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HOMEWORK - I

Q1

(A) In this case both routers are Store & forward-ed Routers
time for the packet transmission at each link = $\frac{1KB \cdot 8 bits/byte}{1Mbps}$

= 8 ms

$\Rightarrow d_{transmission} = 8\ ms$

Propogation delay for ~~pack~~ packet on each link = $\frac{100\ km}{20,000\ km/s}$

= 5 ms

$\Rightarrow d_{propogation} = 5\ ms.$

∴ End to End delay =

3 (transmission time) + ~~3~~ 3 (propogation delay) + 2 (processing time)

$= (3 \times 8\ ms) + (3 \times 5\ ms) + (2 \times 5 \mu s)$

= 39.01 ms.

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(b) Here both Routers are cut through Routers

End to End delay = transmission time + 3(propagation delay) + 2(processing time)

$= 8ms + (3 \times 5 ms) + (2 \times 5 \mu s)$

$= 8ms + 15 ms + 10\mu s$

$= 23.01 ms$ {Calculated transmission time & propagation delay in (A) part}

(c) Packet transmission time $= \frac{1KB \cdot 8 bits/byte}{1 Gbps}$

$= 8 \mu s$

Store and Forward Case:

End to End delay $= 3 \times$ (transmission time) + {propagation delay} + 2(processing time)

$= (3 \times 8 \mu s) + (3 \times 5 ms) + (2 \times 5 \mu s)$

$= 24 \mu s + 15 ms + 10 \mu s$

$= 15.03 ms$

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Cut through case:

End to End delay = transmission time + 3(prop delay) + 2(processing time)

$= 3 \times 5\,ms + 2 \times 5/1000\,ms + 0.008\,ms$

$= 15\,ms + 0.01\,ms + 0.008\,ms$

$= 15.018\,ms$.

(d) For R_1, R_2

$$\text{transmission time } (d_{trans}) = \frac{1KB \times 8 \text{ bits/byte}}{2 \text{ Mbps}}$$

$$= 4 \text{ ms}$$

For R_3,

$$\text{transmission time } (d_{trans}) = \frac{1KB \cdot 8 \text{ bits/byte}}{1 \text{ Mbps}}$$

$$= 8 \text{ ms}$$

Store and forward case:

for Packet 1,

$$\text{End to End delay} = 2 \times 4 \text{ ms} + 8 \text{ ms} + 3 \times 5 \text{ ms}$$

$$= 31 \text{ ms}$$

for Packet 2,

$$\text{End to End delay} = 31 \text{ ms} + 4 \text{ ms}$$

$$= 35 \text{ ms}$$

We have remaining time of 4ms ∴ when last bit of packet 2 arrives at Router 3, packet 1 is still in process.

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for Packet 3,

End to End delay $= 31ms + 8ms$

$= 39ms$

Cut through Case :

Packet 1 :

End to End delay $= 3 \times 5ms + 8ms$

$= 23ms$

Packet 2 :

End to End delay $= 23ms + 4ms$

$= 27ms$

Packet 3 :

