the probability that a single malicious packet, with random sequence number, contains the correct next sequence number?

(c.) Given that the receiver advertises a “Receiver Window Size”, what is a reasonable estimate of the range of sequence numbers that the receiver will accept? What is the probability that the attacker will guess an acceptable sequence number?

(d.) Long-lived TCP connections (such as BGP connections) are also vulnerable to so-called “RST spoofing” in which an attacker sends a RST packet spoofed to be from one sender to the receiver with a randomly generated sequence number. If the sequence falls within the TCP window, the connection will be dropped.

Assume a TCP flow with a window size of 16K.

(i.) What is the expected number of tries before a RST with randomly generated sequence lands in window?
(ii.) How long would it take to generate this many packets from a 10Mb/s connection?

(iii.) Router vendors issued a patch to try and prevent this type of attack. Describe a method they could use to fix the problem.

17. General. Ixflent is a company that rents DVDs by mail: Users order DVDs on-line and they are delivered by regular mail (i.e. the US Postal Service). In this question, we’ll try and estimate the average data-rate delivered by Ixflent to its users (and back again, assuming they return their DVDs!).

We’ll assume a DVD holds $D$ bytes of useful video data, and that Ixflent keeps an inventory of $T$ movies, they have $S$ subscribers who each rent an average of $V$ new videos per week.

(a.) Write down an expression for the average data-rate (in bits per second) of videos delivered by Ixflent to a customer.

(b.) Write down an expression for the average data-rate (in bits per second) of videos delivered by Ixflent to all its users combined.
(c.) If Ixflent has 5 million subscribers – who rent an average of 2 new movies per week – 50,000 titles, and a DVD holds 1Gbyte of useful video data, evaluate your answers to (a) and (b).

Now imagine that Ixflent sent its users a disc drive with all $T$ movies, and then “trickle fed” the disc drive over the network to top it up with new titles. Assume that $N$ new movies are added to every user’s disc drive per week, so they don’t need to stream the movies over the web in real-time.

(d.) If it cost the customer $c per bit to download files, write down an expression for the monthly download cost.

(e.) If disc-drives cost $d per bit of storage, then write down an expression of the cost of a disc drive that would be large enough for two more years of service.

(f.) If it costs $C per bit to download videos in real-time, write down an expression for the value of $C$ so that it is cheaper to download videos than trickle-feed them to the user’s disc drive (again, assuming it’s large enough for two more years of service).

(g.) Evaluate your answer in (f) if we assume the values in (c) above, and further assume there are 100 new titles per week, it costs $0.01 per Megabyte to download files, and $0.02 per Megabyte to download video in real-time, and a disc-drive is $100 per Terabyte.