

Моделирование сетей передачи данных

Лабораторная работа №5: Эмуляция и измерение потерь пакетов в глобальных сетях

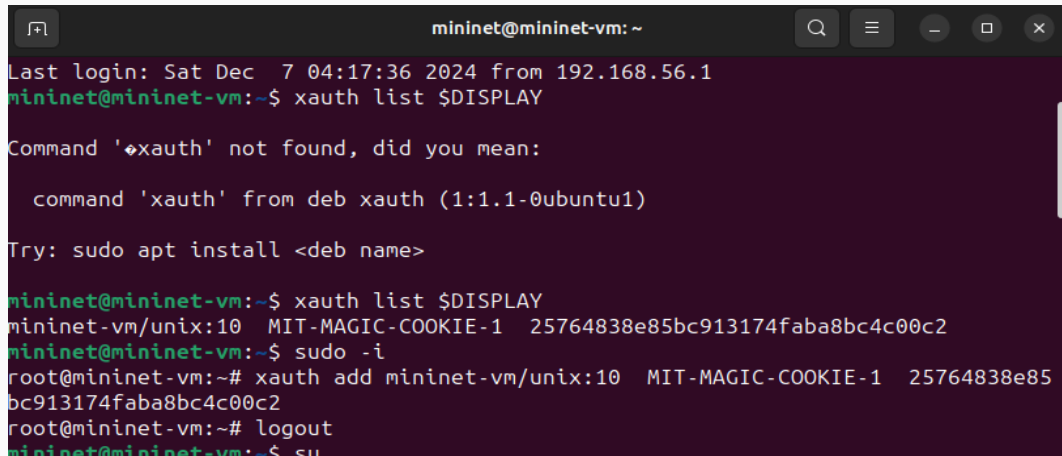
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Цель лабораторной работы

Основной целью работы является получение навыков 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: 1. Запуск лабораторной топологии



```
mininet@mininet-vm: ~  
Last login: Sat Dec 7 04:17:36 2024 from 192.168.56.1  
mininet@mininet-vm:~$ xauth list $DISPLAY  
  
Command 'xauth' not found, did you mean:  
  
  command 'xauth' from deb xauth (1:1.1-0ubuntu1)  
  
Try: sudo apt install <deb name>  
  
mininet@mininet-vm:~$ xauth list $DISPLAY  
mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  25764838e85bc913174faba8bc4c00c2  
mininet@mininet-vm:~$ sudo -i  
root@mininet-vm:~# xauth add mininet-vm/unix:10  MIT-MAGIC-COOKIE-1  25764838e85  
bc913174faba8bc4c00c2  
root@mininet-vm:~# logout  
mininet@mininet-vm:~$ su
```

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

1. Запуск лабораторной топологии

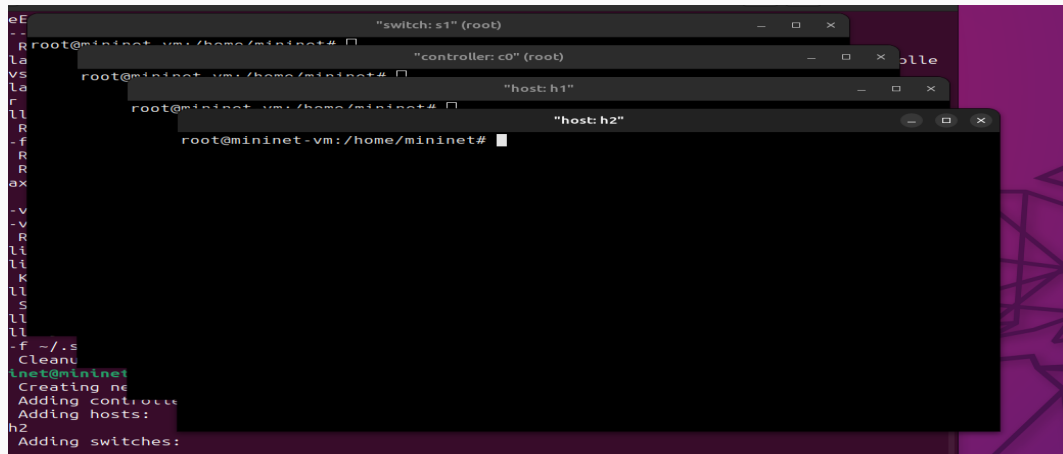
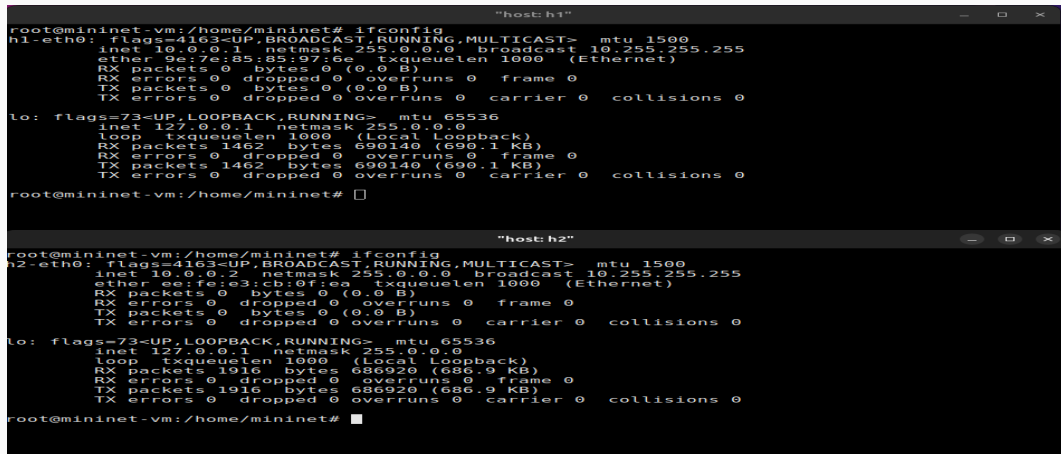


Рис. 2: Создание простейшей топологии

1. Запуск лабораторной топологии



The image displays two terminal windows from a virtual machine named 'mininet-vm'. The top window, titled '"host: h1"', shows the output of the 'ifconfig' command. It details the configuration for the 'h1-eth0' interface, including its IP address (10.0.0.1), netmask (255.0.0.0), broadcast address (10.255.255.255), and MAC address (9e:7e:85:85:97:6e). It also shows the status of the loopback interface 'lo' with IP 127.0.0.1. The bottom window, titled '"host: h2"', shows a similar 'ifconfig' output for the 'h2-eth0' interface with IP 10.0.0.2 and MAC address ee:fe:e3:cb:0f:ea. Both windows show that the interfaces are up and running, and the loopback interface is also configured correctly.

```
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:7e:85:85:97:6e 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 1462 bytes 690140 (690.1 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 1462 bytes 690140 (690.1 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions 0

root@mininet-vm:/home/mininet#

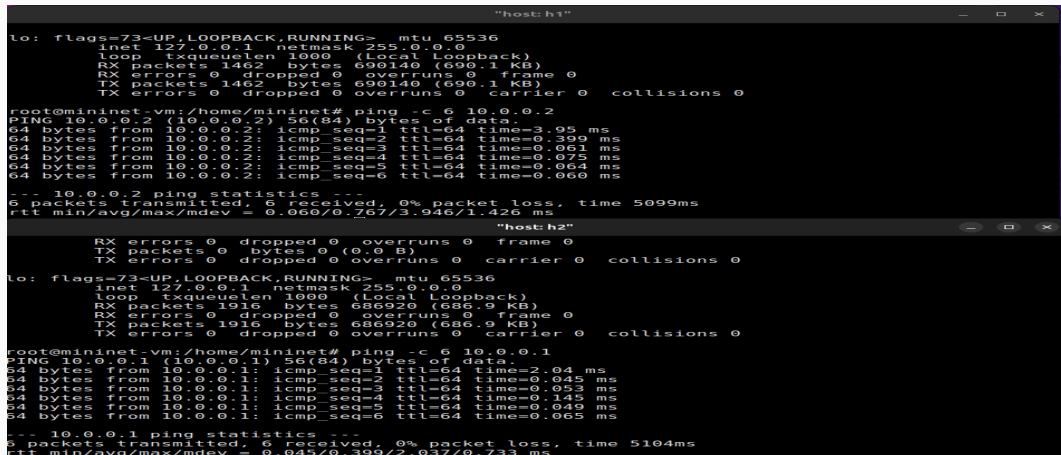
root@mininet-vm:/home/mininet# ifconfig
h2-eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST> mtu 1500
    inet 10.0.0.2 netmask 255.0.0.0 broadcast 10.255.255.255
    ether ee:fe:e3:cb:0f:ea txqueuelen 1000 (Ethernet)
    RX packets 0 bytes 0 (0.0 B)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX 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 1916 bytes 686920 (686.9 KB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 1916 bytes 686920 (686.9 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

1. Запуск лабораторной топологии



```
"host: h1"

