

ECE 6363 Datacenters and Cloud Computing

Lab 4

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(f) Screenshots:

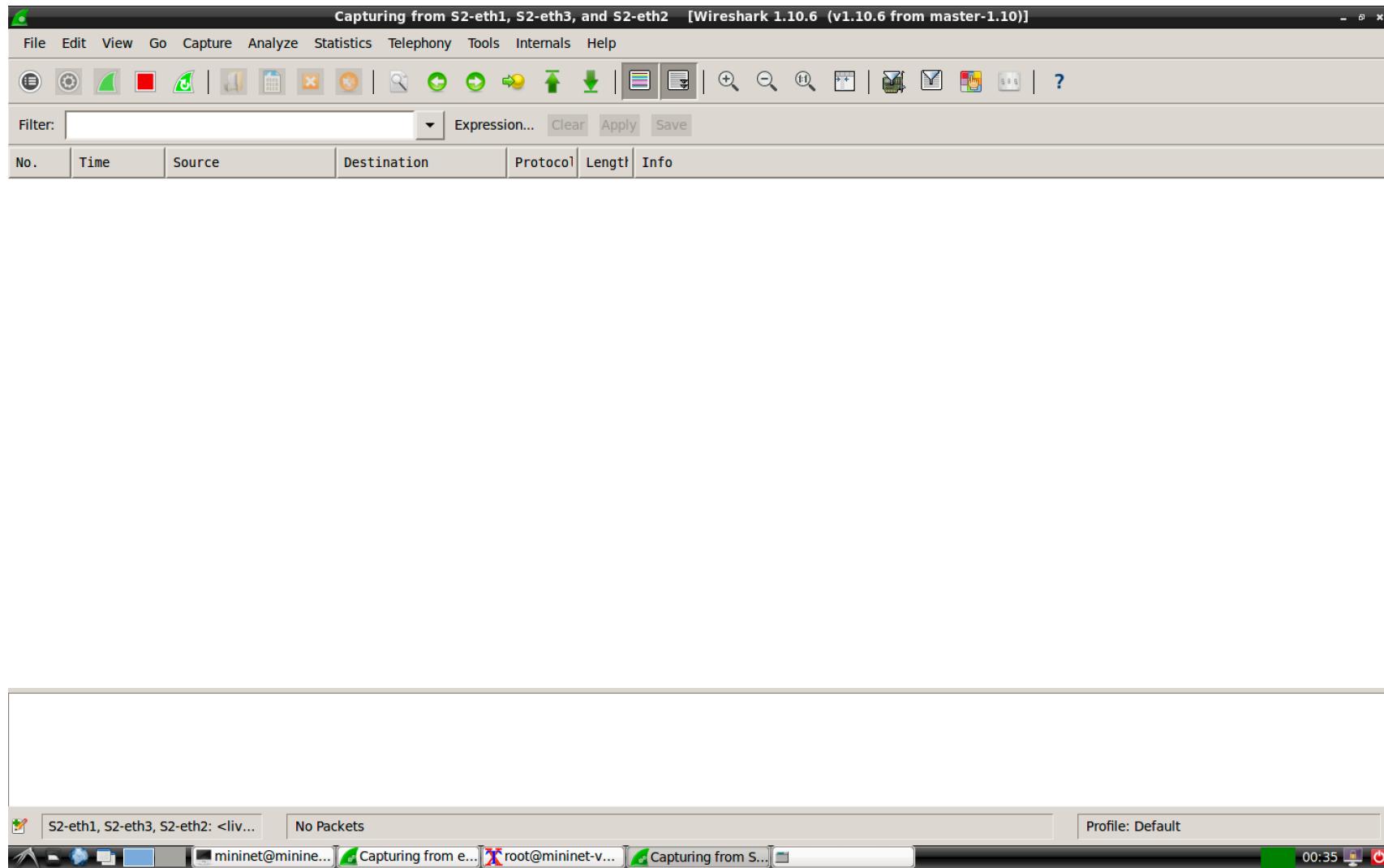
- Ping among all the hosts after setting up the platform

```
Setting remote controller to 192.168.56.1:6653
*** Creating network
*** Adding controller
*** Adding hosts:
H1 H2 H3 H4
*** Adding switches:
S1 S2 S3 S4
*** Adding links:
(H1, S1) (H2, S2) (H3, S3) (H4, S4) (S1, S2) (S2, S3) (S3, S4) (S4, S1)
*** Configuring hosts
H1 H2 H3 H4
*** Starting controller
ryu
*** Starting 4 switches
S1 S2 S3 S4 ...
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
H1 -> H2 H3 H4
H2 -> H1 H3 H4
H3 -> H1 H2 H4
H4 -> H1 H2 H3
*** Results: 0% dropped (12/12 received)
mininet> █
```

- TCP, UDP and ICMP packets on their respective paths

→ TCP shortest path from H1 to H4

S2:



S4:

Capturing from S4-eth1, S4-eth3, and S4-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.0000000000	10.0.0.1	10.0.0.4	TCP	74	45736 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK PERM=1 TSval=38216241 TSecr=0 WS
2	0.0000690000	10.0.0.4	10.0.0.1	TCP	74	commplex-link > 45736 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK PERM=1 TSval=38216241
3	0.0001100000	10.0.0.1	10.0.0.4	TCP	66	45736 > commplex-link [ACK] Seq=1 Ack=1 Win=29696 Len=0 TSval=38216241 TSecr=38216241
4	0.0005080000	10.0.0.1	10.0.0.4	TCP	90	45736 > commplex-link [PSH, ACK] Seq=1 Ack=1 Win=29696 Len=24 TSval=38216241 TSecr=38216241
5	0.0005160000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=25 Win=29184 Len=0 TSval=38216241 TSecr=38216241
6	0.0005640000	10.0.0.1	10.0.0.4	TCP	7306	45736 > commplex-link [ACK] Seq=25 Ack=1 Win=29696 Len=7240 TSval=38216241 TSecr=38216241
7	0.0005680000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=7265 Win=43520 Len=0 TSval=38216241 TSecr=38216241
8	0.0005710000	10.0.0.1	10.0.0.4	TCP	7306	45736 > commplex-link [ACK] Seq=7265 Ack=1 Win=29696 Len=7240 TSval=38216241 TSecr=38216241
9	0.0005740000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=14505 Win=58368 Len=0 TSval=38216241 TSecr=38216241
10	0.0005890000	10.0.0.1	10.0.0.4	TCP	10202	45736 > commplex-link [ACK] Seq=14505 Ack=1 Win=29696 Len=10136 TSval=38216241 TSecr=38216241
11	0.0005890000	10.0.0.1	10.0.0.4	TCP	4410	45736 > commplex-link [PSH, ACK] Seq=24641 Ack=1 Win=29696 Len=4344 TSval=38216241 TSecr=38216241
12	0.0005900000	10.0.0.1	10.0.0.4	TCP	14546	45736 > commplex-link [PSH, ACK] Seq=28985 Ack=1 Win=29696 Len=14480 TSval=38216241 TSecr=38216241
13	0.0005990000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=24641 Win=78336 Len=0 TSval=38216241 TSecr=38216241
14	0.0006000000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=28985 Win=87040 Len=0 TSval=38216241 TSecr=38216241
15	0.0006000000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=43465 Win=116224 Len=0 TSval=38216241 TSecr=38216241
16	0.0006060000	10.0.0.1	10.0.0.4	TCP	14546	45736 > commplex-link [ACK] Seq=43465 Ack=1 Win=29696 Len=14480 TSval=38216241 TSecr=38216241
17	0.0006060000	10.0.0.1	10.0.0.4	TCP	5858	45736 > commplex-link [ACK] Seq=57945 Ack=1 Win=29696 Len=5792 TSval=38216241 TSecr=38216241
18	0.0006060000	10.0.0.1	10.0.0.4	TCP	8754	45736 > commplex-link [PSH, ACK] Seq=63737 Ack=1 Win=29696 Len=8688 TSval=38216241 TSecr=38216241
19	0.0006060000	10.0.0.1	10.0.0.4	TCP	14546	45736 > commplex-link [PSH, ACK] Seq=72425 Ack=1 Win=29696 Len=14480 TSval=38216241 TSecr=38216241
20	0.0006180000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=57945 Win=144896 Len=0 TSval=38216241 TSecr=38216241
21	0.0006190000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=63737 Win=153088 Len=0 TSval=38216241 TSecr=38216241
22	0.0006200000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=72425 Win=147968 Len=0 TSval=38216241 TSecr=38216241
23	0.0006200000	10.0.0.4	10.0.0.1	TCP	66	commplex-link > 45736 [ACK] Seq=1 Ack=86905 Win=140288 Len=0 TSval=38216241 TSecr=38216241
24	0.0000350000	10.0.0.1	10.0.0.4	TCP	74	[TCP Retransmission] 45736 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK PERM=1 TSval=38216241 TSecr=0 WS
25	0.0000410000	10.0.0.1	10.0.0.4	TCP	74	[TCP Retransmission] 45736 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK PERM=1 TSval=38216241 TSecr=0 WS

Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 2

Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:04 (00:00:00:00:00:04)

Internet Protocol Version 4, Src: 10.0.0.1 (10.0.0.1), Dst: 10.0.0.4 (10.0.0.4)

Transmission Control Protocol, Src Port: 45736 (45736), Dst Port: commplex-link (5001), Seq: 0, Len: 0

S4-eth1, S4-eth3, S4-eth2: <liv...> Packets: 58 · Displayed: 58 (100.0%) Profile: Default

mininet@mininet... Capturing from e... root@mininet-v... Capturing from S... 00:48

→ TCP equal path from H1 to H3

S2:

