HELSINKI UNIVERSITY OF TECHNOLOGY
Networking Laboratory
S-38.145 Introduction to Teletraffic Theory, Spring 2005

Examination
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Aalto/Penttinen

1. Consider data traffic at packet level in an output port of a router in an interval $[0, T]$, where $T = 20$ (time unit: μs). The system is empty at time $t = 0$. New packets arrive at times 1, 3, 4, 14, and 15. The transmission times of these packets are 5, 5, 1, 2, and 2, respectively. Packets are sent in their arrival order. No packets are lost.
   (a) Construct a figure that describes the packet arrival times, the waiting and transmission times for all packets, and the number of packets in the system (that is, the traffic process) as a function of time $t \in [0, T]$.
   (b) What is the average waiting time of a packet?
   (c) What is the average total delay (including both the waiting and the transmission time)?

2. Give the definition of the Erlang model, and write the call blocking probability as a function of the model parameters.

3. Consider the M/M/2/2/2 model where the mean idle time of a customer is $1/\nu$ time units and the mean service time is $1/\mu$ time units. Let $X(t)$ denote the number of customers in the system at time t.
   (a) Draw the state transition diagram of Markov process $X(t)$.
   (b) Derive the equilibrium distribution of $X(t)$.
   (c) Determine the time blocking probability (as a function of parameters ν and μ).
   (d) Determine the call blocking probability.

4. Consider data traffic on a link between two routers (from router R1 to router R2) in a packet switched network. Traffic consists of packets arriving to the output buffer of router R1 with mean interarrival time t. Let L and C denote the mean packet length and the link speed, respectively. The buffer is large. Consider this as an $M/M/1$ queueing model. Suppose that $t = 18\,\mu$s, $L = 1500$ bytes, and $C = 1$ Gbps. Determine the mean delay of a packet (including both the waiting and the transmission time).

5. Consider a fully connected network with 3 nodes and 6 links, i.e., there is a link $n \rightarrow m$ for each node pair (n, m). The capacity of each link is 10 capacity units. The network is loaded by the traffic demands given by the traffic matrix $\mathbf{T}$,

$$\mathbf{T} = \begin{pmatrix} 0 & 1 & 2 \\ 1 & 0 & 6 \\ 2 & 6 & 0 \end{pmatrix}.$$

   Packets are routed through the network via shortest paths with the ECMP principle applied.
   (a) Draw the network topology. What is the number of paths?
   (b) Determine the link loads resulting from unit link weights.
   (c) Modify the link weights so that the maximum link load is reduced.