Tutorial 1 | CN-CS331 | 03 Feb 2025

Problem 1:

Link Rate = R bps | Propagation speed = s m/s

distance = m meters | Packet size = L bits

a) End to end delay = Transmission delay + Propagation delay

Ignore → ~~Process~~ (Processing delay, queuing delay)

$$d_{trans} = \frac{L}{R} \qquad d_{prop} = \frac{m}{s}$$

$$= \frac{L}{R} + \frac{m}{s}$$

b). The last bit has just been fully transmitted but has not yet reached host B. It is just starting to propagate through the link. The last bit is just leaving host A and is at the very beginning of the link.

c). ~~At~~ $t = d_{trans}$, the first bit has already been propagating for d_{trans} seconds. Since propagation speed is s, the first bit will have traveled:

$$\text{distance} = s \times d_{trans} = s \times \frac{L}{R}$$

The 1^{st} bit is at a distance $s.\frac{L}{R}$ from Host A, but it has not reached host B.

d). Since $d_{prop} < d_{trans}$, the 1st bit would have reached Host B before d_{trans} is completed. The 1st bit has already arrived at host B before $t = d_{trans}$.

For store & forward = 1st bit is at host B and has been waiting there for $[d_{trans} - (d_{prop}$ time + time to transmit one bit$)]$ seconds.

~~For cut through~~

e). $m = ?$ such that $d_{prop} = d_{trans} \rightarrow \frac{m}{s} = \frac{L}{R}$

$m = \frac{L}{R} \times s$ where $s = 2.5 \times 10^8$ m/s,
$L = 120$ bits
$R = 56$ kbps $= 56 \times 10^3$ bps

$$m = \frac{120}{56 \times 10^3} \times 2.5 \times 10^8 = \frac{300 \times 10^8}{56 \times 10^3} = \frac{300 \times 10^5}{56}$$

$m \approx 5.36 \times 10^5 = 536$ km.

Problem 2.

Total delay 1. Transmission delay for each link ($d_{trans, i}$)

$$d_{trans, i} = \frac{L}{R_i}$$

2 Propagation delay for each link $d_{prop,i}$

$$d_{prop,i} = \frac{d_i}{s_i}$$

3 Processing delay at each packet switch (d_{proc}).
There are 2 packet switches, so the total processing delay is:

$$2\,d_{proc}$$

Total end to end delay $= \sum_{i=1}^{3} \left(d_{trans,i} + d_{prop,i}\right) + 2d_{proc}$

$$= \sum_{i=1}^{3} \left(\frac{L}{R_i} + \frac{d_i}{s_i}\right) + 2d_{proc}.$$

Given: $L = 1500$ bytes $= 1500 \times 8 = 12{,}000$ bits

Propagation speed $= s_1 = s_2 = s_3 = 2.5 \times 10^8$ m/s.

Transmission rates $= R_1 = R_2 = R_3 = 2$ Mbps $= 2 \times 10^6$ bps

Processing delay at each switch $= d_{proc} = 3$ ms.

Link lengths $d_1 = 6000$ km $= 6 \times 10^6$ m

$d_2 = 3000$ km $= 3 \times 10^6$ m

$d_3 = 1000$ km $= 1 \times 10^6$ m

$$d_{trans,i} = \frac{12,000}{2\times10^6} = 6\times10^{-3}s = 6ms$$

$$\sum d_{trans,i} = 3\times6 = 18ms$$

$$d_{prop,1} = \frac{d_1}{s_1} = \frac{6\times10^6}{2.5\times10^8} = 0.024s = 24ms$$

$$d_{prop,2} = \frac{d_2}{s_2} = \frac{3\times10^6}{2.5\times10^8} = 12ms$$

$$d_{prop,3} = \frac{d_3}{s_3} = 4ms.$$

$$\sum_{i=1}^{3} d_{prop,i} = 24+12+4 = 40ms.$$

$$2d_{proc} = 2\times3 = 6ms$$

$$d_{endtoend} = \sum d_{trans,i} + \sum d_{prop,i} + 2d_{proc}$$

$$= 18ms + 40ms + 6ms$$

$$= 64ms.$$

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M	T	W	T	F	S	S
31					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

Problem 3 - Since the 1st bit does not wait for full packet transmission at each switch, the total delay consists of:

1 Transmission delay of only the 1st link:

$$d_{trans} = \frac{L}{R}$$

(Only the 1st link's transmission delay matters.)

