Data-link layer: in-class and practice exercise solutions

1. Find the transmission efficiency of stop-and-wait ARQ when link rate is 1Mbps and round-trip propagation delay is 10ms. Ignore processing delays. Answer as shown on the slide: 49%. Verify this number.

   Answer: Solve the equation for transmission efficiency $\alpha = \dfrac{1 - \dfrac{S_0}{S_f}}{1 + \dfrac{S_a}{S_f} + \dfrac{2(t_{prop} + t_{proc})r}{S_f}}$, with $S_0 = S_a = 200$ bits, $S_f = 10000$ bits, $r = 1Mbps$, $t_{proc} = 0$ and $2t_{prop} = 10ms$. $\alpha = 0.49$.

2. A channel has a bit rate of 4 kbps and a one-way propagation delay of 20ms. At what minimum value of user data frame size does stop-and-wait give a transmission efficiency of 50%? Ignore the transmission delay of the ACK, the frame overhead and the processing delays.

   Answer: 160 bits. See slides on Stop-and-Wait efficiency. Set $S_0 = S_a = t_{proc} = 0$ based on my statement of what parameters to ignore (note that transmission delay of ACK is $\dfrac{S_a}{r}$). Plug in the values of $r = 4kbps$, $t_{prop} = 20ms$, and transmission efficiency is 50%. Find S_f. This works out to be 160bits.

   $0.5 = \dfrac{1}{1 + \dfrac{(2 \times 20ms) \times 4kbps}{S_f}}$ or $S_f = 160bits$.

3. Compute the minimum size of the sending window if sliding-window ARQ is to be used with a transmission efficiency of 100% under error-free conditions. Assume that the user data frame size is 1250 bytes, link rate is 1Mbps and round-trip propagation delay is 10ms. Ignore ACK frame size, header/CRC overhead, and processing delays.

   $W_s \geq \dfrac{(2t_{prop}) \times r}{S_f} + 1$. Therefore $W_s = 2$ frames. Recall W_s is an integer.

4. If the sequence number field in a sliding-window ARQ protocol is 10 bits, is there a limit to the sending window size (i.e., the maximum number of frames that the sender can send without waiting for an acknowledgment)?

   Answer: There is an upper limit for the sending window size. This is $2^m - 1$, where m is the number of bits in the sequence number. Since this is 10, W_s can maximally be 1023.

5. Assume R_{snd} is the same as the physical-layer link transmission rate, and $R_{snd} = 50Mbps$, but $R_{rcv} = 25Mbps$. If the round-trip propagation delay is 50ms, how much space, in bytes, should be left in the receive buffer before the receiver sends out an OFF signal in an ON-OFF flow control scheme?

   Answer: See slides on ON/OFF flow control.

   $B_{left} = 2t_{prop} \times (R_{snd} - R_{rcv}) = \dfrac{50 \times 10^{-3} \times 25 \times 10^6}{8} = 156250$ bytes.

   Since we specified the round-trip delay, 50ms is $2t_{prop}$. Divide by 8 to get bytes.

6. Consider a DLL implementation that uses sliding-window ARQ and sliding-window flow control. Assume that the sending window size is 7 frames. Consider an instant in time when the sender has sent out frames with sequence numbers 0 through 6, and it has received an acknowledgment (ACK) from the receiver indicating it is ready to receive the frame with sequence number 3. Along with the ACK, the receiver also indicates that the flow window is 5 frames.

   a. Does that mean frames 3, 4, 5, 6 are lost?

b. When the sender receives this ACK with flow-window indication, how many more frames can the sender send?

Answers:

a. No, it does not mean that these frames were lost. They could have just been in transit when the receiver, upon receiving frame 2, issued the ACK 3 response.

b. It can send only one frame, since min(W_s, flow window) = min(7,5) = 5. Next, the sender recognizes that 4 frames are already outstanding (sent but unacknowledged, frames 3, 4, 5, 6) and hence it can send only one frame. (Recall slide with three steps, X-Y, where X = min(W_s, flow window) and Y is number of outstanding frames)

7. Consider a DLL scheme in which sliding-window ARQ and sliding-window flow control control are used. Assume the following:

- User data frame size is 1250 bytes
- Link transmission rate is 1Mbps
- One-way propagation delay is 25ms
- Receiver's DLL buffer size = 2500 bytes
- Ignore the ACK size, header and CRC overhead, and processing delays
- Assume that the receive buffer is emptied by the higher-layer very quickly (e.g., even before an ACK is sent).

a. How long will it take to send a file of size 12500 bytes on this link using the specified DLL, assuming no frames are errored or lost?

b. What is the maximum effective rate achieved for this file transfer?

c. Without the DLL, what delay would have been incurred to send this file across the link?

Answer:

The emission delay for one frame is $\frac{1250 \times 8bits}{1Mbps} = 10ms$. Using $W_s \geq \frac{(2t_{prop}) \times r}{S_f} + 1$, since $2t_{prop} = 50ms$, W_s should be at least 6 in order to keep the channel fully utilized (because $S_f = 1250$ bytes and $r = 1Mbps$). However, since the receiver's buffer can hold only 2 frames (2500 bytes/1250 bytes), the sender can only emit two frames before waiting for an ACK and flow-window indication.

