EE 506/CS 513

Introduction to Local and Wide Area Networks

Take-Home Final Examination

July 25, 2009

Due: Beginning of Class on Tuesday, July 28, 2009

Open Book

Open Notes

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There are eleven questions in this examination, and most problems are weighted equally at nine points. You must complete all eleven questions correctly to obtain full credit for the examination.

1. Polynomial codes are typically used for the detection of transmission errors in computer networks. Consider a polynomial code which is based on the generator polynomial $G(X) = X^5 + X^3 + X^2 + 1$.

(a) Given the message polynomial $M(X) = X^{12} + X^{10} + X^8 + X^5 + X^2 + 1$, compute the corresponding valid code polynomial $T(X)$. (5 points)

* See following page for work. *

$$\boxed{T(x) = x^{17} + x^{15} + x^{13} + x^{10} + x^7 + x^5 + x^2 + 1}$$

(b) What error patterns can be detected by this generator polynomial, **and** what fraction of errors can be detected by this generator polynomial? (4 points)

Fraction of errors that can be detected = Fault coverage

$= 1 - 2^{-r}$ ~ $r = 5$ (degree of $G(x)$)

$= 1 - 2^{-5} = .96875$

$$\boxed{\text{Fault Coverage} = 96.875\%}$$

Types of errors detected:

* Note: since $(x+1)$ is NOT a factor, all single bit / odd bit error patterns CANNOT be detected!

~ Given that the degree of $G(x) = r = 5$;

$\boxed{\text{Burst errors of length 5 or less}}$ can be detected.

Problem # 1

Given $\rightarrow$ $G(x) = x^5 + x^3 + x^2 + 1$

$M(x) = x^{12} + x^{10} + x^8 + x^5 + x^2 + 1$

a) Compute $T(x)$:

~ Looking at $G(x) = x^{5} + x^3 + x^2 + 1$, $r = 5$

$\therefore$ $x^5 M(x) = x^{17} + x^{15} + x^{13} + x^{10} + x^7 + x^5$

Perform Long Division:

$$
\begin{array}{r|l}
 & x^{12} + x^9 + x^6 + x^3 + 1 \\
\hline
x^5 + x^3 + x^2 + 1 & x^{17} + (16) + x^{15} + (14) + x^{13} + (12) + (11) + x^{10} + (9) + (8) + x^7 + (6) + x^5 + (4) + (3) + (2) + (1) + (0) \\
 & x^{17} \quad x^{15} \quad x^{14} \quad x^{12} \\
\hline
 & x^{14} + x^{12} \\
 & x^{14} \quad x^{12} \quad x^{11} \quad x^9 \\
\hline
 & x^{11} + x^9 \\
 & x^{11} \quad x^9 \quad x^8 \quad x^6 \\
\hline
 & x^8 + x^6 \\
 & x^8 \quad x^6 \quad x^5 \quad x^3 \\
\hline
 & x^5 + x^3 \\
 & x^5 \quad x^3 \quad x^2 \quad 1 \\
\hline
 & x^2 + 1
\end{array}
$$

$\therefore$ $R(x) = x^2 + 1$

$\Rightarrow$ $T(x) = x^r M(x) + R(x)$

$$\boxed{T(x) = x^{17} + x^{15} + x^{13} + x^{10} + x^7 + x^5 + x^2 + 1}$$

b) Fraction of errors that can be detected = Fault coverage

$= 1 - 2^{-r}$ ~ $r = 5$ (degree of $G(x)$)

$= 1 - 2^{-5} = .96875 = \boxed{96.875\%}$

Types of errors detected:

$\boxed{\rightarrow \text{Burst errors of length 5 or less}}$

* Note: since $(x+1)$ is NOT a factor, all single bit / odd bit error patterns CANNOT be detected!

