



# **BITS Pilani**

## **Hyderabad Campus**

**Department Of Computer Science and Information Systems**

## **Project Report in Advanced Computer Networks**

**Project Title:** Empirical Analysis of ECMP and Least Utilized Path Routing Algorithms in Software Defined Networks

**Under the Supervision of**

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## INTRODUCTION

Data centers require redundant connections to avoid network failures. However, using redundant connections was not helping as it was only used as a backup and inefficient. ECMP routing algorithm weights all links equally and chooses one path out of several possible equally weighted paths. Then the final path is chosen based on a hash function. Hash functions are also purely mathematical, during calculation for one of the equally weighted path Network traffic is not considered. Another way could be to search the network and calculate the utilization of links at specific frequencies and assign these utilizations as link weights. However, the network load can change quickly and get stale values. so, in order to Empirically analyse it is required to determine the ideal frequency of performing probing as well. This analysis also includes comparisons with ECMP and LUP.

## **ABSTRACT**

Redundant connections in the network have great benefits, but they require good routing algorithms. One easy way is to use static routing technique in which path between two nodes of network is always fixed. But this static routing does not consider any advantage provided by the redundant link. Another method is ECMP routing. Here all links have a weight of 1 and shortest path between two nodes in the network is calculated using Dijkstra's algorithm. There could be multiple paths between the source and destination with minimum weight. From those, one of the paths is selected using a hash function using Source IP, Destination IP as input. When a particular path for source and the destination are calculated for some port, it always remains the same. In short, the hash function is a purely mathematical function, not taking into account factors such as: Congestion in the network at a particular time. The proposed algorithm assigns the utilization of the link as the weight of each link. that's why, the shortest route chosen by Dijkstra is the least used route. But due to the virtue of network properties, it is always changing rapidly and the usage assigned may be required to get updated frequently. so, the frequency of how often active probes should be run to determine the link utilizations in the network. For this an empirical analysis which involves various experiments wherein the probing is done at various frequencies is done. In the same analysis, we also compare it with the LUP and ECMP routing algorithms.

## **PROBLEM STATEMENT**

In order to prevent failures, data centres require networks with redundant links. There are other ways to pick the path for traffic from these redundant links, including giving each link in the network an identical weight, assigning varied weights based on link utilisation, etc. It is necessary to conduct an empirical investigation to determine which of these strategies works better in certain circumstances.

# Methodology

## ECMP algorithm

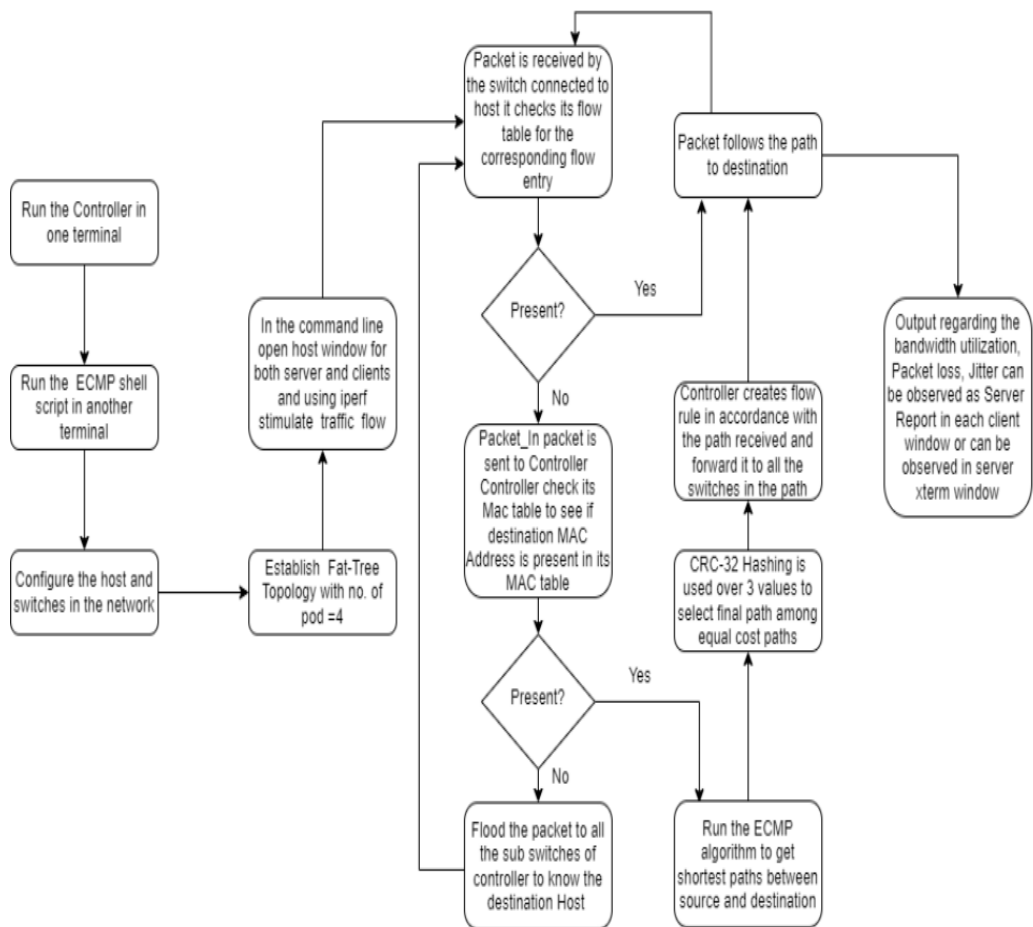
```
1: function MULTIPATHDIJKSTRA(Graph, source)
2:   for each vertex v in Graph:
3:     dist[v] ← INFINITY
4:     visited[v] ← FALSE
5:     previous[v] ← UNDEFINED
6:   end for
7:   dist[source] ← 0
8:   insert source into Q
9:
10:  while Q is not empty do:
11:    u ← vertex in Q with smallest in dist[] and not yet visited;
12:    remove u from Q
13:    visited[u] ← true
14:    for each neighbour v of u:
15:      alt ← dist[u] + dist_between(u, v)
16:      if alt < dist[v]:
17:        dist[v] ← alt
18:        reset the previous[v]
19:        add u into previous[v]
20:      end if
21:      else if alt == dist[v]:
22:        add u into previous[v]
23:      if !visited[v] :
24:        insert v into Q
25:      if
26:    end for
27:  end while
28:  return dist;
29: end function
```

