

Лабораторная работа №5

Моделирование сетей передачи данных

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2025

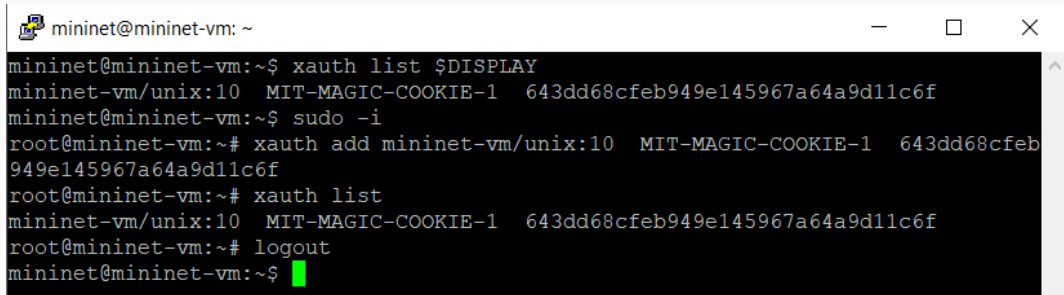
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- Получить навыки проведения интерактивных экспериментов в среде Mininet по исследованию параметров сети, связанных с потерей, дублированием, изменением порядка и повреждением пакетов при передаче данных. Эти параметры влияют на производительность протоколов и сетей.

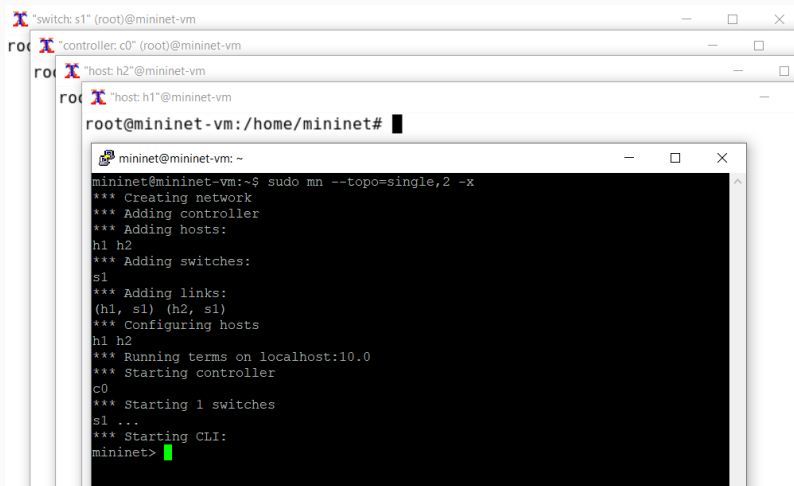
Выполнение лабораторной работы



```
mininet@mininet-vm: ~  
mininet@mininet-vm:~$ xauth list $DISPLAY  
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  643dd68cf949e145967a64a9d11c6f  
mininet@mininet-vm:~$ sudo -i  
root@mininet-vm:~# xauth add mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  643dd68cf949e145967a64a9d11c6f  
root@mininet-vm:~# xauth list  
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  643dd68cf949e145967a64a9d11c6f  
root@mininet-vm:~# logout  
mininet@mininet-vm:~$
```