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 1462  bytes 690140 (690.1 KB)
    RX errors 0  dropped 0  overruns 0  frame 0
    TX packets 1462  bytes 690140 (690.1 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=3.95 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.399 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.061 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.075 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=0.060 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5099ms
rtt min/avg/max/mdev = 0.060/0.767/3.946/1.426 ms

"host: h2"

    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

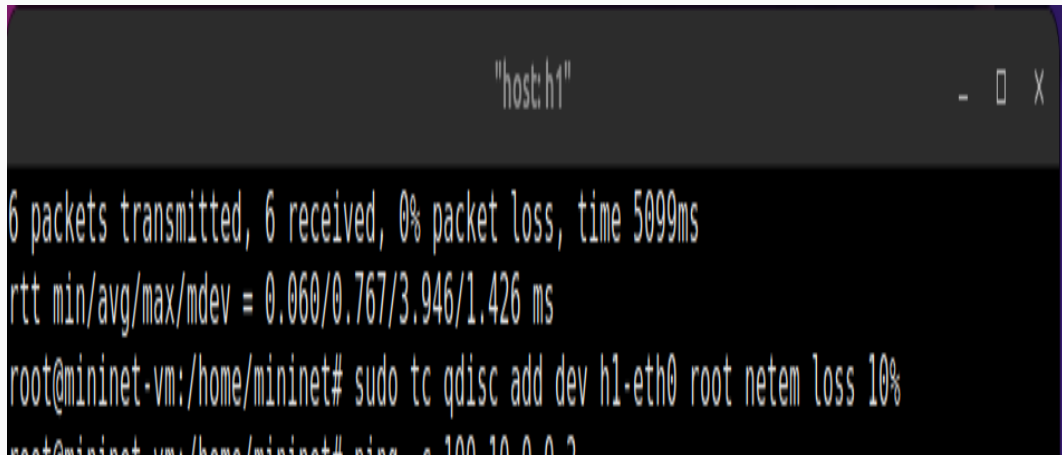
lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
    inet 127.0.0.1  netmask 255.0.0.0
    loop txqueuelen 1000  (local loopback)
    RX packets 1916  bytes 686920 (686.9 KB)
    RX errors 0  dropped 0  overruns 0  frame 0
    TX packets 1916  bytes 686920 (686.9 KB)
    TX errors 0  dropped 0  overruns 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=2.04 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=0.145 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=0.065 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5104ms
rtt min/avg/max/mdev = 0.045/0.399/2.037/0.733 ms
```

Рис. 4: Проверка подключения между хостами

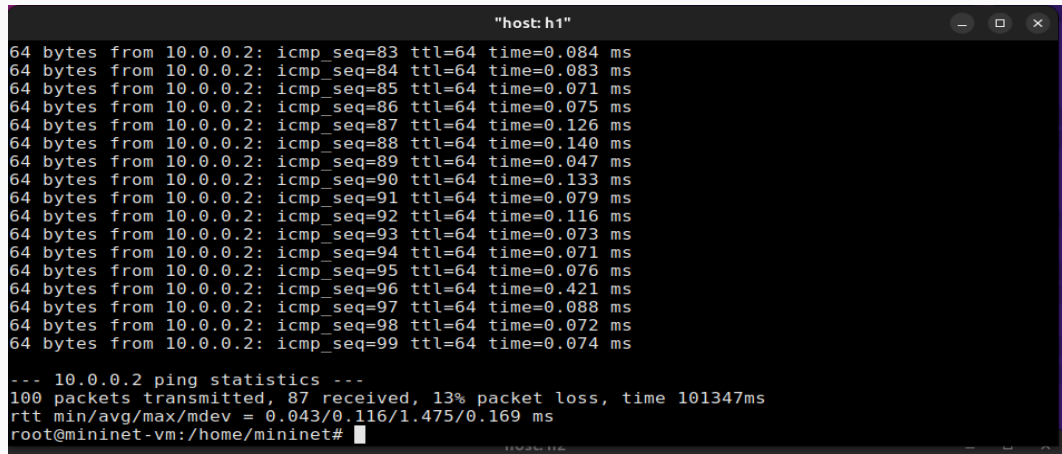
2. Интерактивные эксперименты



```
"host: h1"
6 packets transmitted, 6 received, 0% packet loss, time 5099ms
rtt min/avg/max/mdev = 0.060/0.767/3.946/1.426 ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem loss 10%
root@mininet-vm:/home/mininet# ping -c 100 10.0.0.2
```

Рис. 5: Добавление 10% потерь пакетов к интерфейсу h1-eth0

2. Интерактивные эксперименты

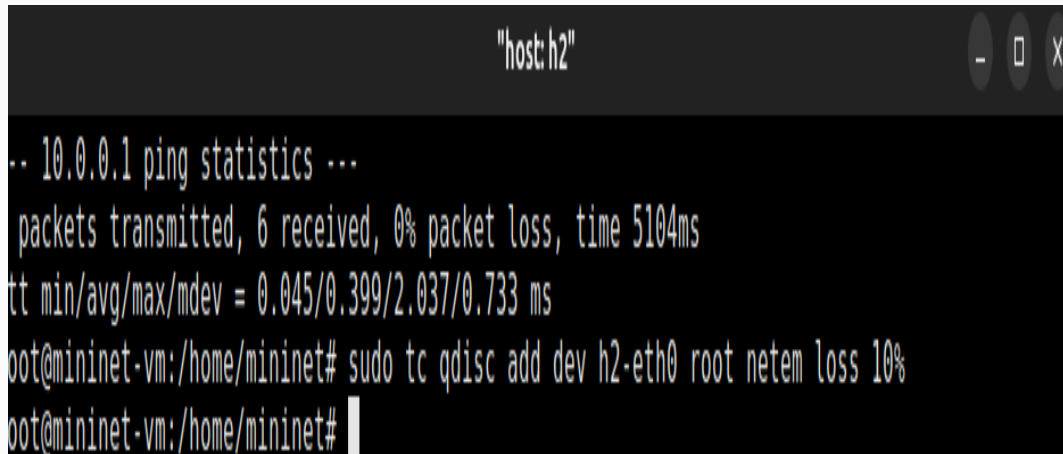


```
"host: h1"
64 bytes from 10.0.0.2: icmp_seq=83 ttl=64 time=0.084 ms
64 bytes from 10.0.0.2: icmp_seq=84 ttl=64 time=0.083 ms
64 bytes from 10.0.0.2: icmp_seq=85 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=86 ttl=64 time=0.075 ms
64 bytes from 10.0.0.2: icmp_seq=87 ttl=64 time=0.126 ms
64 bytes from 10.0.0.2: icmp_seq=88 ttl=64 time=0.140 ms
64 bytes from 10.0.0.2: icmp_seq=89 ttl=64 time=0.047 ms
64 bytes from 10.0.0.2: icmp_seq=90 ttl=64 time=0.133 ms
64 bytes from 10.0.0.2: icmp_seq=91 ttl=64 time=0.079 ms
64 bytes from 10.0.0.2: icmp_seq=92 ttl=64 time=0.116 ms
64 bytes from 10.0.0.2: icmp_seq=93 ttl=64 time=0.073 ms
64 bytes from 10.0.0.2: icmp_seq=94 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=95 ttl=64 time=0.076 ms
64 bytes from 10.0.0.2: icmp_seq=96 ttl=64 time=0.421 ms
64 bytes from 10.0.0.2: icmp_seq=97 ttl=64 time=0.088 ms
64 bytes from 10.0.0.2: icmp_seq=98 ttl=64 time=0.072 ms
64 bytes from 10.0.0.2: icmp_seq=99 ttl=64 time=0.074 ms

--- 10.0.0.2 ping statistics ---
100 packets transmitted, 87 received, 13% packet loss, time 101347ms
rtt min/avg/max/mdev = 0.043/0.116/1.475/0.169 ms
root@mininet-vm: /home/mininet#
```

Рис. 6: Проверка

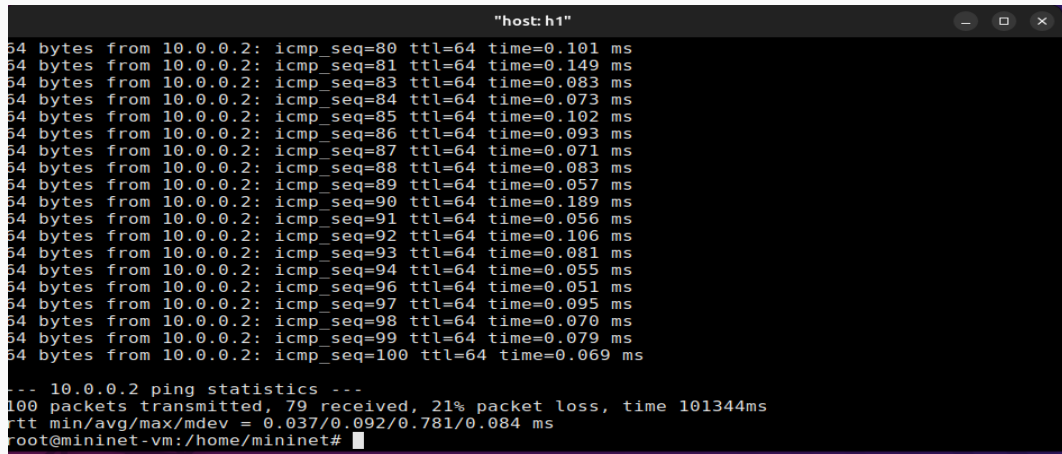
2. Интерактивные эксперименты



