

Презентация по лабораторной работе №4

Моделирование сетей передачи данных

Еюбоглу Тимур

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Российский университет дружбы народов, Москва, Россия

- Еюбоглу Тимур
- Студент группы НПИбд-01-22
- Студ. билет 1032224357
- Российский университет дружбы народов имени Патриса Лумумбы

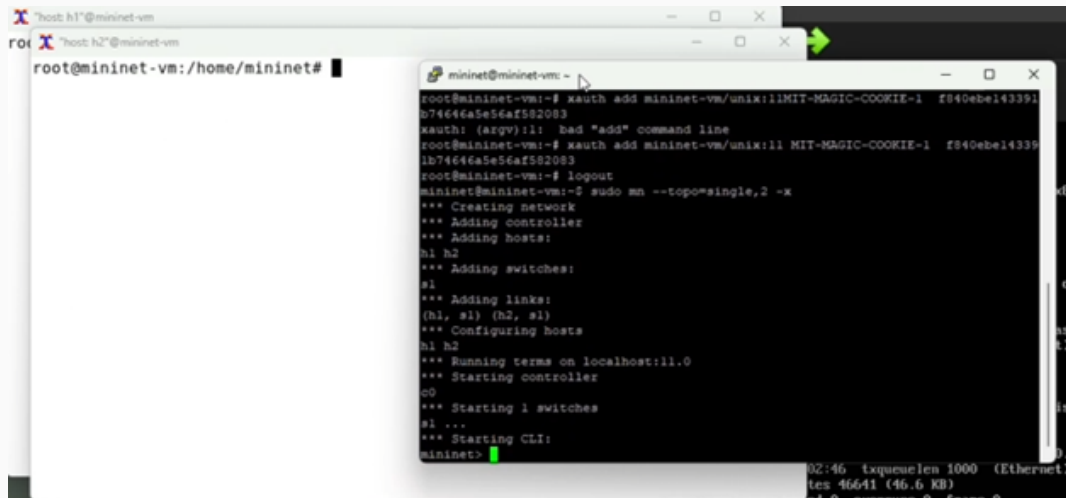
- Познакомиться с NETEM — инструментом для тестирования производительности приложений в виртуальной сети, а также получить навыки проведения интерактивного и воспроизводимого экспериментов по измерению задержки и её дрожания (jitter) в моделируемой сети в среде Mininet.

Выполнение лабораторной работы

```
mininet@mininet-vm:~$ xauth list $DISPLAY
mininet-vm/unix:11 MIT-MAGIC-COOKIE-1 f840ebel43391b74646a5e56af582083
mininet@mininet-vm:~$ sudo -i
root@mininet-vm:~# xauth add mininet-vm/unix:11MIT-MAGIC-COOKIE-1 f840ebel43391
b74646a5e56af582083
xauth: (argv):1: bad "add" command line
root@mininet-vm:~# xauth add mininet-vm/unix:11 MIT-MAGIC-COOKIE-1 f840ebel4339
1b74646a5e56af582083
root@mininet-vm:~# logout
mininet@mininet-vm:~$
```

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

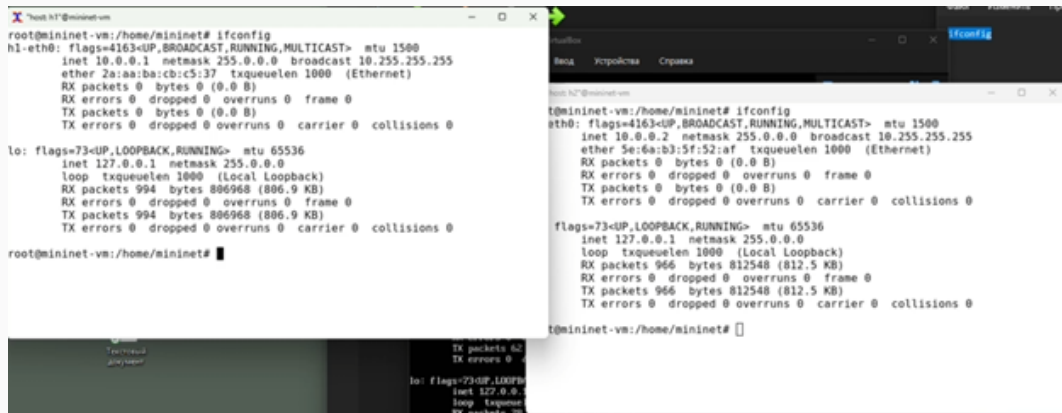
Запуск лабораторной топологии



```
root@mininet-vm:/home/mininet#  
root@mininet-vm:~# kauth add mininet-vm/unix:llMIT-MAGIC-COOKIE-1 f840ebeb143391b74646a5e56af582083  
kauth: (argv):1: bad "add" command line  
root@mininet-vm:~# kauth add mininet-vm/unix:ll MIT-MAGIC-COOKIE-1 f840ebeb143391b74646a5e56af582083  
root@mininet-vm:~# logout  
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:ll.0  
*** Starting controller  
c0  
*** Starting 1 switches  
s1 ...  
*** Starting CLI:  
mininet>
```

Рис. 2: Создание простейшей топологии

Запуск лабораторной топологии



```
root@mininet-virtual-machine:~# 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 2a:aa:ba:cb:c5:37 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 994 bytes 806968 (806.9 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 994 bytes 806968 (806.9 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@mininet-virtual-machine:~#
```

```
t@mininet-virtual-machine:~# ifconfig
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 5e:6a:b3:5f:52:af 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

flags=73<UP,LOOPBACK,RUNNING> mtu 65536
    inet 127.0.0.1 netmask 255.0.0.0
    loop txqueuelen 1000 (Local Loopback)
    RX packets 966 bytes 812548 (812.5 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 966 bytes 812548 (812.5 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

t@mininet-virtual-machine:~#
```

