CSC358H5: Principles of Computer Networking — Winter 2025

Worksheet 3: Probability Review, Abstract Model of Link, Error Detection and Correction

Q0 Knowledge Check (from Week 03 Lecture)

0.a (Bandwidth, Throughput, and Goodput) Erfan claims that he transferred 1000 bytes in 1 second on a 100 Mbps point-to-point link. Determine the bandwidth, throughput, and goodput of this connection.

Bandwidth:	☐ 1000 bps	☐ 100 Mbps	☐ 8 Kbps	☐ Can't be determined
Throughput:	☐ 1000 bps	☐ 100 Mbps	☐ 8 Kbps	☐ Can't be determined
Goodput:	☐ 1000 bps	☐ 100 Mbps	☐ 8 Kbps	☐ Can't be determined

0.b (Error Detection and Correction Codes) In 2-3 sentences, describe Error Detection Codes and Error Correction Codes. Furthermore, specify the advantages and disadvantages of each of these two techniques.

0.c (ARQ vs. FEC) For each cases below, choose the more appropriate technique between Automatic Repeat reQuest (ARQ) and Forward Error Correction (FEC).

Case 1: Sending packets of size 1000 bits over a link with bit error rate of 0.001 with random errors.

☐ ARQ ☐ FEC

Case 2: Sending packets of size 1000 bits over a link with bit error rate of 0.001 with bursty error of 1000 bits.

☐ ARQ ☐ FEC

Case 3: Sending packets of size 1000 bits over a link with bit error rate of 0.001 for real-time application (*e.g.*, teleconference) .

☐ ARQ ☐ FEC

Q1 (Probability Review) The following ARQ-themed questions are designed to provide a concise review of the probability concepts you'll need for this course.

1.a A packet of size 1000 bits is transmitted over a link with an independent and identically distributed (i.i.d.) error model. Given a bit error rate of 0.001, **what is the probability that the packet is transmitted without any errors?** You can use the following estimation: $(1-\epsilon)^k \approx e^{-k\epsilon}$.

[Probability Theory Refresher: The random variable that can be used to model *the error in each bit* is the **Bernoulli random variable**. A Bernoulli random variable models a single experiment with two possible outcomes: success (usually represented as 1) or failure (usually represented as 0). In this case, a bit error can be considered a "success" (even though it's undesirable) and no error can be considered a "failure." In this scenario,, the probability of success (bit error) is given as $p = 0.001$, and the probability of failure (no error) is $q = 1 - p = 0.999$.

We can model each bit transmission as an independent Bernoulli trial with a probability of error (success) of $p = 0.001$. To find the probability that the entire packet is transmitted without error, we are essentially looking for the probability of 1000 consecutive "failures" (no errors).**]**

1.b Referring to the scenario in part **1.a**, suppose Stop-and-Wait ARQ is employed for reliable packet transmission. In Stop-and-Wait ARQ, the sender transmits a single packet and waits for an acknowledgment (ACK) from the receiver before sending the next packet. If no ACK is received due to a timeout, the sender retransmits the same packet. Calculate the average number of transmissions required to successfully deliver one packet. Assume the acknowledgments to be error-free for simplicity.

[**HINT:** The expectation of a geometric random variable with probability success of ρ is $\frac{1}{\rho}$.]

[Probability Theory Refresher: The random variable that can be used to model the number of transmissions for a packet in this Stop-and-Wait ARQ scenario is the **Geometric random variable**. A Geometric random variable models the number of independent Bernoulli trials needed to get the first "success." In this context, a "success" is a successful packet transmission (*i.e.*, the packet is received without errors, and an ACK is received).

We need to determine the probability of a single successful transmission. This involves the packet being transmitted without error and the ACK being received (which we assume to be error-free for simplicity

in this problem). We already calculated this probability in part **1.a**.
As mentioned in the hint, the average number of independent Bernoulli trials needed to get the first "success" is $\frac{1}{\rho}$, where ρ is the probability of success in each trial. Deriving this formula is covered in introductory probability courses and can be reviewed in this Khan Academy video. In CSC358, you are **not** required to derive this expectation. You will be provided with the formula for the expected value of a geometric random variable whenever needed, as demonstrated in this question's hint.**]**

1.c Consider the problem described in part **1.b**. Assume that the link bandwidth is infinity and the one-way delay is 1 ms. Furthermore, assume that the time-out (*i.e.*, the time between sending the last bit of a packet and waiting for its ACK) is set to one round-trip-time (RTT). What is the average time it takes between transmitting the first bit of the packet for the first time and receiving its acknowledgment.

1.d Now, assume that we are sending a message of 10 packets, each with size 1000 bits, with Stop-and-Wait ARQ over the link described in part **1.c**. What is the average time between transmitting the first bit of the first packet for the first time and receiving the acknowledgment for the last packet.

Q2 **(Throughput and Message End-to-end Latency Timeline)** Suppose we have a file of 12.5 Kb to be transmitted over a point-to-point connection. Assume that the propagation delay is 5 ms and packet size is 2.5 Kb. Furthermore, assume that:

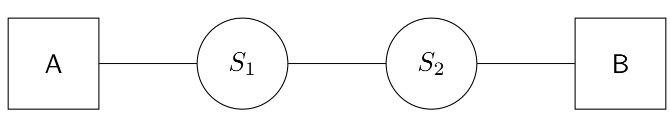
- The packets' header size and queuing delay are negligible.
- Prior to sending the file, we have to spent one round-trip-time (RTT) for "initial handshake," which is a process for establishing the connections.
- After receiving the acknowledgment for the last packet, we have to spent two RTT for "connection termination", which is a process for terminating the established connection between two hosts.
- The size of packets during "initial handshake" and "connection termination" is negligible.

2.a Assume that the bandwidth is 1 Mbps and we must wait for the acknowledgment of each packet before start sending the next one. Assume that the acknowledgment size is negligible and non of the packets and acknowledgments are lost. Draw the message end-to-end timeline diagram and Calculate the link throughput.

2.b Assume the bandwidth is infinite and in each one RTT, only 20 packets are allowed to be sent. Assume that the acknowledgment size is negligible and non of the packets and acknowledgments are lost. Draw the message end-to-end timeline diagram and Calculate the link throughput.

2.c Assume the bandwidth is infinite. During the first RTT we can send 1 packet and receive its ACK. During the second RTT we can send up to 2 packets and receive their ACKs. During the third we can send up to 4 packets and receive their ACKs and so on. Assume that the acknowledgment size is negligible and non of the packets and acknowledgments are lost. Draw the message end-to-end timeline diagram and Calculate the link throughput.

Q3 **(Optimal Packet Size)** Consider sending a large file of F bits from Host A to Host B using packet switching in the network below. There are three hops of links between Host A and Host B, *i.e.*, therefore two switches



along the path that connects Host A to Host B. Assume that

- The propagation delay is negligible.
- Each link has a transmission rate of R bps.
- The links are *uncongested*, *i.e.*, no queuing delays.
- The two switches are store-and-forward switches.

Host A splits the file into chunks of S bits each and adds 80 bits of Transport, Network, and Link layer header to each chunk, forming *frames* of size $L = 80 + S$ bits. Assume that if the last chunk is smaller than S bits, Host A pads it with zeros to ensure it is exactly S bits in size.

3.a Suppose you are the network administrator to decide on the value of S. Discuss, qualitatively, the pros and cons of choices of S values that are very large or very small.

3.b Now do the math. Find the value of S that minimizes the delay of moving the file from Host A to Host B.