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6.02 Practice Problems: Packet and Circuit Switching, and Little's Law

Please read Chapter 16 and solve the problems at the end of that chapter too.

Problem 1. Little's Law.

A. At the supermarket a checkout operator has on average 4 customers and customers arrive every 2 minutes. How long must each customer wait in line on average?

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B. A restaurant holds about 60 people, and the average person will be in there about 2 hours. On average, how many customers arrive per hour? If the restaurant queue has 30 people waiting to be seated, how long does each person have to wait for a table?

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C. A fast-food restaurant uses 3,500 kilograms of hamburger each week. The manager of the restaurant wants to ensure that the meat is always fresh, i.e., the meat should be no more than two days old on average when used. How much hamburger should be kept in the refrigerator as inventory?

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Problem 2.

Calculate the latency (total delay from first bit sent to last bit received) for the following:

A. Sender and receiver are separated by two 1-Gigabit/s links and a single switch. The packet size is 5000 bits, and each link introduces a propagation delay of 10 microseconds. Assume that the switch begins forwarding immediately after it has received the last bit of the packet and the queues are empty.

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B. Same as (A) with three switches and four links.

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Problem 3.

Network designers generally attempt to deploy networks that don't have single points of failure, though they don't always succeed. Network topologies that employ redundancy are of much interest.

A. Draw an example of a six-node network in which the failure of a single link does not disconnect the entire network (that is, any node can still reach any other node).

B. Draw an example of a six-node network in which the failure of any single link cannot disconnect the entire network, but the failure of some single node does disconnect it.

C. Draw an example of a six-node network in which the failure of any single node cannot disconnect the entire network, but the failure of some single link does disconnect it.

Note: Not all the cases above may have a feasible example.

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Problem 4.

Under what conditions would circuit switching be a better network design than packet switching?

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Problem 5.

Circuit switching and packet switching are two different ways of sharing links in a communication network. Indicate True or False for each choice.

A. Switches in a circuit-switched network process connection establishment and tear-down messages, whereas switches in a packet-switched network do not.

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B. Under some circumstances, a circuit-switched network may prevent some senders from starting new conversations.

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C. Once a connection is correctly established, a switch in a circuit-switched network can forward data correctly without requiring data frames to include a destination address.

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D. Unlike in packet switching, switches in circuit-switched networks do not need any information about the network topology to function correctly.

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Problem 6.

Consider a switch that uses time division multiplexing (rather than statistical multiplexing) to share a link between four concurrent connections (A, B, C, and D) whose packets arrive in bursts. The link's data rate is 1 packet per time slot. Assume that the switch runs for a very long time.

A. The average packet arrival rates of the four connections (A through D), in packets per time slot, are 0.2, 0.2, 0.1, and 0.1 respectively. The average delays observed at the switch (in time slots) are 10, 10, 5, and 5. What are the average queue lengths of the four queues (A through D) at the switch?

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B. Connection A's packet arrival rate now changes to 0.4 packets per time slot. All the other connections have the same arrival rates and the switch runs unchanged. What are the average queue lengths of the four queues (A through D) now?

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Problem 7.

Alyssa P. Hacker has set up eight-node shared medium network running the Carrier Sense Multiple Access (CSMA) MAC protocol. The maximum data rate of the network is 10 Megabits/s. Including retries, each node sends traffic according to some unknown random process at an average rate of 1 Megabit/s per node. Alyssa measures the network's utilization and finds that it is 0.75. No packets get dropped in the network except due to collisions, and each node's average queue size is 5 packets. Each packet is 10000 bits long.

A. What fraction of packets sent by the nodes (including retries) experience a collision?

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B. What is the average queueing delay, in milliseconds, experienced by a packet before it is sent over the medium?

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Problem 8.

Little's law can be applied to a variety of problems in other fields. Here are some simple examples for you to work out.

A. F freshmen enter MIT every year on average. Some leave after their SB degrees (four years), the rest leave after their MEng (five years). No one drops out (yes, really). The total number of SB and MEng students at MIT is N. What fraction of students do an MEng?

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B. A hardware vendor manufactures $300 million worth of equipment per year (= invoice$/year). On average, the company has $45 million in accounts receivable (= invoice$). How much time elapses between invoicing and payment?

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C. While reading a newspaper, you come across a sentence claiming that "less than 1% of the people in the world die every year". Using Little's law (and some common sense!), explain whether you would agree or disagree with this claim. Assume that the number of people in the world does not decrease during the year (this assumption holds).

