Spring term 2008
TELCOM 2321 - CS 2520
Wide Area Networks

Mid-term exam

Tuesday Mar 4, 2008

Student's name _____

The exam is open book and notes. Read the questions carefully and focus your answers on what has been asked. You are allowed to ask the instructor for help only in understanding the questions, in case you find them not completely clear. Be concise and precise in your answers and state clearly any assumption you may have made. All your answers must be included in the attached sheets.
You have 90 minutes to complete your exam. Be wise in managing your time.

Evaluation

Question 1 _____

Question 2 _____

Question 3 _____

Question 4 _____

Question 1

Packet scheduling is a key function that network nodes should implement in order to enforce QoS provisioning. Consider a Weighted Fair Queuing (WFQ) scheduler servicing three buffers, where packets belonging to three different traffic flows are stored. Assume that the same weight is assigned to each flow and that the server rate is $C = 1$ unit per second.

1. What ideal scheduling policy is approximated by this scheduler? Explain what is the approximation made.
2. What is the purpose of the virtual time $V(t)$?
3. The following expression can be used to define $V(t)$

$$\begin{aligned} V(t_0) &= 0 \\ V(t) &= V(t_j) + \frac{t - t_j}{N(t)} \quad t \in [t_j, t_{j+1}],\ j = 0, 1, \ldots \end{aligned}$$

   Explain the meaning of this expression and the role of time instants t_j. What kind of trend does this function show?

Now consider the following arrival pattern, where $t_{k,i}$ is the actual arrival time of packet i in flow k and $L_{k,i}$ its length:

- $t_{1,1} = 0$, $L_{1,1} = 2$
- $t_{2,1} = 1$, $L_{2,1} = 3$
- $t_{2,2} = 2$, $L_{2,2} = 1$
- $t_{3,1} = 3$, $L_{3,1} = 5$
- $t_{1,2} = 4$, $L_{1,2} = 1$

To compute the virtual starting ($s_{k,i}$) and ending ($f_{k,i}$) transmission times of the previous packets, consider that when the first packet arrives, only a single queue becomes backlogged and stays like that for $t \in [0, 1]$. Therefore, during this interval $V(t) = t$ and we can compute

$$s_{1,1} = 0 \quad \text{and} \quad f_{1,1} = 2$$

Then at $t = 1$ queue 2 becomes backlogged while packet 1 from queue 1 is still in service, so $V(t) = 1 + \frac{t-1}{2}$ when $t \in [1, 2]$ and

$$s_{2,1} = 1 \quad \text{and} \quad f_{2,1} = 4$$

4. Continue the computation above and find the virtual starting and ending transmission times of the remaining packets.
5. Show the actual packet transmission order according to the WFQ scheduler. Comment on any peculiar behavior caused by the packet-level approximation.

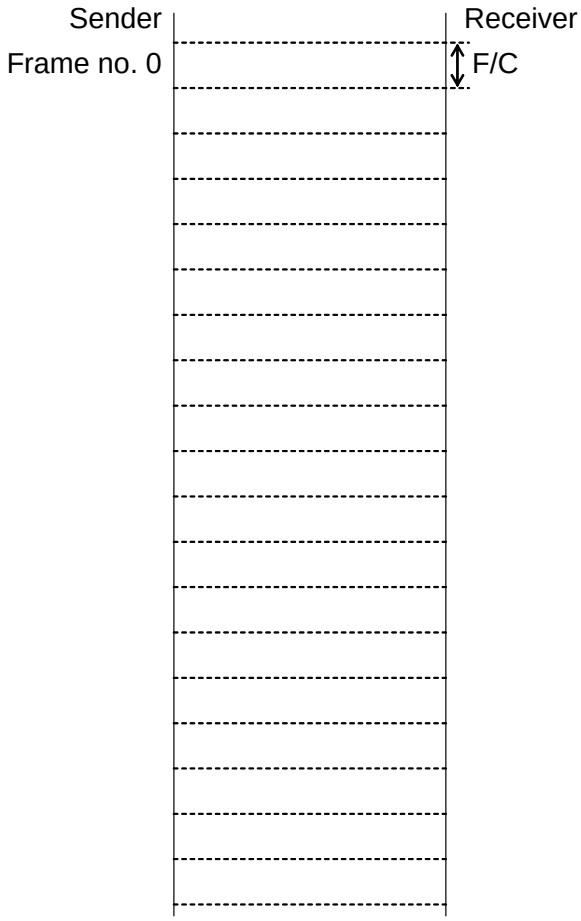
Question 2

Consider a data link layer protocol operating over a full duplex channel with the same characteristics in both directions. The protocol adopts a sliding window flow control scheme with $W = 4$ and $n = 3$ bits for frame sequence number. The receiver is configured to send an acknowledgment after every frame correctly received during regular operations. A go-back-N ARQ scheme is used to deal with errors, where the receiver is required to send a NACK for each frame received out of sequence. Assume that the source has always data waiting to be transmitted and that the propagation time in each direction t_d is twice the frame transmission time F/C. Consider header and acknowledgment transmission times as well as processing delays negligible.

