

Лабораторная работа №4

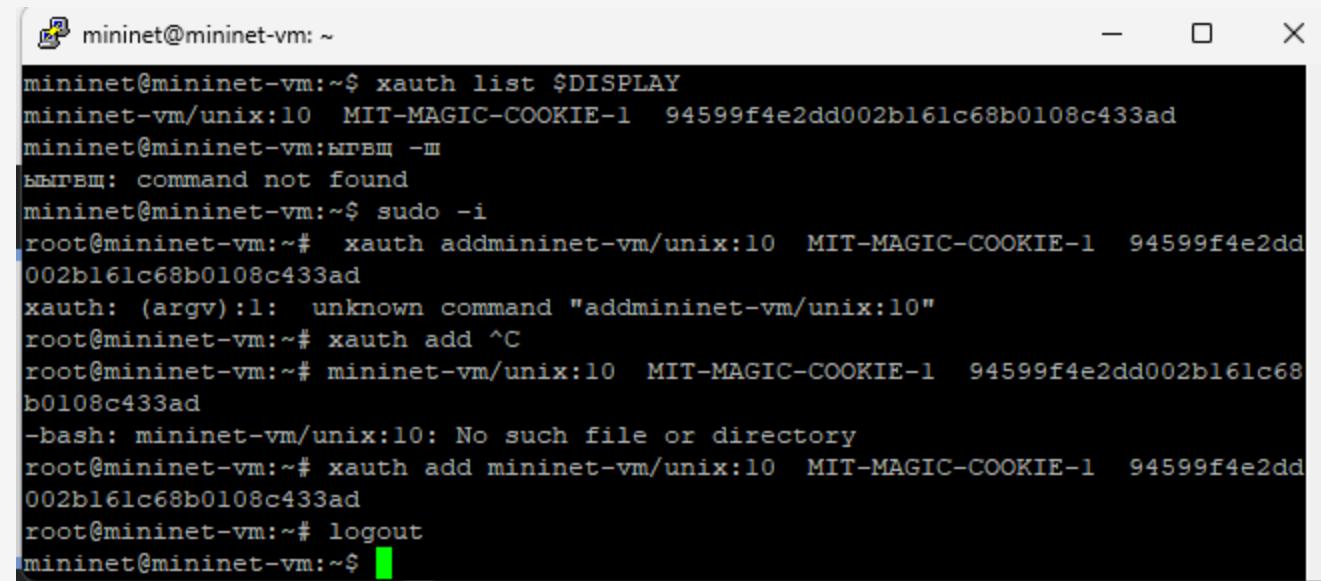
Моделирование сетей передачи данных

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Запуск лабораторной топологии



```
mininet@mininet-vm:~$ xauth list $DISPLAY
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  94599f4e2dd002b161c68b0108c433ad
mininet@mininet-vm:ыгвщ -ш
ыгвщ: command not found
mininet@mininet-vm:~$ sudo -i
root@mininet-vm:~# xauth addmininet-vm/unix:10  MIT-MAGIC-COOKIE-1  94599f4e2dd
002b161c68b0108c433ad
xauth: (argv):1: unknown command "addmininet-vm/unix:10"
root@mininet-vm:~# xauth add ^C
root@mininet-vm:~# mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  94599f4e2dd002b161c68
b0108c433ad
-bash: mininet-vm/unix:10: No such file or directory
root@mininet-vm:~# xauth add mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  94599f4e2dd
002b161c68b0108c433ad
root@mininet-vm:~# logout
mininet@mininet-vm:~$
```

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

Запуск лабораторной топологии

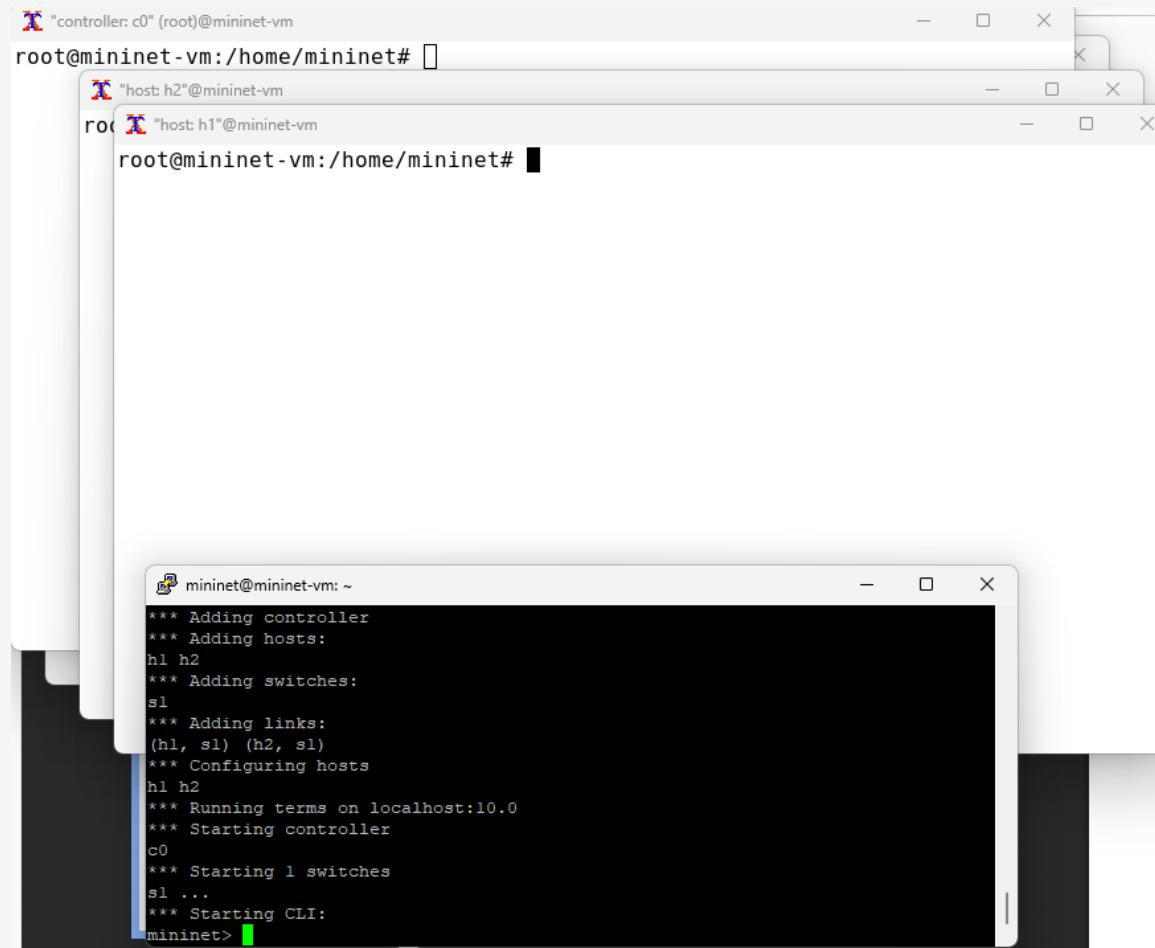
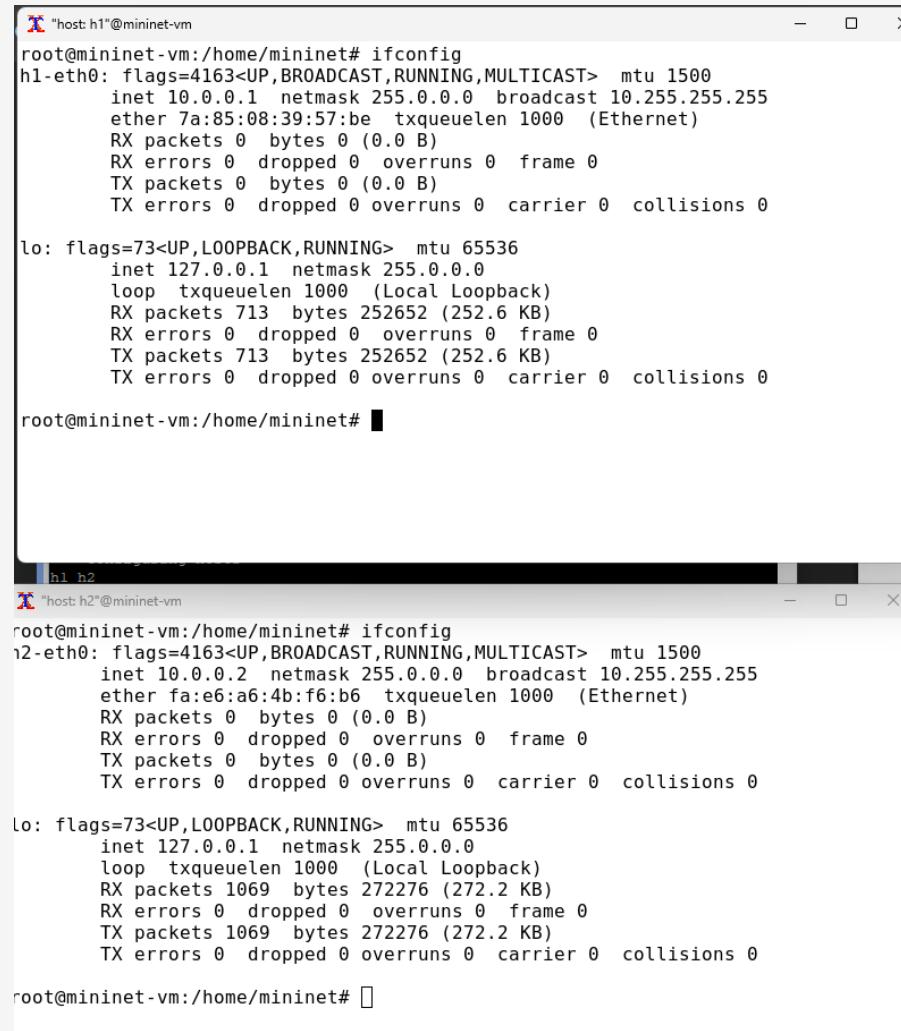


Рис. 2: Создание простейшей топологии

Запуск лабораторной топологии



The image shows two terminal windows side-by-side, both titled "root@mininet-vm:/home/mininet#". The left window is for host h1 and the right window is for host h2. Both windows display the output of the 'ifconfig' command.

Host h1 (Terminal 1):

```
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 7a:85:08:39:57:be 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 713 bytes 252652 (252.6 KB)
        RX errors 0 dropped 0 overruns 0 frame 0
        TX packets 713 bytes 252652 (252.6 KB)
        TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

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

Host h2 (Terminal 2):

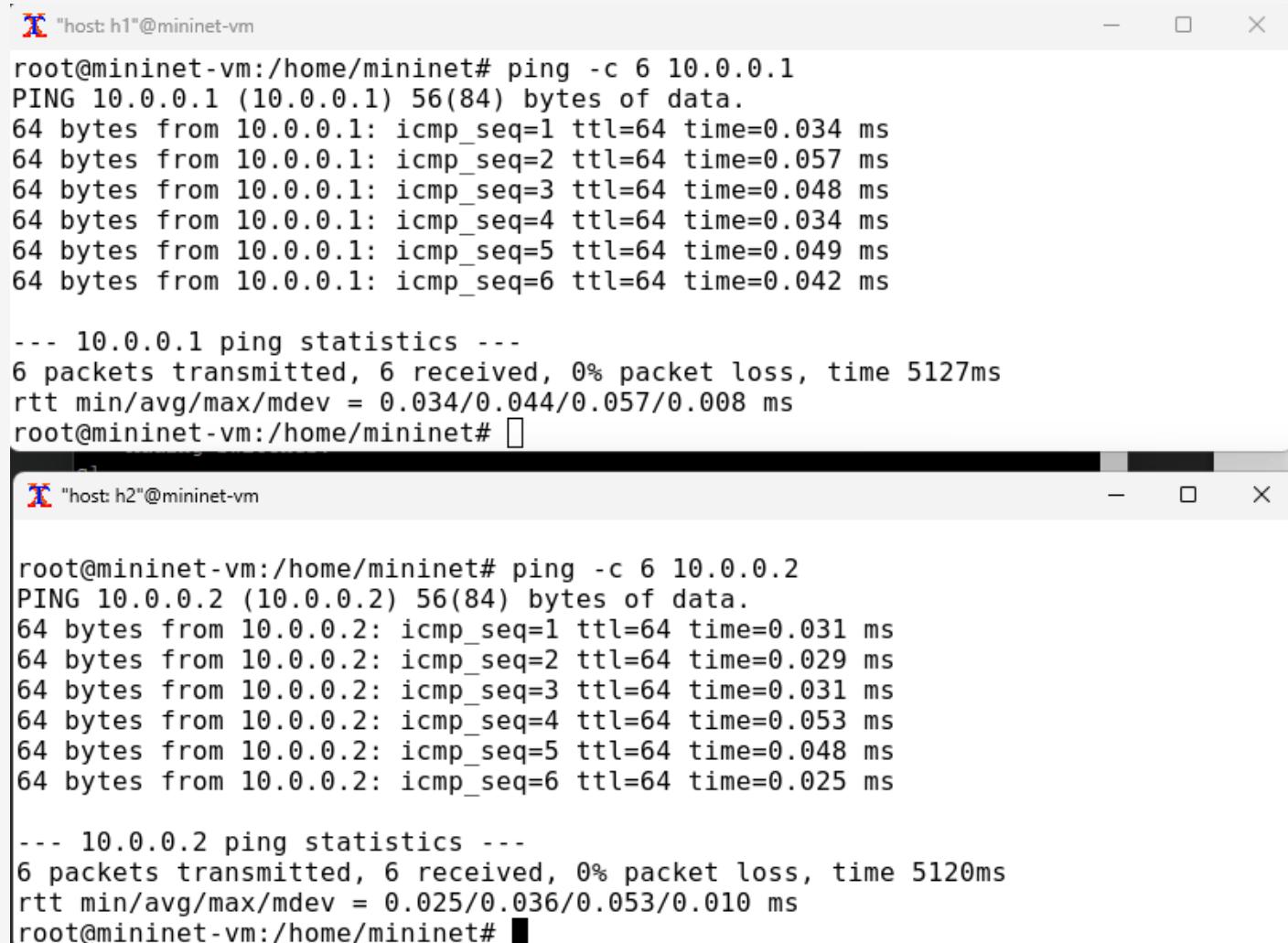
```
root@mininet-vm:/home/mininet# ifconfig
h2-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 10.0.0.2 netmask 255.0.0.0 broadcast 10.255.255.255
        ether fa:e6:a6:4b:f6:b6 txqueuelen 1000 (Ethernet)
        RX packets 0 bytes 0 (0.0 B)
        RX errors 0 dropped 0 overruns 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 1069 bytes 272276 (272.2 KB)
        RX errors 0 dropped 0 overruns 0 frame 0
        TX packets 1069 bytes 272276 (272.2 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 side-by-side. Both windows have a title bar with a red 'X' icon and the text "host h1" or "host h2" followed by "@mininet-vm". The windows are white with black text.