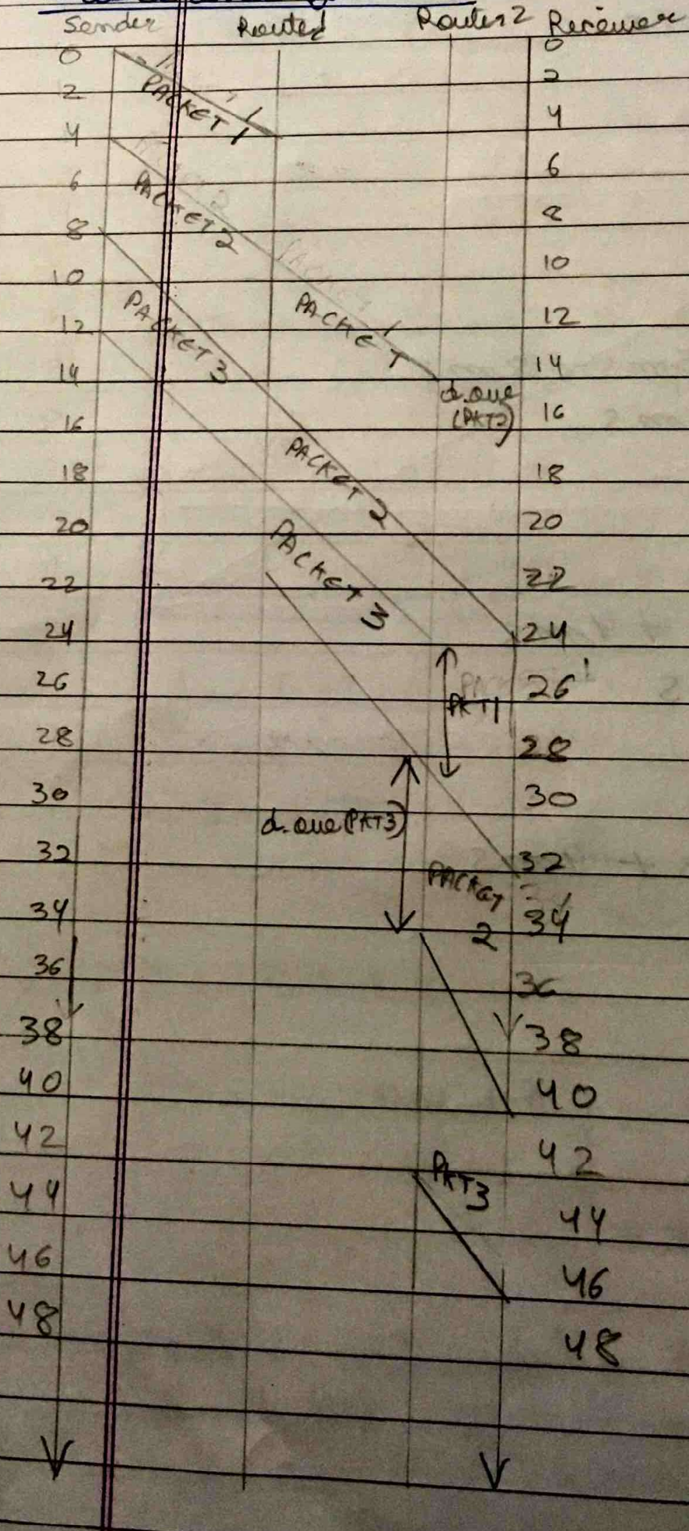
End to End delay $= 27ms + 4ms$

$= 31ms$

(e)

E

Store and forward:



