

# Assignment 1 Part 1

## 1 Ping

To ping *google.com* and *sigcomm.com* 10 times using two different networks. We ping both the websites on IIT Delhi's network and Cellular network through mobile's personal hotspot.

### Google.com

```
jaskaransinghbhalla@JMac-2 ~ % ping -c 10 google.com
PING google.com (142.250.207.206): 56 data bytes
64 bytes from 142.250.207.206: icmp_seq=0 ttl=117 time=6.515 ms
64 bytes from 142.250.207.206: icmp_seq=1 ttl=117 time=6.854 ms
64 bytes from 142.250.207.206: icmp_seq=2 ttl=117 time=15.487 ms
64 bytes from 142.250.207.206: icmp_seq=3 ttl=117 time=6.854 ms
64 bytes from 142.250.207.206: icmp_seq=4 ttl=117 time=7.369 ms
64 bytes from 142.250.207.206: icmp_seq=5 ttl=117 time=15.551 ms
64 bytes from 142.250.207.206: icmp_seq=6 ttl=117 time=15.373 ms
64 bytes from 142.250.207.206: icmp_seq=7 ttl=117 time=12.478 ms
64 bytes from 142.250.207.206: icmp_seq=8 ttl=117 time=15.889 ms
64 bytes from 142.250.207.206: icmp_seq=9 ttl=117 time=16.210 ms

--- google.com ping statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 6.515/11.858/16.210/4.166 ms
```

Figure 1: IIT Delhi Network

```
jaskaransinghbhalla@JMac-2 ~ % ping -c 10 google.com
PING google.com (142.250.206.142): 56 data bytes
64 bytes from 142.250.206.142: icmp_seq=0 ttl=54 time=175.309 ms
64 bytes from 142.250.206.142: icmp_seq=1 ttl=54 time=206.659 ms
64 bytes from 142.250.206.142: icmp_seq=2 ttl=54 time=37.118 ms
64 bytes from 142.250.206.142: icmp_seq=3 ttl=54 time=64.380 ms
64 bytes from 142.250.206.142: icmp_seq=4 ttl=54 time=41.894 ms
64 bytes from 142.250.206.142: icmp_seq=5 ttl=54 time=47.063 ms
64 bytes from 142.250.206.142: icmp_seq=6 ttl=54 time=32.793 ms
64 bytes from 142.250.206.142: icmp_seq=7 ttl=54 time=44.886 ms
64 bytes from 142.250.206.142: icmp_seq=8 ttl=54 time=128.233 ms
64 bytes from 142.250.206.142: icmp_seq=9 ttl=54 time=268.158 ms

--- google.com ping statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 32.793/104.649/268.158/80.537 ms
```

Figure 2: Cellular Network using Hotspot

### Sigcomm.org

```
jaskaransinghbhalla@JMac-2 ~ % ping -c 10 sigcomm.org
PING sigcomm.org (190.92.158.4): 56 data bytes
64 bytes from 190.92.158.4: icmp_seq=0 ttl=49 time=307.161 ms
64 bytes from 190.92.158.4: icmp_seq=1 ttl=49 time=324.013 ms
64 bytes from 190.92.158.4: icmp_seq=2 ttl=49 time=342.685 ms
64 bytes from 190.92.158.4: icmp_seq=3 ttl=49 time=362.012 ms
64 bytes from 190.92.158.4: icmp_seq=4 ttl=49 time=385.471 ms
64 bytes from 190.92.158.4: icmp_seq=5 ttl=49 time=404.242 ms
64 bytes from 190.92.158.4: icmp_seq=6 ttl=49 time=312.822 ms
64 bytes from 190.92.158.4: icmp_seq=7 ttl=49 time=338.812 ms
64 bytes from 190.92.158.4: icmp_seq=8 ttl=49 time=361.268 ms
64 bytes from 190.92.158.4: icmp_seq=9 ttl=49 time=315.566 ms

--- sigcomm.org ping statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 307.161/345.405/404.242/30.851 ms
jaskaransinghbhalla@JMac-2 ~ %
```