2. A channel has a data rate of 64 kbps and a propagation delay of 20 msec. For what range of frames sizes does a stop-and-wait protocol have an efficiency of at least 50%? (9 points)

From Pg. 217 in Tanenbaum :

Pipelining states that given a channel capacity of b bits/sec, a frame size of l bits, and a roundtrip time of R :

$$\text{Efficiency} = \text{line utilization} = \frac{l}{l+bR}$$

$\Rightarrow$ Set efficiency to be atleast 50%:

$$.5 = \frac{l}{l+bR} \sim .5l + .5bR = l \sim l = bR$$

$\Rightarrow$ Given : $b = 64 \times 10^3$ bits/sec

$R = 2 \times (20 \times 10^{-3})$ sec

$\sim$ $b = (64 \times 10^3 \text{ bits/sec})(2 \times (20 \times 10^{-3}) \text{ sec})$

$\boxed{b = 2560 \text{ bits}}$

3. Consider the Go-Back-N and Selective Repeat sliding window protocols given a noise-less (error-free) channel. The frame size is 1000 bits, headers are short and ACKs are always piggybacked. What is the optimal window size that will achieve maximum channel utilization for these protocols over a 64 kbps satellite channel with a round-trip delay time of 0.54 seconds, **and** how many sequence bits are required by **each protocol** to achieve this utilization? (9 points)

Go Back N = Protocol 5
Selective Rep = Protocol 6

Given: $C = 64 \times 10^3$ bits/sec
$2I = 0.54$ sec

→ Maximum channel utilization occurs when $U = 1$
→ Assuming that ACK is negligible, use the following equation to determine the optimal window size:

$$U = \left(\frac{D}{H+D}\right)\left[\frac{W}{1+\left(\frac{2 \cdot C \cdot I}{H+D}\right)}\right]$$

~ Since headers are small, set $H = 0$ ~

$$U = \left(\frac{D}{\cancel{H}+D}\right)\frac{W}{1+\left(\frac{2 \cdot C \cdot I}{D}\right)}$$

Optimal window size, W, $= U\left[1 + \frac{C \cdot 2I}{D}\right] = (1)\left[1 + \frac{64 \times 10^3 \text{ bits/sec} \times .54 \text{ sec}}{1000 \text{ bits}}\right]$

$$\boxed{W = \lceil 34.56 \rceil = 35}$$

~ For: Go Back N (Protocol 5) →

$W < 2^{n-1}$
$35 < 2^{n-1}$
$36 < 2^n$

$n \overset{?}{=} 5$: $36 < 32$ ⊗
$n \overset{?}{=} 6$: $36 < 64$ ✓

$\boxed{\text{6 bits are needed}}$

~ For: Selective Repeat (Protocol 6) →

$$W < \frac{[\overbrace{(2^n-1)}^{\text{MAX-SEQ}}+1]}{2}$$

$2W < 2^n$

$70 < 2^n$

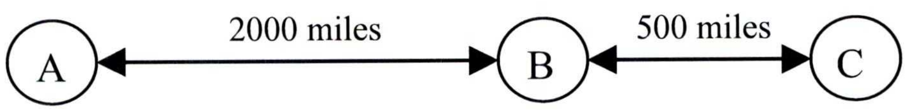
$n \overset{?}{=} 5$: $70 < 32$ ⊗
$n \overset{?}{=} 6$: $70 < 64$ ⊗
$n \overset{?}{=} 7$: $70 < 128$ ✓

$\boxed{\text{7 bits are needed}}$

4. In the network shown below, frames are generated at Node A and sent to Node C through Node B. Nodes B and C acknowledge each data frame immediately upon receipt to Nodes A and B, respectively. The channel data rate between Nodes A and B is 100 kbps. The lines between each pair of nodes are full-duplex, and the propagation delay for each line is 10 μsec/mile. All data frames are 1000 bits long and ACKs are separate frames of negligible length. A sliding window protocol with a window size of 3 is used between Nodes A and B, and a stop-and-wait protocol is used between Nodes B and C. All lines are error-free and no frames can be lost.

Determine the minimum data rate required between Nodes B and C so that the buffers of node B are not flooded. (9 points)

Hint: The buffers of node B will not be flooded if the average number of frames entering and leaving Node B are equal over a long time interval (at steady-state).



∴ First, find propagation and transmission times between A ↔ B and B ↔ C.

A ↔ B Prop time $= 2000 \text{ miles} \times [10 \times 10^{-6} (\text{miles}/\text{sec})^{-1}] = .02 \text{ sec} = 20 \text{ msec}$

A ↔ B Tx / frame $= \dfrac{1000 \text{ bits}}{100 \times 10^3 \text{ bits}/\text{sec}} = .01 \text{ sec} = 10 \text{ msec}$

B ↔ C prop time $= 500 \text{ miles} \times [10 \times 10^{-6} (\text{sec}/\text{mile})] = .005 \text{ sec} = 5 \text{ msec}$

T = B ↔ C Tx / frame $= \dfrac{1000 \text{ bits}}{R}$ → R = minimum channel data rate b/w B ↔ C

→ This is what we are looking for!