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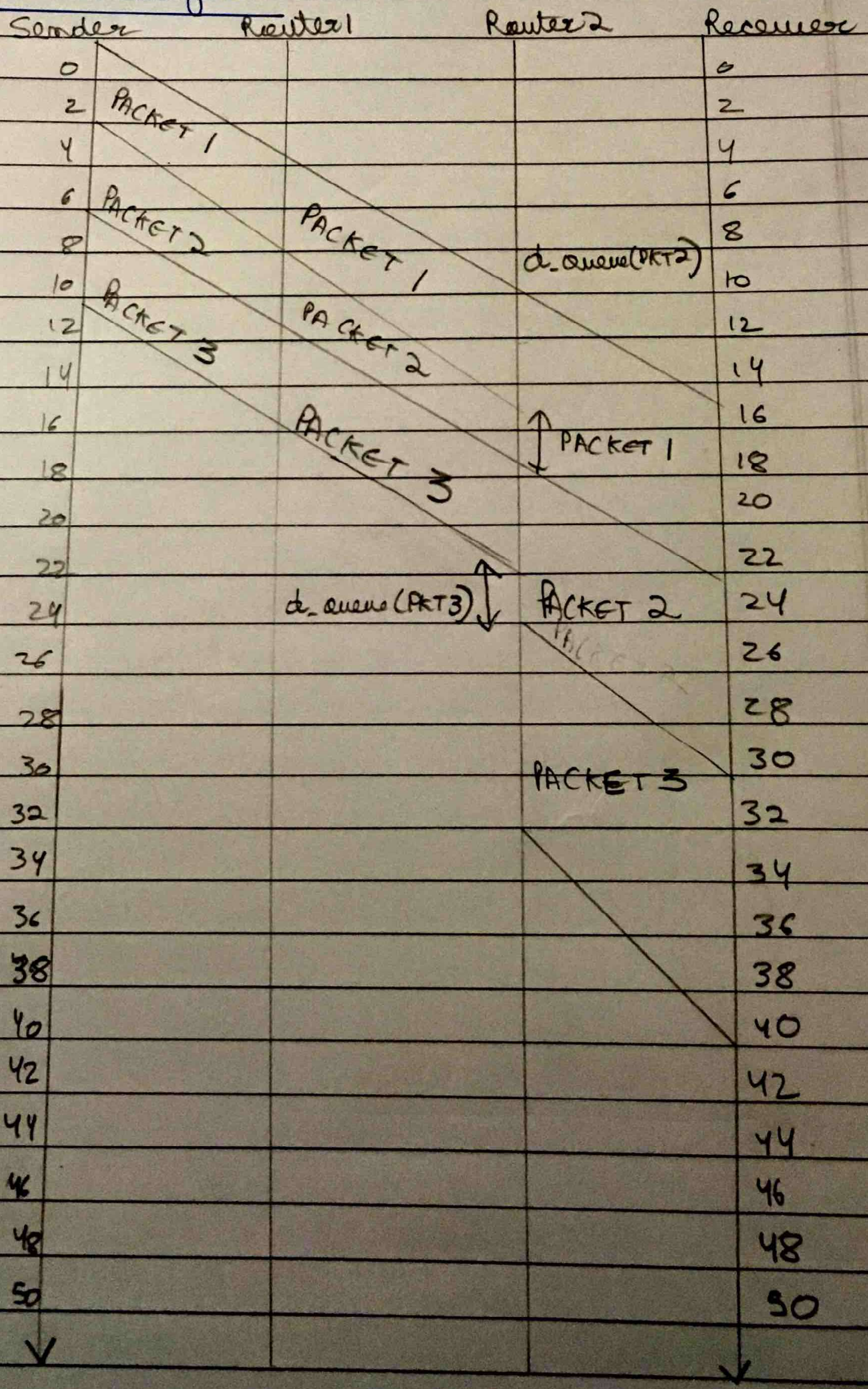
Cut through :



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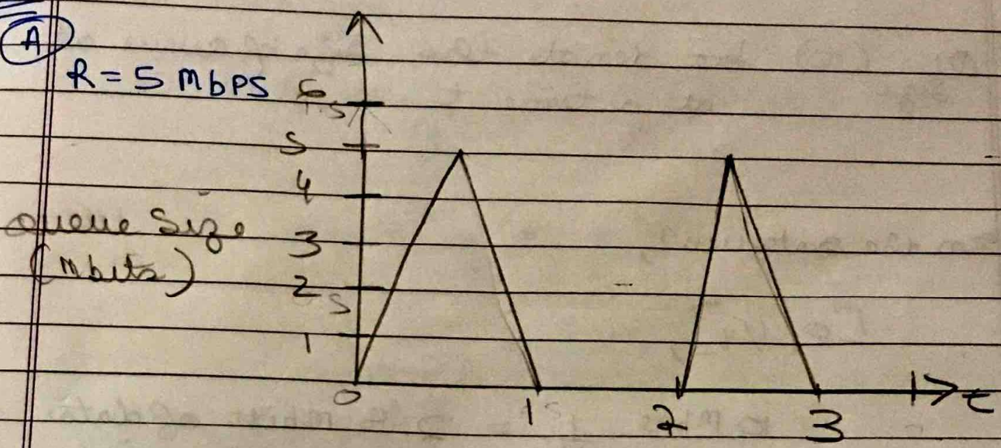
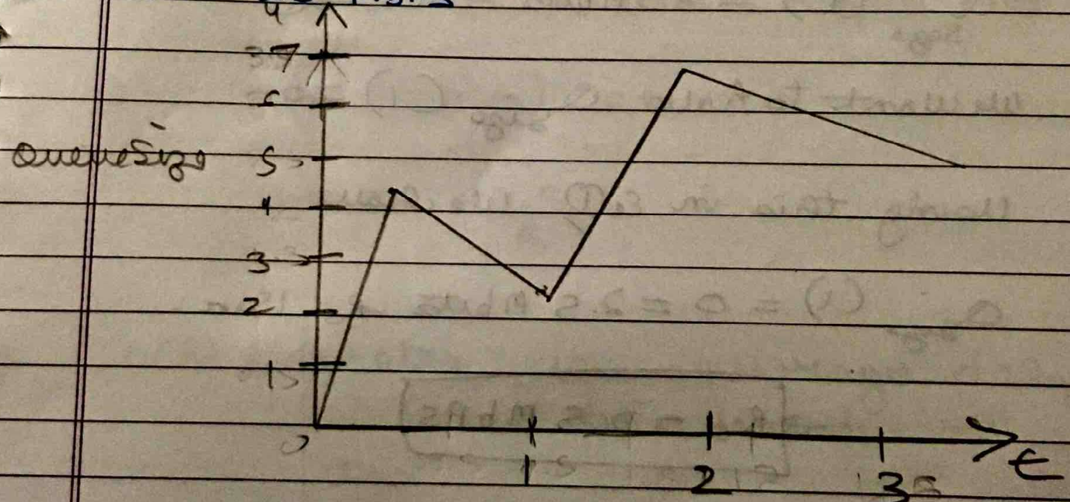
A

