

Лабораторная работа №6

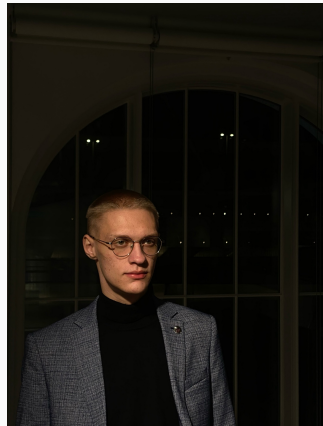
Моделирование сетей передачи данных

Махорин И. С.

2024

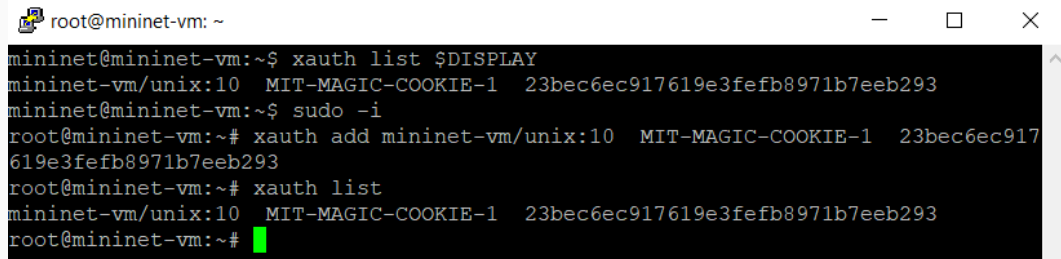
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- Познакомиться с принципами работы дисциплины очереди Token Bucket Filter, которая формирует входящий/исходящий трафик для ограничения пропускной способности, а также получить навыки моделирования и исследования поведения трафика посредством проведения интерактивного и воспроизводимого экспериментов в Mininet.

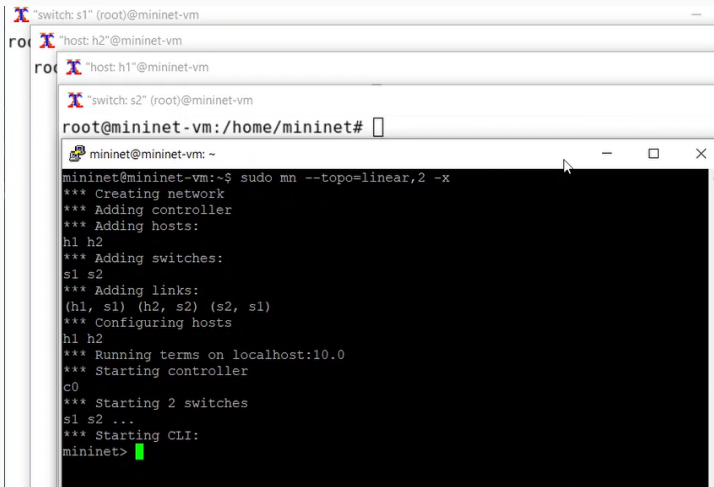
Выполнение лабораторной работы

A terminal window titled 'root@mininet-vm: ~' with standard window controls. The terminal output shows the following sequence of commands and responses:

```
mininet@mininet-vm:~$ xauth list $DISPLAY
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  23bec6ec917619e3fefb8971b7eeb293
mininet@mininet-vm:~$ sudo -i
root@mininet-vm:~# xauth add mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  23bec6ec917619e3fefb8971b7eeb293
root@mininet-vm:~# xauth list
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  23bec6ec917619e3fefb8971b7eeb293
root@mininet-vm:~#
```

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

Запуск лабораторной топологии

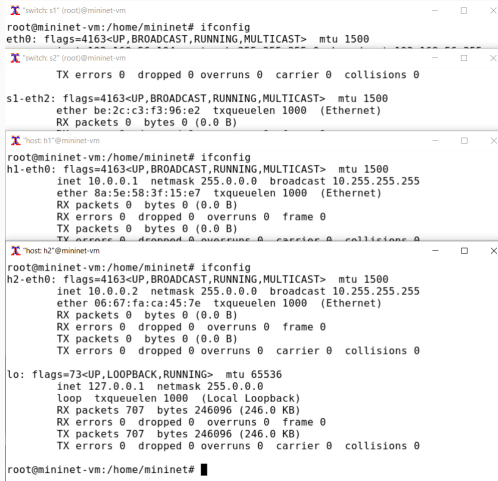


```
"switch: s1" (root)@mininet-vm
root "host: h2" @mininet-vm
root "host: h1" @mininet-vm
"switch: s2" (root)@mininet-vm
root@mininet-vm:~/home/mininet#

mininet@mininet-vm: ~
mininet@mininet-vm:~$ sudo mn --topo=linear,2 -x
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1 s2
*** Adding links:
(h1, s1) (h2, s2) (s2, s1)
*** Configuring hosts
h1 h2
*** Running terms on localhost:10.0
*** Starting controller
c0
*** Starting 2 switches
s1 s2 ...
*** Starting CLI:
mininet>
```

