

# Lab3 实验报告

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# Task 1

```
"Node: h1"
ether 82:a2:86:f1:67:7c txqueuelen 1000 (Ethernet)
RX packets 58 bytes 5624 (5.6 KB)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 9 bytes 726 (726.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
inet 127.0.0.1 netmask 255.0.0.0
inet6 ::1 prefixlen 128 scopeid 0x10<host>
loop txqueuelen 1000 (Local Loopback)
RX packets 0 bytes 0 (0.0 B)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 0 bytes 0 (0.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@liu-virtual-machine:/home/liu/Desktop# iperf -s
-----
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 5001 connected with 10.0.0.2 port 42944
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-10.0007 sec 10.6 GBytes 9.14 Gbits/sec
[ ]

"Node: h2"
root@liu-virtual-machine:/home/liu/Desktop# iperf -c 10.0.0.1
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.2 port 42944 connected with 10.0.0.1 port 5001
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-10.0167 sec 10.6 GBytes 9.12 Gbits/sec
root@liu-virtual-machine:/home/liu/Desktop#
```

## Task 2

```
"Node: h1"
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 0 bytes 0 (0.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

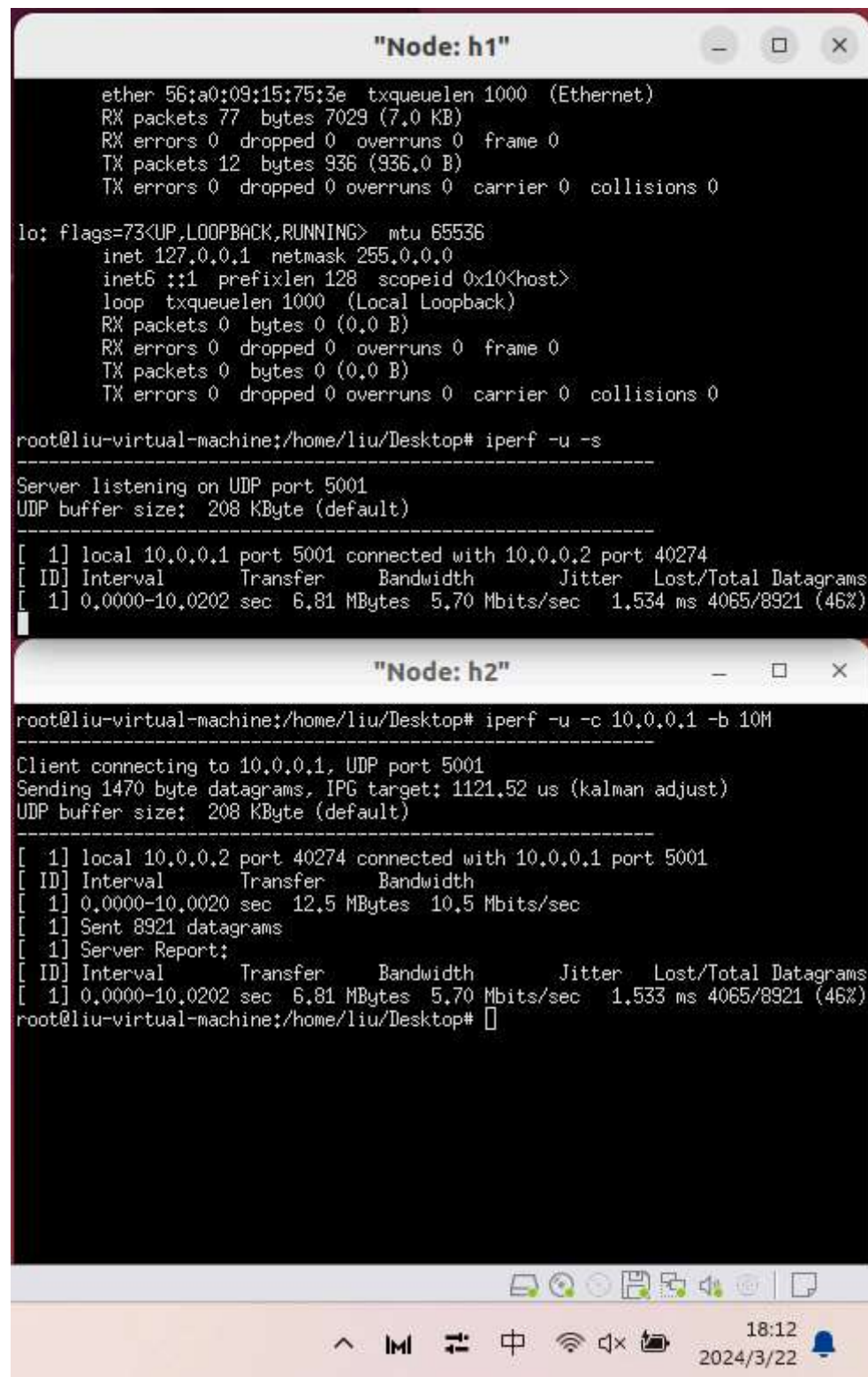
root@liu-virtual-machine:/home/liu/Desktop# iperf -s
-----
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[  1] local 10.0.0.1 port 5001 connected with 10.0.0.2 port 42944
[ ID] Interval      Transfer    Bandwidth
[  1] 0.0000-10.0007 sec  10.6 GBytes  9.14 Gbits/sec
iperf -s
quit
^Croot@liu-virtual-machine:/home/liu/Desktop# ipref -s
Command 'ipref' not found, did you mean:
  command 'iperf' from deb iperf (2.1.5+dfsg1-1)
Try: apt install <deb name>
root@liu-virtual-machine:/home/liu/Desktop# iperf -s
-----
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[]

"Node: h2"

root@liu-virtual-machine:/home/liu/Desktop# iperf -c 10.0.0.1
tcp connect failed: No route to host
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: -1.00 Byte (default)
-----
[  1] local 0.0.0.0 port 0 connected with 10.0.0.1 port 5001
root@liu-virtual-machine:/home/liu/Desktop# []
```