```
"host: h2"  
-- 10.0.0.1 ping statistics --  
packets transmitted, 6 received, 0% packet loss, time 5104ms  
rtt min/avg/max/mdev = 0.045/0.399/2.037/0.733 ms  
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

2. Интерактивные эксперименты

A terminal window titled "host: h1" with standard window controls. It displays the output of a ping command to 10.0.0.2. The output shows 10 successful ICMP echo requests, each with 64 bytes, TTL of 64, and various response times. Below this, it shows ping statistics: 100 packets transmitted, 79 received, 21% packet loss, and a total time of 101344ms. The round-trip time (rtt) statistics are also shown: min/avg/max/mdev = 0.037/0.092/0.781/0.084 ms. The prompt is root@mininet-vm: /home/mininet#.

```

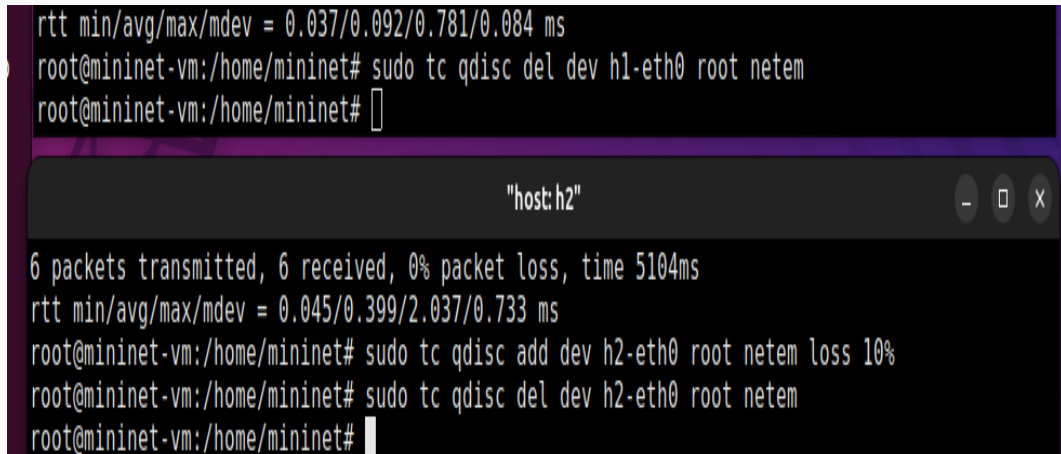
"host: h1"
64 bytes from 10.0.0.2: icmp_seq=80 ttl=64 time=0.101 ms
64 bytes from 10.0.0.2: icmp_seq=81 ttl=64 time=0.149 ms
64 bytes from 10.0.0.2: icmp_seq=83 ttl=64 time=0.083 ms
64 bytes from 10.0.0.2: icmp_seq=84 ttl=64 time=0.073 ms
64 bytes from 10.0.0.2: icmp_seq=85 ttl=64 time=0.102 ms
64 bytes from 10.0.0.2: icmp_seq=86 ttl=64 time=0.093 ms
64 bytes from 10.0.0.2: icmp_seq=87 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=88 ttl=64 time=0.083 ms
64 bytes from 10.0.0.2: icmp_seq=89 ttl=64 time=0.057 ms
64 bytes from 10.0.0.2: icmp_seq=90 ttl=64 time=0.189 ms
64 bytes from 10.0.0.2: icmp_seq=91 ttl=64 time=0.056 ms
64 bytes from 10.0.0.2: icmp_seq=92 ttl=64 time=0.106 ms
64 bytes from 10.0.0.2: icmp_seq=93 ttl=64 time=0.081 ms
64 bytes from 10.0.0.2: icmp_seq=94 ttl=64 time=0.055 ms
64 bytes from 10.0.0.2: icmp_seq=96 ttl=64 time=0.051 ms
64 bytes from 10.0.0.2: icmp_seq=97 ttl=64 time=0.095 ms
64 bytes from 10.0.0.2: icmp_seq=98 ttl=64 time=0.070 ms
64 bytes from 10.0.0.2: icmp_seq=99 ttl=64 time=0.079 ms
64 bytes from 10.0.0.2: icmp_seq=100 ttl=64 time=0.069 ms

--- 10.0.0.2 ping statistics ---
100 packets transmitted, 79 received, 21% packet loss, time 101344ms
rtt min/avg/max/mdev = 0.037/0.092/0.781/0.084 ms
root@mininet-vm: /home/mininet#

```

Рис. 8: Проверка

2. Интерактивные эксперименты



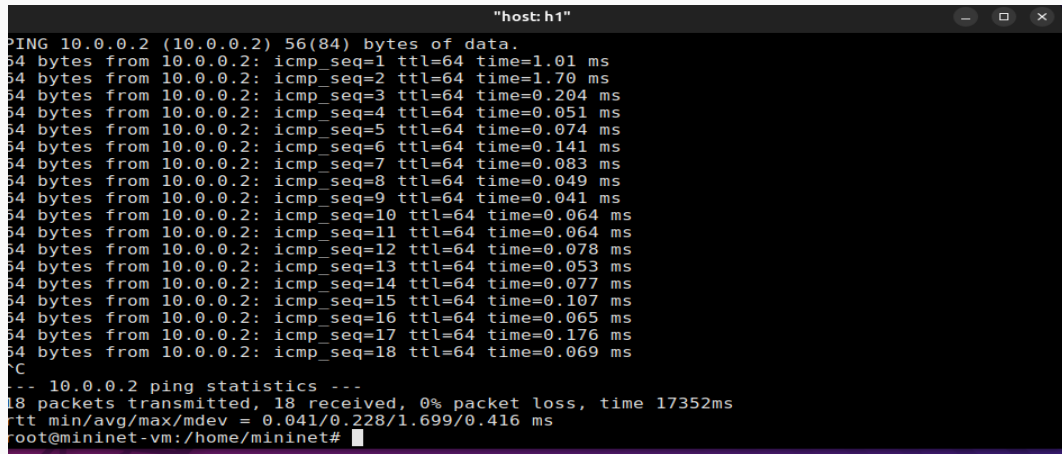
```
rtt min/avg/max/mdev = 0.037/0.092/0.781/0.084 ms
root@mininet-virtual-machine:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-virtual-machine:/home/mininet#
```

"host: h2" [window title bar with minimize, maximize, and close buttons]

```
6 packets transmitted, 6 received, 0% packet loss, time 5104ms
rtt min/avg/max/mdev = 0.045/0.399/2.037/0.733 ms
root@mininet-virtual-machine:/home/mininet# sudo tc qdisc add dev h2-eth0 root netem loss 10%
root@mininet-virtual-machine:/home/mininet# sudo tc qdisc del dev h2-eth0 root netem
root@mininet-virtual-machine:/home/mininet#
```

Рис. 9: Восстановление конфигурацию по умолчанию

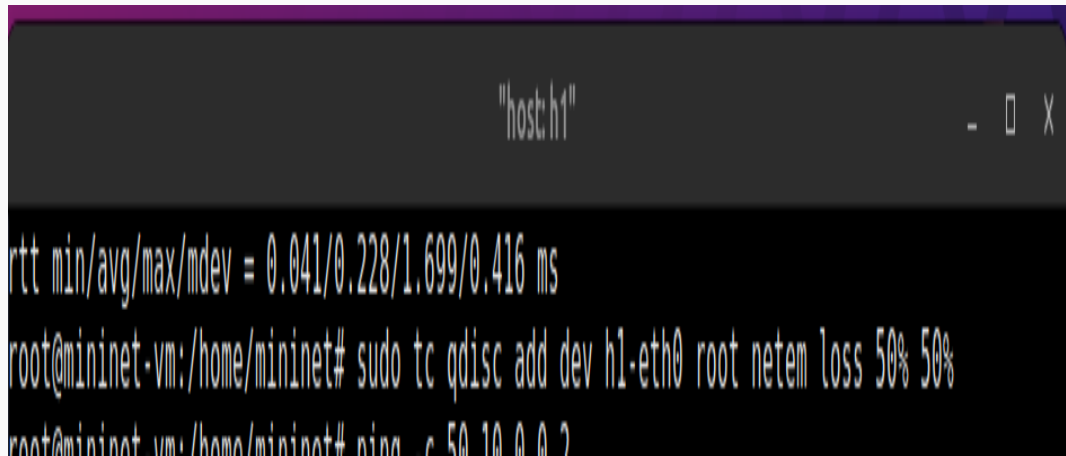
2. Интерактивные эксперименты



```
"host: h1"
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=1.01 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=1.70 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.204 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.051 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.074 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.141 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=0.083 ms
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=0.041 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.064 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=0.064 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.078 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.107 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.176 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.069 ms
^C
--- 10.0.0.2 ping statistics ---
18 packets transmitted, 18 received, 0% packet loss, time 17352ms
rtt min/avg/max/mdev = 0.041/0.228/1.699/0.416 ms
root@mininet-vm:/home/mininet#
```

