

Лабораторная работа №4

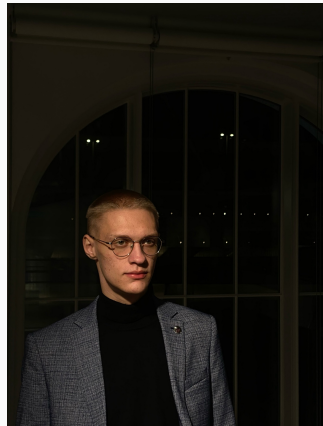
Моделирование сетей передачи данных

Махорин И. С.

2024

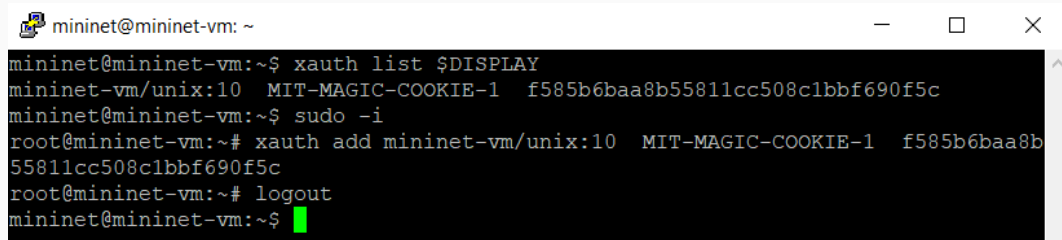
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- Познакомиться с NETEM — инструментом для тестирования производительности приложений в виртуальной сети, а также получить навыки проведения интерактивного и воспроизводимого экспериментов по измерению задержки и её дрожания (jitter) в моделируемой сети в среде Mininet.

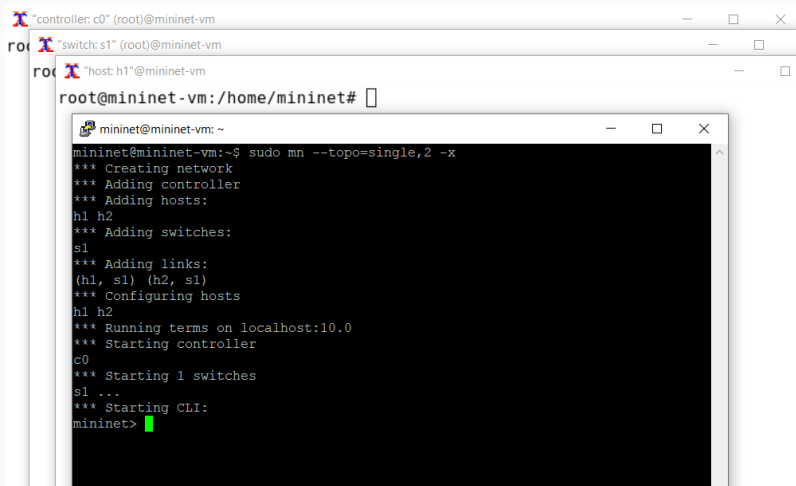
Выполнение лабораторной работы



```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ xauth list $DISPLAY  
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  f585b6baa8b55811cc508c1bbf690f5c  
mininet@mininet-vm:~$ sudo -i  
root@mininet-vm:~# xauth add mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  f585b6baa8b55811cc508c1bbf690f5c  
root@mininet-vm:~# logout  
mininet@mininet-vm:~$
```

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

Запуск лабораторной топологии

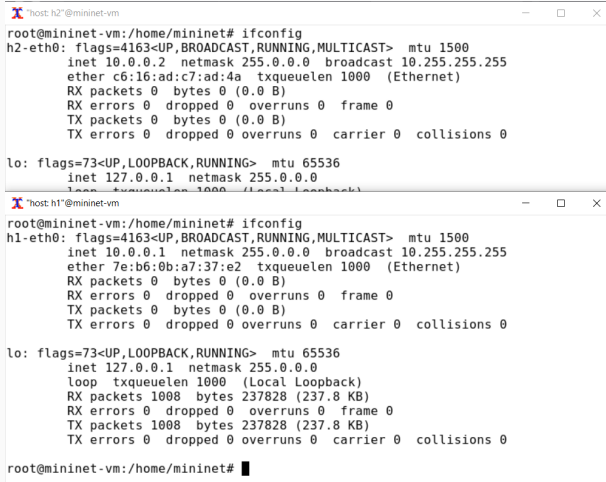


The image shows a series of overlapping terminal windows from the Mininet environment. The top window is titled '"controller: c0" (root)@mininet-vm'. Below it is '"switch: s1" (root)@mininet-vm'. The third window is titled '"host: h1" (root)@mininet-vm'. The bottom-most window is titled 'root@mininet-vm:/home/mininet#' and contains the following text:

```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ sudo mn --topo=single,2 -x  
*** Creating network  
*** Adding controller  
*** Adding hosts:  
h1 h2  
*** Adding switches:  
s1  
*** Adding links:  
(h1, s1) (h2, s1)  
*** Configuring hosts  
h1 h2  
*** Running terms on localhost:10.0  
*** Starting controller  
c0  
*** Starting 1 switches  
s1 ...  
*** Starting CLI:  
mininet>
```

Рис. 2: Создание простейшей топологии

Запуск лабораторной топологии



```

"host: h2"@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 c6:16:ad:c7:ad:4a 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 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

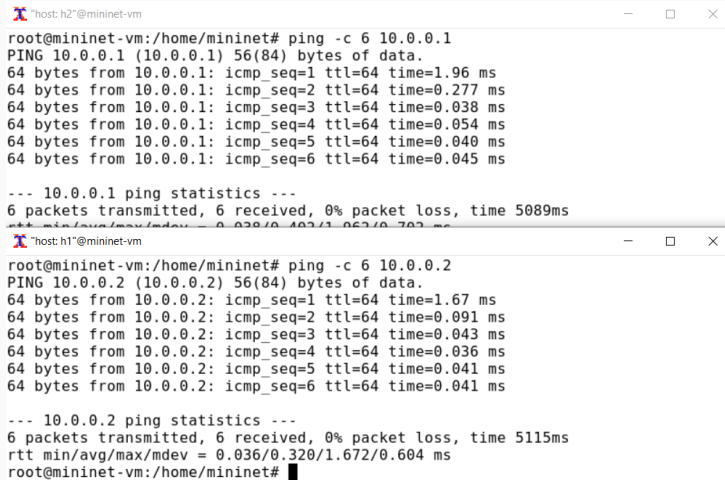
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ifconfig
h1-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
        inet 10.0.0.1 netmask 255.0.0.0 broadcast 10.255.255.255
        ether 7e:b6:0b:a7:37:e2 txqueuelen 1000 (Ethernet)
        RX packets 0 bytes 0 (0.0 B)
        RX errors 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 1008 bytes 237828 (237.8 KB)
        RX errors 0 dropped 0 overruns 0 frame 0
        TX packets 1008 bytes 237828 (237.8 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

Запуск лабораторной топологии



The image shows two terminal windows from a Mininet VM. The top window is titled "host: h2" and shows a ping command from root@mininet-vm to 10.0.0.1. The output shows 6 successful pings with varying times, followed by statistics: 6 packets transmitted, 6 received, 0% packet loss, time 5089ms. The bottom window is titled "host: h1" and shows a ping command from root@mininet-vm to 10.0.0.2. The output shows 6 successful pings with varying times, followed by statistics: 6 packets transmitted, 6 received, 0% packet loss, time 5115ms.

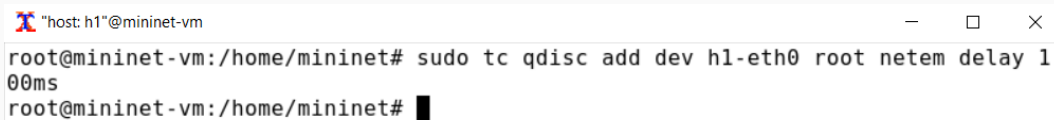
```
root@mininet-vm:/home/mininet# ping -c 6 10.0.0.1
PING 10.0.0.1 (10.0.0.1) 56(84) bytes of data.
64 bytes from 10.0.0.1: icmp_seq=1 ttl=64 time=1.96 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.277 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.038 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.054 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.040 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.045 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5089ms
rtt min/avg/max/mdev = 0.038/0.403/1.062/0.702 ms

