

Моделирование сетей передачи данных

Лабораторная работа №6: Настройка пропускной способности глобальной сети с помощью Token Bucket Filter

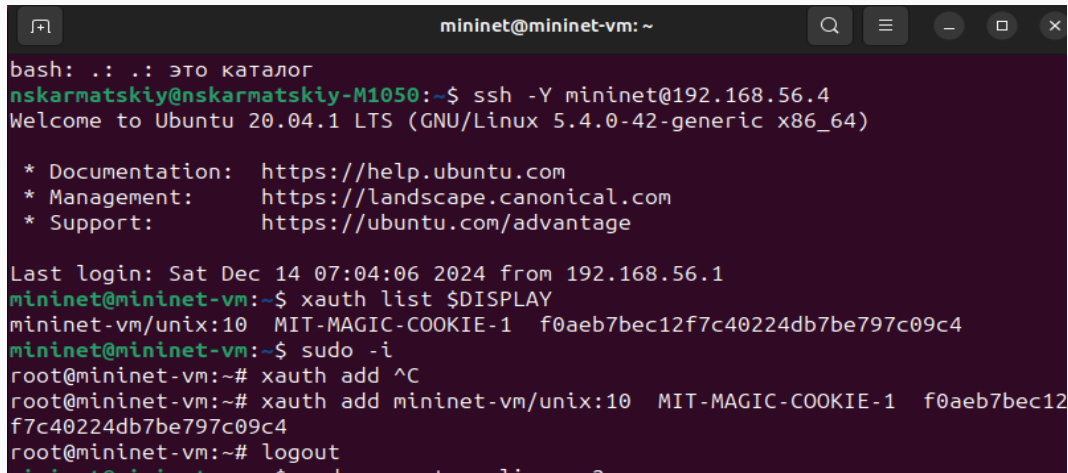
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Цель лабораторной работы

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.

Выполнение лабораторной работы: 1. Запуск лабораторной топологии



```
mininet@mininet-vm: ~  
bash: .: .: это каталог  
nskarmatskiy@nskarmatskiy-M1050:~$ ssh -Y mininet@192.168.56.4  
Welcome to Ubuntu 20.04.1 LTS (GNU/Linux 5.4.0-42-generic x86_64)  
  
* Documentation:  https://help.ubuntu.com  
* Management:    https://landscape.canonical.com  
* Support:       https://ubuntu.com/advantage  
  
Last login: Sat Dec 14 07:04:06 2024 from 192.168.56.1  
mininet@mininet-vm:~$ xauth list $DISPLAY  
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  f0aeb7bec12f7c40224db7be797c09c4  
mininet@mininet-vm:~$ sudo -i  
root@mininet-vm:~# xauth add ^C  
root@mininet-vm:~# xauth add mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  f0aeb7bec12  
f7c40224db7be797c09c4  
root@mininet-vm:~# logout
```

Рис. 1: Исправление прав запуска X-соединения в виртуальной машине mininet

1. Запуск лабораторной топологии

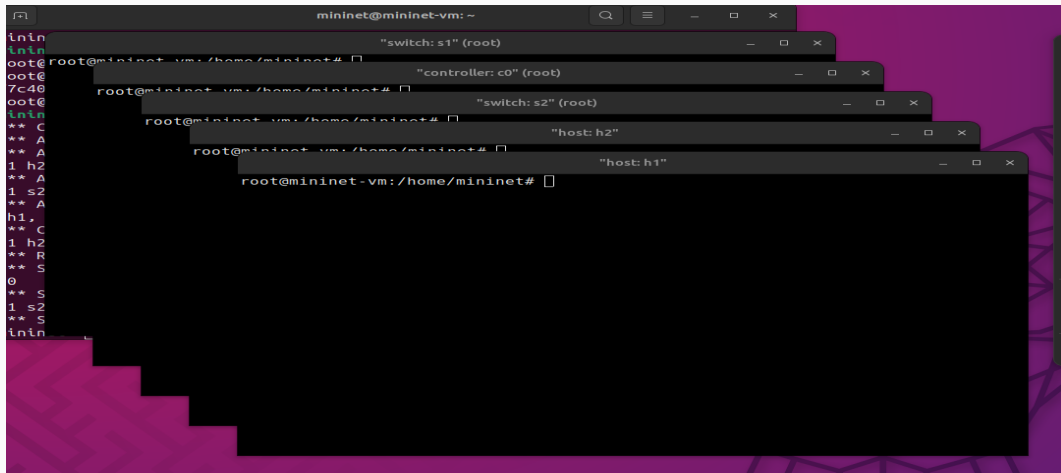
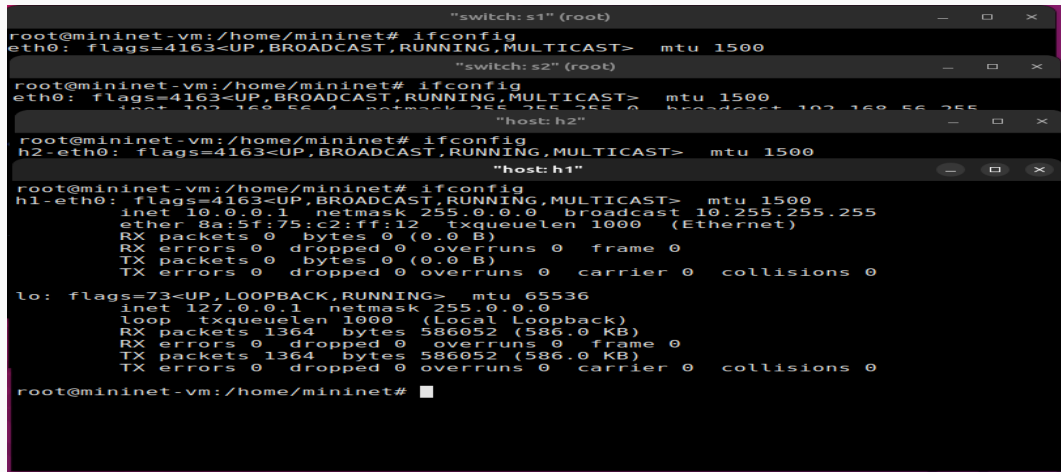


Рис. 2: Создание простейшей топологии с двумя коммутаторами и двумя хостами

1. Запуск лабораторной топологии



```
"switch: s1" (root)
root@mininet-vm:/home/mininet# ifconfig
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500

"switch: s2" (root)
root@mininet-vm:/home/mininet# ifconfig
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
    inet 10.0.0.1  netmask 255.255.255.0  broadcast 10.255.255.255

"host: h2"
root@mininet-vm:/home/mininet# ifconfig
h2-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500

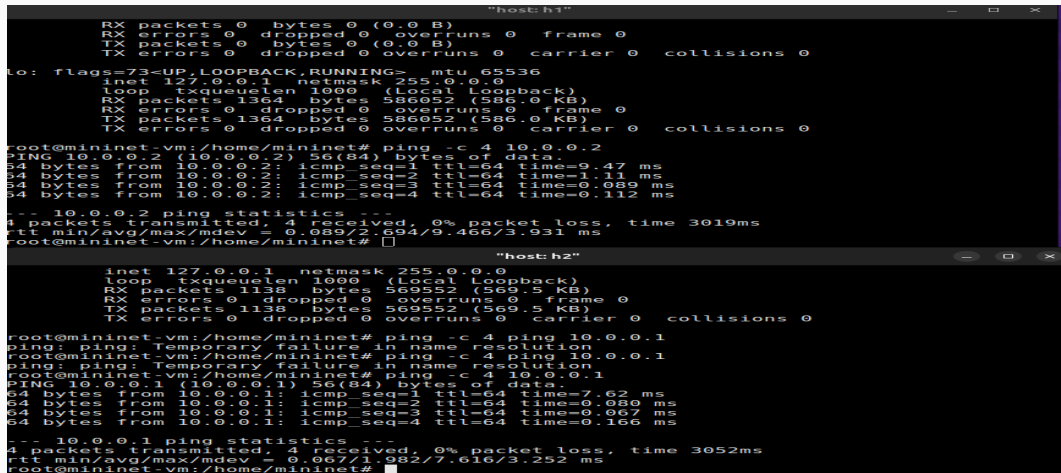
"host: h1"
root@mininet-vm:/home/mininet# ifconfig
h1-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
    inet 10.0.0.1  netmask 255.0.0.0  broadcast 10.255.255.255
    ether 8a:5f:75:c2:ff:12  txqueuelen 1000  (Ethernet)
    RX packets 0  bytes 0 (0.0 B)
    RX errors 0  dropped 0  overruns 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 1364  bytes 586052 (586.0 KB)
    RX errors 0  dropped 0  overruns 0  frame 0
    TX packets 1364  bytes 586052 (586.0 KB)
    TX errors 0  dropped 0  overruns 0  carrier 0  collisions 0

root@mininet-vm:/home/mininet#
```

