

# 实验3： 路由器操作实验

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## 步骤一： 网络拓扑测量

用ping -R来测试，然后画出拓扑图

### S1 ping -R S2和S3

ping S2	ping S3
<pre>PING 192.168.3.100 (192.168.3.100) 56(124) bytes of data. 64 bytes from 192.168.3.100: icmp_req=1 ttl=61 time=58.9 ms RR: 192.168.2.100 192.168.1.9 192.168.1.6 192.168.3.1 192.168.3.100 192.168.3.100 192.168.1.5 192.168.1.10 192.168.2.1</pre>	<pre>PING 192.168.4.100 (192.168.4.100) 56(124) bytes of data. 64 bytes from 192.168.4.100: icmp_req=1 ttl=62 time=30.8 ms RR: 192.168.2.100 192.168.1.9 192.168.4.1 192.168.4.100 192.168.4.100 192.168.1.10 192.168.2.1 192.168.2.100</pre>

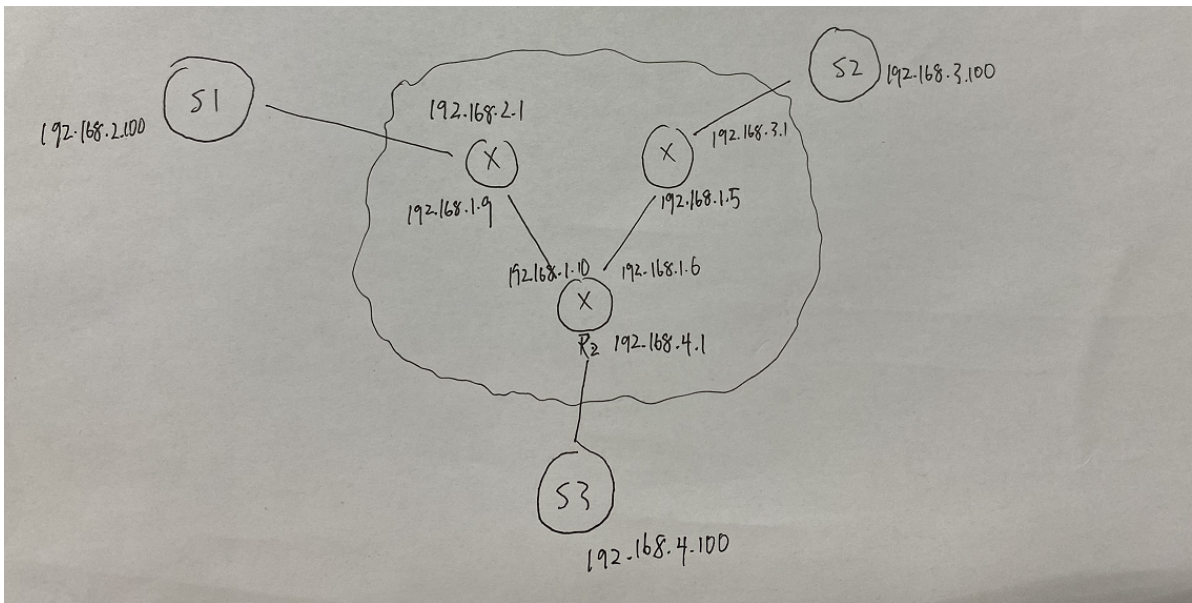
### S2 ping -R S1和S3

ping S1	ping S3
<pre>root@server-02:~# ping -R 192.168.2.100 PING 192.168.2.100 (192.168.2.100) 56(124) bytes of data. 64 bytes from 192.168.2.100: icmp_req=1 ttl=61 time=57.8 ms RR: 192.168.3.100 192.168.1.5 192.168.1.10 192.168.2.1 192.168.2.100 192.168.2.100 192.168.1.9 192.168.1.6 192.168.3.1</pre>	<pre>root@server-02:~# ping -R 192.168.4.100 PING 192.168.4.100 (192.168.4.100) 56(124) bytes of data. 64 bytes from 192.168.4.100: icmp_req=1 ttl=62 time=35.4 ms RR: 192.168.3.100 192.168.1.5 192.168.4.1 192.168.4.100 192.168.4.100 192.168.1.6 192.168.3.1 192.168.3.100</pre>

### S3 ping -R S1和S2

ping S1	ping S2
<pre>root@server-03:~# ping -R 192.168.2.100 PING 192.168.2.100 (192.168.2.100) 56(124) bytes of data. 64 bytes from 192.168.2.100: icmp_req=1 ttl=62 time=35.3 ms RR: 192.168.4.100 192.168.1.10 192.168.2.1 192.168.2.100 192.168.2.100 192.168.1.9 192.168.4.1 192.168.4.100</pre>	<pre>PING 192.168.3.100 (192.168.3.100) 56(124) bytes of data. 64 bytes from 192.168.3.100: icmp_req=1 ttl=62 time=34.1 ms RR: 192.168.4.100 192.168.1.6 192.168.3.1 192.168.3.100 192.168.3.100 192.168.1.5 192.168.4.1 192.168.4.100</pre>

