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1. (a)

A. TCP/IP - Vint Cerf & Bob Kahn
B. Ethernet - Robert Metcalfe
C. Packet Switching - Leonard Kleinrock
D. Email - Ray Tomlinson
E. WWW - Tim Berners-Lee
F. Aloha Network - Norman Abramson

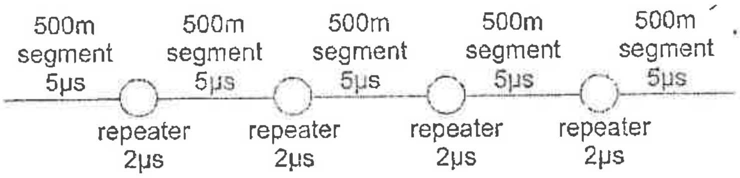
(b)

(i) Context: link failure probability.
Framework: failure probability of cables connected in series = (failure prob)$^{\text{no. of segments}}$.
incorrect
Success probability of cables connected in series = 1 – (failure prob)$^{\text{no. of segments}}$
Application: success probability = 99.9999% = 0.999999; max no. of segments = 5
Calculation: failure probability = 1 – 0.999999 = 0.000001 > b^5; then b < 0.0630957
Check: when b = 0.0630957, success probability = 1 – 0.0630957^5
= 0.9999990000027 > 0.999999
(OK – smaller values of b would result in higher success probability.)

(ii) Context: Slotted Aloha + maximize throughput.
Framework: link utilization for slotted Aloha = Ge^{-G}; G = np;
n = number of stations within the same collision domain;
p = transmission probability of a station.
Application: n = max 5 segments x max 100 stations per segment = 500 stations.
All five segments are included because repeaters propagate collisions, which means all stations on the five segments are in the same collision domain.
Calculation:
Differentiate Ge^{-G} wrt G: d/dG = $(G)((-1)e^{-G}) + (e^{-G})(1) = (e^{-G})(1-G) = 0$
G = 1, max link utilization = 1/e = 0.367; G = 1 = np = 500p → p = 0.002 = 0.2%
Check: when n = 500 and p = 0.2, link utilization = 0.367.

(iii) Context: relationship between min frame size and cable length.
Framework: station must be transmitting for as long as twice the max propagation delay of the network in order to detect collisions. The propagation delay must be considered in both directions.
Application:
Max segment length = 500m
Max length from end to end = 500m/segment x 5 segments = 2500m w 4 repeaters
Propagation speed on cable = 100m/µs = 0.01 µs/m
Time to transmit one bit in 10Mbps = 1s / 10000000 bits = 0.1 µs
Calculation:
Max two way delay propagation = (500 m/segment x 5 segments x 0.01 µs/m + 4 repeaters x 2 µs/repeater) x 2 ways
= (25 µs + 8 µs) x 2 = 66 µs

24



Station must be transmitting its frame for at least 66 µs so that any collisions can be detected.
In 66 µs, 66/0.1 = 660 bits = 82.5 = 83 bytes will be transmitted.
Hence, min frame size = 83 bytes.
Check: 83 bytes is close to the min frame size of 64 bytes for 10Base5 and hence is a reasonable size.
See https://bharathisubramanian.wordpress.com/2009/10/27/relationship-between-ethernet-framepacket-siz/ for full explanation.

2. (a)

(i) Context: control flow, selective reject ARQ

Framework: link utilization = $\begin{cases} 1-P, N \geq 1+2a \\ \frac{N(1-P)}{1+2a}, N < 1+2a \end{cases}$

a = T_{prop}/T_{frame}; T_{prop} = distance x marginal propagation delay; T_{frame} = frame size/transmission speed

Application: P = 0.2, N = 36, distance = 31km, marginal propagation delay = 1ms/km, frame size = 250*8 = 2000 bits, transmission speed = 10^6 bits/s

Calculation: T_{prop} = 31km x 1ms/km = 31ms = 0.031s

T_{frame} = 2000bits/10^6 bits/s = 0.002s

a = 0.031s/0.002s = 15.5; 1+2a = 32 → N = 36 > 32

link utilization = 1-P = 1-0.2 = 0.8

Check: 0 < link utilization ≤ 1 → OK

(ii) Context: window size, N vs frame sequence bits, k for selective reject error control.