2. Propagation delay for all 3 links:

$$d_{prop, total} = \sum_{i=1}^{3} \frac{d_i}{s_i}$$

Total end-to-end delay is:

$$d_{end\text{-}to\text{-}end} = d_{trans, 1} + \sum d_{prop, i}$$

$$= \frac{L}{R} + \frac{d_1}{s_1} + \frac{d_2}{s_2} + \frac{d_3}{s_3}$$

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$L = 1500$ Bytes $= 1500 \times 8 = 12,000$ bits | $R = 2$ Mbps $= 2 \times 10^6$ bps

$s = 2.5 \times 10^8$ m/s | $d_1 = 6 \times 10^6$ m

$d_2 = 3 \times 10^6$ m

$d_3 = 1 \times 10^6$ m

$d_{trans, 1} = 0.006$ sec $= 6$ ms | $d_{prop, 1} = \frac{6 \times 10^6}{2.5 \times 10^8} = 24$ ms

8 $d_{prop,2} = \frac{d_2}{R} = \frac{3 \times 10^6}{2.5 \times 10^8} = 12\ ms$

9

$d_{prop,3} = \frac{d_3}{R} = 4\ ms$

10

11 Total $= 6 + 24 + 12 + 4 = 40\ ms$.

12 Problem 4 – We assume:–

Packet length $= L$ bits
1 Number of links $= N$
Transmission rate of each link $= R$ bps

No propagation delay.
Store & forward switching.

2 Step 1.

- Transmission delay per link

3

The transmission delay (d_{trans}) is the time required to push the
4
entire packet onto a link $= \frac{L}{R}$
5
Since the packet must be fully received before transmission
6 on the next link, each link contributes a delay of d_{trans}.

Step 2. The 1st link starts transmitting immediately. The second link can only start transmission after the 1st link has finished & so on.

Since there are N links, and each introduces a transmission delay,

$$d_{end\ to\ end} = N \times \frac{L}{R}$$

When sending multiple packets back to back, the 1st packet experiences the full delay computed above. However, the second packet can start transmission on the 1st link immediately after the 1st packet ~~finishes~~ finishes transmission there.

Thus, for P packets

The 1st packet takes $N \times \frac{L}{R}$ seconds.

Each subsequent packet leaves the 1st link every $\frac{L}{R}$ seconds, forming a pipeline effect.

$$d_{total} = (N + (P-1)) \times \frac{L}{R}$$

Problem 5.

Little's formula $N = a \cdot d$

N = Avg no. of packets in the system.

a = packet arrival rate | d = Avg total delay per packet (queuing delay + transmission delay).

$N = 10$ | $d_{queue} = 10ms = 0.01 sec$ | Tr. rate = 100 packets/sec

$d = d_{queue} + d_{trans}$ | $d_{trans} = \frac{1}{Tr.\ Rate} = \frac{1}{100} = 0.01 sec.$

$d = 0.01 + 0.01 = 0.02$ sec

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$N = a \cdot d \mid 10 = a \times 0.02 \mid a = \frac{10}{0.02} = 500$ packets/sec.

Problem 6 Shared middle hop with total capacity

$R = 100$ Mbps

Server-to shared link capacity $= 80$ Mbps $= R_s$

Server to client link capacity $= R_c = 50$ Mbps

Path

Server $\rightarrow R_s \rightarrow R \rightarrow R_c \rightarrow$ Client

a) Max achievable end to end throughput per Pair =

$\frac{R}{4} = \frac{100}{4} = 25$ Mbps

b) A bottleneck link is the slowest link along the path that limits throughput.