## Mutipath Dijkstra Algorithm

```
1: function ECMP_HASH(packet)
2:   hash_input ← [0] * 5
3:   if ipv4 is in packet :
4:     ip ← packet
5:     hash_input[0] ← unsigned ip[srcIP]
6:     hash_input[1] ← unsigned ip[dstIP]
7:     hash_input[2] ← unsigned ip[protocol]
8:     if TCP is in ip or UDP is in ip:
9:       l4 ← ip
10:      hash_input[3] ← l4[srcPort]
11:      hash_input[4] ← l4[dstPort]
12:      return crc32(hash_input)
13:   return 0
14: end function
```

## Hashed ECMP Algorithm

# ECMP Work Flow:



## Least utilized path method:

### Initializations:

1. Initialize all link weight as 1
2. Initialize last\_port\_stat (a mapping from port to last bytes received on the port) as 0.

Port statistics essentially tell us how many bytes have ever passed via a port. Therefore, each time we obtain port statistics, we must deduct them from the prior bytes in order to obtain the bytes transferred over the past  $f$  seconds.

### Algorithm 1: Active prober (probing frequency $f$ ) Executed every $f$ seconds

- a. for every switch:
  - a. for every port:
    - i. Send port stats request

**Algorithm 2:** Link weight updater (probing frequency  $f$ ) Executed on reception of port stats at controller Stats are received from each switch as a list. Each entry in the list corresponds to the ports in the switch.

#### 1) for stat in stats:

- a)  $\text{bytes} \leftarrow \text{stat.bytes} - \text{last\_port\_stat}[\text{stat.port}]$
- b)  $\text{last\_port\_stat}[\text{stat.port}] \leftarrow \text{stat.bytes}$
- c)  $\text{utilization} \leftarrow \text{bytes} / f$
- d)  $\text{link\_weight}[\text{stat.switch}][\text{stat.port.connected\_switch}] \leftarrow \text{utilization} / 1$

