EE 284
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Autumn 2017-2018

EE284
Homework Assignment No. 1

Topic: Switching Techniques, Network Topologies
Handed out: September 28, 2017
Due: October 10, 2017 in class
Total Points: 37
ALL WORK MUST BE SHOWN TO RECEIVE FULL OR PARTIAL CREDIT

Problem 1: Circuit Switching vs Packet Switching (6 points)

We are interested in transmitting a fax message of length L bits from a given source location A to a given destination location B. We have two options: the telephone network and a computer network.

Telephone Network:

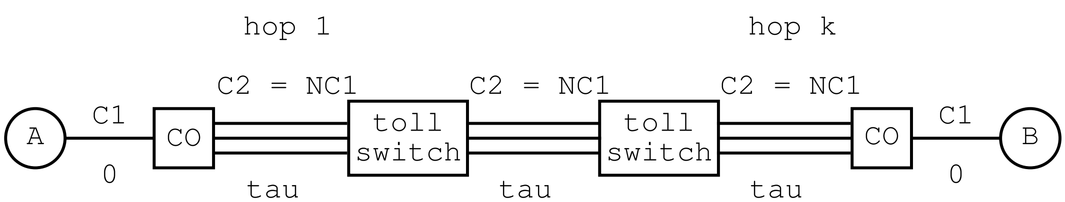

Figure 1: Circuit Switching Network.

The telephone network is a circuit-switched network. The source and destination nodes are connected to their respective central offices (COs) by twisted pairs of capacity C_1 bits/sec (typically 64 kb/s). The propagation delay on these links is considered to be negligible. The switches in the telephone network (CO switches and toll switches) are interconnected by links of capacity $C_2 = N * C_1$. Each link is divided into N separate channels of capacity C_1; one of these channels (referred to as the control channel) is dedicated to carrying call setup and acknowledgement messages. We consider that the source and destination COs are separated by K links and $K-1$ toll switches. The propagation delay on the links is τ sec.

When the user at location A dials the fax number at location B, the source central office to which A is connected creates a setup message of length S bits that is transmitted in a store and forward manner over the control channels to the remote central office connected to B. The setup message reserves one channel of capacity C_1 on each link it traverses. Upon reception of the call setup message, the remote CO sends an acknowledgement message of size S back to the source CO, which gets transmitted also in a store and forward manner over the control channels. When the latter receives the acknowledgement message, it gives A the signal to begin transmitting the fax message on the established end to end circuit.

(a) *(2 points)* Express the delay D_{cs} from the time when A completes dialing B's number until the fax message is entirely received by the fax machine at B, in terms of C_1, C_2, τ, S, L and K. Consider that the processing delay at any CO/switch is negligible and therefore considered to be zero. Also consider that there is no other traffic on network.

Store and Forward Packet-Switched Data Network:

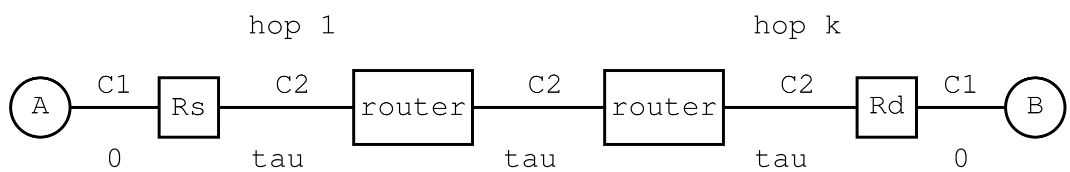

Figure 2: Packet Switching Network.

Source A and destination B are connected to source router Rs and destination router Rd, respectively, by means of twisted pairs of capacity C_1 bits/sec and zero propagation delay. Rs and Rd are separated by $K-1$ routers and K links of capacity $C_2 = N * C_1$ bits/sec (each of which is used as a single high speed channel), and propagation delay τ.

The fax message is broken up by the source machine at A into packets of maximum P data bits and a header and trailer of combined size H bits. Assume that $\frac{L}{P}$ is an integer.

(b) *(4 points)* Express the delay D_{ps} from the time when A begins transmission until the fax message is entirely received by the machine at B in terms of C_1, C_2, τ, P, L, H and K. Consider that the processing delay at any router is negligible and therefore considered to be zero. Also consider that no other traffic is present on the network.