Capturing from S2-eth1, S2-eth3, and S2-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.1	10.0.0.3	TCP	74	39662 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=38407524 TSecr=0 WS
2	0.000103000	10.0.0.3	10.0.0.1	TCP	74	commplex-link > 39662 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK_PERM=1 TSval=38407524 TSecr=38407524
3	0.000142000	10.0.0.1	10.0.0.3	TCP	66	39662 > commplex-link [ACK] Seq=1 Ack=1 Win=29696 Len=0 TSval=38407524 TSecr=38407524
4	0.001109000	10.0.0.1	10.0.0.3	TCP	90	39662 > commplex-link [PSH, ACK] Seq=1 Ack=1 Win=29696 Len=24 TSval=38407525 TSecr=38407524
5	0.001122000	10.0.0.1	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=25 Win=29184 Len=0 TSval=38407525 TSecr=38407525
6	0.001182000	10.0.0.3	10.0.0.1	TCP	7306	39662 > commplex-link [ACK] Seq=25 Ack=1 Win=29696 Len=7240 TSval=38407525 TSecr=38407525
7	0.001189000	10.0.0.1	10.0.0.3	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=7265 Win=43520 Len=0 TSval=38407525 TSecr=38407525
8	0.001193000	10.0.0.1	10.0.0.3	TCP	7306	39662 > commplex-link [ACK] Seq=7265 Ack=1 Win=29696 Len=7240 TSval=38407525 TSecr=38407525
9	0.001198000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=14505 Win=58368 Len=0 TSval=38407525 TSecr=38407525
10	0.001221000	10.0.0.1	10.0.0.3	TCP	10202	39662 > commplex-link [ACK] Seq=14505 Ack=1 Win=29696 Len=10136 TSval=38407525 TSecr=38407525
11	0.001222000	10.0.0.1	10.0.0.3	TCP	4410	39662 > commplex-link [PSH, ACK] Seq=24641 Ack=1 Win=29696 Len=4344 TSval=38407525 TSecr=38407525
12	0.001222000	10.0.0.1	10.0.0.3	TCP	14546	39662 > commplex-link [PSH, ACK] Seq=28985 Ack=1 Win=29696 Len=14480 TSval=38407525 TSecr=38407525
13	0.001237000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=24641 Win=78336 Len=0 TSval=38407525 TSecr=38407525
14	0.001238000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=28985 Win=87040 Len=0 TSval=38407525 TSecr=38407525
15	0.001239000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=43465 Win=116224 Len=0 TSval=38407525 TSecr=38407525
16	0.001245000	10.0.0.1	10.0.0.3	TCP	14546	39662 > commplex-link [ACK] Seq=43465 Ack=1 Win=29696 Len=14480 TSval=38407525 TSecr=38407525
17	0.001245000	10.0.0.1	10.0.0.3	TCP	5858	39662 > commplex-link [ACK] Seq=57945 Ack=1 Win=29696 Len=5792 TSval=38407525 TSecr=38407525
18	0.001245000	10.0.0.1	10.0.0.3	TCP	8754	39662 > commplex-link [PSH, ACK] Seq=63737 Ack=1 Win=29696 Len=8688 TSval=38407525 TSecr=38407525
19	0.001246000	10.0.0.1	10.0.0.3	TCP	14546	39662 > commplex-link [PSH, ACK] Seq=72425 Ack=1 Win=29696 Len=14480 TSval=38407525 TSecr=38407525
20	0.001266000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=57945 Win=144896 Len=0 TSval=38407525 TSecr=38407525
21	0.001266000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=63737 Win=153088 Len=0 TSval=38407525 TSecr=38407525
22	0.001267000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=72425 Win=147968 Len=0 TSval=38407525 TSecr=38407525
23	0.001268000	10.0.0.3	10.0.0.1	TCP	66	commplex-link > 39662 [ACK] Seq=1 Ack=86905 Win=140288 Len=0 TSval=38407525 TSecr=38407525
24	0.000039000	10.0.0.1	10.0.0.3	TCP	74	[TCP Retransmission] 39662 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=38407525 TSecr=38407525
25	0.000039000	10.0.0.3	10.0.0.1	TCP	74	[TCP Retransmission] 39662 > commplex-link [SYN, ACK] Seq=1 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=38407525 TSecr=38407525

Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 1

Ethernet II, Src: 00:00:00:00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:03 (00:00:00:00:00:03)

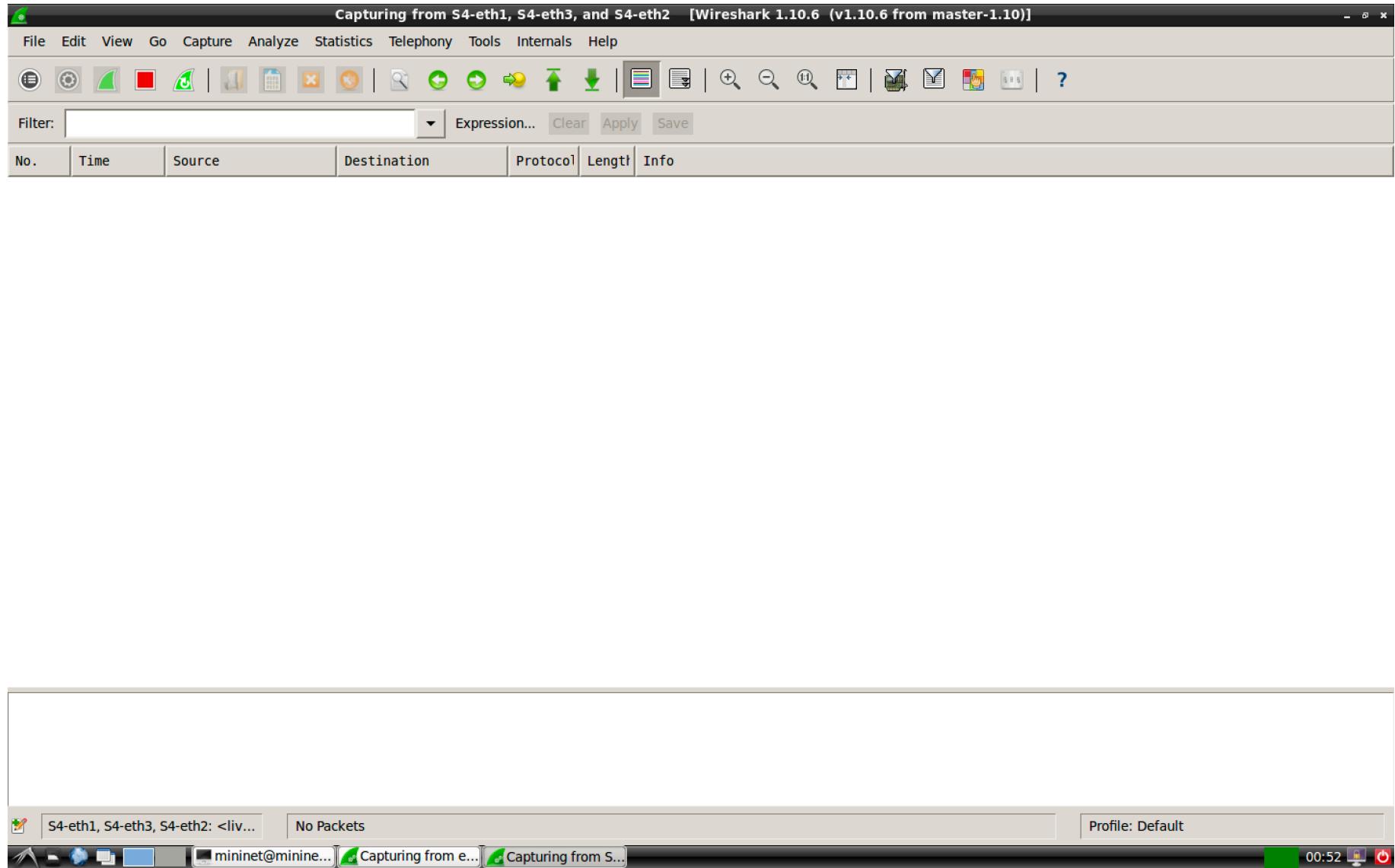
Internet Protocol Version 4, Src: 10.0.0.1 (10.0.0.1), Dst: 10.0.0.3 (10.0.0.3)

Transmission Control Protocol, Src Port: 39662 (39662), Dst Port: commplex-link (5001), Seq: 0, Len: 0

S2-eth1, S2-eth3, S2-eth2: <live...> Packets: 58 · Displayed: 58 (100.0%) Profile: Default

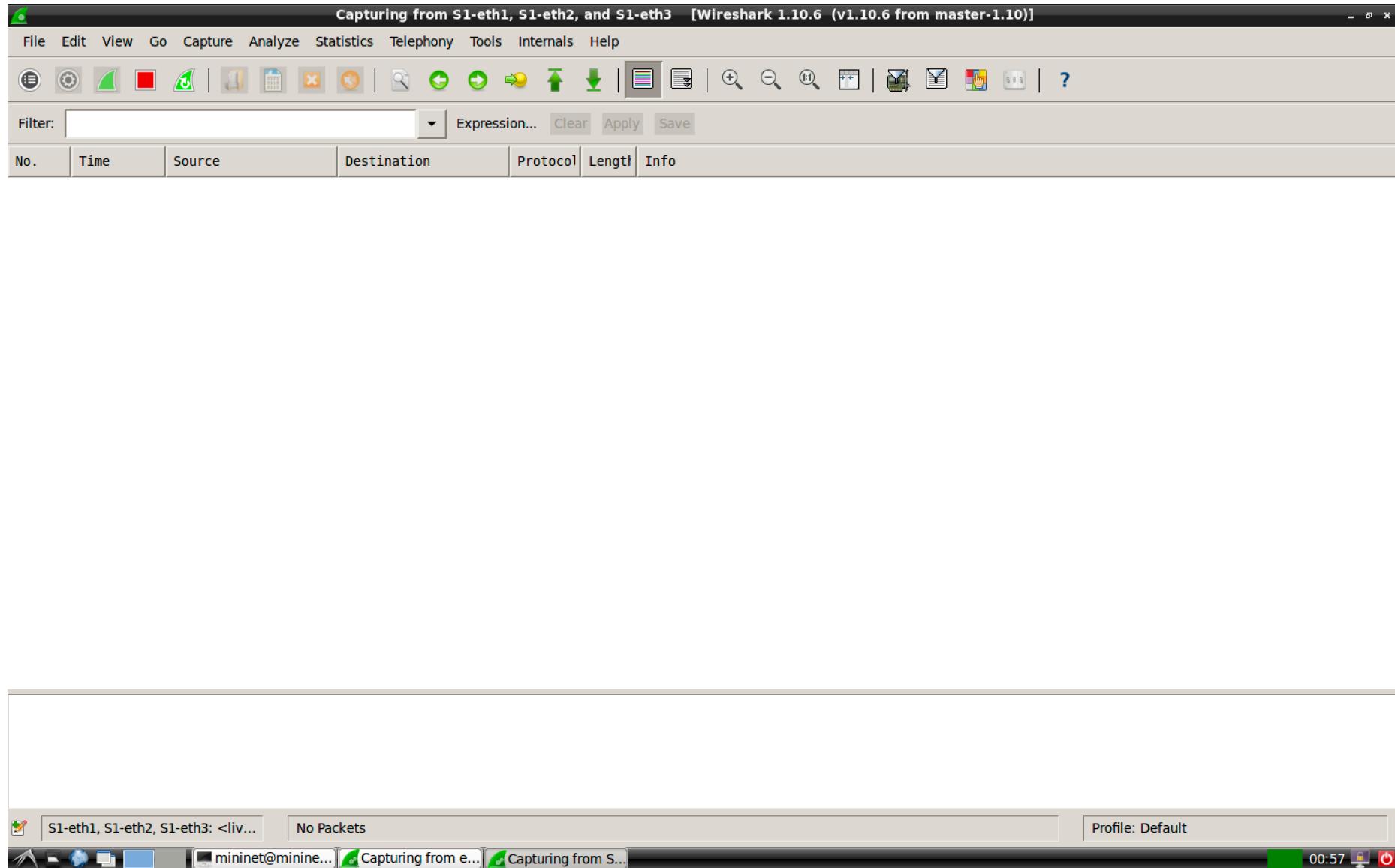
mininet@minine... Capturing from e... Capturing from S... 01:01

S4:



→ TCP equal path from H2 to H4

S1:



S3:

Capturing from S3-eth1, S3-eth3, and S3-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.2	10.0.0.4	TCP	74	35972 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=38387927 TSecr=0 WS
2	0.000092000	10.0.0.4	10.0.0.2	TCP	74	commplex-link > 35972 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS=1460 SACK_PERM=1 TSval=38387927 TSecr=0 WS
3	0.000126000	10.0.0.2	10.0.0.4	TCP	66	35972 > commplex-link [ACK] Seq=1 Ack=1 Win=29696 Len=0 TSval=38387927 TSecr=38387927 WS
4	0.0004196000	10.0.0.2	10.0.0.4	TCP	90	35972 > commplex-link [PSH, ACK] Seq=1 Ack=1 Win=29696 Len=24 TSval=38387929 TSecr=38387927 WS
5	0.0004210000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=25 Win=29184 Len=0 TSval=38387929 TSecr=38387929 WS
6	0.0004376000	10.0.0.2	10.0.0.4	TCP	7306	35972 > commplex-link [ACK] Seq=25 Ack=1 Win=29696 Len=7240 TSval=38387929 TSecr=38387929 WS
7	0.0004383000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=7265 Win=43520 Len=0 TSval=38387929 TSecr=38387929 WS
8	0.0004388000	10.0.0.2	10.0.0.4	TCP	7306	35972 > commplex-link [ACK] Seq=7265 Ack=1 Win=29696 Len=7240 TSval=38387929 TSecr=38387929 WS
9	0.0004391000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=14505 Win=58368 Len=0 TSval=38387929 TSecr=38387929 WS
10	0.0004408000	10.0.0.2	10.0.0.4	TCP	10202	35972 > commplex-link [ACK] Seq=14505 Ack=1 Win=29696 Len=10136 TSval=38387929 TSecr=38387929 WS
11	0.0004408000	10.0.0.2	10.0.0.4	TCP	4410	35972 > commplex-link [PSH, ACK] Seq=24641 Ack=1 Win=29696 Len=4344 TSval=38387929 TSecr=38387929 WS
12	0.0004408000	10.0.0.2	10.0.0.4	TCP	14546	35972 > commplex-link [PSH, ACK] Seq=28985 Ack=1 Win=29696 Len=14480 TSval=38387929 TSecr=38387929 WS
13	0.0004419000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=24641 Win=78336 Len=0 TSval=38387929 TSecr=38387929 WS
14	0.0004420000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=28985 Win=87040 Len=0 TSval=38387929 TSecr=38387929 WS
15	0.0004421000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=43465 Win=116224 Len=0 TSval=38387929 TSecr=38387929 WS
16	0.0004427000	10.0.0.2	10.0.0.4	TCP	14546	35972 > commplex-link [ACK] Seq=43465 Ack=1 Win=29696 Len=14480 TSval=38387929 TSecr=38387929 WS
17	0.0004427000	10.0.0.2	10.0.0.4	TCP	5858	35972 > commplex-link [ACK] Seq=57945 Ack=1 Win=29696 Len=5792 TSval=38387929 TSecr=38387929 WS
18	0.0004427000	10.0.0.2	10.0.0.4	TCP	8754	35972 > commplex-link [PSH, ACK] Seq=63737 Ack=1 Win=29696 Len=8688 TSval=38387929 TSecr=38387929 WS
19	0.0004428000	10.0.0.2	10.0.0.4	TCP	14546	35972 > commplex-link [PSH, ACK] Seq=72425 Ack=1 Win=29696 Len=14480 TSval=38387929 TSecr=38387929 WS
20	0.0004441000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=57945 Win=144896 Len=0 TSval=38387929 TSecr=38387929 WS
21	0.0004442000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=63737 Win=153088 Len=0 TSval=38387929 TSecr=38387929 WS
22	0.0004442000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=72425 Win=147968 Len=0 TSval=38387929 TSecr=38387929 WS
23	0.0004443000	10.0.0.4	10.0.0.2	TCP	66	commplex-link > 35972 [ACK] Seq=1 Ack=86905 Win=140288 Len=0 TSval=38387929 TSecr=38387929 WS
24	0.000032000	10.0.0.2	10.0.0.4	TCP	74	[TCP Retransmission] 35972 > commplex-link [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=38387927 TSecr=0 WS
25	0.000072000	10.0.0.4	10.0.0.2	TCP	74	[TCP Retransmission] 35972 > commplex-link [SYN, ACK] Seq=1 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=38387927 TSecr=0 WS

Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 1

Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:04 (00:00:00:00:00:04)

Internet Protocol Version 4, Src: 10.0.0.2 (10.0.0.2), Dst: 10.0.0.4 (10.0.0.4)

Transmission Control Protocol, Src Port: 35972 (35972), Dst Port: commplex-link (5001), Seq: 0, Len: 0

S3-eth1, S3-eth3, S3-eth2: <live> Packets: 58 · Displayed: 58 (100.0%) Profile: Default

mininet@minine... Capturing from e... Capturing from S... 01:00

→ HTTP reset associated with H2 or H4

S1:

Capturing from S1-eth1, S1-eth2, and S1-eth3 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.1	10.0.0.4	TCP	74	38378 > http [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=43056965 TSerr=0 WS=5
2	0.008345000	10.0.0.4	10.0.0.1	TCP	60	http > 38378 [RST, ACK] Seq=1 Ack=1 Win=0 Len=0

Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 0

Ethernet II, Src: 00:00:00:00:00:01 (00:00:00:00:00:01), Dst: 00:00:00:00:00:04 (00:00:00:00:00:04)

Internet Protocol Version 4, Src: 10.0.0.1 (10.0.0.1), Dst: 10.0.0.4 (10.0.0.4)

Transmission Control Protocol, Src Port: 38378 (38378), Dst Port: http (80), Seq: 0, Len: 0

S1-eth1, S1-eth2, S1-eth3: <live> | Packets: 2 · Displayed: 2 (100.0%) | Profile: Default

mininet@minine... | Capturing from e... | Capturing from S...

15:43

S2:

Capturing from S2-eth1, S2-eth3, and S2-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.2	10.0.0.1	TCP	74	36302 > http [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK PERM=1 TSval=43141128 TSecr=0 WS=51
2	0.001981000	10.0.0.1	10.0.0.2	TCP	60	http > 36302 [RST, ACK] Seq=1 Ack=1 Win=0 Len=0

Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 0

Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)

Internet Protocol Version 4, Src: 10.0.0.2 (10.0.0.2), Dst: 10.0.0.1 (10.0.0.1)

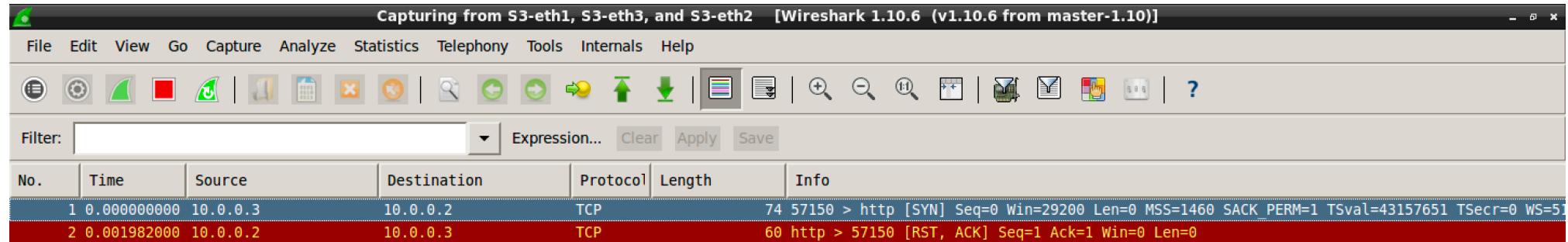
Transmission Control Protocol, Src Port: 36302 (36302), Dst Port: http (80), Seq: 0, Len: 0

S2-eth1, S2-eth3, S2-eth2: <live> | Packets: 2 · Displayed: 2 (100.0%) | Profile: Default

mininet@mininet: ~ | Capturing from e... | Capturing from S...

15:48

S3:



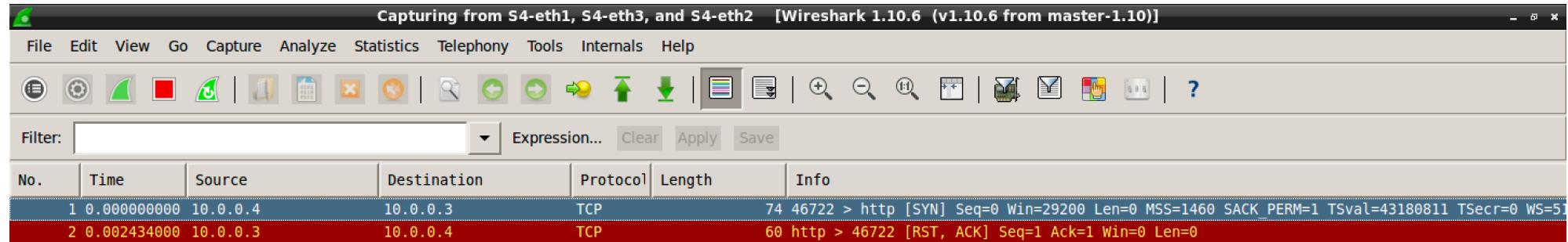
```
Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 0
Ethernet II, Src: 00:00:00_00:00:03 (00:00:00:00:00:03), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)
Internet Protocol Version 4, Src: 10.0.0.3 (10.0.0.3), Dst: 10.0.0.2 (10.0.0.2)
Transmission Control Protocol, Src Port: 57150 (57150), Dst Port: http (80), Seq: 0, Len: 0
```

S3-eth1, S3-eth3, S3-eth2: <live...> Packets: 2 · Displayed: 2 (100.0%) Profile: Default

mininet@minine... Capturing from e... Capturing from S...

15:49

S4:



Frame 1: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on interface 0

Ethernet II, Src: 00:00:00:00:00:04 (00:00:00:00:00:04), Dst: 00:00:00:00:00:03 (00:00:00:00:00:03)

Internet Protocol Version 4, Src: 10.0.0.4 (10.0.0.4), Dst: 10.0.0.3 (10.0.0.3)

Transmission Control Protocol, Src Port: 46722 (46722), Dst Port: http (80), Seq: 0, Len: 0

S4-eth1, S4-eth3, S4-eth2: <live> Packets: 2 · Displayed: 2 (100.0%) Profile: Default

mininet@minine... Capturing from e... Capturing from S...