root@mininet-vm:/home/mininet# ping -c 6 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=1.67 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.091 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.043 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.036 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.041 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.041 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5115ms
rtt min/avg/max/mdev = 0.036/0.320/1.672/0.604 ms
root@mininet-vm:/home/mininet#
```

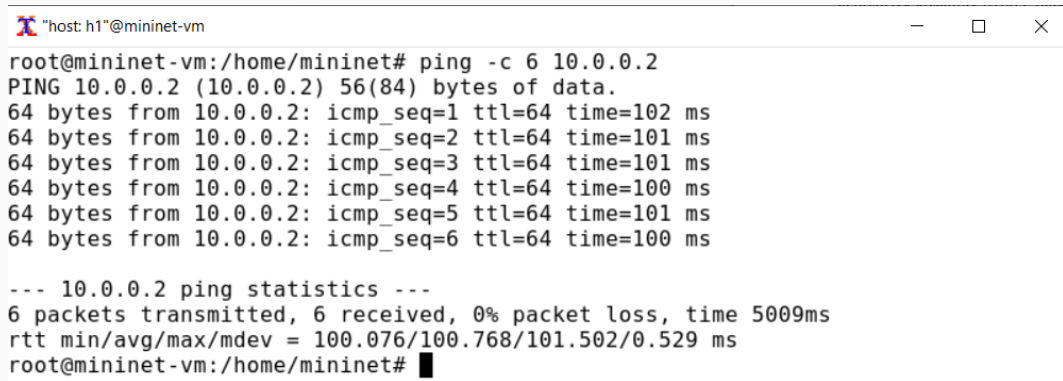
Рис. 4: Проверка подключения между хостами h1 и h2



A terminal window titled "host: h1" @mininet-vm. The prompt is root@mininet-vm:/home/mininet#. The command sudo tc qdisc add dev h1-eth0 root netem delay 100ms has been entered and executed. The prompt is now root@mininet-vm:/home/mininet# followed by a cursor.

```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 100ms
root@mininet-vm:/home/mininet#
```

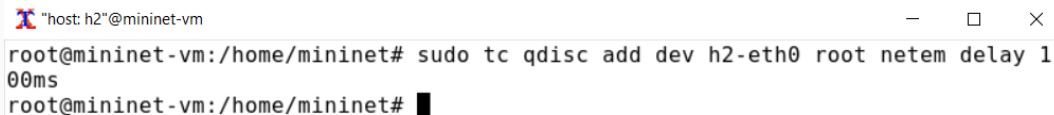
Рис. 5: Добавление задержки в 100 мс к выходному интерфейсу на хосте h1



```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ping -c 6 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=102 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=100 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=100 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5009ms
rtt min/avg/max/mdev = 100.076/100.768/101.502/0.529 ms
root@mininet-vm:/home/mininet#
```

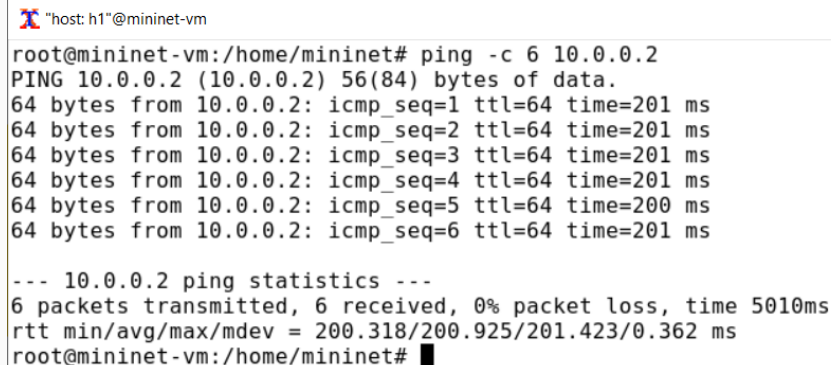
Рис. 6: Проверка



A terminal window titled "host: h2"@mininet-vm. The prompt is root@mininet-vm:/home/mininet#. The command entered is sudo tc qdisc add dev h2-eth0 root netem delay 100ms. The prompt returns to root@mininet-vm:/home/mininet# followed by a black cursor block.

```
"host: h2"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h2-eth0 root netem delay 100ms
root@mininet-vm:/home/mininet#
```

Рис. 7: Добавление задержки в 100 мс к выходному интерфейсу на хосте h2

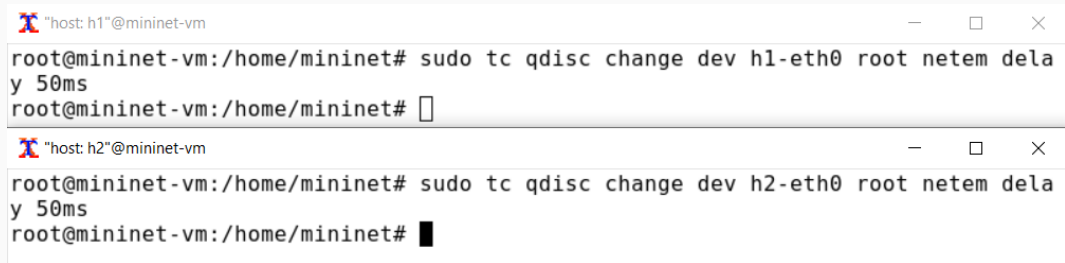


A terminal window titled "host: h1"@mininet-vm. The terminal shows a root user at mininet-vm executing a ping command to 10.0.0.2. The output displays six successful ping responses with 64 bytes of data, TTL of 64, and response times around 200 ms. It also shows the ping statistics: 6 packets transmitted, 6 received, 0% packet loss, and a total time of 5010ms. The round-trip time (rtt) statistics are also provided.

```
root@mininet-vm:/home/mininet# ping -c 6 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=201 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=201 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=201 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=201 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=200 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=201 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5010ms
rtt min/avg/max/mdev = 200.318/200.925/201.423/0.362 ms
root@mininet-vm:/home/mininet#
```

Рис. 8: Проверка

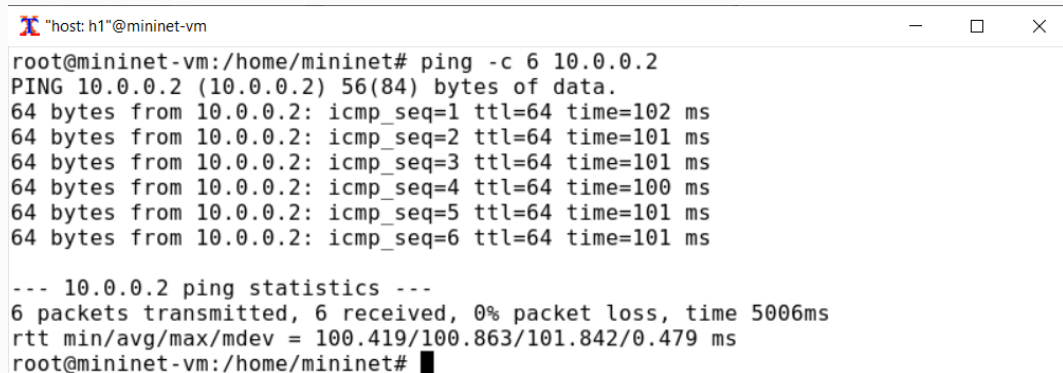


The image displays two terminal windows. The top window, titled '"host: h1"@mininet-vm', shows a root user at the mininet-vm prompt. The user enters the command 'sudo tc qdisc change dev h1-eth0 root netem delay 50ms'. The bottom window, titled '"host: h2"@mininet-vm', shows a similar root user at the mininet-vm prompt, also entering the command 'sudo tc qdisc change dev h2-eth0 root netem delay 50ms'. Both windows show the command being executed successfully, with a cursor visible on the line following the command.