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

Запуск лабораторной топологии

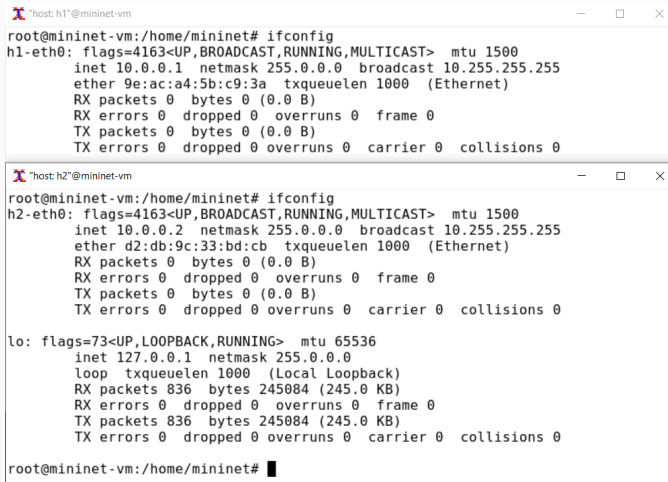


The image shows a series of overlapping terminal windows in a desktop environment. The top-most window is titled "switch: s1" (root)@mininet-vm. Below it, another window is titled "controller: c0" (root)@mininet-vm. A third window is titled "host: h2" (root)@mininet-vm. The bottom-most window is titled "root@mininet-vm:/home/mininet#" and shows the execution of the command `sudo mn --topo=single,2 -x`. The output of this command is as follows:

```
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: 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 9e:ac:a4:5b:c9:3a txqueuelen 1000 (Ethernet)
    RX packets 0 bytes 0 (0.0 B)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 0 bytes 0 (0.0 B)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

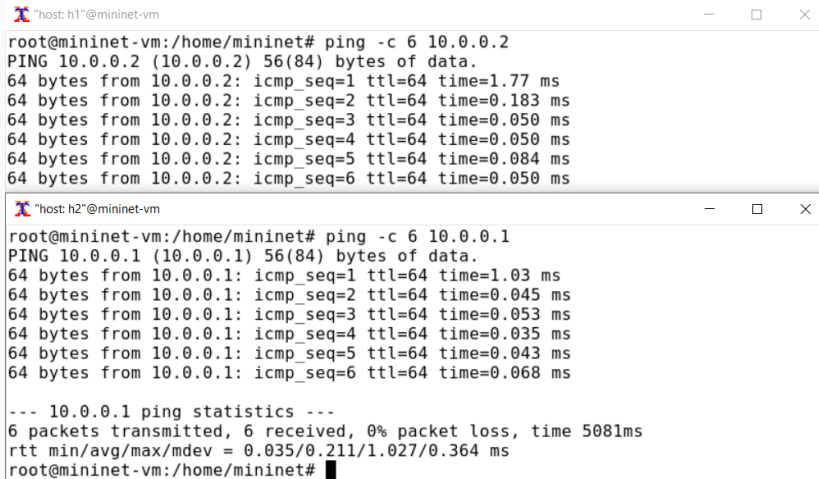
host: h2"@mininet-vm
root@mininet-vm:/home/mininet# ifconfig
h2-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 10.0.0.2 netmask 255.0.0.0 broadcast 10.255.255.255
    ether d2:db:9c:33:bd:cb txqueuelen 1000 (Ethernet)
    RX packets 0 bytes 0 (0.0 B)
    RX errors 0 dropped 0 overruns 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 836 bytes 245084 (245.0 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 836 bytes 245084 (245.0 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

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

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

Запуск лабораторной топологии



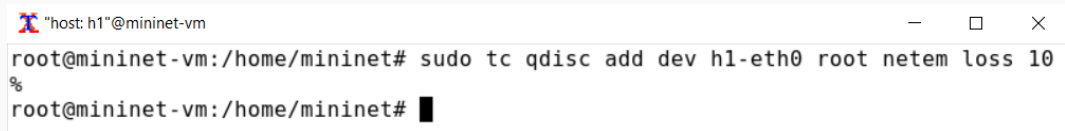
The image shows two terminal windows from a Mininet VM. The top window, titled '"host: h1"@mininet-vm', shows a ping command being executed from root@mininet-vm to 10.0.0.2. The output shows six successful ICMP echo requests with varying response times. The bottom window, titled '"host: h2"@mininet-vm', shows a ping command being executed from root@mininet-vm to 10.0.0.1. The output shows six successful ICMP echo requests with varying response times, followed by a summary of the ping statistics showing 0% packet loss and an average round-trip time of 0.211ms.

```
"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=1.77 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.183 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.050 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.050 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.084 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.050 ms

"host: h2"@mininet-vm
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=1.03 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.045 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.053 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.035 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.043 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.068 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5081ms
rtt min/avg/max/mdev = 0.035/0.211/1.027/0.364 ms
root@mininet-vm:/home/mininet#
```

Рис. 4: Проверка подключения между хостами h1 и h2



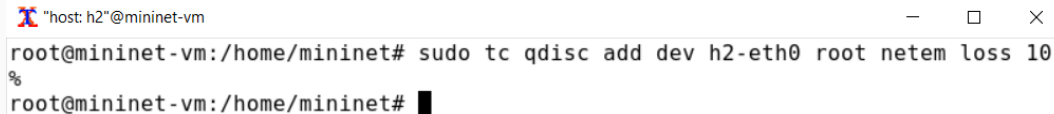
```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem loss 10%
root@mininet-vm:/home/mininet#
```

Рис. 5: Добавление 10% потерь пакетов на хосте h1

```
"host: h1"@mininet-vm
64 bytes from 10.0.0.2: icmp_seq=81 ttl=64 time=0.043 ms
64 bytes from 10.0.0.2: icmp_seq=82 ttl=64 time=0.066 ms
64 bytes from 10.0.0.2: icmp_seq=84 ttl=64 time=0.059 ms
64 bytes from 10.0.0.2: icmp_seq=85 ttl=64 time=0.047 ms
64 bytes from 10.0.0.2: icmp_seq=86 ttl=64 time=0.057 ms
64 bytes from 10.0.0.2: icmp_seq=87 ttl=64 time=0.056 ms
64 bytes from 10.0.0.2: icmp_seq=88 ttl=64 time=0.044 ms
64 bytes from 10.0.0.2: icmp_seq=89 ttl=64 time=0.058 ms
64 bytes from 10.0.0.2: icmp_seq=90 ttl=64 time=0.041 ms
64 bytes from 10.0.0.2: icmp_seq=91 ttl=64 time=0.082 ms
64 bytes from 10.0.0.2: icmp_seq=92 ttl=64 time=0.041 ms
64 bytes from 10.0.0.2: icmp_seq=93 ttl=64 time=0.069 ms
64 bytes from 10.0.0.2: icmp_seq=94 ttl=64 time=0.181 ms
64 bytes from 10.0.0.2: icmp_seq=95 ttl=64 time=0.044 ms
64 bytes from 10.0.0.2: icmp_seq=96 ttl=64 time=0.044 ms
64 bytes from 10.0.0.2: icmp_seq=97 ttl=64 time=0.041 ms
64 bytes from 10.0.0.2: icmp_seq=98 ttl=64 time=0.057 ms
64 bytes from 10.0.0.2: icmp_seq=99 ttl=64 time=0.042 ms
64 bytes from 10.0.0.2: icmp_seq=100 ttl=64 time=0.116 ms