Framework: N ≤ 2^{k-1}, link utilization maximized when N ≥ 1 + 2a

Application: N = 32 (see previous section)

Calculation: 32 ≤ 2^{k-1}, $\log_2 32$ ≤ k-1; 5 ≤ k-1; k = 6

Check: $2^{k-1} = 2^{6-1}$ = 32 → OK

(b)

(i) Context: queueing theory, queue stability.

Framework: λ < µ or arrival rate < service rate for queue stability.

service rate = transmission rate / frame size

Application: transmission rate = 10^6 bits/s, frame size = 2000 bits

Calculation: service rate, µ = 10^6/(250*8) = 500. λ < 500 → max λ = 499 packets/s

Check: 499 packets < 500 packets → OK

(ii) Context: queueing theory, queue delay, re-queueing due to error

Framework: T = $\frac{1}{\mu-\lambda}$; λ_a = λ + (error rate)*λ_a

Application: λ = 360 packets/s, µ = 500 packets/s, error rate = 0.2

Calculation: $\lambda_a = 360 + 0.2\lambda_a \rightarrow \lambda_a = 360/0.8 = 450$; total delay = $\frac{1}{500-450} = 0.02s$;

Check: since $\lambda < \mu$, delay of 0.02s is reasonable.

(iii) Context: components of queue delay.

Framework:

Residual service time when frame arrives, $T_R = \rho/\mu$

Waiting delay for frames in queue ahead of frame, $T_Q = (N-\rho)/\mu$

Service time of frame itself $T_S = 1/\mu$

Probability that server is busy = $\rho = \frac{\lambda}{\mu}$

Number of frames in queue, $N = \lambda T$

Application: $\lambda = 450$, $\mu = 500$, $T = 0.02$ (see previous part)

Calculation: $\rho = 450/500 = 0.9$; $N = 450 \times 0.02 = 9$

$T_R = \rho/\mu = 0.9/500 = 0.0018s$ (0.0018/0.02)*100% = 9%

$T_Q = (N-\rho)/\mu = (9-0.9)/500 = 0.0162s$ (0.0162/0.02)*100% = 81%

$T_S = 1/\mu = 0.002s$ (0.0002/0.02)*100% = 10%

Check: $T_R + T_Q + T_S = 0.0018 + 0.0162 + 0.002 = 0.02 = T \rightarrow$ OK

3. (a)

(i) Incoming payload per packet = 3500 bytes – 20 bytes = 3480 bytes

Outgoing payload per fragment = 1540 bytes – 20 bytes = 1520 bytes

Number of fragments per incoming packet = 3480/1520 = 2.29 = 3 packets

Fragment number	Packet length	Offset header
1	1540	0
2	1540	1520/8 = 190
3	(3480-1520*2)+20 = 460	3040/8 = 380

(ii) Packet received correctly if all fragments are transmitted without loss.

P(success of fragment delivery) = 1-(1/1000) = 0.999

P(success of packet delivery) = 0.999^3 = 0.997002999 = 99.7%

(iii) P(success of fragment delivery) = $1-(1/1000)^2$ = 0.999999

P(success of packet delivery) = 0.999999^3 = 0.999997 = 99.9997%

(b)

(i) Derive IPs that belong to a net by the Source IP and router interface IP with that net.

Net A contains IPs 155.69.36.1 and 155.69.47.100.

155.69.36.1	= 155.69.**0010**0100.1
155.69.47.100	= 155.69.**0010**1111.100
	155.69.00100000.0
Network address	155.69.32.0/20

Net B contains IPs 155.69.58.2 and 155.69.60.4.