三个结果综合起来，画出拓扑结构



## 步骤二：延时测量工具：双向延时ping 和 owping

### S1 ping S2和S3

ping S2	ping S3
<pre> root@server-01: # ping 192.168.3.100 -c 10 -i 3 PING 192.168.3.100 (192.168.3.100) 56(84) bytes of data. 64 bytes from 192.168.3.100: icmp_req=1 ttl=61 time=53.2 ms 64 bytes from 192.168.3.100: icmp_req=2 ttl=61 time=53.1 ms 64 bytes from 192.168.3.100: icmp_req=3 ttl=61 time=51.9 ms 64 bytes from 192.168.3.100: icmp_req=4 ttl=61 time=60.4 ms 64 bytes from 192.168.3.100: icmp_req=5 ttl=61 time=59.1 ms 64 bytes from 192.168.3.100: icmp_req=6 ttl=61 time=55.5 ms 64 bytes from 192.168.3.100: icmp_req=7 ttl=61 time=53.9 ms 64 bytes from 192.168.3.100: icmp_req=8 ttl=61 time=51.0 ms 64 bytes from 192.168.3.100: icmp_req=9 ttl=61 time=51.2 ms 64 bytes from 192.168.3.100: icmp_req=10 ttl=61 time=60.4 ms --- 192.168.3.100 ping statistics --- 10 packets transmitted, 10 received, 0% packet loss, time 27013ms rtt min/avg/max/mdev = 51.062/55.012/60.446/3.512 ms </pre>	<pre> root@server-01: # ping 192.168.4.100 -c 10 -i 3 PING 192.168.4.100 (192.168.4.100) 56(84) bytes of data. 64 bytes from 192.168.4.100: icmp_req=1 ttl=62 time=30.8 ms 64 bytes from 192.168.4.100: icmp_req=2 ttl=62 time=38.9 ms 64 bytes from 192.168.4.100: icmp_req=3 ttl=62 time=35.8 ms 64 bytes from 192.168.4.100: icmp_req=4 ttl=62 time=40.1 ms 64 bytes from 192.168.4.100: icmp_req=5 ttl=62 time=39.5 ms 64 bytes from 192.168.4.100: icmp_req=6 ttl=62 time=37.7 ms 64 bytes from 192.168.4.100: icmp_req=7 ttl=62 time=37.2 ms 64 bytes from 192.168.4.100: icmp_req=8 ttl=62 time=35.9 ms 64 bytes from 192.168.4.100: icmp_req=9 ttl=62 time=32.2 ms 64 bytes from 192.168.4.100: icmp_req=10 ttl=62 time=40.4 ms --- 192.168.4.100 ping statistics --- 10 packets transmitted, 10 received, 0% packet loss, time 27017ms rtt min/avg/max/mdev = 30.823/36.886/40.415/3.094 ms </pre>

### S2 ping S1和S3

ping S1	ping S3
<pre> root@server-02: # ping 192.168.2.100 -c 10 -i 3 PING 192.168.2.100 (192.168.2.100) 56(84) bytes of data. 64 bytes from 192.168.2.100: icmp_req=1 ttl=61 time=54.8 ms 64 bytes from 192.168.2.100: icmp_req=2 ttl=61 time=60.6 ms 64 bytes from 192.168.2.100: icmp_req=3 ttl=61 time=57.1 ms 64 bytes from 192.168.2.100: icmp_req=4 ttl=61 time=55.0 ms 64 bytes from 192.168.2.100: icmp_req=5 ttl=61 time=52.9 ms 64 bytes from 192.168.2.100: icmp_req=6 ttl=61 time=60.6 ms 64 bytes from 192.168.2.100: icmp_req=7 ttl=61 time=57.4 ms 64 bytes from 192.168.2.100: icmp_req=8 ttl=61 time=53.0 ms 64 bytes from 192.168.2.100: icmp_req=9 ttl=61 time=52.4 ms 64 bytes from 192.168.2.100: icmp_req=10 ttl=61 time=54.1 ms --- 192.168.2.100 ping statistics --- 10 packets transmitted, 10 received, 0% packet loss, time 27021ms rtt min/avg/max/mdev = 52.404/55.834/60.626/2.873 ms </pre>	<pre> root@server-02: # ping 192.168.4.100 -c 10 -i 3 PING 192.168.4.100 (192.168.4.100) 56(84) bytes of data. 64 bytes from 192.168.4.100: icmp_req=1 ttl=62 time=40.3 ms 64 bytes from 192.168.4.100: icmp_req=2 ttl=62 time=37.0 ms 64 bytes from 192.168.4.100: icmp_req=3 ttl=62 time=36.3 ms 64 bytes from 192.168.4.100: icmp_req=4 ttl=62 time=35.1 ms 64 bytes from 192.168.4.100: icmp_req=5 ttl=62 time=31.2 ms 64 bytes from 192.168.4.100: icmp_req=6 ttl=62 time=34.7 ms 64 bytes from 192.168.4.100: icmp_req=7 ttl=62 time=34.6 ms 64 bytes from 192.168.4.100: icmp_req=8 ttl=62 time=35.7 ms 64 bytes from 192.168.4.100: icmp_req=9 ttl=62 time=35.8 ms 64 bytes from 192.168.4.100: icmp_req=10 ttl=62 time=32.7 ms --- 192.168.4.100 ping statistics --- 10 packets transmitted, 10 received, 0% packet loss, time 27018ms rtt min/avg/max/mdev = 31.287/35.414/40.371/2.332 ms </pre>