--- 10.0.0.2 ping statistics ---
100 packets transmitted, 93 received, 7% packet loss, time 101324ms
rtt min/avg/max/mdev = 0.037/0.076/0.868/0.100 ms
root@mininet-vm:/home/mininet#
```

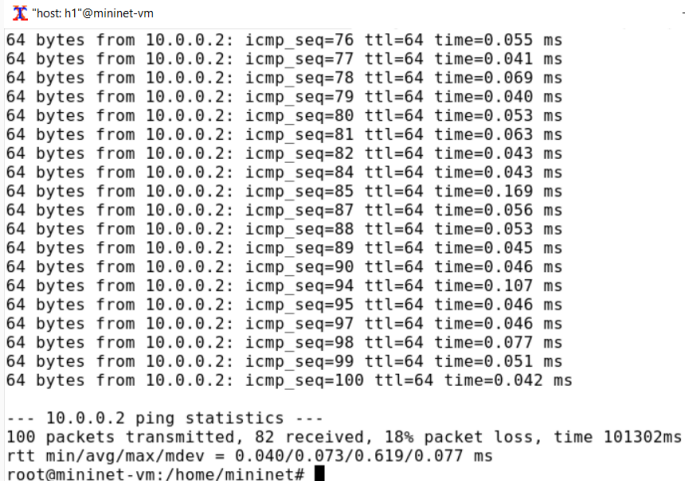
Рис. 6: Проверка



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 loss 10%. The cursor is at the end of the command line.

```
"host: h2"@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h2-eth0 root netem loss 10  
%  
root@mininet-vm:/home/mininet#
```

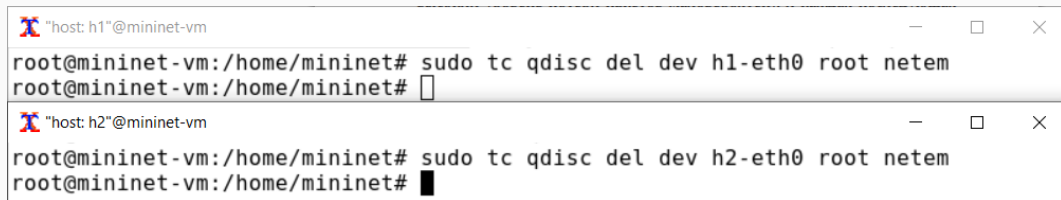
Рис. 7: Добавление 10% потерь пакетов на хосте h2



```
"host: h1"@mininet-vm
64 bytes from 10.0.0.2: icmp_seq=76 ttl=64 time=0.055 ms
64 bytes from 10.0.0.2: icmp_seq=77 ttl=64 time=0.041 ms
64 bytes from 10.0.0.2: icmp_seq=78 ttl=64 time=0.069 ms
64 bytes from 10.0.0.2: icmp_seq=79 ttl=64 time=0.040 ms
64 bytes from 10.0.0.2: icmp_seq=80 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=81 ttl=64 time=0.063 ms
64 bytes from 10.0.0.2: icmp_seq=82 ttl=64 time=0.043 ms
64 bytes from 10.0.0.2: icmp_seq=84 ttl=64 time=0.043 ms
64 bytes from 10.0.0.2: icmp_seq=85 ttl=64 time=0.169 ms
64 bytes from 10.0.0.2: icmp_seq=87 ttl=64 time=0.056 ms
64 bytes from 10.0.0.2: icmp_seq=88 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=89 ttl=64 time=0.045 ms
64 bytes from 10.0.0.2: icmp_seq=90 ttl=64 time=0.046 ms
64 bytes from 10.0.0.2: icmp_seq=94 ttl=64 time=0.107 ms
64 bytes from 10.0.0.2: icmp_seq=95 ttl=64 time=0.046 ms
64 bytes from 10.0.0.2: icmp_seq=97 ttl=64 time=0.046 ms
64 bytes from 10.0.0.2: icmp_seq=98 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=99 ttl=64 time=0.051 ms
64 bytes from 10.0.0.2: icmp_seq=100 ttl=64 time=0.042 ms