Рис. 3: Отображение информации их сетевых интерфейсов и IP-адресов

1. Запуск лабораторной топологии



```

"host: h1"
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 1364 bytes 586052 (586.0 KB)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 1364 bytes 586052 (586.0 KB)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

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=9.47 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=1.11 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.089 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.112 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3019ms
rtt min/avg/max/mdev = 0.089/2.694/9.466/3.931 ms
root@mininet-vm:/home/mininet#

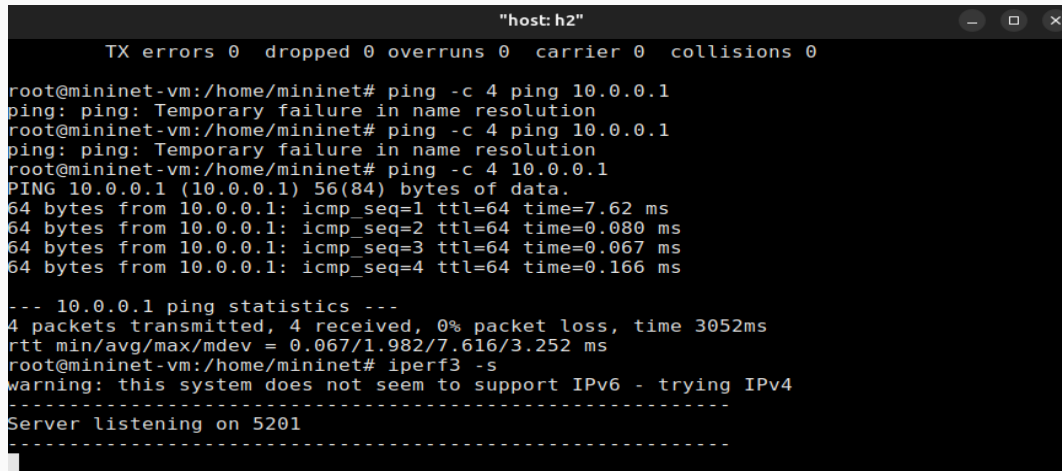
"host: h2"
inet 127.0.0.1 netmask 255.0.0.0
loop txqueuelen 1000 (Local Loopback)
RX packets 1138 bytes 569552 (569.5 KB)
RX errors 0 dropped 0 overruns 0 frame 0
TX packets 1138 bytes 569552 (569.5 KB)
TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@mininet-vm:/home/mininet# ping -c 4 ping 10.0.0.1
ping: ping: Temporary failure in name resolution
root@mininet-vm:/home/mininet# ping -c 4 ping 10.0.0.1
ping: ping: Temporary failure in name resolution
root@mininet-vm:/home/mininet# ping -c 4 10.0.0.1
PING 10.0.0.1 (10.0.0.1) 56(84) bytes of data:
64 bytes from 10.0.0.1: icmp_seq=1 ttl=64 time=7.62 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.080 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.067 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.166 ms

--- 10.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3052ms
rtt min/avg/max/mdev = 0.067/1.982/7.616/3.252 ms
root@mininet-vm:/home/mininet#
```

Рис. 4: Проверка подключения между хостами

2. Интерактивные эксперименты



```

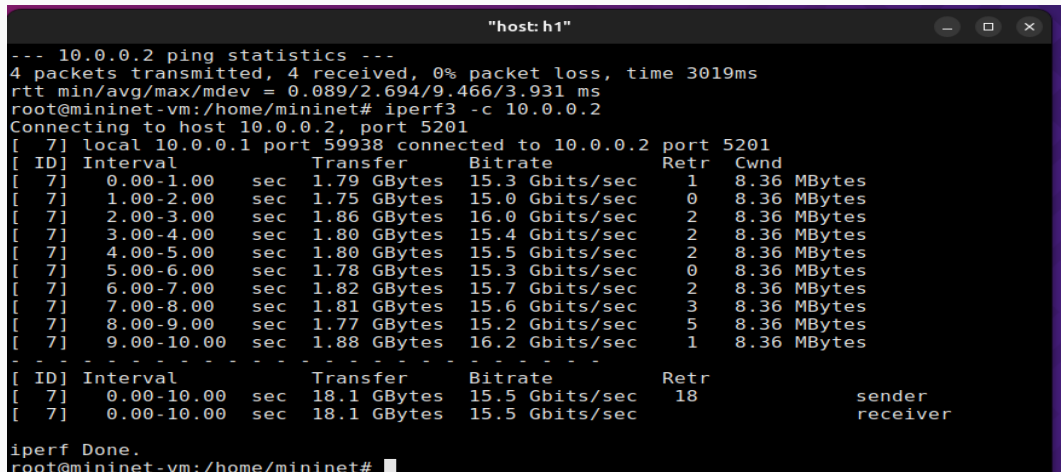
"host: h2"
TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

root@mininet-vm:/home/mininet# ping -c 4 ping 10.0.0.1
ping: ping: Temporary failure in name resolution
root@mininet-vm:/home/mininet# ping -c 4 ping 10.0.0.1
ping: ping: Temporary failure in name resolution
root@mininet-vm:/home/mininet# ping -c 4 10.0.0.1
PING 10.0.0.1 (10.0.0.1) 56(84) bytes of data.
64 bytes from 10.0.0.1: icmp_seq=1 ttl=64 time=7.62 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.080 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.067 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.166 ms

--- 10.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3052ms
rtt min/avg/max/mdev = 0.067/1.982/7.616/3.252 ms
root@mininet-vm:/home/mininet# iperf3 -s
warning: this system does not seem to support IPv6 - trying IPv4
-----
Server listening on 5201
-----
```

Рис. 5: Запуск iPerf3 в режиме сервера на хосте h2

2. Интерактивные эксперименты



```
--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3019ms
rtt min/avg/max/mdev = 0.089/2.694/9.466/3.931 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 59938 connected to 10.0.0.2 port 5201
[ ID] Interval            Transfer           Bitrate          Retr   Cwnd
[ 7]  0.00-1.00      sec    1.79 GBytes    15.3 Gbits/sec     1    8.36 MBytes
[ 7]  1.00-2.00      sec    1.75 GBytes    15.0 Gbits/sec     0    8.36 MBytes
[ 7]  2.00-3.00      sec    1.86 GBytes    16.0 Gbits/sec     2    8.36 MBytes
[ 7]  3.00-4.00      sec    1.80 GBytes    15.4 Gbits/sec     2    8.36 MBytes
[ 7]  4.00-5.00      sec    1.80 GBytes    15.5 Gbits/sec     2    8.36 MBytes
[ 7]  5.00-6.00      sec    1.78 GBytes    15.3 Gbits/sec     0    8.36 MBytes
[ 7]  6.00-7.00      sec    1.82 GBytes    15.7 Gbits/sec     2    8.36 MBytes
[ 7]  7.00-8.00      sec    1.81 GBytes    15.6 Gbits/sec     3    8.36 MBytes
[ 7]  8.00-9.00      sec    1.77 GBytes    15.2 Gbits/sec     5    8.36 MBytes
[ 7]  9.00-10.00     sec    1.88 GBytes    16.2 Gbits/sec     1    8.36 MBytes
- - - - -
[ ID] Interval            Transfer           Bitrate          Retr
[ 7]  0.00-10.00     sec    18.1 GBytes    15.5 Gbits/sec    18
[ 7]  0.00-10.00     sec    18.1 GBytes    15.5 Gbits/sec

iperf Done.
root@mininet-vm:/home/mininet#
```

Рис. 6: Запуск iPerf3 в режиме клиента на хосте h1

2. Интерактивные эксперименты



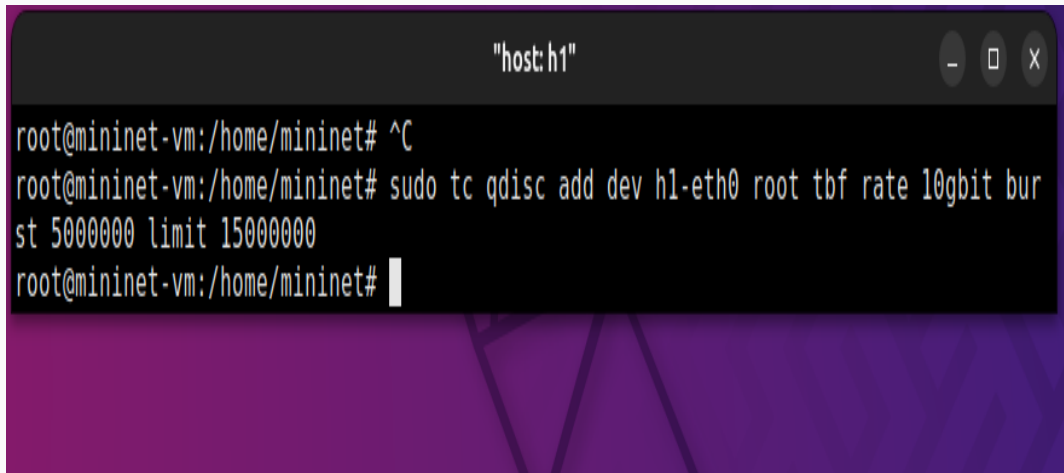
```
root@mininet-virtual-machine: /home/mininet# 
"host: h2"
Accepted connection from 10.0.0.1, port 59936
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 59938
[ ID] Interval      Transfer    Bitrate
[ 7]   0.00-1.00    sec    1.79 GBytes  15.4 Gbits/sec
[ 7]   1.00-2.00    sec    1.75 GBytes  15.0 Gbits/sec
[ 7]   2.00-3.00    sec    1.85 GBytes  15.9 Gbits/sec
[ 7]   3.00-4.00    sec    1.81 GBytes  15.5 Gbits/sec
[ 7]   4.00-5.00    sec    1.79 GBytes  15.4 Gbits/sec
[ 7]   5.00-6.00    sec    1.79 GBytes  15.3 Gbits/sec
[ 7]   6.00-7.00    sec    1.82 GBytes  15.6 Gbits/sec
[ 7]   7.00-8.00    sec    1.82 GBytes  15.7 Gbits/sec
[ 7]   8.00-9.00    sec    1.76 GBytes  15.1 Gbits/sec
[ 7]   9.00-10.00   sec    1.89 GBytes  16.2 Gbits/sec
[ 7]  10.00-10.00   sec      896 KBytes  4.23 Gbits/sec
-----
[ ID] Interval      Transfer    Bitrate
[ 7]   0.00-10.00   sec    18.1 GBytes  15.5 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-virtual-machine: /home/mininet# 
```