### S3 ping S1和S2

## ping S1

```
root@server-03: # ping -R 192.168.2.100 -c 10 -i 3
PING 192.168.2.100 (192.168.2.100) 56(124) bytes of data.
64 bytes from 192.168.2.100: icmp_req=1 ttl=62 time=33.9 ms
RR: 192.168.4.100
    192.168.1.10
    192.168.2.1
    192.168.2.100
    192.168.2.100
    192.168.1.9
    192.168.4.1
    192.168.4.100
64 bytes from 192.168.2.100: icmp_req=2 ttl=62 time=33.3 ms (same route)
64 bytes from 192.168.2.100: icmp_req=3 ttl=62 time=34.9 ms (same route)
64 bytes from 192.168.2.100: icmp_req=4 ttl=62 time=34.5 ms (same route)
64 bytes from 192.168.2.100: icmp_req=5 ttl=62 time=35.4 ms (same route)
64 bytes from 192.168.2.100: icmp_req=6 ttl=62 time=33.8 ms (same route)
64 bytes from 192.168.2.100: icmp_req=7 ttl=62 time=31.7 ms (same route)
64 bytes from 192.168.2.100: icmp_req=8 ttl=62 time=40.3 ms (same route)
64 bytes from 192.168.2.100: icmp_req=9 ttl=62 time=37.0 ms (same route)
64 bytes from 192.168.2.100: icmp_req=10 ttl=62 time=35.5 ms (same route)

--- 192.168.2.100 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 27015ms
rtt min/avg/max/mdev = 31.745/35.070/40.360/2.223 ms
```

## ping S2

```
root@server-03: # ping -R 192.168.3.100 -c 10 -i 3
PING 192.168.3.100 (192.168.3.100) 56(124) bytes of data.
64 bytes from 192.168.3.100: icmp_req=1 ttl=62 time=38.4 ms
RR: 192.168.4.100
    192.168.1.6
    192.168.3.1
    192.168.3.100
    192.168.3.100
    192.168.1.5
    192.168.4.1
    192.168.4.100
64 bytes from 192.168.3.100: icmp_req=2 ttl=62 time=35.8 ms (same route)
64 bytes from 192.168.3.100: icmp_req=3 ttl=62 time=40.8 ms (same route)
64 bytes from 192.168.3.100: icmp_req=4 ttl=62 time=36.8 ms (same route)
64 bytes from 192.168.3.100: icmp_req=5 ttl=62 time=31.8 ms (same route)
64 bytes from 192.168.3.100: icmp_req=6 ttl=62 time=40.4 ms (same route)
64 bytes from 192.168.3.100: icmp_req=7 ttl=62 time=40.3 ms (same route)
64 bytes from 192.168.3.100: icmp_req=8 ttl=62 time=39.0 ms (same route)
64 bytes from 192.168.3.100: icmp_req=9 ttl=62 time=35.4 ms (same route)
64 bytes from 192.168.3.100: icmp_req=10 ttl=62 time=31.2 ms (same route)

--- 192.168.3.100 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 27024ms
rtt min/avg/max/mdev = 31.235/37.048/40.811/3.296 ms
```

## S1 owping S2和S3

### owping S2

```
cisco@server-01: $ owping 192.168.3.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
owping: FILE=capi.c, LINE=298, Unable to connect to "[192.168.3.100]:861"
owping: FILE=owping.c, LINE=142, Unable to open control connection.
cisco@server-01: $ owping 192.168.3.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
Approximately 13.4 seconds until results available

--- owping statistics from [192.168.2.100]:47903 to [192.168.3.100]:55673 ---
SID: c0a80264e54701f29469a329c77d9
first: 2021-11-23T13:59:12.606
last: 2021-11-23T13:59:22.592
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 20.5/25.4/30.9 ms, (unsync)
one-way jitter = 4.3 ms (P95-P50)
Hops = 3 (consistently)
no reordering

--- owping statistics from [192.168.3.100]:53222 to [192.168.2.100]:51865 ---
SID: c0a80264e54701f31a0635a273ac9c
first: 2021-11-23T13:59:12.533
last: 2021-11-23T13:59:22.387
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 13.5/25.8/30.4 ms, (unsync)
one-way jitter = 4.1 ms (P95-P50)
Hops = 3 (consistently)
no reordering
```

### owping S3

```
cisco@server-01: $ owping 192.168.4.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
Approximately 13.3 seconds until results available

--- owping statistics from [192.168.2.100]:37925 to [192.168.4.100]:48595 ---
SID: c0a80464e547034c5218372a8cade3eb
first: 2021-11-23T14:06:05.600
last: 2021-11-23T14:06:16.001
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.5/15.3/20.3 ms, (unsync)
one-way jitter = 4.7 ms (P95-P50)
Hops = 2 (consistently)
no reordering

--- owping statistics from [192.168.4.100]:56885 to [192.168.2.100]:60340 ---
SID: c0a80264e547034c574eac600453fc5b
first: 2021-11-23T14:06:05.718
last: 2021-11-23T14:06:16.104
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.6/15.2/20.3 ms, (unsync)
one-way jitter = 4.8 ms (P95-P50)
Hops = 2 (consistently)
no reordering
```

## S2 owping S1和S3

### owping S1

```
cisco@server-02: $ owping 192.168.2.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
Approximately 13.4 seconds until results available

--- owping statistics from [192.168.3.100]:38563 to [192.168.2.100]:41295 ---
SID: c0a80264e54701d3d513943191168b64
first: 2021-11-23T13:59:49.183
last: 2021-11-23T14:00:00.744
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 20.6/25.5/30.4 ms, (unsync)
one-way jitter = 4.6 ms (P95-P50)
Hops = 3 (consistently)
no reordering
```