Рис. 10: Проверка

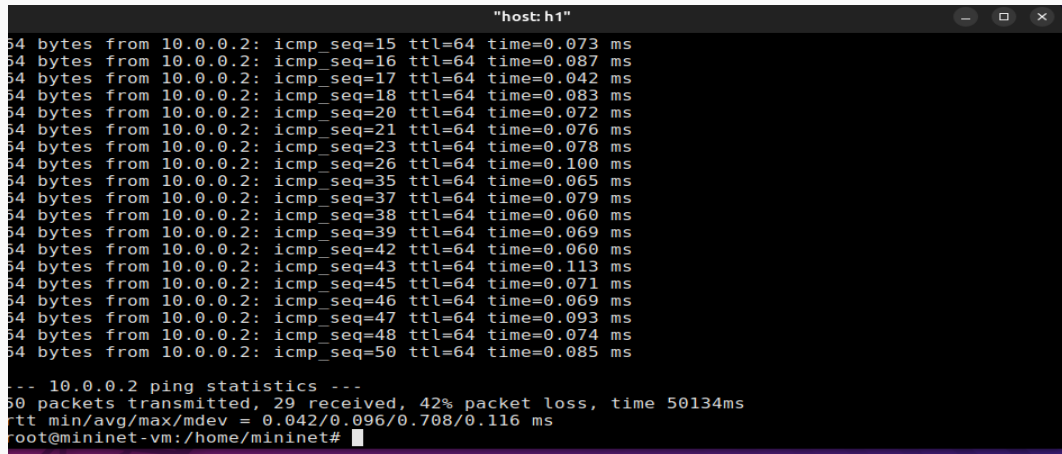
2. Интерактивные эксперименты



```
"host: h1"
rtt min/avg/max/mdev = 0.041/0.228/1.699/0.416 ms
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem loss 50% 50%
root@mininet-vm:/home/mininet# ping -c 50 10.0.0.2
```

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

2. Интерактивные эксперименты

A terminal window titled "host: h1" with standard window controls (minimize, maximize, close). The terminal displays the output of a ping command to 10.0.0.2. It shows 14 successful responses, each 64 bytes from 10.0.0.2 with an icmp_seq number and a time in ms. The sequence numbers are 15, 16, 17, 18, 20, 21, 23, 26, 35, 37, 38, 39, 42, 43, 45, 46, 47, 48, and 50. The times range from 0.042 ms to 0.113 ms. Below this, it shows "ping statistics" for 10.0.0.2: 50 packets transmitted, 29 received, 42% packet loss, time 50134ms, and rtt min/avg/max/mdev = 0.042/0.096/0.708/0.116 ms. The prompt is root@mininet-vm:/home/mininet#.

```

"host: h1"
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.073 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.087 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.042 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.083 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=0.072 ms
64 bytes from 10.0.0.2: icmp_seq=21 ttl=64 time=0.076 ms
64 bytes from 10.0.0.2: icmp_seq=23 ttl=64 time=0.078 ms
64 bytes from 10.0.0.2: icmp_seq=26 ttl=64 time=0.100 ms
64 bytes from 10.0.0.2: icmp_seq=35 ttl=64 time=0.065 ms
64 bytes from 10.0.0.2: icmp_seq=37 ttl=64 time=0.079 ms
64 bytes from 10.0.0.2: icmp_seq=38 ttl=64 time=0.060 ms
64 bytes from 10.0.0.2: icmp_seq=39 ttl=64 time=0.069 ms
64 bytes from 10.0.0.2: icmp_seq=42 ttl=64 time=0.060 ms
64 bytes from 10.0.0.2: icmp_seq=43 ttl=64 time=0.113 ms
64 bytes from 10.0.0.2: icmp_seq=45 ttl=64 time=0.071 ms
64 bytes from 10.0.0.2: icmp_seq=46 ttl=64 time=0.069 ms
64 bytes from 10.0.0.2: icmp_seq=47 ttl=64 time=0.093 ms
64 bytes from 10.0.0.2: icmp_seq=48 ttl=64 time=0.074 ms
64 bytes from 10.0.0.2: icmp_seq=50 ttl=64 time=0.085 ms

--- 10.0.0.2 ping statistics ---
50 packets transmitted, 29 received, 42% packet loss, time 50134ms
rtt min/avg/max/mdev = 0.042/0.096/0.708/0.116 ms
root@mininet-vm:/home/mininet#

```

Рис. 12: Проверка

2. Интерактивные эксперименты

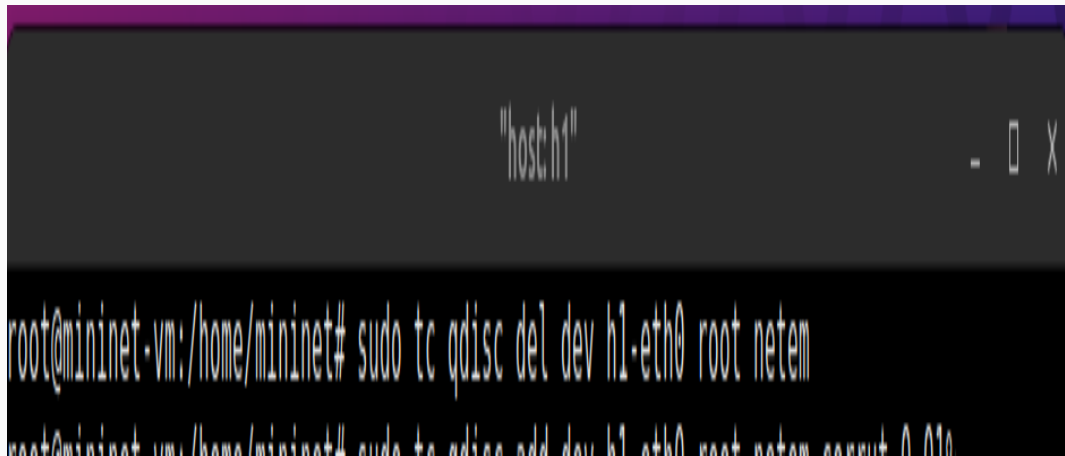
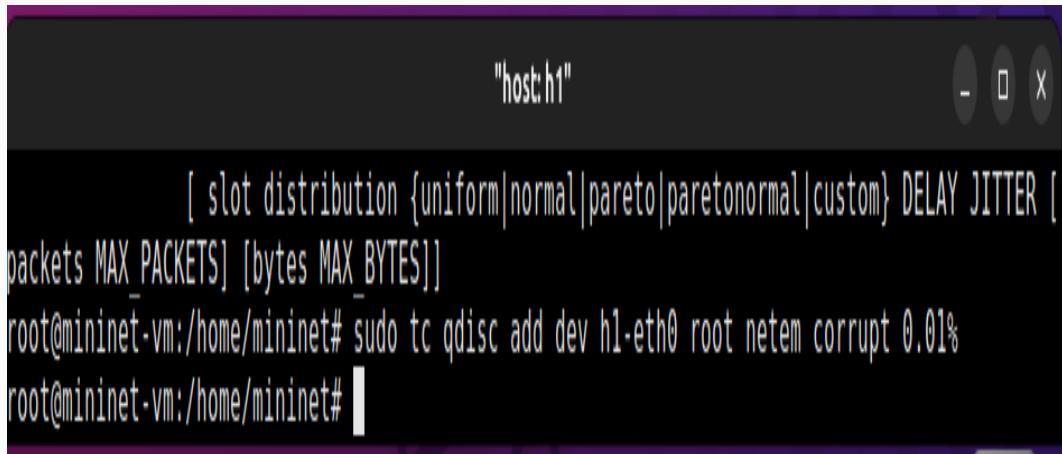