## Experimental setup:

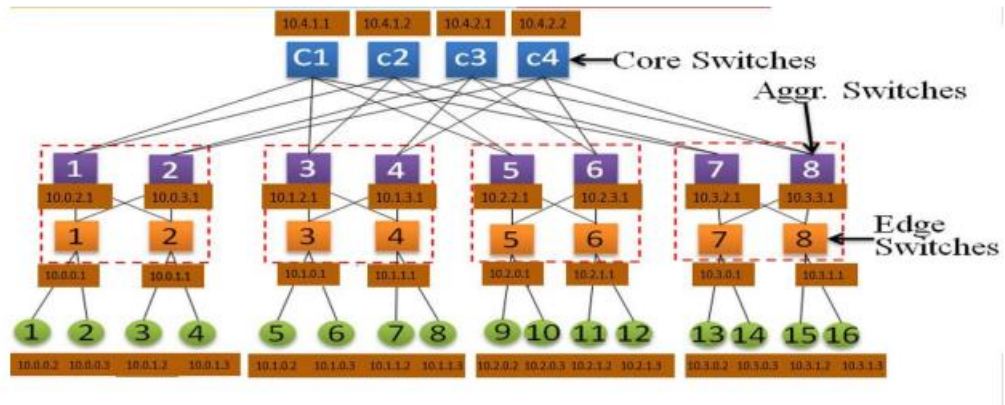


Fig.1 Fat Tree Topology

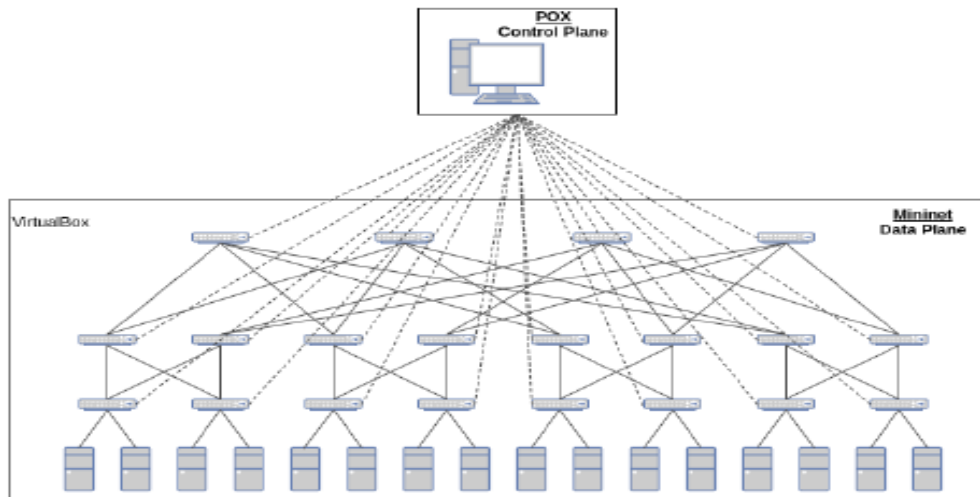


Fig.2 System Design

The three algorithms were applied to the fat-tree topology mentioned above. Utilizations calculated at frequency of 10 sec were used to test the least used path algorithm. For parallel, long, and short flows, it was compared how much packet loss, throughput, and jitter there was.