--- 10.0.0.2 ping statistics ---
100 packets transmitted, 82 received, 18% packet loss, time 101302ms
rtt min/avg/max/mdev = 0.040/0.073/0.619/0.077 ms
root@mininet-vm:/home/mininet#
```

Рис. 8: Проверка

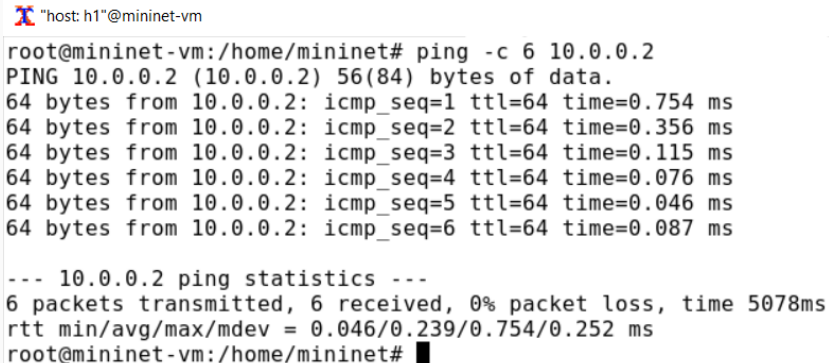


The image shows two terminal windows. The top window is titled '"host: h1"@mininet-vm' and contains the command `sudo tc qdisc del dev h1-eth0 root netem` followed by a prompt. The bottom window is titled '"host: h2"@mininet-vm' and contains the command `sudo tc qdisc del dev h2-eth0 root netem` followed 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. 9: Восстановление конфигурации по умолчанию для хоста h1 и хоста h2

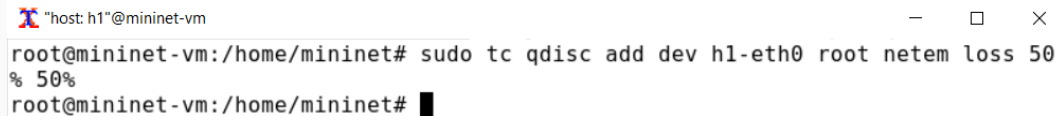


A terminal window titled "host: h1"@mininet-vm. The terminal shows a root user at mininet-vm executing a ping command to 10.0.0.2. The output displays six successful ping attempts with decreasing response times, followed by a summary of the statistics.

```
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=0.754 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.356 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.115 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.076 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.046 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.087 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5078ms
rtt min/avg/max/mdev = 0.046/0.239/0.754/0.252 ms
root@mininet-vm:/home/mininet#
```

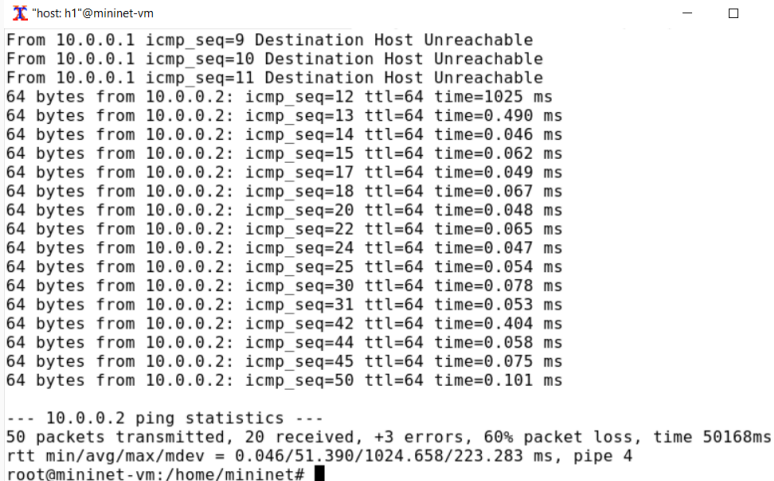
Рис. 10: Проверка



A terminal window titled "host: h1"@mininet-vm. The prompt is root@mininet-vm:/home/mininet#. The command executed is sudo tc qdisc add dev h1-eth0 root netem loss 50% 50%. The output shows the command was successful, and 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 loss 50  
% 50%  
root@mininet-vm:/home/mininet#
```

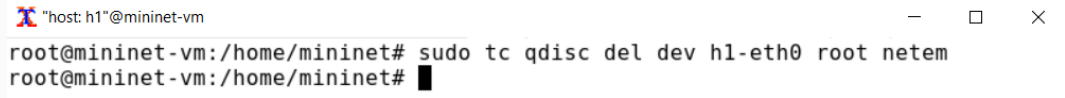
Рис. 11: Добавление на узле h1 коэффициента потери пакетов 50%



```
"host: h1"@mininet-vm
From 10.0.0.1 icmp_seq=9 Destination Host Unreachable
From 10.0.0.1 icmp_seq=10 Destination Host Unreachable
From 10.0.0.1 icmp_seq=11 Destination Host Unreachable
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=1025 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.490 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=0.046 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.062 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.049 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.067 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=0.048 ms
64 bytes from 10.0.0.2: icmp_seq=22 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=24 ttl=64 time=0.047 ms
64 bytes from 10.0.0.2: icmp_seq=25 ttl=64 time=0.054 ms
64 bytes from 10.0.0.2: icmp_seq=30 ttl=64 time=0.078 ms
64 bytes from 10.0.0.2: icmp_seq=31 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=42 ttl=64 time=0.404 ms
64 bytes from 10.0.0.2: icmp_seq=44 ttl=64 time=0.058 ms
64 bytes from 10.0.0.2: icmp_seq=45 ttl=64 time=0.075 ms
64 bytes from 10.0.0.2: icmp_seq=50 ttl=64 time=0.101 ms

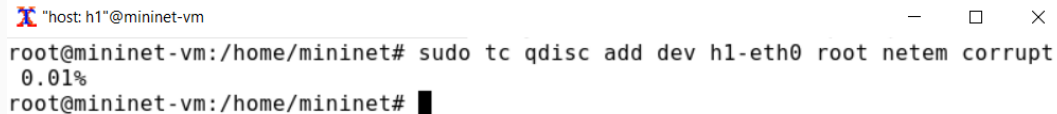
--- 10.0.0.2 ping statistics ---
50 packets transmitted, 20 received, +3 errors, 60% packet loss, time 50168ms
rtt min/avg/max/mdev = 0.046/51.390/1024.658/223.283 ms, pipe 4
root@mininet-vm:/home/mininet#
```