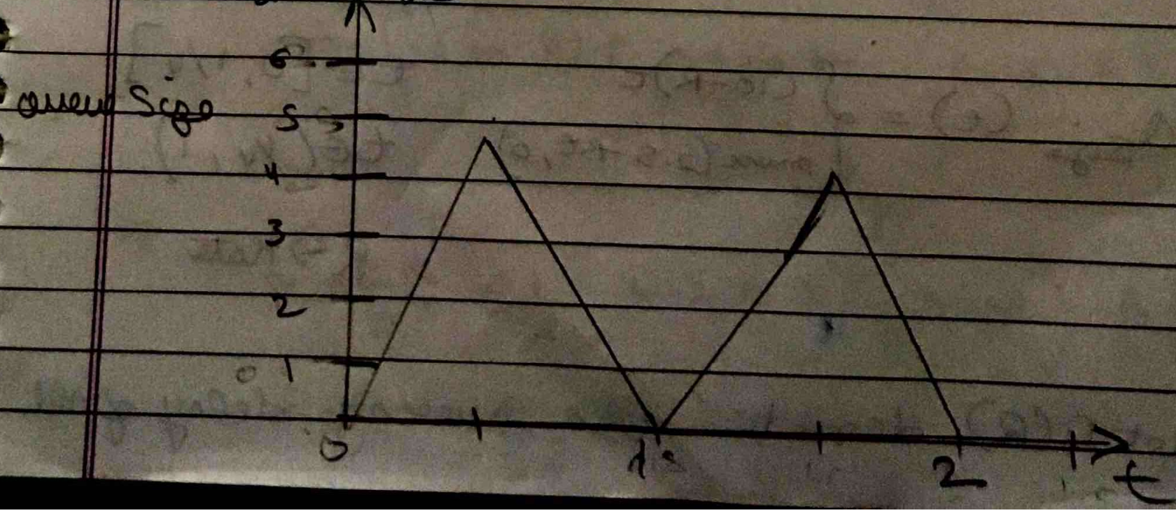
R = 5 Mbps



R = 1.25 Mbps



R = 2.5 Mbps



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(b)

$Q_{size}(t)$ ~~be~~ denote the size of queue at at a time t.

In the interval,

$[0, 1/4]$,

$10\text{ Mbps} \cdot \frac{1}{4} = 2.5$ Mbits of data are Received.

$\Rightarrow Q_{size}(t) = 2.5\text{Mbits} - Rt \rightarrow (1)$

We want to have $Q_{size}(1) = 0$.

Using this in Eq(1), we have.

