1.4. Consider the connection in Figure 1.4. One file of $K \gg 1$ bits must be sent from $A$ to $C$. That file is decomposed into packets of $P$ bits each. Each packet contains 16 error-control bits and 32 bits of address and sequence number, in addition to the $P$ data bits. The transmission rate is $R$ bits per second. Each packet is first sent from $A$ to $B$ and then from $B$ to $C$. Find the value of $P$ that minimizes the transmission time from $A$ to $C$, neglecting the propagation times. (Hint: First assume that the best value of $P$ is such that $K/P \gg 1$ so that one can approximate the number of packets of $P$ bits required to transmit $K$ bits by $K/P$. Then justify your assumption.) Repeat the same problem when the file must go through $N$ communication nodes between $A$ and $C$.

1.5. This is a simple network optimization problem. The network is as indicated in Figure 1.9. The terminal node $A$ transmits $\lambda$ bits per second for terminal node $B$ and also $\lambda$ bits per second for terminal node $C$. The network is built with a link with rate $2\lambda$ from node $A$ to the communication node $S$ and with one link with rate $\lambda$ from $S$ to $B$ and also from $S$ to $C$. The cost of a unit length of link with rate $\alpha$ is assumed to be equal to $K \times \alpha^{0.5}$. Thus, the cost of a link grows more slowly than its rate. This reflects the economy of scale of faster links. Assuming that $S$ is free, find the value of $x$, i.e., the position of $S$, which minimizes the cost of the network. Assume now that the node $S$ costs some amount $J$. For which values of $d$ is it less expensive to use a switch $S$ instead of two direct links from $A$ to $B$ and from $A$ to $C$?

![Network optimization problem](image)

1.6. Each of two links fails one day per month, on the average. The failures of the two links occur independently. How often do the two links fail on the same day?

2.1. Why is digital transmission preferred to analog transmission for voice? (Indicate the correct answer(s).)
   a. Because it is faster.
   b. Because it is less noisy.
   c. Because optical fibers can be used.

2.2. When is packet-switching preferred to circuit-switching? (Indicate the correct answer(s).)
   a. Always.
   b. When delays have to be small.
   c. When the traffic is bursty.
   d. When the transmission rate is large.
2.3. What do virtual-circuits implement? (Indicate the correct answer(s).)
   a. Datagrams.
   b. Point-to-point connections.
   c. Connection-oriented communication services.
   d. Circuit-switched communications.

2.4. Why is the ISO's OSI model important? (Indicate the correct answer(s).)
   a. Because it leads to more efficient protocols.
   b. Because there is no other possible design.
   c. Because compatibility is desirable.
   d. Because it provides one unified way to discuss protocols.

2.5. Assume that writing a program of $N$ lines of code costs $N^2$ units of cost. If the program is written in a modular form, assume that a module of $n$ lines costs $a^2 + n^2$ to develop. The cost $a^2$ is caused by the need to follow the specifications of the modular construction. With these assumptions, what is the number $k$ of modules of $N/k$ lines that minimizes the cost of writing the program? For what values of $N$ is it preferable to decompose a program of $N$ lines into modules rather than to write it as a single program?

2.8. Take a letter-size sheet of paper (8.5 inches by 11 inches). Draw a fine grid with 300 lines per inch both vertically and horizontally. How many points are formed by the intersections of the grid lines? Assume that 3 bits are used to encode the level of gray of each of these points to represent a photograph printed on the page. How many bits do you need to encode the photograph? How many such photographs can you store in an 80-Mbyte hard disk? How long does it take to transmit the photograph by using a 56-kbps modem?

2.10. We want to implement a packet-voice transmission. To do this, we build an electronic board that groups the bits arriving at 64 kbps into packets of 48 bytes. The packets are sent over a 230-km transmission line to a second board. The second board converts the packets into a 64-kbps bit stream. We assume that the packets are transmitted as soon as they are formed and that the second board converts each packet back into the bit stream as soon as it is fully received. The propagation time along the transmission line is 1 ms. What is the delay faced by the bit stream between the input of the first board and the output of the second board?
We want to buy a private branch exchange (PBX), i.e., a telephone switch, to connect our office building to the telephone company's central office. The PBX will enable us to connect telephones inside the building without having to use the services of the telephone company. External telephone calls are connected by the PBX to the appropriate extension inside the building. How many telephone lines should there be between the PBX and the telephone company's central office? Our telecommunication engineer tells us that with $N$ lines the blocking probability $B$ is given by the formula

$$B = \frac{\rho^N}{N!} + \frac{\rho^2}{2!} + \frac{\rho^3}{3!} + \ldots + \frac{\rho^N}{N!}$$

where $m!$ ($m$ factorial) is defined as $1 \times 2 \times 3 \times \ldots \times (m-1) \times m$ for any integer $m$. (Thus, $2! = 2$, $3! = 6$, $4! = 24$.) Here, $\rho$ is $n/30$ where $n$ is the number of telephone sets in the building. Find how many telephones can be accommodated with one, two, three, and four lines if we want $B \leq 2\%$.

Packets arrive at a node to be transmitted. The packets arrive at random times $T_1, T_2, \ldots$ and are transmitted in the order that they arrive. Packets that cannot be transmitted immediately are stored in a buffer until they can be. Assume that each packet is $P$ bits long and the transmission rate is $R$ bps. Draw a diagram showing how many bits are stored in the node buffer as a function of time. That number is zero before time $T_1$. At time $T_1$, that number is assumed to jump instantaneously to $P$. Between $T_1$ and $T_2$, the number of bits stored decreases by $R$ bits every second, and so on. Using your diagram, determine the delay faced by the first, second, and third packets as a function of $(T_1, T_2, T_3)$. Note that the delay of a packet is the sum of the transmission time

$$\frac{P}{R}$$

and some queueing time. Give a simple condition on the arrival times $(T_1, T_2, T_3)$ for the queueing time to be zero. Exhibit arrival times $(T_n, n \geq 1)$ that lead to a very large average queueing time per packet, even though the average arrival rate (in packets per second) is very small. (Hint: Consider infrequent arrivals of large batches of packets.)

A simple telephone system consists of two end offices and a single toll office to which each end office is connected by a 1-MHz full-duplex trunk. The average telephone is used to make four calls per 8-hour workday. The mean call duration is 6 min. Ten percent of the calls are long-distance (i.e., pass through the toll office). What is the maximum number of telephones an end office can support? (Assume 4 kHz per circuit.)

At the low end, the telephone system is star shaped, with all the local loops in a neighborhood converging on an end office. In contrast, cable television consists of a single long cable snaking its way past all the houses in the same neighborhood. Suppose that a future TV cable were 10 Gbps fiber instead of copper. Could it be used to simulate the telephone model of everybody having their own private line to the end office? If so, how many one-telephone houses could be hooked up to a single fiber?