## Outputs

## ECMP:

[illegible][illegible]

```
root@mru-VirtualBox: ~/ECMP org
root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 100 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.2 port 38730 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-100.0 sec  115 MBytes  9.62 Mbits/sec
[ 3] Sent 61795 datagrams
[ 3] Server Report:
[ 3] 0.0-100.5 sec  97.8 MBytes  8.17 Mbits/sec    0.000 ms 12021/61794 (0%)
[ 3] 0.00-100.47 sec  14 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org#

root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 45452 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-10.0 sec  11.5 MBytes  9.68 Mbits/sec
[ 3] Sent 8223 datagrams
[ 3] Server Report:
[ 3] 0.0-10.3 sec  9.99 MBytes  8.10 Mbits/sec    0.000 ms 1105/ 8228 (0%)
[ 3] 0.00-10.34 sec  35 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 53888 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-10.0 sec  11.5 MBytes  9.65 Mbits/sec
[ 3] Sent 8213 datagrams
[ 3] Server Report:
[ 3] 0.0-10.4 sec  3.85 MBytes  3.11 Mbits/sec    0.000 ms 5463/ 8212 (0%)
[ 3] 0.00-10.38 sec  18 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 57898 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-10.0 sec  11.5 MBytes  9.57 Mbits/sec
[ 3] Sent 8221 datagrams
[ 3] Server Report:
[ 3] 0.0-10.2 sec  11.0 MBytes  9.05 Mbits/sec    0.000 ms 397/ 8221 (0%)
[ 3] 0.00-10.17 sec  11 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org#

root@mru-VirtualBox:~/ECMP org# iperf -s -p 12345 -u
Server listening on UDP port 12345
Receiving 1470 byte datagrams
UDP buffer size: 208 KByte (default)

[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 38730
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 45452
[ ID] Interval      Transfer     Bandwidth      Jitter    Lost/Total Datagrams
[ 4] 0.0-10.3 sec  9.39 MBytes  8.10 Mbits/sec  20.155 ms 1105/ 8228 (13%)
[ 4] 0.00-10.34 sec  35 datagrams received out-of-order
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 53888
[ 5] 0.0-10.4 sec  3.85 MBytes  3.11 Mbits/sec  23.824 ms 5463/ 8212 (67%)
[ 4] 0.00-10.39 sec  18 datagrams received out-of-order
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 57898
[ 4] 0.0-100.5 sec  97.8 MBytes  8.17 Mbits/sec  22.366 ms 12021/61794 (15%)
[ 3] 0.00-100.47 sec  14 datagrams received out-of-order
[ 4] 0.0-10.2 sec  11.0 MBytes  9.05 Mbits/sec  4.561 ms 397/ 8221 (4.8%)
[ 4] 0.00-10.17 sec  11 datagrams received out-of-order
```

```
root@mru-VirtualBox: ~/ECMP org
root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 100 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.2 port 35709 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-100.0 sec  50.0 MBytes  4.19 Mbits/sec
[ 3] Sent 35667 datagrams
[ 3] Server Report:
[ 3] 0.0-100.0 sec  50.0 MBytes  4.20 Mbits/sec    0.000 ms 0/35667 (0%)
[ 3] 0.00-99.35 sec  6 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org#

root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 43075 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-10.0 sec  5.00 MBytes  4.19 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec  5.00 MBytes  4.21 Mbits/sec    0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec  7 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 36814 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-10.0 sec  5.00 MBytes  4.19 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec  5.00 MBytes  4.21 Mbits/sec    0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.97 sec  3 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org# iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kalanen adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 52278 connected with 10.1.0.3 port 12345
[ ID] Interval      Transfer     Bandwidth
[ 3] 0.0-10.0 sec  5.00 MBytes  4.19 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-9.9 sec  5.00 MBytes  4.22 Mbits/sec    0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.55 sec  4 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP org#

root@mru-VirtualBox:~/ECMP org# iperf -s -p 12345 -u
Server listening on UDP port 12345
Receiving 1470 byte datagrams
UDP buffer size: 208 KByte (default)

[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 35709
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 43075
[ ID] Interval      Transfer     Bandwidth      Jitter    Lost/Total Datagrams
[ 4] 0.0-10.0 sec  5.00 MBytes  4.21 Mbits/sec  0.023 ms 0/ 3568 (0%)
[ 4] 0.00-9.98 sec  7 datagrams received out-of-order
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 36814
[ 5] 0.0-10.0 sec  5.00 MBytes  4.21 Mbits/sec  0.577 ms 0/ 3568 (0%)
[ 5] 0.00-9.97 sec  3 datagrams received out-of-order
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 52278
[ 4] 0.0-9.9 sec  5.00 MBytes  4.22 Mbits/sec  0.023 ms 0/ 3568 (0%)
[ 4] 0.00-9.55 sec  4 datagrams received out-of-order
[ 3] 0.0-100.0 sec  50.0 MBytes  4.20 Mbits/sec  0.013 ms 0/35667 (0%)
[ 3] 0.00-99.35 sec  6 datagrams received out-of-order
```