$Q_{size}(1) = 0 = 2.5\text{ Mbits} - R_o \cdot 1\text{Sec}$.

$$\Rightarrow \boxed{R_o = 2.5\text{ Mbps}}.$$

(c) Let $Q_{size}(t)$ be queue size at time t.

$$Q_{size}(t) = \begin{cases} (10-R)t & t \in [0, 1/4], \\ \max(2.5 - Rt, 0) & t \in (1/4, 1) \end{cases}$$

$R \rightarrow$ Rate

Let $D(R)$ denote the average delay of all

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bits Received

$$\Rightarrow D(R) = \frac{1}{1/4} \int_0^{1/4} \frac{(10-R)}{R} t \, dt$$

$$= \frac{2(10-R)}{R} t^2 \Big|_0^{1/4}$$

$$= \frac{10-R}{8R}$$

(D)

Let at time t_0, the queue is empty

$$\therefore \frac{1}{4}(10 \text{ Mbps}) - R t_0 = 0$$

$$\Rightarrow t_0 = \frac{2.5}{R}$$

$L(R)$: denotes the average delay over a time period.

$$\therefore L(R) = \int_0^{t_0} Q_{size}(t) \, dt$$

$$= \int_0^{1/4} (10-R) t \, dt + \int_{1/4}^{t_0} (2.5 - R t) \, dt$$

$$= \frac{10-R}{2} \times \frac{1}{16} + 2.5 \times \left(\frac{2.5}{R} - \frac{1}{4}\right) - \frac{R}{2}\left(\frac{(2.5)^2}{(R)^2} - \frac{1}{16}\right)$$

$$= \frac{5}{6} + \frac{(2.5)^2}{2R} - \frac{2.5}{4}$$

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$$\Rightarrow L(R) = \frac{2.5}{R}\left(\frac{10-R}{8}\right)$$

(E) $L(R) = \lambda . D(R)$

$$= 2.5 \times \frac{(10-R)}{8R}$$

Q3

(A) In this scenario, using a circuit switched network will be better choice because once the application starts, it runs for a longer duration & transmits data at steady rate. Also it would allow to reserve bandwidth for steady transmi-ssions for a longer time.

(B). Here No congestion control is needed. This is so as the capacities of each link is bigger than sum of application data rates & in the worst case when ~~the~~ all the applications transmit data at the same time, each and every link is capable of handling data because of greater capacities.

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Q4

(A) The Number of Users that can be Supported is
$= 3 \text{ Mbps} / 150 \text{ kbps} = 3 \times 1000 / 150$
$= 20$

(B) $P = 0.1$

(C) $\cancel{{}^{120}C_m \, (P)^m \, (}$

$${}^{120}C_m \times (P)^m (1-P)^{120-m}$$ Here $P = 0.1$

(D) $$1 - \sum_{m=0}^{20} \left({}^{120}C_m\right) \times \left(P^m\right) \left(1-P\right)^{120-m}$$, Here $P = 0.1$

~~Q5~~

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Q5

(A) total delay = queuing Delay + transmission delay

$$= \frac{IL}{R(1-I)} + \frac{L}{R}$$

$$= \frac{L/R}{1-I}$$

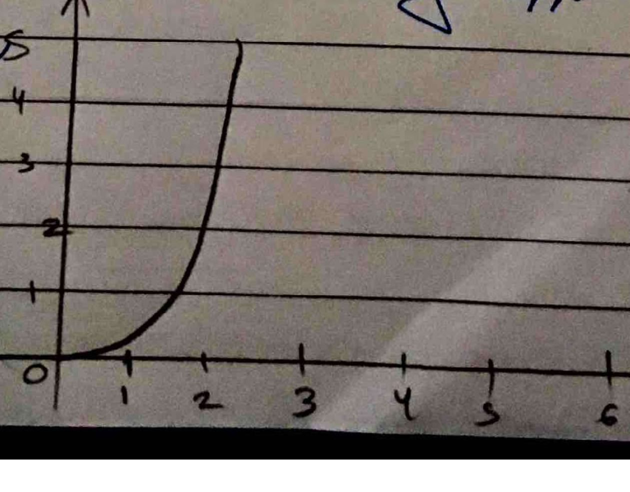
(B) For plotting total delay as a function of L/R,

let us assume $x = L/R$.