Looking @ packet timetable (A → B):

① Tx first frame of 3 size window into channel = 10 ms
② 1st frame arrival at Node B (last bit) = 20 ms ⊕ 50 ms to transmit 3 frames
③ ACK received back @ Node A (negl. length) = 20 ms

Looking @ packet time table (B → C)

① Tx frame into channel = T
② Frame arrival @ Node C = 5 msec ⊕
③ ACK received back @ Node B = 5 msec

$[10 \text{ msec} + T] \times 3$ for stop-and-wait protocol $= (30 + 3T)$ msec to transmit 3 frames

Since we have time for transmission in and out of B for 3 frames:

$50 \text{ msec} = [30 + 3T] \text{ msec}$

$T = \left(\frac{20}{3}\right) \text{ msec}$

∴ $T = \dfrac{1000 \text{ bits}}{R} \approx R = \dfrac{1000 \text{ bits}}{\left(\frac{20}{3}\right) \times 10^{-3} \text{ sec}}$

$\boxed{R = 150 \text{ kbps}}$

5. Ten thousand airline reservation stations are competing for the use of a single slotted ALOHA channel. The average station makes 18 requests/hour and a slot is 125 μsec in duration. What is the approximate total channel load **and** resulting throughput? (9 points)

Given

- → 10,000 airline stations
- → single slotted ALOHA channel
- → average station : 18 requests / hour $\times \frac{1 \text{ hr}}{3600 \text{ sec}} = .005 \frac{\text{requests}}{\text{second}}$
- → slot = 125 μsec = 125×10^{-6} sec

↝ Using information, we find that the total load due to the 10,000 stations is :

$$L = .005 \frac{\text{requests}}{\text{second}} \times 10000 \text{ (stations)} = 50 \frac{\text{requests}}{\text{second}}$$

↝ To find G, divide load seen by the # of slots seen per second:

$$F = \frac{1 \text{ second}}{125 \times 10^{-6} \text{ sec/slot}} = 8000 \text{ slots}$$

∴ $\boxed{G = \frac{L}{F} = .00625}$

Equation for throughput for a single slotted ALOHA channel:

$$S = Ge^{-G} = .00625\, e^{-.00625}$$

$$\boxed{S = .00621}$$

6. Consider designing a 1 km-long, 1 Gbps LAN which uses CSMA/CD and has a propagation speed of 200 m/μsec. What is the minimum frame size **and** the optimal channel efficiency that can be achieved using this frame size? (9 points)

Line rate $= 1 \times 10^9$ bits/sec

Line length $= 1 \times 10^3$ m

Propagation speed $= 200 \text{ m}/\mu\text{sec} \times \frac{10^6 \ \mu\text{sec}}{1 \text{ sec}} = 2 \times 10^8$ m/sec

Calculated roundtrip delay time $= 2\left[\frac{(1\times 10^3 \text{ m})}{2 \times 10^8 \text{ m/sec}}\right] = 1 \times 10^{-5}$ sec

$\therefore$ At 1 Gbps, the line will be filled @ :

$$w = (1 \times 10^9 \text{ bits/sec}) \cdot (1 \times 10^{-5} \text{ sec})$$

$$\boxed{w = 10{,}000 \text{ bits or } 1250 \text{ bytes}}$$

To find optimal channel efficiency, use the following formula:

$$U = \frac{1}{1 + \frac{2BLe}{cF}}$$

$B = 1 \times 10^9$ bits/sec
$L = 1 \times 10^3$ m
$c = 2 \times 10^8$ m/sec
$F = 10{,}000$ bits

$$U = \frac{1}{1 + \frac{2(1\times 10^9 \text{ bits/sec})(1 \times 10^3 \text{ m})e}{(2 \times 10^8 \text{ m/sec})(10{,}000 \text{ bits})}} = \frac{1}{1+e}$$

$$\boxed{U = .2689}$$

7. Consider a CSMA/CD LAN with N independent stations. The probability that a station will transmit on an interference interval when given the opportunity is *p*.

(a) Derive a formula for the probability *P(A)* that one and only one station will transmit on an interference interval. (5 points)

→ The $P[\text{one station Tx}] = p(1-p)^{N-1}$ ~ 1 successful transmission, followed by (N-1) failures.

