به نام خدا

درس آزمایشگاه شبکه‌های کامپیوتری

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تاریخ ارسال: ۱۴۰۱/۱۲/۰۳

سوال اول

```
mininet@TCPIP-VM:~$ ping -c 4 google.com
PING google.com (216.239.38.120) 56(84) bytes of data.
64 bytes from any-in-2678.1e100.net (216.239.38.120): icmp_seq=1 ttl=107 time=78
.2 ms
64 bytes from any-in-2678.1e100.net (216.239.38.120): icmp_seq=2 ttl=107 time=68
.4 ms
64 bytes from any-in-2678.1e100.net (216.239.38.120): icmp_seq=3 ttl=107 time=74
.3 ms
64 bytes from any-in-2678.1e100.net (216.239.38.120): icmp_seq=4 ttl=107 time=68
.1 ms

--- google.com ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3004ms
rtt min/avg/max/mdev = 68.147/72.282/78.236/4.234 ms
```

```
mininet@TCPIP-VM:~$ ping -c 4 github.com
PING github.com (140.82.121.3) 56(84) bytes of data.
64 bytes from lb-140-82-121-3-fra.github.com (140.82.121.3): icmp_seq=1 ttl=43 t
ime=129 ms
64 bytes from lb-140-82-121-3-fra.github.com (140.82.121.3): icmp_seq=2 ttl=43 t
ime=112 ms
64 bytes from lb-140-82-121-3-fra.github.com (140.82.121.3): icmp_seq=3 ttl=43 t
ime=106 ms
64 bytes from lb-140-82-121-3-fra.github.com (140.82.121.3): icmp_seq=4 ttl=43 t
ime=100 ms

--- github.com ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 100.860/112.376/129.023/10.517 ms
mininet@TCPIP-VM:~$ ping -c yahoo.com
ping: bad number of packets to transmit.
```

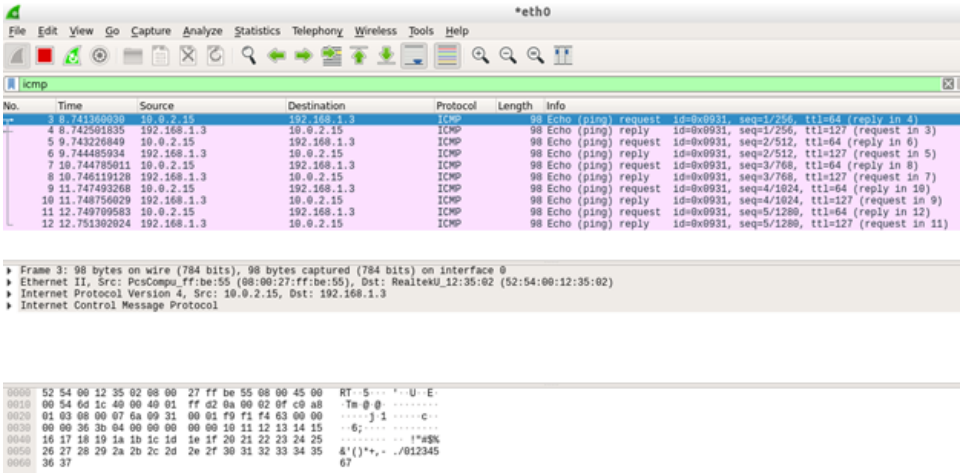
```
mininet@TCPIP-VM:~$ ping -c yahoo.com
ping: bad number of packets to transmit.
mininet@TCPIP-VM:~$ ping -c 4 yahoo.com
PING yahoo.com (74.6.231.20) 56(84) bytes of data.
64 bytes from media-router-fp73.prod.media.vip.ne1.yahoo.com (74.6.231.20): icmp_seq=1 ttl=43 time=232 ms
64 bytes from media-router-fp73.prod.media.vip.ne1.yahoo.com (74.6.231.20): icmp_seq=2 ttl=43 time=209 ms
64 bytes from media-router-fp73.prod.media.vip.ne1.yahoo.com (74.6.231.20): icmp_seq=3 ttl=43 time=220 ms
64 bytes from media-router-fp73.prod.media.vip.ne1.yahoo.com (74.6.231.20): icmp_seq=4 ttl=43 time=227 ms

--- yahoo.com ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 209.343/222.386/232.432/8.668 ms
```

```
mininet@TCPIP-VM:~$ ping -c 4 linkedin.com
PING linkedin.com (13.107.42.14) 56(84) bytes of data.
64 bytes from 13.107.42.14: icmp_seq=1 ttl=109 time=140 ms
64 bytes from 13.107.42.14: icmp_seq=2 ttl=109 time=125 ms
64 bytes from 13.107.42.14: icmp_seq=3 ttl=109 time=148 ms
64 bytes from 13.107.42.14: icmp_seq=4 ttl=109 time=148 ms

--- linkedin.com ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3004ms
rtt min/avg/max/mdev = 125.260/140.520/148.512/9.406 ms
```