### owping S3

```
cisco@server-02: $ owping 192.168.4.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
Approximately 13.3 seconds until results available

--- owping statistics from [192.168.3.100]:34491 to [192.168.4.100]:50501 ---
SID: c0a80464e54703aadd899bf51af04b67
first: 2021-11-23T14:07:40.234
last: 2021-11-23T14:07:48.941
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.3/15.8/20.4 ms, (unsync)
one-way jitter = 3.9 ms (P95-P50)
Hops = 2 (consistently)
no reordering

--- owping statistics from [192.168.4.100]:50051 to [192.168.3.100]:38273 ---
SID: c0a80364e54703aae2c61522d931d15d
first: 2021-11-23T14:07:40.244
last: 2021-11-23T14:07:50.825
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.4/14.8/20.4 ms, (unsync)
one-way jitter = 5.3 ms (P95-P50)
Hops = 2 (consistently)
no reordering
```

## S3 owping S1和S2

### owping S1

```
root@server-03: # owping 192.168.2.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
Approximately 13.3 seconds until results available

--- owping statistics from [192.168.4.100]:54764 to [192.168.2.100]:49753 ---
SID: c0a80264e547036d690aa7db70fabd7
first: 2021-11-23T14:06:38.884
last: 2021-11-23T14:06:48.631
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.3/14.8/20.3 ms, (unsync)
one-way jitter = 5 ms (P95-P50)
Hops = 2 (consistently)
no reordering

--- owping statistics from [192.168.2.100]:52568 to [192.168.4.100]:56438 ---
SID: c0a80464e547036d690aa7db70fabd7
first: 2021-11-23T14:06:38.825
last: 2021-11-23T14:06:49.288
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.4/15.2/20.4 ms, (unsync)
one-way jitter = 4.9 ms (P95-P50)
Hops = 2 (consistently)
no reordering
```

### owping S2

```
root@server-03: # owping 192.168.3.100
owping: FILE=time.c, LINE=112, NTP: Status UNSYNC (clock offset issues likely)
Approximately 13.3 seconds until results available

--- owping statistics from [192.168.4.100]:35729 to [192.168.3.100]:60476 ---
SID: c0a80364e5470435e66cb103010ce029
first: 2021-11-23T14:09:59.182
last: 2021-11-23T14:10:10.263
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.4/14.4/20.3 ms, (unsync)
one-way jitter = 5.6 ms (P95-P50)
Hops = 2 (consistently)
no reordering

--- owping statistics from [192.168.3.100]:41063 to [192.168.4.100]:38807 ---
SID: c0a80464e5470435ebc70c994532d88b
first: 2021-11-23T14:09:59.153
last: 2021-11-23T14:10:09.770
100 sent, 0 lost (0.000%), 0 duplicates
one-way delay min/median/max = 10.5/15.4/21.3 ms, (unsync)
one-way jitter = 4.2 ms (P95-P50)
Hops = 2 (consistently)
no reordering
```

## 思考题

1. 有时第一次ping的延时明显比以后的延时大得多。这种情况会影响测量结果的准确性吗？你认为出现这种情况的原因是什么？如何避免这种情况的发生？【答】第一个ping延时比较高因为arp lookup, 第一个ping需要在arp表找到适合的arp地址。不会影响测量结果的准确性。
2. 用2中的方法测量Server到默认网关的延时。你发现了什么现象？你认为产生这种现象的原因是什么？【答】S1和S2之间的延时比S1/S2和S3之间的延时高，因为S1和S2之间的路由器多（3个 hops）。

结论：用ping来测试，我们定义了 `-i` 和 `-c` 两个参数。`-i` 指定发送的回显请求消息的 IP 标头中的生存时间 (TTL) 字段的值。`-c` 指定ping的次数。owping或单向ping用来测试单向延迟测试。看结果，owping的延时差不多是ping的一半。

## 步骤三：测量带宽工具：iperf（端到端吞吐量）和pchar（逐跳带宽）

### S1 iperf S2和S3

iperf S2	iperf S3
<pre>cisco@server-01:~\$ iperf -c 192.168.3.100 ----- Client connecting to 192.168.3.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.2.100 port 57905 connected with 192.168.3.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.6 sec   3.62 MBytes  2.86 Mbits/sec</pre>	<pre>cisco@server-01:~\$ iperf -c 192.168.4.100 ----- Client connecting to 192.168.4.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.2.100 port 33991 connected with 192.168.4.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.3 sec   5.12 MBytes  4.18 Mbits/sec</pre>

### S2 iperf S1和S3

iperf S1	iperf S3
<pre>cisco@server-02:~\$ iperf -c 192.168.2.100 ----- Client connecting to 192.168.2.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.3.100 port 59136 connected with 192.168.2.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.4 sec   3.50 MBytes  2.83 Mbits/sec</pre>	<pre>cisco@server-02:~\$ iperf -c 192.168.4.100 ----- Client connecting to 192.168.4.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.3.100 port 55360 connected with 192.168.4.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.5 sec   4.88 MBytes  3.89 Mbits/sec</pre>

### S3 iperf S1和S2

第一次：iperf S1 and S2	第二次：iperf S1 and S2
<pre>root@server-03:~# iperf -c 192.168.2.100 ----- Client connecting to 192.168.2.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.4.100 port 49273 connected with 192.168.2.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.2 sec   5.35 MBytes  4.41 Mbits/sec root@server-03:~# iperf -c 192.168.3.100 ----- Client connecting to 192.168.3.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.4.100 port 50248 connected with 192.168.3.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.3 sec   4.62 MBytes  3.78 Mbits/sec</pre>	<pre>root@server-03:~# iperf -c 192.168.2.100 ----- Client connecting to 192.168.2.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.4.100 port 49277 connected with 192.168.2.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.5 sec   5.75 MBytes  4.58 Mbits/sec root@server-03:~# iperf -c 192.168.3.100 ----- Client connecting to 192.168.3.100, TCP port 5001 TCP window size: 85.0 KByte (default) ----- [ 3] local 192.168.4.100 port 50252 connected with 192.168.3.100 port 5001 [ ID] Interval      Transfer    Bandwidth [ 3] 0.0-10.3 sec   5.00 MBytes  4.09 Mbits/sec</pre>

