1. Calculate the total time required to transfer a 1000-KB file in the following cases, assuming an RTT of 50 ms, a packet size of 1 KB data, and an initial 2×RTT of "handshaking" before data is sent. We define the total time of transferring the file as the time elapsed from the starting of initial handshaking to the instant when the last bit arrives at the receiver.

(a) The bandwidth is 1.5 Mbps, and data packets can be sent continuously (i.e., packets are put up on the medium by the transmitter one after another without any wait/whitespace time in between).

(b) The bandwidth is 1.5 Mbps, but after we finish sending each data packet we must wait one RTT before sending the next.

(c) The bandwidth is "infinite," meaning that we take transmit time to be zero, and up to 20 packets can be sent per RTT.

(d) The bandwidth is infinite, and during the first RTT we can send one packet (2^{1-1}), during the second RTT we can send two packets (2^{2-1}), during the third we can send four (2^{3-1}), and so on.

(a) Propagation delay = RTT / 2 = 50 ms /2 = 25ms

Packet size (bits) = 1 KB · 8 bits/byte · 1024 bytes/KB = 8192 bits

Bandwidth (bps) = 1.5 Mbps · 1000000 = 1500000 bps

Transmission time (per packet) = $\frac{8192 \text{ bits}}{1500000 \text{ bps}}$ = 5.461 ms

Total transmission time = 1000 packets · 5.461 ms = 5461.3ms

total time = 100 + 5461.3 + 25 = 5586.3ms

(b) Time per packet (999 packets) = 5.461ms + 50ms = 55.461ms

Time for 999 packets = 999 · 55.461 ms = 55405.9 ms

Last packet time = 5.461ms + 25ms = 30.461 ms

total time = 100 + 55405.9 + 30.461 = 55536.3ms

(c) RTT periods $= \frac{1000}{20} = 50$ periods

time to send packets $= 50$ periods $\cdot$ 50 ms/per. $= 2500$ ms

total time $= 100 + 2500 + 25 = 2625$ ms

(d) $2^x = 1000$

$2^9 = 512$

$2^{10} = 1024$

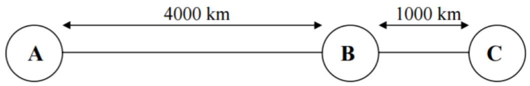
so 10 periods

time to send all packets $= 10$ periods $\cdot$ 50 ms/per. $= 500$ms

total time $= 100 + 500 + 25 = 625$ ms

2. In the figure below, all frames are generated at node A and sent to node C through node B. Determine the minimum transmission rate required between nodes B and C so that the buffers of node B are not flooded, based on the following conditions:

- The data rate between A and B is 100 kilobits/s.
- The propagation delay is 5 μs/km for both lines.
- There are full-duplex lines between the nodes.
- All data frames are 1000 bits long; ACK frames are separate frames of negligible length.
- Between A and B, a sliding-window flow control with a window size of 3 is used.
- Between B and C, stop-and-wait flow control is used.
- There are no errors.



$A + B = 4000\text{ km} \cdot 5\ \mu s/\text{km} = 20000\ \mu s = 20\text{ ms}$

$RTT = \text{trans. time} + 2 \times (\text{prop.})$

$RTT = 10 + 2 \cdot 20 = 50\text{ ms}$

Sliding window size $W = 3$.

$\text{Max. throughput} = \frac{W \cdot L}{RTT} = \frac{3 \cdot 1000}{0.05\text{s}} = 60{,}000\text{ bps} = 60\text{ kb/s}$

$B + C = 1000\text{ km} \times 5\ \mu s/\text{km} = 5000\ \mu s = 5\text{ ms}$

$RTT = 10\text{ ms}$

transmission rate $= R$ (bps), transmit time $= 1000/R$ s.

Stop + wait cycle time $= \frac{1000}{R} + 0.01\text{s}$

$\text{Throughput} = \frac{1000}{(1000/R + 0.01)}\text{ bps}$

$$\frac{1000}{(1000/R + 0.01)} \geq 60\,000$$

$$1000 \geq 60000\,(1000/R + 0.01)$$

$$1000 \geq 60000 \cdot \frac{1000}{R} + 600$$

$$400 \geq 60000 \cdot \frac{1000}{R}$$

$$R \cdot 400 \geq 60000000$$

$$R \geq \frac{60000000}{400}$$

$$R \geq 15{,}000$$

min. $R \geq 150$ Kb/s

3. For each of the following sets of codewords, please give the appropriate (n,k,d) designation where n is number of bits in each codeword, k is the number of message bits transmitted by each code word and d is the minimum Hamming distance between codewords. What is the coding rate (k/n), error detection capability, and error correction capability for each coding scheme?

??

A. {111, 100, 001, 010}
B. {00000, 01111, 10100, 11011}

A. $\{111, 100, 001, 010\}$

$n = 3$

$K = 2$

$d = 2$

$k/n = 2/3$

$d - 1 = 2 - 1 = 1$

$\frac{(d-1)}{2} = \frac{1}{2} = 0$

B. $\{00000, 01111, 10100, 11011\}$

$n = 5$

$K = 2$

$d = 2$

$\frac{K}{n} = \frac{2}{5}$

$d - 1 = 2 - 1 = 1$

$\frac{d-1}{2} = \frac{2-1}{2} = \frac{1}{2} = 0$

4. In an error-correction code, an important constraint that the coding scheme must satisfy is that the number of added check bits should be sufficient to identify unique error patterns (note that no error is also a valid error pattern). Now suppose that we decide to use a (n, 20, 3) error correction code to transmit 20-bit messages. What's the minimum value of n that will allow the code to correct single bit errors? Show the reason and the calculation for full credits.