Top Terminal (host h1):

```
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=0.034 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.057 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.048 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.034 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.049 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.042 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5127ms
rtt min/avg/max/mdev = 0.034/0.044/0.057/0.008 ms
root@mininet-vm:/home/mininet#
```

Bottom Terminal (host h2):

```
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=0.031 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.029 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.031 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.048 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.025 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5120ms
rtt min/avg/max/mdev = 0.025/0.036/0.053/0.010 ms
root@mininet-vm:/home/mininet#
```

Рис. 4: Проверка подключения между хостами h1 и h2

Интерактивные эксперименты

```
X "host: h1"@mininet-vm
-6           use IPv6
-F <flowlabel>    define flow label, default is random
-N <nodeinfo opt>  use icmp6 node info query, try <help> as argument

For more details see ping(8).
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=0.034 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.057 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.048 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.034 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.049 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.042 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5127ms
rtt min/avg/max/mdev = 0.034/0.044/0.057/0.008 ms
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

Интерактивные эксперименты

```
X "host: h1"@mininet-vm
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.042 ms
--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5127ms
rtt min/avg/max/mdev = 0.034/0.044/0.057/0.008 ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 100ms
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=203 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=100 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=101 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 5010ms
rtt min/avg/max/mdev = 100.187/118.025/202.950/37.984 ms
root@mininet-vm:/home/mininet#
```

Рис. 6: Проверка

Интерактивные эксперименты

```
X "host: h2"@mininet-vm
    loop txqueuelen 1000 (Local Loopback)
      RX packets 1069 bytes 272276 (272.2 KB)
      RX errors 0 dropped 0 overruns 0 frame 0
      TX packets 1069 bytes 272276 (272.2 KB)
      TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

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=0.031 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.029 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.031 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.048 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.025 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5120ms
rtt min/avg/max/mdev = 0.025/0.036/0.053/0.010 ms
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

Интерактивные эксперименты

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

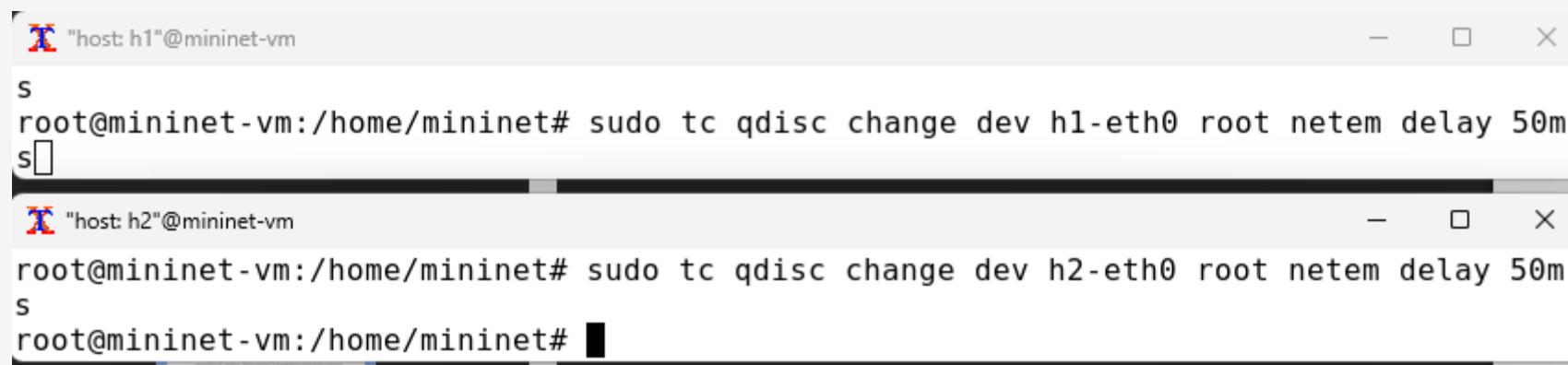
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=101 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=100 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5011ms
rtt min/avg/max/mdev = 100.113/101.432/102.403/0.758 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=203 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=202 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=203 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=201 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 5009ms
rtt min/avg/max/mdev = 200.570/201.731/202.899/0.876 ms
root@mininet-vm:/home/mininet#
```

Рис. 8: Проверка

Интерактивные эксперименты



The image shows two terminal windows side-by-side. The left window is titled "host h1" and the right window is titled "host h2". Both windows are running on a host named "mininet-vm". In both terminals, the user is executing a command to change the queue discipline (qdisc) on a network interface (h1-eth0 for h1, h2-eth0 for h2). The command is: `sudo tc qdisc change dev <interface> root netem delay 50m`. The command is partially typed, with the letter 's' visible at the beginning of the line.

```
"host h1"@mininet-vm
s
root@mininet-vm:/home/mininet# sudo tc qdisc change dev h1-eth0 root netem delay 50m
s
"host h2"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc change dev h2-eth0 root netem delay 50m
s
root@mininet-vm:/home/mininet#
```

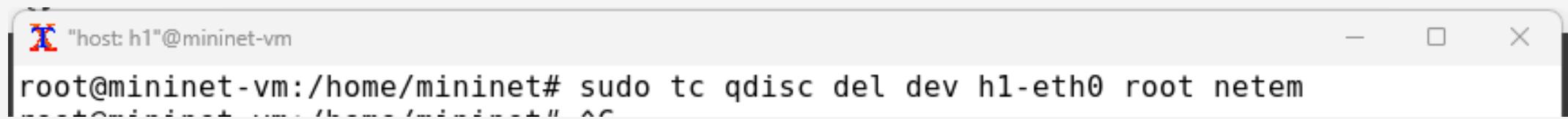
Рис. 9: Изменение задержки со 100 мс до 50 мс

Интерактивные эксперименты

```
X "host: h1"@mininet-vm
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 5009ms
rtt min/avg/max/mdev = 200.570/201.731/202.899/0.876 ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 50ms
Error: Exclusivity flag on, cannot modify.
root@mininet-vm:/home/mininet# sudo tc qdisc change dev h1-eth0 root netem delay 50m
s
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=103 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=101 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=102 ms
--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5010ms
rtt min/avg/max/mdev = 100.788/102.359/104.263/1.306 ms
root@mininet-vm:/home/mininet# █
```

Рис. 10: Проверка

Интерактивные эксперименты



"host: h1"@\mininet-vm

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

Рис. 11: Восстановление конфигураций по умолчанию

Интерактивные эксперименты



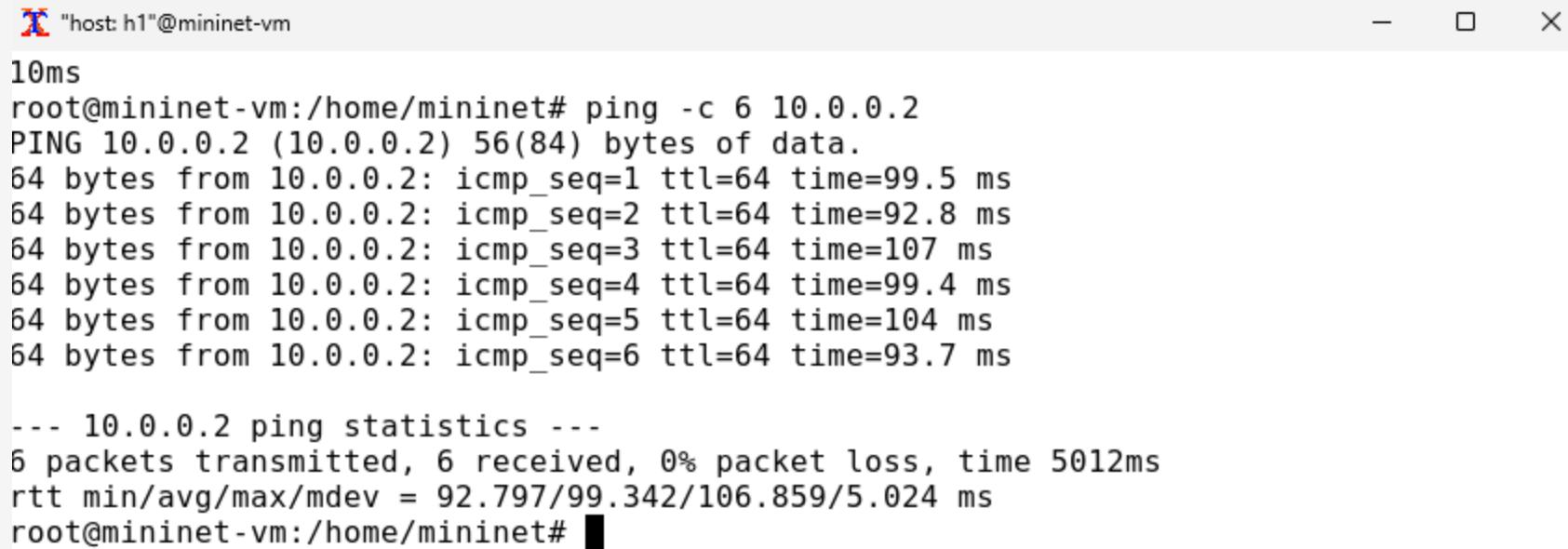
"host h1"@"mininet-vm

```
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=101 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=102 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5010ms
rtt min/avg/max/mdev = 100.788/102.359/104.263/1.306 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-vm:/home/mininet# ^C
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

Интерактивные эксперименты



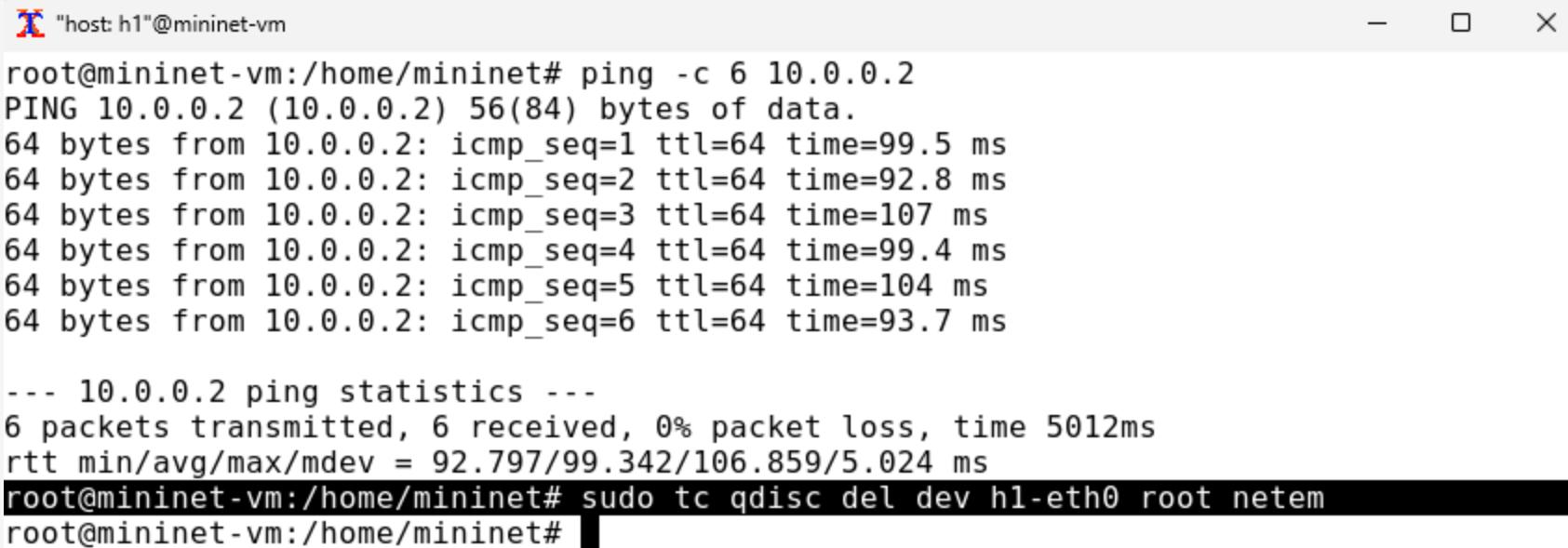
The screenshot shows a terminal window titled "host h1" running on a Mininet VM. The user has run a ping command from the root shell to the IP address 10.0.0.2. The output shows six successful ICMP echo replies, each with a sequence number (seq=1 to seq=6), a TTL of 64, and a time between 92.8 ms and 107 ms. After the replies, the statistics are displayed: 6 packets transmitted, 6 received, 0% packet loss, and an average round-trip time (rtt) of 92.797 ms.

```
10ms
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=99.5 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=92.8 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=99.4 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=93.7 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5012ms
rtt min/avg/max/mdev = 92.797/99.342/106.859/5.024 ms
root@mininet-vm:/home/mininet# █
```