15:51

Command outputs:

```
mininet> H1 iperf -c H4 -p 80
connect failed: Connection refused
mininet> H2 iperf -c H1 -p 80
connect failed: Connection refused
mininet> H3 iperf -c H2 -p 80
Running Iperf Server as a daemon
The Iperf daemon process ID : 2247
connect failed: Connection refused
mininet> H4 iperf -c H3 -p 80
connect failed: Connection refused
mininet>
```

► UDP shortest path from H3 to H2

S2:

Capturing from S2-eth1, S2-eth3, and S2-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]						
No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
2	0.014934000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
3	-0.000031000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
4	0.014928000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
5	0.265737000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
6	0.265729000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
7	0.516664000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
8	0.516658000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
9	0.767115000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
10	0.767121000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
11	1.017661000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
12	1.017656000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
13	1.268364000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
14	1.268422000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
15	1.519740000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
16	1.519733000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
17	1.770392000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
18	1.770397000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
19	2.021184000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
20	2.021178000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
21	2.273061000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link
22	2.273068000	10.0.0.3	10.0.0.2	UDP	1512	Source port: 50266 Destination port: commplex-link

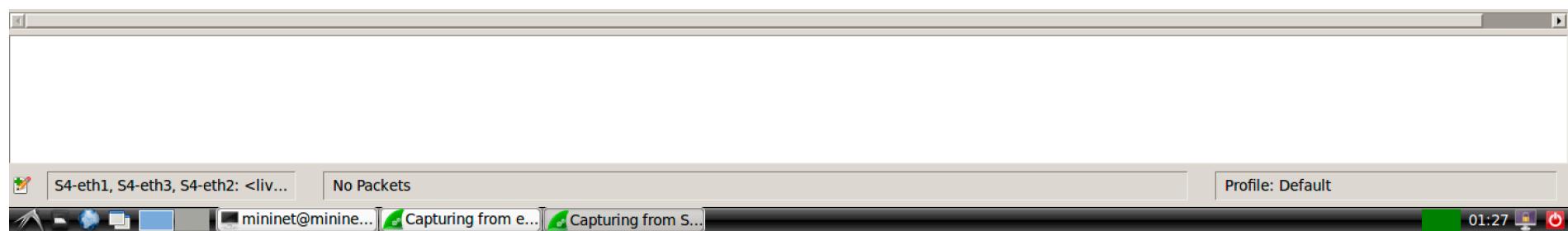
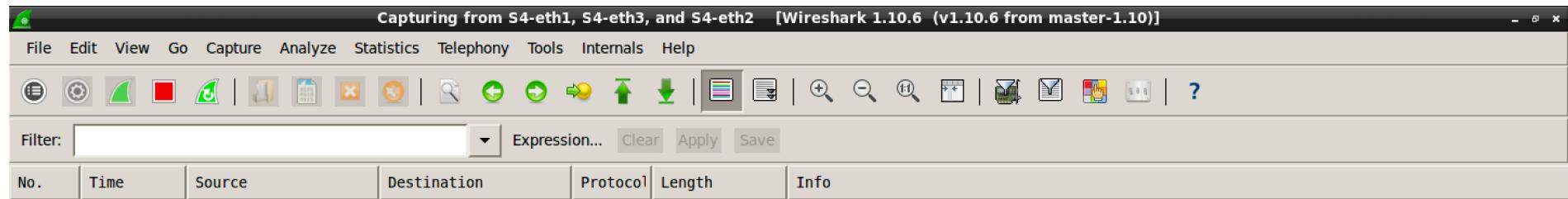
Frame 1: 1512 bytes on wire (12096 bits), 1512 bytes captured (12096 bits) on interface 0
Ethernet II, Src: 00:00:00_00:00:03 (00:00:00:00:00:03), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)
Internet Protocol Version 4, Src: 10.0.0.3 (10.0.0.3), Dst: 10.0.0.2 (10.0.0.2)
User Datagram Protocol, Src Port: 50266 (50266), Dst Port: commplex-link (5001)
Data (1470 bytes)

S2-eth1, S2-eth3, S2-eth2: <liv...> Packets: 22 · Displayed: 22 (100.0%) Profile: Default

mininet@minine... Capturing from e... Capturing from S...

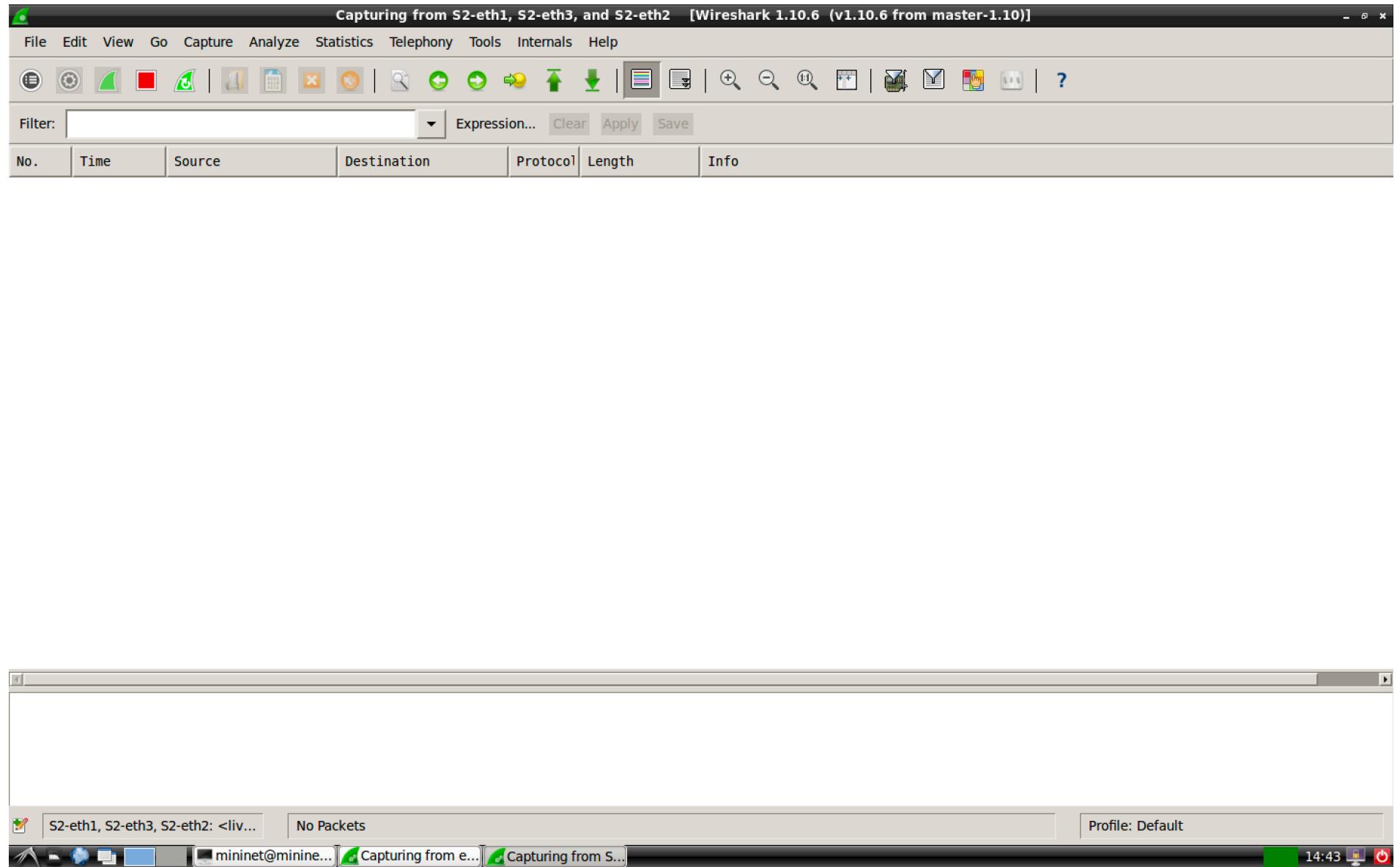
01:25

S4:



→ UDP equal path from H3 to H1

S2:



S4:

Capturing from S4-eth1, S4-eth3, and S4-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
2	0.016038000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
3	-0.000032000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
4	0.016033000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
5	0.266557000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
6	0.266562000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
7	0.517036000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
8	0.517030000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
9	0.767478000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
10	0.767484000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
11	1.017894000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
12	1.017888000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
13	1.269001000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
14	1.269008000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
15	1.519483000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
16	1.519462000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
17	1.769993000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
18	1.769999000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
19	2.023138000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
20	2.023131000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
21	2.273288000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link
22	2.273281000	10.0.0.3	10.0.0.1	UDP	1512	Source port: 55911 Destination port: commplex-link

Frame 1: 1512 bytes on wire (12096 bits), 1512 bytes captured (12096 bits) on interface 2

Ethernet II, Src: 00:00:00_00:00:03 (00:00:00:00:00:03), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)

Internet Protocol Version 4, Src: 10.0.0.3 (10.0.0.3), Dst: 10.0.0.1 (10.0.0.1)

User Datagram Protocol, Src Port: 55911 (55911), Dst Port: commplex-link (5001)

Data (1470 bytes)

S4-eth1, S4-eth3, S4-eth2: <live> | Packets: 22 · Displayed: 22 (100.0%) | Profile: Default

mininet@minine... | Capturing from e... | Capturing from S...

14:44

→ UDP equal path from H2 to H4

S1:

Capturing from S1-eth1, S1-eth2, and S1-eth3 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
2	0.008332000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
3	0.001968000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
4	0.008363000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
5	0.259121000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
6	0.259115000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
7	0.509590000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
8	0.509595000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
9	0.760080000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
10	0.760075000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
11	1.010835000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
12	1.010842000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
13	1.261277000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
14	1.261265000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
15	1.512069000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
16	1.512075000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
17	1.762275000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
18	1.762267000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
19	2.012673000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
20	2.012679000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
21	2.262972000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link
22	2.262967000	10.0.0.2	10.0.0.4	UDP	1512	Source port: 43062 Destination port: commplex-link

Frame 1: 1512 bytes on wire (12096 bits), 1512 bytes captured (12096 bits) on interface 1

Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:04 (00:00:00:00:00:04)

Internet Protocol Version 4, Src: 10.0.0.2 (10.0.0.2), Dst: 10.0.0.4 (10.0.0.4)

User Datagram Protocol, Src Port: 43062 (43062), Dst Port: commplex-link (5001)