$\Rightarrow$ total delay $= \frac{x}{1-ax}$ $\left\{\because I = La/R\right\}$

Now We can observe that, for $x=0$ the total delay is 0 & as We increase x, the total delay increases & when x comes closer to value of $1/a$, the total delay approaches infinity.

for $a = 0.35$



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Q6

N= total Number of packets in System
$= 10 + 1 = 11$

{ ∵ It includes packets in buffer & the packet thats being transmitted }

We know,

$$N = a \times (\text{queuing delay} + \text{transmission delay})$$

$$\Rightarrow 11 = a \times \left(0.01 + 1/100\right)$$

$$\Rightarrow 11 = a \times \left(0.01 + 0.01\right)$$

$$\Rightarrow 11 = a \times (0.02)$$

$$\Rightarrow a = \frac{11 \times 100}{2} = \frac{1100}{2} = 550 \text{ Packets/Sec.}$$

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Q8

(A) Bandwidth Delay product = R× Propagation delay

$= 2\text{ Mbps} * (20000\text{ km}) / 2.5 \times 10^{8}\text{ m/s}$

$= 2 \times 1000000 \times 20000 \times 1000 / 2.5 \times 10^{8}\text{ bits}$

$= 4000000/25$

$= 160{,}000\text{ bits}$

(B) The maximum Number of bits that will be present in a link at a given time : 160,000 bits

(C) The bandwidth delay product is defined as the maximum number of bits that can be in the link.

(D) width of a bit = $\dfrac{\text{length of a link}}{\text{bandwidth delay product}}$

width of a bit is longer than a football field because 1 bit is 125 meters long.

(E) width of a bit = S/R.

7a.

Sample 1

```
storm:6% traceroute www.amazon.com
traceroute to www.amazon.com (23.202.75.20), 30 hops max, 60 byte packets
 1  128.227.205.193 (128.227.205.193)  0.560 ms  0.501 ms  0.488 ms
 2  csev1-core-msfc-1-v104-1.ns.ufl.edu (128.227.254.73)  0.431 ms  0.378 ms  0.391 ms
 3  ctx36-nexus-msfc-1-v41-1.ns.ufl.edu (128.227.236.13)  0.344 ms  0.320 ms  0.301 ms
 4  ctx36-pel-asr9001-1-v17-1.ns.ufl.edu (128.227.236.207)  1.091 ms  1.228 ms  1.308 ms
 5  ctx36-ewan-msfc-1-v18-1.ns.ufl.edu (128.227.236.209)  0.472 ms  0.436 ms  0.441 ms
 6  jax-flrcore-asr9010-1-te0104-1804.net.flrnet.org (108.59.29.242)  6.554 ms  6.300 ms  6.341 ms
 7  orl-flrcore-asr9010-1-hu0701-1.net.flrnet.org (108.59.31.151)  8.671 ms  8.654 ms  8.616 ms
 8  xe-11-3-0.bar2.Orlando1.Level3.net (67.30.142.5)  8.558 ms  8.495 ms  8.453 ms
 9  * * *
10  nap-brdr-01.inet.qwest.net (63.146.26.137)  13.031 ms  13.008 ms  12.869 ms
11  nap-edge-04.inet.qwest.net (205.171.19.53)  13.208 ms  13.002 ms  12.925 ms
12  a23-202-75-20.deploy.static.akamaitechnologies.com (23.202.75.20)  13.897 ms  13.915 ms  13.894 ms
```