Rtt مخفف «Round Trip Time» به معنای «زمان رفت و برگشت در شبکه» مفهومی است که مدت زمان ارسال یک بسته داده و زمان دریافت تصدیق (acknowledge) آن سیگنال را در قالب میلی‌ثانیه اندازه‌گیری می‌کند. زمان انتشار مسیرهای بین دو اندپوینت مرتبط در این تاخیر زمانی گنجانده می‌شود و مهم‌ترین هدف مدیر شبکه کاهش این مقدار است. چرا که این زمان رفت و برگشت، مستقیما کیفیت ارتباطات شبکه بین دو اندپوینت را نشان می‌دهد.
مخفف عبارت Time To Live معیاری است که برای مشخص کردن تعداد روترها یا Hopهای موجود در مسیر از آن استفاده می‌شود. TTL به شبکه یا در مقیاس بزرگتر، به اینترنت، این اجازه را می‌دهد تا بسته‌های داده یا به اصطلاح پکت (Packet) داده‌هایی که بیشتر از چندین مسیریاب (روتر) می‌گذرند را متوقف کرده و جلوی افتادن آن‌ها به حلقه‌های تکراری را بگیرد.
بین این دو رابطه‌ای نیست و با هم کاملا متفاوت اند.

سوال دوم

```
mininet@TCPIP-VM:~$ ping -c 5 192.168.1.3
PING 192.168.1.3 (192.168.1.3) 56(84) bytes of data.
64 bytes from 192.168.1.3: icmp_seq=1 ttl=127 time=1.15 ms
64 bytes from 192.168.1.3: icmp_seq=2 ttl=127 time=1.28 ms
64 bytes from 192.168.1.3: icmp_seq=3 ttl=127 time=1.35 ms
64 bytes from 192.168.1.3: icmp_seq=4 ttl=127 time=1.28 ms
64 bytes from 192.168.1.3: icmp_seq=5 ttl=127 time=1.62 ms

--- 192.168.1.3 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4008ms
rtt min/avg/max/mdev = 1.153/1.341/1.625/0.163 ms
mininet@TCPIP-VM:~$
```



دستور ping از پروتکل icmp استفاده می‌کند برای همین فیلتر این پروتکل را فعال می‌کنیم.

سوال سوم

- الف)

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(h1, s1) (h2, s1)
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1
*** Starting CLI:
mininet> net
h1 h1-eth0:s1-eth1
h2 h2-eth0:s1-eth2
s1 lo:  s1-eth1:h1-eth0 s1-eth2:h2-eth0
c0
mininet> _
```

- ب)

```
mininet@TCPIP-VM:~$ sudo mn --topo linear,2,2
*** Creating network
*** Adding controller
*** Adding hosts:
h1s1 h1s2 h2s1 h2s2
*** Adding switches:
s1 s2
*** Adding links:
(h1s1, s1) (h1s2, s2) (h2s1, s1) (h2s2, s2) (s1, s2)
*** Configuring hosts
h1s1 h1s2 h2s1 h2s2
*** Starting controller
*** Starting 2 switches
s1 s2
*** Starting CLI:
mininet> net
h1s1 h1s1-eth0:s1-eth1
h1s2 h1s2-eth0:s2-eth1
h2s1 h2s1-eth0:s1-eth2
h2s2 h2s2-eth0:s2-eth2
s1 lo:  s1-eth1:h1s1-eth0 s1-eth2:h2s1-eth0 s1-eth3:s2-eth3
s2 lo:  s2-eth1:h1s2-eth0 s2-eth2:h2s2-eth0 s2-eth3:s1-eth3
c0
mininet> _
```

- ج)