Рис. 13: Проверка

Интерактивные эксперименты



The screenshot shows a terminal window titled "host h1" running on a host named "mininet-vm". The terminal displays the output of a ping command and a subsequent command to delete a network traffic control (qdisc) discipline.

```
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=99.5 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=92.8 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=99.4 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=93.7 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5012ms
rtt min/avg/max/mdev = 92.797/99.342/106.859/5.024 ms
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

Интерактивные эксперименты

```
X "host h1"@mininet-vm
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=93.7 ms
--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5012ms
rtt min/avg/max/mdev = 92.797/99.342/106.859/5.024 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
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=2.46 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.618 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.137 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.069 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.048 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.059 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=0.063 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=0.048 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.057 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=0.070 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.139 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.067 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.061 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.063 ms
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=0.062 ms
--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, 0% packet loss, time 19388ms
rtt min/avg/max/mdev = 0.048/0.219/2.460/0.528 ms
root@mininet-vm:/home/mininet# █
```

Рис. 15: Проверка

Интерактивные эксперименты

```
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

Интерактивные эксперименты

```
X "host h1"@mininet-vm
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.057 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=0.070 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.139 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.067 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.061 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.063 ms
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=0.062 ms

--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, 0% packet loss, time 19388ms
rtt min/avg/max/mdev = 0.048/0.219/2.460/0.528 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
Error: Invalid qdisc name.
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
Error: Invalid qdisc name.
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

Интерактивные эксперименты

```
X "host h1"@mininet-vm - □ ×

Error: Invalid qdisc name.
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
Error: Invalid qdisc name.
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 100ms
20ms distribution normal
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=105 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=119 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=109 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=61.5 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=88.9 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=75.0 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=74.8 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=133 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=92.8 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=84.4 ms
--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9021ms
rtt min/avg/max/mdev = 61.549/94.374/133.395/21.013 ms
root@mininet-vm:/home/mininet#
```

Рис. 18: Проверка

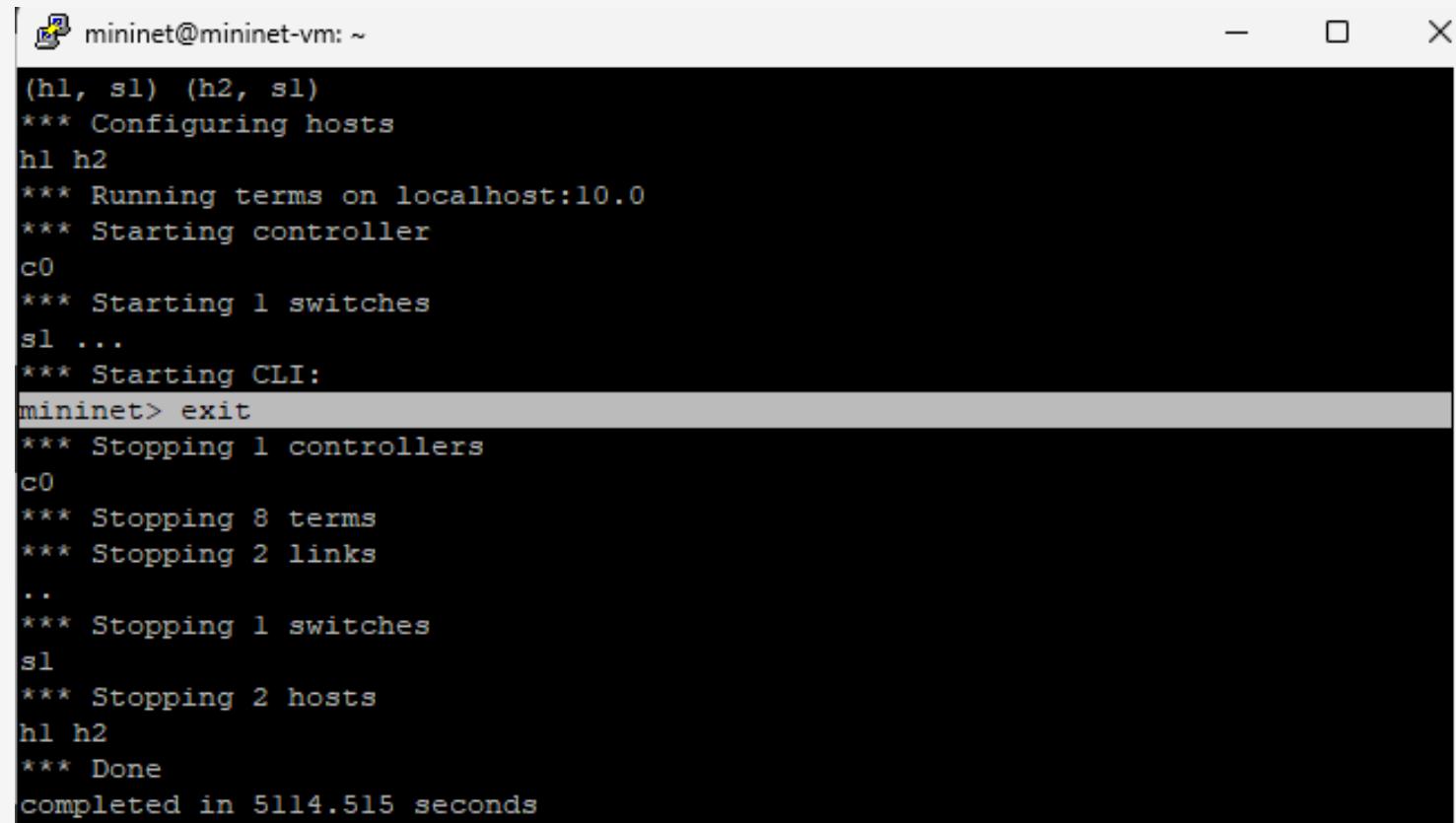
Интерактивные эксперименты

```
X "host h1"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
Error: Invalid qdisc name.
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 100ms
20ms distribution normal
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=105 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=119 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=109 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=61.5 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=88.9 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=75.0 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=74.8 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=133 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=92.8 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=84.4 ms

--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9021ms
rtt min/avg/max/mdev = 61.549/94.374/133.395/21.013 ms
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

Интерактивные эксперименты



mininet@mininet-vm: ~

```
(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 5114.515 seconds
```

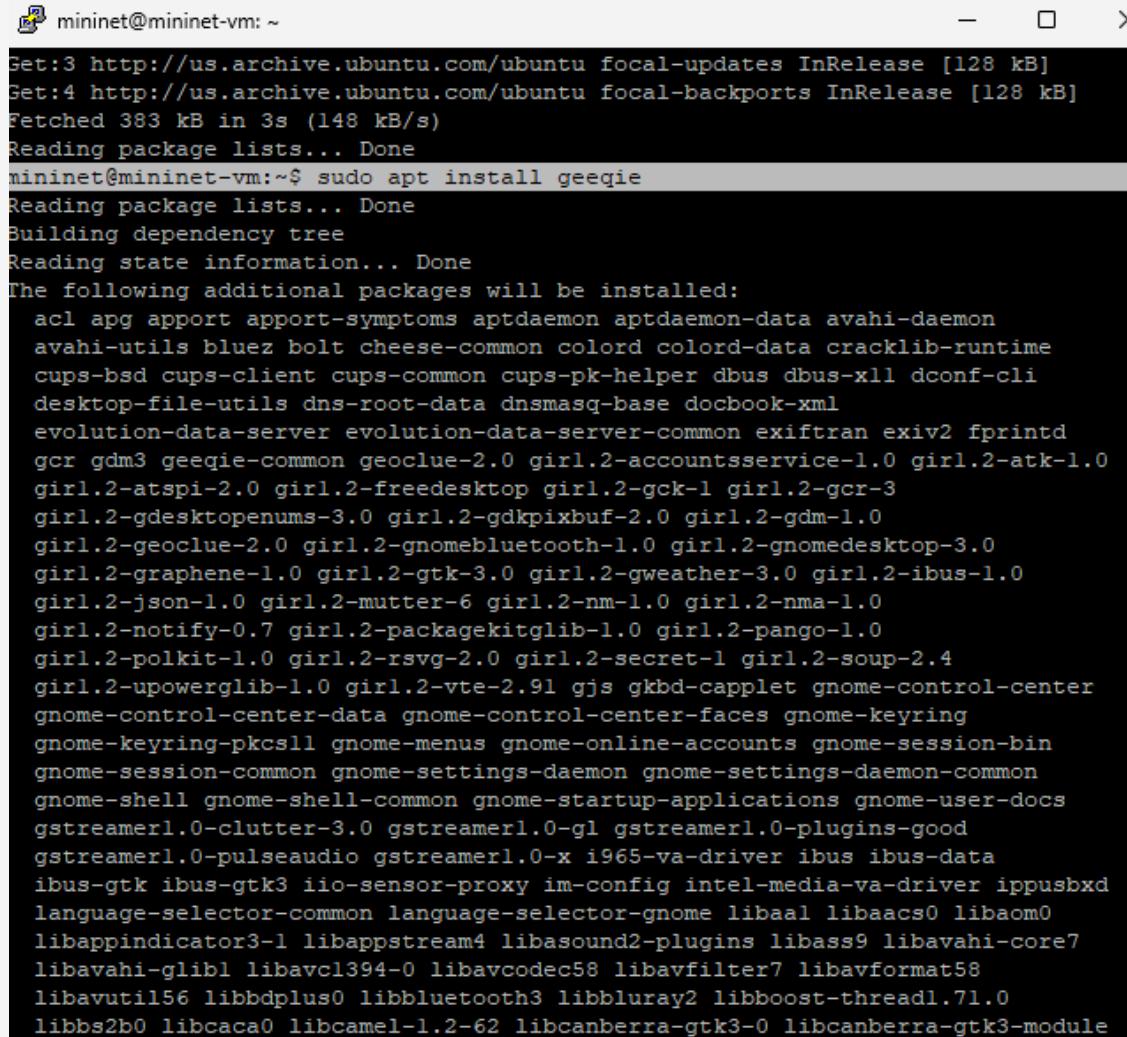
Рис. 20: Завершение работы mininet в интерактивном режиме

Воспроизведение экспериментов

```
mininet@mininet-vm:~$ sudo apt-get update
Hit:1 http://us.archive.ubuntu.com/ubuntu focal InRelease
Get:2 http://security.ubuntu.com/ubuntu focal-security InRelease [128 kB]
Get:3 http://us.archive.ubuntu.com/ubuntu focal-updates InRelease [128 kB]
Get:4 http://us.archive.ubuntu.com/ubuntu focal-backports InRelease [128 kB]
Fetched 383 kB in 3s (148 kB/s)
Reading package lists... Done
mininet@mininet-vm:~$
```

Рис. 21: Обновление репозиториев программного обеспечения на виртуальной машине

Воспроизведение экспериментов



```
mininet@mininet-vm: ~
Get:3 http://us.archive.ubuntu.com/ubuntu focal-updates InRelease [128 kB]
Get:4 http://us.archive.ubuntu.com/ubuntu focal-backports InRelease [128 kB]
Fetched 383 kB in 3s (148 kB/s)
Reading package lists... Done
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 girl.2-accountsservice-1.0 girl.2-atk-1.0
  girl.2-atspi-2.0 girl.2-freedesktop girl.2-gck-1 girl.2-gcr-3
  girl.2-gdesktoopenums-3.0 girl.2-gdkpixbuf-2.0 girl.2-gdm-1.0
  girl.2-geoclue-2.0 girl.2-gnomebluetooth-1.0 girl.2-gnomedesktop-3.0
  girl.2-graphene-1.0 girl.2-gtk-3.0 girl.2-gweather-3.0 girl.2-ibus-1.0
  girl.2-json-1.0 girl.2-mutter-6 girl.2-nm-1.0 girl.2-nma-1.0
  girl.2-notify-0.7 girl.2-packagekitglib-1.0 girl.2-pango-1.0
  girl.2-polkit-1.0 girl.2-rsvg-2.0 girl.2-secret-1 girl.2-soup-2.4
  girl.2-upowerglib-1.0 girl.2-vte-2.91 gjs gkbd-capplet 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-egl 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 ippusbx
  language-selector-common language-selector-gnome libaal libaacso libao
  libappindicator3-1 libappstream4 libasound2-plugins libass9 libavahi-core7
  libavahi-glib libavc1394-0 libavcodec58 libavfilter7 libavformat58
  libavutil56 libbdplus0 libblueooth3 libbluray2 libboost-thread1.71.0
  libbs2b0 libcaca0 libcamel-1.2-62 libcanberra-gtk3-0 libcanberra-gtk3-module
```