Рис. 12: 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. 13: 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 corrupt 0.01%. 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 corrupt  
0.01%  
root@mininet-vm:/home/mininet#
```

Рис. 14: Добавление на узле h1 0.01% повреждения пакетов

Интерактивные эксперименты

```
host: h1@mininet-vm
root@mininet-vm:/home/mininet# iperf3 -c 10.0.0.2
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 56164 connected to 10.0.0.2 port 5201
[ ID] Interval      Transfer    Bitrate      Retr  Cwnd
[ 7]  0.00-1.00    sec  1.65 GBytes  14.2 Gbits/sec  1    3.43 MBytes
[ 7]  1.00-2.00    sec  1.61 GBytes  13.9 Gbits/sec  3    1.19 MBytes
[ 7]  2.00-3.00    sec  1.42 GBytes  12.2 Gbits/sec  0    1.19 MBytes
[ 7]  3.00-4.00    sec  788 MBytes  6.60 Gbits/sec  3    591 KBytes
[ 7]  4.00-5.00    sec  1.08 GBytes  9.31 Gbits/sec  2    609 KBytes
[ 7]  5.00-6.00    sec  1.65 GBytes  14.2 Gbits/sec  0    609 KBytes
[ 7]  6.00-7.00    sec  1.66 GBytes  14.3 Gbits/sec  2    665 KBytes
[ 7]  7.00-8.00    sec  1.67 GBytes  14.4 Gbits/sec  3    621 KBytes
[ 7]  8.00-9.00    sec  1.67 GBytes  14.4 Gbits/sec  4    584 KBytes
[ 7]  9.00-10.00   sec  1.47 GBytes  12.6 Gbits/sec  4    602 KBytes
-----
[ ID] Interval      Transfer    Bitrate      Retr
[ 7]  0.00-10.00   sec  14.7 GBytes  12.6 Gbits/sec  22
[ 7]  0.00-10.00   sec  14.6 GBytes  12.6 Gbits/sec
sender
receiver

host: h2@mininet-vm
Accepted connection from 10.0.0.1, port 56162
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 56164
[ ID] Interval      Transfer    Bitrate      Retr  Cwnd
[ 7]  0.00-1.00    sec  1.63 GBytes  14.0 Gbits/sec  1    3.43 MBytes
[ 7]  1.00-2.00    sec  1.61 GBytes  13.8 Gbits/sec  3    1.19 MBytes
[ 7]  2.00-3.01    sec  1.42 GBytes  12.1 Gbits/sec  0    1.19 MBytes
[ 7]  3.01-4.00    sec  788 MBytes  6.66 Gbits/sec  3    591 KBytes
[ 7]  4.00-5.00    sec  1.08 GBytes  9.29 Gbits/sec  2    609 KBytes
[ 7]  5.00-6.00    sec  1.65 GBytes  14.2 Gbits/sec  0    609 KBytes
[ 7]  6.00-7.00    sec  1.66 GBytes  14.3 Gbits/sec  2    665 KBytes
[ 7]  7.00-8.00    sec  1.67 GBytes  14.4 Gbits/sec  3    621 KBytes
[ 7]  8.00-9.00    sec  1.67 GBytes  14.4 Gbits/sec  4    584 KBytes
[ 7]  9.00-10.00   sec  1.47 GBytes  12.6 Gbits/sec  4    602 KBytes
-----
[ ID] Interval      Transfer    Bitrate
[ 7]  0.00-10.00   sec  14.6 GBytes  12.6 Gbits/sec
receiver
Server listening on 5201
-----
```

Рис. 15: Проверка конфигурации с помощью инструмента iPerf3 для проверки повторных передач



```
"host: h1"@mininet-vm  
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 with standard window controls. The terminal shows a root user at mininet-vm in the directory /home/mininet. The command executed is `sudo tc qdisc add dev h1-eth0 root netem delay 10ms reorder 25% 50%`, which is split across two lines. The prompt returns to `root@mininet-vm:/home/mininet#` followed by a black cursor block.

