

①

Problem 1] Computing end-to-end delays

a) Both routers are store & forward routers

$$\begin{aligned}
 (L) \text{ Total delay} &= d_{\text{total}} = (d_{\text{processing}} + d_{\text{queue}} + d_{\text{transmission}} + d_{\text{propagation}}) \times 3 \\
 &= (5 \mu\text{sec} + 0 \text{sec} + \frac{L}{R} + \frac{d}{s}) \times 3 \text{ links} \\
 &= (5 \mu\text{sec} + 0 \text{sec} + \frac{1 \text{KB} \times 8 \text{bits}}{10^6 \text{bytes}} + \frac{100 \text{KM}}{20,000 \text{km/s}}) \times 3 \text{ links} \\
 &= (5 \times 10^{-6} \text{sec} + 0.008192 \text{sec} + \frac{1}{200} \text{secs}) \times 3 \text{ links} \\
 L &= (0.013197 \text{secs}) \times 3 = \underline{\underline{0.039591 \text{ seconds}}}
 \end{aligned}$$

b) Cut-through routers \Rightarrow 1 transmission delay through both routers

$$\begin{aligned}
 (L) \text{ Total delay} &= d_{\text{total}} = (d_{\text{processing}} + d_{\text{queue}} + d_{\text{propagation}}) \times 3 \text{ links} + d_{\text{transm}} \\
 &= 3(5 \mu\text{sec} + 0 \text{sec} + \frac{100 \text{KM}}{20,000 \text{km/s}}) + \frac{1 \text{KB} \times 8 \text{bits}}{10^6 \text{bytes}} \\
 &= 3(0.005005 \text{sec}) + 0.008192 \text{sec} \\
 L &= \underline{\underline{0.23207 \text{ sec}}}
 \end{aligned}$$

c) Supposing $R1 = R2 = R3 = 1 \text{ Gbps}$ for (a) & (b)

$$\begin{aligned}
 (a) \text{ Total delay} &= d_{\text{total}} = (d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}) \times 3 \text{ links} \\
 &= (5 \mu\text{sec} + 0 \text{sec} + \frac{1 \text{KB} \times 8 \text{bits}}{10^9 \text{bytes}} + \frac{100 \text{KM}}{20,000 \text{KM/sec}}) \times 3 \text{ links} \\
 L &= (0.005006 \text{sec}) \times 3 \\
 L &= \underline{\underline{0.015018 \text{ sec}}}
 \end{aligned}$$

$$\begin{aligned}
 (b) \text{ Total delay} &= d_{\text{total}} = (d_{\text{proc}} + d_{\text{queue}} + d_{\text{prop}}) \times 3 \text{ links} + d_{\text{transm}} \\
 &= 3(5 \mu\text{sec} + 0 \text{sec} + \frac{100 \text{KM}}{20,000 \text{KM/sec}}) + \frac{1 \text{KB} \times 8 \text{bits}}{10^9 \text{bytes}} \\
 &= 3(0.005005) + \frac{2}{10^9} \\
 L &= \underline{\underline{0.01523 \text{ sec}}}
 \end{aligned}$$

d) $R1 = R2 = 2 \text{ Mbps}$ & $R3 = 1 \text{ Mbps}$

(a) $L = d_{\text{total}} = d_{\text{transm } R1, R2} + d_{\text{transm } R3} + 3(d_{\text{proc}} + d_{\text{prop}}) + d_{\text{queue}}$
 $L = 2 \left(\frac{1 \text{ KB} \times 8 \text{ bytes}}{2 \times 10^6} \right) + \frac{1 \text{ KB} \times 8 \text{ bytes}}{10^6} + 3 \left(\frac{100 \text{ km}}{20,000 \text{ km/s}} \right) + \frac{2^{13} \text{ bytes}}{10^6}$

$L = 8.192 \times 10^{-6} + 8.192 \times 10^{-3} + 0.015 + 8.192 \times 10^{-3}$

$L = 0.03139 \text{ sec}$

(b) $L = d_{\text{total}} = d_{\text{transm } R1, R2} + d_{\text{transm } R3} + 3(d_{\text{prop}})$
 $= 2 \left(\frac{1 \text{ KB} \times 8 \text{ bytes}}{2 \times 10^6} \right) + \frac{1 \text{ KB} \times 8 \text{ bytes}}{10^6} + 3 \left(\frac{100 \text{ km}}{20,000 \text{ km/s}} \right)$