Рис. 22: Установка пакета geeqie

Воспроизведение экспериментов

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

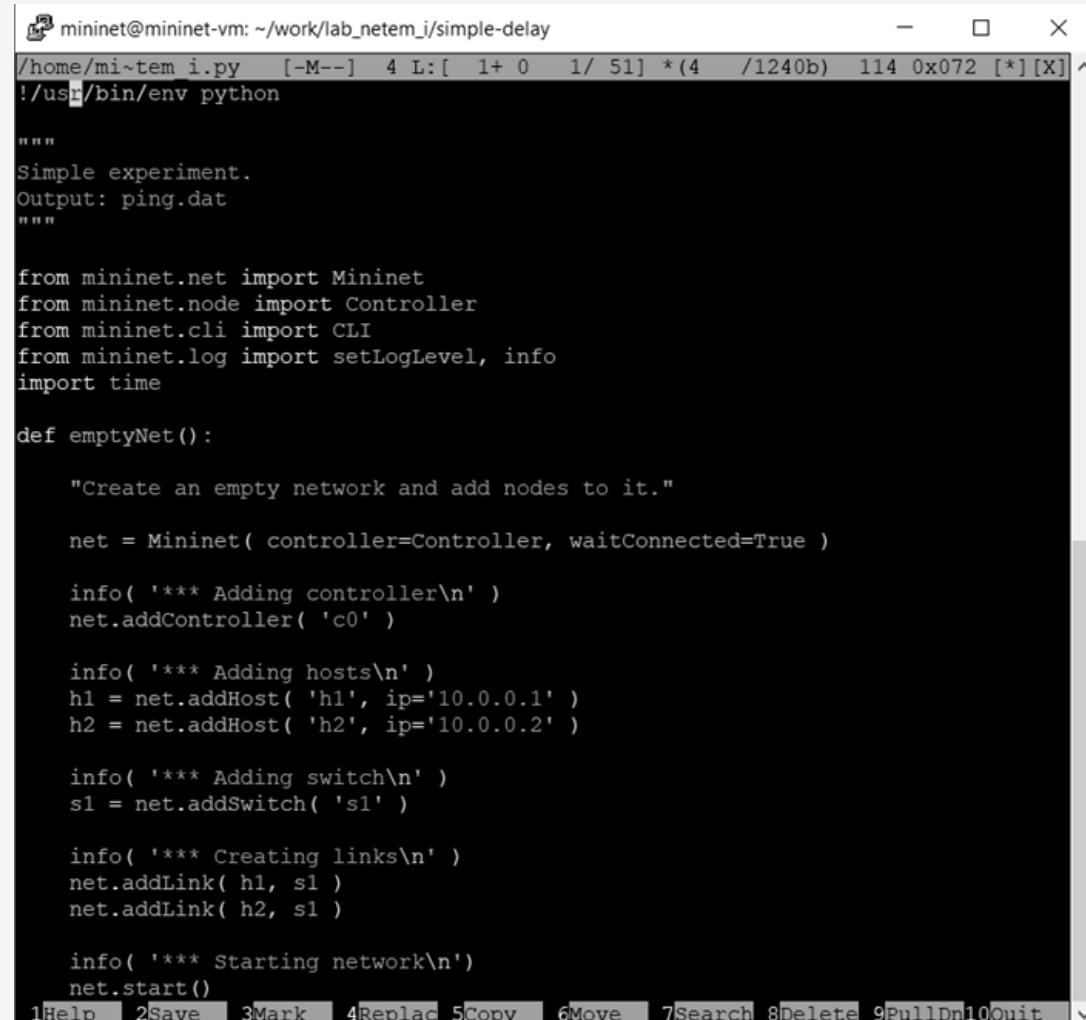
Рис. 23: Создание нового каталога

Воспроизведение экспериментов

```
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$ nano lab_netem_i.py █
```

Рис. 24: Создание каталога simple-delay

Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mininet-i.py [-M--] 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()
net.start()

1Help 2Save 3Mark 4Replace 5Copy 6Move 7Search 8Delete 9PullDown 10Quit
```

Рис. 25: Создание скрипта lab_netem_i.py для эксперимента

Воспроизведение экспериментов

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

Рис. 26: Создание файла ping_plot

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
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. 27: Создание скрипта ping_plot для визуализации результатов эксперимента

Воспроизведение экспериментов

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

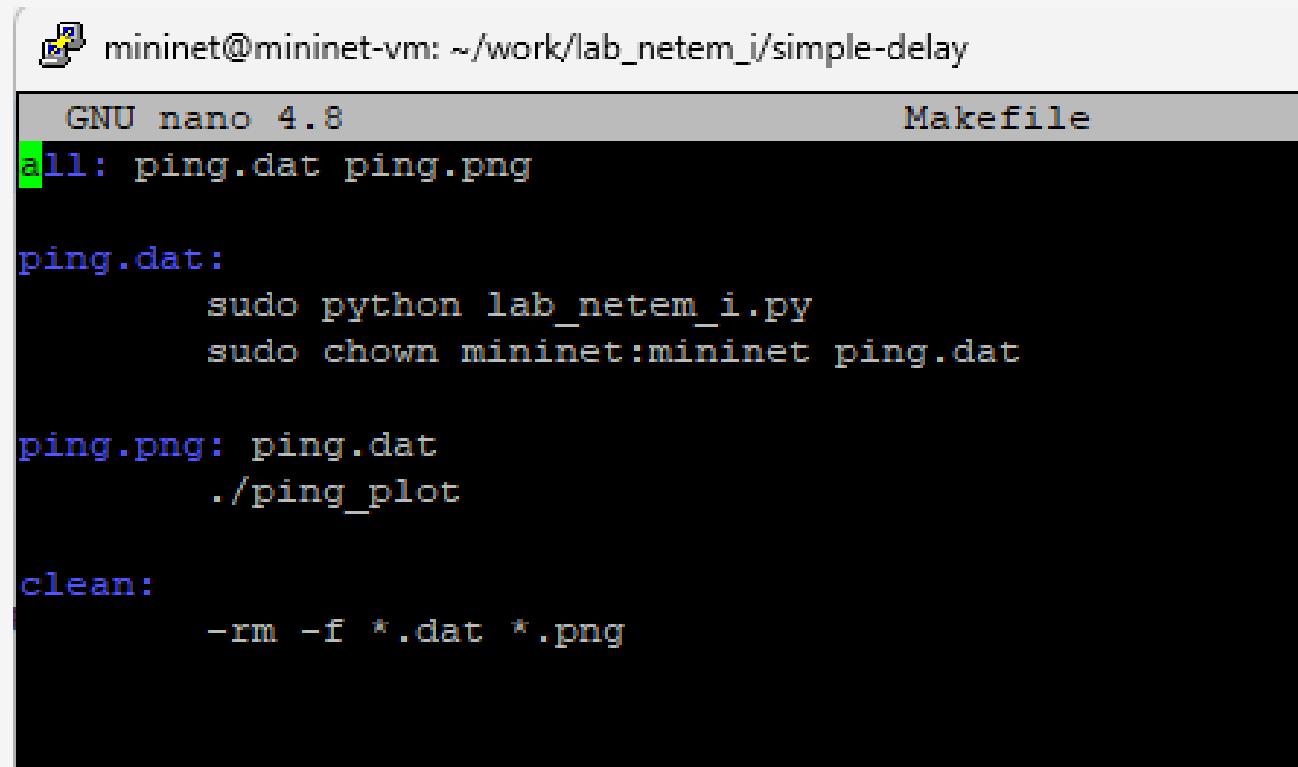
Рис. 28: Настройка прав доступа к файлу скрипта

Воспроизведение экспериментов

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

Рис. 29: Создание файла Makefile

Воспроизведение экспериментов



Screenshot of a terminal window showing a Makefile for experiment control. The terminal title is "mininet@mininet-vm: ~/work/lab_neterm_i/simple-delay". The Makefile contains the following rules:

```
GNU nano 4.8                                     Makefile
all: ping.dat ping.png

ping.dat:
    sudo python lab_neterm_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

Воспроизведение экспериментов

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

Рис. 31: Выполнение эксперимента

Воспроизведение экспериментов

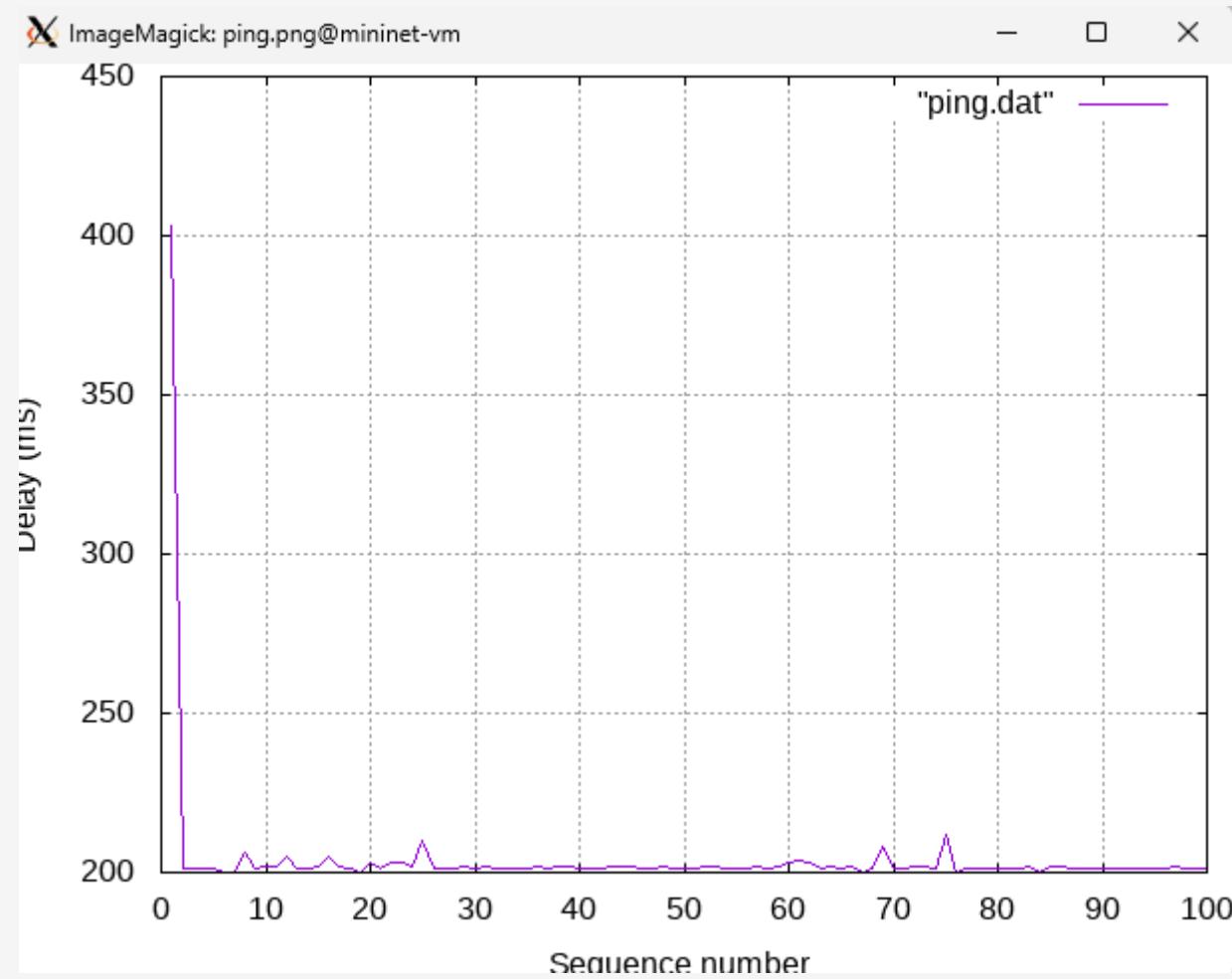
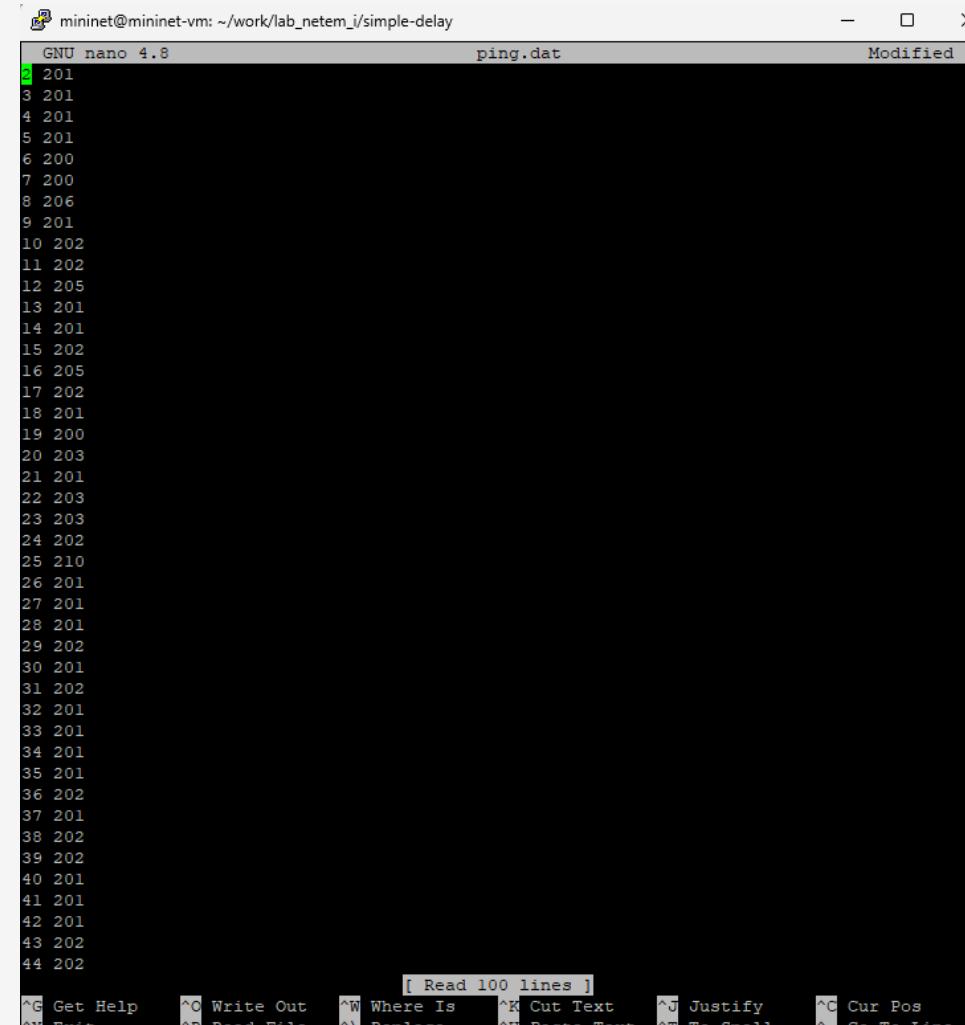