用iperf来测试端到端吞吐量我们可以看到S1和S2之间的吞吐量低相对较小，S1/S2和S3之间的吞吐量会高一些。测试次数越少，吞吐率将显著提高。

### S1 pchar S2和S3

## pchar S2

```
cisco@server-01:~$ sudo pchar -R 3 192.168.3.100
pchar to 192.168.3.100 (192.168.3.100) using UDP/IPv4
Using raw socket input
Packet size increments from 32 to 1500 by 32
46 test(s) per repetition
3 repetition(s) per hop
0: 192.168.2.100 (server-01)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 1.332411 ms, (b = -0.000018 ms/B), r2 = 0.016803
                    stddev rtt = 0.016919, stddev b = 0.000021
  Partial queueing:  avg = 0.000166 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000166 ms (0 bytes)
1: 192.168.2.1 (192.168.2.1)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 21.451662 ms, (b = 0.000000 ms/B), r2 = 0.000006
                    stddev rtt = 0.024353, stddev b = 0.000030
  Partial queueing:  avg = 0.000181 ms (849 bytes)
  Hop char:          rtt = 20.119251 ms, bw = 423782.150605 Kbps
  Hop queueing:      avg = 0.000016 ms (849 bytes)
2: 192.168.1.10 (192.168.1.10)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 41.596774 ms, (b = 0.000038 ms/B), r2 = 0.029018
                    stddev rtt = 0.027060, stddev b = 0.000033
  Partial queueing:  avg = 0.000104 ms (849 bytes)
  Hop char:          rtt = 20.145112 ms, bw = 211055.521659 Kbps
  Hop queueing:      avg = -0.000077 ms (0 bytes)
3: 192.168.1.5 (192.168.1.5)
  Partial loss:      25 / 138 (18%)
  Partial char:      rtt = 51.755584 ms, (b = 0.000016 ms/B), r2 = 0.001743
                    stddev rtt = 0.072955, stddev b = 0.000059
  Partial queueing:  avg = 0.000662 ms (849 bytes)
  Hop char:          rtt = 10.158810 ms, bw = --,--- Kbps
  Hop queueing:      avg = 0.000558 ms (0 bytes)
4: 192.168.3.100 (server-02)
  Path length:      4 hops
  Path char:        rtt = 51.755584 ms r2 = 0.001743
  Path bottleneck:  211055.521659 Kbps
  Path pipe:        1365412 bytes
  Path queueing:    average = 0.000662 ms (849 bytes)
  Start time:       Tue Nov 23 14:20:48 2021
  End time:         Tue Nov 23 14:24:29 2021
```

## pchar S3

```
cisco@server-01:~$ sudo pchar -R 3 192.168.4.100
pchar to 192.168.4.100 (192.168.4.100) using UDP/IPv4
Using raw socket input
Packet size increments from 32 to 1500 by 32
46 test(s) per repetition
3 repetition(s) per hop
0: 192.168.2.100 (server-01)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 1.276842 ms, (b = -0.000002 ms/B), r2 = 0.000093
                    stddev rtt = 0.019268, stddev b = 0.000024
  Partial queueing:  avg = 0.000170 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000170 ms (0 bytes)
1: 192.168.2.1 (192.168.2.1)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 21.487058 ms, (b = -0.000024 ms/B), r2 = 0.010198
                    stddev rtt = 0.028563, stddev b = 0.000035
  Partial queueing:  avg = 0.000205 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000035 ms (0 bytes)
2: 192.168.1.10 (192.168.1.10)
  Partial loss:      26 / 138 (18%)
  Partial char:      rtt = 32.330431 ms, (b = -0.000389 ms/B), r2 = 0.031538
                    stddev rtt = 0.399866, stddev b = 0.000325
  Partial queueing:  avg = 0.000814 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000609 ms (0 bytes)
3: 192.168.4.100 (server-02)
  Path length:      3 hops
  Path char:        rtt = 32.330431 ms r2 = 0.031538
  Path queueing:    average = 0.000814 ms (0 bytes)
  Start time:       Tue Nov 23 14:28:33 2021
  End time:         Tue Nov 23 14:31:32 2021
```