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

Запуск лабораторной топологии

```
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=1.40 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.328 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.059 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.063 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.064 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.050 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5091ms
rtt min/avg/max/mdev = 0.050/0.327/1.398/0.488 ms
root@mininet-vm:/home/mininet#
```

```
root@mininet-vm:/home/mininet# ifconfig
lo: flags=73<UP,LOOPBACK,RUNNING>
    inet 127.0.0.1 netmask 255.0.0.0
    loop txqueuelen 1000 (Local Loopback)
    RX packets 966 bytes 812548 (812.5 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 966 bytes 812548 (812.5 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

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=0.895 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.056 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.054 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.073 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.080 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.060 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5107ms
rtt min/avg/max/mdev = 0.054/0.203/0.895/0.309 ms
root@mininet-vm:/home/mininet#
```

Рис. 4: Проверка подключения между хостами h1 и h2

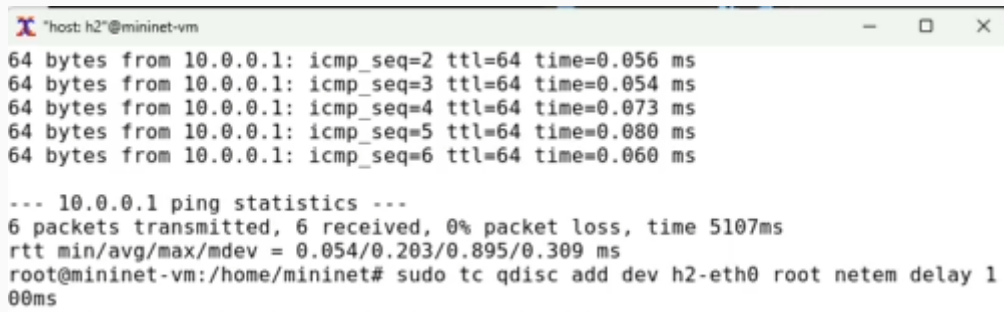

```
--- 10.0.0.2 ping statistics ---  
6 packets transmitted, 6 received, 0% packet loss, time 5091ms  
rtt min/avg/max/mdev = 0.050/0.327/1.398/0.488 ms  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1  
00ms  
root@mininet-vm:/home/mininet# █
```

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

```
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=101 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=100 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 5008ms
rtt min/avg/max/mdev = 100.071/100.507/101.183/0.450 ms
root@mininet-vm:/home/mininet#
```

Рис. 6: Проверка



```
*host: h2" @mininet-vm
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.056 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.054 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.073 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.080 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.060 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5107ms
rtt min/avg/max/mdev = 0.054/0.203/0.895/0.309 ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h2-eth0 root netem delay 100ms
```

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

```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h2-eth0 root netem delay 1
00ms
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=201 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=202 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=201 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=202 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=201 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=201 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5008ms
rtt min/avg/max/mdev = 200.724/201.278/201.968/0.411 ms
```

Рис. 8: Проверка

```
--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5008ms
rtt min/avg/max/mdev = 100.071/100.507/101.183/0.450 ms
root@mininet-virtual-machine:~# sudo tc qdisc add dev h1-eth0 root netem delay 100ms
root@mininet-virtual-machine:~#
Error: Exclusivity flag on, cannot modify.
root@mininet-virtual-machine:~# sudo tc qdisc change dev h1-eth0 root netem delay 50ms
root@mininet-virtual-machine:~#
```

```
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=202 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=201 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=202 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=201 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=201 ms
```

```
--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5008ms
rtt min/avg/max/mdev = 200.724/201.278/201.968/0.411 ms
root@mininet-virtual-machine:~# sudo tc qdisc add dev h2-eth0 root netem delay 50ms
root@mininet-virtual-machine:~#
Error: Exclusivity flag on, cannot modify.
root@mininet-virtual-machine:~# sudo tc qdisc change dev h2-eth0 root netem delay 50ms
root@mininet-virtual-machine:~#
```

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

```
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=101 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 = 100.259/101.092/102.104/0.581 ms
root@mininet-vm:/home/mininet#
```

Рис. 10: Проверка

```
rtt min/avg/max/mdev = 100.259/101.092/102.104/0.581 ms
root@mininet-virtual-machine:~# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-virtual-machine:~#
root@mininet-virtual-machine:~# ping -c 6 10.0.0.1
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=101 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=101 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=100 ms
--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5007ms
rtt min/avg/max/mdev = 100.137/101.030/101.907/0.649 ms
root@mininet-virtual-machine:~# sudo tc qdisc del dev h2-eth0 root netem
root@mininet-virtual-machine:~#
```

Рис. 11: Восстановление конфигураций по умолчанию

```
6 packets transmitted, 6 received, 0% packet loss, time 5115ms
rtt min/avg/max/mdev = 0.045/0.218/0.576/0.189 ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1
00ms 10ms
root@mininet-vm:/home/mininet#
```

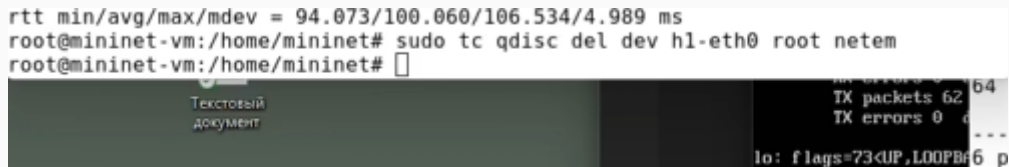
Рис. 12: Добавление на узле h1 задержки в 100 мс со случайным отклонением 10 мс


```
00ms 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=106 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=98.4 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=94.2 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=107 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=94.1 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5009ms
rtt min/avg/max/mdev = 94.073/100.060/106.534/4.989 ms
root@mininet-vm:/home/mininet#
```