Рис. 7: Остановка iPerf3

2. Интерактивные эксперименты




A terminal window titled "host: h1" with standard window controls (minimize, maximize, close). The terminal shows a user at the root of a mininet-vm. The user presses Ctrl-C (^C) to interrupt a previous command. Then, they run the command `sudo tc qdisc add dev h1-eth0 root tbf rate 10gbit burst 5000000 limit 15000000` to configure the traffic control on the h1-eth0 interface. The command is entered across three lines. The prompt returns to the root user.

```
root@mininet-vm:/home/mininet# ^C
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root tbf rate 10gbit burst
5000000 limit 15000000
root@mininet-vm:/home/mininet#
```

Рис. 8: Изменение пропускной способности хоста h1

2. Интерактивные эксперименты

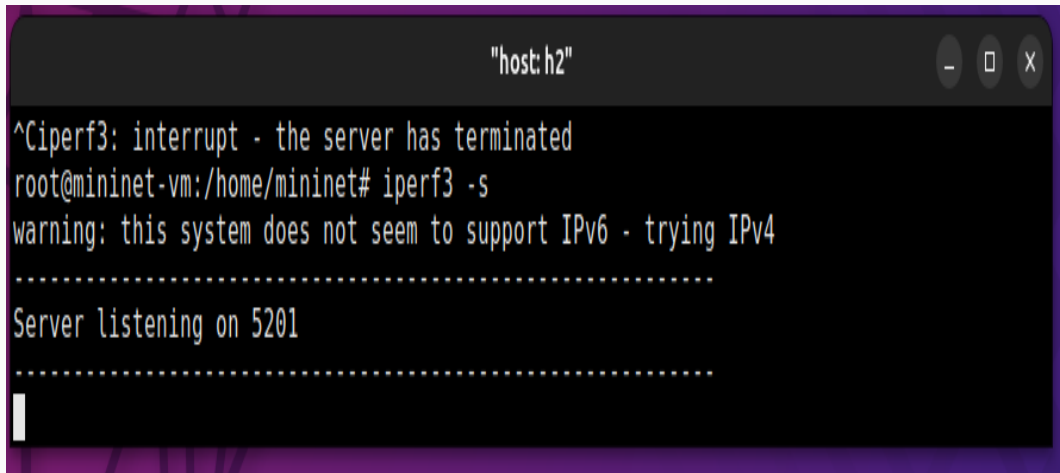


```
host: h1

iperf Done.
root@mininet-vm:/home/mininet# ^C
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root tbf rate 10gbit burst 5000000 limit 15000000
root@mininet-vm:/home/mininet# egrep '^CONFIG_HZ_[0-9]+' /boot/config/`uname -r`
grep: /boot/config/-5.4.0-42-generic: No such file or directory
root@mininet-vm:/home/mininet# egrep '^CONFIG_HZ_[0-9]+' /boot/config-`uname -r`
CONFIG_HZ_250=y
root@mininet-vm:/home/mininet#
```

Рис. 9: Установка значения всплеска при ограничении скорости для фильтра tbf

2. Интерактивные эксперименты

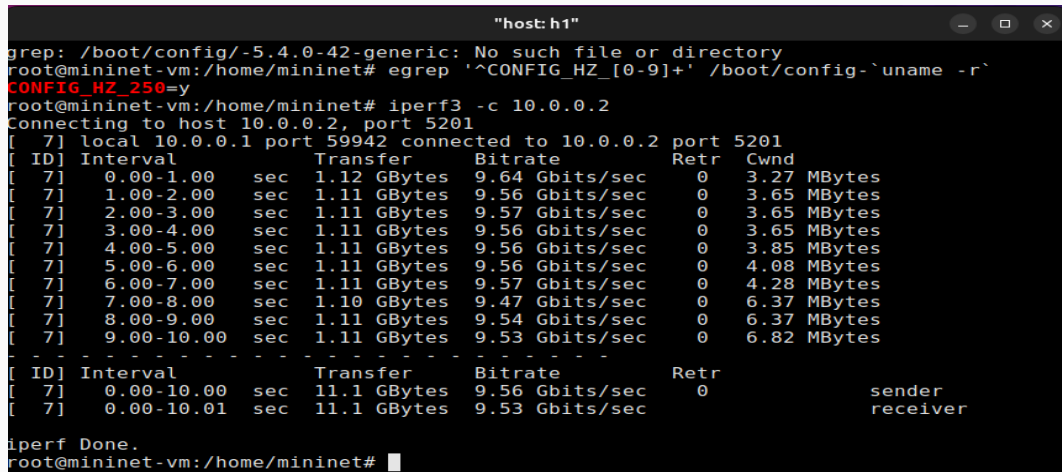


A terminal window titled "host: h2" with standard window controls (minimize, maximize, close). The terminal output shows a previous iPerf3 session being interrupted, followed by the command `iperf3 -s` being executed. A warning message indicates that IPv6 is not supported and IPv4 is being used. The terminal then shows the server listening on port 5201, with dashed lines above and below the message.

```
"host: h2"  
^Ciperf3: interrupt - the server has terminated  
root@mininet-vm:/home/mininet# iperf3 -s  
warning: this system does not seem to support IPv6 - trying IPv4  
.....  
Server listening on 5201  
.....  
|
```

Рис. 10: Запуск iPerf3 в режиме сервера на хосте h2

2. Интерактивные эксперименты

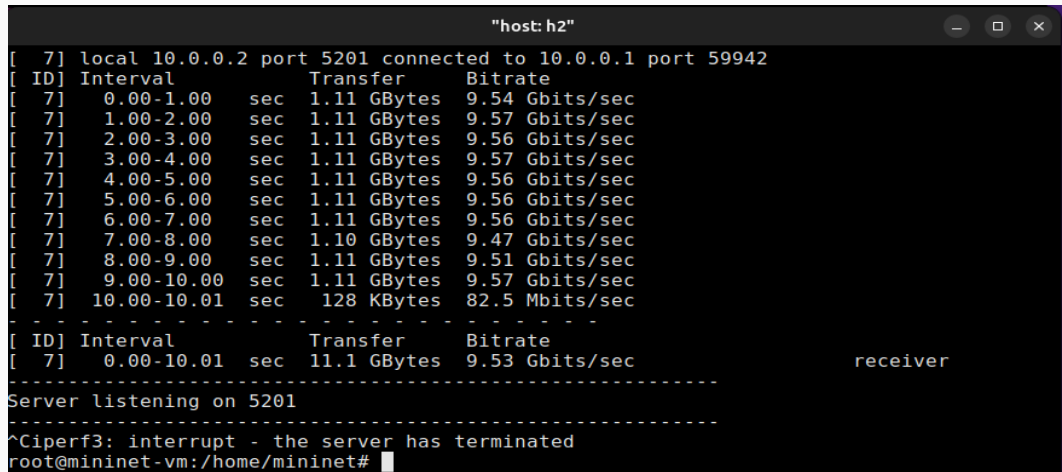


```
"host: h1"
grep: /boot/config/-5.4.0-42-generic: No such file or directory
root@mininet-vm:/home/mininet# egrep '^CONFIG_HZ_[0-9]+' /boot/config-`uname -r`
CONFIG_HZ_250=y
root@mininet-vm:/home/mininet# iperf3 -c 10.0.0.2
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 59942 connected to 10.0.0.2 port 5201
[ ID] Interval            Transfer          Bitrate          Retr   Cwnd
[ 7]  0.00-1.00      sec   1.12 GBytes    9.64 Gbits/sec     0    3.27 MBytes
[ 7]  1.00-2.00      sec   1.11 GBytes    9.56 Gbits/sec     0    3.65 MBytes
[ 7]  2.00-3.00      sec   1.11 GBytes    9.57 Gbits/sec     0    3.65 MBytes
[ 7]  3.00-4.00      sec   1.11 GBytes    9.56 Gbits/sec     0    3.65 MBytes
[ 7]  4.00-5.00      sec   1.11 GBytes    9.56 Gbits/sec     0    3.85 MBytes
[ 7]  5.00-6.00      sec   1.11 GBytes    9.56 Gbits/sec     0    4.08 MBytes
[ 7]  6.00-7.00      sec   1.11 GBytes    9.57 Gbits/sec     0    4.28 MBytes
[ 7]  7.00-8.00      sec   1.10 GBytes    9.47 Gbits/sec     0    6.37 MBytes
[ 7]  8.00-9.00      sec   1.11 GBytes    9.54 Gbits/sec     0    6.37 MBytes
[ 7]  9.00-10.00     sec   1.11 GBytes    9.53 Gbits/sec     0    6.82 MBytes
-- -- -- -- --
[ ID] Interval            Transfer          Bitrate          Retr
[ 7]  0.00-10.00     sec   11.1 GBytes    9.56 Gbits/sec     0
[ 7]  0.00-10.01     sec   11.1 GBytes    9.53 Gbits/sec     0
sender
receiver

iperf Done.
root@mininet-vm:/home/mininet#
```