## S2 pchar S1和S3

### pchar S1

```
cisco@server-02:~$ sudo pchar -R 3 192.168.2.100
pchar to 192.168.2.100 (192.168.2.100) using UDP/IPv4
Using raw socket input
Packet size increments from 32 to 1500 by 32
46 test(s) per repetition
3 repetition(s) per hop
0: 192.168.3.100 (server-02)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 1.338706 ms, (b = 0.000020 ms/B), r2 = 0.007424
                    stddev rtt = 0.028100, stddev b = 0.000035
  Partial queueing:  avg = 0.000201 ms (10073 bytes)
  Hop char:          rtt = 1.338706 ms, bw = 400989.180835 Kbps
  Hop queueing:      avg = 0.000201 ms (10073 bytes)
1: 192.168.3.1 (192.168.3.1)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 21.584653 ms, (b = -0.000021 ms/B), r2 = 0.007856
                    stddev rtt = 0.028657, stddev b = 0.000035
  Partial queueing:  avg = 0.000124 ms (10073 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = -0.000077 ms (0 bytes)
2: 192.168.1.6 (192.168.1.6)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 41.645341 ms, (b = 0.000051 ms/B), r2 = 0.032505
                    stddev rtt = 0.034031, stddev b = 0.000042
  Partial queueing:  avg = 0.000157 ms (10528 bytes)
  Hop char:          rtt = 20.060688 ms, bw = 110892.527983 Kbps
  Hop queueing:      avg = 0.000033 ms (455 bytes)
3: 192.168.1.9 (192.168.1.9)
  Partial loss:      41 / 138 (29%)
  Partial char:      rtt = 53.306902 ms, (b = -0.000782 ms/B), r2 = 0.046724
                    stddev rtt = 0.656216, stddev b = 0.000533
  Partial queueing:  avg = 0.001471 ms (10528 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.001314 ms (0 bytes)
4: 192.168.2.100 (server-01)
  Path length:      4 hops
  Path char:        rtt = 53.306902 ms r2 = 0.046724
  Path bottleneck:  110892.527983 Kbps
  Path pipe:        738917 bytes
  Path queueing:    average = 0.001471 ms (10528 bytes)
  Start time:       Tue Nov 23 14:30:30 2021
  End time:         Tue Nov 23 14:34:52 2021
```

### pchar S3

```
cisco@server-02:~$ sudo pchar -R 3 192.168.4.100
pchar to 192.168.4.100 (192.168.4.100) using UDP/IPv4
Using raw socket input
Packet size increments from 32 to 1500 by 32
46 test(s) per repetition
3 repetition(s) per hop
0: 192.168.3.100 (server-02)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 1.365767 ms, (b = -0.000010 ms/B), r2 = 0.001292
                    stddev rtt = 0.034101, stddev b = 0.000042
  Partial queueing:  avg = 0.000210 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000210 ms (0 bytes)
1: 192.168.3.1 (192.168.3.1)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 21.430703 ms, (b = 0.000067 ms/B), r2 = 0.033010
                    stddev rtt = 0.043966, stddev b = 0.000054
  Partial queueing:  avg = 0.000107 ms (0 bytes)
  Hop char:          rtt = 20.064936 ms, bw = 104224.163905 Kbps
  Hop queueing:      avg = -0.000103 ms (0 bytes)
2: 192.168.1.6 (192.168.1.6)
  Partial loss:      26 / 138 (18%)
  Partial char:      rtt = 32.418348 ms, (b = -0.000506 ms/B), r2 = 0.040246
                    stddev rtt = 0.459051, stddev b = 0.000373
  Partial queueing:  avg = 0.000845 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000738 ms (0 bytes)
3: 192.168.4.100 (server-03)
  Path length:      3 hops
  Path char:        rtt = 32.418348 ms r2 = 0.040246
  Path bottleneck:  104224.163905 Kbps
  Path pipe:        422346 bytes
  Path queueing:    average = 0.000845 ms (0 bytes)
  Start time:       Tue Nov 23 14:25:21 2021
  End time:         Tue Nov 23 14:28:20 2021
cisco@server-02:~$
```

## S3 pchar S1和S2

### pchar S1

```
root@server-03:~# sudo pchar -R 3 192.168.2.100
pchar to 192.168.2.100 (192.168.2.100) using UDP/IPv4
Using raw socket input
Packet size increments from 32 to 1500 by 32
46 test(s) per repetition
3 repetition(s) per hop
0: 192.168.4.100 (server-03)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 1.284361 ms, (b = 0.000065 ms/B), r2 = 0.208917
                    stddev rtt = 0.020040, stddev b = 0.000025
  Partial queueing:  avg = 0.000190 ms (2249 bytes)
  Hop char:          rtt = 1.284361 ms, bw = 94623.538262 Kbps
  Hop queueing:      avg = 0.000190 ms (2249 bytes)
1: 192.168.4.1 (192.168.4.1)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 21.429271 ms, (b = 0.000033 ms/B), r2 = 0.014537
                    stddev rtt = 0.032988, stddev b = 0.000041
  Partial queueing:  avg = 0.000295 ms (2249 bytes)
  Hop char:          rtt = 20.144910 ms, bw = --,--- Kbps
  Hop queueing:      avg = 0.000105 ms (0 bytes)
2: 192.168.1.9 (192.168.1.9)
  Partial loss:      26 / 138 (18%)
  Partial char:      rtt = 30.986776 ms, (b = 0.000918 ms/B), r2 = 0.072472
                    stddev rtt = 0.609642, stddev b = 0.000495
  Partial queueing:  avg = 0.000773 ms (2789 bytes)
  Hop char:          rtt = 9.557505 ms, bw = 9042.754692 Kbps
  Hop queueing:      avg = 0.000478 ms (540 bytes)
3: 192.168.2.100 (server-01)
  Path length:      3 hops
  Path char:        rtt = 30.986776 ms r2 = 0.072472
  Path bottleneck:  9042.754692 Kbps
  Path pipe:        35025 bytes
  Path queueing:    average = 0.000773 ms (2789 bytes)
  Start time:       Tue Nov 23 14:24:12 2021
  End time:         Tue Nov 23 14:27:11 2021
```