The sender sets a timeout for each transmitted frame, starting immediately after frame transmission is completed. When timeout expires and no ACKs or NACKs have been received, the sender transmits a POLL control frame, to which the receiver must explicitly reply with an ACK carrying the expected frame number. Assume that the POLL transmission time is negligible and that $T_{\text{out}} = 3\,t_d$. Duplicate NACKs are ignored before the timeout of a retransmitted frame expires.

1. What is the definition of link utilization? Find the link utilization of the sliding window ARQ described above in case no errors occur. Include a brief discussion that justifies the formula used.

2. Complete the time diagram on the next page, starting from frame no. 0. Assume that an error event occurs on frame no. 6. And remember: propagation time from sender to receiver is twice the frame transmission time.


Sender
Receiver
Frame no. 0
F/C

Question 3

An employee takes the bus every morning at 8:00 to reach his workplace. However, due to highly variable road traffic conditions and limited planning ability from the public transportation company, the bus line he takes is not particularly efficient in following the time schedule. Most of the times the bus is not punctual and it is usually late, although sometimes it arrives earlier than the scheduled time. So the exact time the bus arrives at the stop is not predictable.

1. Describe this situation using what you know about quality of service requirements and propose a possible solution to this problem.
2. In your opinion, could the employee be considered a "real-time" customer? Explain why.

Question 4

Consider a packet-switched network where packets have fixed size $L = 125$ bytes. The network is run by an operator who offers three types of services to its customers according to the following specifications:

Service A : connection-oriented, no more than one packet can be transmitted every t_0 seconds.

Service B : connection-oriented, over a large interval T the maximum amount of data that can be transmitted is the equivalent of M packets sent at any rate plus no more than one packet every t_0 seconds.

Service C : connectionless, packets can be transmitted at an unspecified rate depending on the bandwidth available.

Services A and B must be guaranteed, while C is provided as a best effort service using the spare bandwidth. To this end, the operator adopts an open-loop congestion control scheme, where service A is policed at the ingress node and customers of service B are required to shape their traffic according to the service specification given by the operator. Service C is not guaranteed, so when there are no resources available, packets are simply dropped.

1. What kind of traffic descriptors should be used for services A and B? Justify your answer.
2. What kind of mechanism should be used to police service A traffic? Explain briefly how this traffic policing scheme works and specify the parameters to be used.
3. What kind of shaper should be adopted by service B customers? Explain briefly how this traffic shaper works and specify the parameters to be used.

Using the descriptors found in point 1, the operator adopts a long-term bandwidth allocation technique among the different customers based on a max-min fair share approach. To this end, the following traffic classes are defined:

Class A1 includes connections using service A with $t_0 = 1$ msec.

Class A2 includes connections using service A with $t_0 = 2$ msec.

Class A3 includes connections using service A with $t_0 = 4$ msec.

Class B1 includes connections using service B with $M = 20$ and $t_0 = 0.25$ msec.

Class B2 includes connections using service B with $M = 50$ and $t_0 = 0.5$ msec.

Class C includes service C traffic

At a given time, N_j is the number of active class j connections with $j = A1, A2, A3, B1, B2$, while R_C is the current bandwidth demand of class C traffic. The max-min fair share allocation is applied by aggregating connections based on their class, i.e. each class is considered as a single bandwidth demand whose value depends on the number of active connections.

4. Show how the max-min bandwidth allocation applies when capacity is $C = 125$ Mbps, $R_C = 80$ Mbps and $N_{A1} = 20, N_{A2} = 40, N_{A3} = 80, N_{B1} = 5, N_{B2} = 10$.
5. Show how the max-min bandwidth allocation applies when capacity is still $C = 125$ Mbps, $R_C = 80$ Mbps, and $N_{A1} = 15, N_{A2} = 24, N_{A3} = 60, N_{B1} = 7, N_{B2} = 11$.
6. Given the same number of connections as in the previous point, in case the network operator decides to admit two additional class B1 connections, is it still acceptable to use the max-min fair share allocation scheme? Explain why or why not.