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

Запуск лабораторной топологии



```
*switch: s1* (root@mininet-vm)
root@mininet-vm:/home/mininet# ifconfig
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
      ether 08:00:27:00:00:00 txqueuelen 1000 (Ethernet)
      RX packets 0 bytes 0 (0.0 B)
      TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

*switch: s2* (root@mininet-vm)
s1-eth2: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
      ether be:2c:c3:f3:96:e2 txqueuelen 1000 (Ethernet)
      RX packets 0 bytes 0 (0.0 B)
      TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

*host: h1* (root@mininet-vm)
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:5e:58:3f:15:e7 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

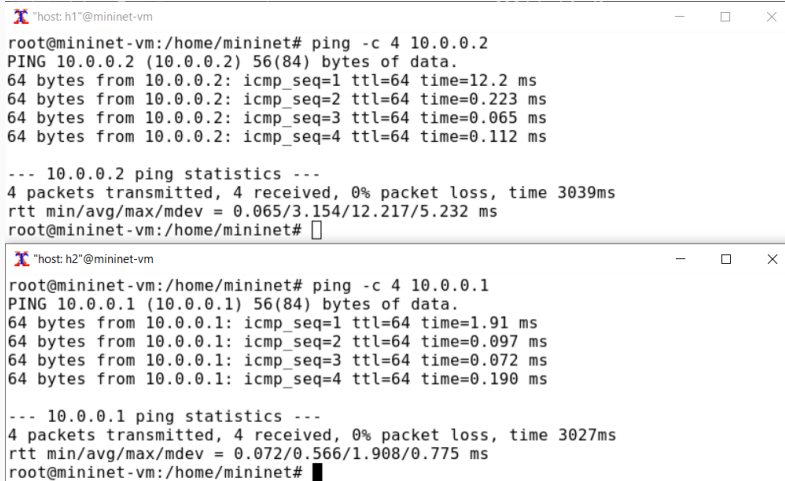
*host: h2* (root@mininet-vm)
root@mininet-vm:/home/mininet# ifconfig
h2-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
      inet 10.0.0.2 netmask 255.0.0.0 broadcast 10.255.255.255
      ether 06:67:fa:ca:45:7e txqueuelen 1000 (Ethernet)
      RX packets 0 bytes 0 (0.0 B)
      RX errors 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 707 bytes 246096 (246.0 KB)
      RX errors 0 dropped 0 overruns 0 frame 0
      TX packets 707 bytes 246096 (246.0 KB)
      TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

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

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

Запуск лабораторной топологии



The image shows two terminal windows from a Mininet VM. The top window is titled "host: h1" and shows a ping command being executed from root@mininet-vm to 10.0.0.2. The output displays four successful ping packets with decreasing times (12.2 ms, 0.223 ms, 0.065 ms, 0.112 ms) and a summary showing 0% packet loss and a total time of 3039ms. The bottom window is titled "host: h2" and shows a ping command being executed from root@mininet-vm to 10.0.0.1. The output displays four successful ping packets with times (1.91 ms, 0.097 ms, 0.072 ms, 0.190 ms) and a summary showing 0% packet loss and a total time of 3027ms.

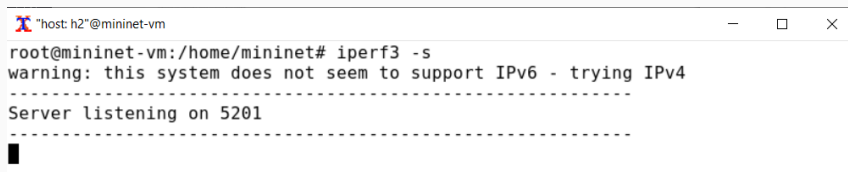
```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ping -c 4 10.0.0.2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=12.2 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.223 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.112 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3039ms
rtt min/avg/max/mdev = 0.065/3.154/12.217/5.232 ms
root@mininet-vm:/home/mininet#

"host: h2"@mininet-vm
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=1.91 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.097 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.072 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.190 ms

--- 10.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3027ms
rtt min/avg/max/mdev = 0.072/0.566/1.908/0.775 ms
root@mininet-vm:/home/mininet#
```

Рис. 4: Проверка подключения между хостами h1 и h2