```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc change dev h1-eth0 root netem delay 50ms
root@mininet-vm:/home/mininet#

"host: h2"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc change dev h2-eth0 root netem delay 50ms
root@mininet-vm:/home/mininet#
```

Рис. 9: Изменение задержки со 100 мс до 50 мс

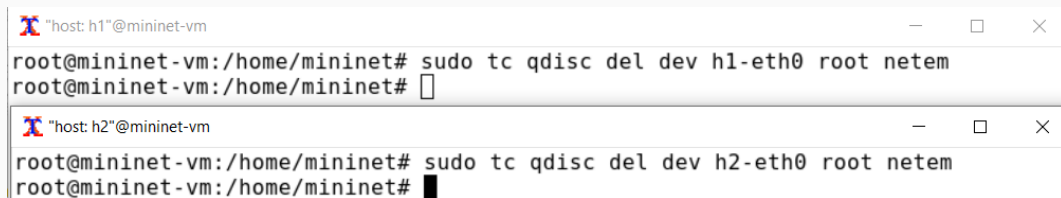


```

X "host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ping -c 6 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=102 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=100 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=101 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5006ms
rtt min/avg/max/mdev = 100.419/100.863/101.842/0.479 ms
root@mininet-vm:/home/mininet#
```

Рис. 10: Проверка

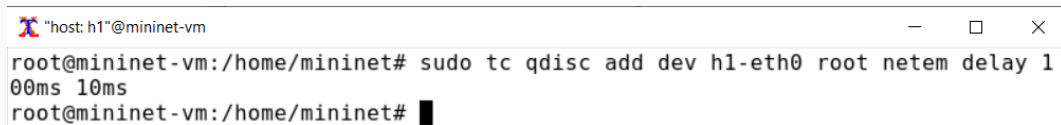


The image shows two terminal windows. The top window is titled '"host: h1"@mininet-vm' and contains the command `sudo tc qdisc del dev h1-eth0 root netem` followed by a prompt. The bottom window is titled '"host: h2"@mininet-vm' and contains the command `sudo tc qdisc del dev h2-eth0 root netem` followed by a prompt. Both windows have standard window controls (minimize, maximize, close) in the top right corner.

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

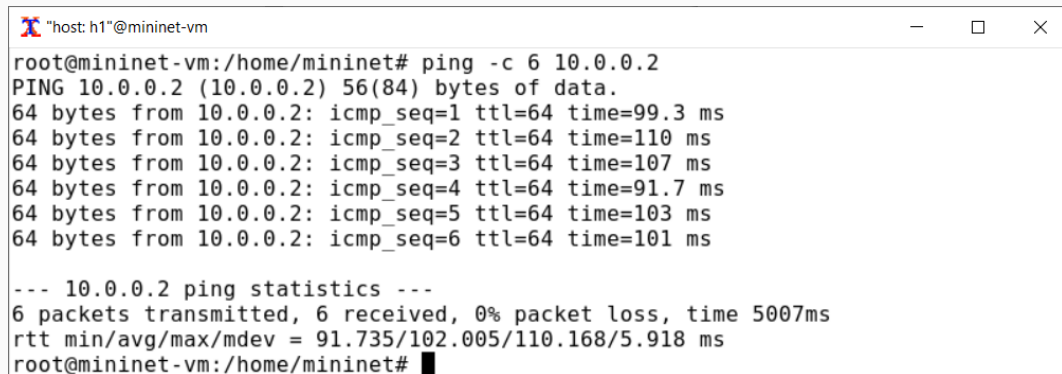
"host: h2"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h2-eth0 root netem
root@mininet-vm:/home/mininet#
```

Рис. 11: Восстановление конфигураций по умолчанию



```
"host: h1"@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 100ms 10ms  
root@mininet-vm:/home/mininet#
```

Рис. 12: Добавление на узле h1 задержки в 100 мс со случайным отклонением 10 мс

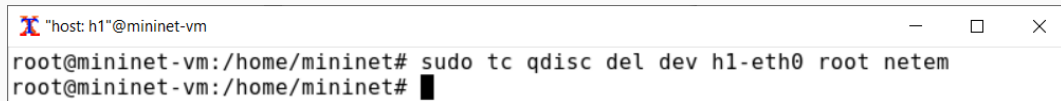


```

X "host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ping -c 6 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=99.3 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=110 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=107 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=91.7 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=103 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=101 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5007ms
rtt min/avg/max/mdev = 91.735/102.005/110.168/5.918 ms
root@mininet-vm:/home/mininet#
```

Рис. 13: Проверка



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

Рис. 14: Восстановление конфигурации интерфейса по умолчанию

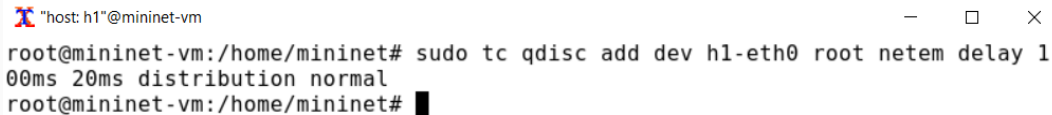
```
X "host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ping -c 20 10.0.0.2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=91.5 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=105 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=92.2 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=91.5 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=94.0 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=93.7 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=98.6 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=91.2 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=93.8 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=106 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=103 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=99.0 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=98.9 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=110 ms
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=99.6 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=104 ms

--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, 0% packet loss, time 19036ms
rtt min/avg/max/mdev = 91.248/98.926/110.048/5.324 ms
root@mininet-vm:/home/mininet# █
```

Рис. 15: Проверка

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

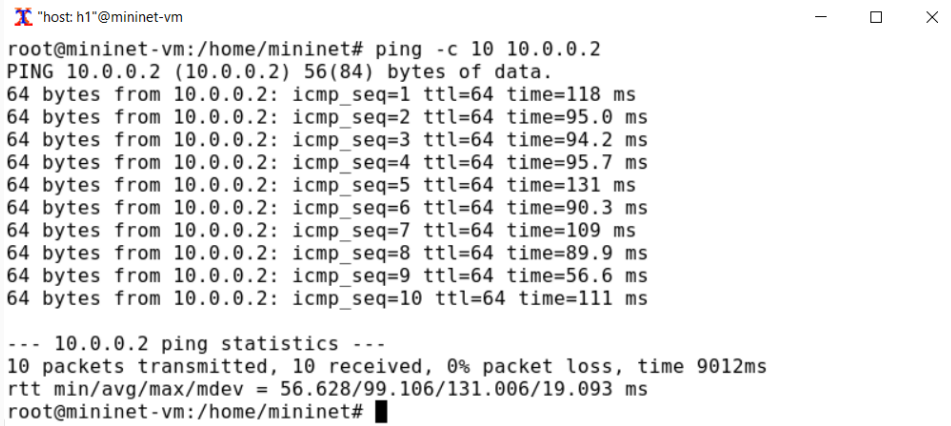
Рис. 16: Восстановление конфигурации интерфейса по умолчанию



