Computer Networks
Jacobs University Bremen
Fezile Manana

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Homework 1

Problem 1.1

Solution:

a) Below are the ping readings for the different websites respectively.
The date and time of these measurements was:
20/02/2019 20:34

Output

```
PING amazon.com 176.32.98.166 5684 bytes of data.
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=1 ttl=233 time=228 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=2 ttl=233 time=147 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=3 ttl=233 time=273 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=4 ttl=233 time=191 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=5 ttl=233 time=218 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=6 ttl=233 time=133 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=7 ttl=233 time=158 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=8 ttl=233 time=183 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=9 ttl=233 time=207 ms
64 bytes from 176.32.98.166 176.32.98.166: icmp_seq=10 ttl=233 time=332 ms

--- amazon.com ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9013ms
rtt min/avg/max/mdev = 133.190/207.437/332.727/57.362 ms


PING d3ag4hukkh62yn.cloudfront.net 52.222.175.28 5684 bytes of data.
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=1 ttl=245 time=11.7 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=2 ttl=245 time=24.8 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=3 ttl=245 time=15.3 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=4 ttl=245 time=20.0 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=5 ttl=245 time=16.6 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=6 ttl=245 time=21.8 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=7 ttl=245 time=17.9 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=8 ttl=245 time=26.2 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=9 ttl=245 time=18.0 ms
64 bytes from server-52-222-175-28.fra54.r.cloudfront.net 52.222.175.28: icmp_seq=10 ttl=245 time=14.9 ms

--- d3ag4hukkh62yn.cloudfront.net ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9014ms
rtt min/avg/max/mdev = 11.753/18.749/26.219/4.303 ms


PING www.jacobs-university.de 148.251.219.204 5684 bytes of data.
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=1 ttl=56 time=19.6 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=2 ttl=56 time=17.6 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=3 ttl=56 time=20.4 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=4 ttl=56 time=20.4 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=5 ttl=56 time=33.5 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=6 ttl=56 time=46.7 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=7 ttl=56 time=29.0 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=8 ttl=56 time=15.4 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=9 ttl=56 time=20.0 ms
64 bytes from static.204.219.251.148.clients.your-server.de 148.251.219.204: icmp_seq=10 ttl=56 time=39.0 ms

--- www.jacobs-university.de ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9012ms
rtt min/avg/max/mdev = 15.469/26.223/46.775/9.930 ms


PING moodle.jacobs-university.de 212.201.46.73 5684 bytes of data.
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=1 ttl=63 time=3.94 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=2 ttl=63 time=3.72 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=3 ttl=63 time=6.71 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=4 ttl=63 time=3.40 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=5 ttl=63 time=7.68 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=6 ttl=63 time=4.61 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=7 ttl=63 time=3.52 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=8 ttl=63 time=3.22 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=9 ttl=63 time=4.11 ms
64 bytes from moodle.jacobs-university.de 212.201.46.73: icmp_seq=10 ttl=63 time=3.94 ms

--- moodle.jacobs-university.de ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9014ms
rtt min/avg/max/mdev = 3.227/4.489/7.682/1.423 ms
```

The table below shows the minimum round-trip times per website pinged over the 10 samples.

Website	Min round-trip time /ms
amazon.com	133
www.amazon.com	11.7
www.jacobs-university.de	15.4
moodle.jacobs-university.de	3.40

The difference in speed between amazon.de and www.amazon.de is accounted in the fact that amazon.de has an IP server which is located further away and thus takes longer to respond while the IP server of www.amazon.de is located closer.

The short response time of moodle.jacobs-university.de is likely due to the fact that Moodle is hosted locally on the university servers while www.jacobs-university.de is hosted externally.

The tool used for the measurements was ping, which is a utility used to check connectivity between a source and destination computer/device over an IP network. It also helps assess the the time it takes to send and receive a response from a network.