```
"host: h2"@mininet-vm
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

Запуск лабораторной топологии

```
"host: h1"@mininet-vm
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 35600 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bitrate      Retr  Cwnd
[ 7]  0.00-1.00      sec   1.78 GBytes  15.2 Gbits/sec    0   8.14 MBytes
[ 7]  1.00-2.00      sec    859 MBytes  7.23 Gbits/sec    0   8.14 MBytes
[ 7]  2.00-3.00      sec   1.25 GBytes  10.8 Gbits/sec    0   8.14 MBytes
[ 7]  3.00-4.00      sec   1.01 GBytes  8.68 Gbits/sec    0   8.14 MBytes
[ 7]  4.00-5.00      sec   1.24 GBytes  10.7 Gbits/sec    0   8.14 MBytes
[ 7]  5.00-6.00      sec   1.01 GBytes  8.70 Gbits/sec    0   8.14 MBytes
[ 7]  6.00-7.00      sec   1.63 GBytes  14.0 Gbits/sec    0   8.14 MBytes
[ 7]  7.00-8.00      sec   1.59 GBytes  13.6 Gbits/sec    0   8.14 MBytes
[ 7]  8.00-9.00      sec   1.64 GBytes  14.1 Gbits/sec    0   8.14 MBytes
[ 7]  9.00-10.00     sec   1.59 GBytes  13.6 Gbits/sec    0   8.14 MBytes
- - - - -
[ ID] Interval           Transfer     Bitrate      Retr
[ 7]  0.00-10.00     sec   13.6 GBytes  11.7 Gbits/sec    0
[ 7]  0.00-10.00     sec   13.6 GBytes  11.6 Gbits/sec    0
sender
receiver

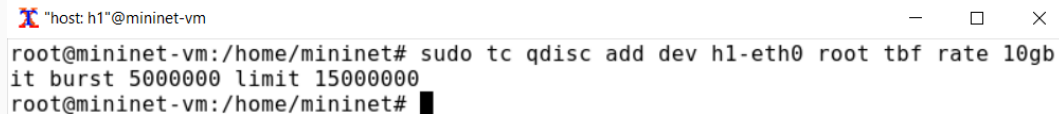
iperf Done.
root@mininet-vm:/home/mininet#
```

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

Запуск лабораторной топологии

```
"host: h2"@mininet-vm
-----
Server listening on 5201
-----
Accepted connection from 10.0.0.1, port 35602
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 35604
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-1.00    sec   1.83 GBytes  15.7 Gbits/sec
[ 7]  1.00-2.00    sec   1.75 GBytes  15.0 Gbits/sec
[ 7]  2.00-3.00    sec   1.84 GBytes  15.8 Gbits/sec
[ 7]  3.00-4.00    sec   1.71 GBytes  14.7 Gbits/sec
[ 7]  4.00-5.00    sec   1.58 GBytes  13.6 Gbits/sec
[ 7]  5.00-6.00    sec   1.88 GBytes  16.1 Gbits/sec
[ 7]  6.00-7.00    sec   1.88 GBytes  16.2 Gbits/sec
[ 7]  7.00-8.00    sec   1.86 GBytes  16.0 Gbits/sec
[ 7]  8.00-9.00    sec   1.89 GBytes  16.2 Gbits/sec
[ 7]  9.00-10.00   sec   1.90 GBytes  16.3 Gbits/sec
-----
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-10.00   sec   18.1 GBytes  15.6 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-vm:/home/mininet#
```

Рис. 7: Остановка iPerf3



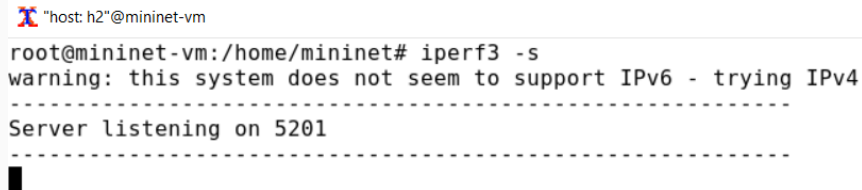
A terminal window titled "host: h1"@mininet-vm. The window contains the following text:

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

Рис. 8: Изменение пропускной способности хоста h1

```
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



A terminal window titled "host: h2"@mininet-vm. The prompt is root@mininet-vm:/home/mininet#. The command iperf3 -s has been entered. The output shows a warning about IPv6 support and that the server is listening on port 5201. The window has standard Linux terminal window controls (minimize, maximize, close) in the top right corner.

```
"host: h2"@mininet-vm
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

```
"host: h1"@mininet-vm
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 35608 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   8.86 MBytes
[ 7]  1.00-2.00    sec   1.11 GBytes  9.56 Gbits/sec    0   8.86 MBytes
[ 7]  2.00-3.00    sec   1.11 GBytes  9.58 Gbits/sec    0   8.86 MBytes
[ 7]  3.00-4.00    sec   1.11 GBytes  9.56 Gbits/sec    0   8.86 MBytes
[ 7]  4.00-5.00    sec   1.11 GBytes  9.56 Gbits/sec    0   8.86 MBytes
[ 7]  5.00-6.00    sec   1.11 GBytes  9.57 Gbits/sec    0  12.5 MBytes
[ 7]  6.00-7.00    sec  1005 MBytes  8.43 Gbits/sec    0  12.5 MBytes
[ 7]  7.00-8.00    sec    672 MBytes  5.64 Gbits/sec    0  12.5 MBytes
[ 7]  8.00-9.00    sec   1.11 GBytes  9.56 Gbits/sec    0  12.5 MBytes
[ 7]  9.00-10.00   sec   1.11 GBytes  9.56 Gbits/sec    0  12.5 MBytes
- - - - -
[ ID] Interval           Transfer     Bitrate      Retr
[ 7]  0.00-10.00    sec   10.6 GBytes  9.07 Gbits/sec    9
[ 7]  0.00-10.00    sec   10.5 GBytes  9.06 Gbits/sec    0
                                     sender
                                     receiver

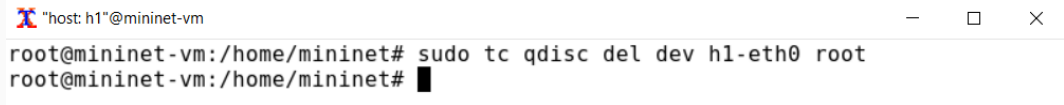
iperf Done.
root@mininet-vm:/home/mininet#
```

