

# Отчет по лабораторной работе №6

## Дисциплина: Моделирование сетей передачи данных

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# Цель работы

Основной целью работы является знакомство с принципами работы дисциплины очереди Token Bucket Filter, которая формирует входящий/исходящий трафик для ограничения пропускной способности, а также получение навыков моделирования и исследования поведения трафика посредством проведения интерактивного и воспроизводимого экспериментов в Mininet.

# Задание

- ① Задайте топологию, состоящую из двух хостов и двух коммутаторов с назначенной по умолчанию mininet сетью 10.0.0.0/8.
- ② Проведите интерактивные эксперименты по ограничению пропускной способности сети с помощью TBF.
- ③ Самостоятельно реализуйте воспроизводимые эксперимент по применению TBF для ограничения пропускной способности. Постройте соответствующие графики.

# Теоретическое введение

Mininet[@mininet] — это эмулятор компьютерной сети.

Под сетью подразумеваются хосты, коммутаторы и OpenFlow-контроллеры.

С помощью простейшего синтаксиса можно разворачивать сети произвольной топологии в одной виртуальной машине.

На хостах можно использовать ifconfig, ping и доступ к терминалу, на коммутаторы можно добавлять правила маршрутизации.

# Запуск лабораторной топологии

Запустим Mininet и создадим топологию: два хоста и два коммутатора.

На хостах h1 и h2 и коммутаторах s1, s2 проверяем интерфейсы:

The image shows two terminal windows side-by-side. The left window is titled "host h1@mininet-vm" and displays network interface statistics for h1. The right window is titled "root@mininet-vm:/home/mininet#" and displays a ping test between h1 and h2.

**Host h1 Statistics:**

```
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

lo: flags=73<UP,LOOPBACK,RUNNING> mtu 65536
inet 127.0.0.1 netmask 255.0.0.0
loop txqueuelen 1000 (Local Loopback)
RX packets 1265 bytes 262820 (262.8 KB)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 1265 bytes 262820 (262.8 KB)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0
```

**Ping Test Output:**

```
root@mininet-vm:/home/mininet# ping 10.0.0.2 -c 4
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=7.62 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.235 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.046 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3037ms
rtt min/avg/max/mdev = 0.046/1.992/7.623/3.251 ms
root@mininet-vm:/home/mininet#
```

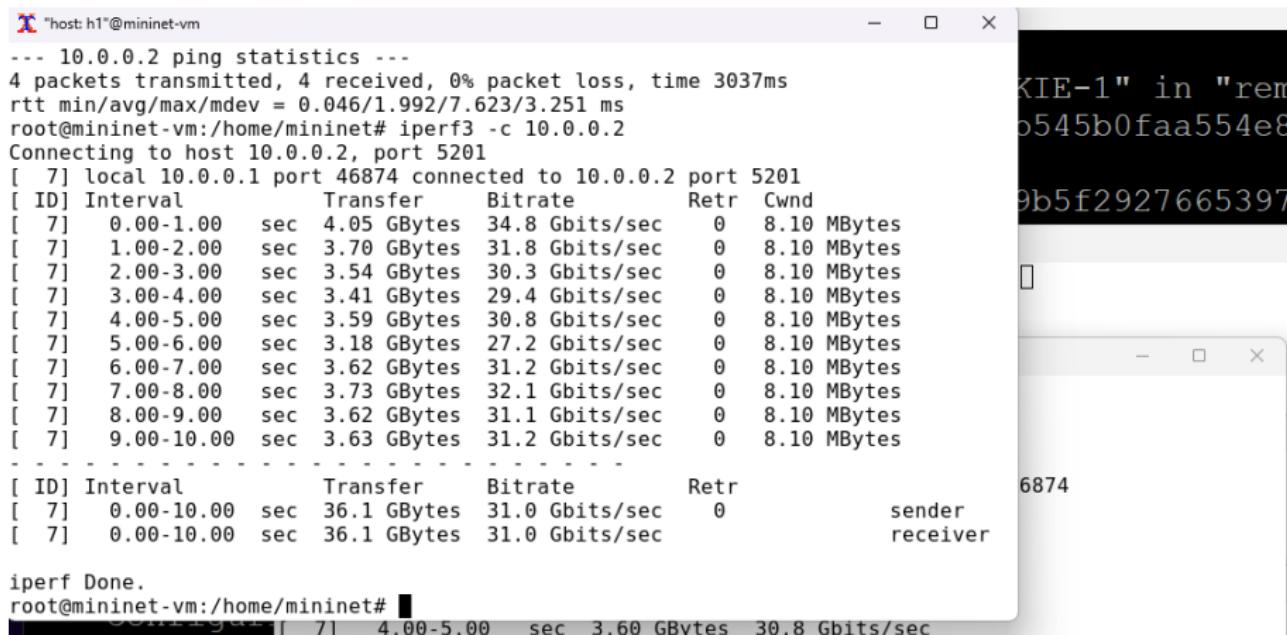
**Host h2 Statistics:**

```
h1 h2 TX packets 1114 bytes 251828 (251.8 KB)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0
```

