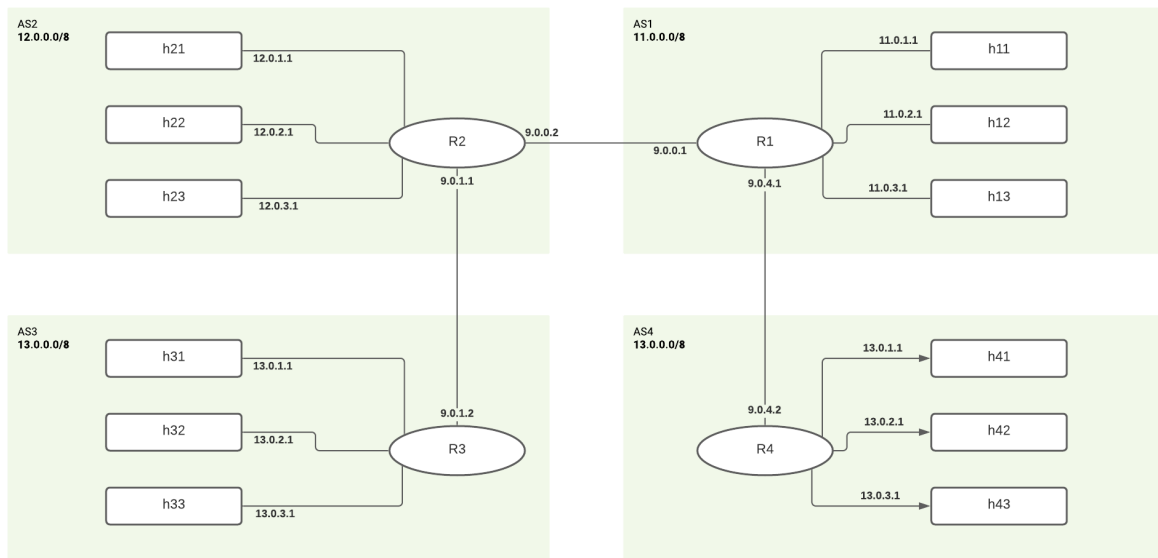


Lab 5: BGP routing

Part 1: Topology with IP addresses of all routers and Hosts/IPs in the ASes



Part 2: BGP traffic observed during re-establishment of routes

Following BGP traffic is seen between routers:

- When “clear bgp external” is run, we see a NOTIFICATION message sent to the other routers with major code 6 - telling them to close the connection^[1]. When the connection is closed.
- After this a three way handshake is done between the two routers and an OPEN KEEPALIVE message is sent to initiate BGP communication. This message includes the IP address of the router and other information necessary to open the connection. The KEEPALIVE message is used to keep the session running even if there are no BGP messages to be passed.
- UPDATE messages are exchanged between the routers which contain Network Layer Reachability Information sections that detail ASes that are reachable from their routers.
- The routers subsequently keep passing KEEPALIVE messages to each other to keep the connection open.

```
▼ Border Gateway Protocol - UPDATE Message
  Marker: ffffffffffffffffffffffffffffffffff
  Length: 53
  Type: UPDATE Message (2)
  Withdrawn Routes Length: 0
  Total Path Attribute Length: 28
  ► Path attributes
  ▼ Network Layer Reachability Information (NLRI)
    ▼ 11.0.0.0/8
      NLRI prefix length: 8
      NLRI prefix: 11.0.0.0
```

Part 3: Reaching 13.0.1.1 from AS1 (h11 and R1), and modifications

Trying to reach h33 from h11:

Yes, we are able to ping h33 from h11, but this is only after the routing table for all the relevant routers have been fully updated, which takes a few seconds.