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

```
"host: h2"@mininet-vm
Server listening on 5201
-----
Accepted connection from 10.0.0.1, port 35606
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 35608
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-1.00    sec   1.12 GBytes  9.60 Gbits/sec
[ 7]  1.00-2.00    sec   1.11 GBytes  9.56 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  9.57 Gbits/sec
[ 7]  5.00-6.00    sec   1.11 GBytes  9.56 Gbits/sec
[ 7]  6.00-7.00    sec    990 MBytes  8.29 Gbits/sec
[ 7]  7.00-8.00    sec    688 MBytes  5.78 Gbits/sec
[ 7]  8.00-9.00    sec   1.11 GBytes  9.56 Gbits/sec
[ 7]  9.00-10.00   sec   1.11 GBytes  9.56 Gbits/sec
[ 7] 10.00-10.00   sec    128 KBytes   233 Mbits/sec
-----
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-10.00   sec   10.5 GBytes  9.06 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-vm:/home/mininet#
```

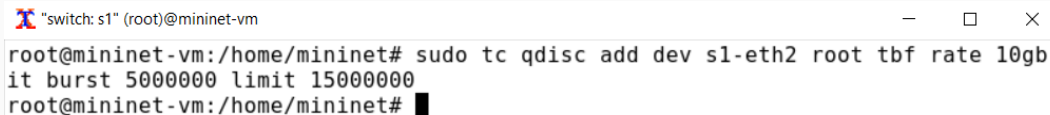
receiver

Рис. 12: Остановка iPerf3



```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root
root@mininet-vm:/home/mininet#
```

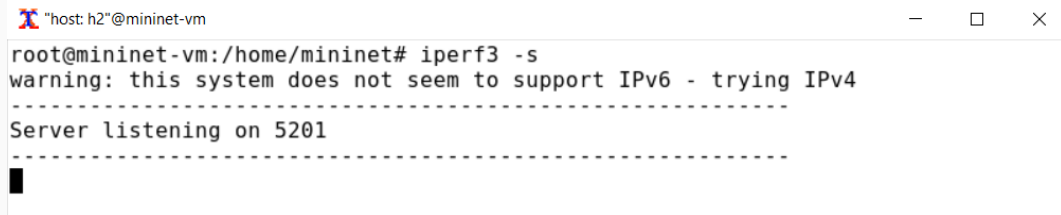
Рис. 13: Удаление модифицированной конфигурации на хосте h1



A terminal window titled "switch: s1" (root)@mininet-vm. The window contains the following text:

```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 root tbf rate 10gb  
it burst 5000000 limit 15000000  
root@mininet-vm:/home/mininet#
```

Рис. 14: Применение правила ограничения скорости tbf



```
"host: h2"@mininet-vm
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

Интерактивные эксперименты

```
"host: h1"@mininet-vm
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 35612 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    0   3.23 MBytes
[ 7]  1.00-2.00      sec   1.11 GBytes  9.56 Gbits/sec    0   3.74 MBytes
[ 7]  2.00-3.00      sec   1.11 GBytes  9.57 Gbits/sec    0   3.74 MBytes
[ 7]  3.00-4.00      sec   1.11 GBytes  9.56 Gbits/sec    0   3.74 MBytes
[ 7]  4.00-5.00      sec   1.11 GBytes  9.57 Gbits/sec    0   3.94 MBytes
[ 7]  5.00-6.00      sec   1.11 GBytes  9.56 Gbits/sec    0   3.94 MBytes
[ 7]  6.00-7.00      sec   1.11 GBytes  9.56 Gbits/sec    0   4.14 MBytes
[ 7]  7.00-8.00      sec   1.08 GBytes  9.28 Gbits/sec    0   6.22 MBytes
[ 7]  8.00-9.00      sec    869 MBytes  7.29 Gbits/sec    0   6.67 MBytes
[ 7]  9.00-10.00     sec   1.11 GBytes  9.56 Gbits/sec    0   6.67 MBytes
- - - - -
[ ID] Interval           Transfer     Bitrate      Retr
[ 7]  0.00-10.00     sec   10.9 GBytes  9.32 Gbits/sec    0
[ 7]  0.00-10.01     sec   10.8 GBytes  9.31 Gbits/sec
sender
receiver

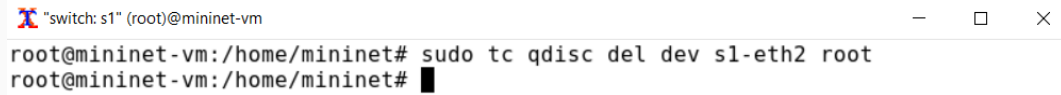
iperf Done.
root@mininet-vm:/home/mininet#
```

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

