Лабораторная работа №3 Дисциплина: Моделирование сетей передачи данных

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Цель работы

Основной целью работы является:

- Ознакомление с NETEM
- Проведение интерактивных и воспроизводимых экспериментов
- Измерение задержки и дрожания (jitter) в Mininet

Задание

- Создать простейшую топологию с 2 хостами и 1 коммутатором
- Добавить/изменить задержку, джиттер, корреляцию и распределение времени задержки
- Реализовать воспроизводимые эксперименты и построить графики

Теоретическое введение

- Mininet — эмулятор компьютерной сети
- Поддержка хостов, коммутаторов и OpenFlow-контроллеров
- Настройка сетевых интерфейсов, проверка ping
- NETEM — инструмент для тестирования задержки и дрожания

Запуск лабораторной топологии

- Подключаемся к виртуальной машине
- Исправляем права запуска X-соединения
- Копируем MIT magic cookie для пользователя root

Простейшая топология

- 2 хоста и 1 коммутатор
- Интерфейсы h1-eth0 и h2-eth0


```
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 aa:51:e1:44:c3:6b  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 1170  bytes 254296 (254.2 KB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 1170  bytes 254296 (254.2 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

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

```
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 86:10:be:4d:89:f4  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)
```

Проверка соединения

- Команда ping -c 6 между h1 и h2


```
X "host: h2"@mininet-vm                                          —    □    ×
        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 1170  bytes 254296 (254.2 KB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 1170  bytes 254296 (254.2 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=1.84 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.042 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.042 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.044 ms
64 bytes from 10.0.0.1: icmp_seq=5 ttl=64 time=0.134 ms
64 bytes from 10.0.0.1: icmp_seq=6 ttl=64 time=0.046 ms

--- 10.0.0.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5105ms
rtt min/avg/max/mdev = 0.042/0.357/1.835/0.661 ms
root@mininet-vm:/home/mininet#
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.118 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.042 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.033 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5094ms
rtt min/avg/max/mdev = 0.033/0.422/2.097/0.750 ms
root@mininet-vm:/home/mininet# ping -c 6 10.0.0.2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=0.084 ms
```

Добавление задержки 100 мс на h1

- sudo tc qdisc add dev h1-eth0 root netem delay 100ms
- Проверка ping -c 6

```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1
00ms
root@mininet-vm:/home/mininet#

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=100 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=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 5009ms
rtt min/avg/max/mdev = 100.124/100.422/100.743/0.232 ms
root@mininet-vm:/home/mininet#
```

Добавление двунаправленной задержки 100 мс

- h1 → h2 и h2 → h1

```
[root@mininet-vm:/home/mininet# sudo tc qdisc add dev h2-eth0 root netem delay 1
00ms
[root@mininet-vm:/home/mininet# []
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=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 5009ms
rtt min/avg/max/mdev = 100.124/100.422/100.743/0.232 ms
root@mininet-vm:/home/mininet# ping -c 6 10.0.0.2
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=202 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=201 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=200 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=201 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=200 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=201 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5011ms
rtt min/avg/max/mdev = 200.489/200.830/201.697/0.408 ms
root@mininet-vm:/home/mininet# []
```

Изменение задержки до 50 мс на каждом хосте

- RTT проверка ping -c 6

```
root@mininet-vm:/home/mininet# sudo tc qdisc change dev h2-eth0 root netem dela
y 50ms
root@mininet-vm:/home/mininet#
;4 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=201 ms

-- 10.0.0.2 ping statistics ---
; packets transmitted, 6 received, 0% packet loss, time 5011ms
`tt min/avg/max/mdev = 200.489/200.830/201.697/0.408 ms
`oot@mininet-vm:/home/mininet# sudo tc qdisc change dev h1-eth0 root netem dela
` 50ms
`oot@mininet-vm:/home/mininet# ping -c 6 10.0.0.2
`ING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
;4 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=101 ms
;4 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=101 ms
;4 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=101 ms
;4 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=101 ms
;4 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=101 ms
;4 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=100 ms