A terminal window titled "host: h1"@mininet-vm. The prompt is root@mininet-vm:/home/mininet#. The command entered is sudo tc qdisc add dev h1-eth0 root netem delay 100ms 20ms distribution normal. The prompt returns to root@mininet-vm:/home/mininet#.

```
"host: h1"@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 100ms 20ms distribution normal  
root@mininet-vm:/home/mininet#
```

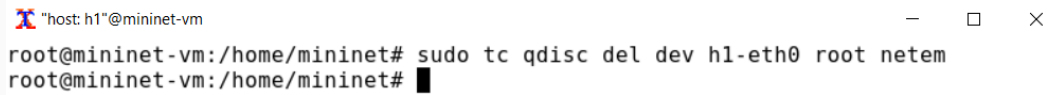
Рис. 17: Настройка нормального распределения задержки на узле h1 в эмулируемой сети



```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# ping -c 10 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=118 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=95.0 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=94.2 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=95.7 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=131 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=90.3 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=109 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=89.9 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=56.6 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=111 ms

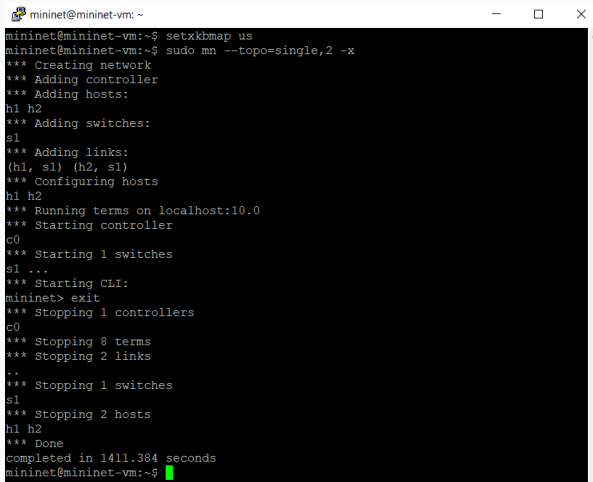
--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9012ms
rtt min/avg/max/mdev = 56.628/99.106/131.006/19.093 ms
root@mininet-vm:/home/mininet#
```

Рис. 18: Проверка



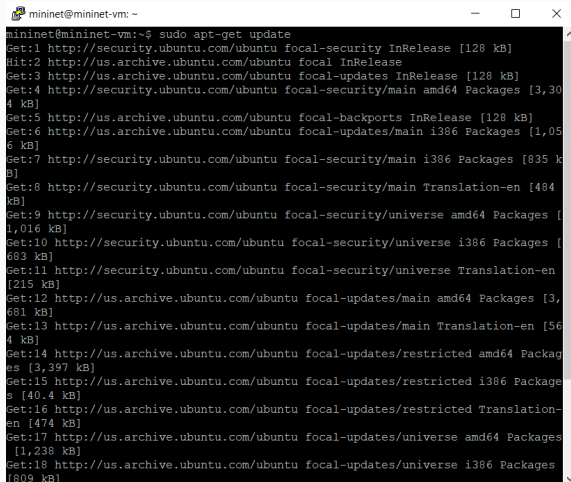
```
"host: h1"@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem  
root@mininet-vm:/home/mininet#
```

Рис. 19: Восстановление конфигурации интерфейса по умолчанию



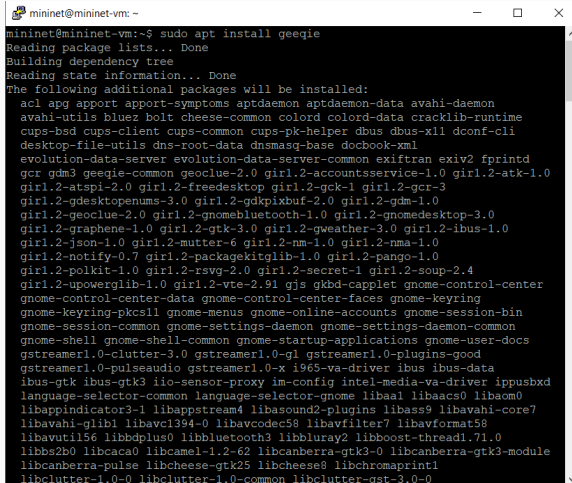
```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ setxkbmap us  
mininet@mininet-vm:~$ sudo mn --topo=single,2 -x  
*** Creating network  
*** Adding controller  
*** Adding hosts:  
h1 h2  
*** Adding switches:  
s1  
*** Adding links:  
(h1, s1) (h2, s1)  
*** Configuring hosts  
h1 h2  
*** Running terms on localhost:10.0  
*** Starting controller  
c0  
*** Starting 1 switches  
s1 ...  
*** Starting CLI:  
mininet> exit  
*** Stopping 1 controllers  
c0  
*** Stopping 8 terms  
*** Stopping 2 links  
..  
*** Stopping 1 switches  
s1  
*** Stopping 2 hosts  
h1 h2  
*** Done  
completed in 1411.384 seconds  
mininet@mininet-vm:~$
```

Рис. 20: Завершение работы mininet в интерактивном режиме



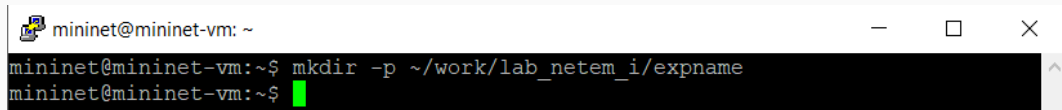
```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ sudo apt-get update  
Get:1 http://security.ubuntu.com/ubuntu focal-security InRelease [128 kB]  
Hit:2 http://us.archive.ubuntu.com/ubuntu focal InRelease  
Get:3 http://us.archive.ubuntu.com/ubuntu focal-updates InRelease [128 kB]  
Get:4 http://security.ubuntu.com/ubuntu focal-security/main amd64 Packages [3,304 kB]  
Get:5 http://us.archive.ubuntu.com/ubuntu focal-backports InRelease [128 kB]  
Get:6 http://us.archive.ubuntu.com/ubuntu focal-updates/main i386 Packages [1,056 kB]  
Get:7 http://security.ubuntu.com/ubuntu focal-security/main i386 Packages [835 kB]  
Get:8 http://security.ubuntu.com/ubuntu focal-security/main Translation-en [484 kB]  
Get:9 http://security.ubuntu.com/ubuntu focal-security/universe amd64 Packages [1,016 kB]  
Get:10 http://security.ubuntu.com/ubuntu focal-security/universe i386 Packages [683 kB]  
Get:11 http://security.ubuntu.com/ubuntu focal-security/universe Translation-en [215 kB]  
Get:12 http://us.archive.ubuntu.com/ubuntu focal-updates/main amd64 Packages [3,681 kB]  
Get:13 http://us.archive.ubuntu.com/ubuntu focal-updates/main Translation-en [564 kB]  
Get:14 http://us.archive.ubuntu.com/ubuntu focal-updates/restricted amd64 Packages [3,397 kB]  
Get:15 http://us.archive.ubuntu.com/ubuntu focal-updates/restricted i386 Packages [40.4 kB]  
Get:16 http://us.archive.ubuntu.com/ubuntu focal-updates/restricted Translation-en [474 kB]  
Get:17 http://us.archive.ubuntu.com/ubuntu focal-updates/universe amd64 Packages [1,238 kB]  
Get:18 http://us.archive.ubuntu.com/ubuntu focal-updates/universe i386 Packages [809 kB]
```