```
"host: h2"@mininet-vm
Server listening on 5201
-----
Accepted connection from 10.0.0.1, port 35610
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 35612
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-1.00      sec  1.12 GBytes  9.58 Gbits/sec
[ 7]  1.00-2.00      sec  1.11 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  9.57 Gbits/sec
[ 7]  4.00-5.00      sec  1.11 GBytes  9.56 Gbits/sec
[ 7]  5.00-6.00      sec  1.11 GBytes  9.57 Gbits/sec
[ 7]  6.00-7.00      sec  1.11 GBytes  9.56 Gbits/sec
[ 7]  7.00-8.00      sec  1.08 GBytes  9.27 Gbits/sec
[ 7]  8.00-9.00      sec   869 MBytes  7.29 Gbits/sec
[ 7]  9.00-10.00     sec  1.11 GBytes  9.57 Gbits/sec
[ 7] 10.00-10.01     sec   256 KBytes   319 Mbits/sec
-----
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-10.01     sec  10.8 GBytes  9.31 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-vm:/home/mininet#
```

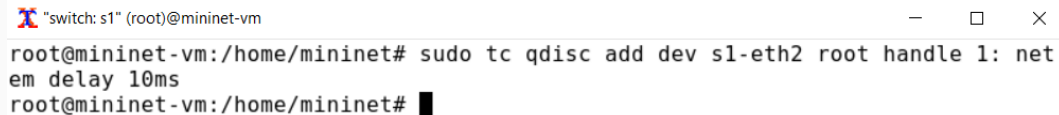
receiver

Рис. 17: Остановка iPerf3



```
"switch: s1" (root)@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc del dev s1-eth2 root  
root@mininet-vm:/home/mininet#
```


Рис. 18: Удаление модифицированной конфигурации на коммутаторе s1



A terminal window titled '"switch: s1" (root)@mininet-vm' with standard window controls. The terminal shows a root user at the mininet-vm prompt, executing the command 'sudo tc qdisc add dev s1-eth2 root handle 1: netem delay 10ms'. The command is entered on two lines, and the prompt returns after execution.

```
"switch: s1" (root)@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 root handle 1: net  
em delay 10ms  
root@mininet-vm:/home/mininet#
```

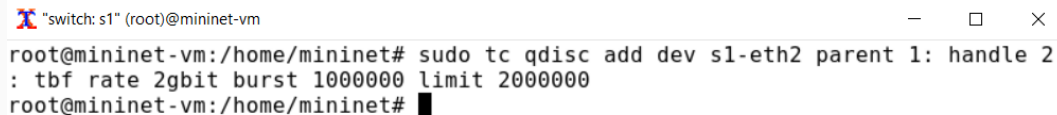
Рис. 19: Объединение NETEM и TBF

 "host: h1"@mininet-vm

```
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=11.5 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=11.3 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=10.7 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 10.717/11.151/11.546/0.318 ms
root@mininet-vm:/home/mininet#
```

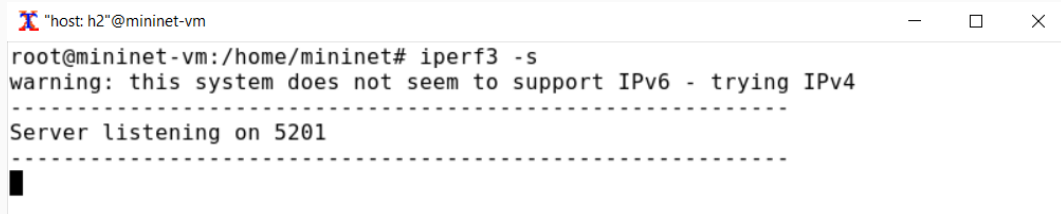
Рис. 20: Проверка задержки



A terminal window titled "switch: s1" (root)@mininet-vm. The window contains the following text:

```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev s1-eth2 parent 1: handle 2
: tbf rate 2gbit burst 1000000 limit 2000000
root@mininet-vm:/home/mininet#
```

Рис. 21: Добавление второго правила на коммутаторе s1