* To account for all single base station probabilities ; we multiply the above result by N. ~ st. 1 TX OR st. 2 TX OR ... OR st. N Tx

$$\boxed{P(A) = N p (1-p)^{N-1}}$$

(b) Compute the value of the probability *p* which maximizes the value of *P(A)*, thereby achieving maximum throughput for this LAN. (5 points)

In order to maximize the value of p, we take the derivative of P(A) with respect to p and set the expression = 0

$$\frac{d}{dp}[P(A)] = 0$$

$$N \cdot \frac{d}{dp}\left[p(1-p)^{N-1}\right] = 0 \quad \sim \text{PRODUCT RULE}$$

$$\underbrace{N \cdot \left[(1)(1-p)^{N-1} + (N-1)(1-p)^{N-2}\right] = 0}$$

Using MATLAB, it is determined that the solution of the equation yields:

$$\boxed{p = \frac{1}{N}}$$

8. Assume that the bridges shown below in Figure 4-42 in Tanenbaum are transparent bridges, and that all stations have sent and received frames to/from all other stations. Construct the bridge tables for both bridges. (9 points)

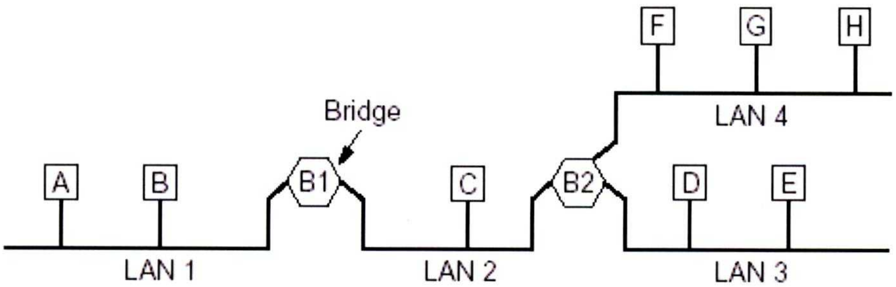
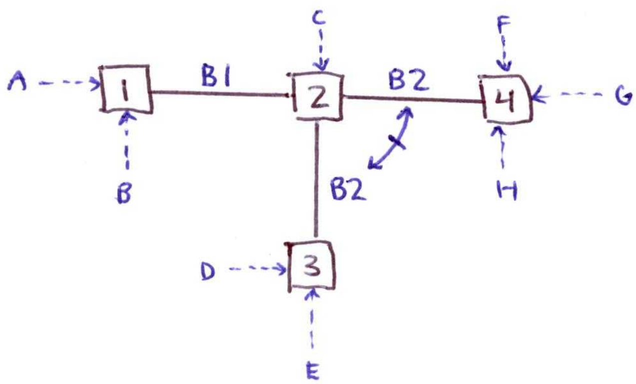


Fig. 4-42. A configuration with four LANs and two bridges.

Take Fig. 4-42 and draw a spanning tree representation:



Based on this network topology, and assuming that all stations have sent and received frames from one another, the bridge (hash) tables will look like:

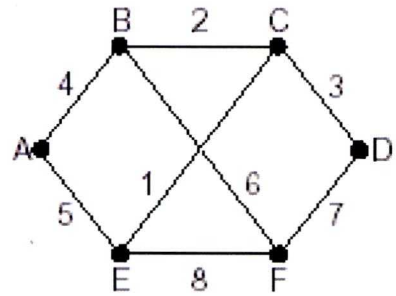
Bridge B1:

Destination	LAN (FWD placement)
A	1
B	1
C	2
D	2
E	2
F	2
G	2
H	2

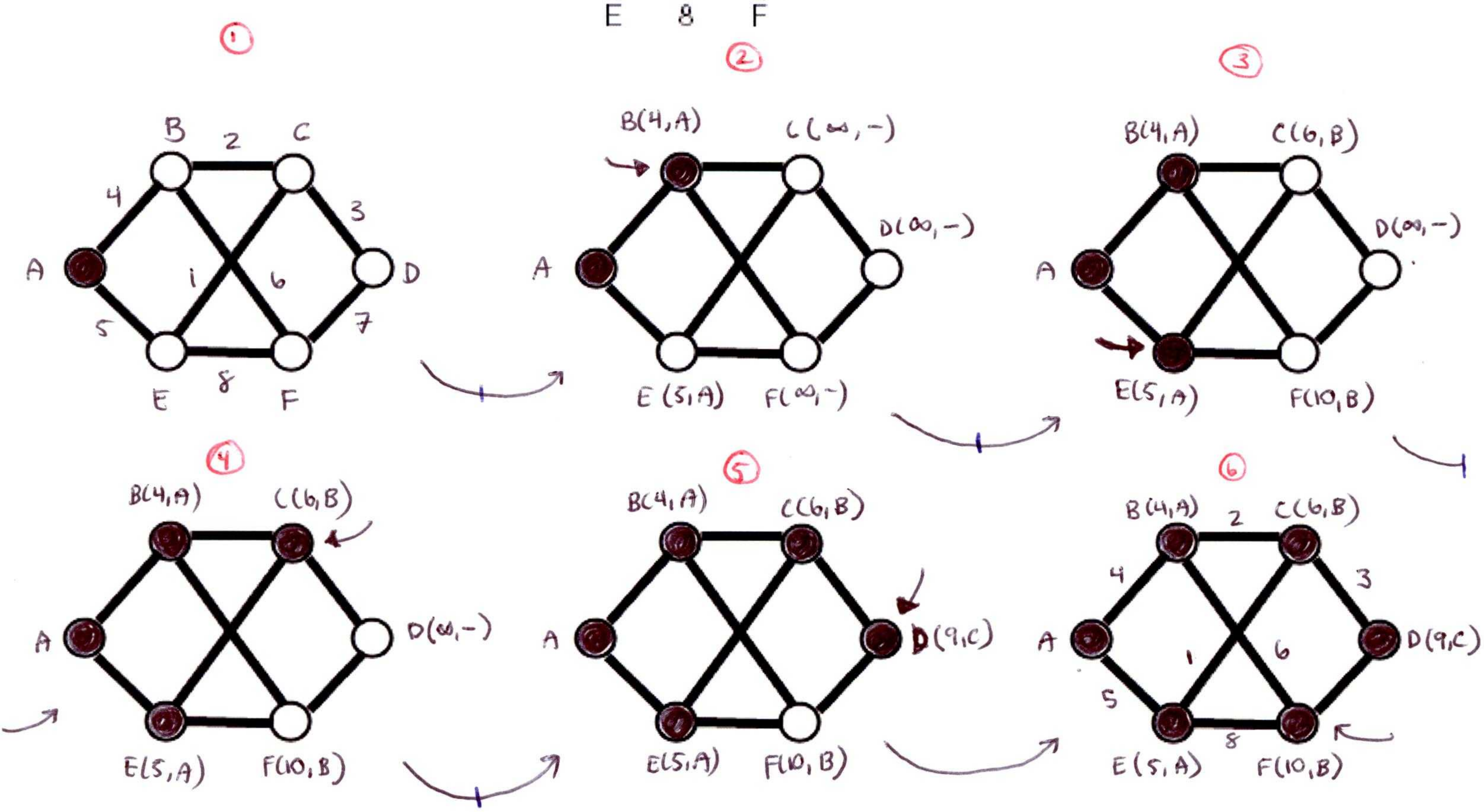
Bridge B2:

Destination	LAN (FWD placement)
A	2
B	2
C	2
D	3
E	3
F	4
G	4
H	4

9. Consider the network shown below from Figure 5-13 in Tanenbaum. The numbers shown for each link are the delays between nearest neighbors for that link. Apply Dijkstra's algorithm to this network starting at node A, and label each node with the shortest path route to node A using the same label techniques shown in Figure 5-7 in Tanenbaum. (9 points)



= • update neighbors of current active node
• select least tentative node in graph



10. An IP network router uses a token bucket scheme for traffic shaping. A new token is put into the bucket every 10 μsec. Assume that the packet size (including the header) for all traffic through this router is 1000 Bytes, and the size of each header is 20 Bytes. What is the maximum sustainable net data rate that the router can achieve not including IP protocol overhead? (9 points)

Given:

→ New token put into bucket each 10 μsec

→ Packet size = 1000 bytes, 20 byte headers

→ Assume that 1 token = 1 cell (packet)

~ with a token arriving every 10 μsec:

$$\text{packets/sec} = \frac{1 \text{ packet (cell)}}{10 \times 10^{-6} \text{ sec}} = 100{,}000 \text{ packets/sec}$$

~ Since asking for NET data rate, subtract out header for a total of 1000 - 20 = 980 bytes of information.