# Task 3

## 3.1



The image shows two terminal windows from a virtual machine named 'liu-virtual-machine'. The top window, titled '"Node: h1"', displays network interface details for 'eth0' (Ethernet) and 'lo' (Local Loopback). The 'eth0' interface has MAC address 56:a0:09:15:75:3e and is configured with a txqueuelen of 1000. It shows 77 RX packets (7.0 KB) and 12 TX packets (936 B). The 'lo' interface is configured with an mtu of 65536 and shows 0 RX and TX packets. Below the interface details, the user runs 'iperf -u -s', which starts a server listening on UDP port 5001. A client connects from 10.0.0.2 port 40274, and the test results show a transfer of 6.81 MBytes at 5.70 Mbits/sec with 1.534 ms jitter and 4065/8921 (46%) lost datagrams.

The bottom window, titled '"Node: h2"', shows the user running 'iperf -u -c 10.0.0.1 -b 10M', which connects to the server on 10.0.0.1 port 5001. The client sends 1470 byte datagrams. The test results show a transfer of 6.81 MBytes at 5.70 Mbits/sec with 1.533 ms jitter and 4065/8921 (46%) lost datagrams. The user then runs 'root@liu-virtual-machine:/home/liu/Desktop#' and a prompt appears.

```
"Node: h1"
ether 56:a0:09:15:75:3e txqueuelen 1000 (Ethernet)
RX packets 77 bytes 7029 (7.0 KB)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 12 bytes 936 (936.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
inet 127.0.0.1 netmask 255.0.0.0
inet6 ::1 prefixlen 128 scopeid 0x10<host>
loop txqueuelen 1000 (Local Loopback)
RX packets 0 bytes 0 (0.0 B)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 0 bytes 0 (0.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@liu-virtual-machine:/home/liu/Desktop# iperf -u -s

Server listening on UDP port 5001
UDP buffer size: 208 KByte (default)

[ 1] local 10.0.0.1 port 5001 connected with 10.0.0.2 port 40274
[ ID] Interval      Transfer      Bandwidth      Jitter    Lost/Total Datagrams
[ 1] 0.0000-10.0202 sec 6.81 MBytes  5.70 Mbits/sec  1.534 ms  4065/8921 (46%)

"Node: h2"
root@liu-virtual-machine:/home/liu/Desktop# iperf -u -c 10.0.0.1 -b 10M

Client connecting to 10.0.0.1, UDP port 5001
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalman adjust)
UDP buffer size: 208 KByte (default)

[ 1] local 10.0.0.2 port 40274 connected with 10.0.0.1 port 5001
[ ID] Interval      Transfer      Bandwidth      Jitter    Lost/Total Datagrams
[ 1] 0.0000-10.0202 sec 6.81 MBytes  5.70 Mbits/sec  1.533 ms  4065/8921 (46%)
[ 1] Sent 8921 datagrams
[ 1] Server Report:
[ ID] Interval      Transfer      Bandwidth      Jitter    Lost/Total Datagrams
[ 1] 0.0000-10.0202 sec 6.81 MBytes  5.70 Mbits/sec  1.533 ms  4065/8921 (46%)
root@liu-virtual-machine:/home/liu/Desktop#
```