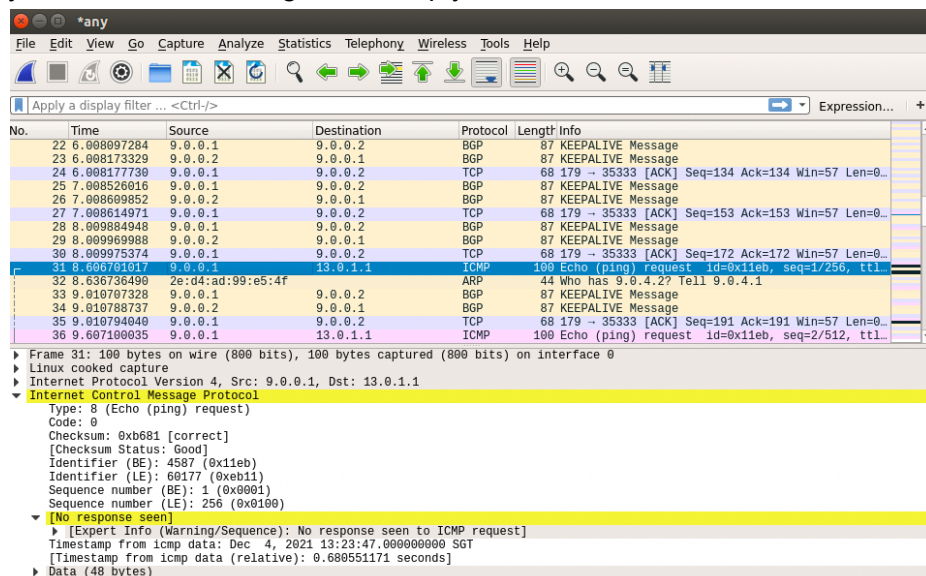
```
mininet> h11 ping h33
PING 13.0.3.1 (13.0.3.1) 56(84) bytes of data.
64 bytes from 13.0.3.1: icmp_seq=1 ttl=61 time=0.045 ms
64 bytes from 13.0.3.1: icmp_seq=2 ttl=61 time=0.042 ms
64 bytes from 13.0.3.1: icmp_seq=3 ttl=61 time=0.045 ms
64 bytes from 13.0.3.1: icmp_seq=4 ttl=61 time=0.038 ms
64 bytes from 13.0.3.1: icmp_seq=5 ttl=61 time=0.045 ms
64 bytes from 13.0.3.1: icmp_seq=6 ttl=61 time=0.033 ms
^C
--- 13.0.3.1 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5135ms
rtt min/avg/max/mdev = 0.033/0.041/0.045/0.006 ms
```

Try to reach 13.0.1.1 from R1:

We are unable to ping 13.0.1.1 from R1 as shown below.

```
Node: R1
root@bowen-VirtualBox:~/Desktop/lab5# ping 13.0.1.1
PING 13.0.1.1 (13.0.1.1) 56(84) bytes of data.
^C
--- 13.0.1.1 ping statistics ---
9 packets transmitted, 0 received, 100% packet loss, time 8064ms
root@bowen-VirtualBox:~/Desktop/lab5#
```

When using wireshark to analyze and monitor the network, it is seen that when router R1 with source IP 9.0.0.1 tries to send an ICMP request generated by the ping utility to host with IP 13.0.1.1, no response was observed. This meant that R1 could reach 13.0.1.1 but there is a possibility of 13.0.1.1 not being able to reply to R1.



When taking a look at the routing tables for all 3 routers R1, R2 and R3, it became evident that the cause for this was due to router R3 not knowing how to route to router R1 that has the IP 9.0.0.0/8.

```

mininet> R1 route
Kernel IP routing table
Destination    Gateway         Genmask         Flags Metric Ref    Use Iface
9.0.0.0        *               255.255.255.0   U        0      0        0 R1-eth4
9.0.4.0        *               255.255.255.0   U        0      0        0 R1-eth5
11.0.1.0       *               255.255.255.0   U        0      0        0 R1-eth1
11.0.2.0       *               255.255.255.0   U        0      0        0 R1-eth2
11.0.3.0       *               255.255.255.0   U        0      0        0 R1-eth3
12.0.0.0       9.0.0.2        255.0.0.0       UG        0      0        0 R1-eth4
13.0.0.0       9.0.0.2        255.0.0.0       UG        0      0        0 R1-eth4

mininet> R2 route
Kernel IP routing table
Destination    Gateway         Genmask         Flags Metric Ref    Use Iface
9.0.0.0        *               255.255.255.0   U        0      0        0 R2-eth4
9.0.1.0        *               255.255.255.0   U        0      0        0 R2-eth5
11.0.0.0       9.0.0.1        255.0.0.0       UG        0      0        0 R2-eth4
12.0.1.0       *               255.255.255.0   U        0      0        0 R2-eth1
12.0.2.0       *               255.255.255.0   U        0      0        0 R2-eth2
12.0.3.0       *               255.255.255.0   U        0      0        0 R2-eth3
13.0.0.0       9.0.1.2        255.0.0.0       UG        0      0        0 R2-eth5

mininet> R3 route
Kernel IP routing table
Destination    Gateway         Genmask         Flags Metric Ref    Use Iface
9.0.1.0        *               255.255.255.0   U        0      0        0 R3-eth4
11.0.0.0       9.0.1.1        255.0.0.0       UG        0      0        0 R3-eth4
12.0.0.0       9.0.1.1        255.0.0.0       UG        0      0        0 R3-eth4
13.0.1.0       *               255.255.255.0   U        0      0        0 R3-eth1
13.0.2.0       *               255.255.255.0   U        0      0        0 R3-eth2
13.0.3.0       *               255.255.255.0   U        0      0        0 R3-eth3

mininet>