Рис. 32: Просмотр графика

Воспроизведение экспериментов



mininet@mininet-vm: ~/work/lab_netem_i/simple-delay

GNU nano 4.8 ping.dat Modified

```
201
3 201
4 201
5 201
6 200
7 200
8 206
9 201
10 202
11 202
12 205
13 201
14 201
15 202
16 205
17 202
18 201
19 200
20 203
21 201
22 203
23 203
24 202
25 210
26 201
27 201
28 201
29 202
30 201
31 202
32 201
33 201
34 201
35 201
36 202
37 201
38 202
39 202
40 201
41 201
42 201
43 202
44 202
```

[Read 100 lines]

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

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

Воспроизведение экспериментов

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make ping.png
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make ping.png
make: 'ping.png' is up to date.
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ display ping.png
[
```

Рис. 34: Повторное построение графика

Воспроизведение экспериментов

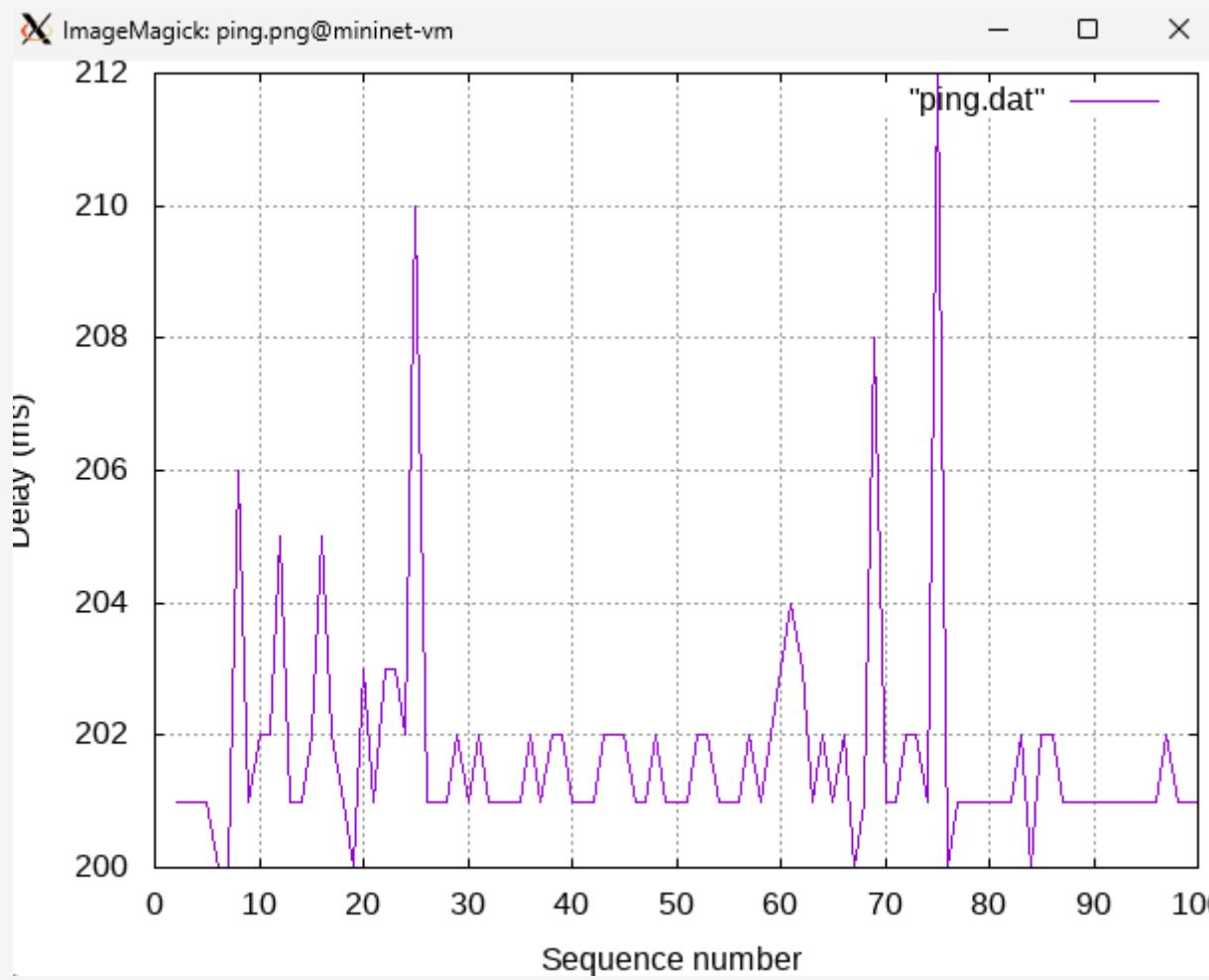
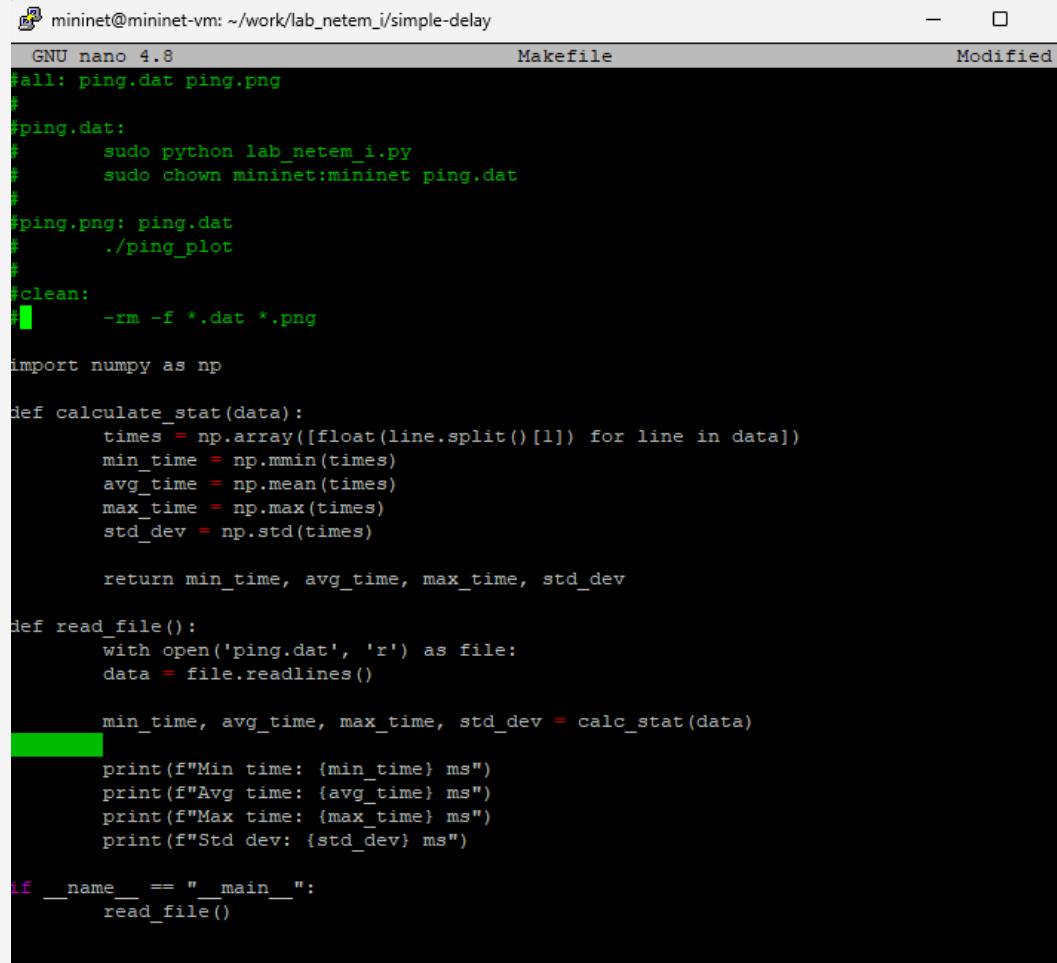


Рис. 35: Просмотр графика

Воспроизведение экспериментов



The screenshot shows a terminal window titled "mininet@mininet-vm: ~/work/lab_netem_i/simple-delay". The window contains a code editor with a Makefile and a Python script. The Python script, named lab_netem_i.py, is used to calculate statistics from a file named ping.dat. It uses the numpy library to perform calculations like mean, max, and standard deviation on the data. The script also prints the results to the console. A green rectangle highlights the section of the code where the statistics are calculated and printed.

```
GNU nano 4.8
Makefile
Modified

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

import numpy as np

def calculate_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()

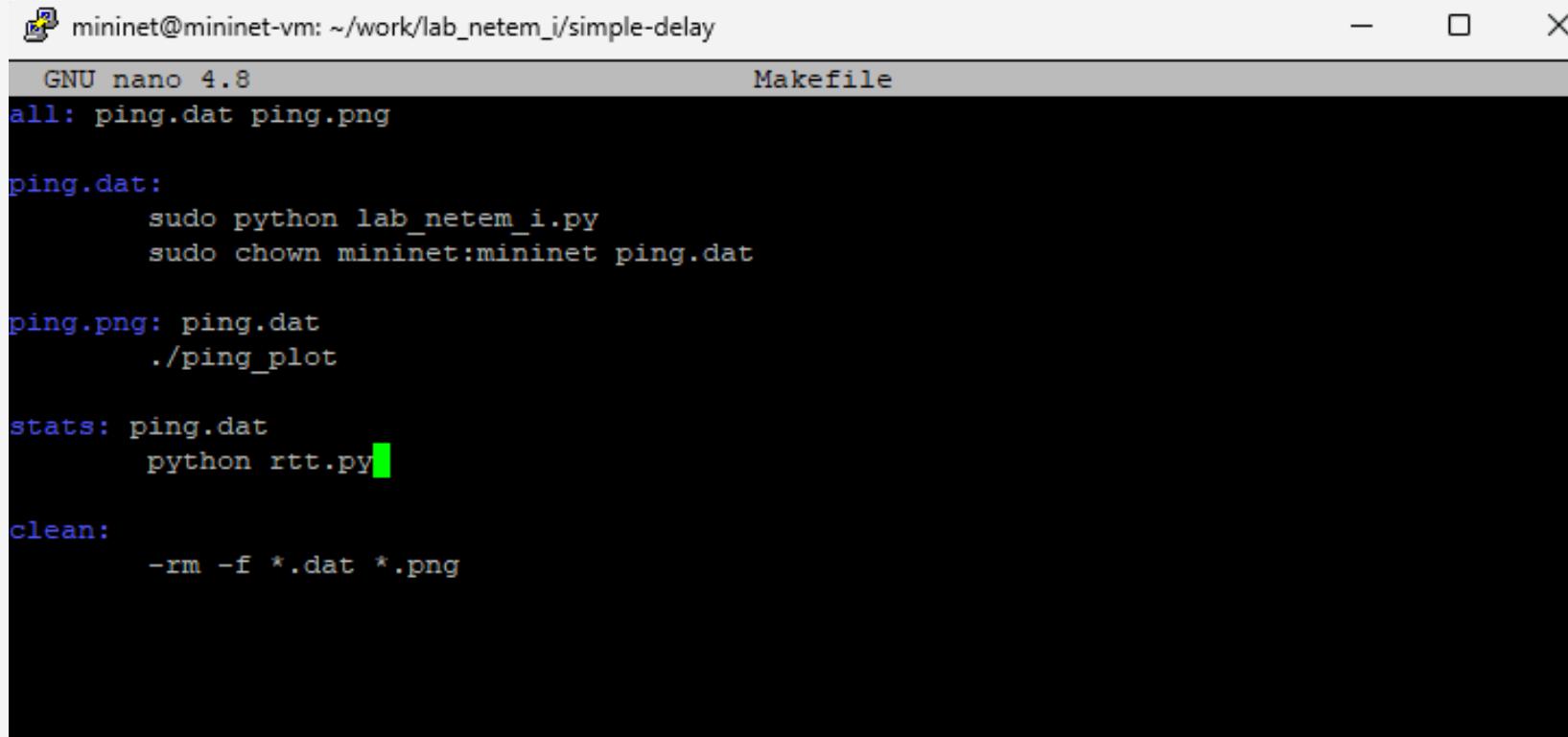
    min_time, avg_time, max_time, std_dev = calc_stat(data)