# Проверка подключения с помощью iPerf3

- На h2: iperf3 -s
- На h1: iperf3 -c 10.0.0.2

После завершения останавливаем iPerf3 на h2 (Ctrl + c).



The image shows two terminal windows side-by-side. The left window is titled "host: h1" and displays the results of an iPerf3 test between host 1 and host 2. The right window is titled "host: h2" and also shows the test results. Both windows show a 10.0.0.2 ping statistics section and a detailed transfer section with 10 intervals of 1.00 seconds each. The transfer rates are consistently around 31.0 Gbytes/sec, and the bitrates are around 30.8 Gbits/sec. The Cwnd value is 8.10 MBytes for most intervals. The right window also shows the sender and receiver roles.

```
"host: h1" @mininet-vm
--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3037ms
rtt min/avg/max/mdev = 0.046/1.992/7.623/3.251 ms
root@mininet-vm:/home/mininet# iperf3 -c 10.0.0.2
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 46874 connected to 10.0.0.2 port 5201
[ ID] Interval Transfer Bitrate Retr Cwnd
[ 7] 0.00-1.00 sec 4.05 GBytes 34.8 Gbits/sec 0 8.10 MBytes
[ 7] 1.00-2.00 sec 3.70 GBytes 31.8 Gbits/sec 0 8.10 MBytes
[ 7] 2.00-3.00 sec 3.54 GBytes 30.3 Gbits/sec 0 8.10 MBytes
[ 7] 3.00-4.00 sec 3.41 GBytes 29.4 Gbits/sec 0 8.10 MBytes
[ 7] 4.00-5.00 sec 3.59 GBytes 30.8 Gbits/sec 0 8.10 MBytes
[ 7] 5.00-6.00 sec 3.18 GBytes 27.2 Gbits/sec 0 8.10 MBytes
[ 7] 6.00-7.00 sec 3.62 GBytes 31.2 Gbits/sec 0 8.10 MBytes
[ 7] 7.00-8.00 sec 3.73 GBytes 32.1 Gbits/sec 0 8.10 MBytes
[ 7] 8.00-9.00 sec 3.62 GBytes 31.1 Gbits/sec 0 8.10 MBytes
[ 7] 9.00-10.00 sec 3.63 GBytes 31.2 Gbits/sec 0 8.10 MBytes
[ ID] Interval Transfer Bitrate Retr
[ 7] 0.00-10.00 sec 36.1 GBytes 31.0 Gbits/sec 0
[ 7] 0.00-10.00 sec 36.1 GBytes 31.0 Gbits/sec
iperf Done.
root@mininet-vm:/home/mininet# [ 7] 4.00-5.00 sec 3.60 GBytes 30.8 Gbits/sec
```

KIE-1" in "rem  
545b0faa554e8  
9b5f2927665397

6874

# Ограничение скорости на конечных хостах

Применяем фильтр Token Bucket Filter (TBF) на h1:

```
sudo tc qdisc add dev h1-eth0 root tbm rate 10gbit
burst 5000000 limit 15000000
```

Проверяем пропускную способность через iPerf3.