```

To resolve this, we had to modify the bgpd-R2.conf file by adding the line “**network 9.0.0.0/8**”. What this does is that R2 will now announce that it has a path to 9.0.0.0/8. Hence, when we observe the routing table for R3 again, we can see that it now knows that there is a path to 9.0.0.0/8, and that it is through R2. Therefore, hosts in R3 will now be able to respond to R1’s ping request. This is confirmed by wireshark showing that there is an ICMP reply to 9.0.0.1

Routing table for R3:

	Network	Next Hop	Metric	LocPrf	Weight	Path
*>	9.0.0.0	9.0.1.1	0		0 2	i
*>	11.0.0.0	9.0.1.1			0 2 1	i
*>	12.0.0.0	9.0.1.1	0		0 2	i
*>	13.0.0.0	0.0.0.0	0		32768	i

```

Node: R1
root@bowen-VirtualBox:~/Desktop/lab5# ping 13.0.1.1
PING 13.0.1.1 (13.0.1.1) 56(84) bytes of data.
64 bytes from 13.0.1.1: icmp_seq=1 ttl=62 time=0.050 ms
64 bytes from 13.0.1.1: icmp_seq=2 ttl=62 time=0.072 ms
^C
--- 13.0.1.1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 999ms
rtt min/avg/max/mdev = 0.050/0.061/0.072/0.011 ms
root@bowen-VirtualBox:~/Desktop/lab5#

```

20	5.648385195	9.0.0.1	13.0.1.1	ICMP	100	Echo (ping) request	id=0x1627, seq=1/256, ttl...
21	5.648410620	13.0.1.1	9.0.0.1	ICMP	100	Echo (ping) reply	id=0x1627, seq=1/256, tt...
22	6.008229492	9.0.0.1	9.0.0.2	BGP	87	KEEPALIVE Message	
23	6.008330241	9.0.0.2	9.0.0.1	BGP	87	KEEPALIVE Message	
24	6.008337181	9.0.0.1	9.0.0.2	TCP	68	43004 → 179 [ACK] Seq=134 Ack=134 Win=58 Len=0...	
25	6.648118892	9.0.0.1	13.0.1.1	ICMP	100	Echo (ping) request	id=0x1627, seq=2/512, ttl...
26	6.648146046	13.0.1.1	9.0.0.1	ICMP	100	Echo (ping) reply	id=0x1627, seq=2/512, ttl...
27	7.009523560	9.0.0.1	9.0.0.2	BGP	87	KEEPALIVE Message	
28	7.009638645	9.0.0.2	9.0.0.1	BGP	87	KEEPALIVE Message	
29	7.009643963	9.0.0.1	9.0.0.2	TCP	68	43004 → 179 [ACK] Seq=153 Ack=153 Win=58 Len=0...	

▶ Frame 21: 100 bytes on wire (800 bits), 100 bytes captured (800 bits) on interface 0
 ▶ Linux cooked capture
 ▶ Internet Protocol Version 4, Src: 13.0.1.1, Dst: 9.0.0.1
 ▼ Internet Control Message Protocol
 Type: 0 (Echo (ping) reply)
 Code: 0
 Checksum: 0x2a65 [correct]
 [Checksum Status: Good]
 Identifier (BE): 5671 (0x1627)
 Identifier (LE): 10006 (0x2716)
 Sequence number (BE): 1 (0x0001)
 Sequence number (LE): 256 (0x0100)
 [Request frame: 20]
 [Response time: 0.025 ms]

Part 4: Malicious attack on BGP

When we run the script `./website.sh R1`, we can see that hosts in AS1 would continuously contact the web server on 13.0.1.1, by using R1's interface IP address of 9.0.0.1, which routes through AS2.