```
"host: h2"@mininet-vm
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

```
"host: h1"@mininet-vm
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 35616 connected to 10.0.0.2 port 5201
[ ID] Interval           Transfer     Bitrate      Retr   Cwnd
[ 7]  0.00-1.00    sec      214 MBytes  1.79 Gbits/sec  855    2.71 MBytes
[ 7]  1.00-2.00    sec      229 MBytes  1.92 Gbits/sec   0     2.86 MBytes
[ 7]  2.00-3.00    sec      228 MBytes  1.91 Gbits/sec   0     2.97 MBytes
[ 7]  3.00-4.00    sec      228 MBytes  1.91 Gbits/sec   0     3.06 MBytes
[ 7]  4.00-5.00    sec      218 MBytes  1.82 Gbits/sec  450     2.20 MBytes
[ 7]  5.00-6.00    sec      214 MBytes  1.79 Gbits/sec   0     2.33 MBytes
[ 7]  6.00-7.00    sec      225 MBytes  1.89 Gbits/sec   0     2.43 MBytes
[ 7]  7.00-8.00    sec      228 MBytes  1.91 Gbits/sec   0     2.51 MBytes
[ 7]  8.00-9.00    sec      229 MBytes  1.92 Gbits/sec   0     2.56 MBytes
[ 7]  9.00-10.00   sec      228 MBytes  1.91 Gbits/sec   0     2.60 MBytes
- - - - -
[ ID] Interval           Transfer     Bitrate      Retr
[ 7]  0.00-10.00   sec      2.19 GBytes  1.88 Gbits/sec  1305
[ 7]  0.00-10.01   sec      2.18 GBytes  1.87 Gbits/sec
sender
receiver

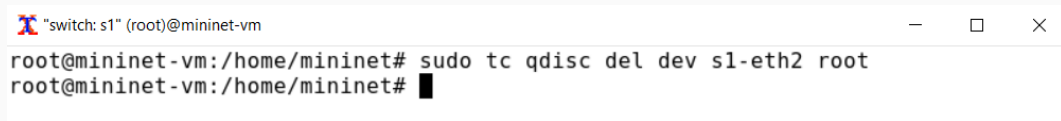
iperf Done.
root@mininet-vm:/home/mininet#
```

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

```
"host: h2"@mininet-vm
Server listening on 5201
-----
Accepted connection from 10.0.0.1, port 35614
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 35616
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-1.00    sec    204 MBytes  1.71 Gbits/sec
[ 7]  1.00-2.00    sec    228 MBytes  1.91 Gbits/sec
[ 7]  2.00-3.00    sec    228 MBytes  1.91 Gbits/sec
[ 7]  3.00-4.00    sec    228 MBytes  1.91 Gbits/sec
[ 7]  4.00-5.00    sec    216 MBytes  1.81 Gbits/sec
[ 7]  5.00-6.00    sec    215 MBytes  1.80 Gbits/sec
[ 7]  6.00-7.00    sec    225 MBytes  1.89 Gbits/sec
[ 7]  7.00-8.00    sec    228 MBytes  1.91 Gbits/sec
[ 7]  8.00-9.00    sec    228 MBytes  1.91 Gbits/sec
[ 7]  9.00-10.00   sec    228 MBytes  1.91 Gbits/sec
[ 7] 10.00-10.01   sec    2.42 MBytes  1.83 Gbits/sec
-----
[ ID] Interval          Transfer    Bitrate
[ 7]  0.00-10.01   sec    2.18 GBytes  1.87 Gbits/sec
-----
Server listening on 5201
-----
^Ciperf3: interrupt - the server has terminated
root@mininet-vm:/home/mininet#
```

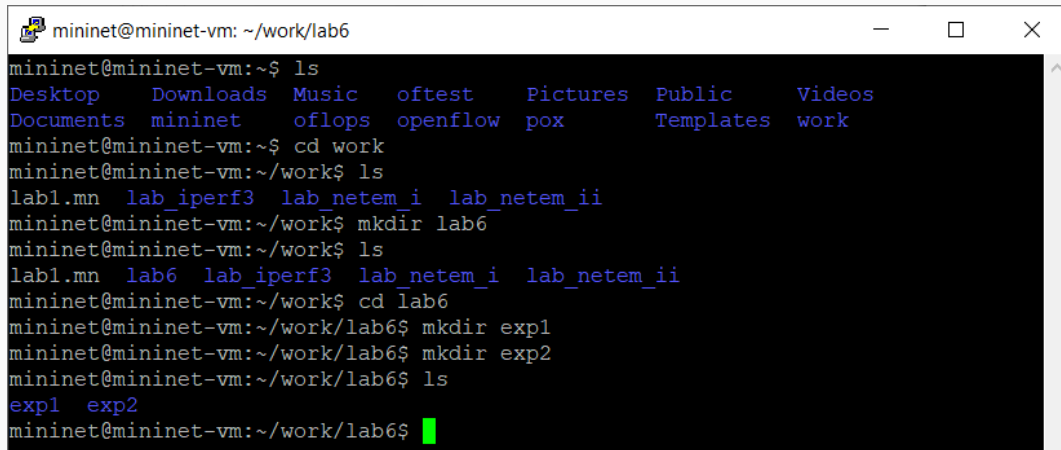
receiver

Рис. 24: Остановка iPerf3



```
"switch: s1" (root)@mininet-vm  
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

A terminal window titled 'mininet@mininet-vm: ~/work/lab6' with standard window controls. The terminal shows a sequence of commands to create a directory structure. First, 'ls' is run in the home directory, showing folders like Desktop, Downloads, Music, oftest, Pictures, Public, Videos, Documents, mininet, oflops, openflow, pox, Templates, and work. Then, 'cd work' is executed. Another 'ls' is run in the work directory, showing lab1.mn, lab_iperf3, lab_netem_i, and lab_netem_ii. Then, 'mkdir lab6' is run. Another 'ls' is run, now showing lab6 along with the previous folders. Then, 'cd lab6' is executed. Finally, 'mkdir exp1' and 'mkdir exp2' are run in sequence. A final 'ls' is run, showing 'exp1' and 'exp2'. The prompt ends with a green cursor.