Рис. 13: Восстановление конфигурацию по умолчанию

2. Интерактивные эксперименты



```
"host: h1"
[ slot distribution {uniform|normal|pareto|paretonormal|custom} DELAY JITTER [
packets MAX_PACKETS] [bytes MAX_BYTES]]
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

2. Интерактивные эксперименты

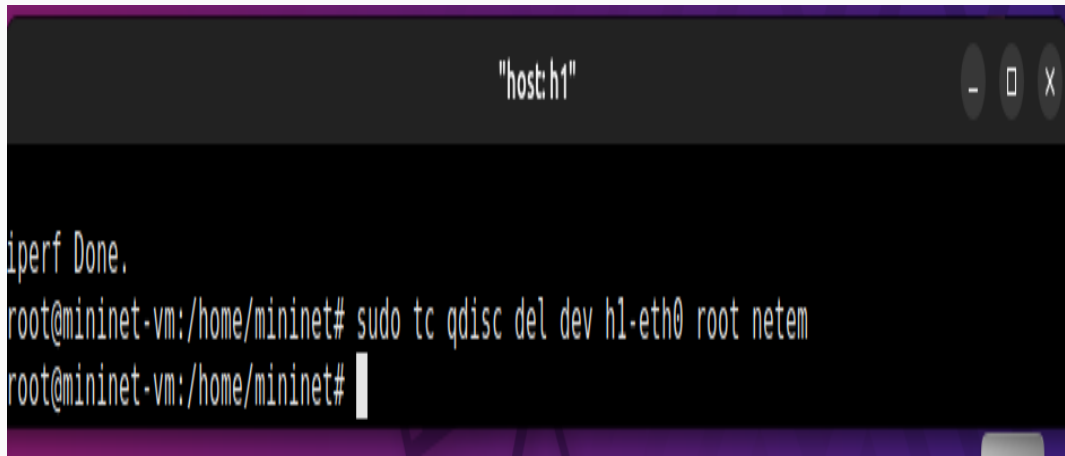
```

"host: h1"
[ slot distribution {uniform|normal|pareto|paretonormal|custom} DELAY JITTER [
packets MAX_PACKETS] [bytes MAX_BYTES]]
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem corrupt 0.01%
Connecting to host 10.0.0.2, port 5201
[ 7] local 10.0.0.1 port 49930 connected to 10.0.0.2 port 5201
[ ID] Interval      Transfer      Bitrate      Retr      Cwnd
[ 7] 0.00-1.00      sec 1.97 GBytes  16.9 Gbits/sec  17      4.10 MBytes
[ 7] 1.00-2.00      sec 1.82 GBytes  15.0 Gbits/sec  13      4.10 MBytes
[ 7] 2.00-3.00      sec 1.52 GBytes  13.0 Gbits/sec  15      2.87 MBytes
[ 7] 3.00-4.00      sec 1.83 GBytes  15.7 Gbits/sec  17      2.01 MBytes
[ 7] 4.00-5.00      sec 1.84 GBytes  15.8 Gbits/sec  17      1.41 MBytes
[ 7] 5.00-6.00      sec 1.74 GBytes  14.9 Gbits/sec  18      1008 KBytes
[ 7] 6.00-7.00      sec 1.77 GBytes  15.2 Gbits/sec  17      1.41 MBytes
[ 7] 7.00-8.00      sec 1.77 GBytes  15.2 Gbits/sec  15      714 KBytes
[ 7] 8.00-9.00      sec 1.64 GBytes  14.1 Gbits/sec  17      1010 KBytes
[ 7] 9.00-10.00     sec 1.65 GBytes  14.2 Gbits/sec  16      706 KBytes
- - - - -
[ ID] Interval      Transfer      Bitrate      Retr      sender
[ 7] 0.00-10.00     sec 17.6 GBytes  15.1 Gbits/sec  162
[ 7] 0.00-10.00     sec 17.5 GBytes  15.1 Gbits/sec
iperf Done.
root@mininet-vm:/home/mininet#

"host: h2"
-----
server listening on 5201
-----
accepted connection from 10.0.0.1, port 49928
[ 7] local 10.0.0.2 port 5201 connected to 10.0.0.1 port 49930
[ ID] Interval      Transfer      Bitrate
[ 7] 0.00-1.00      sec 1.95 GBytes  16.7 Gbits/sec
[ 7] 1.00-2.00      sec 1.82 GBytes  15.6 Gbits/sec
[ 7] 2.00-3.00      sec 1.52 GBytes  13.0 Gbits/sec
[ 7] 3.00-4.00      sec 1.83 GBytes  15.7 Gbits/sec
[ 7] 4.00-5.00      sec 1.84 GBytes  15.8 Gbits/sec
[ 7] 5.00-6.00      sec 1.74 GBytes  14.9 Gbits/sec
[ 7] 6.00-7.00      sec 1.77 GBytes  15.2 Gbits/sec
[ 7] 7.00-8.00      sec 1.77 GBytes  15.2 Gbits/sec
[ 7] 8.00-9.00      sec 1.64 GBytes  14.1 Gbits/sec
[ 7] 9.00-10.00     sec 1.65 GBytes  14.2 Gbits/sec
- - - - -
[ ID] Interval      Transfer      Bitrate
[ 7] 0.00-10.00     sec 17.5 GBytes  15.1 Gbits/sec
-----
server listening on 5201
-----
receiver
```

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

2. Интерактивные эксперименты

A terminal window with a dark background and a purple title bar. The title bar contains the text "host: h1" and standard window control buttons (minimize, maximize, close). The terminal text shows the completion of an iperf test, followed by a command to delete a tc configuration. The prompt is root@mininet-vm:/home/mininet#.

```

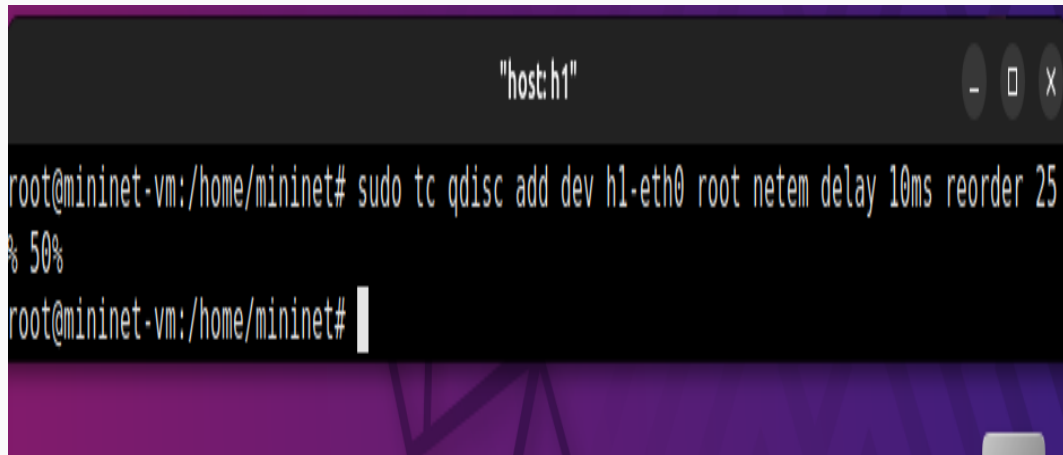
"host: h1"

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

```

Рис. 16: Восстановление конфигурацию по умолчанию

2. Интерактивные эксперименты

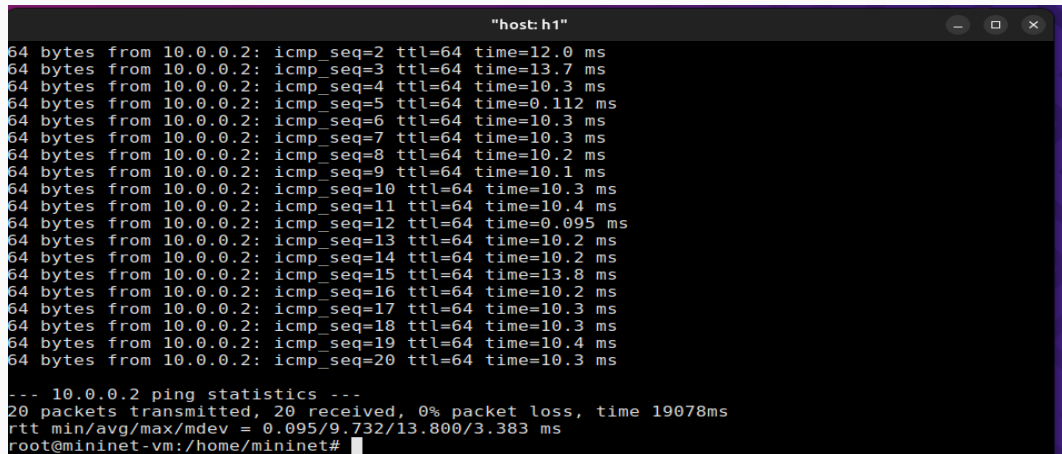


A terminal window titled "host: h1" with standard window controls (minimize, maximize, close). The terminal shows a root user at a mininet-vm prompt. The command entered is `sudo tc qdisc add dev h1-eth0 root netem delay 10ms reorder 25 % 50%`. The prompt returns to `root@mininet-vm:/home/mininet#` with a cursor.