Figure 3: IIT Delhi Network

```
jaskaransinghbhalla@JMac-2 ~ % ping -c 10 sigcomm.org
PING sigcomm.org (190.92.158.4): 56 data bytes
64 bytes from 190.92.158.4: icmp_seq=0 ttl=41 time=737.850 ms
64 bytes from 190.92.158.4: icmp_seq=1 ttl=41 time=543.680 ms
64 bytes from 190.92.158.4: icmp_seq=2 ttl=41 time=342.205 ms
64 bytes from 190.92.158.4: icmp_seq=3 ttl=41 time=795.259 ms
64 bytes from 190.92.158.4: icmp_seq=4 ttl=41 time=465.063 ms
64 bytes from 190.92.158.4: icmp_seq=5 ttl=41 time=352.691 ms
64 bytes from 190.92.158.4: icmp_seq=6 ttl=41 time=549.590 ms
64 bytes from 190.92.158.4: icmp_seq=7 ttl=41 time=459.068 ms
64 bytes from 190.92.158.4: icmp_seq=8 ttl=41 time=689.251 ms
64 bytes from 190.92.158.4: icmp_seq=9 ttl=41 time=612.845 ms

--- sigcomm.org ping statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 342.205/554.750/795.259/147.033 ms
```

Figure 4: Cellular Network using Hotspot

## 1.1 Comparison of the Ping Latency

Ping latency is a measure of the time taken by a signal (a data packet) to travel from a source to a destination and back again. This round-trip time is measured in milliseconds (ms).

### 1.1.1 Different websites on the same network

We can observe that the average ping for *google.com* is 11.858 ms and the average ping for *sigcomm.org* is 345.405 ms on IIT Delhi's Network.

Similarly the average ping for *google.com* is 104.649 ms and the average ping for *sigcomm.com* is 554.750 ms on cellular network. It is clearly observed that the average ping for *google.com* is greater than *sigcomm.com* for both the networks.

### 1.1.2 Same website on different networks

The average ping for *google.com* is 11.858 ms on IIT Delhi's network and is 104.649 ms on cellular network.

The average ping for *sigcomm.com* is 345.405 ms on IIT Delhi's network and is 554.750 ms on cellular network.

We can see that the ping is different for same website on different networks. One possible reason for it could be the bandwidth of the network or the speed of the network.

## 1.2 Protocol related questions

### 1.2.1 ICMP Protocol

Ping command uses ICMP (Internet Control Message Protocol) to send a request and obtain the response from the gateway or host. It sends packets as Echo request to the server and pings the server to test its availability and it returns an Echo response. It measures the round trip time between the host and the destination. A typical ICMP response consists of ICMP echo reply packet, RTT(Round-Trip Time), Packet loss, TTL (Time To Live), Response Size and Sequence number. This protocol is a network layer protocol and is important for error reporting and testing. It is implemented in routers. This protocol doesn't require a handshake in order to be executed, so it's a connectionless protocol.

### 1.2.2 Theoretical Upper limit on packet size

In order to determine the theoretical upper limit of packet size for the ping protocol, we need to understand what the packet size depends on and understand a typical ICMP packet. ICMP packets include an ICMP header after a normal IP header. IPv4 and IPv6 are two versions of Internet Protocol (IP) that are used commonly and they have different sizes for the headers. ICMP header comes after IPv4 and IPv6 packet header. The theoretical upper limit of the packet size for the ping protocol is determined by the underlying network protocol, which is typically IPv4 or IPv6. Size of IPv4 header is 20 bytes and IPv6 header is 40 bytes. Size of ICMP header is 8 bytes. This size can further increase based upon the options used.