$R_s = 80$ Mbps

$R = 100$ Mbps

$R_c = 50$ Mbps

The bottleneck is R.

(c) Utilization of R_s $= \frac{\text{Actual Data Rate}}{\text{Link Capacity}} = \frac{25}{80} = \frac{5}{16} = 0.3125$

(d) Utilization of R_c $= \frac{25}{50} = 0.5$

(e) The shared link carries four flows, each at 25 Mbps, for a total of:

$$4 \times 25 = 100 \text{ Mbps}$$

Since the link capacity is also 100 Mbps,

$\therefore$ Utilization of R $= \frac{100}{100} = 1$

Problem-7

(A). Given N packets arrive at the same time.

Length of each packet = L bits

Link transmission rate = R bps

Transmission delay per packet

$$d_{trans} = \frac{L}{R} \text{ sec}$$

1^{st} packet experiences 0 queuing delay.

2^{nd} packet waits for 1 transmission time before starting transmission.

3^{rd} packet waits for 2 transmission times before starting & so on,

k^{th} packet waits for $(k-1).d_{trans}$.

Total queuing delay $= 0 + d_{trans} + 2d_{trans} + \ldots + (N-1)d_{trans}$

$$\Sigma = d_{trans} \times [1+2+\ldots+N-1]$$

$$= d_{trans} \times \frac{N(N-1)}{2}$$

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For avg, divide by N.

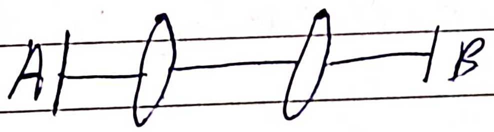
$$= \frac{L}{R} \times \frac{N(N-1)}{2N} = \frac{(N-1)L}{2R}$$

(B) N such packets arrive at the Link every $\frac{LN}{R}$ seconds.

Avg queuing delay will be same

$$= \frac{(N-1)L}{2R}$$

Problem 8:



File size = F bits
Segment size = S bits

Header size = 80 bits
Packet size = (S + 80) bits

Number of segments (packets) = $N = \frac{F}{S}$

Using formula derived in Problem 4.

$$d_{total} = [N + (P-1)] \times \frac{L}{R} = \left(\frac{F}{S} + 3 - 1\right)\frac{(80+S)}{R}$$

$$= \frac{160}{R} + \frac{2S}{R} + \frac{80F}{SR} + \frac{F}{R}$$

Taking derivative of d_{total} w.r.t S.

$$\frac{d(d_{total})}{dS} = 0 + \frac{2}{R} - \frac{80F}{S^2 R} + 0 = 0$$

$$\frac{2}{R} = \frac{80F}{S^2 R} \Rightarrow S = \sqrt{40F}$$

Problem 9.

My computer → Resolver.

1). Resolver → Root DNS → Response (TLD server for .in)

2. " → TLD DNS(.in) → " (Authoritative server for .ac.in)

3). " → Authoritative DNS (ac.in) → Response (Authoritative server for iitgn.ac.in.

4). Resolver → Authoritative DNS (iitgn.ac.in) → Response (IP address of www.iitgn.ac.in)

Total number of query-response pairs is 4.

Problem 10. Number of SMTP servers (hops) = 3

Processing delay per SMTP server = 30 ms.

Number of links = 4.

Propagation delay per link = 20 ms.

Total processing delay = 3 × 30 ms = 90 ms

" Propagation delay = 4 × 20 ms = 80 ms

Total Delay = 80 + 90 = 170 ms.

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Problem 11 Given Data

1 HTML file = 5KB	5 images = 50KB each.
3 CSS " = 2KB each	Total objects = 1+3+5 = 9.
RTT time = 50ms (0.05 sec)	Bandwidth = 10 Mbps = 10×10^6 bps.

Download time = $\frac{\text{File size (in bits)}}{\text{Bandwidth (in bps)}}$

a). Each object requires:
① 1 RTT for TCP connection establishment.
② 1 RTT for HTTP request & 1st byte response.
③ Download time.

Download time for each object.