Mon Dec 6 12:16:16	SGT 2021	--	<h1>Default web server</h1>
Mon Dec 6 12:16:17	SGT 2021	--	<h1>Default web server</h1>
Mon Dec 6 12:16:18	SGT 2021	--	<h1>Default web server</h1>
Mon Dec 6 12:16:19	SGT 2021	--	<h1>Default web server</h1>

4	0.166411974	9.0.0.1	13.0.1.1	TCP	76 40056 → 80	[SYN] Seq=0 Win=29200 Len=0 MSS=146...
5	0.166480392	13.0.1.1	9.0.0.1	TCP	76 80 → 40056	[SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0...
6	0.166488274	9.0.0.1	13.0.1.1	TCP	68 40056 → 80	[ACK] Seq=1 Ack=1 Win=29696 Len=0 T...
7	0.166610857	9.0.0.1	13.0.1.1	HTTP	140 GET / HTTP/1.1	
8	0.166651266	13.0.1.1	9.0.0.1	TCP	68 80 → 40056	[ACK] Seq=1 Ack=73 Win=29184 Len=0 ...
9	0.166827353	13.0.1.1	9.0.0.1	TCP	85 80 → 40056	[PSH, ACK] Seq=1 Ack=73 Win=29184 L...
10	0.166829177	9.0.0.1	13.0.1.1	TCP	68 40056 → 80	[ACK] Seq=73 Ack=18 Win=29696 Len=0...
11	0.166843050	13.0.1.1	9.0.0.1	TCP	105 80 → 40056	[PSH, ACK] Seq=18 Ack=73 Win=29184 ...
12	0.166844830	9.0.0.1	13.0.1.1	TCP	68 40056 → 80	[ACK] Seq=73 Ack=55 Win=29696 Len=0...
13	0.166859703	13.0.1.1	9.0.0.1	TCP	105 80 → 40056	[PSH, ACK] Seq=55 Ack=73 Win=29184 ...
14	0.166860688	9.0.0.1	13.0.1.1	TCP	68 40056 → 80	[ACK] Seq=73 Ack=92 Win=29696 Len=0...
15	0.166868790	13.0.1.1	9.0.0.1	TCP	93 80 → 40056	[PSH, ACK] Seq=92 Ack=73 Win=29184 ...
16	0.166869687	9.0.0.1	13.0.1.1	TCP	68 40056 → 80	[ACK] Seq=73 Ack=117 Win=29696 Len=...
17	0.166878400	13.0.1.1	9.0.0.1	TCP	70 80 → 40056	[PSH, ACK] Seq=117 Ack=73 Win=29184...

To be able to perform the attack, we had to modify the **bgpd-R4.conf** file by having R4 announce that it has a path to **13.0.0.0/8** instead. This will update the path in the routing table of R1 if the attacker has advertised a route to the same destination IP address but with a **better path**, which is the case as seen in the routing table below, since the path to 13.0.0.0 is now via 9.0.4.2.

bgpd-R4.conf file

```
router bgp 4
  bgp router-id 9.0.4.2
  ! change the following line to mount the BGP attack
  network 13.0.0.0/8
  neighbor 9.0.4.1 remote-as 1
  neighbor 9.0.4.1 ebgp-multihop
  neighbor 9.0.4.1 next-hop-self
  neighbor 9.0.4.1 timers 5 5
```

Routing table of R1 when attack has started

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 9.0.0.0	9.0.0.2	0		0 2	i
*> 11.0.0.0	0.0.0.0	0		32768	i
*> 12.0.0.0	9.0.0.2	0		0 2	i
*> 13.0.0.0	9.0.4.2	0		0 4	i
*	9.0.0.2			0 2 3	i

When the attack has started, it can be seen that the website results are now different from before, as R1 has actually contacted the attacker web server instead of the default web server

```

bowen@bowen-VirtualBox: ~/Desktop/lab5
Thu Dec 2 18:40:45 SGT 2021 -- <h1>*** Attacker web server ***</h1>
Thu Dec 2 18:40:47 SGT 2021 -- <h1>*** Attacker web server ***</h1>
Thu Dec 2 18:40:48 SGT 2021 -- <h1>*** Attacker web server ***</h1>
Thu Dec 2 18:40:49 SGT 2021 -- <h1>*** Attacker web server ***</h1>
Thu Dec 2 18:40:50 SGT 2021 -- <h1>*** Attacker web server ***</h1>
Thu Dec 2 18:40:51 SGT 2021 -- <h1>*** Attacker web server ***</h1>

```

When using wireshark to monitor the results, it is now observed that for hosts in AS1 to get to the destination 13.0.1.1, they use R1's interface IP address of **9.0.4.1** instead, which is linked to R4 and goes through AS4 that is used by the malicious attacker. Hence, the malicious attacker has successfully redirected users in AS1 to its own web server by broadcasting a better path to the same destination.