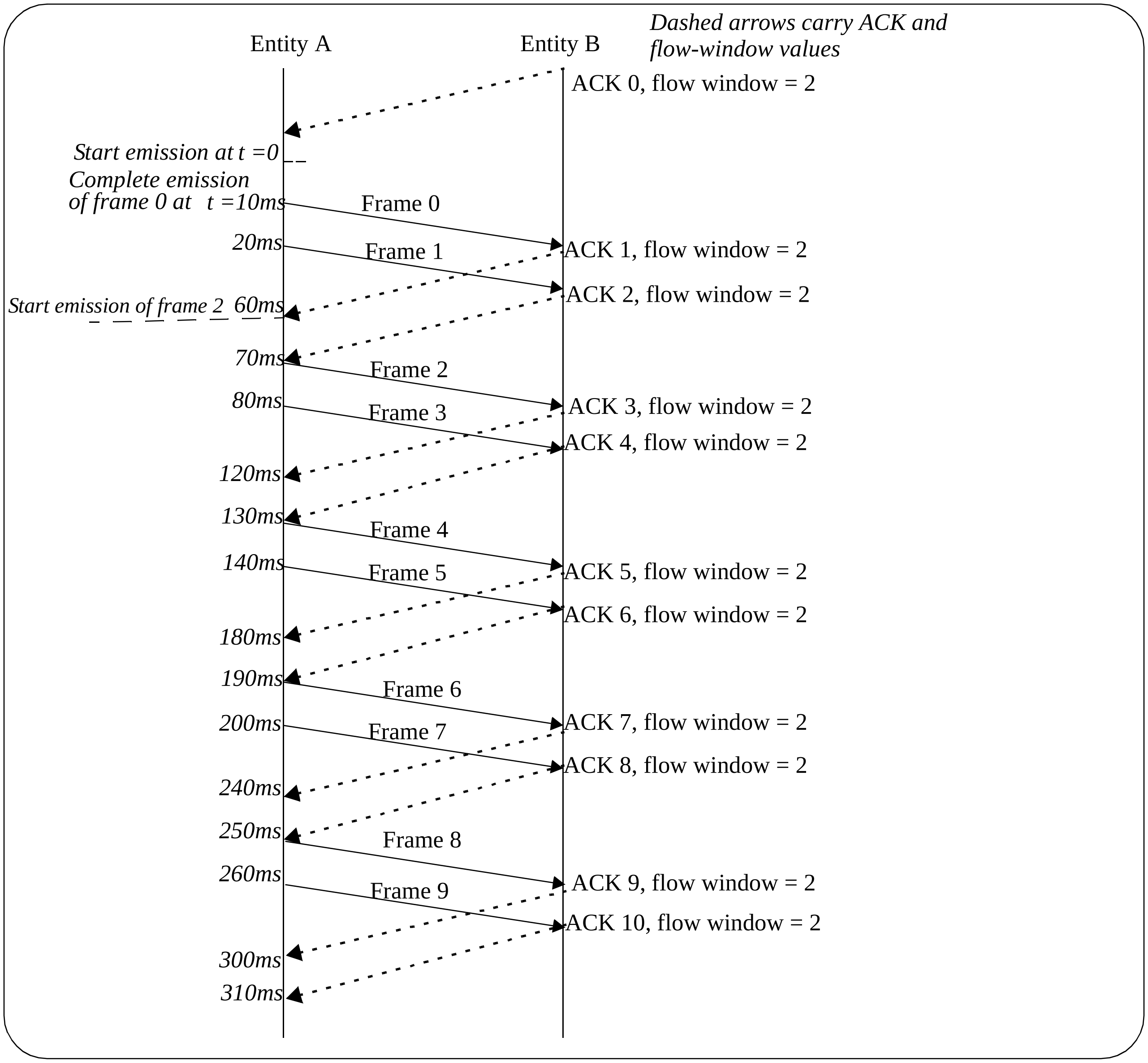
File size = 12500bytes = 10 frames.

In the flow shown in the figure, note that when the ACK 1, flow window =2 signal is received by the sender, it starts emitting frame 2 at t=60ms. It finishes emitting the frame at t=70ms. We see from the figure that it took 310ms in total (answer to part (a)).

The answer to part (b) is $\frac{12500 \times 8bits}{310ms} = 322.6kbps$.

If the question was for a 2500-byte file, the answer for delay is 70ms and the effective rate is $\frac{2500 \times 8bits}{70ms} = 285.7kbps$.

The answer to part (c) is $\frac{12500 \times 8bits}{1Mbps} + 25ms = 125ms$. This is what we learned in the PHY-layer lecture where the time to send a file across a link is the emission delay plus one-way propagation delay. Adding the DLL functions, requiring ACKs, and watching the flow-control window (receiver buffer), slows down the sending of data. At the least, the receiver buffer and the sending window should have been 6 frames in order to keep the link fully utilized. We learned this requirement for the sending window, i.e., $W_s \geq \frac{(2t_{prop}) \times r}{S_f} + 1$, but when sliding-window ARQ is combined with sliding-window flow control, the receiver buffer should also be, at least, that large.



Dashed arrows carry ACK and flow-window values
Entity A
Entity B
ACK 0, flow window = 2
Start emission at t =0
Complete emission of frame 0 at t =10ms
Frame 0
20ms
Frame 1
ACK 1, flow window = 2
ACK 2, flow window = 2
Start emission of frame 2 60ms
70ms
Frame 2
80ms
Frame 3
ACK 3, flow window = 2
ACK 4, flow window = 2
120ms
130ms
Frame 4
140ms
Frame 5
ACK 5, flow window = 2
ACK 6, flow window = 2
180ms
190ms
Frame 6
200ms
Frame 7
ACK 7, flow window = 2
ACK 8, flow window = 2
240ms
250ms
Frame 8
260ms
Frame 9
ACK 9, flow window = 2
ACK 10, flow window = 2
300ms
310ms