    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()
```

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

Воспроизведение экспериментов



The screenshot shows a terminal window titled "mininet@mininet-vm: ~/work/lab_netem_i/simple-delay". The window contains a "GNU nano 4.8" editor displaying a "Makefile". The file content is as follows:

```
GNU nano 4.8                                     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

stats: ping.dat
    python rtt.py

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

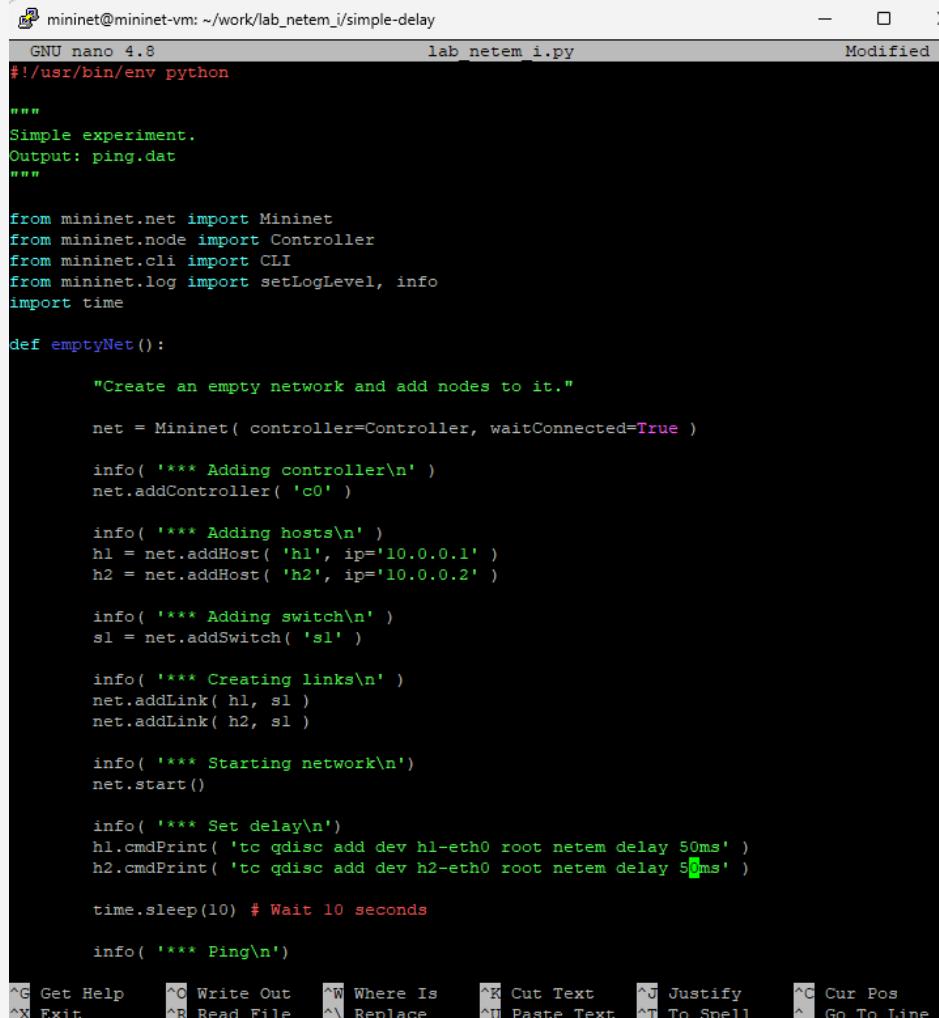
Рис. 37: Добавление правила запуска скрипта в Makefil

Воспроизведение экспериментов

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 200.0 ms
Avg time: 201.737373737373 ms
Max time: 212.0 ms
Std dev: 1.7842512992020527 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ █
```

Рис. 38: Проверка

Воспроизведение экспериментов



mininet@mininet-vm: ~/work/lab_neterm_i/simple-delay

GNU nano 4.8 lab_neterm_i.py Modified

```
#!/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' )
    sl = net.addSwitch( 's1' )

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

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

    info( '*** Set delay\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem delay 50ms' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 5ms' )

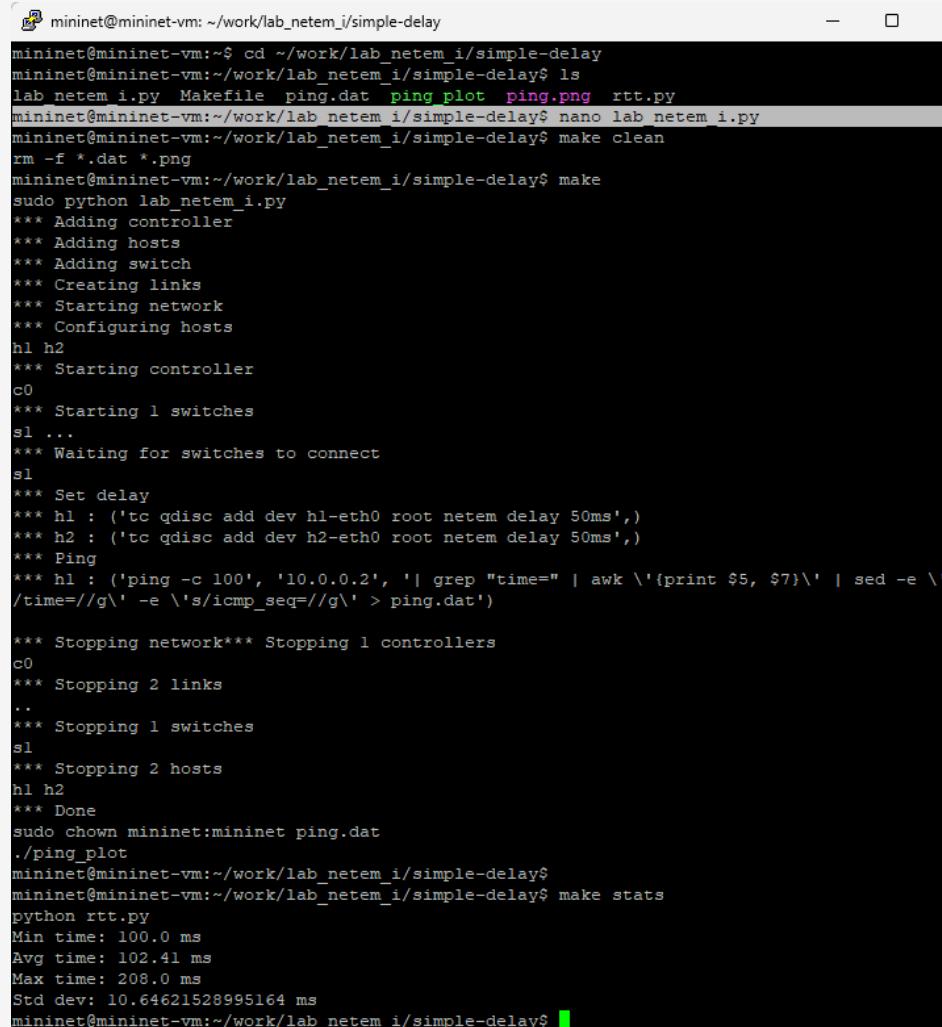
    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )

^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   ^L Go To Line
```

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$ ls
lab netem_i.py Makefile ping.dat ping_plot ping.png rtt.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ nano 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$ mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 100.0 ms
Avg time: 102.41 ms
Max time: 208.0 ms
Std dev: 10.64621528995164 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 40: Воспроизводимый эксперимент по изменению задержки

Воспроизведение экспериментов

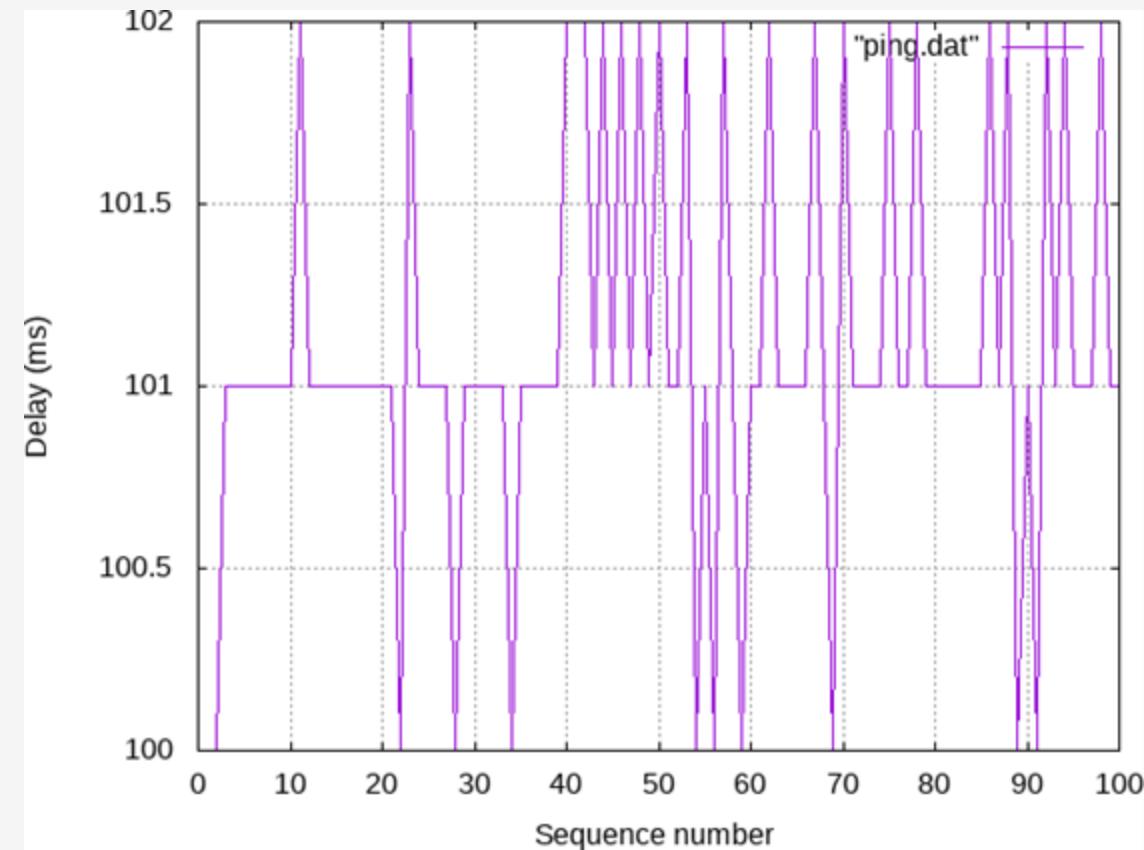
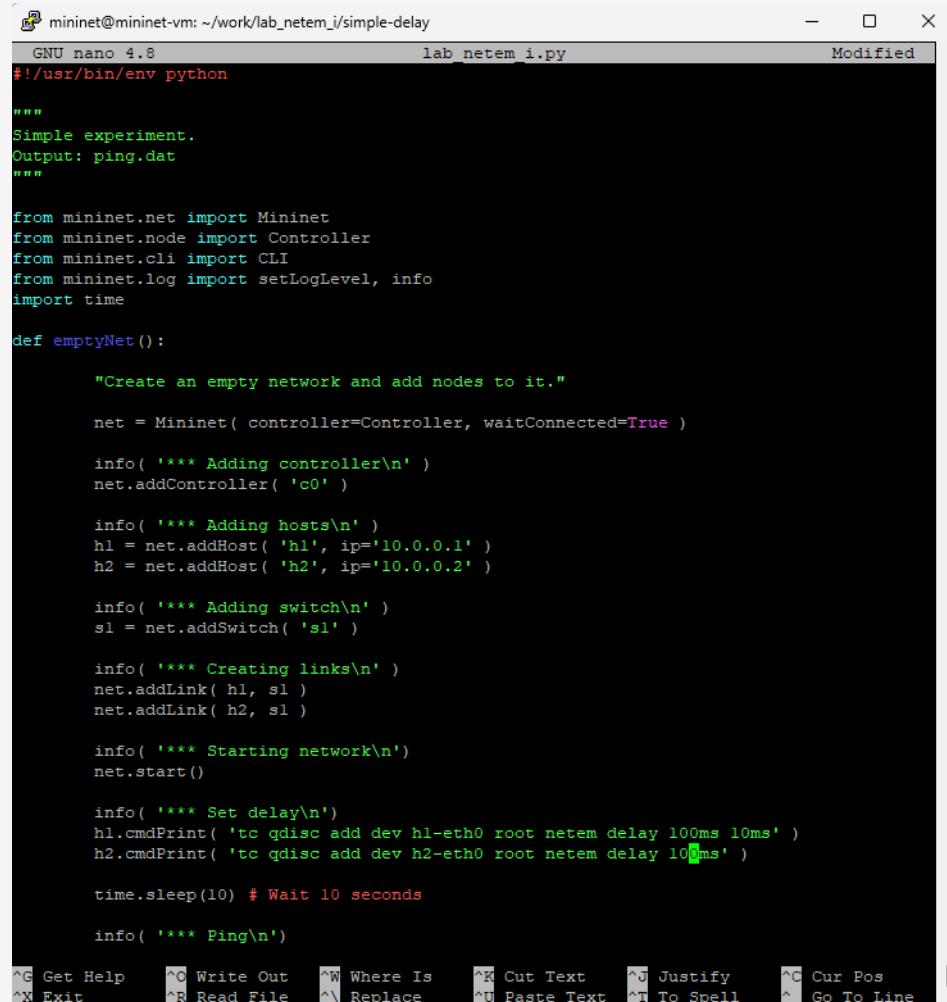


Рис. 41: Просмотр графика

Воспроизведение экспериментов



mininet@mininet-vm: ~/work/lab_netem_i/simple-delay

GNU nano 4.8 lab_netem_i.py Modified