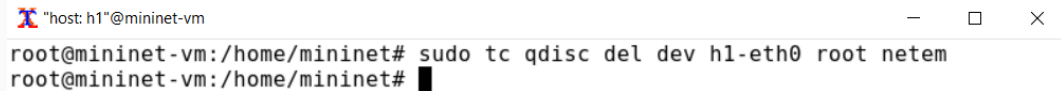
```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1
0ms reorder 25% 50%
root@mininet-vm:/home/mininet# █
```

Рис. 17: Добавление на узле h1 правила из лабораторной работы

```
"host: h1"@mininet-vm
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=10.3 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=11.2 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=10.3 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=10.6 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=10.6 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=10.3 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=0.061 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=0.046 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=10.9 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=10.8 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=10.4 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.063 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=10.8 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=10.8 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=10.7 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=10.7 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=10.1 ms
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=0.384 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=10.8 ms

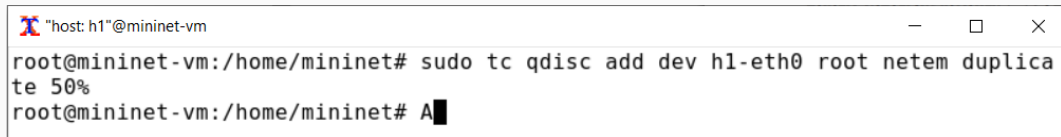
--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, 0% packet loss, time 19090ms
rtt min/avg/max/mdev = 0.046/8.530/11.194/4.202 ms
root@mininet-vm:/home/mininet#
```

Рис. 18: Проверка



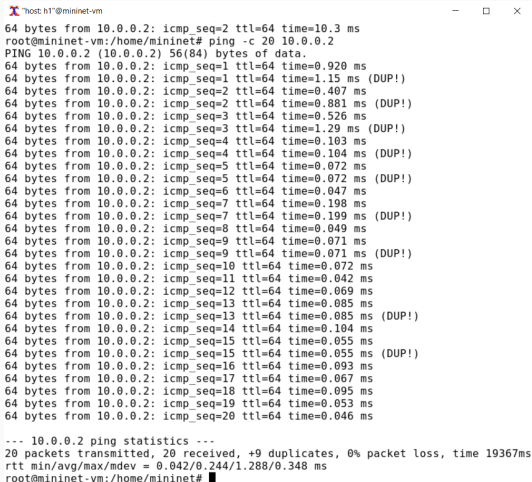
```
"host: h1"@mininet-vm  
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem  
root@mininet-vm:/home/mininet#
```

Рис. 19: Восстановление конфигурации интерфейса по умолчанию



```
"host: h1"@mininet-vm
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem duplica
te 50%
root@mininet-vm:/home/mininet# A
```

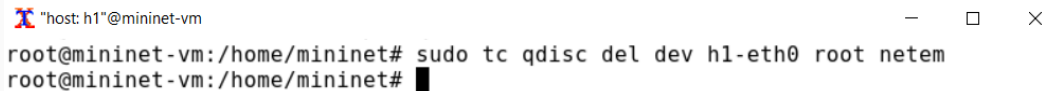
Рис. 20: Добавление на узле h1 правила с дублированием 50% пакетов



```
root@mininet-vm:~# 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=2 ttl=64 time=10.3 ms
 64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=0.920 ms
 64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=1.15 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.407 ms
 64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.881 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.526 ms
 64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=1.29 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.103 ms
 64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.104 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.072 ms
 64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.072 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.047 ms
 64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=0.198 ms
 64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=0.199 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=0.049 ms
 64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=0.071 ms
 64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=0.071 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.072 ms
 64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=0.042 ms
 64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.069 ms
 64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.085 ms
 64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.085 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=0.104 ms
 64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.055 ms
 64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.055 ms (DUP!)
 64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.093 ms
 64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.067 ms
 64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.095 ms
 64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=0.053 ms
 64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=0.046 ms

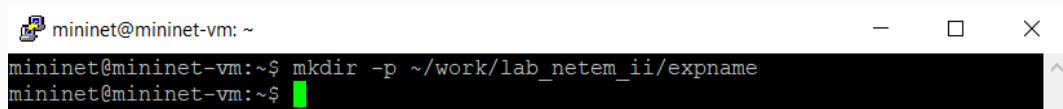
--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, +9 duplicates, 0% packet loss, time 19367ms
rtt min/avg/max/mdev = 0.042/0.244/1.288/0.348 ms
root@mininet-vm:~#
```

Рис. 21: Проверка



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

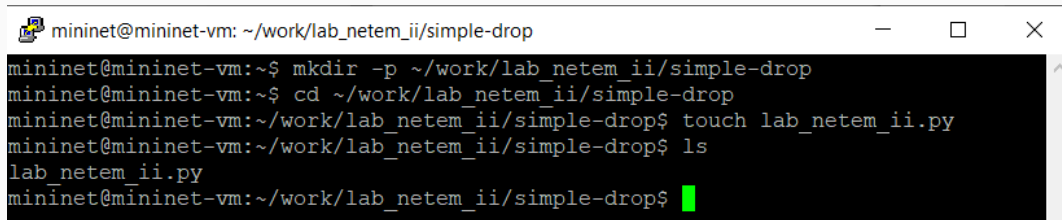
Рис. 22: Восстановление конфигурации интерфейса по умолчанию



A terminal window with a title bar containing a window icon, the text "mininet@mininet-vm: ~", and standard window controls (minimize, maximize, close). The terminal content shows two lines: the first is the prompt "mininet@mininet-vm:~\$" followed by the command "mkdir -p ~/work/lab_netem_ii/expname"; the second is the prompt "mininet@mininet-vm:~\$" followed by a green cursor. A vertical scrollbar is visible on the right side of the terminal area.