155.69.58.2	= 155.69.**00111**010.2
155.69.60.4	= 155.69.**00111**100.4
	155.69.00111000.0

25

Network address 155.69.56.0/21

Net C contains IPs 155.69.52.3 and 155.69.51.25.

155.69.52.3	= 155.69.**00110**100.3
155.69.51.25	= 155.69.**00110**011.25
	155.69.00110000.0
Network address 155.69.48.0/21	

(ii) Ping packet sent by Station A:

Destination MAC	Source MAC	Destination IP	Source IP	Source Station
5a-01-59-45-32-56	E6-b1-5b-bc-ac-a2 (MAC of station A)	155.69.60.4 (IP of station B)	155.69.47.100 (IP of station A)	A

Ping packet received by station B:

Destination MAC	Source MAC	Destination IP	Source IP	Source Station
F8-b1-56-bc-d5-B8 (MAC of station B)	1B-22-21-81-61-72	155.69.60.4 (IP of station B)	155.69.47.100 (IP of station A)	A

Source and destination IP does not change.
Source and destination MAC changes depending on the MAC of the next hop in the route.
At each hop, there is a lookup in the ARP cache for the MAC address of the next hop, using the packet's destination IP address.
The packet's destination MAC address is rewritten to the corresponding next hop's MAC.
The packet's source MAC address is rewritten to the current hop's MAC.

4. (a) Max no. segments = 32

Initial ssthresh = half max no of segments = 16

Initial cwnd = 1

Transmission round	# packets sent this round	ssthresh	Phase
1	1	16	Slow start ssthresh = 16
2	2		
3	4		
4	8		
5	16	8	Triple duplicate loss event ssthresh = floor(cwnd/2) = 8 cwnd = ssthresh = 8 Go to collision avoidance
6	8		Collision avoidance
7	9		
8	10		
9	11		
10	12	6	Triple duplicate loss event ssthresh = floor(cwnd/2) = 6 cwnd = ssthresh = 6
11	6		Collision avoidance
12	7		
13	8		
14	9		
15	10	5	Triple duplicate loss event ssthresh = floor(cwnd/2) = 5 cwnd = ssthresh = 5
16	5		Collision avoidance
17	6		
18	7		
19	8		
20	9	4	Triple duplicate loss event ssthresh = floor(cwnd/2) = 4 cwnd = ssthresh = 4
21	4		Collision avoidance
22	5		
23	6		
24	7		
25	8		Triple duplicate loss event ssthresh = floor(cwnd/2) = 4 cwnd = ssthresh = 4

Rounds 21 to 25 will repeat every second due to the triple duplicate ACK event every second. Assume rounds 21 to 25 occur the majority of the time and ignore the initial rounds.

Average packets transmitted per transmission round = (4+5+6+7+8)/5 = 6 packets

TCP throughput: (cwnd * MSS) / RTT
cwnd = 6 packets
MSS = 512 bytes
Transmission rate in bits = $10 * 10^9 = 10^{10}$ bits/s
Assumptions:

- ((cwnd * MSS * 8)/transmission rate) is much less than RTT, ie, transmission speed is not the limiting factor.
  - o $((6 * 512 * 8)/(10^{10})) = 2.4576 \times 10^{-6}$ s << 0.2s (OK)
- No buffer constraint.

Average throughput in bytes = (6 packets * 512 bytes per packet)/0.2s = 15,360 bytes/s

(b) Link state advertisement at node A:

A	B	C	D	E
B = 4 E = 10	A = 4 C = 10 D = 11 E = 3	B = 10 D = 2	B = 11 C = 2 E = 2	A = 10 B = 3 D = 2

	B	C	D	E
{A}	4	∞	∞	10
{A,B}	4	14	15	7
{A,B,E}	4	14	9	7
{A,B,E,D}	4	11	9	7
{A,B,E,D,C}	4	11	9	7

← missing path

(c) w = 401, x = 401, y = 801

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Thank you and all the best for your exams! ☺