Рис. 13: Проверка

```
rtt min/avg/max/mdev = 94.073/100.060/106.534/4.989 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-vm:/home/mininet#
```



Текстовый документ

TX packets 62 64
TX errors 0
lo: flags=73<UP,LOOPBACK> p

Рис. 14: Восстановление конфигурации интерфейса по умолчанию

```
root@mininet-vm:~# ping -c 20 10.0.0.2
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=91.2 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=99.5 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=94.0 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=96.0 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=103 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=100 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=105 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=96.8 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=92.5 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=97.8 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=91.0 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=96.7 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=107 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=99.4 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=97.7 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=92.5 ms
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=103 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 19033ms
rtt min/avg/max/mdev = 90.995/98.435/107.431/4.703 ms
root@mininet-vm:/home/mininet#
```

```
--- 10.0.0.2 ping statistics ---  
20 packets transmitted, 20 received, 0% packet loss, time 19033ms  
rtt min/avg/max/mdev = 90.995/98.435/107.431/4.703 ms  
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

```
20 packets transmitted, 20 received, 0% packet loss, time 19033ms
rtt min/avg/max/mdev = 90.995/98.435/107.431/4.703 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1
00ms 20ms distribution normal
root@mininet-vm:/home/mininet# █
```

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

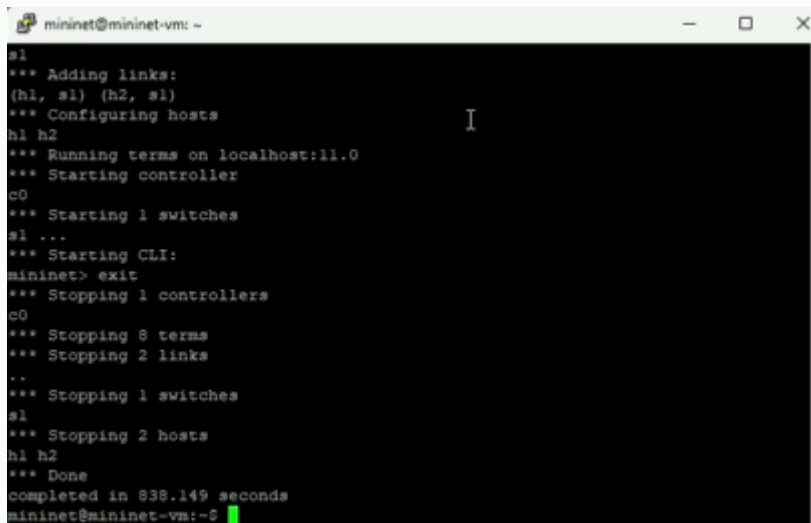
```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1
00ms 20ms distribution normal
root@mininet-vm:/home/mininet# ping -c 10 10.0.0.2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data:
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=102 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=49.4 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=126 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=84.0 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=137 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=96.2 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=90.5 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=94.3 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=122 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=105 ms

--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9014ms
rtt min/avg/max/mdev = 49.384/100.638/136.604/23.466 ms
root@mininet-vm:/home/mininet#
```

Рис. 18: Проверка

```
10 packets transmitted, 10 received, 0% packet loss, time 9014ms  
rtt min/avg/max/mdev = 49.384/100.638/136.604/23.466 ms  
root@mininet-virtual-machine:~# sudo tc qdisc del dev h1-eth0 root netem  
root@mininet-virtual-machine:~#
```

Рис. 19: Восстановление конфигурации интерфейса по умолчанию



```
mininet@mininet-vm: ~  
sl  
*** Adding links:  
(h1, s1) (h2, s1)  
*** Configuring hosts  
h1 h2  
*** Running terms on localhost:11.0  
*** 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 838.149 seconds  
mininet@mininet-vm:~$
```

Рис. 20: Завершение работы mininet в интерактивном режиме


```
*** Stopping 2 hosts
hl h2
*** Done
completed in 838.149 seconds
mininet@mininet-vm:~$ sudo apt-get update
Hit:1 http://security.ubuntu.com/ubuntu focal-security InRelease
Hit:2 http://us.archive.ubuntu.com/ubuntu focal InRelease
Hit:3 http://us.archive.ubuntu.com/ubuntu focal-updates InRelease
Hit:4 http://us.archive.ubuntu.com/ubuntu focal-backports InRelease
Reading package lists... Done
mininet@mininet-vm:~$
```

```
eth1: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 10.0.2.15 netmask 255.255.255.0 broadcast 10.0.2.255
    ether 08:00:27:06:02:46 txqueuelen 1000 (Ethernet)
    RX packets 60 bytes 6995 (6.9 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
```

Рис. 21: Обновление репозитория программного обеспечения на виртуальной машине

Воспроизведение экспериментов



mininet@mininet-vm: ~