Problem 2: Packet switched Network with different link speeds (10 points)

Consider a packet-switched, store-and-forward network consisting of three nodes, (two end nodes A and B and one intermediate node with unlimited buffer capacity), and two transmission links (as shown in figure 3). The first link has bandwidth W_1 bits/sec and propagation delay τ_1; the second link has bandwidth W_2 bits/sec and propagation delay τ_2.

Node A has a file of M bits to be transmitted to node B. Each packet has a fixed size header of H bits and a data field of maximum size equal to P bits. Node A starts to send the file at time $t = 0$.

a) [6 points total] Consider first that M/P is an integer. For each case below, draw the time-space diagram, and give and expression for the time at which node B receives the entire file.

   i) $W_1 > W_2$

   ii) $W_1 < W_2$

b) [4 points total] Repeat the above when M/P is not an integer.

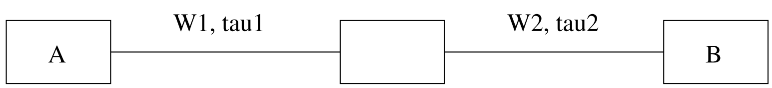

Figure 3: Packet Switched Network with different link speeds

Problem 3: Transmission of digitized voice over packet networks (8 points)

Consider a PCM voice encoder which produces a digitized voice signal of constant data rate V bits/s (i.e., it takes 1/V seconds to generate each bit). Voice data is transmitted to a receiving node over a dedicated circuit of bandwidth W bits/s. The end-to-end propagation across the circuit is τ sec. For interactive voice communication purposes, it is imperative that *each* bit produced by the voice encoder be delivered to the destination within a maximum end-to-end delay, denoted by D_{max}. Consider a packet-switched mode of operation whereby voice data is packetized into packets each containing B bits of voice data and H bits of header control information. After a complete packet is formed, it is transmitted over the dedicated circuit. A voice packet needs to be formed in its entirety at the source before transmission of the packet on the circuit can begin. Also, a voice packet needs to be received in its entirety at the destination before the content of the packet is available to the decoder.

a) [5 points total] Find the relationships among the system parameters H, B, V, W, τ and D_{max} that must be satisfied in order for the system to be stable [2 points] and for the end-to-end delay incurred by voice data bits to be below the maximum allowed [3 points].

b) [3 points] Find the minimum circuit bandwidth W that is necessary to achieve interactive packet voice communication and the corresponding optimum voice packet size B in terms of known quantities (i.e., V, H, D_{max} and τ).

Problem 4: Network topologies (13 points)

In this problem, we investigate how the cost of a network depends on its topology.

A wide area store-and-forward network connecting N sites consists of a collection of switching nodes and links. Three network topologies are considered as described below.

A) Fully-connected topology (see Figure 4 for an example). A switching node exists at each site, and each pair of nodes is connected by a point-to-point link.

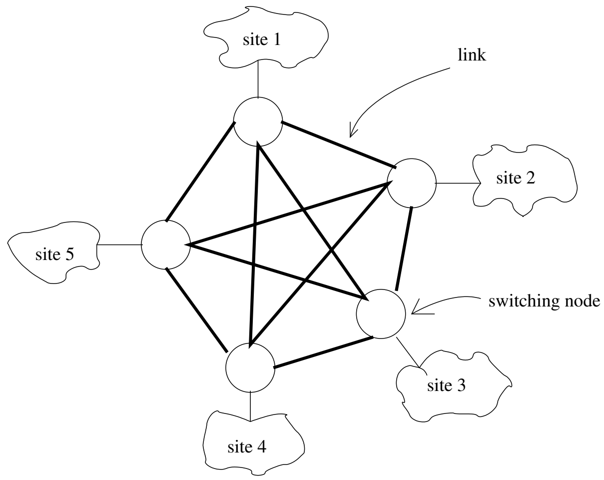

Figure 4: Fully-connected topology with $N = 5$

B) Ring topology (see Figure 5 for an example). A switching node exists at each site, and there exists one link connecting each pair of neighboring sites.