# LUP(least Utilized Path)

```
root@mru-VirtualBox: ~/ECMP modified
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 100 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.2 port 57563 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-100.0 sec 115 MBytes 9.63 Mbits/sec
[ 3] Sent 82380 datagrams
[ 3] Server Report:
[ 3] 0.0-100.1 sec 95.6 MBytes 8.01 Mbits/sec 0.000 ms 14160/82380 (0x)
[ 3] 0.0-100.14 sec 45 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 48972 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 11.6 MBytes 9.72 Mbits/sec
[ 3] Sent 8328 datagrams
[ 3] Server Report:
[ 3] 0.0-10.8 sec 1.79 MBytes 1.33 Mbits/sec 0.000 ms 7015/ 8295 (0x)
[ 3] 0.0-10.81 sec 3 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 46601 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.1 sec 11.6 MBytes 9.58 Mbits/sec
[ 3] Sent 8189 datagrams
[ 3] Server Report:
[ 3] 0.0-10.5 sec 7.28 MBytes 5.80 Mbits/sec 0.000 ms 2991/ 8187 (0x)
[ 3] 0.0-10.54 sec 3 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 50578 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.1 sec 11.7 MBytes 9.77 Mbits/sec
[ 3] Sent 8350 datagrams
[ 3] Server Report:
[ 3] 0.0-10.8 sec 10.7 MBytes 8.32 Mbits/sec 0.000 ms 711/ 8349 (0x)
[ 3] 0.0-10.78 sec 3 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -s -p 12345 -u
Server listening on UDP port 12345
Receiving 1470 byte datagrams
UDP buffer size: 208 KByte (default)

[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 57563
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 48972
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 4] 0.0-10.8 sec 1.79 MBytes 1.33 Mbits/sec 58.006 ms 7015/ 8295 (85x)
[ 4] 0.0-10.81 sec 3 datagrams received out-of-order
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 46601
[ 5] 0.0-10.5 sec 7.28 MBytes 5.80 Mbits/sec 38.731 ms 2991/ 8187 (37x)
[ 5] 0.0-10.54 sec 3 datagrams received out-of-order
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 50578
[ 4] 0.0-10.8 sec 10.7 MBytes 8.32 Mbits/sec 47.790 ms 711/ 8349 (8.5x)
[ 4] 0.0-10.78 sec 3 datagrams received out-of-order
[ 3] 0.0-100.1 sec 95.6 MBytes 8.01 Mbits/sec 4.575 ms 14160/82380 (17x)
[ 3] 0.0-100.14 sec 45 datagrams received out-of-order
```

```
root@mru-VirtualBox:~/ECMP modified
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 100 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.2 port 40983 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-100.0 sec 115 MBytes 9.70 Mbits/sec
[ 3] Sent 82498 datagrams
[ 3] Server Report:
[ 3] 0.0-100.2 sec 94.1 MBytes 7.88 Mbits/sec 0.000 ms 15363/82498 (0x)
[ 3] 0.0-100.16 sec 44 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 52087 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.1 sec 11.7 MBytes 9.77 Mbits/sec
[ 3] Sent 8352 datagrams
[ 3] Server Report:
[ 3] 0.0-10.2 sec 9.52 MBytes 7.63 Mbits/sec 0.000 ms 1563/ 8352 (0x)
[ 3] 0.0-10.20 sec 22 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 35671 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.1 sec 11.7 MBytes 9.74 Mbits/sec
[ 3] Sent 8326 datagrams
[ 3] Server Report:
[ 3] 0.0-10.1 sec 6.51 MBytes 7.07 Mbits/sec 0.000 ms 2257/ 8326 (0x)
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 32943 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 11.7 MBytes 9.76 Mbits/sec
[ 3] Sent 8338 datagrams
[ 3] WARNING: did not receive ack of last datagram after 10 tries.
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 58319 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 11.7 MBytes 9.77 Mbits/sec
[ 3] Sent 8350 datagrams
[ 3] Server Report:
[ 3] 0.0-10.3 sec 8.55 MBytes 2.22 Mbits/sec 0.000 ms 2244/ 8346 (0x)
[ 3] 0.0-45.9 sec 2.52 MBytes 461 Kbits/sec 0.000 ms 6495/ 8294 (0x)
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 59064 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 11.7 MBytes 9.77 Mbits/sec
[ 3] Sent 8346 datagrams