## 3.2

```
"Node: h4"
inet6 ::1 prefixlen 128 scopeid 0x10<host>
loop txqueuelen 1000 (Local Loopback)
RX packets 0 bytes 0 (0.0 B)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 0 bytes 0 (0.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@liu-virtual-machine:/home/liu/Desktop# iperf -u -s
-----
Server listening on UDP port 5001
UDP buffer size: 208 KByte (default)
-----
[ 1] local 10.0.0.4 port 5001 connected with 10.0.0.3 port 57232
[ ID] Interval      Transfer      Bandwidth      Jitter    Lost/Total Datagrams
[ 1] 0.0000-10.1774 sec 5.90 MBytes  4.86 Mbits/sec  9.056 ms  0/4209 (0%)
[ 5] WARNING: ack of last datagram failed.
[ 2] local 10.0.0.4 port 5001 connected with 10.0.0.3 port 57232
recvmsg failed: Connection refused
[ ID] Interval      Transfer      Bandwidth      Jitter    Lost/Total Datagrams
[ 2] 0.0000-0.0023 sec 1.44 KBytes  5.01 Mbits/sec  0.000 ms  4217/4219 (1e+02
%)
[ 2] 0.0000-0.0023 sec 1 datagrams received out-of-order
write-ackfin failed: Connection refused
█

"Node: h3"
root@liu-virtual-machine:/home/liu/Desktop# iperf -u -c 10.0.0.4 -b 10M
-----
Client connecting to 10.0.0.4, UDP port 5001
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalman adjust)
UDP buffer size: 208 KByte (default)
-----
[ 1] local 10.0.0.3 port 57232 connected with 10.0.0.4 port 5001
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-10.0634 sec 5.90 MBytes  4.92 Mbits/sec
[ 1] Sent 4210 datagrams
[ 1] Server Report:
[ ID] Interval      Transfer      Bandwidth      Jitter    Lost/Total Datagrams
[ 1] 0.0000-10.1774 sec 5.90 MBytes  4.86 Mbits/sec  9.056 ms  0/4209 (0%)
root@liu-virtual-machine:/home/liu/Desktop# █
```