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D. (This problem is actually almost related to networks.) Your friendly 6.02 professor receives 200 non-spam emails every day on average. He estimates that of these, 50 need a reply. Over a period of time, he finds that the average number of unanswered emails in his inbox that still need a reply is 100.

    i. On average, how much time does it take for the professor to send a reply to an email that needs a response?

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    ii. On average, 6.02 constitutes 25% of his emails that require a reply. He responds to each 6.02 email in 60 minutes, on average. How much time on average does it take him to send a reply to any non-6.02 email?

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Problem 9.

You send a stream of packets of size 1000 bits each across a network path from Cambridge to Berkeley. You find that the one-way delay varies between 50 ms (in the absence of any queueing) and 125 ms (full queue), with an average of 75 ms. The transmission rate at the sender is 1 Mbit/s; the receiver gets packets at the same rate without any packet loss.

A. What is the mean number of packets in the queue at the bottleneck link along the path (assume that any queueing happens at just one switch).

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You now increase the transmission rate to 2 Mbits/s. You find that the receiver gets packets at a rate of 1.6 Mbits/s. The average queue length does not change appreciably from before.

B. What is the packet loss rate at the switch?

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C. What is the average one-way delay now?

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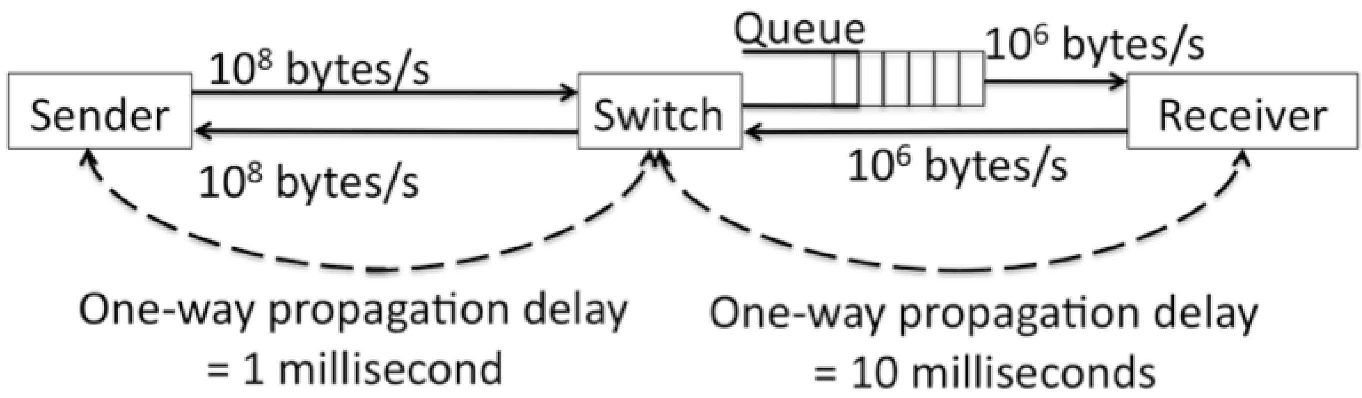
Problem 10.

Consider the network topology shown below. Assume that the processing delay at all the nodes is negligible.



A. The sender sends two 1000-byte data packets back-to-back with a negligible inter-packet delay. The queue has no other packets. What is the time delay between the arrival of the first bit of the second packet and the first bit of the first packet at the receiver?

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B. The receiver acknowledges each 1000-byte data packet to the sender, and each acknowledgment has a size A = 100 bytes. What is the minimum possible round trip time between the sender and receiver? The round trip time is defined as the duration between the transmission of a packet and the receipt of an acknowledgment for it.

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Problem 11.

Annette Werker has developed a new switch. In this switch, 10% of the packets are processed on the "slow path", which incurs an average delay of 1 millisecond. All the other packets are processed on the "fast path", incurring an average delay of 0.1 milliseconds. Annette observes the switch over a period of time and finds that the average number of packets in it is 19. What is the average rate, in packets per second, at which the switch processes packets?

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Problem 12.

Alyssa P. Hacker designs a switch for a circuit-switched network to send data on a 1 Megabit/s link using time division multiplexing (TDM). The switch supports a maximum of 20 different simultaneous conversations on the link, and any given sender transmits data in frames of size 2000 bits. Over a period of time, Alyssa finds that the average number of conversations simultaneously using the link is 10. The switch forwards a data frame sent by a given sender every δ seconds according to TDM. Determine the value of δ

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