[ 3] Server Report:
[ 3] 0.0-10.3 sec 8.55 MBytes 2.22 Mbits/sec 0.000 ms 2244/ 8346 (0x)
[ 3] 0.0-45.9 sec 2.52 MBytes 461 Kbits/sec 0.000 ms 6495/ 8294 (0x)
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -s -p 12345 -u
Server listening on UDP port 12345
Receiving 1470 byte datagrams
UDP buffer size: 208 KByte (default)

[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 59126
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 53349
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 4] 0.0-10.1 sec 5.06 MBytes 4.13 Mbits/sec 4.882 ms 4839/ 8392 (57x)
[ 4] 0.0-10.14 sec 16 datagrams received out-of-order
read failed: Connection refused
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 35932
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 59064
[ 4] 0.0-10.3 sec 8.55 MBytes 2.22 Mbits/sec 4.576 ms 2244/ 8346 (27x)
[ 6] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 48916
[ 6] 0.0-45.9 sec 2.52 MBytes 461 Kbits/sec 13.605 ms 6495/ 8294 (78x)
[ 6] 0.0-45.90 sec 1 datagrams received out-of-order
[ 3] 0.0-100.2 sec 95.4 MBytes 8.33 Mbits/sec 4.468 ms 11677/82616 (14x)
[ 3] 0.0-100.17 sec 35 datagrams received out-of-order
read failed: Connection refused
```

```
root@mru-VirtualBox:~/ECMP modified
root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 100 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.2 port 59126 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-100.0 sec 116 MBytes 9.71 Mbits/sec
[ 3] Sent 82616 datagrams
[ 3] Server Report:
[ 3] 0.0-100.2 sec 99.4 MBytes 8.33 Mbits/sec 0.000 ms 11677/82616 (0x)
[ 3] 0.0-100.17 sec 35 datagrams received out-of-order
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 59064 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 11.6 MBytes 9.71 Mbits/sec
[ 3] Sent 8256 datagrams
[ 3] Server Report:
[ 3] 0.0-10.3 sec 8.55 MBytes 2.22 Mbits/sec 0.000 ms 2244/ 8346 (0x)
[ 3] 0.0-45.9 sec 2.52 MBytes 461 Kbits/sec 0.000 ms 6495/ 8294 (0x)
root@mru-VirtualBox:~/ECMP modified#

root@mru-VirtualBox:~/ECMP modified# iperf -c 10.1.0.3 -p 12345 -t 10 -b 10M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 1121.52 us (kcalman adjust)
UDP buffer size: 208 KByte (default)

[ 3] local 10.0.0.3 port 48319 connected with 10.1.0.3 port 12345
[ ID] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 11.6 MBytes 9.71 Mbits/sec
[ 3] Sent 8256 datagrams
[ 3] Server Report:
[ 3] 0.0-10.3 sec 8.55 MBytes 2.22 Mbits/sec 0.000 ms 2244/ 8346 (0x)
[ 3] 0.0-45.9 sec 2.52 MBytes 461 Kbits/sec 0.000 ms 6495/ 8294 (0x)
root@mru-VirtualBox:~/ECMP modified#

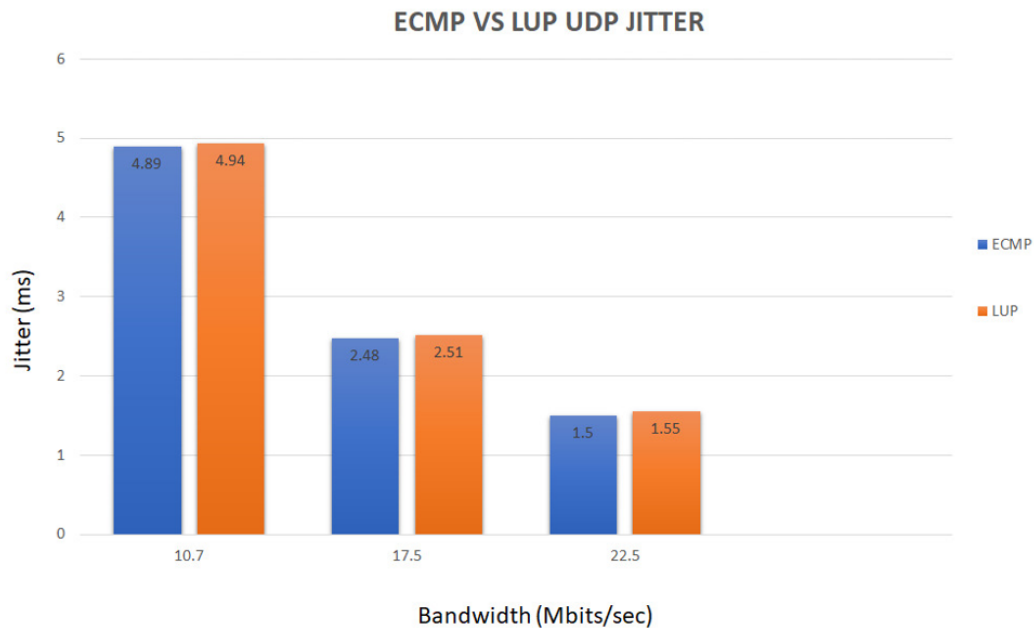
root@mru-VirtualBox:~/ECMP modified# iperf -s -p 12345 -u
Server listening on UDP port 12345
Receiving 1470 byte datagrams
UDP buffer size: 208 KByte (default)

[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 59126
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 53349
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 4] 0.0-10.1 sec 5.06 MBytes 4.13 Mbits/sec 4.882 ms 4839/ 8392 (57x)
[ 4] 0.0-10.14 sec 16 datagrams received out-of-order
read failed: Connection refused
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 35932
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 59064
[ 4] 0.0-10.3 sec 8.55 MBytes 2.22 Mbits/sec 4.576 ms 2244/ 8346 (27x)
[ 6] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 48916
[ 6] 0.0-45.9 sec 2.52 MBytes 461 Kbits/sec 13.605 ms 6495/ 8294 (78x)
[ 6] 0.0-45.90 sec 1 datagrams received out-of-order
[ 3] 0.0-100.2 sec 95.4 MBytes 8.33 Mbits/sec 4.468 ms 11677/82616 (14x)
[ 3] 0.0-100.17 sec 35 datagrams received out-of-order
read failed: Connection refused
```

```
root@mrnu-VirtualBox: ~/ECMP modified