```
mininet@TCPIP-VM:~$ sudo mn --topo tree,2,3
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2 h3 h4 h5 h6 h7 h8 h9
*** Adding switches:
s1 s2 s3 s4
*** Adding links:
(h1, s2) (h2, s2) (h3, s2) (h4, s3) (h5, s3) (h6, s3) (h7, s4) (h8, s4) (h9, s4) (s1, s2) (s1, s3) (s1, s4)
*** Configuring hosts
h1 h2 h3 h4 h5 h6 h7 h8 h9
*** Starting controller
*** Starting 4 switches
s1 s2 s3 s4
*** Starting CLI:
mininet> net
h1 h1-eth0:s2-eth1
h2 h2-eth0:s2-eth2
h3 h3-eth0:s2-eth3
h4 h4-eth0:s3-eth1
h5 h5-eth0:s3-eth2
h6 h6-eth0:s3-eth3
h7 h7-eth0:s4-eth1
h8 h8-eth0:s4-eth2
h9 h9-eth0:s4-eth3
s1 lo:  s1-eth1:s2-eth4 s1-eth2:s3-eth4 s1-eth3:s4-eth4
s2 lo:  s2-eth1:h1-eth0 s2-eth2:h2-eth0 s2-eth3:h3-eth0 s2-eth4:s1-eth1
s3 lo:  s3-eth1:h4-eth0 s3-eth2:h5-eth0 s3-eth3:h6-eth0 s3-eth4:s1-eth2
s4 lo:  s4-eth1:h7-eth0 s4-eth2:h8-eth0 s4-eth3:h9-eth0 s4-eth4:s1-eth3
c0
```

سوال چهارم

- با $Bw = 100$ و ثابت:

$Delay = 0.01$

```
mininet@TCPIP-VM:~$ sudo mn (--topo minimal) --link tc,bw=100,delay=0.01ms
bash: syntax error near unexpected token `('
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=0.01ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 0.01ms delay) (100.00Mbit 0.01ms delay) (h1, s1) (100.00Mbit 0.01ms delay)
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 0.01ms delay) (100.00Mbit 0.01ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=5.11 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.956 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.151 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.194 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3002ms
rtt min/avg/max/mdev = 0.151/1.603/5.112/2.051 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
waiting for iperf to start up...*** Results: ['93.9 Mbits/sec', '109 Mbits/sec']
mininet>
```

$Delay = 0.05$

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=0.05ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 0.05ms delay) (100.00Mbit 0.05ms delay) (h1, s1) (100.00Mbit 0
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 0.05ms delay) (100.00Mbit 0.05ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=5.80 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=1.31 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.359 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.923 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 0.359/2.100/5.802/2.164 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['93.9 Mbits/sec', '109 Mbits/sec']
mininet>
```

Delay = 0.1

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=0.1ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 0.1ms delay) (100.00Mbit 0.1ms delay) (h1, s1) (100.00Mbit 0.
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 0.1ms delay) (100.00Mbit 0.1ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=6.30 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=1.81 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.603 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.582 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 0.582/2.326/6.308/2.352 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['95.3 Mbits/sec', '111 Mbits/sec']
mininet>
```

Delay = 0.5

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=0.5ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 0.5ms delay) (100.00Mbit 0.5ms delay) (h1, s1) (100.00Mbit 0.
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 0.5ms delay) (100.00Mbit 0.5ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=9.08 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=2.50 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=2.13 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=2.12 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3004ms
rtt min/avg/max/mdev = 2.129/3.960/9.081/2.960 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['95.2 Mbits/sec', '110 Mbits/sec']
```

Delay = 1.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 1.0ms delay) (100.00Mbit 1.0ms delay) (h1, s1) (100.00Mbit 1
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 1.0ms delay) (100.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=12.2 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.37 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.54 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=5.12 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 4.378/6.837/12.295/3.180 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['94.1 Mbits/sec', '109 Mbits/sec']
mininet>
```

Delay = 5.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=5.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 5.0ms delay) (100.00Mbit 5.0ms delay) (h1, s1) (100.00Mbit 5.0ms
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 5.0ms delay) (100.00Mbit 5.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=46.4 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=21.5 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=21.7 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=20.2 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3006ms
rtt min/avg/max/mdev = 20.265/27.501/46.417/10.937 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['94.3 Mbits/sec', '111 Mbits/sec']
mininet>
```

Delay = 10.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=10.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 10.0ms delay) (100.00Mbit 10.0ms delay) (h1, s1) (100.00Mbit 10.0
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 10.0ms delay) (100.00Mbit 10.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=85.9 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=43.4 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=41.2 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=43.2 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 41.246/53.484/85.992/18.788 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['92.7 Mbits/sec', '107 Mbits/sec']
mininet>
```

Delay = 50.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=50.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 50.0ms delay) (100.00Mbit 50.0ms delay) (h1, s1) (100.00Mbit 50
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 50.0ms delay) (100.00Mbit 50.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=409 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

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 200.758/253.306/409.372/90.105 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['74.2 Mbits/sec', '84.2 Mbits/sec']
mininet>
```