$2^{n-k} \geq n+1$

$k=20$

$2^{n-20} \geq n+1$

$n=24$

$2^{24-20} \geq 24+1$

$2^{4} \geq 25$

$16 \geq 25$ X

$n=25$

$2^{25-20} \geq 25+1$

$2^{5} \geq 26$

$32 \geq 26$ ✓

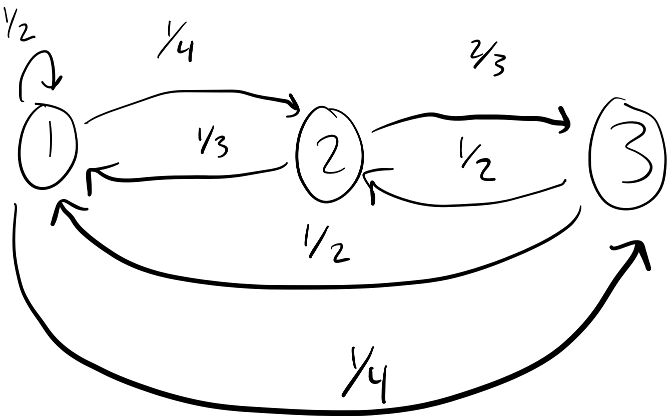
$n=25$

5. Consider the Markov chain with three states, S={1, 2, 3}, that has the following transition matrix

$$P = \begin{bmatrix} \frac{1}{2} & \frac{1}{4} & \frac{1}{4} \\ \frac{1}{3} & 0 & \frac{2}{3} \\ \frac{1}{2} & \frac{1}{2} & 0 \end{bmatrix}.$$

(a) Draw the state transition diagram for this chain.
(b) If we know P(X1=1)=P(X1=2)=1/4, find P(X1=3, X2=2, X3=1).

(a)



(b) $X_{11}=\frac{1}{4}$ $X_{12}=\frac{1}{4}$

$P(X_1=3) = 1-\frac{1}{4}-\frac{1}{4} = \frac{1}{2}$

$P(X_1=3, X_2=2, X_3=1) = P(X_1=3) \times P(X_2=2|X_1=3) \times P(X_3=1|X_2=2)$

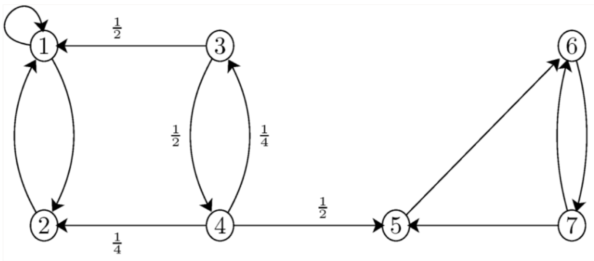
$P(X_2=2|X_1=3) = P(X_3=2) = \frac{1}{2}$

$P(X_3=1|X_2=2) = P(X_2=1) = \frac{1}{3}$

$P(X_1=3, X_2=2, X_3=1) = \frac{1}{2}\cdot\frac{1}{2}\cdot\frac{1}{3} = \frac{1}{12}$

$P(X_1=3, X_2=2, X_3=1) = \frac{1}{12}$

6. Consider the Markov chain in the following figure. There are two recurrent classes, R1={1, 2} and R2={5,6,7}. Assuming initial state X0=3. Find the probability that the chain gets absorbed in R1.



$$\begin{array}{c|c} & \begin{array}{cccc} R1 & 3 & 4 & R2 \end{array} \\ \begin{array}{c} R1 \\ 3 \\ 4 \\ R2 \end{array} & \begin{bmatrix} 0 & 0 & 0 & 0 \\ \frac{1}{2} & 0 & \frac{1}{2} & 0 \\ \frac{1}{4} & \frac{1}{4} & 0 & \frac{1}{2} \\ 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

$$\pi_3 = \frac{1}{2}(\pi R_1) + \frac{1}{2}(\pi_4)$$

$$\pi_4 = \frac{1}{4}(\pi R_1) + \frac{1}{4}(\pi_3) + \frac{1}{2}(\pi R_2)$$

$$\pi_3 = \frac{1}{2}(1) + \frac{1}{2}(\pi_4)$$

$$\pi_4 = \frac{1}{4}(1) + \frac{1}{4}(\pi_3) + \frac{1}{2}(0)$$

$$\pi_3 = \frac{1}{2} + \frac{1}{2}\pi_4$$

$$\pi_4 = \frac{1}{4} + \frac{1}{4}\pi_3$$

$$\pi_3 = \frac{1}{2} + \frac{1}{2}\left(\frac{1}{4} + \frac{1}{4}\pi_3\right)$$

$$\pi_3 = \frac{1}{2} + \frac{1}{8} + \frac{1}{8}\pi_3$$

$$\frac{7}{8}\pi_3 = \frac{5}{8}$$

$$\pi_3 = \frac{5}{7}$$