[ 3] local 10.0.0.2 port 34700 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-9.9 sec 5.00 MBytes 4.22 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 14 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.2 port 52900 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 13 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.2 port 55655 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 5.00 MBytes 4.21 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 18 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.2 port 39846 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 11 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.2 port 34974 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 11 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.3 port 47660 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 11 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.3 port 41957 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 4.99 MBytes 4.18 Mbits/sec
[ 3] Sent 3567 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 4.99 MBytes 4.20 Mbits/sec 0.000 ms 0/ 3567 (0%)
[ 3] 0.00-9.97 sec 12 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.3 port 36875 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 4.99 MBytes 4.13 Mbits/sec
[ 3] Sent 3563 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 4.99 MBytes 4.21 Mbits/sec 0.000 ms 0/ 3561 (0%)
[ 3] 0.00-9.98 sec 4 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.3 port 34543 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 5.00 MBytes 4.13 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 5.00 MBytes 4.21 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 15 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Client connecting to 10.1.0.3, UDP port 12345
Sending 1470 byte datagrams, IPG target: 2803.80 us (kaiman adjust)
UDP buffer size: 208 KByte (default)
[ 3] local 10.0.0.3 port 41677 connected with 10.1.0.3 port 12345
[ 1] Interval Transfer Bandwidth
[ 3] 0.0-10.0 sec 4.99 MBytes 4.18 Mbits/sec
[ 3] Sent 3568 datagrams
[ 3] Server Report:
[ 3] 0.0-10.0 sec 4.99 MBytes 4.20 Mbits/sec 0.000 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 15 datagrams received out-of-order
root@mrnu-VirtualBox:~/ECMP modified iperf -c 10.1.0.3 -p 12345 -t 10 -b 4M -u
Server listening on UDP port 12345
Receiving 1470 byte datagrams
UDP buffer size: 208 KByte (default)
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 34700
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 47660
[ 1] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 3] 0.0-9.9 sec 5.00 MBytes 4.22 Mbits/sec 0.133 ms 0/ 3568 (0%)
[ 3] 0.00-9.94 sec 14 datagrams received out-of-order
[ 3] 0.00-9.99 sec 11 datagrams received out-of-order
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 52900
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 41957
[ 3] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 0.326 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 13 datagrams received out-of-order
[ 3] 0.00-9.97 sec 12 datagrams received out-of-order
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 55655
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 36875
[ 3] 0.0-10.0 sec 5.00 MBytes 4.21 Mbits/sec 0.399 ms 0/ 3568 (0%)
[ 3] 0.00-9.96 sec 18 datagrams received out-of-order
[ 3] 0.0-10.0 sec 4.99 MBytes 4.21 Mbits/sec 0.185 ms 0/ 3561 (0%)
[ 3] 0.00-9.96 sec 4 datagrams received out-of-order
[ 5] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 39846
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 34543
[ 3] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 1.063 ms 0/ 3568 (0%)
[ 3] 0.0-10.0 sec 5.00 MBytes 4.21 Mbits/sec 0.474 ms 0/ 3568 (0%)
[ 4] local 10.1.0.3 port 12345 connected with 10.0.0.2 port 34974
[ 3] local 10.1.0.3 port 12345 connected with 10.0.0.3 port 41677
[ 4] 0.0-10.0 sec 5.00 MBytes 4.20 Mbits/sec 0.692 ms 0/ 3568 (0%)
[ 3] 0.00-9.98 sec 11 datagrams received out-of-order
[ 3] 0.0-10.0 sec 4.99 MBytes 4.20 Mbits/sec 0.143 ms 0/ 3568 (0%)
[ 3] 0.00-9.96 sec 16 datagrams received out-of-order
```