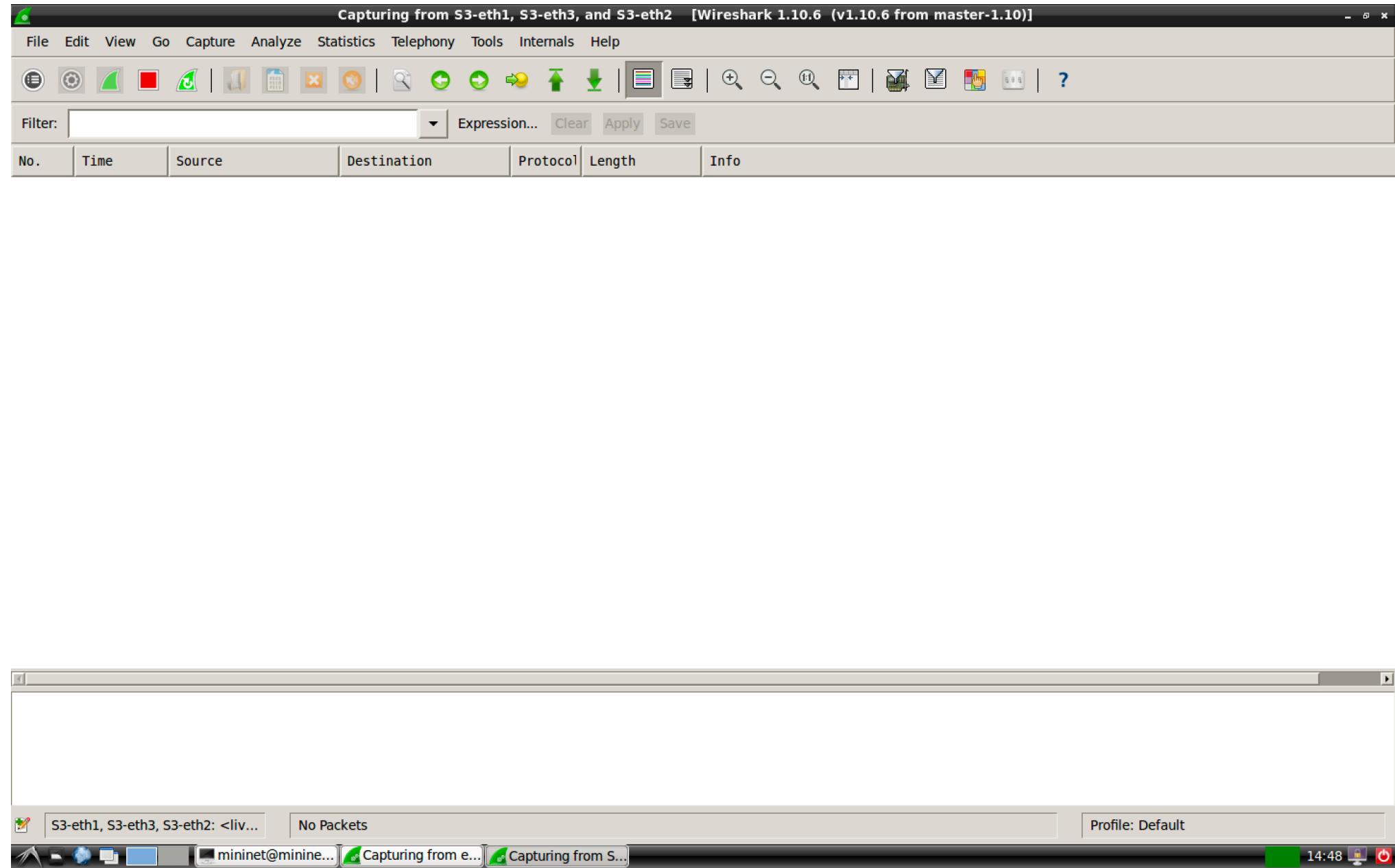
Data (1470 bytes)

S1-eth1, S1-eth2, S1-eth3: <live> | Packets: 22 · Displayed: 22 (100.0%) | Profile: Default

mininet@minine... | Capturing from e... | Capturing from S...

14:47

S3:



→ UDP dropped from H1 or H4

S1-eth1:

Capturing from S1-eth1 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
2	0.030347000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
3	0.280663000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
4	0.531191000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
5	0.782456000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
6	1.033155000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
7	1.283901000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
8	1.534238000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
9	1.784926000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
10	2.035350000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link
11	2.285728000	10.0.0.1	10.0.0.3	UDP	1512	Source port: 51038 Destination port: commplex-link

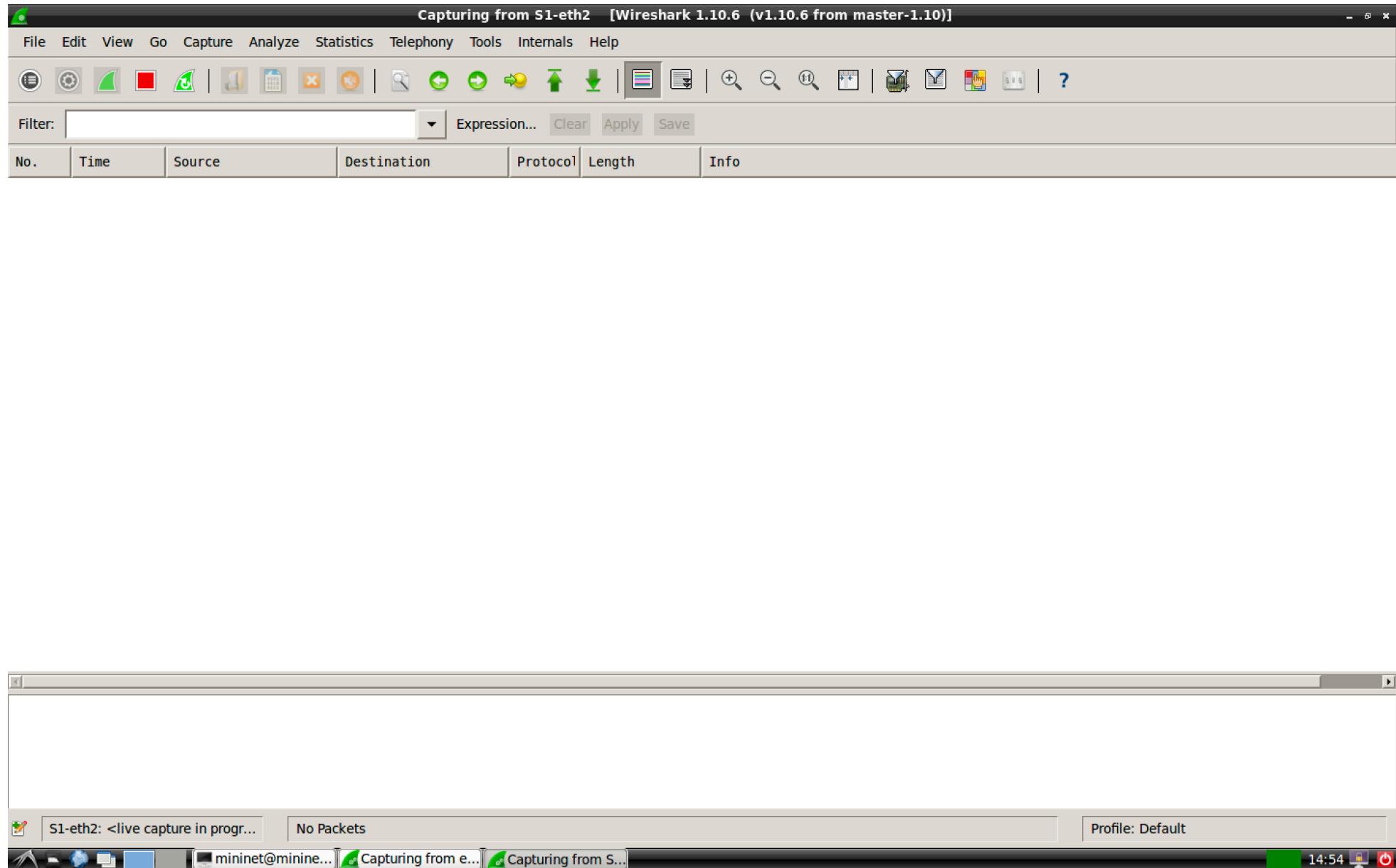
```
Frame 1: 1512 bytes on wire (12096 bits), 1512 bytes captured (12096 bits) on interface 0
Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:03 (00:00:00:00:00:03)
Internet Protocol Version 4, Src: 10.0.0.1 (10.0.0.1), Dst: 10.0.0.3 (10.0.0.3)
User Datagram Protocol, Src Port: 51038 (51038), Dst Port: commplex-link (5001)
Data (1470 bytes)
```

S1-eth1: <live capture in progress...> Packets: 11 · Displayed: 11 (100.0%) Profile: Default

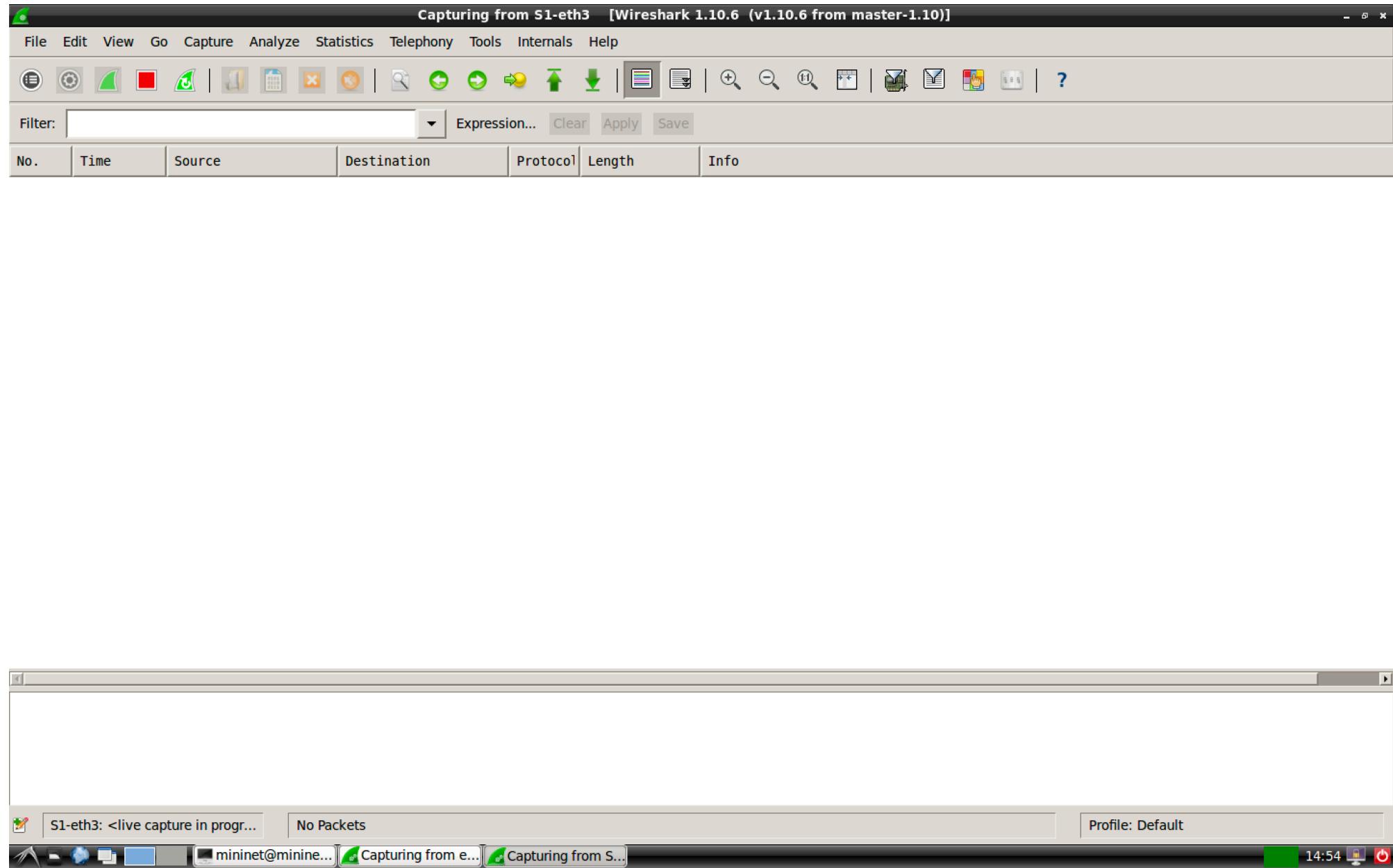
mininet@mininet: ~ Capturing from e... Capturing from S...