```
mininet@mininet-vm: ~/work/lab6
mininet@mininet-vm:~$ ls
Desktop    Downloads  Music     oftest    Pictures  Public    Videos
Documents  mininet    oflops    openflow  pox       Templates work
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

Воспроизводимые эксперименты



```
mininet@mininet-vm: ~/work/lab6/exp1
/home/mininet/exp1.py [----] 50 L: [ 17+ 0 17/ 59] *(318 /1560b) 10 0x00A [*][X]
"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 switches\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()

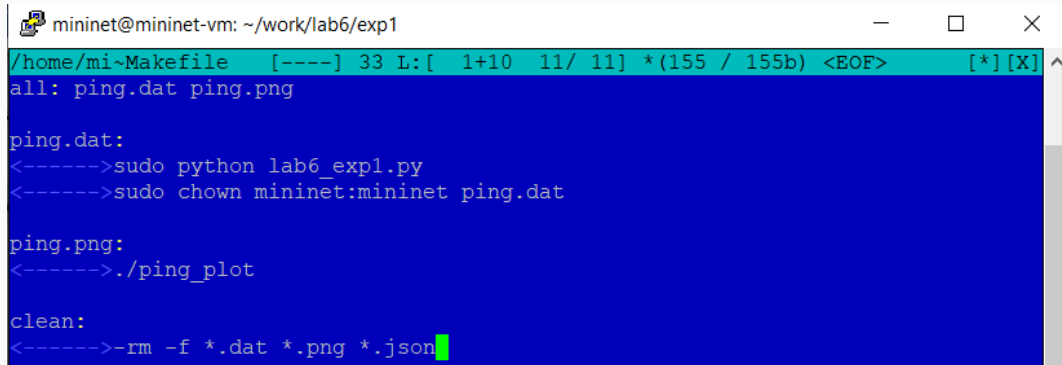
info( "**** Set delay\n" )
s1.cmdPrint( 'tc qdisc add dev s1-eth2 root handle 1: netem delay 10ms' )
s2.cmdPrint( 'tc qdisc add dev s1-eth2 parent 1: handle 2: tbf rate 2gbit bu

info( "**** Traffic generation\n" )
h2.cmdPrint( 'iperf3 -s -B -i' )
time.sleep(10) # Wait 10 seconds
h1.cmdPrint( 'iperf3 -c', h2.IP(), '-J > iperf_result.json' )
h1.cmdPrint( 'ping -c 100', h2.IP(), '{ grep "time" | awk \"{print $5, $1}\"' )

info( "**** Stopping network" )
net.stop()

if __name__ == '__main__':
    setLogLevel( 'info' )
    emptyNet()
```

Рис. 27: Написание 1 скрипта



The screenshot shows a terminal window titled "mininet@mininet-vm: ~/work/lab6/exp1". The terminal content displays a Makefile and its execution. The Makefile defines targets for "all", "ping.dat", "ping.png", and "clean". The "all" target depends on "ping.dat" and "ping.png". The "ping.dat" target runs "sudo python lab6_exp1.py" and "sudo chown mininet:mininet ping.dat". The "ping.png" target runs "./ping_plot". The "clean" target runs "rm -f *.dat *.png *.json". The terminal output shows the execution of these commands, with the "clean" command being the last one shown.

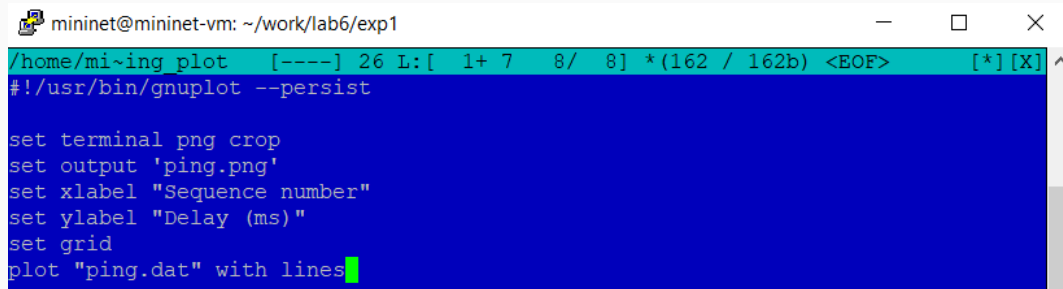
```
mininet@mininet-vm: ~/work/lab6/exp1
/home/mininet@mininet-vm: ~/work/lab6/exp1
all: ping.dat ping.png

ping.dat:
<----->sudo python lab6_exp1.py
<----->sudo chown mininet:mininet ping.dat

ping.png:
<----->./ping_plot

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

Рис. 28: Написание 2 скрипта

A terminal window with a title bar showing 'mininet@mininet-vm: ~/work/lab6/exp1'. The terminal has a blue background and white text. The first line is a prompt and command: '/home/mininet@mininet-vm:~/work/lab6/exp1\$ gnuplot --persist'. The subsequent lines are gnuplot commands: 'set terminal png crop', 'set output 'ping.png'', 'set xlabel "Sequence number"', 'set ylabel "Delay (ms)"', 'set grid', and 'plot "ping.dat" with lines'. The cursor is at the end of the last line.