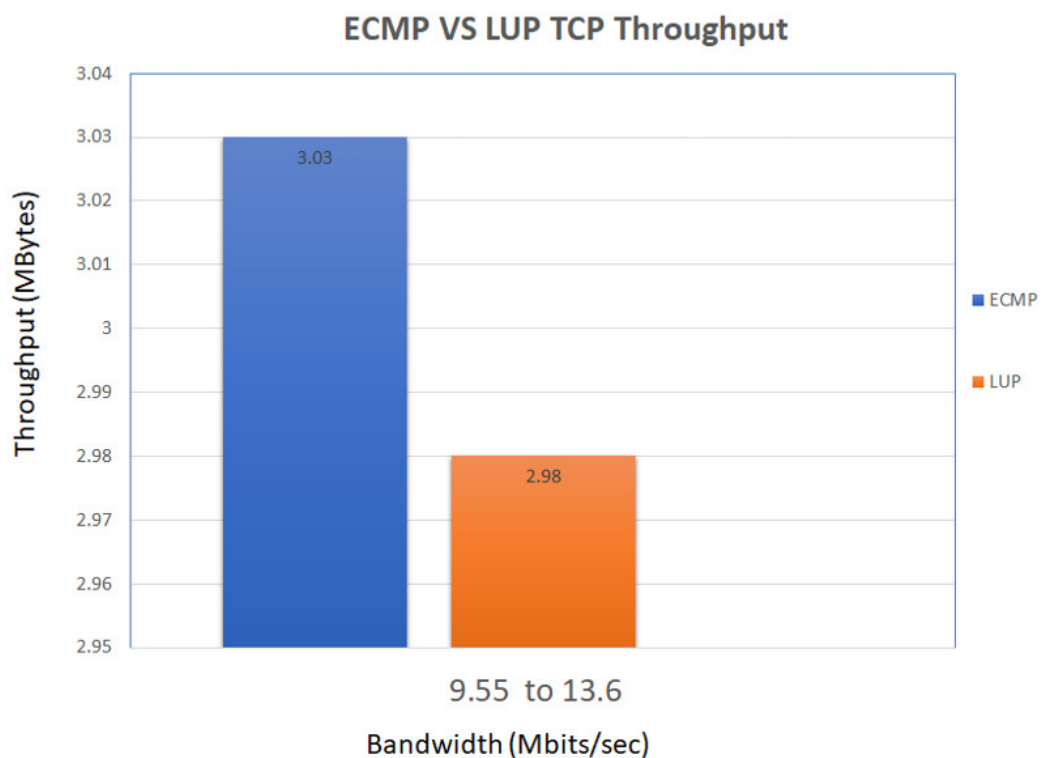
# Results

## a) Jitter



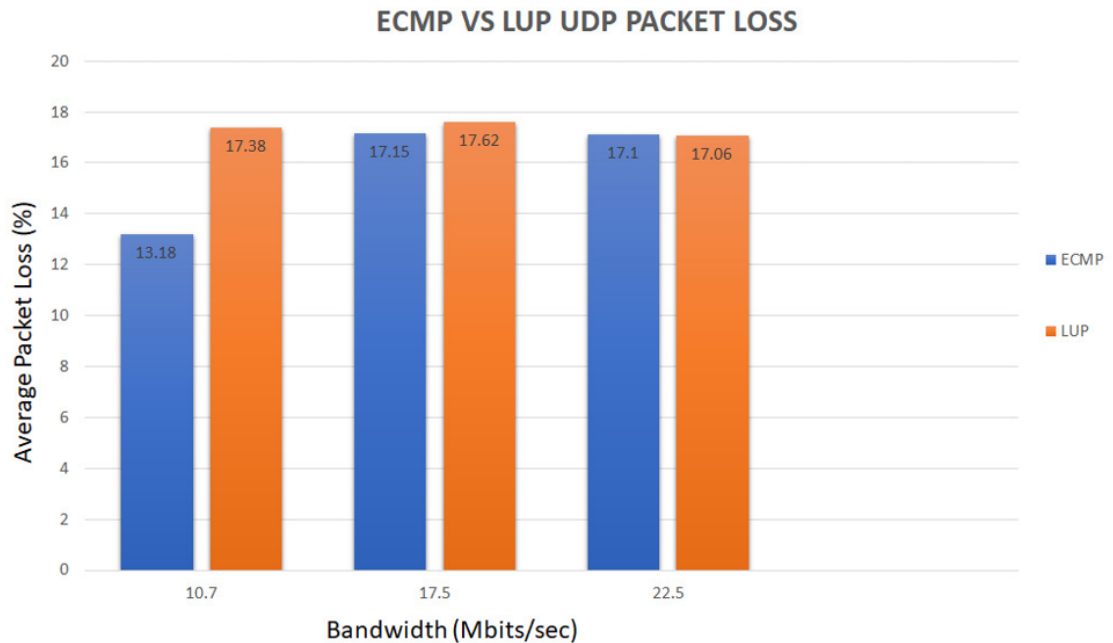
Jitter is defined as the variation in delay. As can be seen from the above graphs that in terms of jitter the performance of ECMP and Least Utilized Path is approximately same for three different bandwidths of 10.7 Mbps, 17.5 Mbps and 22.5 Mbps.

## b) Throughput



Throughput is defined as the amount of data that is sent successfully per unit time. As we can see from the above graphs that for the bandwidth in the range of 9.55 to 13.6 Mbps the throughput of ECMP is better than the Least Utilized Path.

### c) Packet Loss



Packet Loss is given in percentage which refers that in UDP connection the number of datagrams which are lost out of the total number of datagrams which are sent from sender to receiver. From the above graph it can be seen that although ECMP performs slightly better than UDP but still we can consider their performance to be approximately same in terms of packet loss.