third bit from the left is inverted during transmission. Show that this error is detected at the receiver’s end. Give an example of bit errors in the bit string transmitted that will not be detected by the receiver.

25. A bit stream 11100110 is transmitted using the standard CRC method described in the text. The generator polynomial is x4 + x3 + 1. Show the actual bit string transmitted. Suppose that the third bit from the left is inverted during transmission. Show that this error is detected at the receiver’s end. Give an example of bit errors in the bit string transmitted that will not be detected by the receiver.
26. Data link protocols always put the CRC in a trailer rather than in a header. Why?
27. In the discussion of ARQ protocol in Section 3.3.3, a scenario was outlined that resulted in the receiver accepting two copies of the same frame due to a loss of acknowledgement frame. Is it possible that a receiver may accept multiple copies of the same frame when none of the frames (message or acknowledgement) are lost?
28. A channel has a bit rate of 4 kbps and a propagation delay of 20 msec. For what range of frame sizes does stop-and-wait give an efficiency of at least 50%?
29. Two protocols, A and B, only differ in their sending window sizes. Protocol A uses a sending window of 20 frames. Protocol B is a stop-and-wait protocol. The two protocols run on two identical channels. If Protocol A achieves almost 100% bandwidth efficiency, what is the bandwidth efficiency of Protocol B?

30. A stop-and-wait protocol achieves 25% bandwidth efficiency using 900-bit frames over a channel with a one-way propagation delay of 50 msec. What is the bandwidth of this channel in bits per second?
31. A stop-and-wait protocol achieves 60% bandwidth efficiency using 300-bit frames over a channel with a bandwidth of 50 kbps. What is the one-way propagation delay of this channel?
32. A stop-and-wait protocol that uses 800-bit frames runs on a channel with a one-way propagation delay of 8 msec and a bandwidth of 1200 kbps. What is the bandwidth efficiency this protocol achieves on this channel?
33. A sliding window protocol uses 1000-bit frames and a fixed sending window size of 3. It achieves almost 100% bandwidth efficiency on a 250 kbps channel. The same protocol is used on an upgraded channel that has the same delay, but double the bandwidth. What is the protocol's bandwidth efficiency on the new channel?
34. In protocol 3, is it possible for the sender to start the timer when it is already running? If so, how might this occur? If not, why is it impossible?
35. A 3000-km-long T1 trunk is used to transmit 64-byte frames using protocol 5. If the propagation speed is 6 μsec/km, how many bits should the sequence numbers be?
36. Imagine a sliding window protocol using so many bits for sequence numbers that wraparound never occurs. What relations must hold among the four window edges and the window size, which is constant and the same for both the sender and the receiver?

37. In protocol 6, when a data frame arrives, a check is made to see if the sequence number differs from the one expected and *no_nak* is true. If both conditions hold, a NAK is sent. Otherwise, the auxiliary timer is started. Suppose that the else clause were omitted. Would this change affect the protocol's correctness?
38. Suppose that the three-statement while loop near the end of protocol 6 was removed from the code. Would this affect the correctness of the protocol or just the performance? Explain your answer.
39. In the previous problem, suppose a sliding window protocol is used instead. For what send window size will the link utilization be 100%? You may ignore the protocol processing times at the sender and the receiver.
40. Suppose that the case for checksum errors were removed from the switch statement of protocol 6. How would this change affect the operation of the protocol?
41. In protocol 6, the code for *frame_arrival* has a section used for NAKs. This section is invoked if the incoming frame is a NAK and another condition is met. Give a scenario where the presence of this other condition is essential.
42. Consider the operation of protocol 6 over a 1-Mbps error-free line. The maximum frame size is 1000 bits. New packets are generated 1 second apart. The timeout interval is 10 msec. If the special acknowledgement timer were eliminated, unnecessary timeouts would occur. How many times would the average message be transmitted?

43. In protocol 6, MAX_SEQ = 2n - 1. While this condition is obviously desirable to make efficient use of header bits, we have not demonstrated that it is essential. Does the protocol work correctly for MAX_SEQ = 4, for example?
44. Frames of 1000 bits are sent over a 1-Mbps channel using a geostationary satellite whose propagation time from the earth is 270 msec. Acknowledgements are always piggybacked onto data frames. The headers are very short. Three-bit sequence numbers are used. What is the maximum achievable channel utilization for
    a. Stop-and-wait?
    b. Protocol 5?
    c. Protocol 6?

45. Negative acknowledgements directly trigger a response at the sender, while the lack of positive acknowledgements only triggers an action after a timeout. Is it possible to build a reliable communication channel using only negative acknowledgements, and no positive acknowledgements? If it is possible, give an example. If it is impossible, explain why.
46. Consider an error-free 64-kbps satellite channel used to send 512-byte data frames in one direction, with very short acknowledgements coming back the other way. What is the maximum throughput for window sizes of 1, 7, 15, and 127? The earth-satellite propagation time is 270 msec.
47. A 100-km-long cable runs at the T1 data rate. The propagation speed in the cable is 2/3 the speed of light in vacuum. How many bits fit in the cable?