Рис. 21: Обновление репозитиев программного обеспечения на втртуальной машине



```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ sudo apt install geeqie  
Reading package lists... Done  
Building dependency tree  
Reading state information... Done  
The following additional packages will be installed:  
acl apg apport apport-symptoms aptdaemon aptdaemon-data avahi-daemon  
avahi-utils bluez bolt cheese-common colord colord-data cracklib-runtime  
cups-bsd cups-client cups-common cups-pk-helper dbus dbus-x11 dconf-cli  
desktop-file-utils dns-root-data dnsmasq-base docbook-xml  
evolution-data-server evolution-data-server-common exiftran exiv2 fprintd  
gcr gdm3 geeqie-common geoclue-2.0 gird1.2-accountsservice-1.0 gird1.2-atk-1.0  
gird1.2-atspi-2.0 gird1.2-freedesktop gird1.2-gck-1 gird1.2-gcr-3  
gird1.2-gdesktopenums-3.0 gird1.2-gdkpixbuf-2.0 gird1.2-gdm-1.0  
gird1.2-geoclue-2.0 gird1.2-gnomebluetooth-1.0 gird1.2-gnomedesktop-3.0  
gird1.2-graphene-1.0 gird1.2-gtk-3.0 gird1.2-gweather-3.0 gird1.2-ibus-1.0  
gird1.2-json-1.0 gird1.2-mutter-6 gird1.2-nm-1.0 gird1.2-nma-1.0  
gird1.2-notify-0.7 gird1.2-packagekitglib-1.0 gird1.2-pango-1.0  
gird1.2-polkit-1.0 gird1.2-rsvg-2.0 gird1.2-secret-1 gird1.2-soup-2.4  
gird1.2-upowerglib-1.0 gird1.2-vte-2.91 gjs gkbd-caplet gnome-control-center  
gnome-control-center-data gnome-control-center-faces gnome-keyring  
gnome-keyring-pkcs11 gnome-menus gnome-online-accounts gnome-session-bin  
gnome-session-common gnome-settings-daemon gnome-settings-daemon-common  
gnome-shell gnome-shell-common gnome-startup-applications gnome-user-docs  
gstreamer1.0-clutter-3.0 gstreamer1.0-gi gstreamer1.0-plugins-good  
gstreamer1.0-pulseaudio gstreamer1.0-x i965-va-driver ibus ibus-data  
ibus-gtk ibus-gtk3 iio-sensor-proxy im-config intel-media-va-driver ippusbxd  
language-selector-common language-selector-gnome libaa1 libaacs0 libaom0  
libappindicator3-1 libappstream4 libasound2-plugins libass9 libavahi-core7  
libavahi-glib1 libavc1394-0 libavcodec58 libavfilter7 libavformat58  
libavutil56 libbdplus0 libbluetooth3 libbluray2 libboost-thread1.71.0  
libbs2b0 libcaca0 libcamel-1.2-62 libcanberra-gtk3-0 libcanberra-gtk3-module  
libcanberra-pulse libcheese-gtk25 libcheese8 libchromaprint1  
libclutter-1.0-0 libclutter-1.0-common libclutter-gst-3.0-0
```

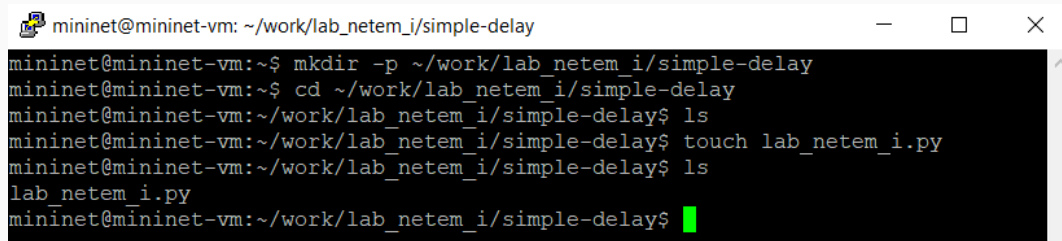
Рис. 22: Установка пакета geeqie



A terminal window titled "mininet@mininet-vm: ~" with standard window controls (minimize, maximize, close). The terminal shows the command `mkdir -p ~/work/lab_netem_i/expname` being executed. The prompt `mininet@mininet-vm:~$` is followed by a green cursor. A vertical scrollbar is visible on the right side of the terminal window.

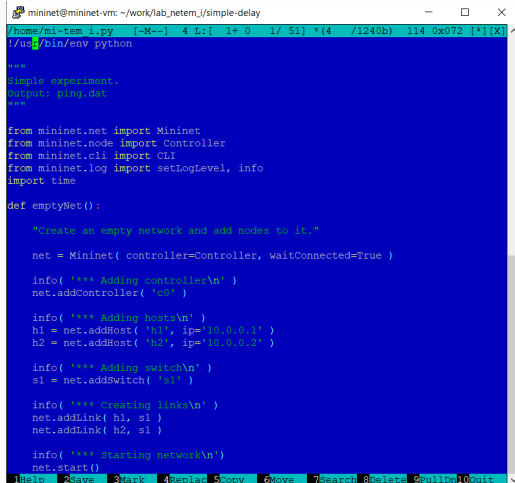
```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ mkdir -p ~/work/lab_netem_i/expname  
mininet@mininet-vm:~$
```

Рис. 23: Создание нового каталога



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~$ mkdir -p ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~$ cd ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ ls
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ touch lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ ls
lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 24: Создание каталога simple-delay



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mininet-vm: [~] 4 L: [ 1+ 0 1/ 51] *(4 /1240b) 114 0x072 [*][X] ^
! /usr/bin/env python

***
Simple experiment.
Output: ping.dat
***

from mininet.net import Mininet
from mininet.node import Controller
from mininet.cli import CLI
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 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' )

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

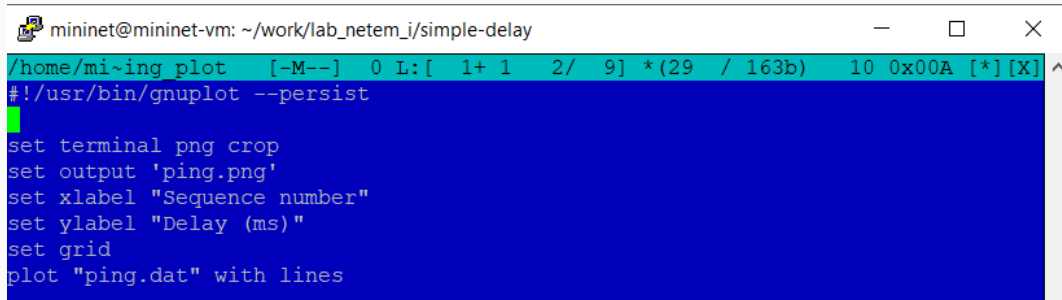
    info( '*** Starting network\n' )
    net.start()

1#Help 2$ave 3$ark 4$eplac 5$opy 6$ove 7$earch 8$elete 9$ullDn 10$uit
```

Рис. 25: Создание скрипта lab_netem_i.py для эксперимента

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ touch ping_plot  
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ ls  
lab_netem_i.py  ping_plot  
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 26: Создание файла ping_plot



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
#!/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
```