### pchar S2

```
root@server-03:~# sudo pchar -R 3 192.168.3.100
pchar to 192.168.3.100 (192.168.3.100) using UDP/IPv4
Using raw socket input
Packet size increments from 32 to 1500 by 32
46 test(s) per repetition
3 repetition(s) per hop
0: 192.168.4.100 (server-03)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 1.306706 ms, (b = -0.000010 ms/B), r2 = 0.002925
                    stddev rtt = 0.022295, stddev b = 0.000028
  Partial queueing:  avg = 0.000194 ms (0 bytes)
  Hop char:          rtt = 0.000000 ms, bw = 0.000000 Kbps
  Hop queueing:      avg = 0.000194 ms (0 bytes)
1: 192.168.4.1 (192.168.4.1)
  Partial loss:      0 / 138 (0%)
  Partial char:      rtt = 21.475265 ms, (b = 0.000020 ms/B), r2 = 0.004919
                    stddev rtt = 0.034672, stddev b = 0.000043
  Partial queueing:  avg = 0.000239 ms (1486 bytes)
  Hop char:          rtt = 20.168559 ms, bw = 267326.120557 Kbps
  Hop queueing:      avg = 0.000044 ms (1486 bytes)
2: 192.168.1.5 (192.168.1.5)
  Partial loss:      26 / 138 (18%)
  Partial char:      rtt = 31.672730 ms, (b = 0.000083 ms/B), r2 = 0.001378
                    stddev rtt = 0.417160, stddev b = 0.000339
  Partial queueing:  avg = 0.001140 ms (15692 bytes)
  Hop char:          rtt = 10.197465 ms, bw = 126126.258670 Kbps
  Hop queueing:      avg = 0.000901 ms (14206 bytes)
3: 192.168.3.100 (server-02)
  Path length:      3 hops
  Path char:        rtt = 31.672730 ms r2 = 0.001378
  Path bottleneck:  126126.258670 Kbps
  Path pipe:        499345 bytes
  Path queueing:    average = 0.001140 ms (15692 bytes)
  Start time:       Tue Nov 23 14:32:26 2021
  End time:         Tue Nov 23 14:35:25 2021
```



pchar是用来测量两个主机之间的网络路径的特征，是通过将不同大小的 UDP 数据包发送到网络并等待 ICMP 消息响应来测量网络吞吐量和往返时间，比iperf看到的信息多。S1和S2之间路径有4个hops，S1/S2和S3之间只有三个。结果和iperf一样，S1/S2和S3之间的吞吐量会高一些,化的时间end time - start time也会少一点（大概3秒，S1和S2之间大概4秒）。

## 步骤四：tcpdump

S1

```
cisco@server-01:~$ more tcpdump.tmp
20:41:43.655281 IP server-01.telnet > 192.168.2.254.50251: Flags [P.], seq 1899513889:1899514038, ack 469097024, win 227, options [nop,nop,TS val 26307202 ecr 26307104], length 149
 0x0000: 4510 00c9 2e95 4000 4006 84d7 c0a8 0264
 0x0010: c0a8 02fe 0017 c44b 7138 4821 1bf5 da40
 0x0020: 8018 00e3 0036 0000 0101 080a 0191 6a82
 0x0030: 0191 6a20 7463 7064 756d 703a 2076 6572
 0x0040: 626f 7365 206f 7574 7075 7420 7375 7070
 0x0050: 7265 7373 6564 2c20 7573 6520 2d76 206f
 0x0060: 7220 2d76 7620 666f 7220 6675 6c6c 2070
 0x0070: 726f 746f 636f 6c20 6465 636f 6465 0d0a
 0x0080: 6c69 7374 656e 696e 6720 6f6e 2076 6531
 0x0090: 2c20 6c69 6e6b 2d74 7970 6520 454e 3130
 0x00a0: 4442 2028 4574 6865 726e 6574 292e 2063
 0x00b0: 6170 7475 7265 2073 697e 6520 3635 3533
 0x00c0: 3520 6279 7465 730d 0a
20:41:43.655562 IP server-01.54709 > 192.168.2.254.domain: 7486+ PTR? 254.2.168.192.in-addr.arpa. (44)
 0x0000: 4500 0048 80dc 4000 4011 3316 c0a8 0264
 0x0010: c0a8 02fe d5b5 0035 0034 c1f8 1d3e 0100
 0x0020: 0001 0000 0000 0000 0332 3534 0132 0331
 0x0030: 3638 0331 3932 0769 6e2d 6164 6472 0461
 0x0040: 7270 6100 0000 0001
20:41:43.655897 IP 192.168.2.254.50251 > server-01.telnet: Flags [.] , ack 149, win 613, options [nop,nop,TS val 26307202 ecr 26307202], length 0
 0x0000: 4510 0034 1d97 4000 4006 966a c0a8 02fe
 0x0010: c0a8 0264 c44b 0017 1bf5 da40 7138 48b6
 0x0020: 8010 0265 a0f7 0000 0101 080a 0191 6a82
 0x0030: 0191 6a82
20:41:43.655858 IP 192.168.2.254.domain > server-01.54709: 7486 NXDomain 0/1/0 (79)
 0x0000: 4500 0048 80dc 4000 4011 3316 c0a8 0264
 0x0010: c0a8 02fe d5b5 0035 0034 c1f8 1d3e 0100
 0x0020: 0001 0000 0000 0000 0332 3534 0132 0331
 0x0030: 3638 0331 3932 0769 6e2d 6164 6472 0461
 0x0040: 7270 6100 0000 0001
```