```
host: h1
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 10ms reorder 25
% 50%
root@mininet-vm:/home/mininet#
```

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

2. Интерактивные эксперименты

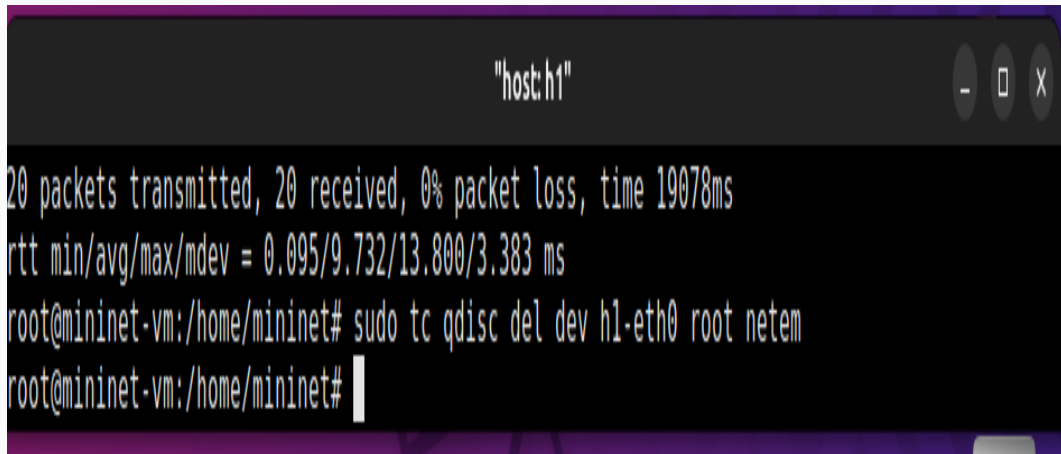
A terminal window titled "host: h1" with standard Linux window controls (minimize, maximize, close). The terminal displays the output of a ping command to 10.0.0.2. It shows 20 individual ping results, each with 64 bytes, TTL of 64, and a response time. The times range from 0.095 ms to 13.8 ms. Below the individual results, it shows a summary: "10.0.0.2 ping statistics ---", "20 packets transmitted, 20 received, 0% packet loss, time 19078ms", and "rtt min/avg/max/mdev = 0.095/9.732/13.800/3.383 ms". The prompt "root@mininet-vm:/home/mininet#" is visible at the bottom.

```
host: h1
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=12.0 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=13.7 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=0.112 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=10.3 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=10.2 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=10.1 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=10.3 ms
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=10.4 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.095 ms
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=10.2 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=10.2 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=13.8 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=10.2 ms
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=10.3 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=10.3 ms
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=10.4 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=10.3 ms

--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, 0% packet loss, time 19078ms
rtt min/avg/max/mdev = 0.095/9.732/13.800/3.383 ms
root@mininet-vm:/home/mininet#
```

Рис. 18: Проверка

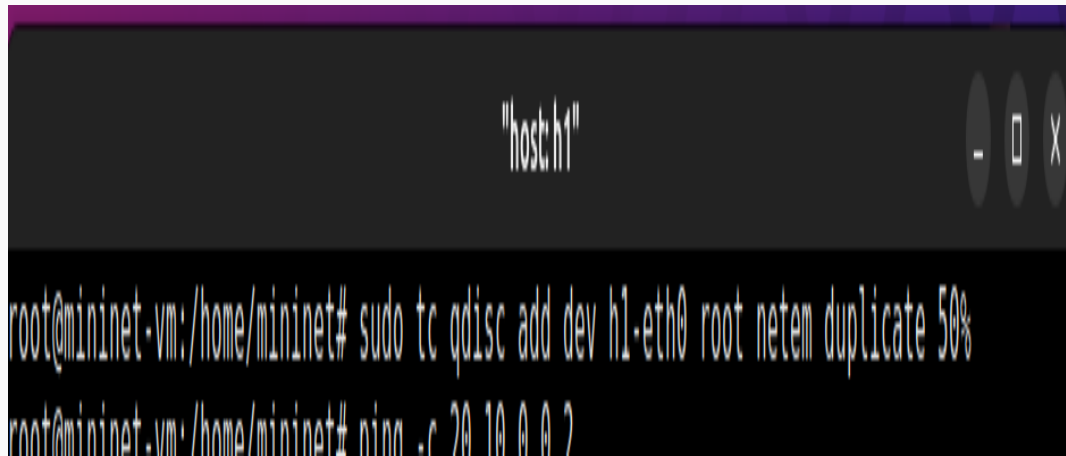
2. Интерактивные эксперименты



```
"host: h1"
20 packets transmitted, 20 received, 0% packet loss, time 19078ms
rtt min/avg/max/mdev = 0.095/9.732/13.800/3.383 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-vm:/home/mininet#
```

Рис. 19: Восстановление конфигурацию по умолчанию

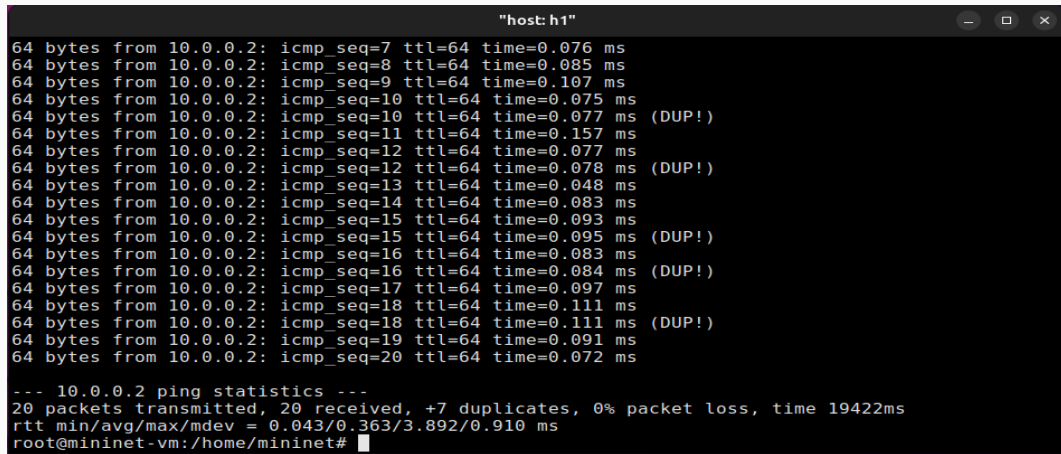
2. Интерактивные эксперименты

A terminal window with a dark background and a purple title bar. The title bar contains the text "host: h1" and three window control buttons (minimize, maximize, close). The terminal shows two commands being executed. The first command is "sudo tc qdisc add dev h1-eth0 root netem duplicate 50%", which is partially visible. The second command is "ping -c 20 10.0.0.2", which is also partially visible.

```
host: h1  
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem duplicate 50%  
root@mininet-vm:/home/mininet# ping -c 20 10.0.0.2
```

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

2. Интерактивные эксперименты

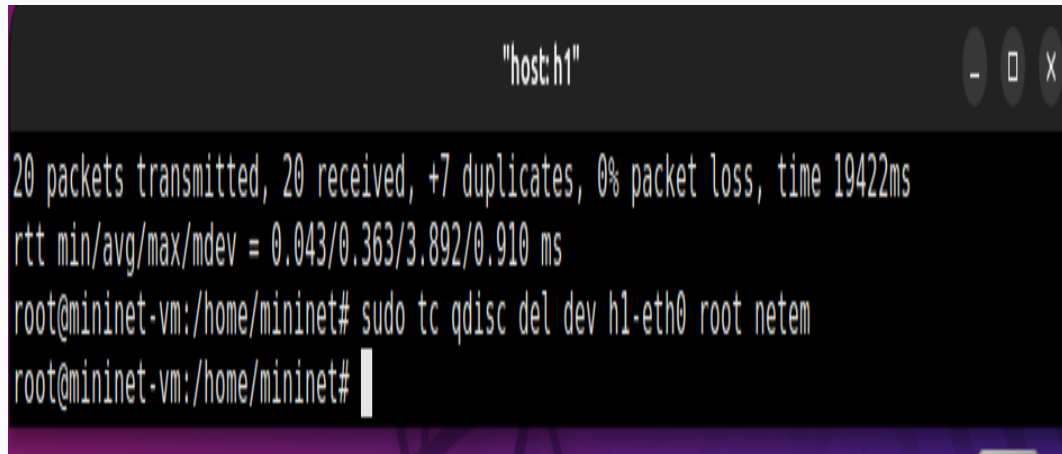


```
host: h1
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=0.076 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=0.085 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=0.107 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.075 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.077 ms (DUP!)
64 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=0.157 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=0.078 ms (DUP!)
64 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=0.048 ms
64 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=0.083 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.093 ms
64 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=0.095 ms (DUP!)
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.083 ms
64 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=0.084 ms (DUP!)
64 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=0.097 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.111 ms
64 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=0.111 ms (DUP!)
64 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=0.091 ms
64 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=0.072 ms

--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, +7 duplicates, 0% packet loss, time 19422ms
rtt min/avg/max/mdev = 0.043/0.363/3.892/0.910 ms
root@mininet-vm:/home/mininet#
```

Рис. 21: Проверка

2. Интерактивные эксперименты