Upper limit on the packet size on internet is determined by Maximum Transmission Unit (MTU) of the network resources. Theoretically, the maximum packet size, or Maximum Transmission Unit (MTU), for an IPv4 packet is 65,535 bytes. However, this includes the IPv4 header (typically 20 bytes without options) and the ICMP header (8 bytes). Therefore, the maximum ICMP payload size for an IPv4 packet is 65,507 bytes (65,535 - 20 - 8). The maximum packet size for an IPv6 packet is also 65,535 bytes. The IPv6 header is 40 bytes, and the ICMP header is 8 bytes, resulting in a maximum ICMP payload size of 65,487 bytes (65,535 - 40 - 8).

- IPv4: Theoretical maximum ICMP payload size is 65,507 bytes.
- IPv6: Theoretical maximum ICMP payload size is 65,487 bytes.

### 1.2.3 Ping the websites at maximum theoretical limit

We try to ping *google.com* using max limit for IPv4. By default when we use `ping` command, it pings the destination using IPv4 protocol.

Here's a screenshot showing the output when we ping at the theoretical max value.

```
--- google.com ping statistics ---
7 packets transmitted, 0 packets received, 100.0% packet loss
jaskaransinghbhall@JMac-2 ~ % ping -c 2 -s 65507 google.com
PING google.com (142.250.207.206): 65507 data bytes
ping: sendto: Message too long
ping: sendto: Message too long
Request timeout for icmp_seq 0

--- google.com ping statistics ---
2 packets transmitted, 0 packets received, 100.0% packet loss
```

Generally, the packet size gets restricted by the Maximum Transmission Unit (MTU) of network resources. Practically the MTU of Ethernet and WLAN (Wifi) is around 1500 bytes. Due to this we are not able to ping at the maximum theoretical value. Also the value gets decreased based upon the options provided in the headers.

So, due to common MTU settings, practical ICMP payload sizes are:

- IPv4: 1,472 bytes.
- IPv6: 1,452 bytes.

### 1.3 Forcing the networks to ping using IPv6 protocol

We can ping the networks using IPv6 protocol using, `ping6` command. It forces ping using v6 IP protocol. Some networks might not fully support IPv6 or might have specific configurations that affect how IPv6 addresses are resolved. For instance, corporate or private networks might have restrictions or specific settings that affect IPv6 connectivity.

#### Google.com

```
jaskaransinghbhalla@JMac-2 ~ % ping6 -c 10 google.com
PING6(56=40+8+8 bytes) 2001:df4:e000:3fc1:d8c0:93d:954c:87be -> 2404:6800:4002:826::200e
16 bytes from 2404:6800:4002:826::200e, icmp_seq=0 hlim=116 time=57.039 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=1 hlim=116 time=106.555 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=2 hlim=116 time=512.568 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=3 hlim=116 time=50.657 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=4 hlim=116 time=69.669 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=5 hlim=116 time=22.410 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=6 hlim=116 time=17.419 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=7 hlim=116 time=14.424 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=8 hlim=116 time=14.363 ms
16 bytes from 2404:6800:4002:826::200e, icmp_seq=9 hlim=116 time=10.731 ms

--- google.com ping6 statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/std-dev = 10.731/87.584/512.568/144.700 ms
```

Figure 5: IIT Delhi Network

#### Sigcomm.org

```
jaskaransinghbhalla@JMac-2 ~ % ping6 -c 10 sigcomm.org
ping6: getaddrinfo -- nodename nor servname provided, or not known
```

Figure 7: IIT Delhi Network

```
jaskaransinghbhalla@JMac-2 ~ % ping6 -c 10 google.com
PING6(56=40+8+8 bytes) 2409:40d0:2031:4f52:5d9c:3b3:6a13:a81c -> 2404:6800:4002:820::200e
16 bytes from 2404:6800:4002:820::200e, icmp_seq=0 hlim=57 time=56.764 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=1 hlim=57 time=71.929 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=2 hlim=57 time=94.386 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=3 hlim=57 time=60.487 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=4 hlim=57 time=72.364 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=5 hlim=57 time=58.615 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=6 hlim=57 time=32.754 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=7 hlim=57 time=75.707 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=8 hlim=57 time=75.856 ms
16 bytes from 2404:6800:4002:820::200e, icmp_seq=9 hlim=57 time=54.828 ms

--- google.com ping6 statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/std-dev = 32.754/65.369/94.386/15.714 ms
```