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

Рис. 23: Создание каталога expname



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

Рис. 24: Создание каталога simple-drop и дальнейшее его открытие



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-drop
/home/mininet@mininet-vm: [~] 4 L: [ 1+ 0 1/ 50] *(4 /1234b) 115 0x073 [*][X]
#1762/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( "*** Starting 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 loss 10%' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem loss 10%' )

    time.sleep(10) # Wait 10 seconds

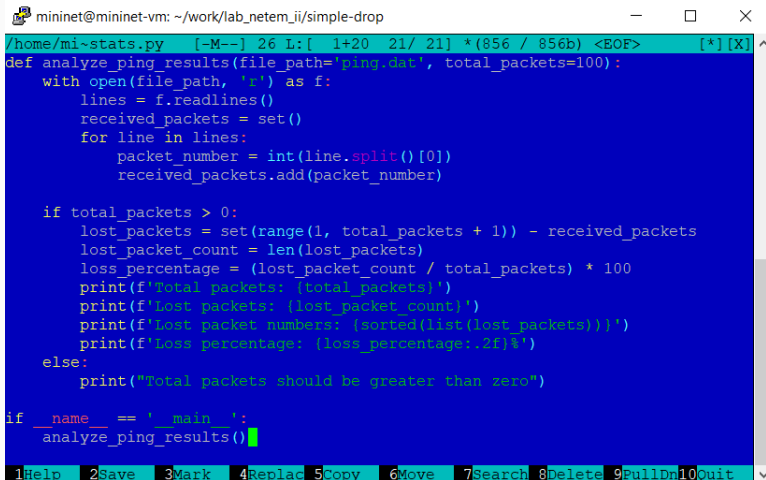
    info( "*** Ping\n" )
    h1.cmdPrint( 'ping -c 100', h2.IP(), '| grep "times=" | awk '{print $5, $7}' )

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

1 Help 2 Save 3 Mark 4 Repeat 5 Copy 6 Move 7 Search 8 Delete 9 Pull Down 10 Quit
```

Рис. 25: Создание скрипта для эксперимента

Воспроизведение экспериментов



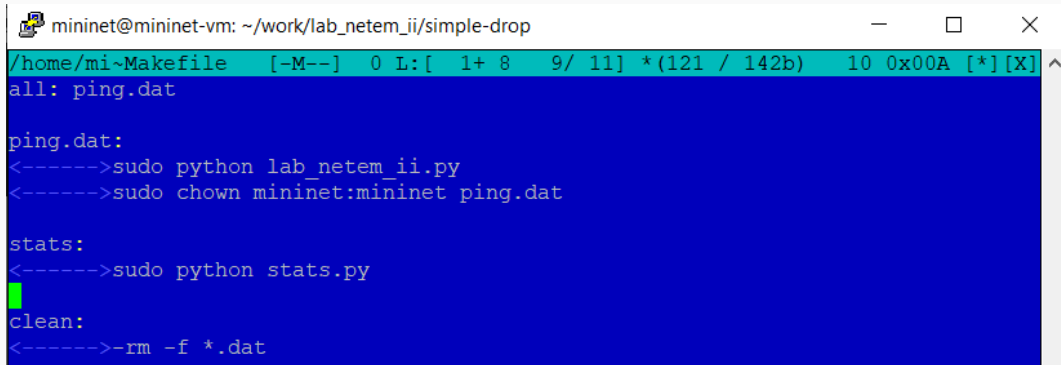
```
mininet@mininet-vm: ~/work/lab_netem_ij/simple-drop
/home/mininet/stats.py [-M--] 26 L: [ 1+20 21/ 21] *(856 / 856b) <EOF> [*][X] ^
def analyze_ping_results(file_path='ping.dat', total_packets=100):
    with open(file_path, 'r') as f:
        lines = f.readlines()
        received_packets = set()
        for line in lines:
            packet_number = int(line.split()[0])
            received_packets.add(packet_number)

    if total_packets > 0:
        lost_packets = set(range(1, total_packets + 1)) - received_packets
        lost_packet_count = len(lost_packets)
        loss_percentage = (lost_packet_count / total_packets) * 100
        print(f'Total packets: {total_packets}')
        print(f'Lost packets: {lost_packet_count}')
        print(f'Lost packet numbers: {sorted(list(lost_packets))}')
        print(f'Loss percentage: {loss_percentage:.2f}%')
    else:
        print("Total packets should be greater than zero")

if __name__ == '__main__':
    analyze_ping_results()
```

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

Рис. 26: Создание нового скрипта для вывода информации о потере пакетов



The screenshot shows a terminal window with a title bar that reads "mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop". The terminal content displays a Makefile with the following rules:

```
/home/mi~Makefile  [-M--]  0 L:[ 1+ 8  9/ 11] *(121 / 142b) 10 0x00A [*][X] ^
all: ping.dat

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

stats:
<----->sudo python stats.py

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

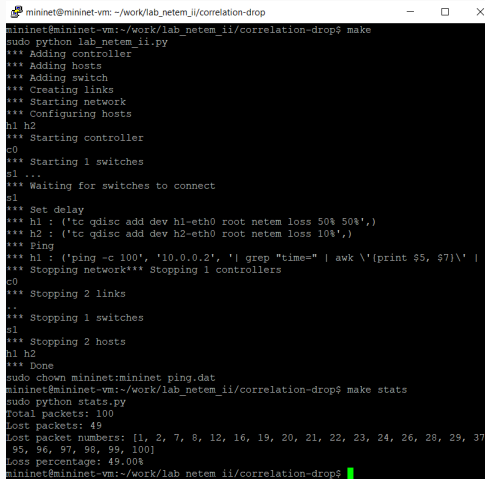
The terminal background is blue, and the text is white. A green cursor is visible on the line following the 'stats' rule.