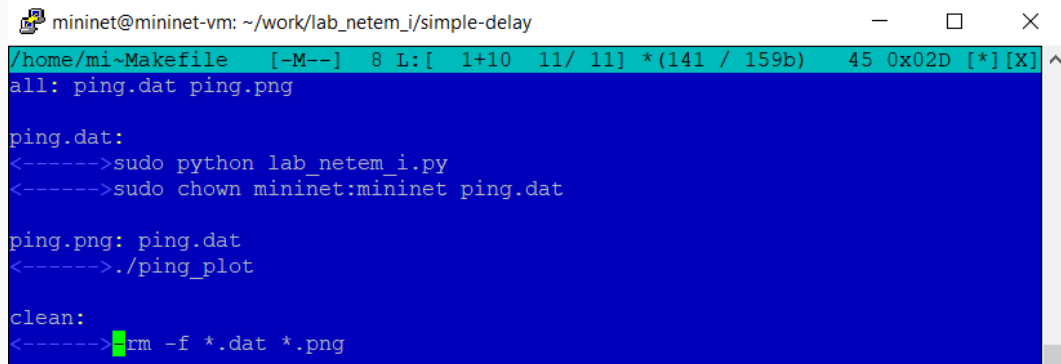
Рис. 27: Создание скрипта ping_plot для визуализации результатов эксперимента

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ chmod +x ping_plot  
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 28: Настройка прав доступа к файлу скрипта


```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ touch Makefile  
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ █
```

Рис. 29: Создание файла Makefile



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ cat Makefile
all: ping.dat ping.png

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

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

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

Рис. 30: Добавления скрипта в Makefile для управления процессом проведения эксперимента

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make
sudo python lab_netem_i.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 1 switches
s1 ...
*** Waiting for switches to connect
s1
*** Set delay
*** h1 : ('tc qdisc add dev h1-eth0 root netem delay 100ms',)
*** h2 : ('tc qdisc add dev h2-eth0 root netem delay 100ms',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'(print $5, $7)\' |
sed -e \'s/time=//g\' -e \'s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
...
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 31: Выполнение эксперимента

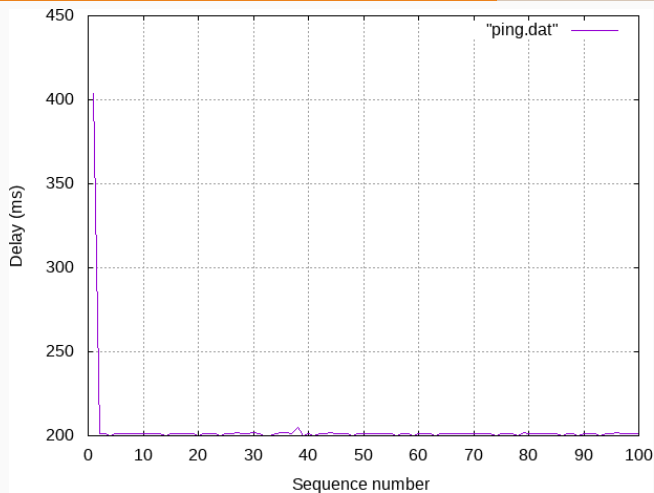
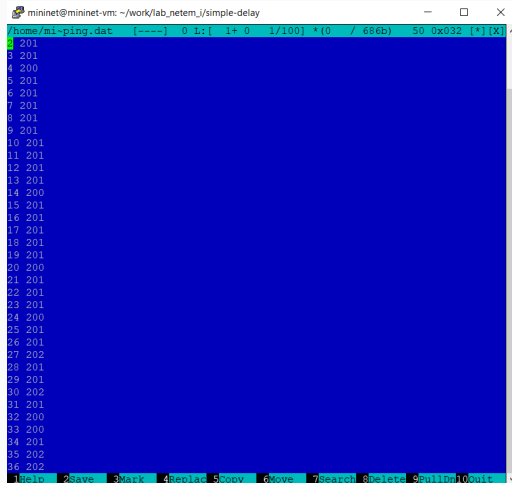


Рис. 32: Просмотр графика



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mi-ping.dat  [----]  0 L: [ 1+ 0 1/100] * {0 / 686b} 50 0x032 [*][X] ^
2 201
3 201
4 200
5 201
6 201
7 201
8 201
9 201
10 201
11 201
12 201
13 201
14 200
15 201
16 201
17 201
18 201
19 201
20 200
21 201
22 201
23 201
24 200
25 201
26 201
27 202
28 201
29 201
30 202
31 201
32 200
33 200
34 201
35 202
36 202
1 Help 2 Save 3 Mark 4 Replace 5 Copy 6 Move 7 Search 8 Delete 9 PullDn 10 Quit
```

Рис. 33: Удаление первой строчки из файла ping.dat

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make ping.png  
./ping_plot  
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 34: Повторное построение графика

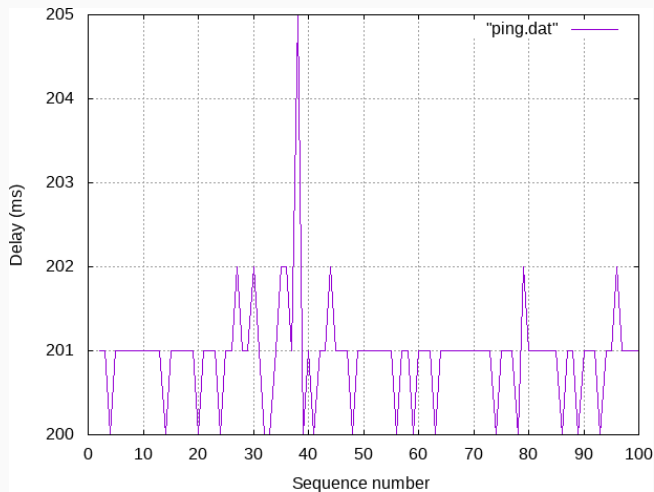
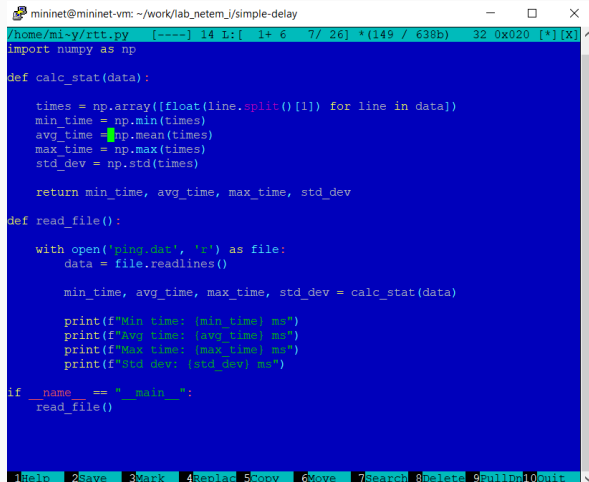


Рис. 35: Просмотр графика

Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mi-y/rtt.py [----] 14 L: [ 1+ 6 7/ 26] *(149 / 638b) 32 0x020 [*][X] ^
import numpy as np

def calc_stat(data):

    times = np.array([float(line.split()[1]) for line in data])
    min_time = np.min(times)
    avg_time = np.mean(times)
    max_time = np.max(times)
    std_dev = np.std(times)

    return min_time, avg_time, max_time, std_dev

def read_file():

    with open('ping.dat', 'r') as file:
        data = file.readlines()

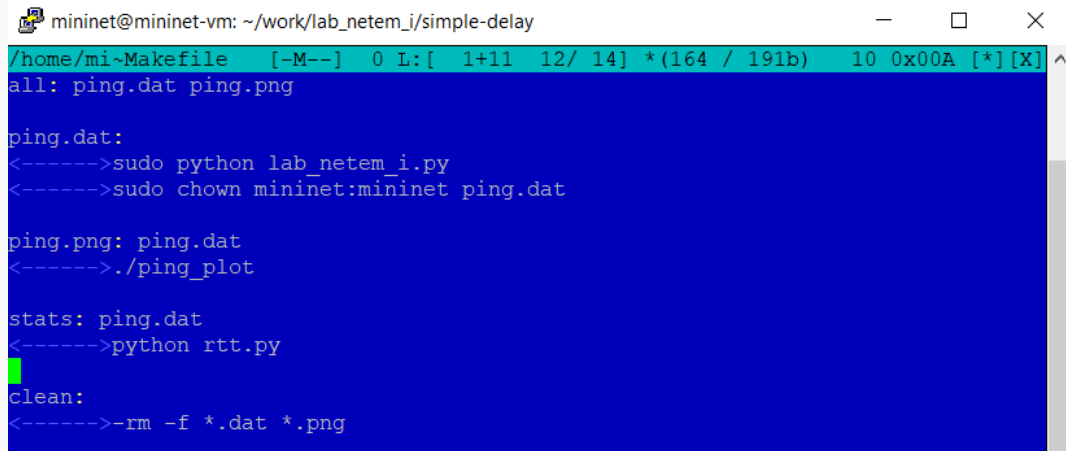
        min_time, avg_time, max_time, std_dev = calc_stat(data)

        print(f"Min time: {min_time} ms")
        print(f"Avg time: {avg_time} ms")
        print(f"Max time: {max_time} ms")
        print(f"Std dev: {std_dev} ms")

if __name__ == "__main__":
    read_file()
```