```
20 packets transmitted, 20 received, +7 duplicates, 0% packet loss, time 19422ms
rtt min/avg/max/mdev = 0.043/0.363/3.892/0.910 ms
root@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
root@mininet-vm:/home/mininet#
```

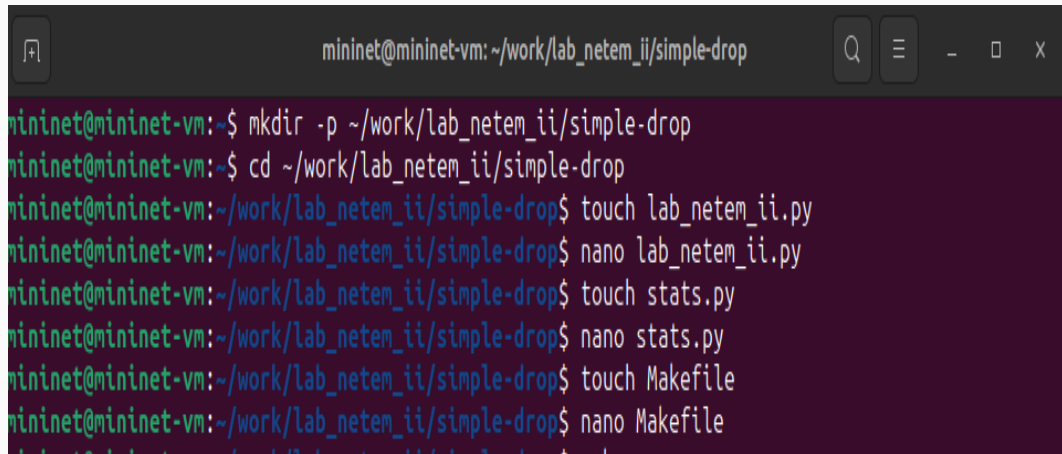
Рис. 22: Восстановление конфигурации по умолчанию

3. Воспроизведение экспериментов

```
completed in 1390.418 seconds  
mininet@mininet-vm:~$ mkdir -p ~/work/lab_netem_ii/expname  
mininet@mininet-vm:~$
```

Рис. 23: Создание каталога

3. Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_i/simple-drop
mininet@mininet-vm:~$ mkdir -p ~/work/lab_netem_i/simple-drop
mininet@mininet-vm:~$ cd ~/work/lab_netem_i/simple-drop
mininet@mininet-vm:~/work/lab_netem_i/simple-drop$ touch lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simple-drop$ nano lab_netem_i.py
mininet@mininet-vm:~/work/lab_netem_i/simple-drop$ touch stats.py
mininet@mininet-vm:~/work/lab_netem_i/simple-drop$ nano stats.py
mininet@mininet-vm:~/work/lab_netem_i/simple-drop$ touch Makefile
mininet@mininet-vm:~/work/lab_netem_i/simple-drop$ nano Makefile
```

Рис. 24: Создание каталога simple-drop

3. Воспроизведение экспериментов



The screenshot shows a terminal window with the title bar "mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop". The terminal is running GNU nano 4.8, editing a file named "lab_netem_ii.py". The file content is a Python script for Mininet. It starts with a docstring: "Simple experiment. Output: ping.dat". Then it imports Mininet, Controller, CLI, and setLogLevel from mininet.net, mininet.node, mininet.cli, and mininet.log respectively. A function "emptyNet()" is defined, which creates a Mininet object with a Controller, adds a controller 'c0', two hosts 'h1' and 'h2' with IP addresses 10.0.0.1 and 10.0.0.2, a switch 's1', and links between h1-s1 and h2-s1. It then starts the network and sets a delay of 10 seconds. Finally, it runs "tc qdisc add dev h1-eth0 root netem loss 10%" on both hosts. The script ends with "time.sleep(10) # Wait 10 seconds".

```
GNU nano 4.8 lab_netem_ii.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' )

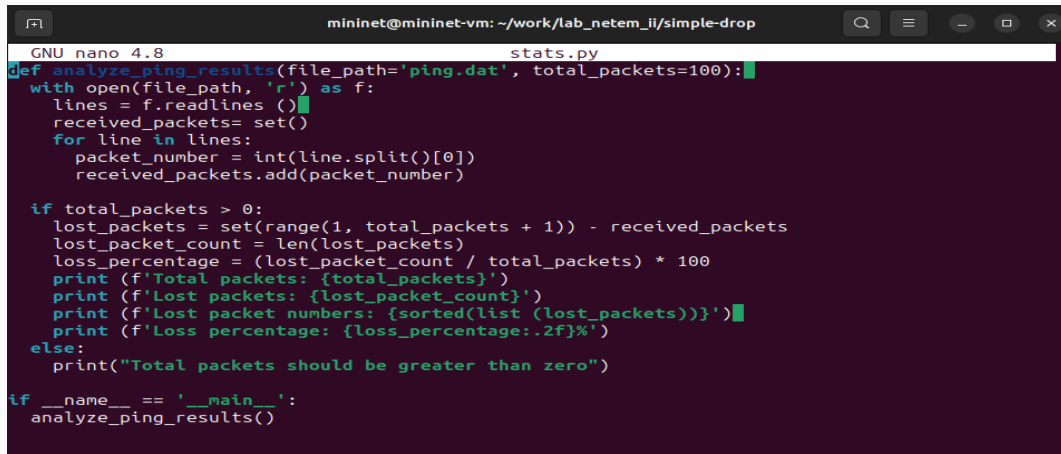
    info( '*** Creating links\n' )
    net.addLink( h1, s1 )
    net.addLink( h2, s1 )

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

    info( '*** Set delay\n' )
    h1.cmdPrint( 'tc qdisc add dev h1-eth0 root netem loss 10%' )
    h2.cmdPrint( 'tc qdisc add dev h2-eth0 root netem loss 10%' )
    time.sleep(10) # Wait 10 seconds
```

Рис. 25: Создание скрипта для эксперимента lab_netem_ii.py

3. Воспроизведение экспериментов



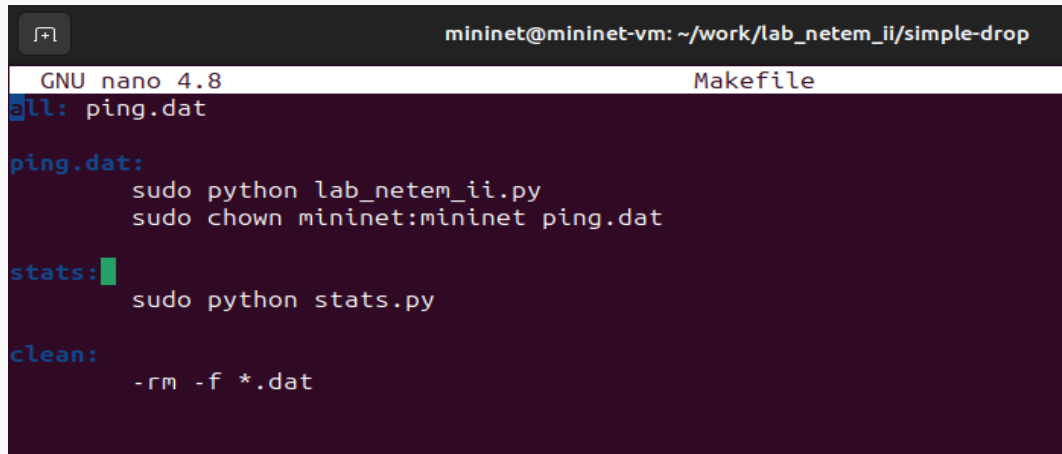
```
mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop
GNU nano 4.8 stats.py
def analyze_ping_results(file_path='ping.dat', total_packets=100):
    with open(file_path, 'r') as f:
        lines = f.readlines()
        received_packets= set()
        for line in lines:
            packet_number = int(line.split()[0])
            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()
```