S2

```
cisco@server-02:~$ more tcpdump.tmp
14:59:24.119999 IP server-02.telnet > 192.168.3.254.44143: Flags [P.], seq 3496804981:3496805055, ack 3712888797, win 227, options [nop,nop,TS val 21172318 ecr 21172228], length 74
 0x0000: 4510 007e d300 4000 4006 deb6 c0a8 0364
 0x0010: c0a8 03fe 0017 ac6f d06d 0275 dd4e 2fdd
 0x0020: 8018 00e3 54b3 0000 0101 080a 0143 105e
 0x0030: 0143 1004 7463 7064 756d 703a 2076 6572
 0x0040: 626f 7365 206f 7574 7075 7420 7375 7070
 0x0050: 7265 7373 6564 2c20 7573 6520 2d76 206f
 0x0060: 7220 2d76 7620 666f 7220 6675 6c6c 2070
 0x0070: 726f 746f 636f 6c20 6465 636f 6465
14:59:24.120099 IP 192.168.3.254.44143 > server-02.telnet: Flags [.] , ack 74, win 1444, options [nop,nop,TS val 21172318 ecr 21172318], length 0
 0x0000: 4510 0034 962c 4000 4006 1bd5 c0a8 03fe
 0x0010: c0a8 0364 ac6f 0017 dd4e 2fdd d06d 02bf
 0x0020: 8010 05a4 3845 0000 0101 080a 0143 105e
 0x0030: 0143 105e
14:59:24.120126 IP server-02.telnet > 192.168.3.254.44143: Flags [P.], seq 74:76, ack 1, win 227, options [nop,nop,TS val 21172318 ecr 21172318], length 2
 0x0000: 4510 0036 d301 4000 4006 defd c0a8 0364
 0x0010: c0a8 03fe 0017 ac6f d06d 02bf dd4e 2fdd
 0x0020: 8018 00e3 2ff2 0000 0101 080a 0143 105e
 0x0030: 0143 105e 0d0a
14:59:24.120146 IP 192.168.3.254.44143 > server-02.telnet: Flags [.] , ack 76, win 1444, options [nop,nop,TS val 21172318 ecr 21172318], length 0
 0x0000: 4510 0034 962d 4000 4006 1bd4 c0a8 03fe
 0x0010: c0a8 0364 ac6f 0017 dd4e 2fdd d06d 02c1
 0x0020: 8010 05a4 3843 0000 0101 080a 0143 105e
 0x0030: 0143 105e
--More--(43%)66 IP server-02.telnet > 192.168.3.254.44143: Flags [P.], seq 76:147, ack 1, win 227, options [nop,nop,TS v
```

S3

```
cisco@server-03:~$ more tcpdump.tmp
14:34:29.155193 IP server-03.telnet > 192.168.4.254.40127: Flags [P.], seq 2665366998:2665367072, ack 3361635407, win 227, options [nop,nop,TS val 215198577 ecr 215198462], length 74
 0x0000: 4510 007e 3add 4000 4006 71da c0a8 0464
 0x0010: c0a8 04fe 0017 9cbf 9ede 45d6 c85e 7c4f
 0x0020: 8018 00e3 cbe0 0000 0101 080a 0cd3 ab71
 0x0030: 0cd3 ab7f 7463 7064 756d 703a 2076 6572
 0x0040: 626f 7365 206f 7574 7075 7420 7375 7070
 0x0050: 7265 7373 6564 2c20 7573 6520 2d76 206f
 0x0060: 7220 2d76 7620 666f 7220 6675 6c6c 2070
 0x0070: 726f 746f 636f 6c20 6465 636f 6465
14:34:29.155306 IP 192.168.4.254.40127 > server-03.telnet: Flags [.] , ack 74, win 6143, options [nop,nop,TS val 215198577 ecr 215198577], length 0
 0x0000: 4510 0034 1ed3 4000 4006 912e c0a8 04fe
 0x0010: c0a8 0464 9cbf 0017 c85e 7c4f 9ede 4620
 0x0020: 8010 17ff 9cfe 0000 0101 080a 0cd3 ab71
 0x0030: 0cd3 ab71
14:34:29.155323 IP server-03.telnet > 192.168.4.254.40127: Flags [P.], seq 74:76, ack 1, win 227, options [nop,nop,TS val 215198577 ecr 215198577], length 2
 0x0000: 4510 0036 3dde 4000 4006 7221 c0a8 0464
 0x0010: c0a8 04fe 0017 9cbf 9ede 4620 c85e 7c4f
 0x0020: 8018 00e3 a706 0000 0101 080a 0cd3 ab71
 0x0030: 0cd3 ab71 0d0a
14:34:29.155342 IP 192.168.4.254.40127 > server-03.telnet: Flags [.] , ack 76, win 6143, options [nop,nop,TS val 215198577 ecr 215198577], length 0
 0x0000: 4510 0034 1ed4 4000 4006 912d c0a8 04fe
 0x0010: c0a8 0464 9cbf 0017 c85e 7c4f 9ede 4622
 0x0020: 8010 17ff 9cfe 0000 0101 080a 0cd3 ab71
 0x0030: 0cd3 ab71
```

tcpdump会描述和给出网络接口上数据包内容。tcpdump 会显示收到包的时间，协议（IP），发送者，，收货者。然后是TCP的flags。我们可以看第一个没有flags,除了ack. 第二个包的Flags包括P（Flags[P,]), 这代表PSH或PUSH，用于要求接收端不要缓存数据包，而是在收到后立即处理。“seq”是数据包中的序列号以及该数据包之后的下一个数据将具有的序列号。“ack”是数据包中的确认号。默认情况下，tcpdump 显示相对于初始序列号的序列号和确认号。“长度”是 TCP 段中数据的长度。

tcpdump空困时间和iperf时的对比：iperf时会抓到很多包。但是iperf的丢包也多。