### 3.3

```
"Node: h6"
root@liu-virtual-machine:/home/liu/Desktop/ovs# iperf -u -s
-----
Server listening on UDP port 5001
UDP buffer size: 208 KByte (default)
-----
[ 1] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 53735
[ ID] Interval      Transfer    Bandwidth      Jitter    Lost/Total Datagrams
[ 1] 0.0000-10.0144 sec 6.38 MBytes 5.34 Mbits/sec  0.858 ms 4373/8921 (49%)
[ 5] WARNING: ack of last datagram failed.
[ 2] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 53735
[ ID] Interval      Transfer    Bandwidth      Jitter    Lost/Total Datagrams
[ 2] 0.0000-0.0102 sec 2.87 KBytes 2.30 Mbits/sec  0.640 ms 8930/8932 (1e+02%)
[ 6] WARNING: ack of last datagram failed.
[ 3] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 53735
[ ID] Interval      Transfer    Bandwidth      Jitter    Lost/Total Datagrams
[ 3] 0.0000-0.0098 sec 2.87 KBytes 2.39 Mbits/sec  0.614 ms 8941/8943 (1e+02%)
[ 5] WARNING: ack of last datagram failed.
[ 4] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 53735
[ ID] Interval      Transfer    Bandwidth      Jitter    Lost/Total Datagrams
[ 4] 0.0000-0.0104 sec 2.87 KBytes 2.27 Mbits/sec  0.648 ms 8952/8954 (1e+02%)
[ 6] WARNING: ack of last datagram failed.
```



```
"Node: h6"
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams
[ 15] 0.0000-0.0103 sec 2.87 KBytes 2.28 Mbits/sec 0.644 ms 9072/9074 (1e+02
%)
[ 5] WARNING: ack of last datagram failed.
[ 16] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 43761
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams
[ 16] 0.0000-0.0100 sec 2.87 KBytes 2.36 Mbits/sec 0.624 ms 9083/9085 (1e+02
%)
[ 6] WARNING: ack of last datagram failed.
[ 17] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 43761
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams
[ 17] 0.0000-0.0102 sec 2.87 KBytes 2.30 Mbits/sec 0.638 ms 9094/9096 (1e+02
%)
[ 5] WARNING: ack of last datagram failed.
[ 18] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 43761
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams
[ 18] 0.0000-0.0103 sec 2.87 KBytes 2.28 Mbits/sec 0.644 ms 9105/9107 (1e+02
%)
[ 6] WARNING: ack of last datagram failed.
[ 19] local 10.0.0.6 port 5001 connected with 10.0.0.5 port 43761
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams
[ 19] 0.0000-0.0102 sec 2.87 KBytes 2.30 Mbits/sec 0.639 ms 9116/9118 (1e+02
%)
[ ]

"Node: h5"
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 0 bytes 0 (0.0 B)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@liu-virtual-machine:/home/liu/Desktop# ethtool -K h5-eth0 tx off
Actual changes:
tx-checksum-ip-generic: off
tx-tcp-segmentation: off [not requested]
tx-tcp-ecn-segmentation: off [not requested]
tx-tcp-mangleid-segmentation: off [not requested]
tx-tcp6-segmentation: off [not requested]
tx-checksum-sctp: off
root@liu-virtual-machine:/home/liu/Desktop# iperf -u -c 10.0.0.6 -b 10M
-----
Client connecting to 10.0.0.6, UDP port 5001
Sending 1470 byte datagrams, IPG target: 1121.52 us (kalman adjust)
UDP buffer size: 208 KByte (default)
-----
[ 1] local 10.0.0.5 port 43761 connected with 10.0.0.6 port 5001
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-10.0020 sec 12.5 MBytes 10.5 Mbits/sec
[ 1] Sent 8921 datagrams
[ 5] WARNING: did not receive ack of last datagram after 10 tries.
root@liu-virtual-machine:/home/liu/Desktop#
```

## Question 1

```
$ ovs-ofctl add-flow s1 in_port=5,action=meter:1,output:6 -O openflow13
```

这条指令的作用是向s1网桥添加一条流表规则。

- add-flow: 添加新流表条目。
- in\_port=5: 规则匹配输入端口为5的数据包。
- action=meter:1: 对匹配的数据包应用计量器1进行速率限制处理。
- output:6: 如果数据包经过计量后未被丢弃，则将数据包输出到端口6。

- -O openflow13: 表示使用OpenFlow 1.3版本进行交互。

其中，计量器1由line11的指令创建，类型为“drop”，即当流量超过阈值时丢弃数据包，速率限制为5000kbps。

```
$ ovs-ofctl dump-flows s1 -O openflow13
```

这条命令的作用是从名为s1的OVS网桥中获取当前所有的OpenFlow流表项信息。

- dump-flows: 用于输出当前OVS网桥上的流表条目（即已配置好的匹配规则和对对应动作）。
- s1: 是目标OVS网桥的名称。
- -O openflow13: 表示使用OpenFlow 1.3版本进行交互。

该命令与line2的命令相同，再次执行这条命令是为了查看在设置了流表规则之后，s1网桥上最新的流表状态，确认限速规则是否成功添加并生效。

## Question 2

限速方式	参数设置	传输带宽	接收带宽	抖动
网卡限速	ingress_policing_rate=5000kbps	10.5Mbits/sec	5.70Mbit/sec	1.534ms
队列限速	max_rate=5000kbps	4.92Mbit/sec	4.86Mbit/sec	9.056ms
流表限速	type=drop,rate=5000kbps	10.5Mbit/sec	5.34Mbit/sec	0.858ms

限速方式	丢包率	说明
网卡限速	46%	限制网卡上接收分组（ingress）的速率，当速率超过了配置速率，就简单的把数据包丢弃。
队列限速	0%	使用队列queue，可以缓存和调度数据包发送顺序
流表限速	49%	在交换机上设置流表规则，对匹配的数据包应用计量器进行速率限制处理。

从传输带宽来看，网卡限速和流表限速的传输带宽都达到了10.5Mbits/sec，而队列限速的传输带宽只有4.92Mbit/sec。其原因在于，队列限速会在尽量不中断连接的前提下来平滑网络流量。因此传输带宽会受到发送速率和接收速率的限制。而网卡限速和流表限速是对接收的数据包进行限速，因此传输带宽不受发送速率的限制。