Рис. 11: Запуск iPerf3 в режиме клиента на хосте h1

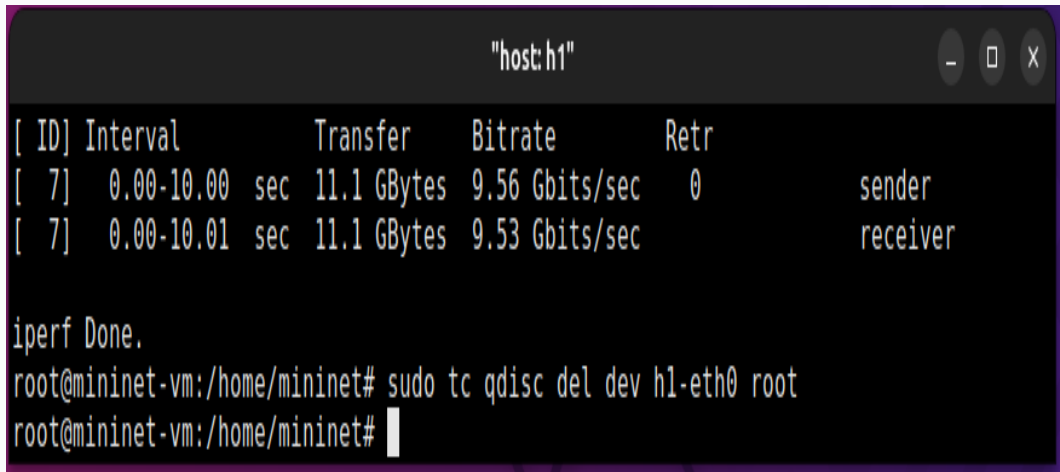
2. Интерактивные эксперименты



```
"host: h2"
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 59942
[ ID] Interval          Transfer      Bitrate
[ 7]   0.00-1.00      sec   1.11 GBytes   9.54 Gbits/sec
[ 7]   1.00-2.00      sec   1.11 GBytes   9.57 Gbits/sec
[ 7]   2.00-3.00      sec   1.11 GBytes   9.56 Gbits/sec
[ 7]   3.00-4.00      sec   1.11 GBytes   9.57 Gbits/sec
[ 7]   4.00-5.00      sec   1.11 GBytes   9.56 Gbits/sec
[ 7]   5.00-6.00      sec   1.11 GBytes   9.56 Gbits/sec
[ 7]   6.00-7.00      sec   1.11 GBytes   9.56 Gbits/sec
[ 7]   7.00-8.00      sec   1.10 GBytes   9.47 Gbits/sec
[ 7]   8.00-9.00      sec   1.11 GBytes   9.51 Gbits/sec
[ 7]   9.00-10.00     sec   1.11 GBytes   9.57 Gbits/sec
[ 7]  10.00-10.01     sec    128 KBytes   82.5 Mbits/sec
-----
[ ID] Interval          Transfer      Bitrate
[ 7]   0.00-10.01     sec   11.1 GBytes   9.53 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-vm:/home/mininet#
```

Рис. 12: Остановка iPerf3

2. Интерактивные эксперименты

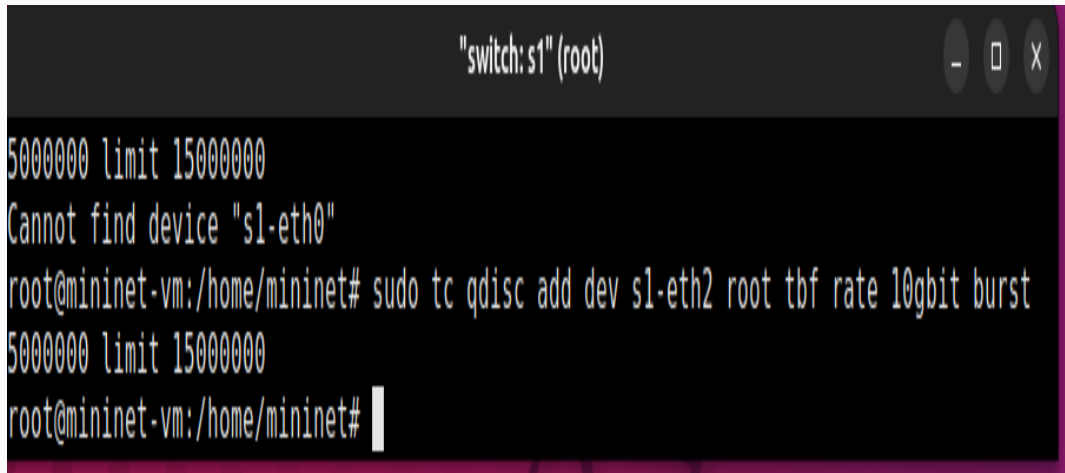


```
"host: h1"
[ ID] Interval          Transfer    Bitrate      Retr
[  7]  0.00-10.00  sec  11.1 GBytes  9.56 Gbits/sec    0      sender
[  7]  0.00-10.01  sec  11.1 GBytes  9.53 Gbits/sec      receiver

iperf Done.
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root
root@mininet-vm:/home/mininet#
```

Рис. 13: Восстановление конфигурацию по умолчанию

2. Интерактивные эксперименты

A terminal window titled '"switch: s1" (root)' with standard window controls. The terminal shows a sequence of commands and outputs: a 'limit' command, an error message 'Cannot find device "s1-eth0"', a 'sudo tc' command to add a tbf rule on 's1-eth2' at 10gbit, another 'limit' command, and the prompt returning to the user.

```
"switch: s1" (root)
50000000 limit 150000000
Cannot find device "s1-eth0"
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 root tbf rate 10gbit burst
50000000 limit 150000000
root@mininet-vm:/home/mininet#
```

Рис. 14: Применение правила ограничения скорости tbf

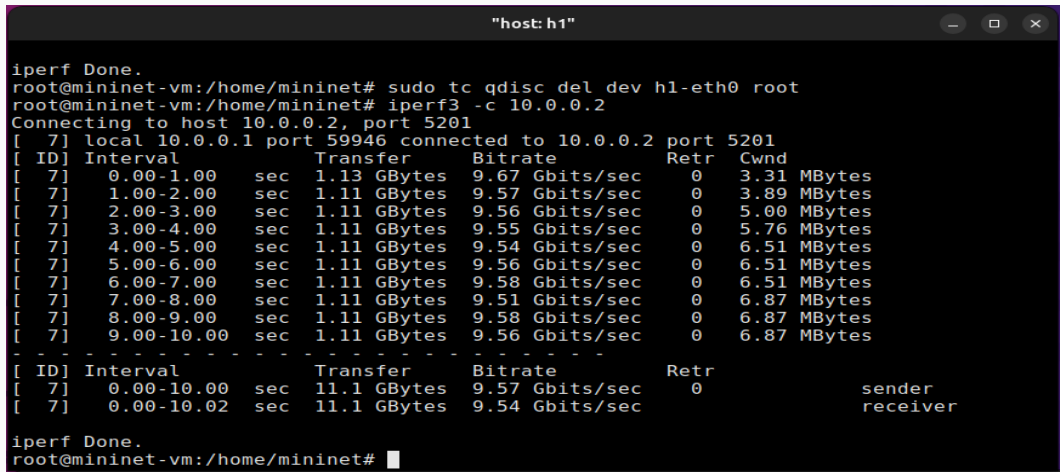
2. Интерактивные эксперименты



```
-----  
^Ciperf3: interrupt - the server has terminated  
root@mininet-vm:/home/mininet# iperf3 -s  
warning: this system does not seem to support IPv6 - trying IPv4  
-----  
Server listening on 5201  
-----  
█
```