· This means that each packet (cell) contains:

$$980 \text{ bytes} \times \frac{8 \text{ bits}}{1 \text{ byte}} = 7840 \text{ bits}$$

∴ Maximum sustainable data rate $= 7840 \frac{\text{bits}}{\text{packet}} \times 100{,}000 \frac{\text{packet}}{\text{sec}}$

$= 784 \times 10^6$ bits/sec

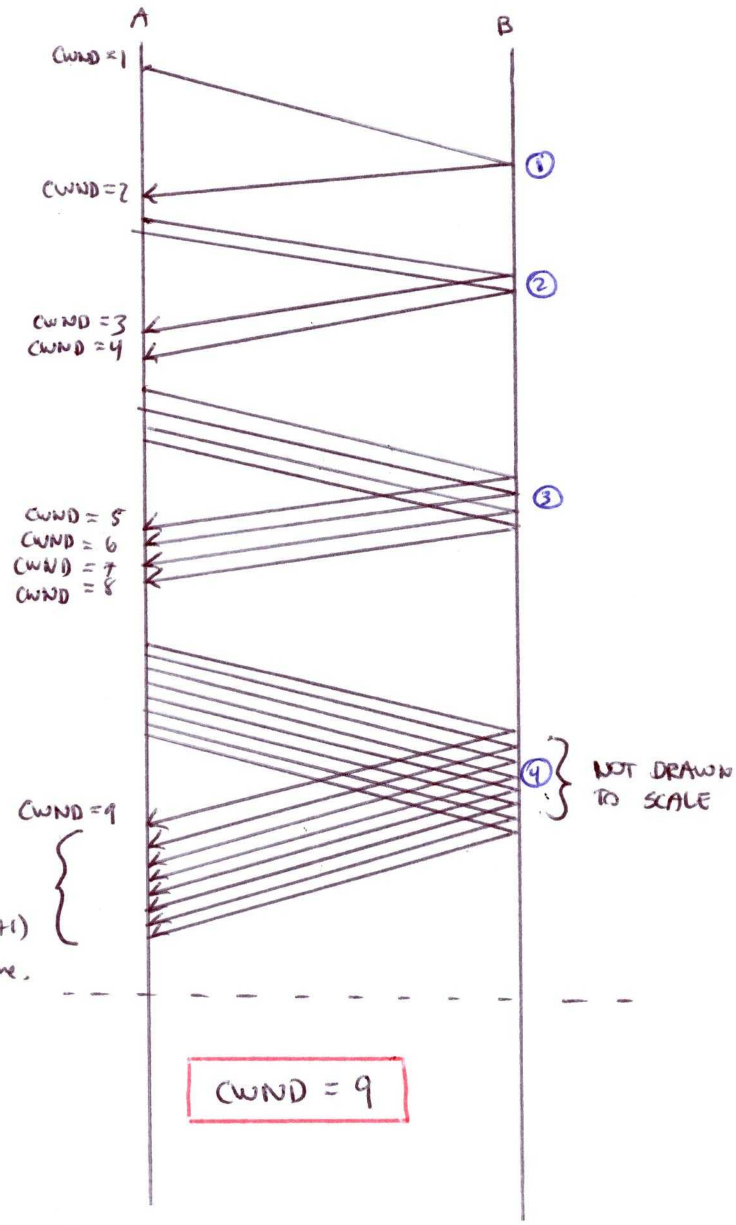
$= \boxed{784 \text{ Mbps}}$

11. A TCP entity opens a new connection and uses Jacobson's slow start initialization process with dynamic window sizing to transmit segments to its peer. The congestion window size reaches a value of 18 when a timeout occurs. Assuming that all subsequent transmission bursts of segments are received successfully and the sending entity always has segments to send within the currently available window size, how big will the congestion window size be if the next four transmission bursts are received and acknowledged successfully? (9 points)

~ Since the congestion reaches a timeout @ 18, this next iteration of Jacobson's slow start will have:

$$ssthresh = \frac{CWND_{prev}}{2} = 9$$

~ Assuming four successful transmission bursts, map will look like:



Since CWND ≥ ssthresh, we can only increase CWND linearly (+1) for each future round trip time.

$\boxed{CWND = 9}$