从接收带宽来看，网卡限速和流表限速的接受带宽都略高于我们的设置目标5Mbit/sec，而队列限速的接受带宽为4.86Mbit/sec，在我们设定的范围之内。其原因在于网卡限速和流表限速都是通过丢弃超出速率的数据包来达到限速目的，所以实际接收到的数据量受限于设定的速率。但由于网络环境、控制算法、测量误差等因素的影响，实际接受带宽略高于设置的限速。



抖动是指数据包在网络中传输时，相对于理想情况下各数据包之间的时间间隔发生的变化。在本次测试中，流表限速的抖动最小，为0.858ms；网卡限速的抖动次之，为1.534ms；而队列限速的抖动最大，为9.056ms。一般情况下，队列限速的抖动应该相对较小，因为队列能够缓存和有序调度数据包，有助于平滑发送。但是本次出现反常现象的原因可能是数据包在队列中等待调度时，受网络负载不均衡、调度算法效率、以及网络设备本身的处理能力的影响，导致数据包接受的延时增大，从而导致抖动增加。此外，在此次测试中，流表限速方案实现了最低的抖动。其原因可能是流表限速利用 OpenFlow的计量器机制对流量进行精细控制，能够在交换机层面实时调控数据包的发送速率，有效地减少了数据包到达时间间隔的波动，从而降低了抖动。

丢包率是指在网络传输过程中，由于网络拥塞、传输错误等原因导致数据包丢失的比例。在本次测试中，队列限速的丢包率为0%，这是因为队列提供了缓冲空间，即使在网络繁忙时也能暂时存储超出速率的数据包，从而避免了丢包现象的发生。网卡限速和流表限速的丢包率分别为46%、49%。这是因为这两种限速方法在达到设定速率后直接丢弃超出的数据包，没有提供额外的缓冲或重传机制。