Рис. 15: Запуск iPerf3 в режиме сервера на хосте h2

2. Интерактивные эксперименты

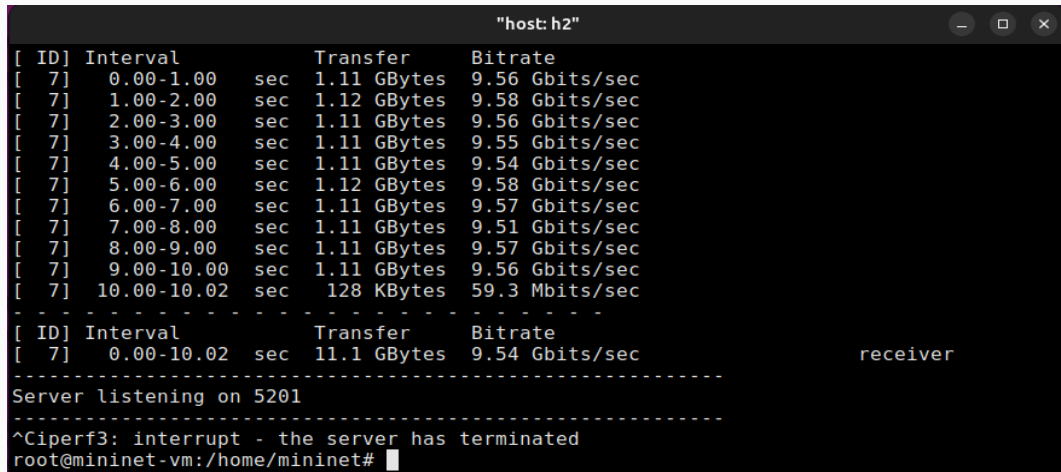


```
iperf Done.
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root
root@mininet-vm:/home/mininet# iperf3 -c 10.0.0.2
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 59946 connected to 10.0.0.2 port 5201
[ ID] Interval            Transfer           Bitrate          Retr  Cwnd
[ 7]  0.00-1.00      sec   1.13 GBytes      9.67 Gbits/sec    0   3.31 MBytes
[ 7]  1.00-2.00      sec   1.11 GBytes      9.57 Gbits/sec    0   3.89 MBytes
[ 7]  2.00-3.00      sec   1.11 GBytes      9.56 Gbits/sec    0   5.00 MBytes
[ 7]  3.00-4.00      sec   1.11 GBytes      9.55 Gbits/sec    0   5.76 MBytes
[ 7]  4.00-5.00      sec   1.11 GBytes      9.54 Gbits/sec    0   6.51 MBytes
[ 7]  5.00-6.00      sec   1.11 GBytes      9.56 Gbits/sec    0   6.51 MBytes
[ 7]  6.00-7.00      sec   1.11 GBytes      9.58 Gbits/sec    0   6.51 MBytes
[ 7]  7.00-8.00      sec   1.11 GBytes      9.51 Gbits/sec    0   6.87 MBytes
[ 7]  8.00-9.00      sec   1.11 GBytes      9.58 Gbits/sec    0   6.87 MBytes
[ 7]  9.00-10.00     sec   1.11 GBytes      9.56 Gbits/sec    0   6.87 MBytes
- - - - -
[ ID] Interval            Transfer           Bitrate          Retr
[ 7]  0.00-10.00     sec   11.1 GBytes      9.57 Gbits/sec    0
[ 7]  0.00-10.02     sec   11.1 GBytes      9.54 Gbits/sec
sender
receiver

iperf Done.
root@mininet-vm:/home/mininet#
```

Рис. 16: Запуск iPerf3 в режиме клиента на хосте h1

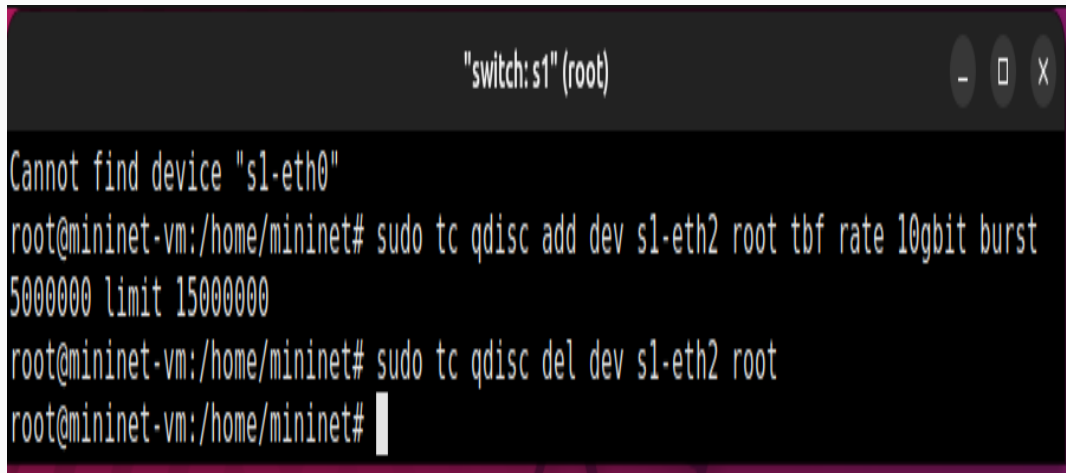
2. Интерактивные эксперименты



```
"host: h2"
[ ID] Interval      Transfer    Bitrate
[  7]  0.00-1.00    sec  1.11 GBytes  9.56 Gbits/sec
[  7]  1.00-2.00    sec  1.12 GBytes  9.58 Gbits/sec
[  7]  2.00-3.00    sec  1.11 GBytes  9.56 Gbits/sec
[  7]  3.00-4.00    sec  1.11 GBytes  9.55 Gbits/sec
[  7]  4.00-5.00    sec  1.11 GBytes  9.54 Gbits/sec
[  7]  5.00-6.00    sec  1.12 GBytes  9.58 Gbits/sec
[  7]  6.00-7.00    sec  1.11 GBytes  9.57 Gbits/sec
[  7]  7.00-8.00    sec  1.11 GBytes  9.51 Gbits/sec
[  7]  8.00-9.00    sec  1.11 GBytes  9.57 Gbits/sec
[  7]  9.00-10.00   sec  1.11 GBytes  9.56 Gbits/sec
[  7] 10.00-10.02   sec   128 KBytes 59.3 Mbits/sec
-----
[ ID] Interval      Transfer    Bitrate
[  7]  0.00-10.02   sec  11.1 GBytes  9.54 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-vm: /home/mininet#
```

Рис. 17: Остановка iPerf3

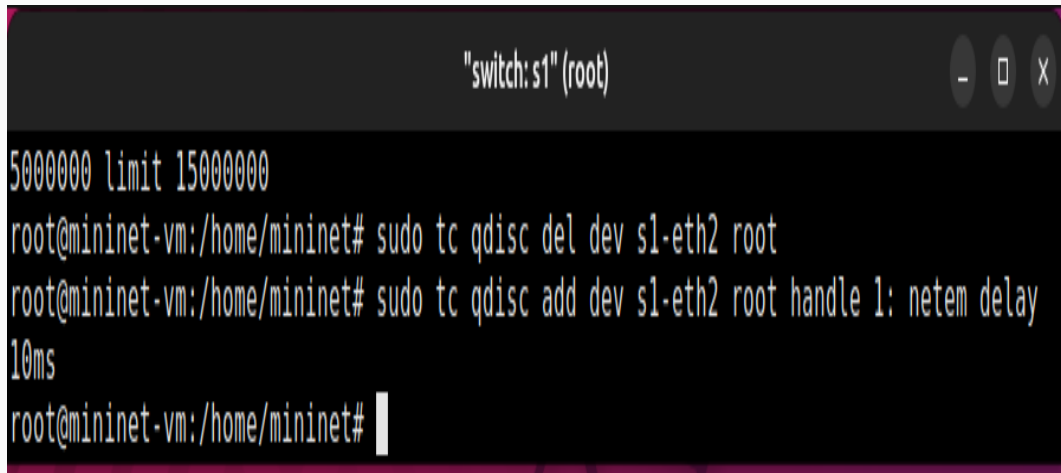
2. Интерактивные эксперименты



```
"switch: s1" (root)
Cannot find device "s1-eth0"
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 root tbf rate 10gbit burst
50000000 limit 150000000
root@mininet-vm:/home/mininet# sudo tc qdisc del dev s1-eth2 root
root@mininet-vm:/home/mininet#
```

Рис. 18: Восстановление конфигурацию по умолчанию на коммутаторе s1

2. Интерактивные эксперименты

A terminal window titled "switch: s1" (root) with standard window controls. The terminal shows a configuration for a traffic class with a 50000000 limit and a 150000000 limit. It then shows the deletion of an existing qdisc on s1-eth2 and the addition of a new qdisc using netem delay 10ms.

```
"switch: s1" (root)
50000000 limit 150000000
root@mininet-vm:/home/mininet# sudo tc qdisc del dev s1-eth2 root
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 root handle 1: netem delay
10ms
root@mininet-vm:/home/mininet#
```