```
#!/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' )
    sl = net.addSwitch( 's1' )

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

    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 10ms' )

    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )

^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. 42: Воспроизводимый эксперимент по изменению джиттера

Воспроизведение экспериментов

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 100.0 ms
Avg time: 102.41 ms
Max time: 208.0 ms
Std dev: 10.64621528995164 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ ls
lab netem_i.py Makefile ping.dat ping_plot ping.png rtt.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ nano 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, $7)\' | sed -e \'s/time=/g\' -e \'s/icmp_seq=/g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 43: Воспроизводимый эксперимент по изменению джиттера

Воспроизведение экспериментов

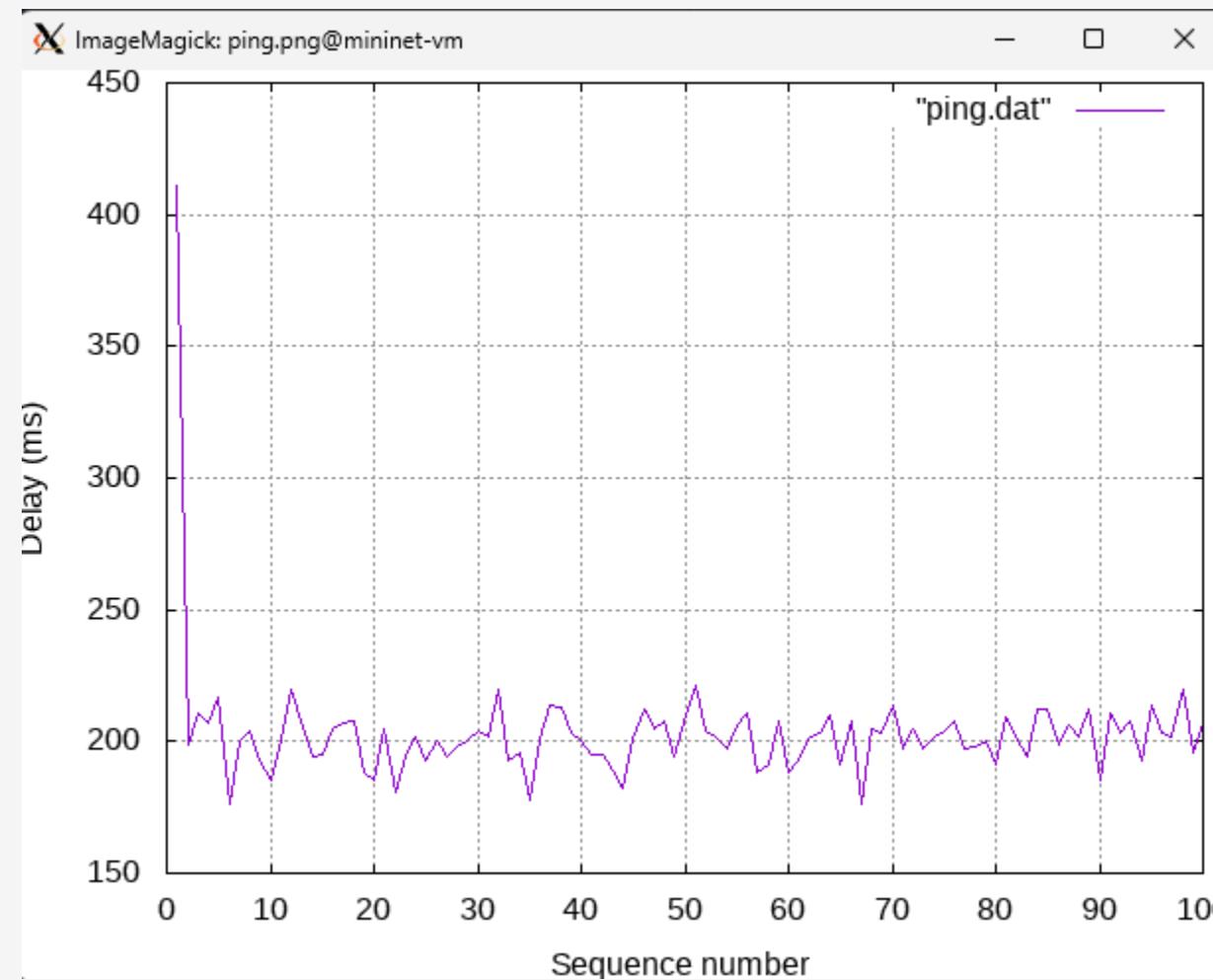
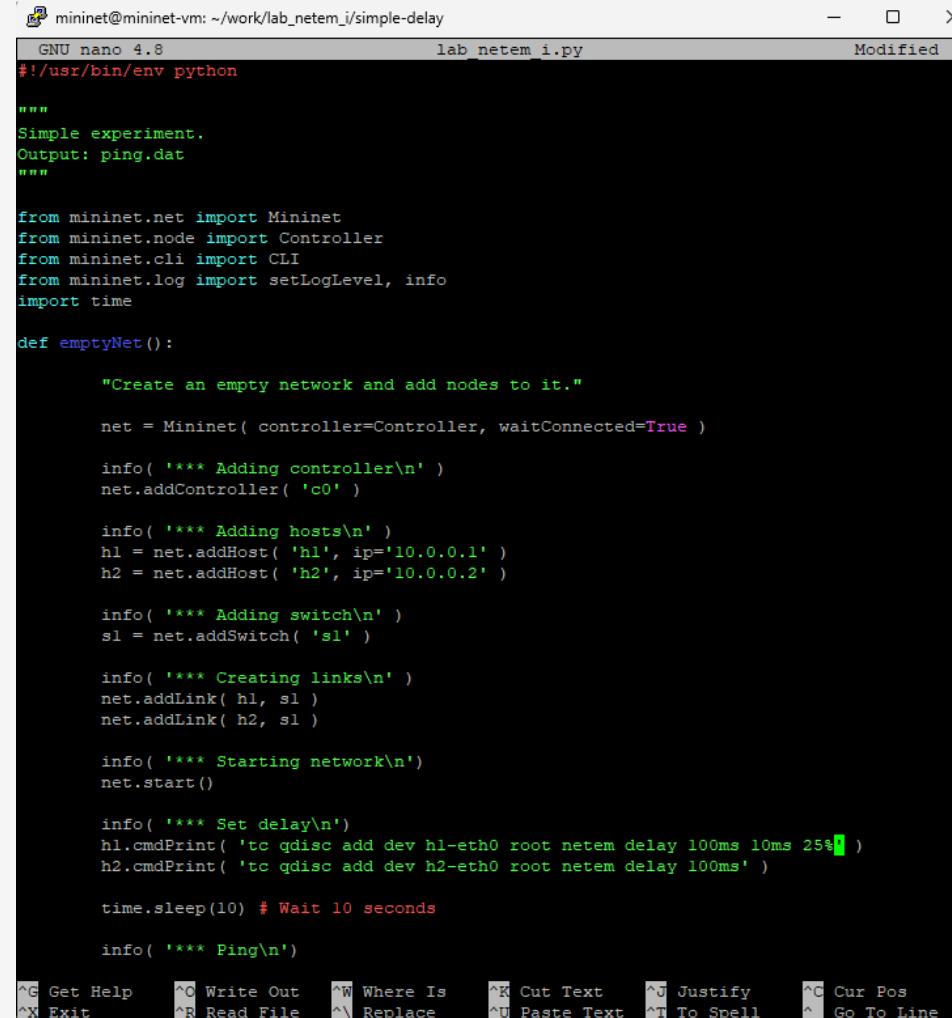


Рис. 44: Просмотр графика

Воспроизведение экспериментов



The screenshot shows a terminal window titled "mininet@mininet-vm: ~/work/lab_netem_i/simple-delay". The window contains a Python script named "lab_netem_i.py". The script performs the following steps:

- Imports necessary modules from mininet.
- Defines an empty network function ("emptyNet") which creates an empty network, adds two hosts (h1 and h2) with specific IP addresses, adds a switch (s1), and connects them.
- Creates links between hosts and the switch.
- Starts the network.
- Configures queue discipline (qdisc) on both hosts to add a netem delay of 100ms, 10ms, and 25% jitter.
- Waits for 10 seconds.
- Performs a ping test between the two hosts.

```
GNU nano 4.8          lab_netem_i.py          Modified
#!/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( '*** 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' )

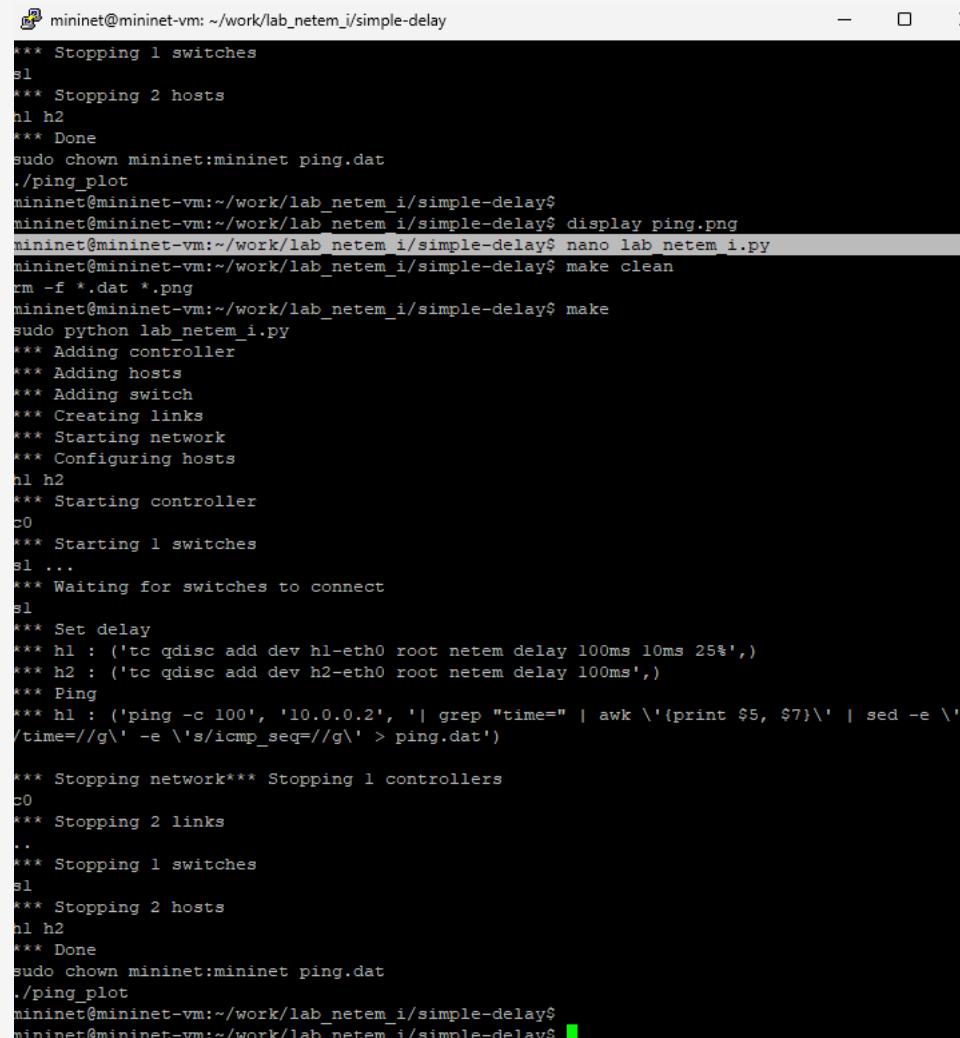
    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )

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

Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_neterm_i/simple-delay
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_neterm_i/simple-delay$ display ping.png
mininet@mininet-vm:~/work/lab_neterm_i/simple-delay$ nano lab_neterm_i.py
mininet@mininet-vm:~/work/lab_neterm_i/simple-delay$ make clean
rm -f *.dat *.png
mininet@mininet-vm:~/work/lab_neterm_i/simple-delay$ make
sudo python lab_neterm_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_neterm_i/simple-delay$ mininet@mininet-vm:~/work/lab_neterm_i/simple-delay$
```