## Task 4

```
"Node: h3"
[ 1] 2,0000-3,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 3,0000-4,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 4,0000-5,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 5,0000-6,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 6,0000-7,0000 sec 474 KBytes 3,88 Mbits/sec
[ 1] 7,0000-8,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 8,0000-9,0000 sec 408 KBytes 3,34 Mbits/sec
[ 1] 9,0000-10,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 10,0000-11,0000 sec 405 KBytes 3,32 Mbits/sec
[ 1] 11,0000-12,0000 sec 403 KBytes 3,30 Mbits/sec
[ 1] 12,0000-13,0000 sec 409 KBytes 3,35 Mbits/sec
[ 1] 13,0000-14,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 14,0000-15,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 15,0000-16,0000 sec 352 KBytes 2,88 Mbits/sec
[ 1] 16,0000-17,0000 sec 461 KBytes 3,77 Mbits/sec
[ 1] 17,0000-18,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 18,0000-19,0000 sec 409 KBytes 3,35 Mbits/sec
[ 1] 19,0000-20,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 0,0000-20,1169 sec 8,35 MBytes 3,48 Mbits/sec
[ 1] Sent 5958 datagrams
[ 1] Server Report:
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0,0000-20,2979 sec 8,35 MBytes 3,45 Mbits/sec 19,056 ms 0/5957 (0%)
root@liu-virtual-machine:/home/liu/Desktop/ovs#

"Node: h4"
[ 1] 2,0000-3,0000 sec 365 KBytes 2,99 Mbits/sec
[ 1] 3,0000-4,0000 sec 408 KBytes 3,34 Mbits/sec
[ 1] 4,0000-5,0000 sec 405 KBytes 3,32 Mbits/sec
[ 1] 5,0000-6,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 6,0000-7,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 7,0000-8,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 8,0000-9,0000 sec 471 KBytes 3,86 Mbits/sec
[ 1] 9,0000-10,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 10,0000-11,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 11,0000-12,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 12,0000-13,0000 sec 408 KBytes 3,34 Mbits/sec
[ 1] 13,0000-14,0000 sec 402 KBytes 3,29 Mbits/sec
[ 1] 14,0000-15,0000 sec 408 KBytes 3,34 Mbits/sec
[ 1] 15,0000-16,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 16,0000-17,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 17,0000-18,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 18,0000-19,0000 sec 403 KBytes 3,30 Mbits/sec
[ 1] 19,0000-20,0000 sec 472 KBytes 3,87 Mbits/sec
[ 1] 0,0000-20,0759 sec 7,83 MBytes 3,27 Mbits/sec
[ 1] Sent 5589 datagrams
[ 1] Server Report:
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0,0000-20,1263 sec 7,83 MBytes 3,27 Mbits/sec 12,433 ms 0/5588 (0%)
root@liu-virtual-machine:/home/liu/Desktop/ovs#

"Node: h1"
root@liu-virtual-machine:/home/liu/Desktop/ovs# iperf -u -s
Server listening on UDP port 5001
UDP buffer size: 208 KByte (default)
-----
[ 1] local 10.0.0.1 port 5001 connected with 10.0.0.3 port 40771
[ 2] local 10.0.0.1 port 5001 connected with 10.0.0.4 port 33000
[ 3] local 10.0.0.1 port 5001 connected with 10.0.0.2 port 59826
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0,0000-20,2979 sec 8,35 MBytes 3,45 Mbits/sec 19,056 ms 0/5957 (0%)
[ 5] WARNING: ack of last datagram failed.
[ 4] local 10.0.0.1 port 5001 connected with 10.0.0.3 port 40771
[ 4] 0,0000-0,0000 sec 2,87 KBytes -nan bits/sec 0,002 ms 5966/5968 (1e+02%)
[ 8] WARNING: ack of last datagram failed.
[ 2] 0,0000-20,1263 sec 7,83 MBytes 3,27 Mbits/sec 12,433 ms 0/5588 (0%)
[ 6] WARNING: ack of last datagram failed.
[ 5] local 10.0.0.1 port 5001 connected with 10.0.0.4 port 33000
[ 5] 0,0000-0,0579 sec 2,87 KBytes 406 Kbits/sec 3,618 ms 5597/5599 (1e+02%)
write-ackfin failed: Connection refused
[ 3] 0,0000-19,9504 sec 8,06 MBytes 3,39 Mbits/sec 0,245 ms 0/5751 (0%)
[ 7] WARNING: ack of last datagram failed.
root@liu-virtual-machine:/home/liu/Desktop/ovs#

"Node: h2"
[ 1] 2,0000-3,0000 sec 342 KBytes 2,80 Mbits/sec
[ 1] 3,0000-4,0000 sec 403 KBytes 3,30 Mbits/sec
[ 1] 4,0000-5,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 5,0000-6,0000 sec 409 KBytes 3,35 Mbits/sec
[ 1] 6,0000-7,0000 sec 350 KBytes 2,87 Mbits/sec
[ 1] 7,0000-8,0000 sec 458 KBytes 3,75 Mbits/sec
[ 1] 8,0000-9,0000 sec 409 KBytes 3,35 Mbits/sec
[ 1] 9,0000-10,0000 sec 337 KBytes 2,76 Mbits/sec
[ 1] 10,0000-11,0000 sec 339 KBytes 2,78 Mbits/sec
[ 1] 11,0000-12,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 12,0000-13,0000 sec 403 KBytes 3,30 Mbits/sec
[ 1] 13,0000-14,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 14,0000-15,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 15,0000-16,0000 sec 342 KBytes 2,80 Mbits/sec
[ 1] 16,0000-17,0000 sec 342 KBytes 2,80 Mbits/sec
[ 1] 17,0000-18,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 18,0000-19,0000 sec 406 KBytes 3,33 Mbits/sec
[ 1] 19,0000-20,0000 sec 866 KBytes 7,09 Mbits/sec
[ 1] 0,0000-20,0009 sec 8,06 MBytes 3,38 Mbits/sec
[ 1] Sent 5752 datagrams
[ 1] Server Report:
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0,0000-19,9504 sec 8,06 MBytes 3,39 Mbits/sec 0,244 ms 0/5751 (0%)
root@liu-virtual-machine:/home/liu/Desktop/ovs#
```

通过对h1进行队列限速，发现当三个Client同时传输数据且稳定后，他们的带宽都在3.3Mbps/sec左右，且丢包率为0。这说明服务器端的队列限流机制按照某种公平原则对客户端进行了带宽分配，保证了三个客户端之间的带宽大致均衡。

## Task 5

我选择使用了流表并结合每个端口队列来实现QoS框架。

首先使用以下命令为Server端创建三个队列，用于分别接收来自h2、h3和h4的数据包，并根据要求对数据包进行速率限制：

```
sudo ovs-vsctl set port s1-eth1 qos=@qos1 -- \
--id=@qos1 create qos type=linux-htb queues=2=@q2,3=@q3,4=@q4 -- \
--id=@q2 create queue other-config:min-rate=5000000 other-config:max-rate=5500000 -- \
--id=@q3 create queue other-config:min-rate=3000000 other-config:max-rate=3500000 -- \
--id=@q4 create queue other-config:min-rate=0 other-config:max-rate=1500000
```

