This problem set has five questions, some with multiple parts. Answer them as clearly and concisely as possible. Turn in your solutions during class on Monday, November 26, 2007.

1 Smart Movie Backups

Over many months, you and your friends have painstakingly collected a 1,000 Gigabytes (aka 1 Terabyte) worth of movies on computers in your dorm (we won’t ask where the movies came from). To avoid losing it, you’d like to back the data up on to a computer belonging to one of your friends in New York.

You have two options:

A. Send the data over the Internet to the computer in New York. The data rate for transmitting information across the Internet from your dorm to New York is 1 Megabyte per second.

B. Copy the data over to a set of disks, which you can do at 100 Megabytes per second (thank you, firewire!). Then rely on the US Postal Service to send the disks by mail, which takes 7 days.

Which of these two options (A or B) is faster? And by how much?

2 Geostationary Satellite

It is sometimes beneficial to communicate using radio between terrestrial computers via a switch on a geostationary satellite, positioned 36,000 kilometers above the surface of the earth. What is the minimum round-trip time for any network communication between two computers so connected? (The round-trip time from A to B is defined as the time to send a small packet from A to B and to receive a response or acknowledgment from B at A.) Radio signals travel at the speed of light, of course (≈ 3 × 10^8 meters per second in air and vacuum).

3 A Little Queueing

You send a stream of packets of size 1000 bytes each across a network path from Cambridge to Berkeley. You find that the one-way delay varies between 50 and 125 ms 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 (i.e., the queue length) at the bottleneck link along the path (assume that any queueing happens at just one switch).

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?

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

4 TDM v. FDM

Ben Bitdiddle is designing a network to control a nuclear power plant from a remote computer over a shared radio channel. The source of data is a set of \( N \) sensors in the power plant that each generate data continuously (and forever) at a fixed bit rate, 1 bit every 10 microseconds. This data is shipped to a “sink” computer for analysis over a radio (each sensor and the sink have radios attached to them). The aggregate data rate available over the network between the sensors and the sink is 10 Mbits/s.

Ben has two choices: use time-division multiplexing (TDM) or use frequency division multiplexing (FDM). In TDM, each sensor gets to send a packet of size 1000 bits every \( N_{\text{max}} \) timeslots, where \( N_{\text{max}} \) is the maximum number of sensors that can share the available bandwidth such that each sensor’s data is delivered to the sink without loss. In FDM, each sensor is allocated a fraction of the \( 1/N_{\text{max}} \) of the available bandwidth, over which it streams the bits as they are generated. Assume that there are no bit errors.

A. What is the value \( N_{\text{max}} \) for the parameters given above?

B. For each scheme (TDM and FDM), sketch a graph with the following axes. The x-axis is the time at which a bit is produced. The y-axis is the time at which the sink gets it. Assume that the propagation+processing delay between a sensor and sink is 100 microseconds. Label the axes clearly with numbers that will allow us to infer the derivatives of any curves you draw.

5 A Little More TDM

Alyssa P. Hacker is running some experiments on a TDM circuit-switched network switch. All packets are of the same size. The rate of the link connected to the switch is \( \mu = 1000 \) packets per second. The link can support 24 concurrent conversations between different pairs of nodes.

In a given experiment, she picks a random number of conversations, \( r \), and has them communicate using the switch. She measures the expected per-frame delay at the receiver (\( D \)), and also monitors the number of frames in the switch with time (if a frame shows up earlier than its allocated time slot, the switch stores the frame until it is ready to be sent). The expected number of frames in the switch is \( N \). No frames are dropped in her experiments.

Somewhat to her surprise, she finds that the product \( D \cdot \mu \) is often not equal to \( N \). Explain this ostensible violation of Little’s law.