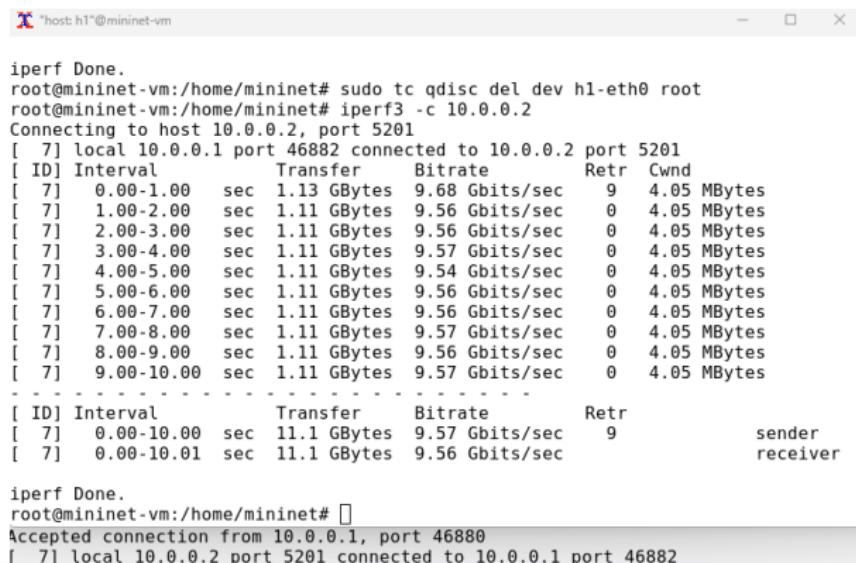
```
X "host: h1" @mininet-vm
iperf Done.
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root tbm rate 10gb
it burst 5000000 limit 15000000
root@mininet-vm:/home/mininet# iperf3 -c 10.0.0.2
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 46878 connected to 10.0.0.2 port 5201
[ ID] Interval      Transfer     Bitrate    Retr  Cwnd
[ 7]  0.00-1.00  sec   1.13 GBytes   9.68 Gbytes/sec   0  8.11 MBytes
[ 7]  1.00-2.00  sec   1.11 GBytes   9.53 Gbits/sec   0  8.11 MBytes
[ 7]  2.00-3.00  sec   1.10 GBytes   9.43 Gbits/sec   0  8.11 MBytes
[ 7]  3.00-4.00  sec   1.06 GBytes   9.10 Gbits/sec   0  8.11 MBytes
[ 7]  4.00-5.00  sec   1.10 GBytes   9.43 Gbits/sec   0  8.11 MBytes
[ 7]  5.00-6.00  sec   1.11 GBytes   9.57 Gbits/sec   0  8.11 MBytes
[ 7]  6.00-7.00  sec   1.11 GBytes   9.50 Gbits/sec   0  8.11 MBytes
[ 7]  7.00-8.00  sec   1.11 GBytes   9.50 Gbits/sec   0  8.11 MBytes
[ 7]  8.00-9.00  sec   1.11 GBytes   9.56 Gbits/sec   0  8.11 MBytes
[ 7]  9.00-10.00 sec   1.11 GBytes   9.50 Gbits/sec   0  8.11 MBytes
[ 7]  10.00-11.00 sec   1.11 GBytes   9.48 Gbits/sec   0
[ 7]  11.00-12.00 sec   1.11 GBytes   9.46 Gbits/sec   0
iperf Done.
```

# Ограничение скорости на коммутаторах

Применяем TBF на интерфейсе s1-eth2 коммутатора s1:

```
sudo tc qdisc add dev s1-eth2 root tbm rate 10gbit
burst 5000000 limit 15000000
```

Проверяем пропускную способность через iPerf3.