```
python3-talloc python3-tz python3-wadllib rtkit rygel samba-libs sane-utils  
session-migration sgml-base sgml-data switcheroo-control  
system-config-printer system-config-printer-common  
system-config-printer-udev ubuntu-docs ubuntu-session ubuntu-wallpapers  
ubuntu-wallpapers-focal update-inetd upower usb-modeswitch  
usb-modeswitch-data usbmuxd va-driver-all vdpau-driver-all  
whoopsie-preferences wpasupplicant xdg-dbus-proxy xfonts-base  
xfonts-encodings xfonts-utils xml-core xserver-common xserver-xephyr  
xserver-xorg xserver-xorg-core xserver-xorg-input-all  
xserver-xorg-input-libinput xserver-xorg-input-wacom xserver-xorg-legacy  
xserver-xorg-video-all xserver-xorg-video-amdgpu xserver-xorg-video-ati  
xserver-xorg-video-fbdev xserver-xorg-video-intel xserver-xorg-video-nouveau  
xserver-xorg-video-qxl xserver-xorg-video-radeon xserver-xorg-video-vesa  
xserver-xorg-video-vmware xwayland yaru-theme-gnome-shell yelp yelp-xsl  
zenity zenity-common
```

The following packages will be upgraded:

```
dbus language-selector-common libcups2 libdbus-1-3 libdrm-amdgpu1 libegl1  
libgl1 libgl1-glx2.0-0 libglvnd0 libglx0 libgstreamer-plugins-basel.0-0  
libgstreamer1.0-0 libp11-kit0 libpolkit-gobject-1-0 libpulse0 libtdb1  
libwebp-mux3
```

17 upgraded, 410 newly installed, 0 to remove and 377 not upgraded.

Need to get 181 MB of archives. |

After this operation, 744 MB of additional disk space will be used.

Do you want to continue? [Y/n]

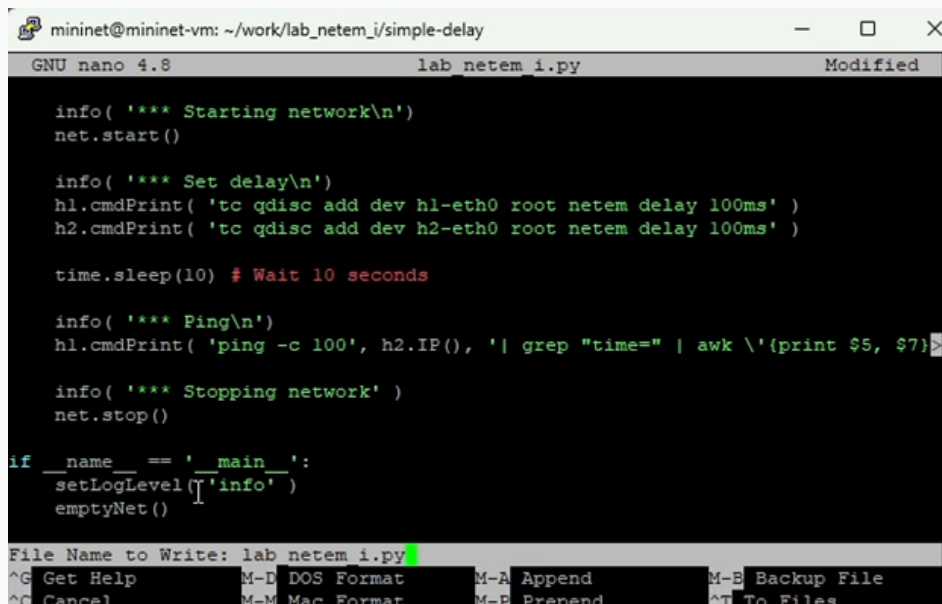
```
Processing triggers for rygel (0.38.3-lubuntu1) ...  
Processing triggers for sgml-base (1.29.1) ...  
mininet@mininet-vm:~$ mkdir -p ~/work/lab_netem_i/expname  
mininet@mininet-vm:~$
```

Рис. 23: Создание нового каталога

```
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

Воспроизведение экспериментов



The screenshot shows a terminal window titled "mininet@mininet-vm: ~/work/lab_netem_i/simple-delay". The window contains the GNU nano 4.8 editor editing the file "lab_netem_i.py". The script defines a network, sets a delay on two interfaces, waits 10 seconds, and then pings them. The cursor is at the end of the ping command line.

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
GNU nano 4.8 lab_netem_i.py Modified

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

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

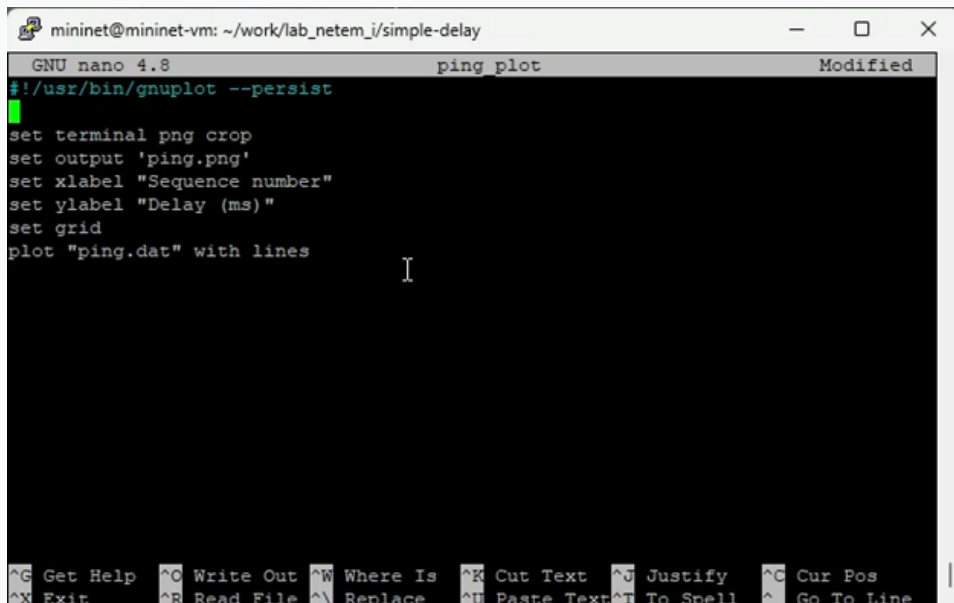
if __name__ == '__main__':
    setLogLevel('info')
    emptyNet()
```

File Name to Write: lab_netem_i.py

^G Get Help	M-D DOS Format	M-A Append	M-B Backup File
^C Cancel	M-M Mac Format	M-E Prepend	^T To Files

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

Рис. 26: Создание файла ping_plot



The screenshot shows a terminal window titled "mininet@mininet-vm: ~/work/lab_netem_i/simple-delay". Inside the terminal, the GNU nano 4.8 editor is open, editing a file named "ping_plot". The editor's status bar at the top indicates "GNU nano 4.8", the filename "ping_plot", and the word "Modified". The script content is as follows:

```
#!/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
```

A cursor is visible on the line "plot 'ping.dat' with lines". The bottom of the terminal window displays a row of keyboard shortcuts for the nano editor:

^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

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

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$ ls
```

Рис. 29: Создание файла Makefile

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
/home/mi~Makefile  [-M--]  0 L:[  1+10  11/ 11] *(140 / 159b) 0009 0x009 [*][X]
all: ping.dat ping.png

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

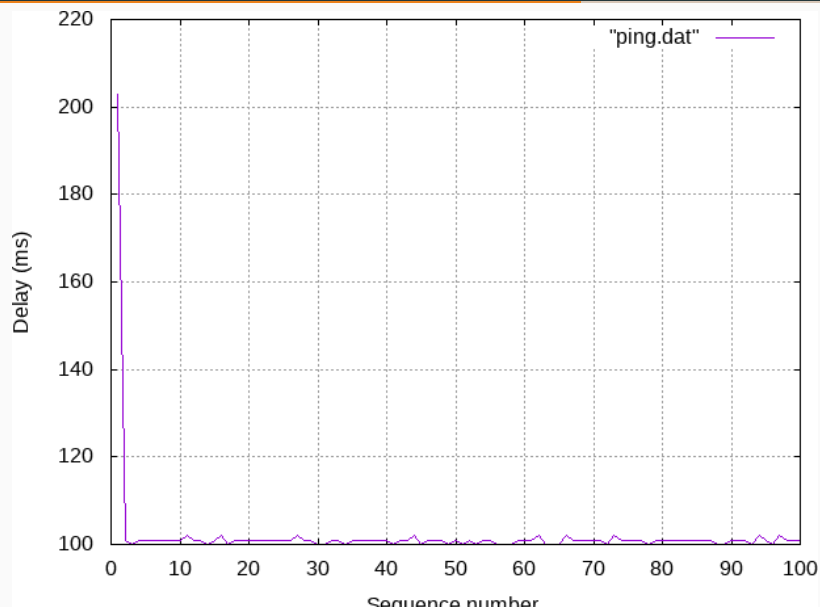
ping.png: ping.dat
<----->./ping_plot

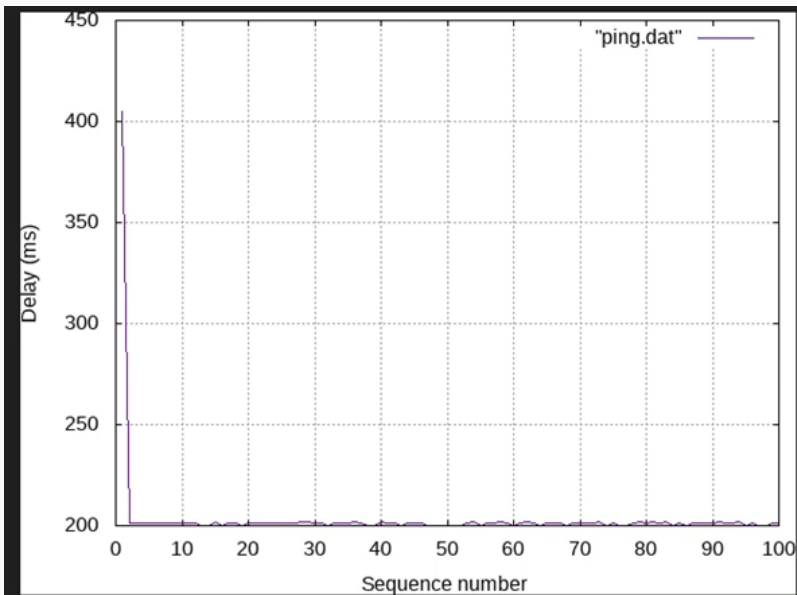
clean:
<----->-rm -f *.dat *.png

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

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

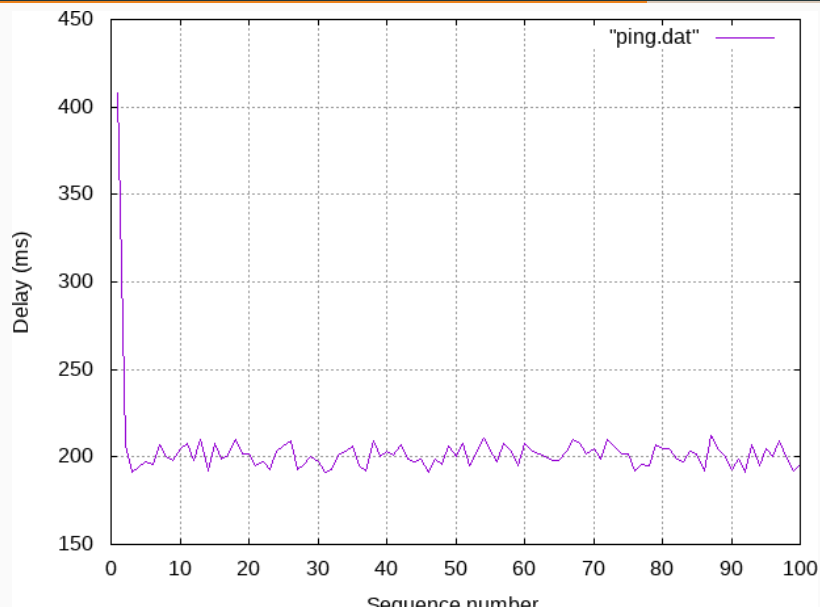


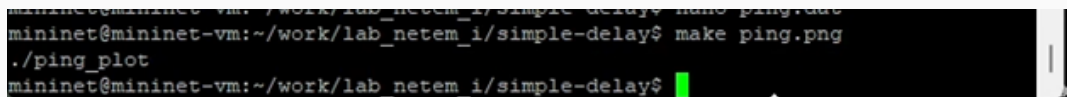


Воспроизведение экспериментов



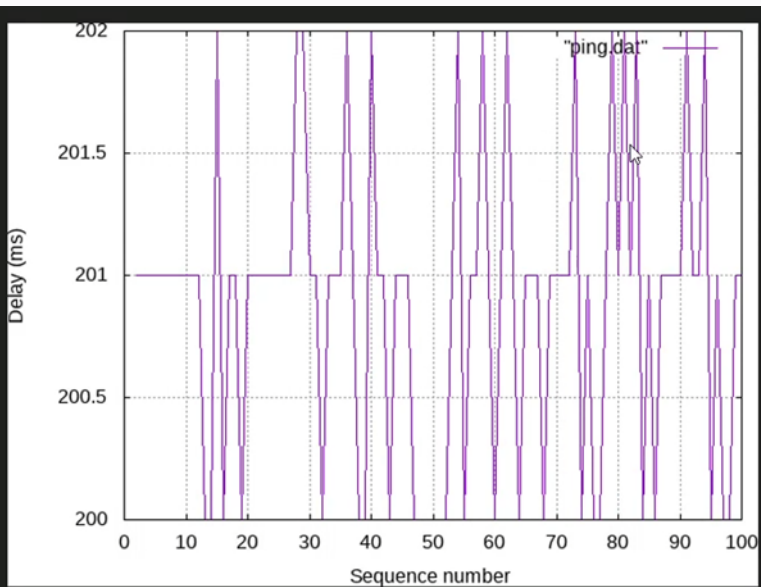
```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