14:52

S1-eth2:



S1-eth3:



S4-eth1:

Capturing from S4-eth1 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.0000000000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
2	0.0167060000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
3	0.2673780000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
4	0.5177530000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
5	0.7680990000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
6	1.0187000000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
7	1.2693690000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
8	1.5199990000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
9	1.7701350000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
10	2.0204800000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link
11	2.2708840000	10.0.0.4	10.0.0.2	UDP	1512	Source port: 56564 Destination port: commplex-link

Frame 1: 1512 bytes on wire (12096 bits), 1512 bytes captured (12096 bits) on interface 0

Ethernet II, Src: 00:00:00_00:00:04 (00:00:00:00:00:04), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)

Internet Protocol Version 4, Src: 10.0.0.4 (10.0.0.4), Dst: 10.0.0.2 (10.0.0.2)

User Datagram Protocol, Src Port: 56564 (56564), Dst Port: commplex-link (5001)

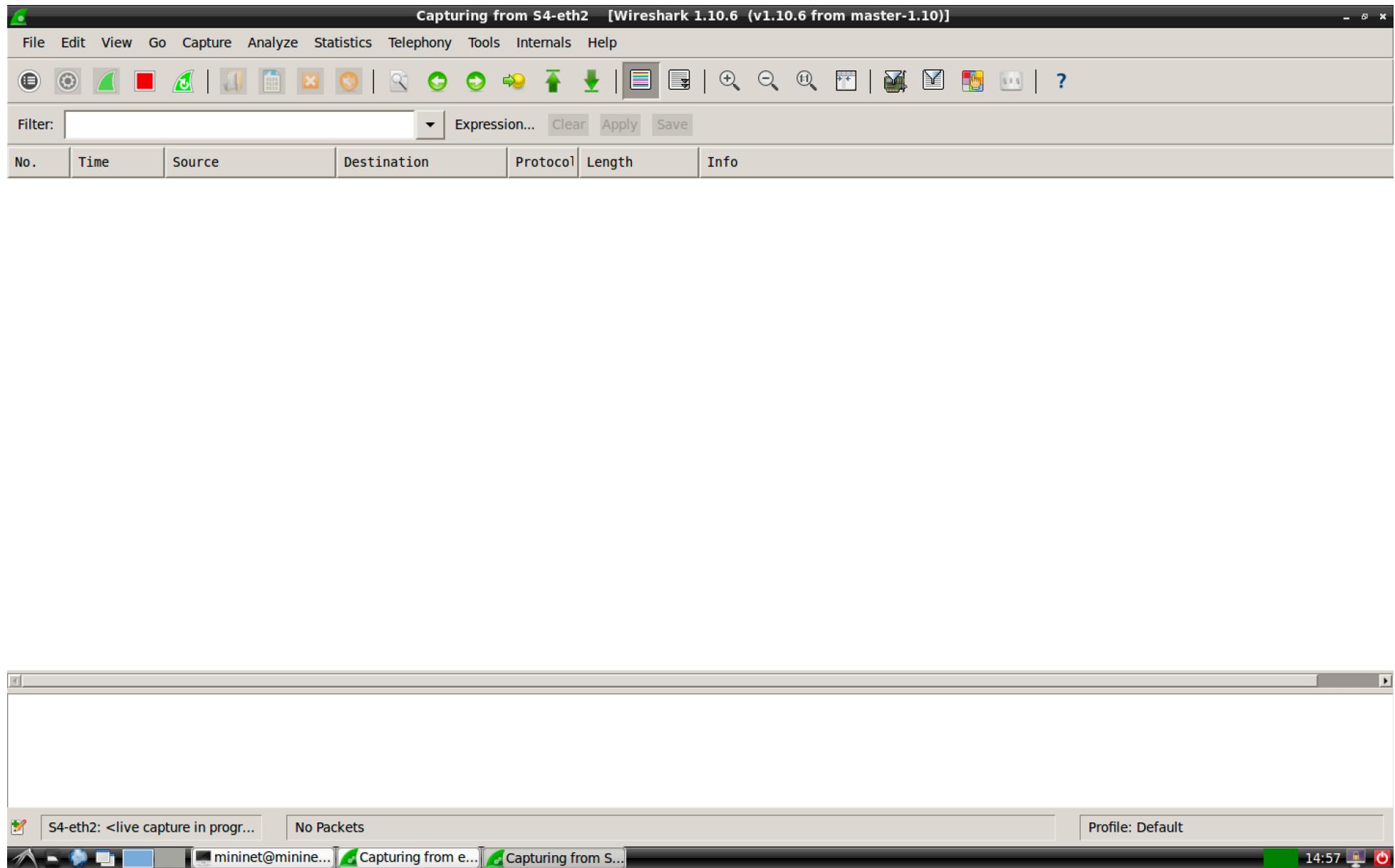
Data (1470 bytes)

S4-eth1: <live capture in progress...> Packets: 11 · Displayed: 11 (100.0%) Profile: Default

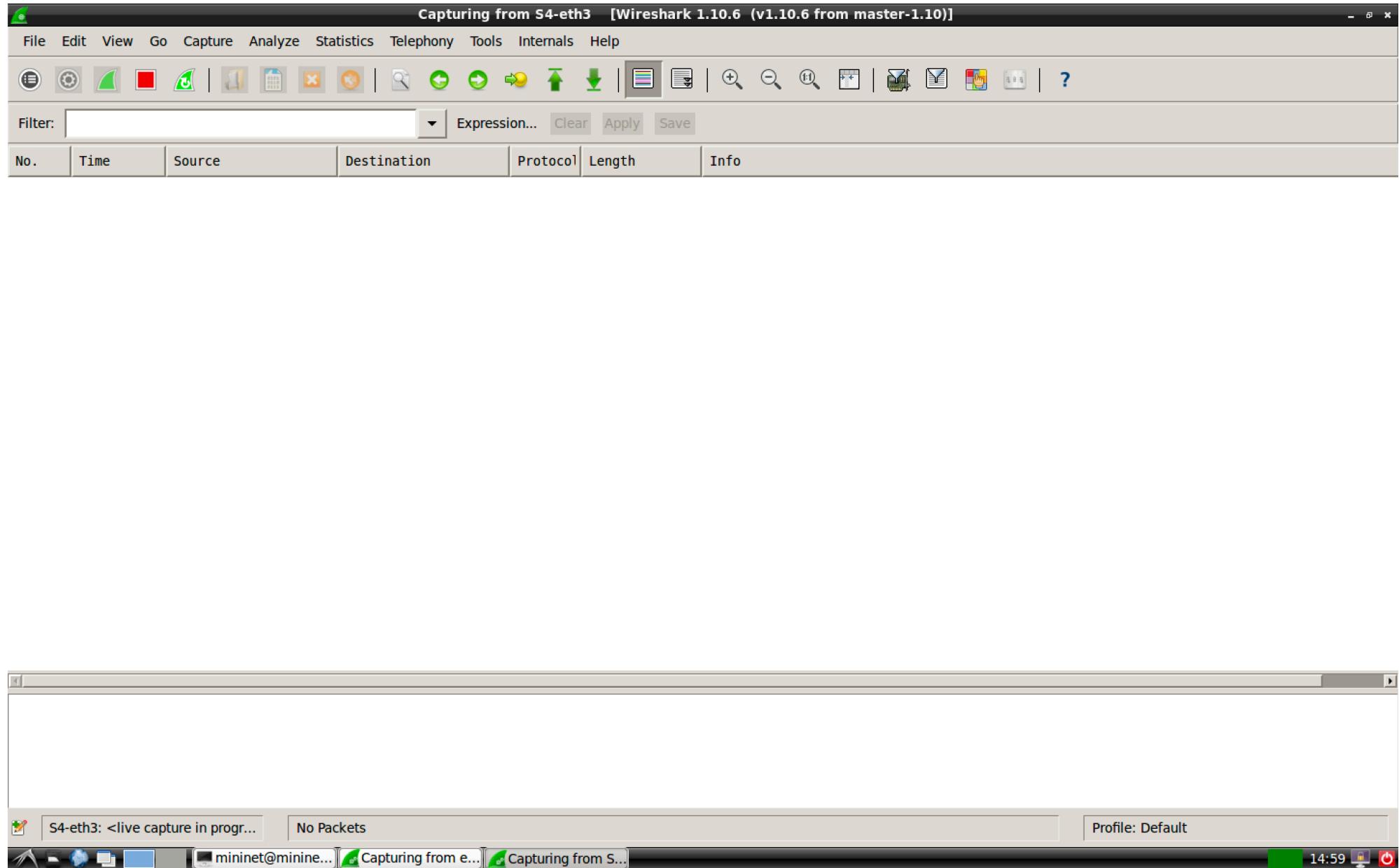
mininet@mininet: ~ Capturing from S4-eth1 Capturing from S...

14:56

S4-eth2:

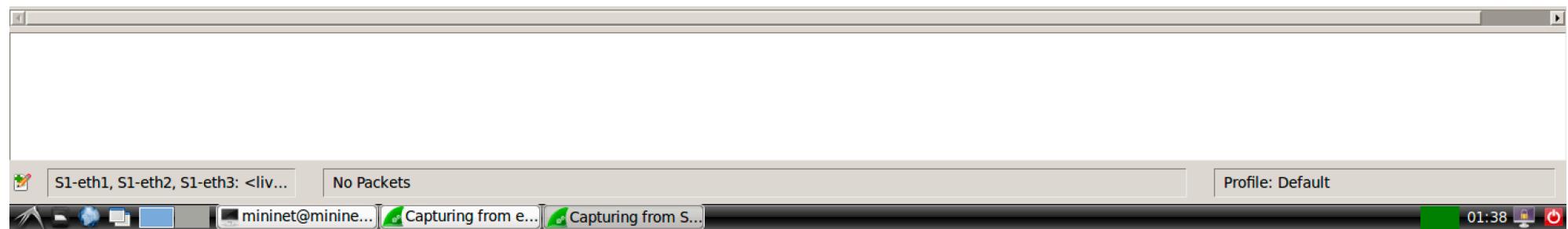
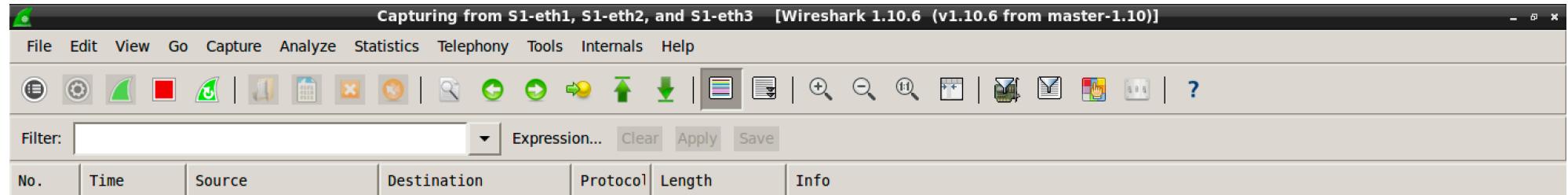


S4-eth3:



→ ICMP shortest path from H2 to H3

S1:



S3:

Capturing from S3-eth1, S3-eth3, and S3-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.2	10.0.0.3	ICMP	98	Echo (ping) request id=0x7591, seq=1/256, ttl=64 (reply in 2)
2	0.000008000	10.0.0.3	10.0.0.2	ICMP	98	Echo (ping) reply id=0x7591, seq=1/256, ttl=64 (request in 1)
3	-0.000030000	10.0.0.2	10.0.0.3	ICMP	98	Echo (ping) request id=0x7591, seq=1/256, ttl=64 (reply in 4)
4	0.000025000	10.0.0.3	10.0.0.2	ICMP	98	Echo (ping) reply id=0x7591, seq=1/256, ttl=64 (request in 3)

Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 0

Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:03 (00:00:00:00:00:03)

Internet Protocol Version 4, Src: 10.0.0.2 (10.0.0.2), Dst: 10.0.0.3 (10.0.0.3)

Internet Control Message Protocol

S3-eth1, S3-eth3, S3-eth2: <live> | Packets: 4 · Displayed: 4 (100.0%) | Profile: Default

mininet@minine... | Capturing from e... | Capturing from S...