然后使用以下命令为Server端创建流表规则，将来自h2、h3和h4的数据包分别发送到对应的队列：

```
sudo ovs-ofctl add-flow s1 in_port=2,action=set_queue:2,output:1 -O openflow13
sudo ovs-ofctl add-flow s1 in_port=3,action=set_queue:3,output:1 -O openflow13
sudo ovs-ofctl add-flow s1 in_port=4,action=set_queue:4,output:1 -O openflow13
```

最后三个Client端同时发送数据包，观察Server端的带宽和丢包率情况。

```
iperf -u -c 10.0.0.1 -b 10M -t 20 -i 1
```

最终运行结果如下：

```
"Node: h3"
[ 1] 2.0000-3.0000 sec 369 KBytes 3.02 Mbits/sec
[ 1] 3.0000-4.0000 sec 435 KBytes 3.56 Mbits/sec
[ 1] 4.0000-5.0000 sec 435 KBytes 3.56 Mbits/sec
[ 1] 5.0000-6.0000 sec 368 KBytes 3.01 Mbits/sec
[ 1] 6.0000-7.0000 sec 458 KBytes 3.75 Mbits/sec
[ 1] 7.0000-8.0000 sec 379 KBytes 3.10 Mbits/sec
[ 1] 8.0000-9.0000 sec 436 KBytes 3.58 Mbits/sec
[ 1] 9.0000-10.0000 sec 368 KBytes 3.01 Mbits/sec
[ 1] 10.0000-11.0000 sec 435 KBytes 3.56 Mbits/sec
[ 1] 11.0000-12.0000 sec 436 KBytes 3.58 Mbits/sec
[ 1] 12.0000-13.0000 sec 369 KBytes 3.02 Mbits/sec
[ 1] 13.0000-14.0000 sec 461 KBytes 3.77 Mbits/sec
[ 1] 14.0000-15.0000 sec 375 KBytes 3.07 Mbits/sec
[ 1] 15.0000-16.0000 sec 436 KBytes 3.58 Mbits/sec
[ 1] 16.0000-17.0000 sec 369 KBytes 3.02 Mbits/sec
[ 1] 17.0000-18.0000 sec 434 KBytes 3.55 Mbits/sec
[ 1] 18.0000-19.0000 sec 435 KBytes 3.56 Mbits/sec
[ 1] 19.0000-20.0000 sec 368 KBytes 3.01 Mbits/sec
[ 1] 0.0000-20.0204 sec 8.11 MBytes 3.40 Mbits/sec
[ 1] Sent 5786 datagrams
[ 1] Server Report:
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0.0000-20.1885 sec 8.11 MBytes 3.37 Mbits/sec 12.889 ms 0/5785 (0%)
root@liu-virtual-machine:/home/liu/Desktop/ovs#

"Node: h4"
[ 1] 2.0000-3.0000 sec 212 KBytes 1.74 Mbits/sec
[ 1] 3.0000-4.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 4.0000-5.0000 sec 152 KBytes 1.25 Mbits/sec
[ 1] 5.0000-6.0000 sec 214 KBytes 1.75 Mbits/sec
[ 1] 6.0000-7.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 7.0000-8.0000 sec 212 KBytes 1.74 Mbits/sec
[ 1] 8.0000-9.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 9.0000-10.0000 sec 223 KBytes 1.82 Mbits/sec
[ 1] 10.0000-11.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 11.0000-12.0000 sec 212 KBytes 1.74 Mbits/sec
[ 1] 12.0000-13.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 13.0000-14.0000 sec 197 KBytes 1.61 Mbits/sec
[ 1] 14.0000-15.0000 sec 171 KBytes 1.40 Mbits/sec
[ 1] 15.0000-16.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 16.0000-17.0000 sec 212 KBytes 1.74 Mbits/sec
[ 1] 17.0000-18.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 18.0000-19.0000 sec 223 KBytes 1.82 Mbits/sec
[ 1] 19.0000-20.0000 sec 145 KBytes 1.19 Mbits/sec
[ 1] 0.0000-20.1182 sec 3.56 MBytes 1.48 Mbits/sec
[ 1] Sent 2538 datagrams
[ 1] Server Report:
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0.0000-20.5129 sec 3.56 MBytes 1.45 Mbits/sec 28.911 ms 0/2537 (0%)
root@liu-virtual-machine:/home/liu/Desktop/ovs#

"Node: h1"
[ 1] local 10.0.0.1 port 5001 connected with 10.0.0.3 port 55915
[ 2] local 10.0.0.1 port 5001 connected with 10.0.0.4 port 57351
[ 3] local 10.0.0.1 port 5001 connected with 10.0.0.2 port 38317
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0.0000-20.1885 sec 8.11 MBytes 3.37 Mbits/sec 12.889 ms 0/5785 (0%)
[ 2] 0.0000-20.5129 sec 3.56 MBytes 1.45 Mbits/sec 28.911 ms 0/2537 (0%)
[ 6] WARNING: ack of last datagram failed.
[ 4] local 10.0.0.1 port 5001 connected with 10.0.0.4 port 57351
[ 4] 0.0000-0.0077 sec 2.87 KBytes 3.05 Mbits/sec 0.483 ms 2546/2548 (1e+02%)
[ 8] WARNING: ack of last datagram failed.
[ 5] 0.0000-20.1175 sec 12.6 MBytes 5.26 Mbits/sec 8.293 ms 0/9003 (0%)
[ 5] local 10.0.0.1 port 5001 connected with 10.0.0.4 port 57351
[ 7] WARNING: ack of last datagram failed.
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 5] 0.0000-0.0079 sec 2.87 KBytes 2.98 Mbits/sec 0.493 ms 2557/2559 (1e+02%)
[ 5] WARNING: ack of last datagram failed.
[ 6] local 10.0.0.1 port 5001 connected with 10.0.0.4 port 57351
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 6] 0.0000-0.0080 sec 2.87 KBytes 2.95 Mbits/sec 0.498 ms 2568/2570 (1e+02%)
[ 6] WARNING: ack of last datagram failed.

"Node: h2"
[ 1] 2.0000-3.0000 sec 675 KBytes 5.53 Mbits/sec
[ 1] 3.0000-4.0000 sec 609 KBytes 4.99 Mbits/sec
[ 1] 4.0000-5.0000 sec 678 KBytes 5.55 Mbits/sec
[ 1] 5.0000-6.0000 sec 609 KBytes 4.99 Mbits/sec
[ 1] 6.0000-7.0000 sec 675 KBytes 5.53 Mbits/sec
[ 1] 7.0000-8.0000 sec 607 KBytes 4.97 Mbits/sec
[ 1] 8.0000-9.0000 sec 676 KBytes 5.54 Mbits/sec
[ 1] 9.0000-10.0000 sec 612 KBytes 5.01 Mbits/sec
[ 1] 10.0000-11.0000 sec 673 KBytes 5.52 Mbits/sec
[ 1] 11.0000-12.0000 sec 609 KBytes 4.99 Mbits/sec
[ 1] 12.0000-13.0000 sec 676 KBytes 5.54 Mbits/sec
[ 1] 13.0000-14.0000 sec 607 KBytes 4.97 Mbits/sec
[ 1] 14.0000-15.0000 sec 679 KBytes 5.56 Mbits/sec
[ 1] 15.0000-16.0000 sec 646 KBytes 5.29 Mbits/sec
[ 1] 16.0000-17.0000 sec 620 KBytes 5.08 Mbits/sec
[ 1] 17.0000-18.0000 sec 624 KBytes 5.12 Mbits/sec
[ 1] 18.0000-19.0000 sec 679 KBytes 5.56 Mbits/sec
[ 1] 19.0000-20.0000 sec 609 KBytes 4.99 Mbits/sec
[ 1] 0.0000-20.0097 sec 12.6 MBytes 5.29 Mbits/sec
[ 1] Sent 9004 datagrams
[ 1] Server Report:
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams
[ 1] 0.0000-20.1175 sec 12.6 MBytes 5.26 Mbits/sec 8.293 ms 0/9003 (0%)
root@liu-virtual-machine:/home/liu/Desktop/ovs#
```

从结果可以看出，h2、h3和h4的带宽分别为5.26Mbits/sec、3.37Mbits/sec和1.45Mbits/sec，且丢包率均为0。总的接收带宽为10.08Mbits/sec。说明这种配置方法能够完成所给的既定任务，并较好的利用了带宽限制。