GNU nano 4.8 ping.dat Modified
2 201
3 201
4 201
5 201
6 201
7 201
8 201
9 201
10 201
11 201
12 201
13 200
14 200
15 202
16 200
17 201
18 201
19 200
20 201
21 201
[ Read 100 lines ]
^G Get Help ^O Write Out ^W Where Is ^K Cut Text ^J Justify ^C Cur Pos
^X Exit ^R Read File ^\ Replace ^U Paste Text ^T To Spell ^_ Go To Line
```





```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay$ nano 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. 36: Разработка скрипта для вычисления на основе данных файла ping.dat минимального, среднего, максимального и стандартного отклонения времени приёма-передачи



Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
GNU nano 4.8                                rtt.py                                Modified
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()

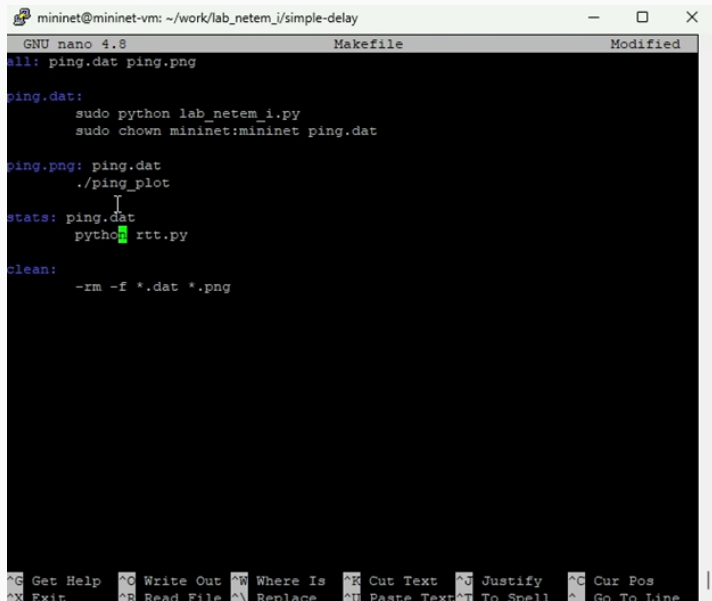
    min_time, avg_time, max_time, std_dev = calc_stat(data)

    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()

File Name to Write: rtt.py
^G Get Help      M-D DOS Format  M-A Append      M-B Backup File
^C Cancel        M-M Mac Format  M-E Prepend     ^T To Files
```