01:39

→ ICMP equal path from H3 to H1

S2:

Capturing from S2-eth1, S2-eth3, and S2-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.3	10.0.0.1	ICMP	98	Echo (ping) request id=0x75ad, seq=1/256, ttl=64 (reply in 2)
2	0.000044000	10.0.0.1	10.0.0.3	ICMP	98	Echo (ping) reply id=0x75ad, seq=1/256, ttl=64 (request in 1)
3	-0.000031000	10.0.0.3	10.0.0.1	ICMP	98	Echo (ping) request id=0x75ad, seq=1/256, ttl=64 (reply in 4)
4	0.000058000	10.0.0.1	10.0.0.3	ICMP	98	Echo (ping) reply id=0x75ad, seq=1/256, ttl=64 (request in 3)

Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 1

Ethernet II, Src: 00:00:00_00:00:03 (00:00:00:00:00:03), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)

Internet Protocol Version 4, Src: 10.0.0.3 (10.0.0.3), Dst: 10.0.0.1 (10.0.0.1)

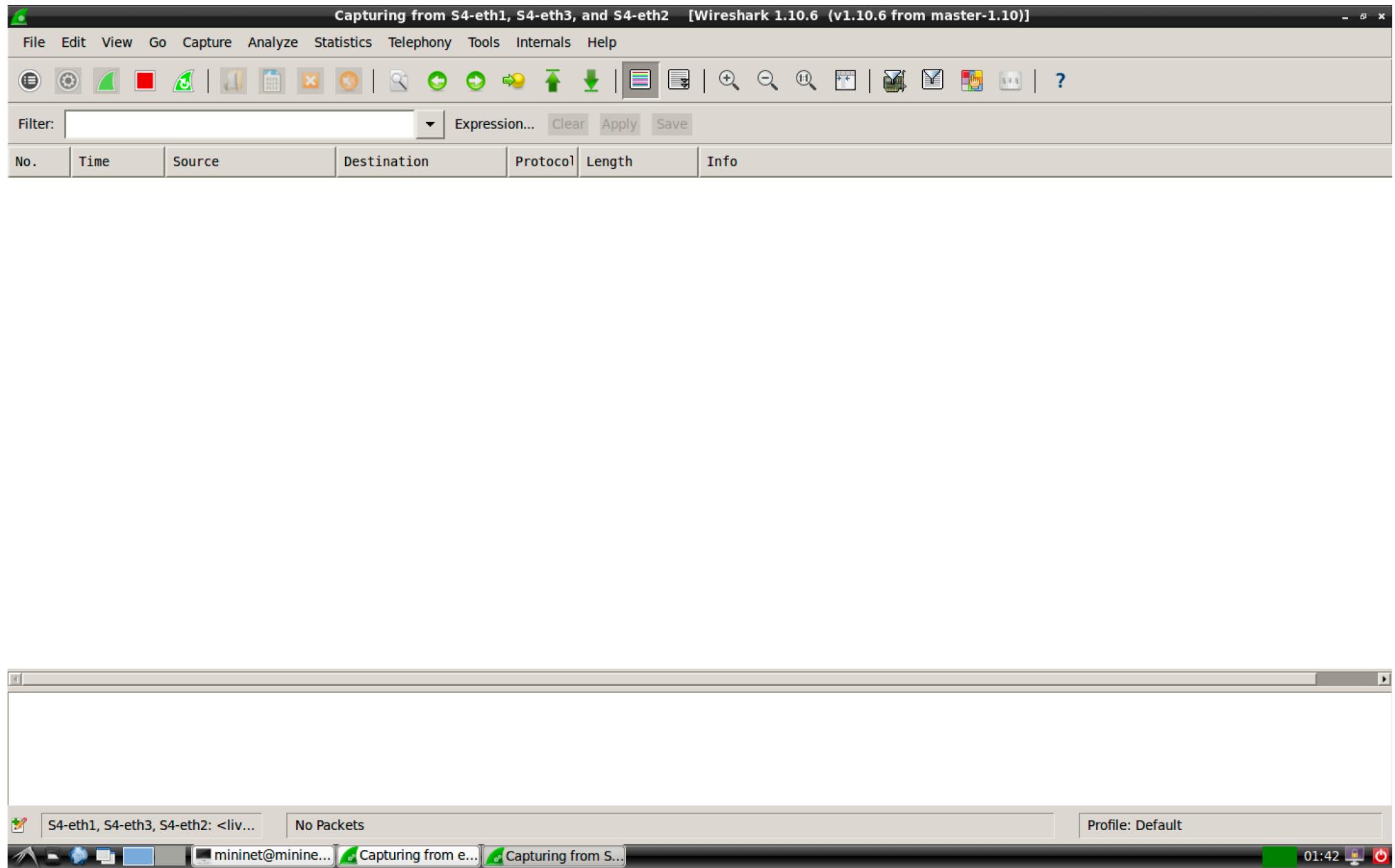
Internet Control Message Protocol

S2-eth1, S2-eth3, S2-eth2: <live> | Packets: 4 · Displayed: 4 (100.0%) | Profile: Default

mininet@minine... | Capturing from e... | Capturing from S...

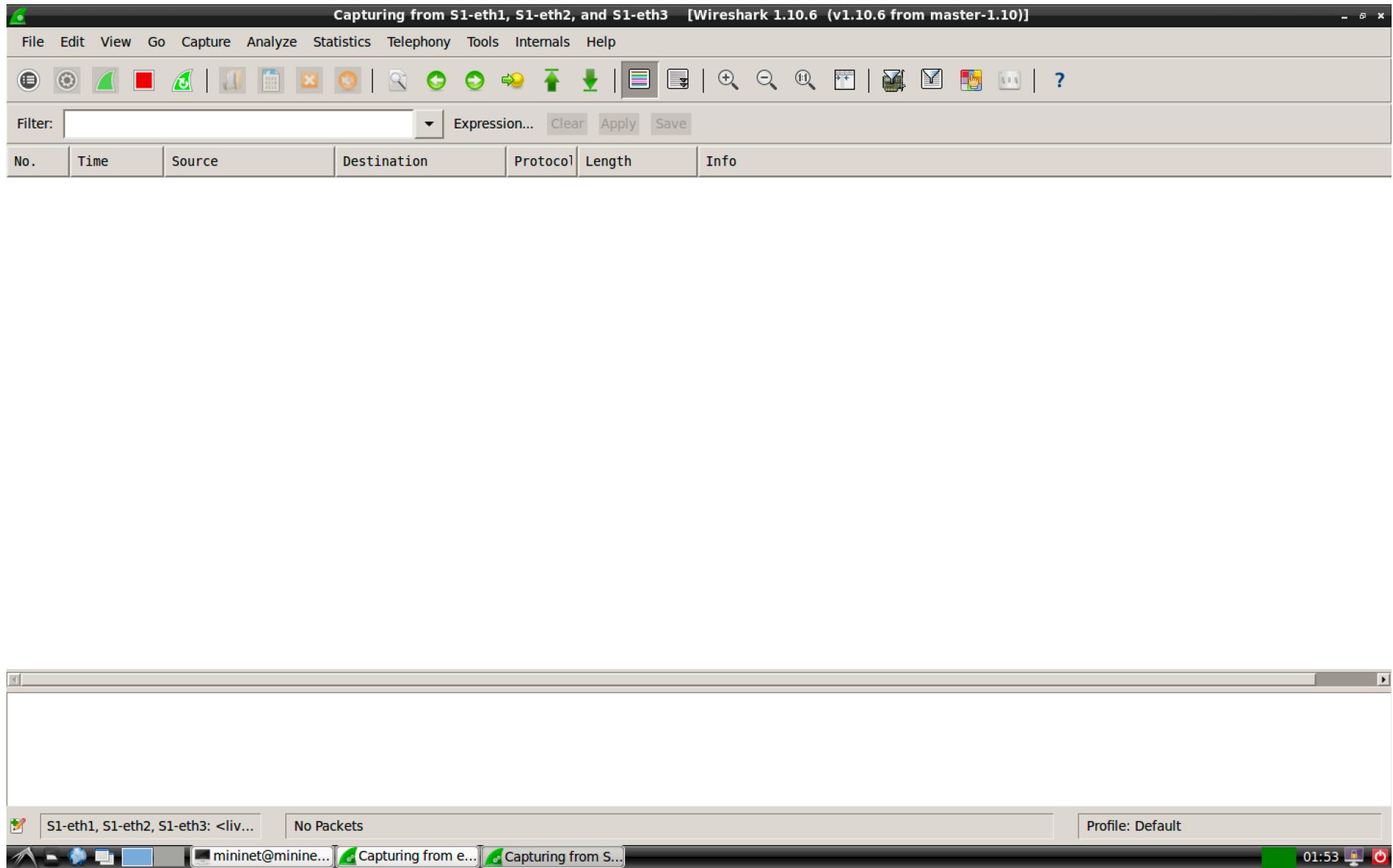
01:41

S4:



► ICMP equal path from H4 to H2

S1:



S3:

Capturing from S3-eth1, S3-eth3, and S3-eth2 [Wireshark 1.10.6 (v1.10.6 from master-1.10)]

File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help

Filter: Expression... Clear Apply Save

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.0.0.4	10.0.0.2	ICMP	98	Echo (ping) request id=0x7683, seq=1/256, ttl=64 (reply in 2)
2	0.000044000	10.0.0.2	10.0.0.4	ICMP	98	Echo (ping) reply id=0x7683, seq=1/256, ttl=64 (request in 1)
3	-0.000032000	10.0.0.4	10.0.0.2	ICMP	98	Echo (ping) request id=0x7683, seq=1/256, ttl=64 (reply in 4)
4	0.000059000	10.0.0.2	10.0.0.4	ICMP	98	Echo (ping) reply id=0x7683, seq=1/256, ttl=64 (request in 3)

Frame 1: 98 bytes on wire (784 bits), 98 bytes captured (784 bits) on interface 1

Ethernet II, Src: 00:00:00_00:00:04 (00:00:00:00:00:04), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)

Internet Protocol Version 4, Src: 10.0.0.4 (10.0.0.4), Dst: 10.0.0.2 (10.0.0.2)

Internet Control Message Protocol

S3-eth1, S3-eth3, S3-eth2: <live> | Packets: 4 · Displayed: 4 (100.0%) | Profile: Default

mininet@minine... | Capturing from e... | Capturing from S...