Figure 6: Cellular Network using Hotspot

```
jaskaransinghbhalla@JMac-2 ~ % ping6 -c 10 sigcomm.org
PING6(56=40+8+8 bytes) 2409:40d0:2031:4f52:5d9c:3b3:6a13:a81c -> 64:ff9b:be5c:9e04
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=0 hlim=48 time=617.544 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=1 hlim=48 time=835.289 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=2 hlim=48 time=749.662 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=3 hlim=48 time=493.786 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=4 hlim=48 time=587.311 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=5 hlim=48 time=376.516 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=6 hlim=48 time=813.659 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=7 hlim=48 time=639.743 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=8 hlim=48 time=562.950 ms
16 bytes from 64:ff9b:be5c:9e04, icmp_seq=9 hlim=48 time=390.433 ms

--- sigcomm.org ping6 statistics ---
10 packets transmitted, 10 packets received, 0.0% packet loss
round-trip min/avg/max/std-dev = 376.516/576.689/835.289/137.239 ms
```

Figure 8: Cellular Network using Hotspot

The above screenshots show the result of ping on *google.com* and *sigcomm.org* using IIT Delhi's network and cellular network. The `ping6` request succeeds for most of the cases, but it failed for *sigcomm.org* using IIT Delhi's network. There can be multiple reasons that may cause this. It is possible that the domain for *sigcomm.org* doesn't have an IPv6 address. This can be verified using `nslookup -type=AAAA` and this command verifies that the *sigcomm.org* does have an IPv6 address, which is also confirmed by the fact that we are able to ping it using IPv6 request on cellular network. This brings us to the conclusion, that IIT Delhi's Wifi network has some restrictions or maybe it lacks somewhere due to which it is not able to ping this address. This is often the case in private or enterprise organizations as some networks might not fully support IPv6 or might have specific configurations that affect how IPv6 addresses are resolved. For instance, corporate or private networks might have restrictions or specific settings that affect IPv6 connectivity. So this might be the reason for failure.

## 2 Trace route

### 2.1 Logging Server IPs and Packet paths

We used `nslookup` to log the server IP address of both the websites hosts on the IIT Delhi's network and Cellular network via hotspot . Then we have used `traceroute` command to log the path taken by the packets.

#### Google.com

```
jaskaransinghbhalla@JMac-2 ~ % nslookup google.com
Server:      2001:df4:e000:29::104
Address:     2001:df4:e000:29::104#53

Non-authoritative answer:
Name:   google.com
Address: 142.250.206.142

jaskaransinghbhalla@JMac-2 ~ % traceroute google.com
traceroute to google.com (142.250.207.206), 64 hops max, 40 byte packets
 1  10.194.0.13 (10.194.0.13)  45.869 ms  33.527 ms  48.537 ms
 2  10.254.239.5 (10.254.239.5)  3.928 ms
 3  10.254.239.1 (10.254.239.1)  4.137 ms  4.531 ms
 4  10.255.107.3 (10.255.107.3)  3.862 ms  4.316 ms  4.360 ms
 5  10.119.233.65 (10.119.233.65)  4.129 ms  7.948 ms  4.240 ms
 6  * * *
 7  10.119.234.162 (10.119.234.162)  8.388 ms  6.210 ms  5.786 ms
 8  72.14.195.56 (72.14.195.56)  6.318 ms  6.650 ms  7.140 ms
 9  142.251.226.85 (142.251.226.85)  7.904 ms
 10 192.178.83.243 (192.178.83.243)  7.044 ms
 11 142.251.226.85 (142.251.226.85)  8.243 ms
 12 142.251.76.169 (142.251.76.169)  7.933 ms  7.459 ms
 13 142.251.76.171 (142.251.76.171)  7.853 ms
 14 dell12s10-in-f14.1e100.net (142.250.207.206)  8.953 ms  7.003 ms  8.282 ms
jaskaransinghbhalla@JMac-2 ~ %
```