-- 10.0.0.2 ping statistics ---
; packets transmitted, 6 received, 0% packet loss, time 5009ms
`tt min/avg/max/mdev = 100.184/100.728/101.197/0.361 ms
`oot@mininet-vm:/home/mininet#
```

Восстановление исходных значений

- sudo tc qdisc del dev h1-eth0 root netem
- sudo tc qdisc del dev h2-eth0 root netem

```
root@mininet-vm:/nome/mininet# sudo tc qdisc del dev h2-eth0 root netem
root@mininet-vm:/home/mininet#
tt min/avg/max/mdev = 100.184/100.728/101.197/0.361 ms
oot@mininet-vm:/home/mininet#
oot@mininet-vm:/home/mininet#
oot@mininet-vm:/home/mininet#
oot@mininet-vm:/home/mininet#
oot@mininet-vm:/home/mininet#
oot@mininet-vm:/home/mininet# sudo tc qdisc del dev h1-eth0 root netem
oot@mininet-vm:/home/mininet# ping -c 6 10.0.0.2
ING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
4 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=1.83 ms
4 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.481 ms
4 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.161 ms
4 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.048 ms
4 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.053 ms
4 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.040 ms

-- 10.0.0.2 ping statistics ---
packets transmitted, 6 received, 0% packet loss, time 5077ms
tt min/avg/max/mdev = 0.040/0.435/1.828/0.641 ms
oot@mininet-vm:/home/mininet# []
```

Добавление дрожания ±10 мс

- RTT проверка ping -c 6

```
root@mininet-vm:/home/mininet# sudo tc qdisc add dev h1-eth0 root netem delay 1
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=103 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=96.3 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=104 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=91.6 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=93.1 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=92.9 ms

--- 10.0.0.2 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5010ms
rtt min/avg/max/mdev = 91.591/96.824/103.618/4.927 ms
root@mininet-vm:/home/mininet# []
```

Добавление корреляции 25% для джиттера

- Задержка 100 ms ± 10 ms
- Проверка ping -c 20


```
"host: h1"@mininet-vm                                          —    □    ×
54 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=98.4 ms
54 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=104 ms
54 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=110 ms
54 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=99.1 ms
54 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=92.7 ms
54 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=90.4 ms
54 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=102 ms
54 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=99.9 ms
54 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=103 ms
54 bytes from 10.0.0.2: icmp_seq=11 ttl=64 time=95.5 ms
54 bytes from 10.0.0.2: icmp_seq=12 ttl=64 time=103 ms
54 bytes from 10.0.0.2: icmp_seq=13 ttl=64 time=110 ms
54 bytes from 10.0.0.2: icmp_seq=14 ttl=64 time=90.2 ms
54 bytes from 10.0.0.2: icmp_seq=15 ttl=64 time=109 ms
54 bytes from 10.0.0.2: icmp_seq=16 ttl=64 time=91.2 ms
54 bytes from 10.0.0.2: icmp_seq=17 ttl=64 time=108 ms
54 bytes from 10.0.0.2: icmp_seq=18 ttl=64 time=96.7 ms
54 bytes from 10.0.0.2: icmp_seq=19 ttl=64 time=95.5 ms
54 bytes from 10.0.0.2: icmp_seq=20 ttl=64 time=93.6 ms