Sample 2

```
storm:15% traceroute www.amazon.com
traceroute to www.amazon.com (23.202.75.20), 30 hops max, 60 byte packets
 1  128.227.205.193 (128.227.205.193)  0.500 ms  0.460 ms  0.524 ms
 2  csev1-core-msfc-1-v104-1.ns.ufl.edu (128.227.254.73)  0.421 ms  0.384 ms  0.535 ms
 3  ctx36-nexus-msfc-1-v41-1.ns.ufl.edu (128.227.236.13)  0.489 ms  0.424 ms  0.503 ms
 4  ctx36-pel-asr9001-1-v17-1.ns.ufl.edu (128.227.236.207)  0.949 ms  1.171 ms  3.410 ms
 5  ctx36-ewan-msfc-1-v18-1.ns.ufl.edu (128.227.236.209)  0.485 ms  0.471 ms  0.470 ms
 6  jax-flrcore-asr9010-1-te0104-1804.net.flrnet.org (108.59.29.242)  6.545 ms  6.570 ms  6.529 ms
 7  orl-flrcore-asr9010-1-hu0701-1.net.flrnet.org (108.59.31.151)  8.785 ms  8.737 ms  8.691 ms
 8  xe-11-3-0.bar2.Orlando1.Level3.net (67.30.142.5)  8.585 ms  8.573 ms  8.532 ms
 9  * * *
10  nap-brdr-01.inet.qwest.net (63.146.26.137)  12.924 ms  12.906 ms  12.860 ms
11  nap-edge-04.inet.qwest.net (205.171.19.53)  13.081 ms  13.038 ms  12.980 ms
12  a23-202-75-20.deploy.static.akamaitechnologies.com (23.202.75.20)  13.905 ms  13.946 ms  13.909 ms
```

Sample 3

```
storm:17% traceroute www.amazon.com
traceroute to www.amazon.com (23.202.75.20), 30 hops max, 60 byte packets
 1  128.227.205.193 (128.227.205.193)  0.477 ms  0.465 ms  0.457 ms
 2  csev1-core-msfc-1-v104-1.ns.ufl.edu (128.227.254.73)  0.520 ms  0.431 ms  0.376 ms
 3  ctx36-nexus-msfc-1-v41-1.ns.ufl.edu (128.227.236.13)  0.427 ms  0.383 ms  0.351 ms
 4  ctx36-pel-asr9001-1-v17-1.ns.ufl.edu (128.227.236.207)  1.135 ms  3.557 ms  3.491 ms
 5  ctx36-ewan-msfc-1-v18-1.ns.ufl.edu (128.227.236.209)  0.529 ms  0.494 ms  0.463 ms
 6  jax-flrcore-asr9010-1-te0104-1804.net.flrnet.org (108.59.29.242)  6.301 ms  6.392 ms  6.354 ms
 7  orl-flrcore-asr9010-1-hu0701-1.net.flrnet.org (108.59.31.151)  8.687 ms  8.646 ms  8.613 ms
 8  xe-11-3-0.bar2.Orlando1.Level3.net (67.30.142.5)  8.523 ms  8.505 ms  8.447 ms
 9  * * *
10  nap-brdr-01.inet.qwest.net (63.146.26.137)  12.994 ms  12.981 ms  13.053 ms
11  nap-edge-04.inet.qwest.net (205.171.19.53)  13.039 ms  13.149 ms  12.913 ms
12  a23-202-75-20.deploy.static.akamaitechnologies.com (23.202.75.20)  13.866 ms  14.043 ms  13.935 ms
```

Mean, Standard Deviation for each sample for Intra continent

1. 13.902, 0.011

2. 13.91, 0.03

3. 13.948, 0.089

b. There are 12 routers in the path . No, the path didn't change.

c. There are 4 ISP . Yes, the largest delays occurred at the peering interfaces between adjacent ISPs.

d. Intercontinent

Sample 1

```
storm:19% traceroute www.amazon.in
traceroute to www.amazon.in (104.92.16.18), 30 hops max, 60 byte packets
 1  128.227.205.193 (128.227.205.193)  0.450 ms  0.452 ms  0.476 ms
 2  csev1-core-msfc-1-v104-1.ns.ufl.edu (128.227.254.73)  10.319 ms  10.278 ms  10.228 ms
 3  ctx36-nexus-msfc-1-v41-1.ns.ufl.edu (128.227.236.13)  0.675 ms  0.630 ms  0.583 ms
 4  ctx36-pel-asr9001-1-v17-1.ns.ufl.edu (128.227.236.207)  1.027 ms  3.523 ms  3.488 ms
 5  ctx36-ewan-msfc-1-v18-1.ns.ufl.edu (128.227.236.209)  0.556 ms  0.492 ms  0.456 ms
 6  ssrb230a-ewan-msfc-1-v723-1.ns.ufl.edu (128.227.0.97)  0.392 ms  0.535 ms  0.475 ms
 7  wsip-184-188-101-186.at.at.cox.net (184.188.101.186)  1.320 ms  1.129 ms  1.324 ms
 8  ip68-105-160-3.ga.at.cox.net (68.105.160.3)  0.890 ms  0.903 ms  0.859 ms
 9  maribprj02.ae0.0.rd.at.cox.net (68.1.0.251)  14.292 ms  14.362 ms  14.297 ms
10  68.105.31.182 (68.105.31.182)  2498.640 ms  2498.625 ms  2498.584 ms
11  a104-92-16-18.deploy.static.akamaitechnologies.com (104.92.16.18)  14.844 ms  14.804 ms  14.956 ms
```