Воспроизведение экспериментов



The screenshot shows a terminal window with a title bar indicating the user is 'mininet' on a 'mininet-vm' at the directory '~/work/lab_netem_i/simple-delay'. The terminal is running the GNU nano 4.8 text editor, editing a file named 'Makefile'. The Makefile contains the following content:

```
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

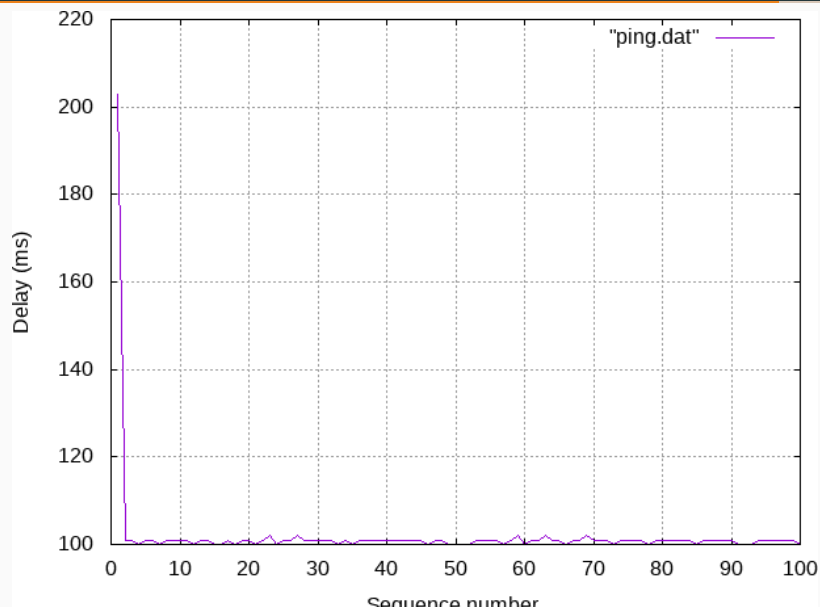
stats: ping.dat
    python rtt.py

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

The bottom of the terminal window displays a status bar with various keyboard shortcuts for the nano editor, such as '^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', and '^_ Go To Line'.

```
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$ make stats
python rtt.py
Min time: 200.0 ms
Avg time: 200.87878787878788 ms
Max time: 202.0 ms
Std dev: 0.6239775843022425 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```

Рис. 40: Воспроизводимый эксперимент по изменению задержки



Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_i/simple-delay
GNU nano 4.8 lab_netem_i.py Modified
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 50ms' )
h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 50ms' )

time.sleep(10) # Wait 10 seconds

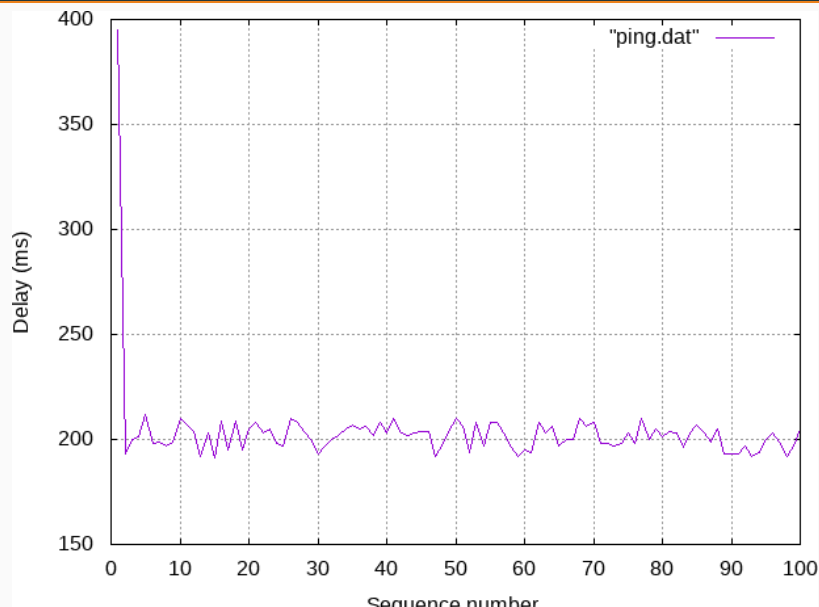
info( '*** Ping\n' )
h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "time=" | awk \'{print $5, $7}\'' )

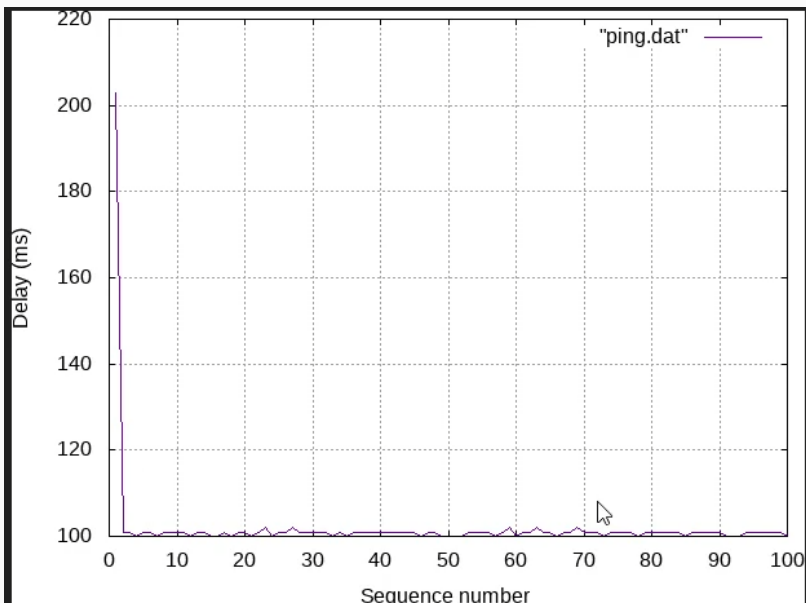
info( '*** Stopping network' )
net.stop()

if __name__ == '__main__':
    ^G Get Help    ^O Write Out    ^W Where Is    ^K Cut Text    ^J Justify    ^C Cur Pos
    ^Y Exit       ^P Read File   ^\ Replace    ^H Paste Text  ^T To Spell   ^_ Go To Line
```

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 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: 101.82 ms
Max time: 203.0 ms
Std dev: 10.181728733373324 ms
mininet@mininet-vm:~/work/lab_netem_i/simple-delay$
```





