ESD5 – Fall 2024
Problem Set 1

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Problem 1 – The Price of a Protocol

Consider that Alice wants to transmit 5,000 bytes of data to Bob. The communication protocol between Alice and Bob consists of the following elements: an error detection mechanism based on CRC, a feedback mechanism based on ARQ with sequence number, and a two-way connection with piggybacking in order to enable transmission/feedback from/to either Alice or Bob. The accordingly frame structure is shown in Fig. 1.

(a) What is the minimum number of frames required to be transmitted by Alice in order to convey the 5,000 bytes of data to Bob?

(b) Consider that the communication channel that connects Alice and Bob supports a data rate of 1 kbit/s. What would be the minimum time required for Alice's data to reach Bob if the ARQ procedure was not present and communication was error-free?

In computer network terminology, **throughput** refers to the rate of successful messages (frames) transmitted over a communication channel during a certain time period. For example, in (b), the throughput would be equal to the data rate of the channel of 1 kbit/s, since the communication is error-free. However, a message is comprised of bits that are useless to Alice, but still useful for the protocol; these are called control bits. Moreover, the

preamble	pkt length	own seq number	other seq number	CRC error detection	data
1 byte	6 bits	1 bit	1 bit	1 byte	1-64 bytes

Figure 1: Protocol frame adopted by Alice and Bob.

bits that are useful for Alice are called data bits. Hence, another useful metric to measure the efficiency of the communication is the so-called **goodput**, which is the rate of successful useful information transmitted over a communication channel during a certain time period. Thus, the goodput excludes the protocol overhead, giving us a better sense of communication efficiency with respect to the complexity of the adopted protocol.

(c) What is the efficiency of the protocol adopted? Then, what is the goodput in bit/s following the considerations made in (b)?

(d) Considering a very specific scenario where only Alice transmits and Bob receives with a fixed data packet length of 64 bytes. How would you change the frame to make the protocol more efficient? What is the efficiency gain and the new goodput when comparing the new protocol to the old one?

Problem 2 – Feedback Latency

Consider the same scenario introduced in Problem 1 and the frame depicted in Fig. 1. Now, assume that a frame sent by Alice takes from 5 to 20 ms to be received by Bob, which is also valid from Bob to Alice. On average, this delay in receiving is 10 ms. Recall that Alice wants to transmit 5,000 bytes of data to Bob.

(a) What is the minimum time required by Alice to know that a frame has been lost? And the maximum?

(b) Assuming that all frames are received successfully, what is the *average* throughput in bit/s of Alice's transmission by considering now the ACKs from Bob?

Consider now that Alice transmits 10,000 frames to Bob and assume that every 100-th frame is lost in transmission. Consider only that frames from Alice can be in error, while ACKs/NACKs are perfectly sent from Bob.

(c) How many retransmissions would occur?

(d) How long would it take to transmit all frames on average? Assume that all retransmission is successful.

Problem 3 – RS-232

For this problem, assume that Alice and Bob are connected via a serial link and their communication follows the recommended standard 232 (RS-232).

(a) Draw a diagram showing the evolution over time of the voltage levels within an RS-232 frame to transmit the lowercase ASCII character "`h`" from Alice to Bob.[1]

[1]For reference, look at the ASCII table available on `https://www.asciitable.com/`. Hint: Note the difference between the ASCII of lowercase and uppercase letters.

(b) Consider a baud rate of 9,600 bit/s. How long would it take for to Alice send the sentence "`hello world`" to Bob assuming error-free communication? Assume that each RS-232 frame is comprised of a start bit and a stop bit and that there are no parity bits.

(c) Assume the use of the parity bit now and consider the even parity bit scheme[2]. The transmitter wants to send the following ASCII character: `0 1 1 0 0 0 0 1`. Which character is it? What is the parity check bit that needs to be appended to this data? Consider the following reception situations for the data sent:

   (i) `0 1 1 1 0 0 0 1`. Which character was received? Can the error be detected?

   (ii) `0 1 1 1 0 1 0 1`. Which character was received? Can the error be detected?

Problem 4 – ARQ with Limited Retransmissions

In Example 3 of Lecture 5, we show the average delay under the assumption of infinite retransmissions. This assumption means that, if we have an unbounded time to receive data, then the transmission success probability over the *Binary Symmetric Channel* (BSC) is always 1. These are the theoretical insights obtained by our analysis. However, infinite retransmission attempts might not be practical, considering the communication system's stringent latency requirement. So, in this problem, we investigate the performance when we set the constraint for the number of retransmissions. Let K be the maximum number of retransmissions for a single packet. We consider a scenario where Alice wants to deliver M packets to Bob in a BSC where the *Packet Error Rate* (PER) is $p_{\mathrm{PER}} = 0.1$.

(a) Let us focus on the case where $M = 1$. Calculate the probability of successful packet transmission for $K = 1$, and then for $K = 2$.

(b) Calculate the throughput for $K = 1$, and then for $K = 2$.

(c) Characterize the relationship between the throughput, the probability of successful packet transmission, and the value of K.

(d) Let us consider the case where $M = 2$, meaning that Alice wants to send 2 packets to Bob. In this case, we are interested in the probability of the 2 data packets being transmitted by a deadline of 5 slots. This probability is known as the *reliability* of the communication system. Does the number of retransmissions that Alice can send for each packet affect the reliability? Explain it.

[2]Please, read more about parity bit in `https://en.wikipedia.org/wiki/Parity_bit`.