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 Problem Set 1

1	2	3
10	10	5

## Problem 1:

a) The TDM scheme is not work-conserving: if one session is transmitting and the others are idle, the link will be idle during the time slots for the other connections even though packets are queued in the active session's queue.

The statistical multiplexing scheme is work-conserving: the link is only idle when there are no packets in the single queue, which means no frames are waiting for service.

b) Consider first the statistical multiplexing case. Since packet arrivals are a Poisson process with parameter  $N\lambda$  and service times are exponentially distributed with parameter  $\mu$ , and there is a single server, we have a M/M/1 queuing process. Since  $\mu > N\lambda$ , the system converges to a steady state, and a basic result from queuing theory tells us that the expected time in the system for each packet, including the time spent transmitting it over the link, is  $\frac{1}{\mu - N\lambda}$ .

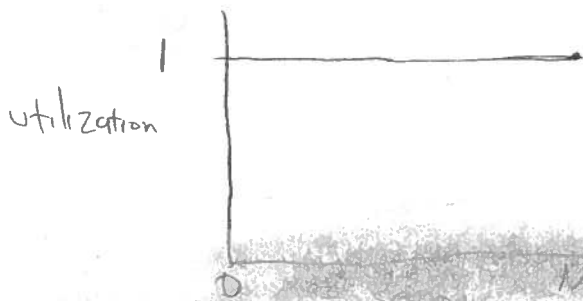
In statistical multiplexing, since the size of a slot is much smaller than the packet transmit time, we can treat the system as  $N$  separate links, each of which transmits at an average rate of  $\mu/n$  frames/second. Each link has a separate queue, where packet arrivals are a Poisson process with parameter  $\lambda$ . This is also a M/M/1 queuing system, and so the average delay for a frame is  $\frac{1}{\mu/n - \lambda} = \frac{N}{\mu - \lambda} \rightarrow \frac{N}{\mu - N\lambda}$

This tells us that the average delay for a frame in TDM is  $N$  times greater than the average delay for a frame in statistical multiplexing because the queues are being processed at a rate that is slower by a factor of  $N$ . As we'd expect, the delay increases as the packet arrival rate  $\lambda N$  approaches the average service rate  $\mu$  (and queue lengths fail to converge if it exceeds this rate).

c) In statistical multiplexing, the output link is always fully utilized because the aggregate input rate is the same as the output link capacity  $\mu$ , and the multiplexing scheme is work-conserving.

In the TDM scheme, the link is only utilized during the time slots corresponding to the  $A$  active sessions, and it is fully utilized during this time, since the aggregate input rate  $\mu$  is greater than the effective output rate  $\mu \frac{A}{N}$ . So the link is utilized  $\frac{A}{N}$  of the time.

Stat. mux



TDM



d) TDM has less jitter because it maintains an individual queue for each session. Regardless of utilization, each queue is always guaranteed to receive  $\frac{1}{N}$  of the output link. Queue lengths for these individual queues are smaller, as is their variance, compared to having a single queue containing every packet.

**Problem 2:**

a) All ACKs will be sent by the interval timer if the interval  $\delta$  is shorter than the time required for the next packet to arrive. This time is  $s/r$ . So normal delayed ACKs will never be sent if

$$\delta < \frac{s}{r}$$

b) The interval timer will trigger an ACK for every packet if

$$50 \text{ ms} < \frac{512 \text{ bytes}}{r}$$
$$r < \frac{512 \text{ bytes}}{50 \text{ ms}} = 10 \text{ Kbyte/s}$$

This is not likely to be a problem on today's Internet connections, except for slow connections such as dialup.

**Problem 3:**

The recipient should discard the packet and treat it as a dropped packet. Sending a duplicate ACK would indicate to the original sender that an out-of-order packet had been received, causing it to (erroneously) assume that one of the other packets in its window has been received. It will then adjust its window size and transmit a new packet erroneously, which is incorrect.

If the recipient ignores the packet completely, the next packet received will be out of order and trigger a duplicate ACK with the appropriate sequence number. This will cause the sender to retransmit the corrupted packet.

It's also possible that the checksum error indicates that part of the packet header was corrupted. If this means that the source or destination host, port, or sequence number is incorrect, then sending a duplicate ACK is even more incorrect.

**Problem 4:**

Submitted by email, or available from <http://www.ambulatoryclam.net/svn/classes/6.829/ps1/rmtp/>.