Output

```
Start: 2019-02-20T20:47:26+0100
HOST: -------                     Loss%   Snt   Last   Avg  Best  Wrst StDev
  1. AS???    10.81.255.251        0.0%    10    3.4   5.4   1.1  19.3   5.8
  2. AS???    192.168.242.3        0.0%    10    1.3   6.6   1.1  45.4  13.7
  3. AS680    vkr-g2-5-1.x-win.un  0.0%    10    3.0   4.6   1.9  18.3   5.1
  4. AS680    cr-han2-be15.x-win.  0.0%    10    4.9   6.5   4.5  18.4   4.2
  5. AS680    cr-fra2-be12.x-win.  0.0%    10    9.5  12.8   9.1  25.8   5.0
  6. AS1299   ffm-b12-link.telia.  0.0%    10   11.0  12.0  10.6  15.8   1.6
  7. AS1299   ffm-bb3-link.telia.  0.0%    10  120.2 124.8 114.6 203.9  27.8
  8. AS1299   prs-bb3-link.telia.  0.0%    10  114.3 114.7 113.7 117.3   1.2
  9. AS1299   ash-bb3-link.telia. 10.0%    10  104.6 105.2 101.9 117.3   4.8
 10. AS1299   ash-b1-link.telia.n  0.0%    10  111.8 115.9 111.4 128.7   6.2
 11. AS1299   vadata-ic-157230-as  0.0%    10  110.1 111.6 109.4 120.1   3.6
 12. AS16509  54.239.108.34        0.0%    10  121.3 125.9 109.2 135.5   8.2
 13. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 14. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 15. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 16. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 17. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 18. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 19. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 20. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 21. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 22. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 23. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 24. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 25. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 26. AS16509  176.32.98.166        0.0%    10  321.2 139.2 113.2 321.2  64.3

Start: 2019-02-20T20:47:43+0100
HOST: -------                     Loss%   Snt   Last   Avg  Best  Wrst StDev
  1. AS???    10.81.255.251        0.0%    10    4.1   2.8   1.0   5.1   1.6
  2. AS???    192.168.242.3        0.0%    10    1.9   1.9   1.2   2.8   0.6
  3. AS680    vkr-g2-5-1.x-win.un  0.0%    10    4.0   4.3   1.7  12.4   3.3
  4. AS680    cr-han2-be15.x-win.  0.0%    10    6.5   5.8   4.5   7.8   1.1
  5. AS680    cr-fra2-be12.x-win.  0.0%    10   10.7  12.9   9.5  25.2   5.7
  6. AS680    kr-fra262.x-win.dfn 10.0%    10   10.6  10.0   9.0  12.2   1.1
  7. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
  8. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
  9. AS16509  54.239.4.219         0.0%    10   12.6  12.9  11.0  16.3   1.5
 10. AS16509  54.239.5.223         0.0%    10   13.3  12.3   9.2  18.9   2.9
 11. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 12. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 13. AS???    ???                 100.0    10    0.0   0.0   0.0   0.0   0.0
 14. AS16509  server-52-222-175-2  0.0%    10   13.2  11.1   9.3  16.2   2.2

Start: 2019-02-20T20:47:59+0100
HOST: -------                     Loss%   Snt   Last   Avg  Best  Wrst StDev
  1. AS???    10.81.255.251        0.0%    10    1.3   4.9   1.0  30.9   9.2
  2. AS???    192.168.242.3        0.0%    10    2.5   4.1   1.2   9.2   2.5
  3. AS680    vkr-g2-5-1.x-win.un  0.0%    10    3.9   5.2   2.3  14.5   3.4
  4. AS680    cr-han2-be15.x-win.  0.0%    10    7.1   6.4   4.4   7.6   1.1
  5. AS680    cr-fra2-be12.x-win.  0.0%    10   11.0  12.1   9.1  22.4   3.8
  6. AS???    decix-gw.hetzner.de  0.0%    10   18.0  23.6  17.2  62.8  14.2
  7. AS24940  core23.fsn1.hetzner  0.0%    10   14.9  14.7  13.4  17.2   1.3
  8. AS24940  ex9k1.dc11.fsn1.het  0.0%    10   24.0  23.6  21.7  26.8   1.8
  9. AS24940  static.204.219.251.  0.0%    10   15.2  18.2  13.2  33.3   7.7

Start: 2019-02-20T20:48:15+0100
HOST: -------                     Loss%   Snt   Last   Avg  Best  Wrst StDev
  1. AS???    10.81.255.251        0.0%    10    3.3   4.9   3.0  10.9   2.3
  2. AS680    moodle.jacobs-unive  0.0%    10    2.9   4.2   2.9   7.4   1.3

Start: 2019-02-20T20:50:23+0100
HOST: -------                     Loss%   Snt   Last   Avg  Best  Wrst StDev
  1. AS???    10.81.255.251        0.0%    10    4.7   8.1   2.5  33.9   9.3
  2. AS680    moodle.jacobs-unive  0.0%    10    3.2  57.6   2.6 503.8 156.9
```

Solution:
b) All routes pass through the autonomous system with the AS number AS680 first. This is likely the ISP to which Jacobs is connected. The varying AS numbers after AS680 are due to the varyin paths taken to reach the final destination based on the request.