Sample 2

```
storm:20% traceroute www.amazon.in
traceroute to www.amazon.in (104.92.16.18), 30 hops max, 60 byte packets
 1  128.227.205.193 (128.227.205.193)  0.445 ms  0.429 ms  0.669 ms
 2  csev1-core-msfc-1-v104-1.ns.ufl.edu (128.227.254.73)  0.439 ms  0.388 ms  0.352 ms
 3  ctx36-nexus-msfc-1-v41-1.ns.ufl.edu (128.227.236.13)  5.799 ms  5.783 ms  5.738 ms
 4  ctx36-pel-asr9001-1-v17-1.ns.ufl.edu (128.227.236.207)  1.017 ms  1.271 ms  1.260 ms
 5  ctx36-ewan-msfc-1-v18-1.ns.ufl.edu (128.227.236.209)  0.524 ms  0.506 ms  0.506 ms
 6  ssrb230a-ewan-msfc-1-v723-1.ns.ufl.edu (128.227.0.97)  0.398 ms  0.412 ms  0.446 ms
 7  wsip-184-188-101-186.at.at.cox.net (184.188.101.186)  1.564 ms  1.544 ms  1.511 ms
 8  ip68-105-160-3.ga.at.cox.net (68.105.160.3)  0.804 ms  0.873 ms  0.839 ms
 9  maribprj02.ae0.0.rd.at.cox.net (68.1.0.251)  24.310 ms  24.275 ms  24.157 ms
10  * 68.105.31.182 (68.105.31.182)  408.861 ms *
11  a104-92-16-18.deploy.static.akamaitechnologies.com (104.92.16.18)  14.901 ms  14.865 ms  14.785 ms
```

Sample 3

```
storm:21% traceroute www.amazon.in
traceroute to www.amazon.in (104.92.16.18), 30 hops max, 60 byte packets
 1  128.227.205.193 (128.227.205.193)  0.510 ms  0.491 ms  0.533 ms
 2  csev1-core-msfc-1-v104-1.ns.ufl.edu (128.227.254.73)  0.466 ms  0.416 ms  0.367 ms
 3  ctx36-nexus-msfc-1-v41-1.ns.ufl.edu (128.227.236.13)  0.401 ms  0.386 ms  0.360 ms
 4  ctx36-pel-asr9001-1-v17-1.ns.ufl.edu (128.227.236.207)  1.033 ms  1.263 ms  1.248 ms
 5  ctx36-ewan-msfc-1-v18-1.ns.ufl.edu (128.227.236.209)  0.491 ms  0.501 ms  0.471 ms
 6  ssrb230a-ewan-msfc-1-v723-1.ns.ufl.edu (128.227.0.97)  0.412 ms  0.512 ms  0.451 ms
 7  wsip-184-188-101-186.at.at.cox.net (184.188.101.186)  1.231 ms  1.188 ms  1.160 ms
 8  ip68-105-160-3.ga.at.cox.net (68.105.160.3)  0.992 ms  0.957 ms  0.917 ms
 9  maribprj02.ae0.0.rd.at.cox.net (68.1.0.251)  14.276 ms  14.278 ms  14.245 ms
10  68.105.31.182 (68.105.31.182)  354.808 ms  354.793 ms  354.750 ms
11  a104-92-16-18.deploy.static.akamaitechnologies.com (104.92.16.18)  14.870 ms  14.845 ms  14.804 ms
```

Mean,Standard Deviation for each Sample

1. 14.868, 0.07879
2. 14.85, 0.059
3. 14.8396, 0.0333