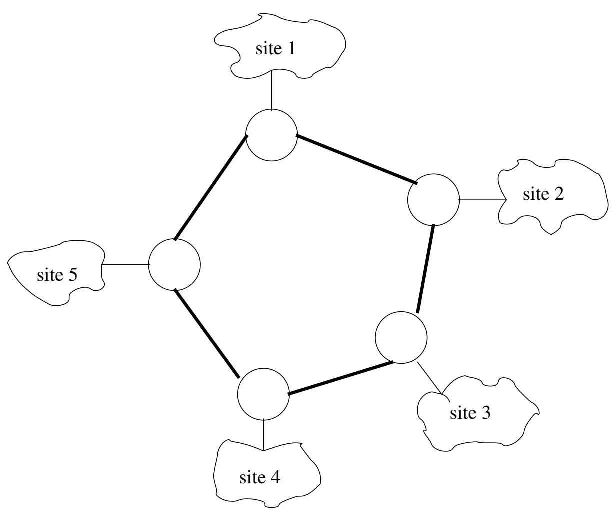

Figure 5: Ring topology with $N = 5$

C) Star topology (see Figure 6 for an example). A node exists at each site, and each such node is connected to a central switching node by a point-to-point link.

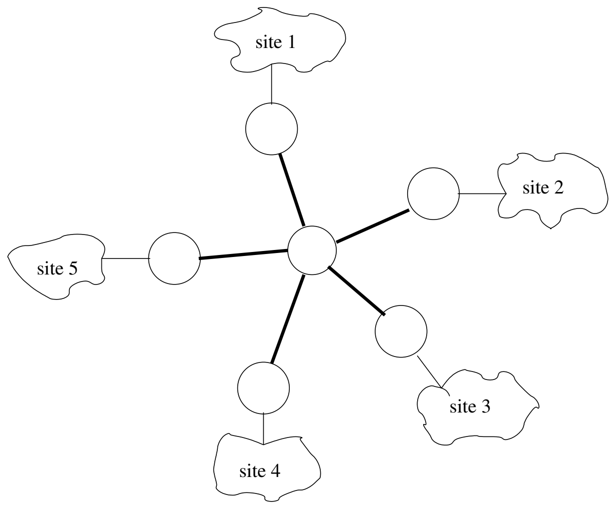

Figure 6: Star topology with $N = 5$

Links used in these topologies are bidirectional, i.e. the links can carry traffic in both directions. If there exist several paths between a source and a destination, the shortest path (in number of hops) is used; if there exists more than one path with the smallest number of hops, the traffic between the source and the destination is split equally among all those paths. Denote by γ_{jk} the amount of traffic in bits/sec that originates at site j and is destined to site k.

We consider in this problem that all source-destination traffic is uniform and that all sources are sending traffic simultaneously; i.e.,

$$\gamma_{jk} = \begin{cases} \gamma_0 & \forall j, k : j \neq k \\ 0 & j = k \end{cases} .$$

For each topology,

a) [1 point each] Find the number of (bidirectional) links M used.

b) [1 point each] For a bidirectional link i in the topology, let C_i^1 and C_i^2 denote the minimum capacity of the link in each direction required to support the traffic. Note that due to the symmetry in the topologies and the traffic requirement, $C_i^1 = C_i^2 = C_i$. Find the expression for C_i in terms of N and γ_0.

   For the ring topology, show that the expression for C_{1N} is given by:

$$C_{1N} = \begin{cases} \frac{1}{8}(N^2 - 1)\gamma_0, & \text{for } N \text{ odd,} \\ \frac{1}{8}N^2\gamma_0, & \text{for } N \text{ even.} \end{cases}$$

c) [3 points] Consider that the cost of a bidirectional link i, denoted by d_i, is given by:

$$d_i = 2\alpha C_i.$$

For each topology, find the total link cost D of the network. Assuming that N is large (going to infinity), rank the topologies according to their cost. Determine the smallest value of N for which this ranking is true. Calculate the cost for each topology when $N = 100$.

d) [3 points] Consider now that the cost of a *bidirectional* link is given by

$$d_i = 2\beta\sqrt{C_i},$$

to reflect an economy of scale (in bandwidth).
For each topology, find the total link cost D of the network. Assuming that N is large (going to infinity), rank the topologies according to their cost. Determine the smallest value of N for which this ranking is true. Calculate the cost for each topology when $N = 100$.

e) [1 point] Briefly comment on the difference between the two rankings.