Download time
HTML = 5KB = 40,000 bits → 4 ms
CSS (each) = 2KB = 16,000 " → 1.6 ms
Image (each) = 50KB = 400,000 " → 40 ms.

Each object has a delay of 2RTT + download time.
HTML $2 \times 0.05 + 0.004 = 0.104$ s
3 CSS Files $3 \times (2 \times 0.05 + 0.0016) = 0.3048$ s
5 images $5 \times (2 \times 0.05 + 0.04) = 5 \times 0.14 = 0.7$ s

Total = $0.104 + 0.3048 + 0.7 = 1.1088$ sec

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(c) HTTP/2 with multiplexing.

Single TCP connection is used.
Total data to download = 5 + (3×2) + (5×50)

= 261 KB.

Total download time = $\frac{261 \times 8{,}000}{10{,}000{,}000}$ = 0.2088 sec.

Adding 1 RTT (connection) + 1 RTT (Request Response):

0.05 + 0.05 + 0.2088 = 0.3088 sec.

Problem 12.

Cache Hit Rate = 80%   Cache Lookup time = 1 ms.
Cache Miss Rate = 20%
External resolution follows these steps:
1. Query to the root server → RTT = 50 ms.
2. TLD server → RTT = 70 ms
3. Authoritative server → RTT = 100 ms.
4. Total external resolution time = 50 + 70 + 100 = 220 ms.
Invalid queries = 10%
They don't go through the external resolution process.
Valid queries = 90%.
Either caching or external resolution.

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T_{avg} = (Cache Hit Rate × T_{cache}) + (Valid Cache ~~Mis~~ Miss Rate × $T_{external}$)
+ (Invalid query rate × $T_{invalid}$)

$T_{avg} = 0.80 \times 2 + 0.18 \times 220 + 0.1 \times 10$

$= 0.8 + 39.6 + 2 = 41.4$ ms.

2 Hit Rate = 95 %

$T_{avg,new} = 0.95 \times 1 + 0.05 \times 220 + 0.1 \times 10$

$= 0.95 + 11 + 1 = 12.95$ ms.

Improvement in % $= \frac{(41.4 - 12.95)}{41.4} \times 100$

$= \frac{28.45}{41.4} \times 100 = 68.73\%$ faster.

Problem 13.

I Time for base web page (Single object).

2. DNS resolution.

Client requires local DNS resolver (RTT_0 = 1ms).

If IP is not cached, the local DNS contacts the external DNS server (RTT_1 = 47ms)

Total DNS Time = $RTT_0 + RTT_1 = 1 + 47 = 48$ ms.

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1RTT_HTTP = 72 ms → For TCP 3-way handshake.

1RTT_HTTP = 72 ms For client sends an HTTP request.

1RTT_HTTP = 72 ms Server responds

Total Time = 48 + 72 + 72 = 192 ms

II 1. Steps from part I : 192 ms for DNS + base object.
2. Each add. object requires a new TCP connection (each taking 2 RTTs).
7 objects × [2 × RTT(HTTP)] = 7 × 144 = 1008 ms