Figure 9: IIT Delhi Network

```
jaskaransinghbhalla@jmac ~ % nslookup google.com
Server:      2401:4900:47f9:f6b4::50
Address:     2401:4900:47f9:f6b4::50#53

Non-authoritative answer:
Name:   google.com
Address: 172.217.167.238

jaskaransinghbhalla@jmac ~ % traceroute google.com
traceroute to google.com (142.250.193.206), 64 hops max, 40 byte packets
 1  192.168.1.58 (192.168.1.58)  13.792 ms  25.395 ms  13.219 ms
 2  192.168.59.1 (192.168.59.1)  27.706 ms  28.425 ms  24.714 ms
 3  192.168.27.57 (192.168.27.57)  31.566 ms  201.361 ms  53.792 ms
 4  192.168.27.107 (192.168.27.107)  51.362 ms  54.291 ms
 5  192.168.27.105 (192.168.27.105)  47.228 ms
 6  nsg-corporate-5.39.185.122.airtel.in (122.185.39.5)  33.884 ms
 7  nsg-corporate-1.39.185.122.airtel.in (122.185.39.1)  39.806 ms  25.761 ms
 8  * * *
 9  142.251.49.114 (142.251.49.114)  52.484 ms * *
 10 dell1s17-in-f14.1e100.net (142.250.193.206)  51.344 ms *
 11 142.251.54.97 (142.251.54.97)  80.200 ms
```

Figure 10: Cellular Network using Hotspot

#### Sigcomm.org

```
jaskaransinghbhalla@jmac ~ % nslookup sigcomm.org
Server:      2001:df4:e000:29::104
Address:     2001:df4:e000:29::104#53

Non-authoritative answer:
Name:   sigcomm.org
Address: 190.92.158.4

jaskaransinghbhalla@jmac ~ % traceroute sigcomm.org
traceroute to sigcomm.org (190.92.158.4), 64 hops max, 40 byte packets
 1  10.194.0.13 (10.194.0.13)  5.337 ms  4.675 ms  4.882 ms
 2  10.254.239.5 (10.254.239.5)  92.296 ms
 3  10.254.239.1 (10.254.239.1)  4.468 ms  4.451 ms
 4  10.255.107.3 (10.255.107.3)  3.972 ms  4.975 ms  4.476 ms
 5  10.119.233.65 (10.119.233.65)  4.338 ms  4.818 ms  4.989 ms
 6  * * *
 7  10.119.234.162 (10.119.234.162)  93.762 ms  6.589 ms  6.101 ms
 8  136.232.148.177 (136.232.148.177)  6.919 ms  7.452 ms  7.386 ms
 9  * * *
10  49.45.4.103 (49.45.4.103)  269.829 ms  460.609 ms  305.470 ms
11  4.7.26.61 (4.7.26.61)  240.897 ms
12  49.45.4.103 (49.45.4.103)  266.340 ms  257.787 ms
13  * * ae2.2.bar2.detroit1.net.lumen.tech (4.69.203.81)  328.147 ms
14 ae0.11.bar2.detroit1.net.lumen.tech (4.69.202.222)  409.092 ms
15 a2-hosting.bar2.detroit1.level3.net (4.31.124.142)  317.189 ms
16 ae0.11.bar2.detroit1.net.lumen.tech (4.69.202.222)  307.633 ms
17 a2-hosting.bar2.detroit1.level3.net (4.31.124.142)  316.240 ms  307.305 ms
18 e1-1.mi3-c1-e02.09-33.a2webhosting.com (69.48.136.9)  425.435 ms
19 e1-1.mi3-c1-e02.09-33.a2webhosting.com (69.48.136.9)  395.063 ms
20 server.hosting3.acm.org (190.92.158.4)  315.169 ms  318.857 ms
```