```
mininet@mininet-vm: ~/work/lab6/exp1
/home/mininet@mininet-vm:~/work/lab6/exp1$ 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: Написание 3 скрипта

Воспроизводимые эксперименты

```
mininet@mininet-vm: ~/work/lab6/exp1
mininet@mininet-vm:~/work/lab6/exp1$ make
sudo python lab6 expl.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
*** 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 2000000',)
*** Traffic generation
*** h2 : ('iperf3 -s -D -l',)
*** h1 : ('iperf3 -c', '10.0.0.2', '-J > iperf_result.json')
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'{print $5, $7}\'' | sed -e \'s/time=//g\' -e \'s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 3 links
...
*** Stopping 2 switches
s1 s2
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab6/exp1$ ls
iperf_result.json lab6 expl.py Makefile ping.dat ping_plot ping.png
mininet@mininet-vm:~/work/lab6/exp1$
```

Рис. 30: Выполнение скриптов

Воспроизводимые эксперименты

```
mininet@mininet-vm: ~/work/lab6/exp1
/home/mininet/work/lab6/exp1.py [-M--] 92 1: [ 12+32 44/ 56] *(1029/14696) 39 0x027
from mininet.log import setLogLevel, info
import time

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

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

    info( '*** Adding controllers\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 switches\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 h1-eth0 root tbf rate 1000000 limit 1500000 ' )

    info( '*** Traffic generation\n' )
    h2.cmdPrint( 'iperf3 -s -B -l1' )
    time.sleep(10) # Wait 10 seconds
    h1.cmdPrint( 'iperf3 -c', h2.IP(), '-d > iperf_result.json' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "time=" | awk '{print $5, $7}' | sed -e 's/time=//g' -e 's/comp_seq//g' > ping.dat' )

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

if __name__ == '__main__':
    setLogLevel('info')
    emptyNet()
```

Рис. 31: Изменение параметров

```
mininet@mininet-vm: ~/work/lab6/exp1
mininet@mininet-vm:~/work/lab6/exp1$ make
sudo python lab6_exp1.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
*** s1 : ('tc qdisc add dev h1-eth0 root tbf rate 10gbit burst 5000000 limit 15000000',)
Cannot find device "h1-eth0"
*** 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, $7)\' | sed -e \'s/time=//g\' -e \'s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 3 links
...
*** Stopping 2 switches
s1 s2
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab6/exp1$ ls
iperf_result.json lab6_exp1.py Makefile ping.dat ping_plot ping.png
mininet@mininet-vm:~/work/lab6/exp1$
```

Рис. 32: Выполнение скриптов

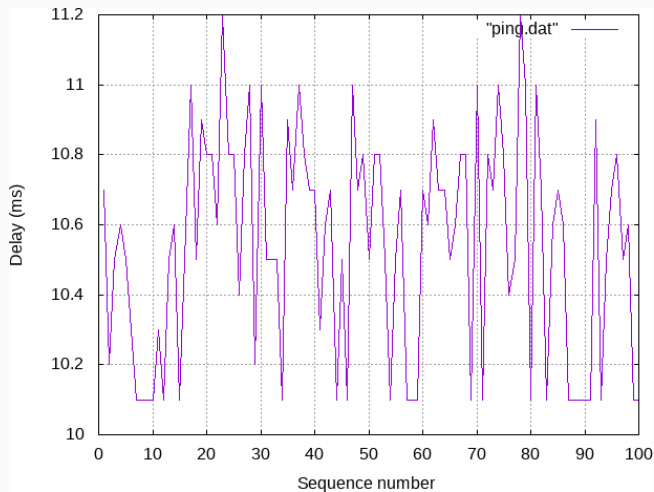


Рис. 33: График №1

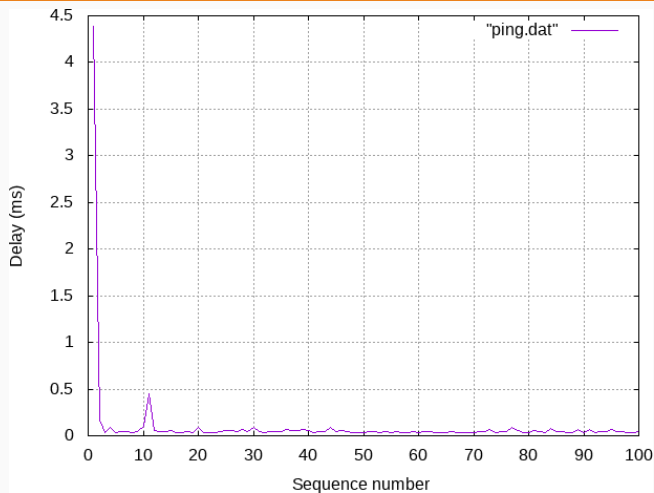


Рис. 34: График №2

Вывод

- 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.

Список литературы. Библиография

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