Рис. 27: Создание Makefile и помещение в него скрипта

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make
sudo python lab_netem_ii.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 loss 10%',)
*** h2 : ('tc qdisc add dev h2-eth0 root netem loss 10%',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'[print $5, $7]\'' | sed -e \'s/time=//g\' -e \'s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 21
Lost packet numbers: [3, 5, 8, 15, 29, 37, 42, 54, 56, 60, 65, 68, 71, 75, 76, 83, 86, 87, 88, 95, 100]
Loss percentage: 21.00%
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make clean
rm -f *.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$
```

Рис. 28: Выполнение эксперимента и последующая очистка каталога



```
mininet@mininet-vm: ~/work/lab_netem_i/correlation-drop
mininet@mininet-vm:~/work/lab_netem_i/correlation-drop$ 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 loss 50% 50%,')
*** h2 : ('tc qdisc add dev h2-eth0 root netem loss 10%,')
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk \'{print $5, $7}\'' |
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_i/correlation-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 49
Lost packet numbers: [1, 2, 7, 8, 12, 16, 19, 20, 21, 22, 23, 24, 26, 28, 29, 37,
95, 96, 97, 98, 99, 100]
Loss percentage: 49.00%
mininet@mininet-vm:~/work/lab_netem_i/correlation-drop$
```

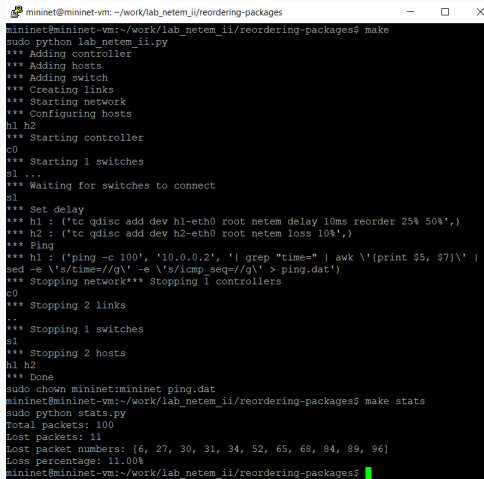
Рис. 29: Реализация воспроизводимого эксперимента по исследованию параметров сети

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_ii/package-damage
mininet@mininet-vm:~/work/lab_netem_ii/package-damage$ make
sudo python lab_netem_ii.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 corrupt 0.01%,')
*** h2 : ('tc qdisc add dev h2-eth0 root netem loss 10%,')
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk '{print $5, $7}' |
sed -e 's/time=//g\' -e 's/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/package-damage$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 8
Lost packet numbers: [15, 17, 18, 26, 38, 82, 85, 95]
Loss percentage: 8.00%
mininet@mininet-vm:~/work/lab_netem_ii/package-damage$
```

Рис. 30: Реализация воспроизводимого эксперимента по исследованию параметров сети

Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_i/reordering-packages
mininet@mininet-vm:~/work/lab_netem_i/reordering-packages$ 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 10ms reorder 25% 50%,)
*** h2 : ('tc qdisc add dev h2-eth0 root netem loss 10%,)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk '{print $5, $7}' |
sed -e 's/tlme=//g\' -e 's/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_i/reordering-packages$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 11
Lost packet numbers: [6, 27, 30, 31, 34, 52, 65, 68, 84, 89, 96]
Loss percentage: 11.00%
mininet@mininet-vm:~/work/lab_netem_i/reordering-packages$
```

Рис. 31: Реализация воспроизводимого эксперимента по исследованию параметров сети

Воспроизведение экспериментов

```
mininet@mininet-vm: ~/work/lab_netem_ii/duplicating-packages
mininet@mininet-vm:~/work/lab_netem_ii/duplicating-packages$ make
sudo python lab_netem_ii.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 duplicate 50%',)
*** h2 : ('tc qdisc add dev h2-eth0 root netem',)
*** Ping
*** h1 : ('ping -c 100', '10.0.0.2', '| grep "time=" | awk '{print $5, $7}' |
sed -e 's/time=//g\' -e 's/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/duplicating-packages$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 0
Lost packet numbers: []
Loss percentage: 0.00%
mininet@mininet-vm:~/work/lab_netem_ii/duplicating-packages$
```

Рис. 32: Реализация воспроизводимого эксперимента по исследованию параметров сети

Вывод

- В ходе выполнения лабораторной работы получили навыки проведения интерактивных экспериментов в среде Mininet по исследованию параметров сети, связанных с потерей, дублированием, изменением порядка и повреждением пакетов при передаче данных.

Список литературы. Библиография

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