The screenshot shows a terminal window with the following content:

```
iperf Done.
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root
root@mininet-vm:/home/mininet# iperf3 -c 10.0.0.2
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 46882 connected to 10.0.0.2 port 5201
[ ID] Interval      Transfer     Bitrate      Retr  Cwnd
[ 7]  0.00-1.00    sec   1.13 GBytes   9.68 Gbits/sec   9  4.05 MBytes
[ 7]  1.00-2.00    sec   1.11 GBytes   9.56 Gbits/sec   0  4.05 MBytes
[ 7]  2.00-3.00    sec   1.11 GBytes   9.56 Gbits/sec   0  4.05 MBytes
[ 7]  3.00-4.00    sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  4.00-5.00    sec   1.11 GBytes   9.54 Gbits/sec   0  4.05 MBytes
[ 7]  5.00-6.00    sec   1.11 GBytes   9.56 Gbits/sec   0  4.05 MBytes
[ 7]  6.00-7.00    sec   1.11 GBytes   9.56 Gbits/sec   0  4.05 MBytes
[ 7]  7.00-8.00    sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  8.00-9.00    sec   1.11 GBytes   9.56 Gbits/sec   0  4.05 MBytes
[ 7]  9.00-10.00   sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  10.00-11.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  11.00-12.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  12.00-13.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  13.00-14.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  14.00-15.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  15.00-16.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  16.00-17.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  17.00-18.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  18.00-19.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  19.00-20.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  20.00-21.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  21.00-22.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  22.00-23.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  23.00-24.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  24.00-25.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  25.00-26.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  26.00-27.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  27.00-28.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  28.00-29.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  29.00-30.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  30.00-31.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  31.00-32.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  32.00-33.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  33.00-34.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  34.00-35.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  35.00-36.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  36.00-37.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  37.00-38.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  38.00-39.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  39.00-40.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  40.00-41.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  41.00-42.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  42.00-43.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  43.00-44.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  44.00-45.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  45.00-46.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  46.00-47.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  47.00-48.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  48.00-49.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  49.00-50.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  50.00-51.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  51.00-52.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  52.00-53.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  53.00-54.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  54.00-55.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  55.00-56.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  56.00-57.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  57.00-58.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  58.00-59.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  59.00-60.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  60.00-61.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  61.00-62.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  62.00-63.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  63.00-64.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  64.00-65.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  65.00-66.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  66.00-67.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  67.00-68.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  68.00-69.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  69.00-70.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  70.00-71.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  71.00-72.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  72.00-73.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  73.00-74.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  74.00-75.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  75.00-76.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  76.00-77.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  77.00-78.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  78.00-79.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  79.00-80.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  80.00-81.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  81.00-82.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  82.00-83.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  83.00-84.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  84.00-85.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  85.00-86.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  86.00-87.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  87.00-88.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  88.00-89.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  89.00-90.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  90.00-91.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  91.00-92.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  92.00-93.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  93.00-94.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  94.00-95.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  95.00-96.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  96.00-97.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  97.00-98.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  98.00-99.00  sec   1.11 GBytes   9.57 Gbits/sec   0  4.05 MBytes
[ 7]  99.00-100.00 sec   1.11 GBytes  9.57 Gbits/sec  0  4.05 MBytes
[ 7]  100.00-101.00 sec  11.1 GBytes  9.57 Gbits/sec  9
[ 7]  101.00-102.00 sec  11.1 GBytes  9.56 Gbits/sec  0
[ 7]  102.00-103.00 sec  11.1 GBytes  9.56 Gbits/sec  0
iperf Done.
root@mininet-vm:/home/mininet#
```

# Объединение NETEM и TBF

- На s1-eth2 добавляем задержку и джиттер:

```
sudo tc qdisc add dev s1-eth2 root handle 1: netem  
delay 10ms
```

- Добавляем ограничение скорости TBF:

```
sudo tc qdisc add dev s1-eth2 parent 1: handle 2:  
tbf rate 2gbit burst 1000000 limit 2000000
```

```
"host: h1" @mininet-vm
```

```
iperf Done.  
root@mininet-vm:/home/mininet# ^C  
root@mininet-vm:/home/mininet# ping 10.0.0.2 -c 4  
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.  
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=15.7 ms  
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=10.8 ms  
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=11.1 ms  
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=10.2 ms  
  
--- 10.0.0.2 ping statistics ---  
4 packets transmitted, 4 received, 0% packet loss, time 3006ms  
rtt min/avg/max/mdev = 10.239/11.956/15.719/2.192 ms  
root@mininet-vm:/home/mininet# ping -c 4 10.0.0.2  
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.  
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=10.6 ms  
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=11.0 ms  
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=10.2 ms  
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=10.3 ms  
  
--- 10.0.0.2 ping statistics ---  
4 packets transmitted, 4 received, 0% packet loss, time 3005ms  
rtt min/avg/max/mdev = 10.229/10.509/10.961/0.290 ms  
root@mininet-vm:/home/mininet#
```

# Выводы

В результате выполнения работы:

- Познакомились с принципами работы Token Bucket Filter для ограничения пропускной способности.
- Получили навыки моделирования трафика с помощью Mininet.
- Научились комбинировать NETEM и TBF для изменения задержки, джиттера и ограничения скорости.