--- 10.0.0.2 ping statistics ---
20 packets transmitted, 20 received, 0% packet loss, time 19033ms
```
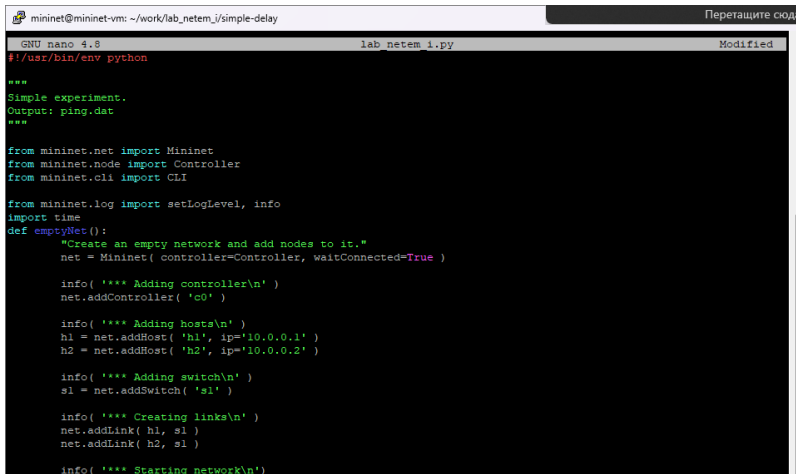
Нормальное распределение задержки ±20 мс

- Проверка ping -c 10
- Завершение работы Mininet

```
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=125 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=113 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=82.5 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=115 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=103 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=98.8 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=96.8 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=95.1 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=78.0 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=116 ms

--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9015ms
rtt min/avg/max/mdev = 77.957/102.259/124.701/14.327 ms
root@mininet-vm:/home/mininet# 
```

Воспроизводимые эксперименты

- Создание каталогов `simple-delay`, `change-delay` и т.п.
- Скрипты lab_netem_i.py для экспериментов
- Скрипты ping_plot для визуализации

Визуализация результатов

- Скрипт ping_plot строит график по данным эксперимента


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

  GNU nano 4.8
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
```
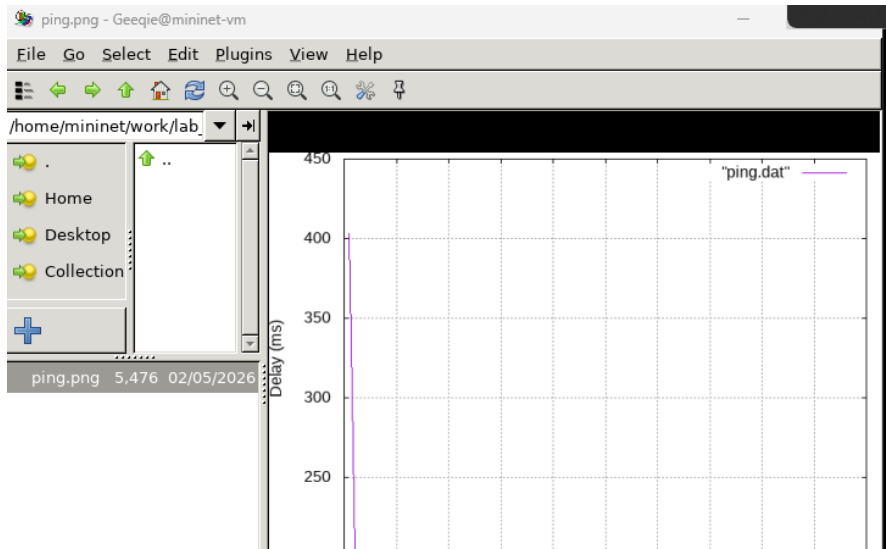
Настройка прав на скрипт

- chmod +x ping_plot

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

Результаты экспериментов

- Графики RTT

Скрипт анализа RTT

- Расчет минимального, среднего, максимального и стандартного отклонения


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

  GNU nano 4.8
with open('ping.dat', 'r') as f:
        s = []
        for line in f.readline():
                if '\n' in line:
                        line.replace('\n', "")
                        s.append([int(j) for j in (line.split(" "))])
        s = [j[1] for j in s]
        std = (sum([(i - (sum(s)/len(s)))**2 for i in s])/(len(s)-1))**0.5
        print(f"min: {{min(s)}} \max: {mas(s)} \n avg: {sum(s)/len(s)} \n std: {std}")
```

Выводы

- Ознакомился с NETEM для тестирования задержки
- Провел интерактивные и воспроизводимые эксперименты
- Измерил jitter и распределение задержки
- Построил графики и проверил корректность экспериментов