261	10.683370017	9.0.4.1	13.0.1.1	TCP	76	37865 → 80	[SYN] Seq=0 Win=29200 Len=0 MSS=146...
262	10.683399221	13.0.1.1	9.0.4.1	TCP	76	80 → 37865	[SYN, ACK] Seq=0 Ack=1 Win=28960 Le...
263	10.683407186	9.0.4.1	13.0.1.1	TCP	68	37865 → 80	[ACK] Seq=1 Ack=1 Win=29696 Len=0 T...
264	10.683527878	9.0.4.1	13.0.1.1	HTTP	140	GET / HTTP/1.1	
265	10.683541203	13.0.1.1	9.0.4.1	TCP	68	80 → 37865	[ACK] Seq=1 Ack=73 Win=29184 Len=0 ...
266	10.683715294	13.0.1.1	9.0.4.1	TCP	85	80 → 37865	[PSH, ACK] Seq=1 Ack=73 Win=29184 L...
267	10.683717532	9.0.4.1	13.0.1.1	TCP	68	37865 → 80	[ACK] Seq=73 Ack=18 Win=29696 Len=0...
268	10.683730182	13.0.1.1	9.0.4.1	TCP	105	80 → 37865	[PSH, ACK] Seq=18 Ack=73 Win=29184 ...
269	10.683731973	9.0.4.1	13.0.1.1	TCP	68	37865 → 80	[ACK] Seq=73 Ack=55 Win=29696 Len=0...
270	10.683745771	13.0.1.1	9.0.4.1	TCP	105	80 → 37865	[PSH, ACK] Seq=55 Ack=73 Win=29184 ...
271	10.683746724	9.0.4.1	13.0.1.1	TCP	68	37865 → 80	[ACK] Seq=73 Ack=92 Win=29696 Len=0...
272	10.683753795	13.0.1.1	9.0.4.1	TCP	93	80 → 37865	[PSH, ACK] Seq=92 Ack=73 Win=29184 ...
273	10.683754634	9.0.4.1	13.0.1.1	TCP	68	37865 → 80	[ACK] Seq=73 Ack=117 Win=29696 Len=...

Extra

Nodes:

```
mininet> nodes
available nodes are:
R1 R2 R3 R4 c0 h11 h12 h13 h21 h22 h23 h31 h32 h33 h41 h42 h43
```

Links:

```
mininet> net
h11 h11-eth0:R1-eth1
h12 h12-eth0:R1-eth2
h13 h13-eth0:R1-eth3
h21 h21-eth0:R2-eth1
h22 h22-eth0:R2-eth2
h23 h23-eth0:R2-eth3
h31 h31-eth0:R3-eth1
h32 h32-eth0:R3-eth2
h33 h33-eth0:R3-eth3
h41 h41-eth0:R4-eth1
h42 h42-eth0:R4-eth2
h43 h43-eth0:R4-eth3
R1 R1-eth1:h11-eth0 R1-eth2:h12-eth0 R1-eth3:h13-eth0 R1-eth4:R2-eth4 R1-eth5:R4-eth4
R2 R2-eth1:h21-eth0 R2-eth2:h22-eth0 R2-eth3:h23-eth0 R2-eth4:R1-eth4 R2-eth5:R3-eth4
R3 R3-eth1:h31-eth0 R3-eth2:h32-eth0 R3-eth3:h33-eth0 R3-eth4:R2-eth5
R4 R4-eth1:h41-eth0 R4-eth2:h42-eth0 R4-eth3:h43-eth0 R4-eth4:R1-eth5
c0
```

All info:

```
mininet> dump
<Host h11: h11-eth0:10.0.0.1 pid=5560>
<Host h12: h12-eth0:10.0.0.2 pid=5561>
<Host h13: h13-eth0:10.0.0.3 pid=5562>
<Host h21: h21-eth0:10.0.0.4 pid=5564>
<Host h22: h22-eth0:10.0.0.5 pid=5565>
<Host h23: h23-eth0:10.0.0.6 pid=5566>
<Host h31: h31-eth0:10.0.0.7 pid=5567>
<Host h32: h32-eth0:10.0.0.8 pid=5568>
<Host h33: h33-eth0:10.0.0.9 pid=5569>
<Host h41: h41-eth0:10.0.0.10 pid=5570>
<Host h42: h42-eth0:10.0.0.11 pid=5571>
<Host h43: h43-eth0:10.0.0.12 pid=5572>
<Router R1: R1-eth1:None,R1-eth2:None,R1-eth3:None,R1-eth4:None,R1-eth5:None pid=5573>
<Router R2: R2-eth1:None,R2-eth2:None,R2-eth3:None,R2-eth4:None,R2-eth5:None pid=5574>
<Router R3: R3-eth1:None,R3-eth2:None,R3-eth3:None,R3-eth4:None pid=5575>
<Router R4: R4-eth1:None,R4-eth2:None,R4-eth3:None,R4-eth4:None pid=5576>
<OVSController c0: 127.0.0.1:6633 pid=5552>
```