Delay = 100.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=100.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 100.0ms delay) (100.00Mbit 100.0ms delay) (h1, s1) (100.00Mbit
)
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 100.0ms delay) (100.00Mbit 100.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=807 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=401 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=401 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=400 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3002ms
rtt min/avg/max/mdev = 400.615/502.661/807.508/176.004 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['44.4 Mbits/sec', '48.8 Mbits/sec']
mininet>
```

Delay = 500.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100,delay=500.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 500.0ms delay) (100.00Mbit 500.0ms delay) (h1, s1) (100.00Mbit 500.0
)
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 500.0ms delay) (100.00Mbit 500.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=4006 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=3006 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=2007 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=2000 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 2999ms
rtt min/avg/max/mdev = 2000.956/2755.526/4006.913/830.429 ms, pipe 4
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['419 Kbits/sec', '524 Kbits/sec']
mininet> _
```

- با $\text{Delay} = 1\text{ms}$ و ثابت:

$\text{BW} = 0.01$

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=0.01,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(0.01Mbit 1.0ms delay) (0.01Mbit 1.0ms delay) (h1, s1) (0.01Mbit 1.0ms del
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (0.01Mbit 1.0ms delay) (0.01Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=17.1 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=5.14 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=4.93 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.44 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3002ms
rtt min/avg/max/mdev = 4.449/7.921/17.155/5.337 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['9.39 Kbits/sec', '58.8 Kbits/sec']
mininet>
```

$\text{BW} = 0.05$

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=0.05,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(0.05Mbit 1.0ms delay) (0.05Mbit 1.0ms delay) (h1, s1) (0.05Mbit 1.0ms delay)
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (0.05Mbit 1.0ms delay) (0.05Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=16.0 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=5.53 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=4.97 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=5.64 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 4.972/8.041/16.010/4.608 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['47.5 Kbits/sec', '307 Kbits/sec']
mininet>
```

BW = 0.1

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=0.1,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(0.10Mbit 1.0ms delay) (0.10Mbit 1.0ms delay) (h1, s1) (0.10Mbit 1.0ms delay)
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (0.10Mbit 1.0ms delay) (0.10Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=14.3 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.48 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.80 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=6.04 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 4.488/7.680/14.382/3.915 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['95.9 Kbits/sec', '231 Kbits/sec']
mininet>
```

BW = 0.5

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=0.5,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(0.50Mbit 1.0ms delay) (0.50Mbit 1.0ms delay) (h1, s1) (0.50Mbit 1.0ms de
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (0.50Mbit 1.0ms delay) (0.50Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=27.9 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.96 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.80 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.97 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 4.960/10.930/27.982/9.851 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['479 Kbits/sec', '983 Kbits/sec']
mininet>
```

BW = 1.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=1.0,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(1.00Mbit 1.0ms delay) (1.00Mbit 1.0ms delay) (h1, s1) (1.00Mbit 1.0ms de
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (1.00Mbit 1.0ms delay) (1.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=15.1 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.46 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.62 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=5.44 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3004ms
rtt min/avg/max/mdev = 4.467/7.670/15.145/4.339 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['958 Kbits/sec', '1.63 Mbits/sec']
mininet> _
```

BW = 5.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=5.0,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(5.00Mbit 1.0ms delay) (5.00Mbit 1.0ms delay) (h1, s1) (5.00Mbit 1.0ms de
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (5.00Mbit 1.0ms delay) (5.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=14.1 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=5.04 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.81 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.48 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 4.484/7.378/14.173/3.951 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['4.77 Mbits/sec', '5.95 Mbits/sec']
mininet>
```

BW = 10.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=10.0,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(10.00Mbit 1.0ms delay) (10.00Mbit 1.0ms delay) (h1, s1) (10.00Mbit 1.0ms
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (10.00Mbit 1.0ms delay) (10.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=16.6 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.64 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.37 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.72 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3004ms
rtt min/avg/max/mdev = 4.641/7.850/16.659/5.093 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['9.50 Mbits/sec', '11.3 Mbits/sec']
mininet>
```

BW = 50.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=50.0,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(50.00Mbit 1.0ms delay) (50.00Mbit 1.0ms delay) (h1, s1) (50.00Mbit 1.0ms
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (50.00Mbit 1.0ms delay) (50.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=15.0 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.54 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=4.93 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.24 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 4.240/7.181/15.009/4.526 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['46.9 Mbits/sec', '54.5 Mbits/sec']
mininet>
```