Below are tables containing information on the AS hops for the different destinations.

Amazon.com:

AS number	number of hops
AS680	3
AS1299	6
AS16509	2

www.amazon.com:

AS number	number of hops
AS680	4
AS16509	3

Jacobs-university.de:

AS number	number of hops
AS680	3
AS24940	3

moodle:

AS number	number of hops
AS680	1

The tool used for the results was the mtr utility version 0.92.
Date: 20/02/2019 20:50

Problem 1.2

Solution:
Solution:
a) The registries that assigned the AS numbers

AS number	registries	name
AS680	RIPE	DFN
AS1299	RIPE	TELIANET
AS16509	ARIN	AMAZON-02
AS24940	RIPE	HETZNER-AS

b) 2001:638:709::/48 is being used by the university. This IPv6 is not globally announced however the prefix 2001:638::/32 is instead announced.

Problem 1.3

Solution:
a)

Output

```
mininet> h2 iperf -s &
mininet> h1 iperf -c h2 -i 10 -t 60
------------------------------------------------------------
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.1 port 57984 connected with 10.0.0.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  12.1 MBytes  10.2 Mbits/sec
[  3] 10.0-20.0 sec  11.1 MBytes  9.33 Mbits/sec
[  3] 20.0-30.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3] 30.0-40.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 40.0-50.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 50.0-60.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3]  0.0-60.2 sec  69.1 MBytes  9.63 Mbits/sec
```

The network behaves as expected, with a bandwidth of around 10 Mbits/s and a transfer rate of about 10 MBytes/10 secs, which is what is expected on a 10 Mbps line.

Solution:
b) Without iPerf:

Output

```
mininet> h1 ping h2 -c 10
PING 10.0.0.2 10.0.0.2 5684 bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=0.018 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.052 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.025 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=0.052 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=0.053 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=0.078 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=0.077 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=0.078 ms

--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 8999ms
rtt min/avg/max/mdev = 0.018/0.056/0.078/0.021 ms
```

With iPerf:

Output

```
mininet> h1 iperf -c h2 -i 10 -t 60 &
mininet> h1 ping h2 -c 10
------------------------------------------------------------
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.1 port 57986 connected with 10.0.0.2 port 5001
PING 10.0.0.2 10.0.0.2 5684 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=24.8 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=24.8 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=21.5 ms
64 bytes from 10.0.0.2: icmp_seq=5 ttl=64 time=18.2 ms
64 bytes from 10.0.0.2: icmp_seq=6 ttl=64 time=26.5 ms
64 bytes from 10.0.0.2: icmp_seq=7 ttl=64 time=23.1 ms
64 bytes from 10.0.0.2: icmp_seq=8 ttl=64 time=13.3 ms
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  12.1 MBytes  10.2 Mbits/sec
64 bytes from 10.0.0.2: icmp_seq=9 ttl=64 time=23.0 ms
64 bytes from 10.0.0.2: icmp_seq=10 ttl=64 time=19.0 ms

--- 10.0.0.2 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9014ms
rtt min/avg/max/mdev = 13.304/21.067/26.588/4.087 ms
```

The delay is the result of iPerf trying to flood the flood the network and consume as much bandwidth in order to measure the capacity of the network. This thereby causes a delay in the delivery of packets and as a result the ping measurements are much slower. This is a transmition delay.