$L = 0.0232 \text{ sec}$

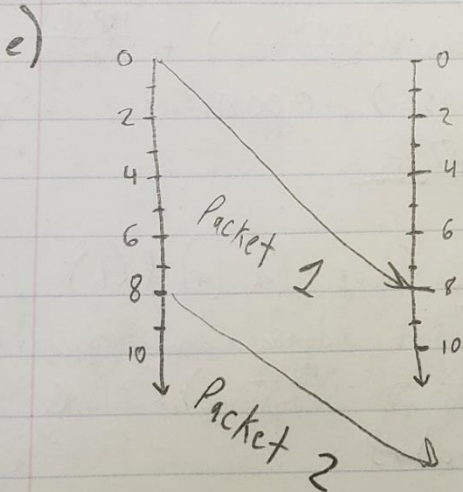
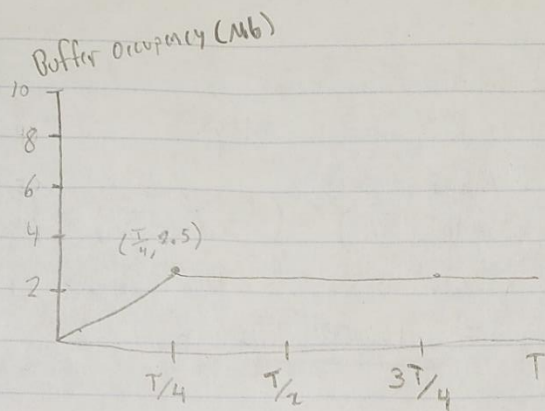


Figure 2

Problem 2]

(a)



b) The minimum value of R_0 must be 2.5 Mbps, since the throughput is 10 Mbps and there are 2 arriving traffic links

c) $D(R) \rightarrow T = \frac{L}{R} \rightarrow R = \frac{L}{T}$

d) $L(R) = \left(10 \left(\frac{T}{4} \right) + 0 \left(\frac{3T}{4} \right) \right) L$
 $= \underline{\underline{2.5 L}}$

e) $L(R) = \lambda D(R)$
 $2.5 LT = 2.5 \left(\frac{L}{T} \right)$

(3)

P3] a) In this case, circuit-switched network. The data flow is steady and predictable. It will be able to handle the set data flow to a complete bandwidth. It is because the data is so laid out for us, it is better to use circuit-switched network.

b) If packet-switched network is used, the data sent by the application is less than the capabilities, therefore there will be no congestion. There will be enough bandwidth to not need a congestion device.

P8] 3 Mbps link, 150 kbps transmission, but each user transmits only 10%.

$$a) \# \text{ users} = \frac{\text{transmission rate of user}}{\text{transmission required}} = \frac{3 \text{ Mbps}}{150 \text{ kbps}} = \frac{3 \times 10^6}{150 \times 10^3} = \frac{3000}{150} = 20 \text{ users}$$

b) Probability is 10%.

$$c) 120 \text{ users, } n \text{ users transmitting, } p = .10$$

$$\text{Binomial Cdf } (N=120, p=0.10) \rightarrow {}^N C_n (p)^n (1-p)^{N-n}$$

$$= {}^{120} C_n (0.1)^n (0.9)^{120-n}$$

$$d) P(X \geq 21) \rightarrow 1 - P(X \leq 20)$$

← remove all less than 21

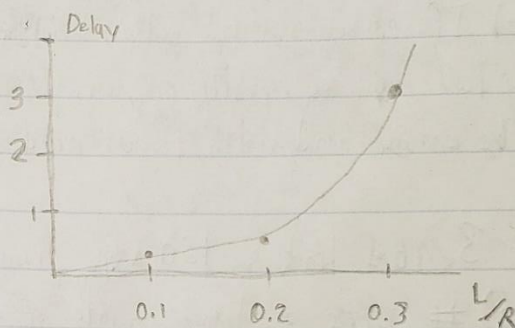
$$\text{at least 21} \quad 1 - \sum_{n=0}^{20} {}^{120} C_n (0.1)^n (0.9)^{120-n}$$

P14] $I = La/R$, queuing delay: $L/R(1-I)$ for $I < 1$

a) Total Delay = $d_{\text{transmission}} + d_{\text{queue}}$

$$\frac{L}{R} + \frac{IR}{R(1-I)} \rightarrow \frac{L}{R} \left[1 + \frac{I}{1-I} \right] \text{ Sec}$$