BW = 100.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=100.0,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(100.00Mbit 1.0ms delay) (100.00Mbit 1.0ms delay) (h1, s1) (100.00Mbit 1.0ms
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (100.00Mbit 1.0ms delay) (100.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=15.9 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.58 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.67 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.42 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 4.423/7.663/15.973/4.822 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['94.2 Mbits/sec', '110 Mbits/sec']
mininet>
```

BW = 500.0

```
mininet@TCPIP-VM:~$ sudo mn --topo minimal --link tc,bw=500.0,delay=1.0ms
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2
*** Adding switches:
s1
*** Adding links:
(500.00Mbit 1.0ms delay) (500.00Mbit 1.0ms delay) (h1, s1) (500.00Mbit 1.0m
*** Configuring hosts
h1 h2
*** Starting controller
*** Starting 1 switches
s1 (500.00Mbit 1.0ms delay) (500.00Mbit 1.0ms delay)
*** Starting CLI:
mininet> h1 ping h2 -c 4
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=15.8 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=4.54 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=5.08 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=4.49 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3003ms
rtt min/avg/max/mdev = 4.491/7.497/15.866/4.837 ms
mininet> iperf h1 h2
*** Iperf: testing TCP bandwidth between h1 and h2
*** Results: ['462 Mbits/sec', '480 Mbits/sec']
mininet>
```

پهنای باند ثابت (bw=100Mbps)، تأخیر متغیر

Delay (ms)	RTT (ms)	Measured Bandwidth
0.01	0.151/1.603/5.112/2.051	[93.9 Mbits/sec, 109 Mbits/sec]
0.05	0.359/2.100/5.802/2.164	[93.9 Mbits/sec, 109 Mbits/sec]
0.1	0.582/2.326/6.308/2.352	[95.3 Mbits/sec, 111 Mbits/sec]
0.5	2.129/3.960/9.081/2.960	[95.2 Mbits/sec, 110 Mbits/sec]
1.0	4.378/6.837/12.295/3.180	[94.1 Mbits/sec, 109 Mbits/sec]
5.0	20.265/27.501/46.417/10.937	[94.3 Mbits/sec, 111 Mbits/sec]
10.0	41.246/53.484/85.992/18.788	[92.7 Mbits/sec, 107 Mbits/sec]
50.0	200.758/253.306/409.372/90.105	[74.2 Mbits/sec, 84.2 Mbits/sec]
100.0	400.615/502.661/807.508/176.004	[44.4 Mbits/sec, 48.8 Mbits/sec]
500.0	2000.956/2755.526/4006.913/830.429	[419 Kbits/sec, 524 Kbits/sec]

از جدول بالا، نتیجه می‌گیریم در پهنای باند ثابت، با افزایش Delay، RTT افزایش یافته و پهنای باند اندازه‌گیری شده نیز کاهش می‌یابد.

تأخیر ثابت (delay=1ms)، پهنای‌باند متغیر

Bandwidth (Mbits/sec)	RTT (ms)	Measured Bandwidth
0.01	4.449/7.921/17.155/5.337	[9.39 Kbits/sec, 58.8 Kbits/sec]
0.05	4.972/8.041/16.010/4.608	[47.5 Kbits/sec, 307 Kbits/sec]
0.1	4.488/7.680/14.382/3.915	[95.9 Kbits/sec, 231 Kbits/sec]
0.5	4.960/10.930/27.982/9.851	[479 Kbits/sec, 983 Kbits/sec]
1.0	4.467/7.670/15.145/4.339	[958 Kbits/sec, 1.63 Mbits/sec]
5.0	4.484/7.378/14.173/3.951	[4.77 Mbits/sec, 5.95 Mbits/sec]
10.0	4.641/7.850/16.659/5.093	[9.50 Mbits/sec, 11.3 Mbits/sec]
50.0	4.240/7.181/15.009/4.526	[46.9 Mbits/sec, 54.5 Mbits/sec]
100.0	4.423/7.663/15.973/4.822	[94.2 Mbits/sec, 110 Mbits/sec]
500.0	4.491/7.497/15.866/4.837	[462 Mbits/sec, 480 Mbits/sec]

جدول بالا، نشان می‌دهد با تاخیر (Delay) ثابت، با افزایش پهنای باند، RTT تقریبا ثابت است و تغییر چندانی ندارد و پهنای باند اندازه‌گیری شده افزایش می‌یابد.