1Help 2Save 3Mark 4Replac 5Copy 6Move 7Search 8Delete 9PullDn10Quit

Рис. 36: Разработка скрипта для вычисления на основе данных файла ping.dat минимального, среднего, максимального и стандартного отклонения времени приёма-передачи



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mi~Makefile  [-M--]  0 L:[ 1+11 12/ 14] *(164 / 191b) 10 0x00A [*] [X] ^
all: ping.dat ping.png

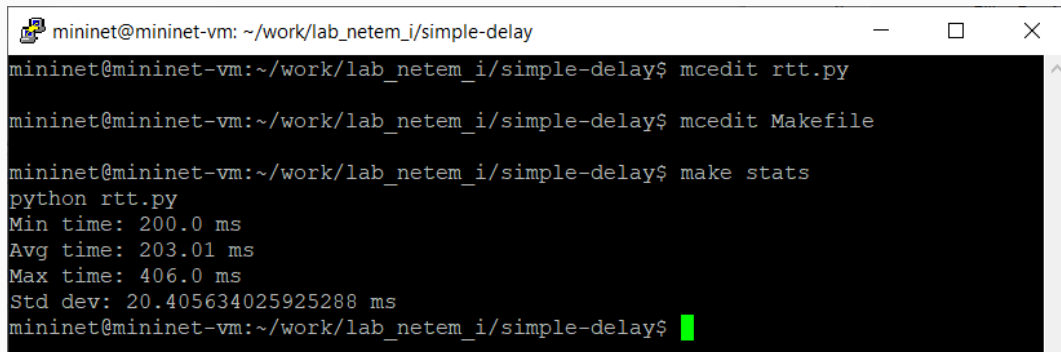
ping.dat:
<----->sudo python lab_netem_i.py
<----->sudo chown mininet:mininet ping.dat

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

stats: ping.dat
<----->python rtt.py

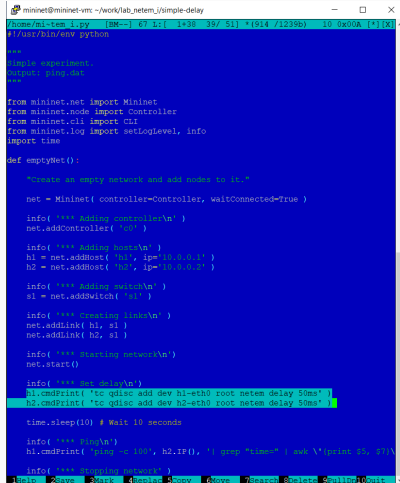
clean:
<----->-rm -f *.dat *.png
```

Рис. 37: Добавление правила запуска скрипта в Makefile



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ mcedit rtt.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ mcedit Makefile
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 200.0 ms
Avg time: 203.01 ms
Max time: 406.0 ms
Std dev: 20.405634025925288 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 38: Проверка



```
mininet@mininet-vm: ~/work/lab_netem/js/simple-delay
/home/mininet$ python
#!/usr/bin/env python

'''
Simple experiment.
Output: ping.dat
'''

from mininet.net import Mininet
from mininet.node import Controller
from mininet.cli import CLI
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 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' )

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

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

    info( '*** Net done\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem delay 50ms' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 50ms' )

    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), ': grep "times" | awk \'{print $5, $7/\
```

Рис. 39: Воспроизводимый эксперимент по изменению задержки

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ mcedit lab_netem_i.py

mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make clean
rm -f *.dat *.png
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make
sudo python lab_netem_i.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 1 switches
s1 ...
*** Waiting for switches to connect
s1
*** Set delay
*** h1 : ('tc qdisc add dev h1-eth0 root netem delay 50ms',)
*** h2 : ('tc qdisc add dev h2-eth0 root netem delay 50ms',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', ' | grep "time=" | awk \'{print $5, $7}\'' |
sed -e 's/time=//g\' -e 's/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 100.0 ms
Avg time: 102.13 ms
Max time: 203.0 ms
Std dev: 10.15249230484811 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 40: Воспроизводимый эксперимент по изменению задержки

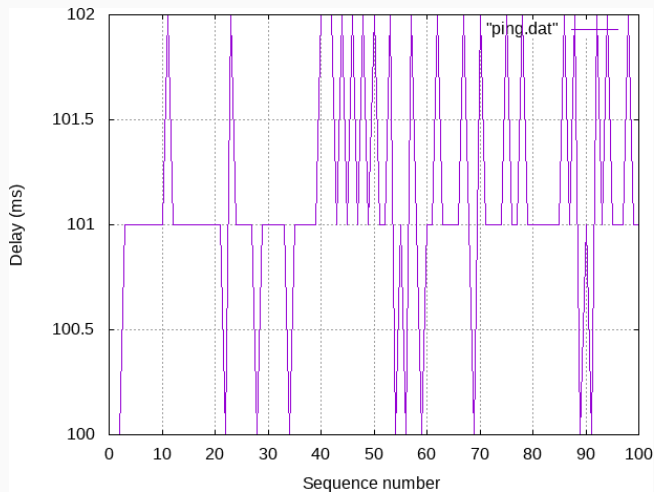


Рис. 41: Просмотр графика

```
mininet@mininet-vm: ~/work/lab_netem/jsimple-delay
/home/ml-tem/lipy [B---] 0 L: [ 1437 38/ 51] *(779 /124kb) 32 0x020 [*][X]
~/usr/bin/env python

***
Simple experiment.
Script: ping.dat
***

from mininet.net import Mininet
from mininet.node import Controller
from mininet.cli import CLI
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 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' )

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

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

    info( '*** Set delay\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem delay 100ms 10ms' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 100ms' )

    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "time=" | awk \'{print $5, $7}\'' )