Figure 11: IIT Delhi Network

```
jaskaransinghbhalla@jmac ~ % nslookup sigcomm.org
Server:      2401:4900:47f9:f6b4::50
Address:     2401:4900:47f9:f6b4::50#53

Non-authoritative answer:
Name:   sigcomm.org
Address: 190.92.158.4

jaskaransinghbhalla@jmac ~ % traceroute sigcomm.org
traceroute to sigcomm.org (190.92.158.4), 64 hops max, 40 byte packets
 1  192.168.1.58 (192.168.1.58)  21.384 ms  8.412 ms  5.106 ms
 2  192.168.59.1 (192.168.59.1)  24.501 ms  23.771 ms  25.316 ms
 3  192.168.27.57 (192.168.27.57)  23.324 ms  36.355 ms
 4  192.168.27.107 (192.168.27.107)  40.511 ms
 5  192.168.27.109 (192.168.27.109)  22.785 ms
 6  192.168.27.111 (192.168.27.111)  26.428 ms
 7  192.168.27.107 (192.168.27.107)  28.196 ms
 8  nsg-corporate-5.39.185.122.airtel.in (122.185.39.5)  30.362 ms  62.396 ms  23.990 ms
 9  182.79.247.94 (182.79.247.94)  267.722 ms  301.562 ms  276.911 ms
10  * * *
11  * * *
12  * * *
13  * * *
14  * * *
15  * * *
16  * * *
17  80.142.132.50 (80.142.132.50)  381.881 ms  506.973 ms  466.270 ms
18  e1-2.mi3-c1-e02.09-33.a2webhosting.com (190.92.147.9)  343.326 ms  714.990 ms  723.986 ms
19  server.hosting3.acm.org (190.92.158.4)  343.916 ms  332.195 ms  584.389 ms
```

Figure 12: Cellular Network using Hotspot

### 2.2 Number of hops and Autonomous systems

In computer networks, a hop refers to the journey of a packet of data from one router to another router, in travelling from source to destination. Number of hops is therefore an indicator of the number of routers, a data packet passes through in going from source to destination. Using `traceroute` command we can calculate the number of hops by the line number that is logged. Each line with a number represents a single hop.

So, the number of hops for google.com on IIT Delhi's network are 10 and on cellular network are 9. Similarly, for sigcomm.org, number of hops on IIT Delhi's network are 15 and on cellular network are 19.

To list the number of autonomous systems observed we can use `whois` command and look for origin or originAS code to get the AS number. For google.com on IIT Delhi's network and cellular network, we have list of AS = [AS15169]. It contains a single autonomous system. For sigcomm also we observed AS = [AS55293] on IIT Delhi's network and AS=[AS174, AS55293]. To compute this we ran `whois` for each IP address in the `traceroute` output for both the networks.

## 2.3 Asterisk (\*) in output

Yes we observed Asterisk in the logs from `traceroute` we got. They typically indicate a timeout response, which means that the probe packet sent to that particular hop did not return a response within the expected time frame. With reference we can have either of the three situations in which Asterisk appear

**Single Asterisk on a Hop:** This means that the request timed out on just one of the three attempts. This can be a sign that there is an intermittent problem at that hop.

**Three Asterisks, Then Failure:** If we see all three attempts at a hop have asterisks and then the `traceroute` errors out, it means that the hop is completely down.

**Three Asterisks, Then Success:** If we see three attempts at a hop failing but then the rest of the `traceroute` continues without an issue, that is actually not a problem at all. This simply means that (as mentioned earlier), the device at that hop is configured not to respond to pings or `traceroutes`, so the attempt times out.