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

Воспроизведение экспериментов

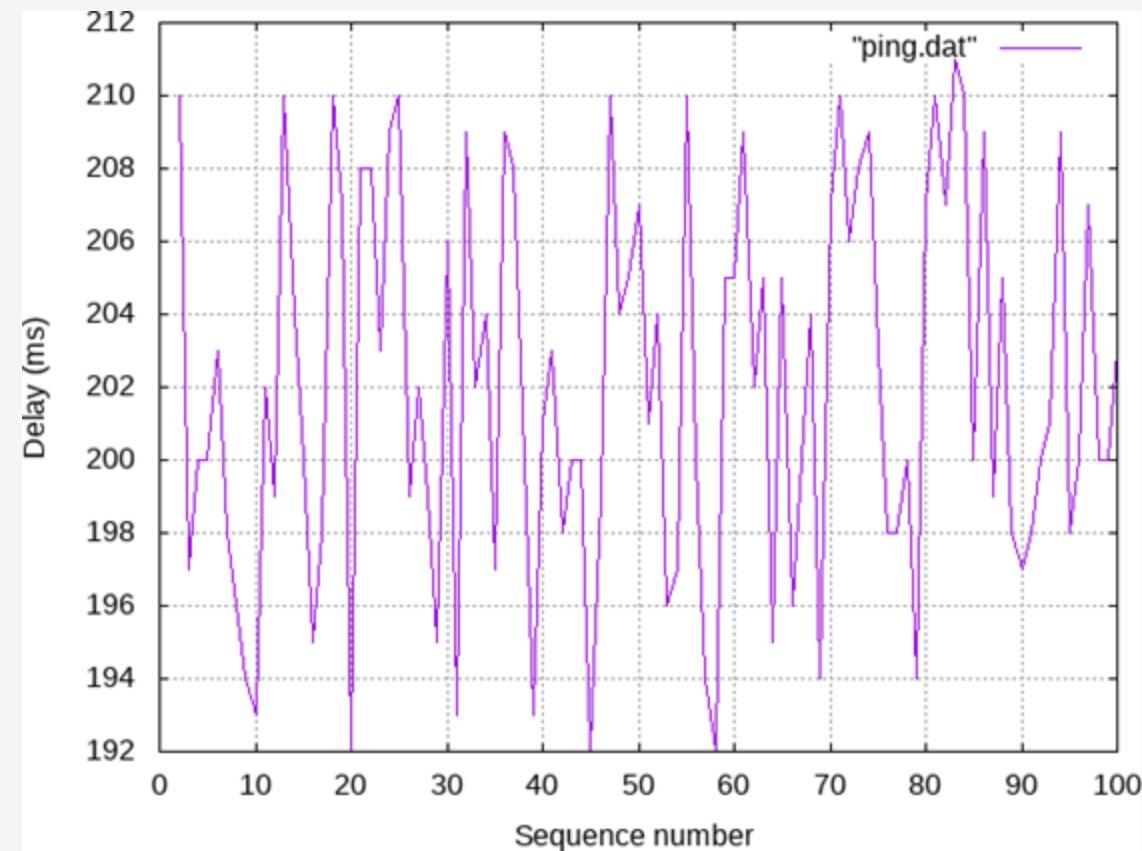
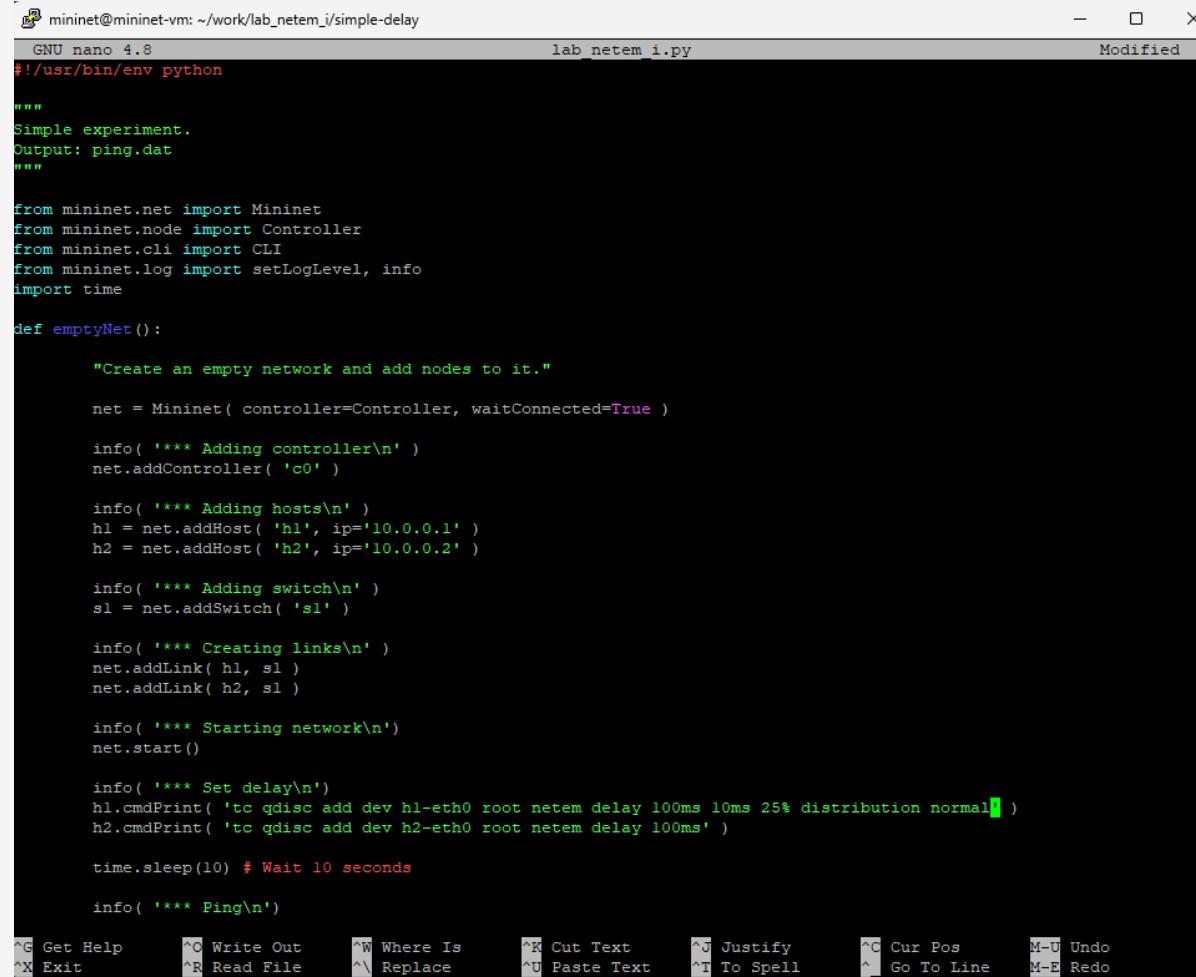


Рис. 47: Просмотр графика

Воспроизведение экспериментов



mininet@mininet-vm: ~/work/lab_neterm_i/simple-delay

```
GNU nano 4.8          lab_neterm_i.py          Modified
#!/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( '*** 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' )

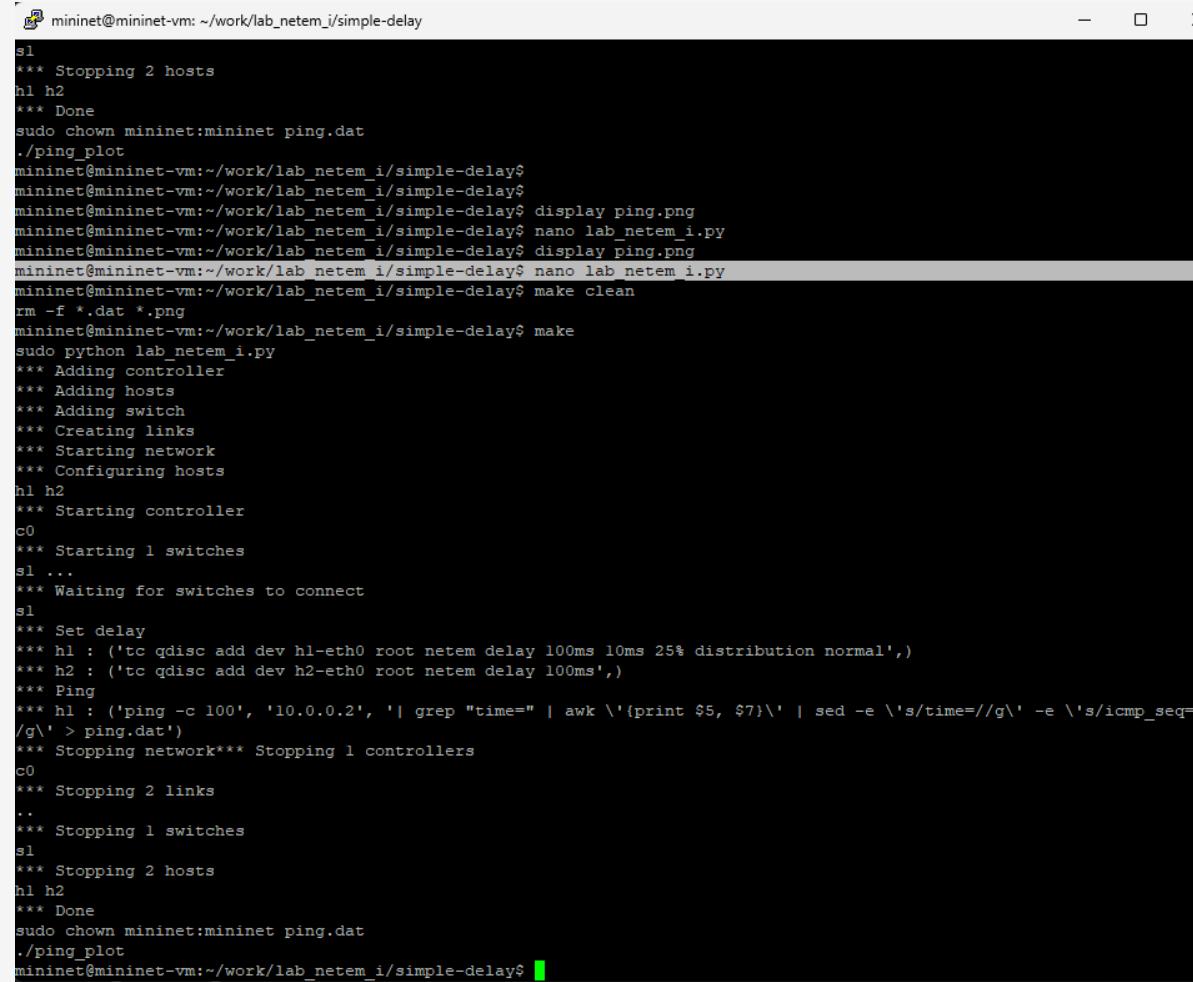
    time.sleep(10) # Wait 10 seconds

    info( '*** Ping\n' )

^G Get Help      ^O Write Out      ^N Where Is      ^K Cut Text      ^J Justify      ^C Cur Pos      M-U Undo
^X Exit         ^R Read File      ^\ Replace      ^U Paste Text     ^T To Spell     ^ Go To Line   M-E Redo
```

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

Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ display ping.png
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ nano lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ display ping.png
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ nano 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, $7}\' | sed -e \'s/time=/\\g\' -e \'s/icmp_seq=/\\g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
./ping_plot
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

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

Воспроизведение экспериментов

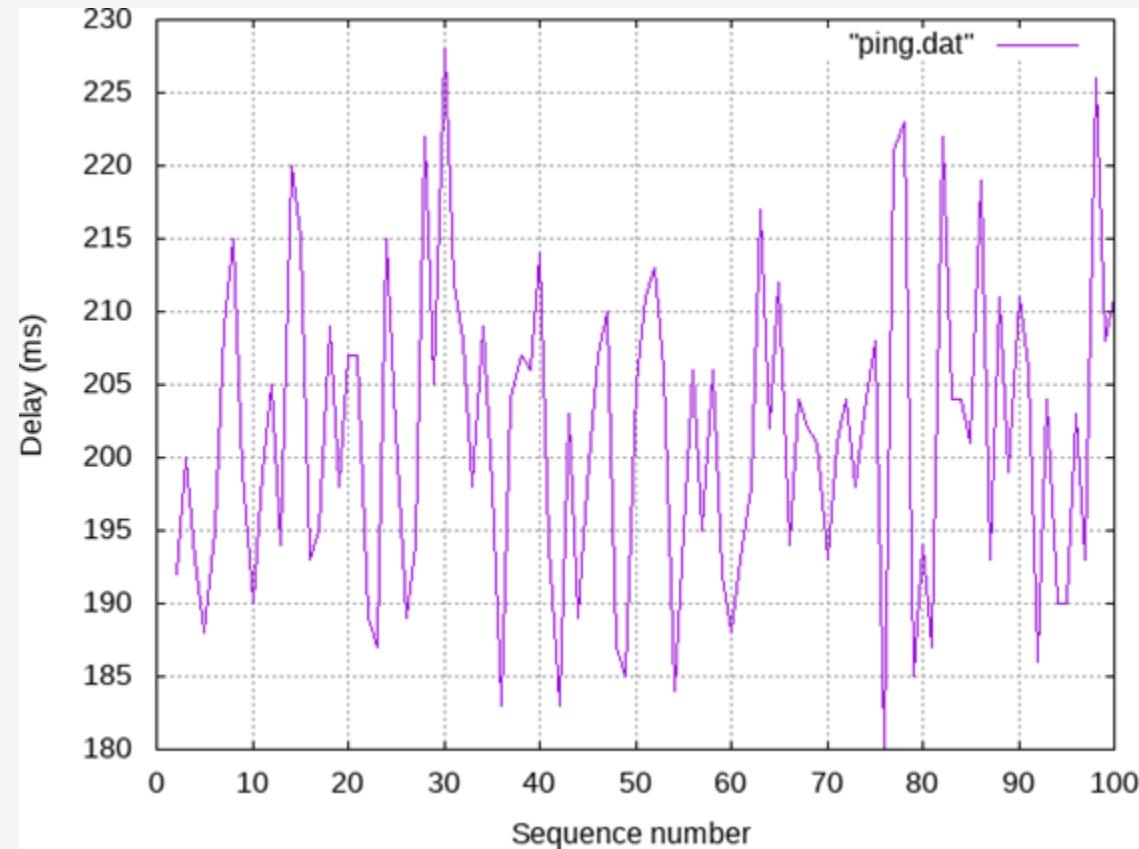


Рис. 50: Просмотр графика

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] Julia Documentation: <https://docs.julialang.org/en/v1/>