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

1:help 2:save 3:mark 4:replace 5:copy 6:move 7:search 8:delete 9:pull 10:quit
```

Рис. 42: Воспроизводимый эксперимент по изменению джиттера

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ mcedit lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make clean
rm -f *.dat *.png
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make
sudo python lab_netem_i.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 1 switches
s1 ...
*** Waiting for switches to connect
s1
*** Set delay
*** h1 : ('tc qdisc add dev h1-eth0 root netem delay 100ms 10ms',)
*** h2 : ('tc qdisc add dev h2-eth0 root netem delay 100ms',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk '{print $5, $7}' |
sed -e 's/time=/g\' -e 's/icmp_seq=/g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
eggy: command not found
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 191.0 ms
Avg time: 202.09 ms
Max time: 404.0 ms
Std dev: 21.051885901267852 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 43: Воспроизводимый эксперимент по изменению джиттера

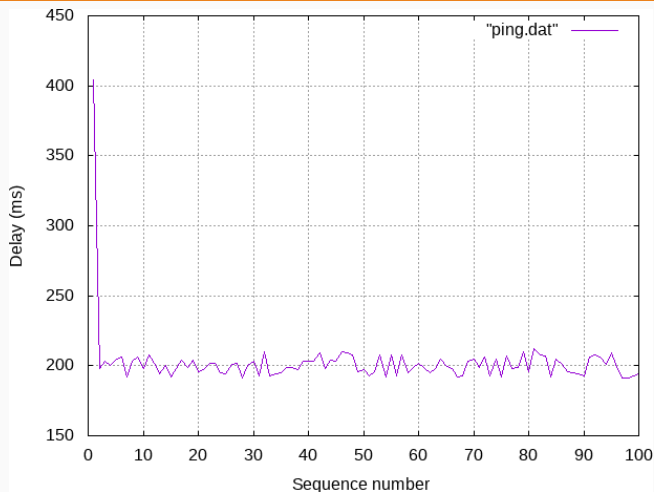


Рис. 44: Просмотр графика


```
mininet@mininet-vm: ~/work/lab_netem/jsimple-delay
/home/mi-tem.1.py [-M--] 74 L: 6+32 38/ 51 *(853 /1250b) 39 0x027 [*]{X}

from mininet.net import Mininet
from mininet.node import Controller
from mininet.cli import CLI
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 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' )

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

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

    info( '*** Set delay\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem delay 100ms 10ms 25% ' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 100ms ' )

    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), 'i' grep "time=" | awk '{print $5, $7}'\n' )

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

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

Рис. 45: Воспроизводимый эксперимент по изменению значения корреляции для джиттера и задержки

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-demccedit lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simplemake clean
rm -f *.dat *.png
mininet@mininet-vm:~/work/lab_netem_i/smake
sudo python lab_netem_i.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 1 switches
s1 ...
*** Waiting for switches to connect
s1
*** Set delay
*** h1 : ('tc qdisc add dev h1-eth0 root netem delay 100ms 10ms 25%,)
*** h2 : ('tc qdisc add dev h2-eth0 root netem delay 100ms',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk '{print $5, $7}' |
sed -e 's/time=//g\' -e 's/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 190.0 ms
Avg time: 202.43 ms
Max time: 408.0 ms
Std dev: 21.35989466266161 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 46: Воспроизводимый эксперимент по изменению значения корреляции для джиттера и задержки

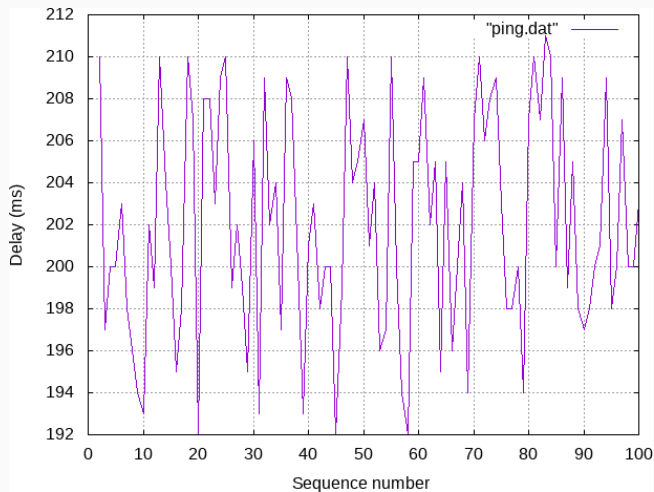
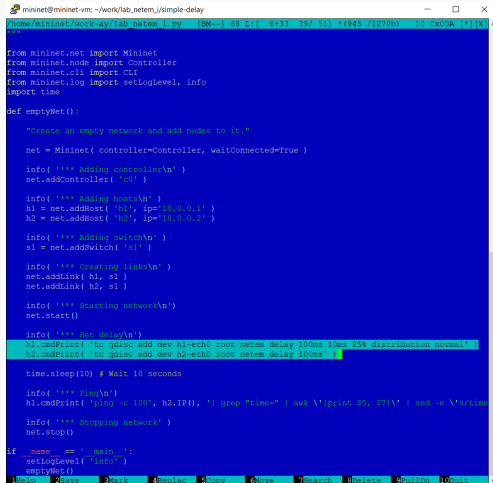


Рис. 47: Просмотр графика

Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_j/simple-delay
/home/mininet/work-ay/lab_netem_j/1.py [RM--] 68 L: 6+33 39/ 51] *(945 /1270b) 10 0x00A [*]X]
...
from mininet.net import Mininet
from mininet.node import Controller
from mininet.cli import CLI
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='18.8.0.1' )
    h2 = net.addHost( 'h2', ip='18.8.0.2' )

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

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

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

    info( '*** Set delay\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem delay 100ms 10ms 25% distribution normal' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 100ms' )

    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )
    h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "time=" | awk \'{print $5, $7}\'' ) and -e \\'s/time

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

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

1:help 2:save 3:mark 4:replac 5:copy 6:move 7:search 8:delete 9:pullin 10:quit
```

Рис. 48: Воспроизводимый эксперимент по изменению распределения времени задержки в эмулируемой глобальной сети

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ mcedit lab_netem_i.py

mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make clean
rm -f *.dat *.png
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make
sudo python lab_netem_i.py
*** Adding controller
*** Adding hosts
*** Adding switch
*** Creating links
*** Starting network
*** Configuring hosts
h1 h2
*** Starting controller
c0
*** Starting 1 switches
s1 ...
*** Waiting for switches to connect
s1
*** Set delay
*** h1 : ('tc qdisc add dev h1-eth0 root netem delay 100ms 10ms 25% distribution normal',)
*** h2 : ('tc qdisc add dev h2-eth0 root netem delay 100ms',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'{print $5, $7}\'} | sed -e \'s/time=//g\' -e \'s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 180.0 ms
Avg time: 203.65 ms
Max time: 413.0 ms
Std dev: 23.55732370198279 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 49: Воспроизводимый эксперимент по изменению распределения времени задержки в эмулируемой глобальной сети

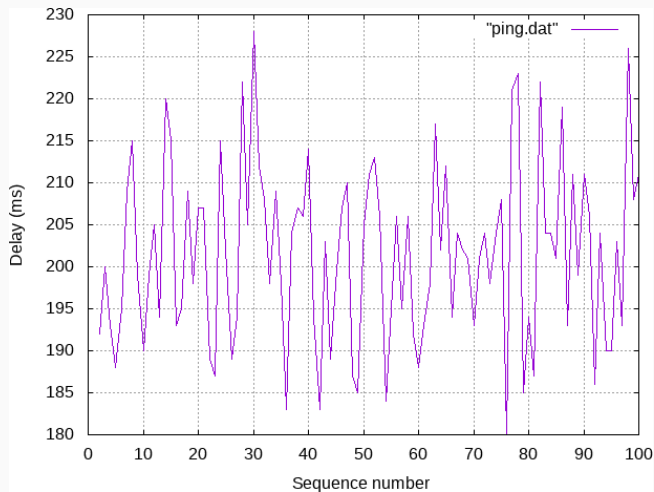


Рис. 50: Просмотр графика

Вывод

- В ходе выполнения лабораторной работы познакомились с NETEM — инструментом для тестирования производительности приложений в виртуальной сети, а также получили навыки проведения интерактивного и воспроизводимого экспериментов по измерению задержки и её дрожания (jitter) в моделируемой сети в среде Mininet.

Список литературы. Библиография

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