01:54

- Rules installed at each switch

S1:

```
mininet@mininet-vm:~$ sudo ovs-ofctl -O openflow13 dump-flows S1
OFPST_FLOW reply (OF1.3) (xid=0x2):
  cookie=0x0, duration=132.306s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=3,nw_dst=10.0.0.1 actions=output:1
  cookie=0x0, duration=405.349s, table=0, n_packets=25, n_bytes=132746, priority=1,tcp,in_port=1,nw_dst=10.0.0.3 actions=output:2
  cookie=0x0, duration=431.239s, table=0, n_packets=26, n_bytes=132820, priority=1,tcp,in_port=1,nw_dst=10.0.0.4 actions=output:3
  cookie=0x0, duration=542.027s, table=0, n_packets=3, n_bytes=294, priority=1,icmp,in_port=2,nw_dst=10.0.0.1 actions=output:1
  cookie=0x0, duration=541.894s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.4 actions=output:3
  cookie=0x0, duration=541.974s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.3 actions=output:2
  cookie=0x0, duration=541.89s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=3,nw_dst=10.0.0.1 actions=output:1
  cookie=0x0, duration=542.039s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.2 actions=output:2
  cookie=0x0, duration=431.232s, table=0, n_packets=25, n_bytes=1638, priority=1,tcp,in_port=3,nw_dst=10.0.0.1 actions=output:1
  cookie=0x0, duration=110.815s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=2,nw_dst=10.0.0.4 actions=output:3
  cookie=0x0, duration=405.338s, table=0, n_packets=24, n_bytes=1584, priority=1,tcp,in_port=2,nw_dst=10.0.0.1 actions=output:1
  cookie=0x0, duration=82.889s, table=0, n_packets=10, n_bytes=15120, priority=2,udp,in_port=1,nw_src=10.0.0.1 actions=drop
  cookie=0x0, duration=586.796s, table=0, n_packets=12, n_bytes=5322, priority=0 actions=CONTROLLER:65535
mininet@mininet-vm:~$ █
```

S2:

```
mininet@mininet-vm:~$ sudo ovs-ofctl -O openflow13 dump-flows S2
OFPST_FLOW reply (0F1.3) (xid=0x2):
  cookie=0x0, duration=165.59s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=1,nw_dst=10.0.0.4
  actions=output:3
  cookie=0x0, duration=596.743s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=3,nw_dst=10.0.0.3
  actions=output:2
  cookie=0x0, duration=446.95s, table=0, n_packets=25, n_bytes=132746, priority=1,tcp,in_port=1,nw_dst=10.0.0.4
  actions=output:2
  cookie=0x0, duration=596.802s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=3,nw_dst=10.0.0.2
  actions=output:1
  cookie=0x0, duration=596.578s, table=0, n_packets=3, n_bytes=294, priority=1,icmp,in_port=2,nw_dst=10.0.0.2
  actions=output:1
  cookie=0x0, duration=460.116s, table=0, n_packets=25, n_bytes=132746, priority=1,tcp,in_port=3,nw_dst=10.0.0.3
  actions=output:2
  cookie=0x0, duration=596.739s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=2,nw_dst=10.0.0.1
  actions=output:3
  cookie=0x0, duration=596.52s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.4
  actions=output:2
  cookie=0x0, duration=207.706s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=2,nw_dst=10.0.0.2
  actions=output:1
  cookie=0x0, duration=446.938s, table=0, n_packets=24, n_bytes=1584, priority=1,tcp,in_port=2,nw_dst=10.0.0.2
  actions=output:1
  cookie=0x0, duration=596.58s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.3
  actions=output:2
  cookie=0x0, duration=460.109s, table=0, n_packets=24, n_bytes=1584, priority=1,tcp,in_port=2,nw_dst=10.0.0.1
  actions=output:3
  cookie=0x0, duration=596.798s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.1
  actions=output:3
  cookie=0x0, duration=641.475s, table=0, n_packets=14, n_bytes=4080, priority=0 actions=CONTROLLER:65535
mininet@mininet-vm:~$ █
```

S3:

```
mininet@mininet-vm:~$ sudo ovs-ofctl -O openflow13 dump-flows S3
OFPST_FLOW reply (0F1.3) (xid=0x2):
  cookie=0x0, duration=522.493s, table=0, n_packets=24, n_bytes=1584, priority=1,tcp,in_port=1,nw_dst=10.0.0.1
  actions=output:3
  cookie=0x0, duration=659.124s, table=0, n_packets=3, n_bytes=294, priority=1,icmp,in_port=3,nw_dst=10.0.0.3
  actions=output:1
  cookie=0x0, duration=658.901s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=3,nw_dst=10.0.0.4
  actions=output:2
  cookie=0x0, duration=249.466s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=1,nw_dst=10.0.0.1
  actions=output:2
  cookie=0x0, duration=509.329s, table=0, n_packets=25, n_bytes=132746, priority=1,tcp,in_port=3,nw_dst=10.0.0.4
  actions=output:2
  cookie=0x0, duration=658.897s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=2,nw_dst=10.0.0.2
  actions=output:3
  cookie=0x0, duration=522.495s, table=0, n_packets=25, n_bytes=132746, priority=1,tcp,in_port=3,nw_dst=10.0.0.3
  actions=output:1
  cookie=0x0, duration=270.093s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=1,nw_dst=10.0.0.2
  actions=output:3
  cookie=0x0, duration=658.768s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.4
  actions=output:2
  cookie=0x0, duration=509.322s, table=0, n_packets=24, n_bytes=1584, priority=1,tcp,in_port=2,nw_dst=10.0.0.2
  actions=output:3
  cookie=0x0, duration=658.961s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.2
  actions=output:3
  cookie=0x0, duration=659.122s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.1
  actions=output:3
  cookie=0x0, duration=658.765s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=2,nw_dst=10.0.0.3
  actions=output:1
  cookie=0x0, duration=703.737s, table=0, n_packets=14, n_bytes=4080, priority=0 actions=CONTROLLER:65535
mininet@mininet-vm:~$ █
```

S4:

```
mininet@mininet-vm:~$ sudo ovs-ofctl -O openflow13 dump-flows S4
OFPST_FLOW reply (OF1.3) (xid=0x2):
  cookie=0x0, duration=393.721s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=3,nw_dst=10.0.0.1 actions=output:2
  cookie=0x0, duration=803.16s, table=0, n_packets=3, n_bytes=294, priority=1,icmp,in_port=3,nw_dst=10.0.0.4 actions=output:1
  cookie=0x0, duration=692.645s, table=0, n_packets=25, n_bytes=1638, priority=1,tcp,in_port=1,nw_dst=10.0.0.1 actions=output:2
  cookie=0x0, duration=653.583s, table=0, n_packets=24, n_bytes=1584, priority=1,tcp,in_port=1,nw_dst=10.0.0.2 actions=output:3
  cookie=0x0, duration=692.647s, table=0, n_packets=26, n_bytes=132820, priority=1,tcp,in_port=2,nw_dst=10.0.0.4 actions=output:1
  cookie=0x0, duration=653.585s, table=0, n_packets=25, n_bytes=132746, priority=1,tcp,in_port=3,nw_dst=10.0.0.4 actions=output:1
  cookie=0x0, duration=803.304s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=2,nw_dst=10.0.0.4 actions=output:1
  cookie=0x0, duration=803.026s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.3 actions=output:3
  cookie=0x0, duration=803.158s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.2 actions=output:3
  cookie=0x0, duration=372.225s, table=0, n_packets=10, n_bytes=15120, priority=1,udp,in_port=2,nw_dst=10.0.0.4 actions=output:1
  cookie=0x0, duration=803.303s, table=0, n_packets=1, n_bytes=98, priority=1,icmp,in_port=1,nw_dst=10.0.0.1 actions=output:2
  cookie=0x0, duration=318.626s, table=0, n_packets=10, n_bytes=15120, priority=2,udp,in_port=1,nw_src=10.0.0.4 actions=drop
  cookie=0x0, duration=847.917s, table=0, n_packets=13, n_bytes=5396, priority=0 actions=CONTROLLER:65535
mininet@mininet-vm:~$
```

(g) Challenges:

1. While the official mininet VM uses python2 and OF1.0 by default, we find Ryu is distributed with more recent versions of python and OF protocol.

We decided to use python3 and OF1.3, but apply minimal changes to the old configured environment, which is the virtualbox mininet VM, and use our local machine as a remote controller. So we started to install Ryu in python3 and seek a way of reconciling it with a mininet app. Here are what we did:

a. Knowing that OF1.3 is supported but requires enabled by mininet, we figured out the way to specify the OF protocol version either via mn launch tool or by running a script file.

b. We learned Ryu API through the official OF1.3 examples, and tested successfully with py2 OVSSwitches connected to a py3 Ryu controller. Thus no need to reconfigure a new environment for mininet.

2. Need to take care of ARP request from hosts to perform an ICMP test, but the topology is a loop that disrupts the address learning.

Installing fixed rules for ARP handling is burdensome. We enabled Proxy ARP for each switch, since the simplicity of the topology allows to do so, and ARP packets are not the focus of this lab. We further found out mininet has a feature "autoSetArp" that can make this part even easier.

3. Particular handling of HTTP and UDP is a tricky part.

We added a flow-forward entry to redirect specified http traffic to the controller every time, and only need to add once, with a higher priority over regular TCP packets. We also figured out the subtlety to construct a reset packet for correct implementation. For UDP drop, there is no drop action, so we made the action list empty, and worked it out.

(e) Describe how you generate traffic to test your controller and switch behavior

We used pingall and iperf tools to generate verifying traffic. Specifically, the Mininet pingall command would generate ICMP traffic between all host pairs. The iperf tool can be used to generate TCP and UDP traffic. For example, if we want to send UDP traffic from H2 to H3, we would start a iperf server in H3 by a Mininet command “ H3 iperf -sDu ”, and then send the traffic in H2 by a Mininet command “ H2 iperf -c H3 -u ”.

(a) Write a pseudo code to implement spanning tree in SDN network.

The most general pseudo code for a Minimum Spanning tree is the following

GENERIC-MST(G)

- 1 A = empty_set**
- 2 while A does not form a spanning tree of G**
- 3 do find an edge (u, v) that is safe for A**
- 4 A = A ∪ {(u, v)}**
- 5 return A**

where a safe edge is defined as an edge that maintains the invariant: A is always a minimum spanning tree of the subset of A being maintained.

reference: *CLRS Introduction to Algorithms* is a book on computer programming by Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein.

(b) List the advantages of using OpenVSwitch and SDN controller compared to IP networks.

- With SDN, only the controller – not each router – is aware of the global topology of the network. This increases efficiency and security.
- With SDN, one can control which hosts in a network are allowed to talk to one another. This increases security.
- With SDN, one can set limits on the type of data being shared across the network, allowing both increases in performance and security.
- In SDN the performance of the network is easily configurable through a central controller.