L/R	Delay
0	0
0.1	0.14
0.2	0.50
0.3	3



P16] N = average packets in buffer, a = rate of packets arriving

d = average total delay

$N = a \cdot d$, 10 packets, 10 msec delay

a) $A = \frac{N}{d} \rightarrow \frac{10 \text{ packets}}{10 \text{ msec}} = \underline{0.01 \text{ packet per second}}$

b) Avg queuing delay at each node, so $d = \text{transm} + \text{queue}$

$$= \frac{10}{.01} \text{ sec} + 10 \text{ msec} = 0.01 + 0.01$$

$$A = \frac{10 \text{ packets}}{0.02 \text{ sec}} = \underline{500 \text{ packets/sec}}$$

$$= 0.02$$

Student Right-to-Know and Campus Security Act

Under the Student Right-to-Know and Campus Security Act, Florida International University will, upon request, make

(4)

P 18] Trace route

a) I chose Stadfast Networks (AS32748) in the US

Tracing route to lookingglass.cdi.stadfast.net via IPv4 from Chicago

Trace 1 @ 6PM 0.523 ms, 0.521 ms, 0.514 ms $\mu = 0.528_{ms}$ $\sigma = 0.011_{ms}$

Trace 2 @ 11PM 0.499 ms, 0.495 ms, 0.426 ms $\mu = 0.473_{ms}$ $\sigma = 0.041$

Trace 3 @ 12 AM 0.556 ms, 0.598 ms, 0.544 ms $\mu = 0.563_{ms}$ $\sigma = 0.032$

b) All trace routes showed 4 routers & the paths never changed

c) The tracroute passed through 3 ISP networks. In my experiment, the largest delay occurred in peering interfaces between adjacent ISPs.

d) I tried to do a tracroute from New Jersey to UK, but the site never finished completing. I would assume that means that intercontinental trace route takes a longer time

P Problem 25] 20,000 kilometers, direct link $R = 2 \text{ Mbps}$, $\text{prop} = 2.5 \times 10^8 \text{ m/s}$

a) Bandwidth = $R \times \text{propagation delay}$

$$\begin{aligned} &= 2 \text{ Mbps} \times \left(\frac{d}{s} \right) \\ &= (2 \times 10^6 \text{ bits/s}) \times \left(\frac{20,000 \times 1000 \text{ m}}{2.5 \times 10^8 \text{ m/s}} \right) \\ &= (2 \times 10^6 \text{ bits/s}) \times (0.08 \text{ sec}) \\ &= \underline{160,000 \text{ bits}} \end{aligned}$$

b) 800,000 bits, max bits?

File size does not matter as it does not affect the max bits able to be sent. It is the bandwidth that controls max bits, so it is 160,000 bits

c) Bandwidth-delay product is the maximum bits able to be on a transmission link

$$\text{d) width (L)} \rightarrow \frac{\text{prop rate}}{\text{transmission rate}} = \frac{2.5 \times 10^8}{2 \text{ Mbps}} = \frac{2.5 \times 10^8}{2 \times 10^6} = \underline{125 \text{ meters}}$$

A football field is 120 meters, so yes it is longer.

e) The equation for width of a bit is $\boxed{\frac{s}{d}}$, as used in the previous answer

Traceroute used for P18

The screenshot shows a web browser window with the URL `steadfast.net/network-test`. The page is titled "Remote Host" and contains the following fields:

- Host: `lookingglass.edi.steadfast.net`
- City: `Chicago, IL`
- Network: `IPv4 (Normal)`

Below these fields are two green buttons: "TRACEROUTE" and "PING". The "TRACEROUTE" button has been clicked, and the results are displayed below:

Tracing route to `lookingglass.edi.steadfast.net` via IPv4 from Chicago...

```
traceroute to lookingglass.edi.steadfast.net (69.162.170.5), 30 hops max, 60 byte packets
 1 vll11.dist01.chi02.steadfast.net (208.100.4.50)  0.556 ms  0.598 ms  0.544 ms
 2 xe-0-0-2.core3.chi02.steadfast.net (208.100.32.32)  0.948 ms  0.889 ms  0.915 ms
 3 ae2.core2.edi03.steadfast.net (216.86.149.59)  16.407 ms  16.383 ms  16.389 ms
 4 ae1.dist.edi03.steadfast.net (67.202.117.13)  16.477 ms  16.645 ms  16.681 ms
 5 * * *
 6 * * *
 7 * * *
 8 * * *
```

The Windows taskbar at the bottom shows the search bar with "Type here to search", several application icons, and the system clock displaying "12:02 AM 9/15/2020".