3. Total time : 192 + 1008 = 1200 ms.

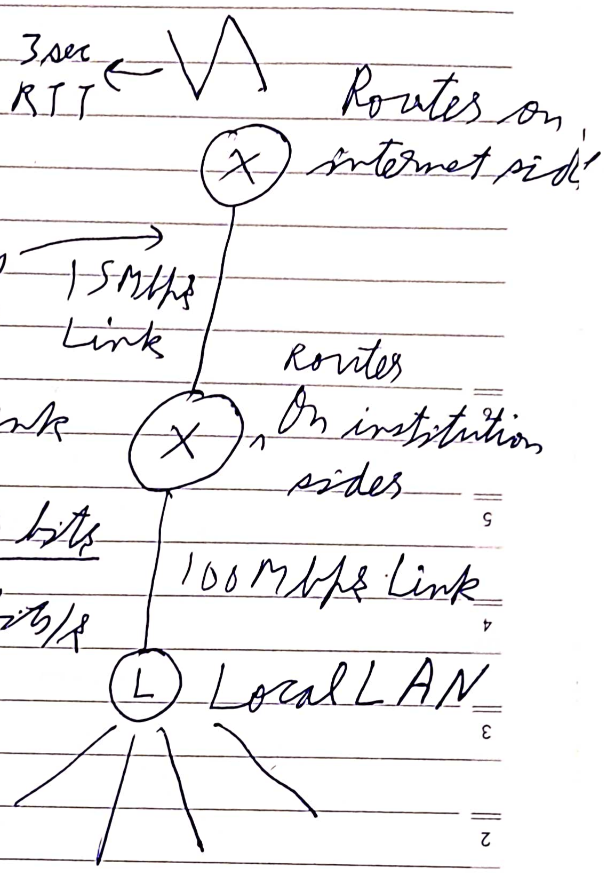
III 1. DNS + Base Page = 192 ms
2. Batch 1 (5 Objects) = 144 ms.
3. Batch 2 (2 ") = 144 ms.
Total = 480 ms

IV 1. DNS + Base Page = 192 ms.
2. Batch 1 (5 objects, 1 RTT) : 72 ms.
3. " 2 (2 " , 1 RTT) : 72 ms.

192 + 72 + 72 = 336 ms.

V Fastest method is Persistent HTTP with Parallel connection (336 ms)

~~Exercise~~ Problem-14



a). Total avg. response

$$\text{Time} = \frac{\Delta}{1-\Delta\beta}$$

$\Delta \rightarrow$ avg. time to send on access link

$$= \frac{\text{avg. object size}}{\text{bandwidth of access link.}} = \frac{8,50,000 \text{ bits}}{15\times10^6 \text{ bits/s}}$$

$\Delta = 0.056$ sec

$\beta \rightarrow$ arrival rate of objects to access link.

$\beta = 16$ requests per second.

$$\text{Avg total response time.} = \frac{\Delta}{1-\Delta\beta} = \frac{0.056 \text{ sec}}{1-0.056\times16}$$

$$= 0.61 \text{ sec}$$

For each request on avg, 3 sec are needed as RTT. from Routes on Internet side for request-response.

Total avg. resp. time $= 3 + 0.61$ s $= \boxed{3.61 \text{ sec}}$

b). Now cache is installed on LAN.

Hit Rate = 60%.

60% do an RTT from Host to local cache over a 100Mbps link.

$$\alpha = 0.6 \times \left(\frac{1}{100 \times 10^6 \text{ b/s}} \times 8{,}50{,}000 \text{ b} \times 2\right)$$

$$\alpha = 0.017 \text{ sec}$$

40% of the bits query to cache, fail & finally again travel on the access link (15 Mbps)

Avg. response time for this.

$$= \frac{\Delta}{1 - \Delta \beta_{new}} + \underbrace{3 \text{ sec}}_{\text{for RTT}}$$

$$\beta_{new} = 0.4 \times \beta = 0.4 \times 16 \text{ requests/sec} = 6.4 \text{ req./s.}$$

Avg. response time for miss $= \dfrac{\Delta}{1 - \Delta \times 6.4} + 3$

$$= 3.089 \text{ s}$$

Total time =

$$0.6 \times (\alpha) + 0.4((\alpha) + 3.089 \text{ s}) = \underset{(\alpha)}{\alpha} + 0.4 \times 3.089$$

$$= 0.017 + 1.2356 \text{ s}$$

$$= 1.2526 \text{ s} = \text{Total response time.}$$

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Problem 15. Total time accounts for all below pts.

2. DNS lookup time $= \sum_{i=1}^{n} RTT_i = RTT_1 + RTT_2 + \ldots + RTT_n$

2. TCP connection establishment $= 2RTT$.

3: HTTP Request & Response $= 2RTT$

$$T_{total} = \sum_{i=1}^{n} RTT_i + 2RTT_0 + 2RTT$$

$$= \sum_{i=1}^{n} RTT_i + 2RTT$$