Рис. 19: Объединение NETEM и TBF

2. Интерактивные эксперименты

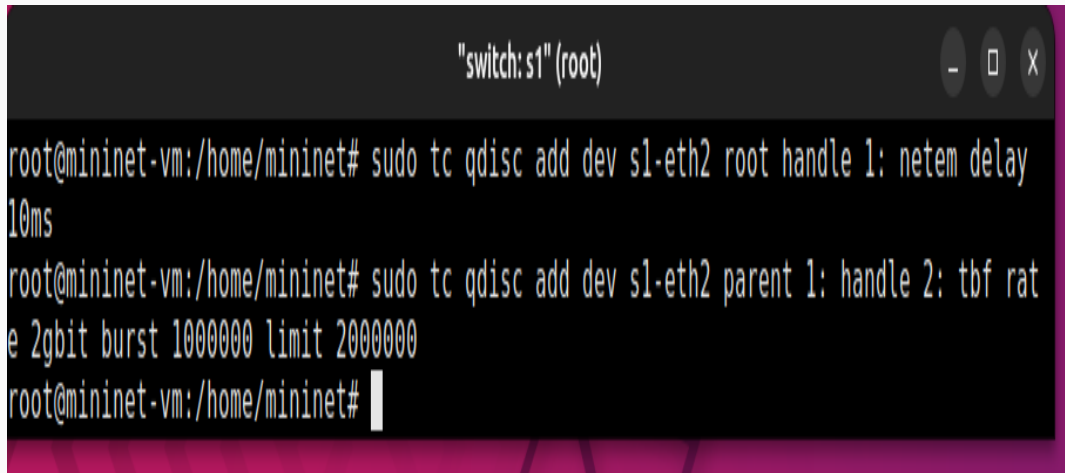
```
"host: h1"
[ 7] 3.00-4.00 sec 1.11 GBytes 9.55 Gbits/sec 0 5.76 MBytes
[ 7] 4.00-5.00 sec 1.11 GBytes 9.54 Gbits/sec 0 6.51 MBytes
[ 7] 5.00-6.00 sec 1.11 GBytes 9.56 Gbits/sec 0 6.51 MBytes
[ 7] 6.00-7.00 sec 1.11 GBytes 9.58 Gbits/sec 0 6.51 MBytes
[ 7] 7.00-8.00 sec 1.11 GBytes 9.51 Gbits/sec 0 6.87 MBytes
[ 7] 8.00-9.00 sec 1.11 GBytes 9.58 Gbits/sec 0 6.87 MBytes
[ 7] 9.00-10.00 sec 1.11 GBytes 9.56 Gbits/sec 0 6.87 MBytes
- - - - -
[ ID] Interval      Transfer    Bitrate      Retr
[ 7] 0.00-10.00 sec 11.1 GBytes 9.57 Gbits/sec 0
[ 7] 0.00-10.02 sec 11.1 GBytes 9.54 Gbits/sec
sender
receiver

iperf Done.
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=15.2 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=12.4 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=11.0 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=10.5 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3007ms
rtt min/avg/max/mdev = 10.475/12.276/15.217/1.838 ms
root@mininet-vm:/home/mininet#
```

Рис. 20: Проверка задержки

2. Интерактивные эксперименты



```
"switch: s1" (root)
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 root handle 1: netem delay 10ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 parent 1: handle 2: tbf rate 2gbit burst 10000000 limit 20000000
root@mininet-vm:/home/mininet#
```

Рис. 21: Добавление второго правила на коммутаторе s1

2. Интерактивные эксперименты

A terminal window titled "host: h2" with standard window controls (minimize, maximize, close). The terminal output shows a sequence of events: a dotted line, a message about iPerf3 server termination, a command to start the server, a warning about IPv6, another dotted line, and the server listening on port 5201.

```
.....  
^Ciperf3: interrupt - the server has terminated  
root@mininet-vm:/home/mininet# iperf3 -s  
warning: this system does not seem to support IPv6 - trying IPv4  
.....  
Server listening on 5201  
.....
```

Рис. 22: Запуск iPerf3 в режиме сервера на хосте h2

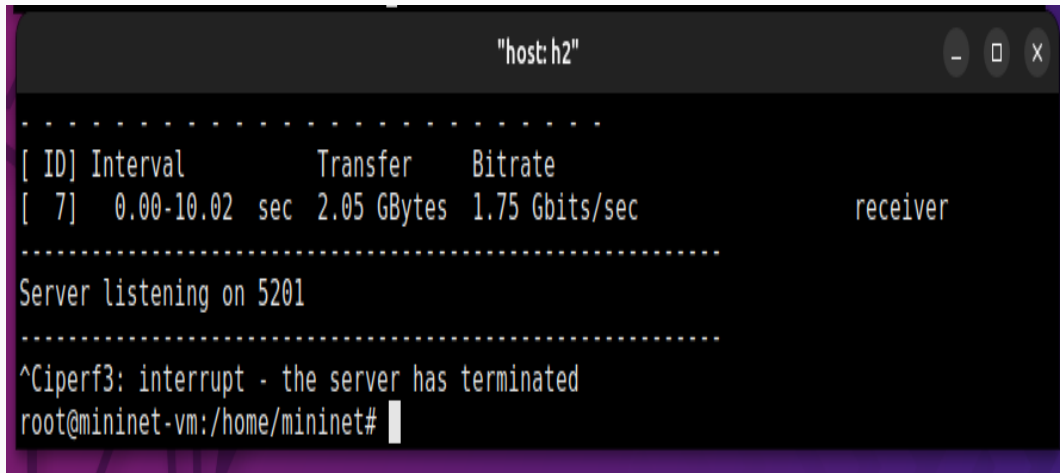
2. Интерактивные эксперименты

```
"host: h1"
--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3007ms
rtt min/avg/max/mdev = 10.475/12.276/15.217/1.838 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 59950 connected to 10.0.0.2 port 5201
[ ID] Interval            Transfer          Bitrate          Retr   Cwnd
[ 7]  0.00-1.00      sec    188 MBytes    1.58 Gbits/sec    765   2.30 MBytes
[ 7]  1.00-2.00      sec    220 MBytes    1.85 Gbits/sec     0   2.43 MBytes
[ 7]  2.00-3.00      sec    228 MBytes    1.91 Gbits/sec     0   2.53 MBytes
[ 7]  3.00-4.00      sec    228 MBytes    1.91 Gbits/sec     0   2.61 MBytes
[ 7]  4.00-5.00      sec    229 MBytes    1.92 Gbits/sec     0   2.67 MBytes
[ 7]  5.00-6.00      sec    228 MBytes    1.91 Gbits/sec     0   2.71 MBytes
[ 7]  6.00-7.00      sec    198 MBytes    1.66 Gbits/sec    90   1.97 MBytes
[ 7]  7.00-8.00      sec    185 MBytes    1.55 Gbits/sec     0   2.08 MBytes
[ 7]  8.00-9.00      sec    198 MBytes    1.66 Gbits/sec     0   2.16 MBytes
[ 7]  9.00-10.00     sec    205 MBytes    1.72 Gbits/sec     0   2.22 MBytes
- - - - -
[ ID] Interval            Transfer          Bitrate          Retr
[ 7]  0.00-10.00     sec    2.06 GBytes    1.77 Gbits/sec    855
[ 7]  0.00-10.02     sec    2.05 GBytes    1.75 Gbits/sec
                                     sender
                                     receiver

iperf Done.
root@mininet-vm:/home/mininet#
```

Рис. 23: Запуск iPerf3 в режиме клиента на хосте h1

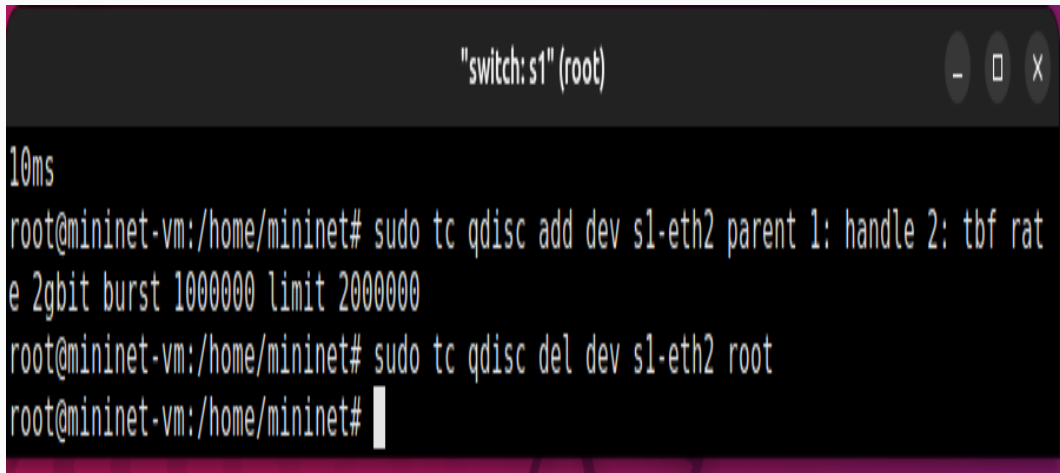
2. Интерактивные эксперименты



```
"host: h2"
- - - - -
[ ID] Interval      Transfer    Bitrate
[  7]  0.00-10.02  sec  2.05 GBytes  1.75 Gbits/sec      receiver
- - - - -
Server listening on 5201
- - - - -
^Ciperf3: interrupt - the server has terminated
root@mininet-vm:/home/mininet#
```