Problem 1.4

Solution:

a) Without iPerf:

Output

```
mininet> h3 ping h4 -c 10
PING 10.0.0.4 10.0.0.4 5684 bytes of data.
64 bytes from 10.0.0.4: icmp_seq=1 ttl=64 time=2.50 ms
64 bytes from 10.0.0.4: icmp_seq=2 ttl=64 time=1.66 ms
64 bytes from 10.0.0.4: icmp_seq=3 ttl=64 time=0.233 ms
64 bytes from 10.0.0.4: icmp_seq=4 ttl=64 time=0.070 ms
64 bytes from 10.0.0.4: icmp_seq=5 ttl=64 time=0.060 ms
64 bytes from 10.0.0.4: icmp_seq=6 ttl=64 time=0.067 ms
64 bytes from 10.0.0.4: icmp_seq=7 ttl=64 time=0.070 ms
64 bytes from 10.0.0.4: icmp_seq=8 ttl=64 time=0.070 ms
64 bytes from 10.0.0.4: icmp_seq=9 ttl=64 time=0.064 ms
64 bytes from 10.0.0.4: icmp_seq=10 ttl=64 time=0.069 ms

--- 10.0.0.4 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9006ms
rtt min/avg/max/mdev = 0.060/0.486/2.503/0.821 ms
```

With iPerf:

Output

```
mininet> h2 iperf -s &
mininet> h1 iperf -c h2 -i 10 -t 60 &
mininet> h3 ping h4 -c 10
PING 10.0.0.4 10.0.0.4 5684 bytes of data.
64 bytes from 10.0.0.4: icmp_seq=1 ttl=64 time=0.792 ms
64 bytes from 10.0.0.4: icmp_seq=2 ttl=64 time=1.54 ms
64 bytes from 10.0.0.4: icmp_seq=3 ttl=64 time=0.205 ms
64 bytes from 10.0.0.4: icmp_seq=4 ttl=64 time=0.056 ms
64 bytes from 10.0.0.4: icmp_seq=5 ttl=64 time=0.055 ms
64 bytes from 10.0.0.4: icmp_seq=6 ttl=64 time=0.057 ms
64 bytes from 10.0.0.4: icmp_seq=7 ttl=64 time=0.059 ms
64 bytes from 10.0.0.4: icmp_seq=8 ttl=64 time=0.056 ms
64 bytes from 10.0.0.4: icmp_seq=9 ttl=64 time=0.058 ms
64 bytes from 10.0.0.4: icmp_seq=10 ttl=64 time=0.053 ms

--- 10.0.0.4 ping statistics ---
10 packets transmitted, 10 received, 0% packet loss, time 9003ms
rtt min/avg/max/mdev = 0.053/0.293/1.545/0.471 ms
```

The load on the bandwidth does not affect the ping rate between h3 and h4. This is due to the advantages of the star topology which sends traffic to a central switch, allowing all paths to work independently without affecting other links.

b) h1 to h2 and h3 to h4 simultaneous reading:

Output

```
[  3] local 10.0.0.3 port 34808 connected with 10.0.0.4 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  12.1 MBytes  10.2 Mbits/sec
[  3] 10.0-20.0 sec  11.1 MBytes  9.33 Mbits/sec
[  3] 20.0-30.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3] 30.0-40.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 40.0-50.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 50.0-60.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3]  0.0-60.2 sec  69.1 MBytes  9.63 Mbits/sec
```

h3 to h4 and h1 to h2 simultaneous reading:

Output

```
mininet> h2 iperf -s &
mininet> h4 iperf -s &
mininet> h3 iperf -c h4 -i 10 -t 60 &
mininet> h1 iperf -c h2 -i 10 -t 60
------------------------------------------------------------
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.1 port 58012 connected with 10.0.0.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  12.1 MBytes  10.2 Mbits/sec
[  3] 10.0-20.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 20.0-30.0 sec  11.2 MBytes  9.44 Mbits/sec
[  3] 30.0-40.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 40.0-50.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 50.0-60.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3]  0.0-60.1 sec  69.1 MBytes  9.64 Mbits/sec
```

The simultaneous measurements do not appear to affect one another.

Problem 1.5

Solution:

a) h1 to h4 and h3 to h2 simultaneous measurements:

Output

```
------------------------------------------------------------
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.4 port 32940 connected with 10.0.0.1 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  13.0 MBytes  10.9 Mbits/sec
[  3] 10.0-20.0 sec  12.2 MBytes  10.3 Mbits/sec
[  3] 20.0-30.0 sec  14.8 MBytes  12.4 Mbits/sec
[  3] 30.0-40.0 sec  12.4 MBytes  10.4 Mbits/sec
[  3] 40.0-50.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3] 50.0-60.0 sec  11.8 MBytes  9.86 Mbits/sec
[  3]  0.0-62.7 sec  75.8 MBytes  10.1 Mbits/sec

------------------------------------------------------------
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.2 port 47182 connected with 10.0.0.3 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  12.8 MBytes  10.7 Mbits/sec
[  3] 10.0-20.0 sec  13.4 MBytes  11.2 Mbits/sec
[  3] 20.0-30.0 sec  13.9 MBytes  11.6 Mbits/sec
[  3] 30.0-40.0 sec  13.0 MBytes  10.9 Mbits/sec
[  3] 40.0-50.0 sec  12.0 MBytes  10.1 Mbits/sec
[  3] 50.0-60.0 sec  8.00 MBytes  6.71 Mbits/sec
[  3]  0.0-60.7 sec  73.1 MBytes  10.1 Mbits/sec
```

Average data rate is 10.8 Mbits/sec

h1 to h3 and h2 to h4 simultaneous measurements:

Output

```
------------------------------------------------------------
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.3 port 55396 connected with 10.0.0.1 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  9.12 MBytes  7.65 Mbits/sec
[  3] 10.0-20.0 sec  11.8 MBytes  9.86 Mbits/sec
[  3] 20.0-30.0 sec  8.12 MBytes  6.82 Mbits/sec
[  3] 30.0-40.0 sec  4.00 MBytes  3.36 Mbits/sec
[  3] 40.0-50.0 sec  3.88 MBytes  3.25 Mbits/sec
[  3] 50.0-60.0 sec  4.00 MBytes  3.36 Mbits/sec
[  3] 60.0-70.0 sec  0.00 Bytes  0.00 bits/sec
[  3]  0.0-72.9 sec  41.0 MBytes  4.72 Mbits/sec

------------------------------------------------------------
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.4 port 39246 connected with 10.0.0.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  7.25 MBytes  6.08 Mbits/sec
[  3] 10.0-20.0 sec  9.38 MBytes  7.86 Mbits/sec
[  3] 20.0-30.0 sec  7.50 MBytes  6.29 Mbits/sec
[  3] 30.0-40.0 sec  8.75 MBytes  7.34 Mbits/sec
[  3] 40.0-50.0 sec  7.50 MBytes  6.29 Mbits/sec
[  3] 50.0-60.0 sec  7.62 MBytes  6.40 Mbits/sec
[  3]  0.0-69.6 sec  48.1 MBytes  5.80 Mbits/sec
```

The results show the network maintains full capacity when transmitting packets in opposite directions on the line whereas there is a decrease in both bandwidth and transfer speed when sending packets in the same direction. This is due to a transfer delay as nodes constantly check where the line is free of packets before sending.

b)

Output

```
------------------------------------------------------------
Client connecting to 10.0.0.4, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.1 port 39672 connected with 10.0.0.4 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  12.1 MBytes  10.2 Mbits/sec
[  3] 10.0-20.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 20.0-30.0 sec  11.2 MBytes  9.44 Mbits/sec
[  3] 30.0-40.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 40.0-50.0 sec  11.4 MBytes  9.54 Mbits/sec
[  3] 50.0-60.0 sec  11.5 MBytes  9.65 Mbits/sec
[  3]  0.0-60.1 sec  69.1 MBytes  9.64 Mbits/sec

------------------------------------------------------------
Client connecting to 10.0.0.6, TCP port 5001
TCP window size: 85.3 KByte default
------------------------------------------------------------
[  3] local 10.0.0.3 port 38944 connected with 10.0.0.6 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.0 sec  9.62 MBytes  8.07 Mbits/sec
[  3] 10.0-20.0 sec  8.38 MBytes  7.03 Mbits/sec
[  3] 20.0-30.0 sec  9.12 MBytes  7.65 Mbits/sec
[  3] 30.0-40.0 sec  8.50 MBytes  7.13 Mbits/sec
[  3] 40.0-50.0 sec  8.38 MBytes  7.03 Mbits/sec
[  3] 50.0-60.0 sec  9.00 MBytes  7.55 Mbits/sec
[  3]  0.0-60.2 sec  53.1 MBytes  7.40 Mbits/sec
```

The above information shows that the bandwidth from h1 to h4 is close to the maximum capacity while the bandwidth from h3 to h6 is much lower than the maximum capacity. This is likely due to the queuing delay caused by the s2 switch having to handle traffic from h1 to h4 and from h3 to h6.