Рис. 26: Создание скрипта для вывода информации о потерях пакетов

3. Воспроизведение экспериментов



The screenshot shows a terminal window with a dark background. At the top, a status bar indicates the user is 'mininet@mininet-vm' in the directory '~/work/lab_netem_ii/simple-drop'. Below this, the 'GNU nano 4.8' editor is open, editing a file named 'Makefile'. The content of the Makefile is as follows:

```
all: ping.dat

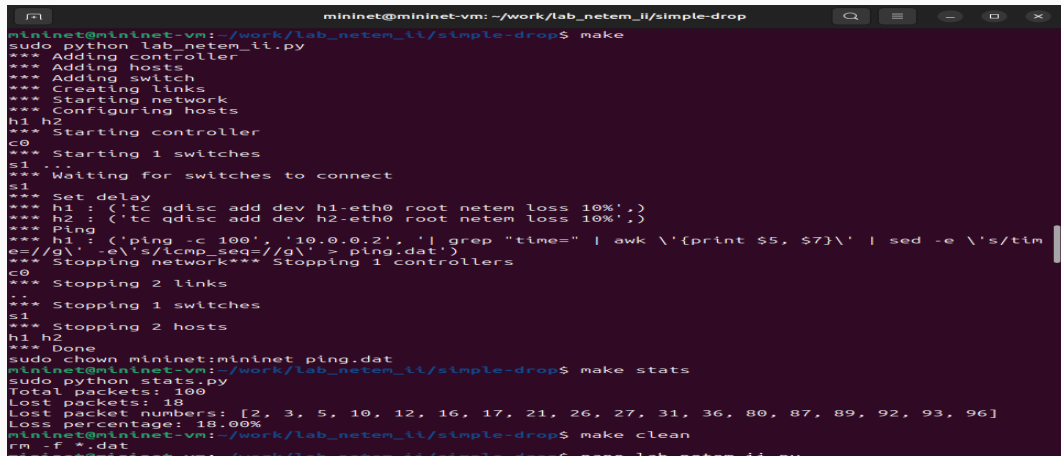
ping.dat:
    sudo python lab_netem_ii.py
    sudo chown mininet:mininet ping.dat

stats:
    sudo python stats.py

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

Рис. 27: Создание файла Makefile

3. 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, $7\}\' | sed -e \'s/tim
e=//g\' -e \'s/lcmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 18
Lost packet numbers: [2, 3, 5, 10, 12, 16, 17, 21, 26, 27, 31, 36, 80, 87, 89, 92, 93, 96]
Loss percentage: 18.00%
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

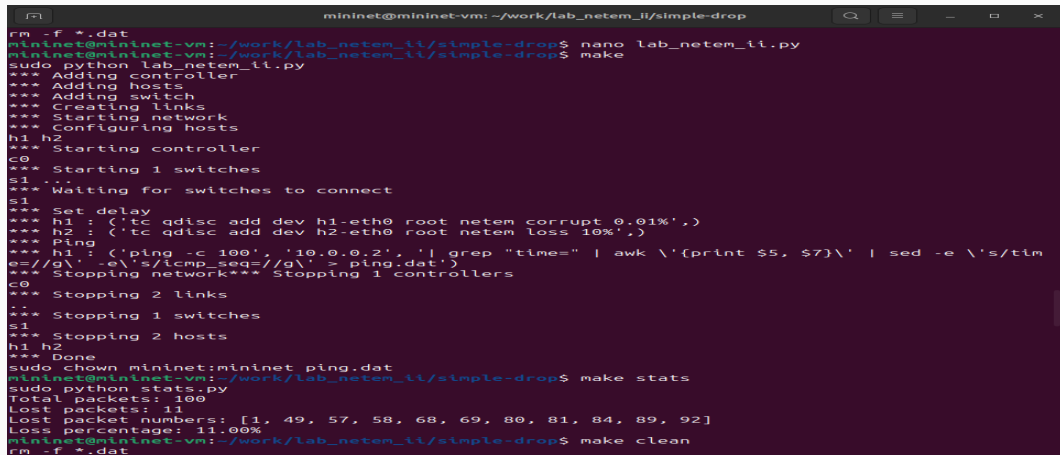
3. Воспроизведение экспериментов



```
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 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, $7}\'' | sed -e \'/s/tim
e//g\' -e \'/s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 50
Lost packet numbers: [3, 4, 5, 7, 11, 14, 17, 18, 24, 26, 32, 33, 34, 35, 42, 44, 45, 46, 47,
48, 50, 51, 52, 53, 55, 56, 58, 59, 60, 61, 62, 63, 66, 72, 74, 75, 76, 77, 78, 79, 80, 81, 85
, 86, 87, 88, 91, 93, 95, 96]
Loss percentage: 50.00%
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make clean
rm -f *.dat
```

Рис. 29: Реализация воспроизводимого эксперимента по исследованию параметров сети

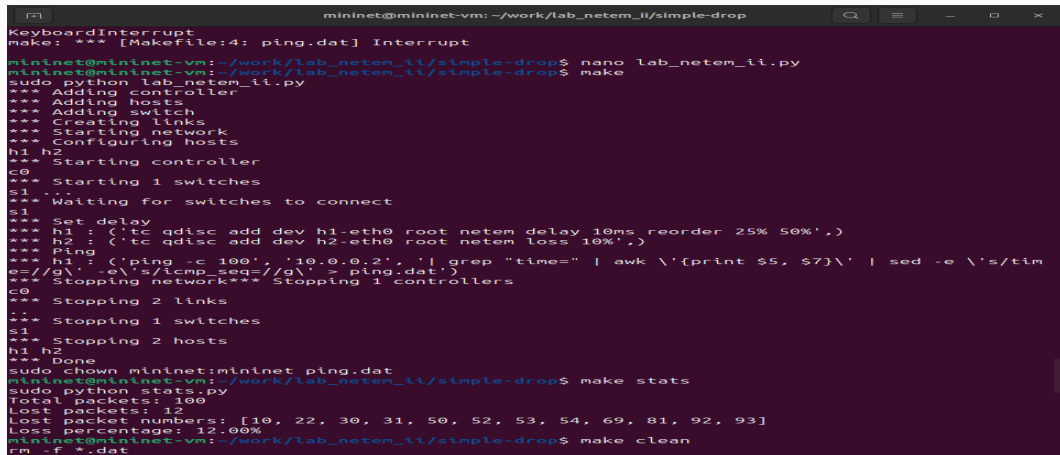
3. Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop
rm -f *.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ nano lab_netem_ii.py
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 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, $7}\'' | sed -e \'/s/tim
e=/g\' -e \'/s/icmp_seq=/g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 11
Lost packet numbers: [1, 49, 57, 58, 68, 69, 80, 81, 84, 89, 92]
Loss percentage: 11.00%
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make clean
rm -f *.dat
```

Рис. 30: Реализация воспроизводимого эксперимента по исследованию параметров сети

3. Воспроизведение экспериментов

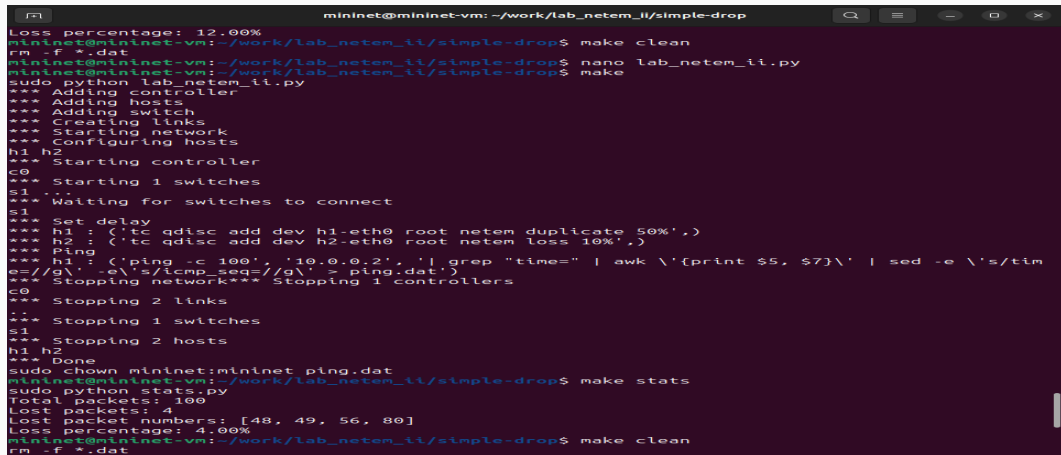


```
mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop
KeyboardInterrupt
make: *** [Makefile:4: ping.dat] Interrupt

mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ nano lab_netem_ii.py
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 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, $7}\'' | sed -e \'/s/tim
e=//g\' -e \'/s/icmp_seq=//g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 12
Lost packet numbers: [10, 22, 30, 31, 50, 52, 53, 54, 69, 81, 92, 93]
Loss percentage: 12.00%
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make clean
rm -f *.dat
```

Рис. 31: Реализация воспроизводимого эксперимента по исследованию параметров сети

3. Воспроизведение экспериментов



```
mininet@mininet-vm: ~/work/lab_netem_ii/simple-drop
Loss percentage: 12.00%
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make clean
rm -f *.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ nano lab_netem_ii.py
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 duplicate 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, $7}\'' | sed -e \'/tim
e=/g\' -e \'/icmp_seq=/g\' > ping.dat')
*** Stopping network*** Stopping 1 controllers
c0
*** Stopping 2 links
..
*** Stopping 1 switches
s1
*** Stopping 2 hosts
h1 h2
*** Done
sudo chown mininet:mininet ping.dat
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make stats
sudo python stats.py
Total packets: 100
Lost packets: 4
Lost packet numbers: [48, 49, 56, 80]
Loss percentage: 4.00%
mininet@mininet-vm:~/work/lab_netem_ii/simple-drop$ make clean
rm -f *.dat
```

Рис. 32: Реализация воспроизводимого эксперимента по исследованию параметров сети

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.

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