## 2.4 Multiple IP addresses for same hop count

In a `traceroute` output, observing multiple IP addresses for the same hop is quite common and can be attributed to several factors. Routers often have multiple network interfaces, each with its own IP address, so a single router might appear with different IPs if it has more than one interface. Additionally, many networks use load balancing to distribute traffic across various paths. This means that `traceroute` might show different IP addresses for the same hop because packets are routed through different interfaces to balance the network load. Redundancy and failover mechanisms also play a role; networks are designed with backup paths to ensure reliability, so if a primary path fails, packets might take an alternate route, resulting in different IP addresses for the same hop. Hostname resolution can further contribute to this phenomenon, as a single hostname might resolve to multiple IP addresses, leading to various IPs appearing in the `traceroute`. Lastly, complex network configurations, particularly in large networks, might use different IP addresses for distinct types of traffic or network segments. These factors, combined, reflect the sophisticated and resilient design of modern network infrastructures.

## 2.5 Internet Architecture on traceroute

If we look at the list of IP addresses hopped for all four {network, website} combinations,. We find "10.194.0.13", "10.254.239.5", "10.254.239.1", "10.255.107.3", "10.119.233.65", and "10.119.234.162" are common routes hopped when we use both websites using the IIT Delhi network. Certainly, this means that these routes belong to IIT Delhi's network. Similarly, for a common cellular network, "192.168.1.58", "192.168.59.1", and "192.168.27.57" are common, indicating the local internet service provider. These routes therefore represent the lowest internet provider in the Internet architecture.

We get the IP addresses on IIT Delhi's network for google.com as follows: "72.14.195.56", "142.251.226.85", "192.178.83.243", "142.251.76.169", "142.251.76.171", "142.250.207.206" These IP address give "Google LLC" on running `whois` command and checking the OrgName attribute. This means that these servers are belong to Google, and we checked over Internet to find that these servers were owned by Google cloud computing. Similarly for cellular network the set of IP addresses traced are different "192.168.27.107", "192.168.27.105", "122.185.39.5", "122.185.39.1", "142.251.49.114", "142.250.193.206", "142.251.54.97" but they have the OrgName set to "Google LLC". This indicates the second level in the internet architecture for google.com. Google has 2-Tier architecture, where the local internet provide is directly connected to the Google's backbone internet.

For sigcomm running `whois` command on both the networks gave different providers. The end provider for this website is "A2 Hosting, Inc.". On cellular network we had two intermediate providers. One is an local network provider whose OrgName information was not visible. Then it hopped to a global ISP, who was also not traceable, Then it went to a American regional ISP "PSINet, Inc.", before reaching local ISP "A2 Hostings", which hosts sigcomm.org. So sigcomm followed a 3-Tier internet architecture on cellular network. On IIT Delhi's network we observed multiple hops from multiple providers. But the end provider was "A2 Hosting, Inc.". Intermediate providers included "Asia Pacific Network Info Center", "Level 3 Parent, LLC" owned by Lumen Technologies. Here we can see IIT Delhi's network is the local provider, ASNIC is the regional provider. Then it hopped from "49.45.4.103" which is the global Internet provider, "Level 3 Parent, LLC" is regional provider in America and "A2 Hosting, Inc." is another local provider. So this definitely shows a 3-tier internet architecture.

## **2.6 Geo locating the IP address**

### **2.6.1 Reverse DNS lookup**

To find the Geo-location of the server using their IP address, we use `curl ipinfo.io/$ip` for performing reverse DNS-lookup. For Google on cellular network, the network request goes to "Dadri, Uttar Pradesh", "Delhi, India". On IIT Delhi's network it originates from "Delhi, India" and then goes to "Deoli, India" and returns back to "Delhi, India". For sigcomm.org, on cellular network the network request goes to "Dadri, Uttar Pradesh", "Chennai, Tamil Nadu", "South field, Michigan". On IIT Delhi's network the request goes from "Delhi, India", "Los Angeles, California", "Detroit, Michigan".

### **2.6.2 Comparison of Geo locations with RTTs**

Since the geolocation of the server is very close to the origin of the request, it justifies our short duration of round trip time (RTT) of 11.858 ms and 345.405 ms.

For sigcomm.org, as the final server is located far away in Michigan, US. This justifies a longer RTT for this website, which was 345.405 ms and 554,750 ms. So this indicates that closer location of the server is to location of request being sent, less is the round trip time and faster is the response.