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' )

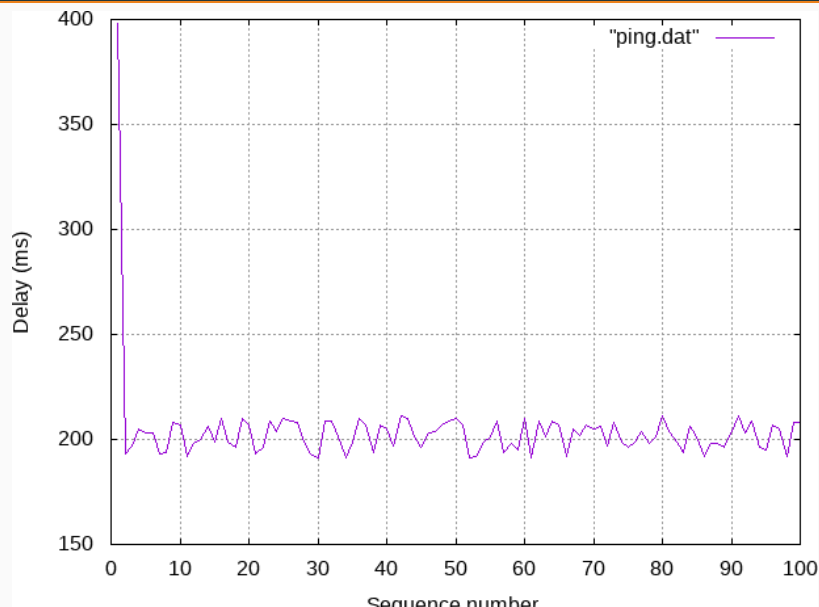
    info( '*** Adding switch\n' )
    s1 = net.addSwitch( 's1' )

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

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

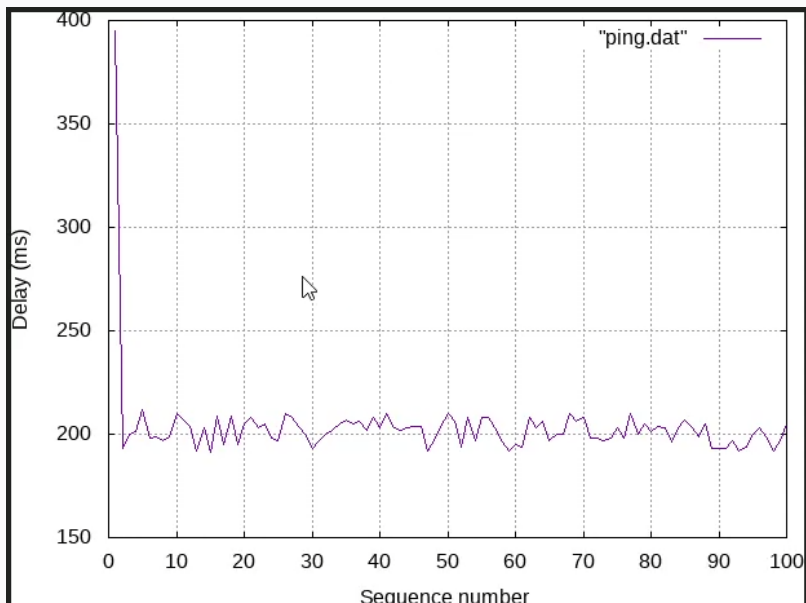
    info( '*** Set delay\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem delay 100ms 10ms' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem delay 100ms 10ms' )

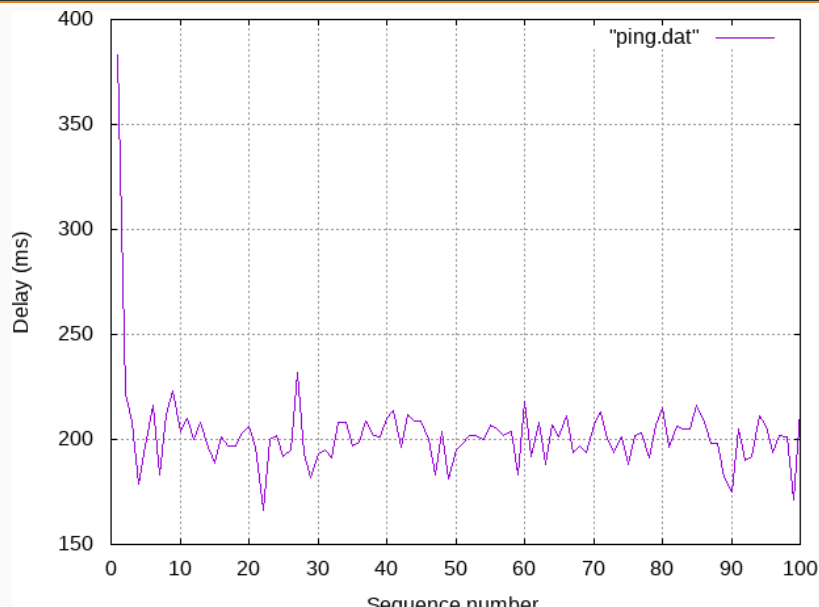
Get Help  Write Out  Where Is  Cut Text  Justify  Cur Pos
Exit      Read File  Delete  Back To Top  To Scroll  Go To Line
```



Воспроизведение экспериментов

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





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/>