Рис. 24: Остановка iPerf3

2. Интерактивные эксперименты



A terminal window titled "switch: s1" (root) with standard window controls. The terminal shows a sequence of commands and their output. First, "10ms" is printed. Then, a command to add a tc qdisc is executed. Finally, a command to delete the qdisc is executed, and the prompt returns.

```
"switch: s1" (root)  
10ms  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 parent 1: handle 2: tbf rate  
e 2gbit burst 1000000 limit 2000000  
root@mininet-vm:/home/mininet# sudo tc qdisc del dev s1-eth2 root  
root@mininet-vm:/home/mininet#
```

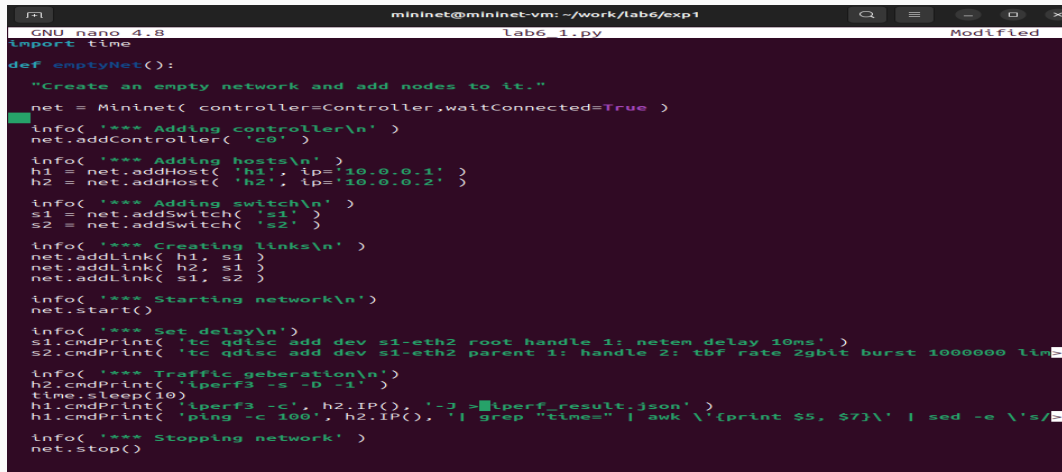
Рис. 25: Удаление модифицированной конфигурации на коммутаторе s1

3. Воспроизведение экспериментов

```
mininet@mininet-vm:~$ ls
Desktop    Downloads  mininet.orig  oflops  openflow  pox      Templates  work
Documents  mininet    Music          oftest  Pictures  Public   Videos
mininet@mininet-vm:~$ cd work/
mininet@mininet-vm:~/work$ ls
lab1.mn  lab_iperf3  lab_netem_i  lab_netem_ii
mininet@mininet-vm:~/work$ mkdir lab6
mininet@mininet-vm:~/work$ ls
lab1.mn  lab6  lab_iperf3  lab_netem_i  lab_netem_ii
mininet@mininet-vm:~/work$ cd lab6
mininet@mininet-vm:~/work/lab6$ mkdir exp1
mininet@mininet-vm:~/work/lab6$ mkdir exp2
mininet@mininet-vm:~/work/lab6$ ls
exp1  exp2
mininet@mininet-vm:~/work/lab6$
```

Рис. 26: Создание необходимых каталогов

3. Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab6/exp1
GNU nano 4.8 lab6_1.py Modified
import time

def emptyNet():
    "Create an empty network and add nodes to it."

    net = Mininet( controller=Controller,waitConnected=True )

    info( '*** Adding controller\n' )
    net.addController( 'c0' )

    info( '*** Adding hosts\n' )
    h1 = net.addHost( 'h1', ip='10.0.0.1' )
    h2 = net.addHost( 'h2', ip='10.0.0.2' )

    info( '*** Adding switch\n' )
    s1 = net.addSwitch( 's1' )
    s2 = net.addSwitch( 's2' )

    info( '*** Creating links\n' )
    net.addLink( h1, s1 )
    net.addLink( h2, s1 )
    net.addLink( s1, s2 )

    info( '*** Starting network\n' )
    net.start()

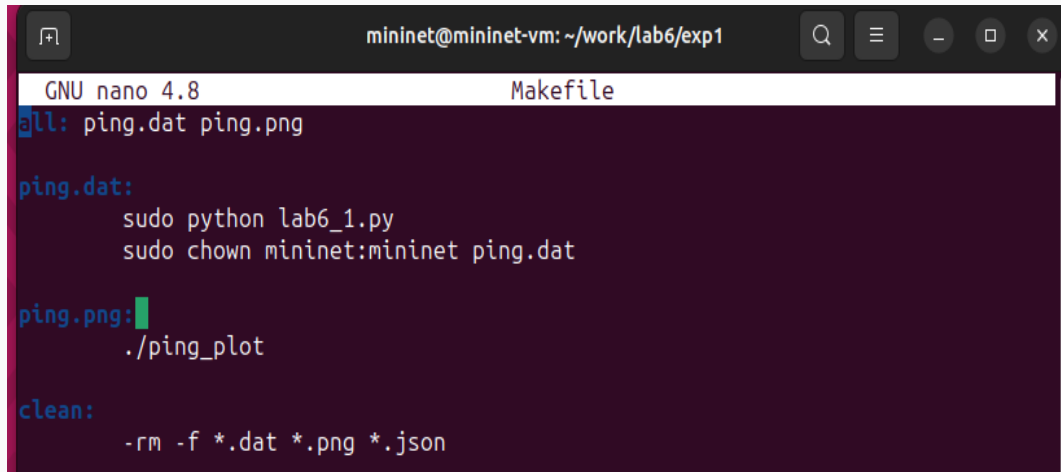
    info( '*** Set delay\n' )
    s1.cmdPrint( 'tc qdisc add dev s1-eth2 root handle 1: netem delay 10ms' )
    s2.cmdPrint( 'tc qdisc add dev s1-eth2 parent 1: handle 2: tbf rate 2gbit burst 1000000 lim

    info( '*** Traffic geberation\n' )
    h2.cmdPrint( 'iperf3 -s -D -1' )
    time.sleep(10)
    h1.cmdPrint( 'iperf3 -c', h2.IP(), '-J >iperf_result.json' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "time=" | awk \'{print $5, $7}\'' | sed -e 's/

    info( '*** Stopping network' )
    net.stop()
```

Рис. 27: Создание скрипта 1

3. Воспроизведение экспериментов



The image shows a terminal window with a dark background. At the top, the title bar reads "mininet@mininet-vm: ~/work/lab6/exp1". Below the title bar, the terminal shows the GNU nano 4.8 editor editing a file named "Makefile". The content of the Makefile is as follows:

```
all: ping.dat ping.png

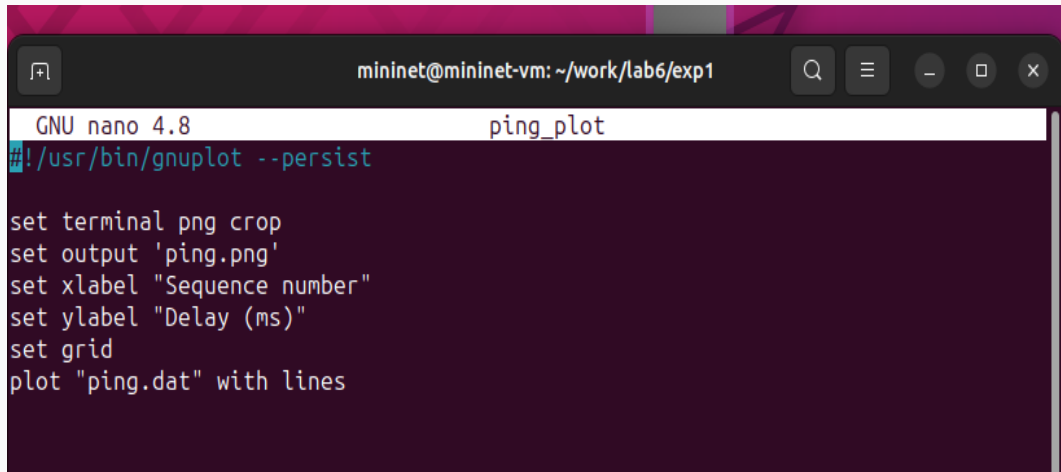
ping.dat:
    sudo python lab6_1.py
    sudo chown mininet:mininet ping.dat

ping.png:
    ./ping_plot

clean:
    -rm -f *.dat *.png *.json
```

Рис. 28: Создание скрипта 2

3. Воспроизведение экспериментов



The image shows a terminal window with a dark background and a light-colored title bar. The title bar contains the text "mininet@mininet-vm: ~/work/lab6/exp1" and standard window control buttons (search, menu, zoom, close). The terminal content shows the GNU nano 4.8 editor interface. The filename "ping_plot" is displayed in the top right of the editor area. The script content is as follows:

```
GNU nano 4.8                                ping_plot
#!/usr/bin/gnuplot --persist

set terminal png crop
set output 'ping.png'
set xlabel "Sequence number"
set ylabel "Delay (ms)"
set grid
plot "ping.dat" with lines
```

Рис. 29: Создание скрипта 3

3. Воспроизведение экспериментов

```
*** Shutting down some connects
pkill -9 -f Tunnel=Ethernet
pkill -9 -f .ssh/mn
rm -f ~/.ssh/mn/*
*** Cleanup complete.
mininet@mininet-vm:~/work/lab6/exp1$ nano lab6_1.py
mininet@mininet-vm:~/work/lab6/exp1$ make
sudo python lab6_1.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 2 switches
s1 s2 ...
*** Waiting for switches to connect
s2 s1
*** Set delay
*** s1 : ('tc qdisc add dev s1-eth2 root handle 1: netem delay 10ms',)
*** s2 : ('tc qdisc add dev s1-eth2 parent 1: handle 2: tbf rate 2gbit burst 1000000 limit 200
0000',)
*** Traffic geberation
*** h2 : ('iperf3 -s -D -1',)
*** h1 : ('iperf3 -c', '10.0.0.2', '-J > iperf_result.json')
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'{print $5, $7}\'' | sed -e \'s/tim
e//g\' -e \'s/icmp_seq="//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 3 links
...
*** Stopping 2 switches
s1 s2
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab6/exp1$ ls
iperf_result.json lab6_1.py Makefile ping.dat ping_plot ping.png
mininet@mininet-vm:~/work/lab6/exp1$
```

Рис. 30: Выполнение скриптов

3. Воспроизведение экспериментов

```
import time
def emptyNet():
    "Create an empty network and add nodes to it."
    net = Mininet( controller=Controller,waitConnected=True )
    info( '*** Adding controller\n' )
    net.addController( 'c0' )
    info( '*** Adding hosts\n' )
    h1 = net.addHost( 'h1', ip='10.0.0.1' )
    h2 = net.addHost( 'h2', ip='10.0.0.2' )
    info( '*** Adding switch\n' )
    s1 = net.addSwitch( 's1' )
    s2 = net.addSwitch( 's2' )
    s1.cmd('ip link del s1-eth2')
    s2.cmd('ip link del s2-eth1')
    info( '*** Creating links\n' )
    net.addLink( h1, s1 )
    net.addLink( h2, s1 )
    net.addLink( s1, s2 )
    info( '*** Starting network\n' )
    net.start()
    info( '*** Set delay\n' )
    # s1.cmdPrint( 'tc qdisc add dev s1-eth2 root handle 1: netem delay 10ms' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root tbf rate 10gbit burst 5000000 limit 15000000' )
    info( '*** Traffic geberation\n' )
    h2.cmdPrint( 'iperf3 -s -D -1' )
    time.sleep(10)
    h1.cmdPrint( 'iperf3 -c', h2.IP(), '-J > iperf_result.json' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "time=" | awk \'{print $5, $7}\'} | sed -e \'/s/
```

^G Get Help	^O Write Out	^W Where Is	^K Cut Text	^J Justify	^C Cur Pos
^X Exit	^R Read File	^_ Replace	^U Paste Text	^T To Spell	^_ Go To Line

Рис. 31: Изменение параметров

3. Воспроизведение экспериментов

```
mininet@mininet-vm:~/work/lab6/exp1$ make lab6_1.py
sudo python lab6_1.py
File "lab6_1.py", line 34
    info( '*** Creating links\n' )
    ^
SyntaxError: invalid syntax
make: *** [Makefile:4: ping.dat] Error 1
mininet@mininet-vm:~/work/lab6/exp1$ nano lab6_1.py
mininet@mininet-vm:~/work/lab6/exp1$ make
sudo python lab6_1.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 2 switches
s1 s2 ...
*** Waiting for switches to connect
s1 s2
*** Set delay
*** h1 : ('tc qdisc add dev h1-eth0 root tbf rate 10gbit burst 5000000 limit 15000000',)
*** Traffic generation
*** h2 : ('iperf3 -s -D -1',)
*** h1 : ('iperf3 -c', '10.0.0.2', '-J > iperf_result.json')
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'{print $5, $7}\'' | sed -e \\'s/tim
e//g\' -e \\'s/icmp_seq="//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 3 links
...
*** Stopping 2 switches
s1 s2
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab6/exp1$ nano lab6_1.py
mininet@mininet-vm:~/work/lab6/exp1$
```

Рис. 32: Выполнение скриптов

3. Воспроизведение экспериментов

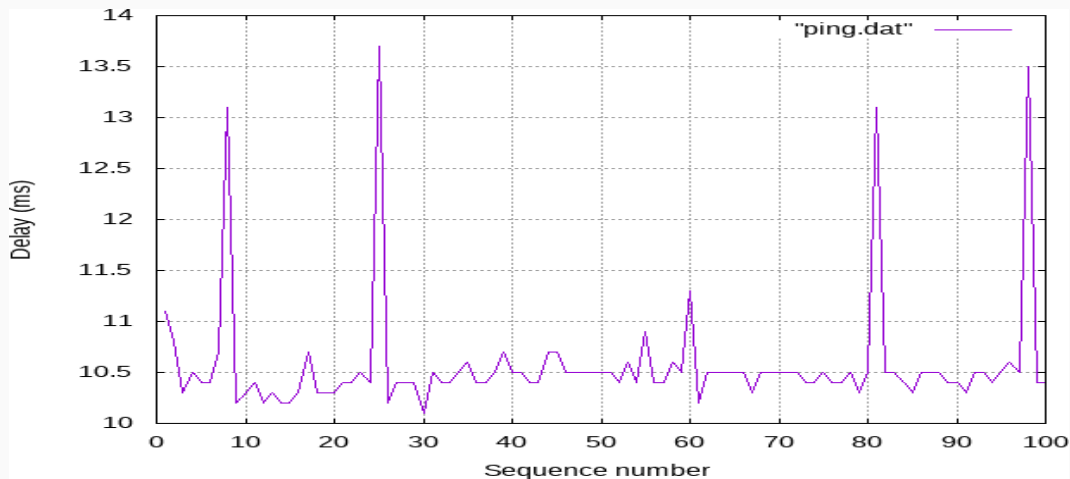


Рис. 33: График 1

3. Воспроизведение экспериментов

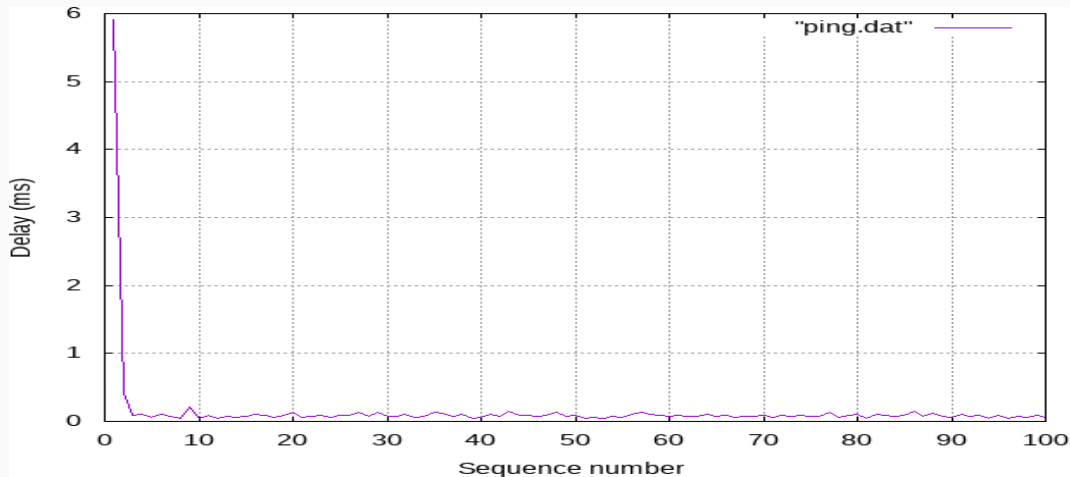


Рис. 34: График 2

В ходе выполнения лабораторной работы познакомились с принципами работы дисциплины очереди Token Bucket Filter, которая формирует входящий/исходящий трафик для ограничения пропускной способности, а также получили навыки моделирования и исследования поведения трафика посредством проведения интерактивного и воспроизводимого экспериментов в Mininet.

[1] Mininet: <https://mininet.org/>