

Building BT Network

by

Zhihao DAI

Yunsong ZHANG

Huijing LEI

Changrong CHEN

Yan HUANG

**19COP502 Building Secure Networks
Lab Report**

Loughborough University

© BT NETWORK 2019

Nov. 2019

Abstract

TODO

Contents

Abstract	i
List of Figures	iv
List of Tables	v
1 Introduction	1
1.1 Network Services	1
1.2 Business Relationships with Neighbouring ISPs	2
1.2.1 Provider: Central Network	2
1.2.2 Peer: Virgin Network	3
1.2.3 Customer: DT Network	3
1.3 Roles of Network Components	3
1.3.1 Routers	3
1.3.2 Laptops	3
1.4 Organisation of the Report	4
2 Network Architecture	5
2.1 Network Diagram	5
2.1.1 Description	5
2.1.2 IP Addresses and Interfaces	7
2.2 IP Addresses of Interfaces	10
2.2.1 Implementation	10
2.2.2 Evaluation	12
3 Routing Protocols in the Network	15
3.1 Intra-domain Routing Protocol: IS-IS	15
3.1.1 Design	15
3.1.2 Loopback Addresses and NSAP for Routers	15

CONTENTS

3.1.3	Implementation	16
3.1.4	Evaluation	18
3.1.5	Commentary	24
3.2	Inter-domain Routing Protocol: BGP	26
3.2.1	Design	26
3.2.2	Routing Policies	27
3.2.3	Implementation	27
3.2.4	Evaluation	29
3.2.5	Commentary	34
4	Applications in the Network	35
4.1	Secure Remote Access to Routers through SSH	35
4.1.1	Design	35
4.1.2	Implementation	35
4.1.3	Evaluation	36
4.1.4	Commentary	37
4.2	World Wide Web Service	38
4.2.1	Design	38
4.2.2	Implementation	38
4.2.3	Evaluation	38
4.2.4	Commentary	38
4.3	Domain Name System Service	39
4.3.1	Design	39
4.3.2	Implementation	39
4.3.3	Evaluation	39
4.3.4	Commentary	39
4.4	Email Service	40
4.4.1	Design	40
4.4.2	Implementation	40
4.4.3	Evaluation	40
4.4.4	Commentary	40
5	Discussion	41
5.1	Conclusions	41
5.2	Further Work	41

CONTENTS

6 Contributions	42
6.1 Group Leader: Zhihao DAI	42
6.2 Technical Director: Yunsong ZHANG	42
6.3 Network Engineer: Huijing LEI	42
6.4 Network Engineer: Changrong CHEN	42
6.5 Network Engineer: Yan HUANG	42
References	43
A Routers Configuration	44
A.1 Router 1 Configuration	44
A.2 Router 2 Configuration	44
A.3 Router 3 Configuration	44
B Laptops Configuration	45
B.1 Laptop 1 Configuration	45
B.2 Laptop 2 Configuration	45
B.3 Laptop 3 Configuration	45

LIST OF FIGURES

List of Figures

1.1	Business Relationships of BT Network with Neighbouring ISPs.	2
2.1	Full Network Diagram of BT Network.	6
2.2	Physical Connections within BT Network.	7
2.3	Sucessful Assignment of IPv4 Addresses to Routers' Interfaces.	13
2.4	Sucessful Assignment of IPv6 Addresses to Routers' Interfaces.	13
2.5	Sucessful Assignment of IPv4 and IPv6 Addresses to Laptops' Interfaces. . .	14
3.1	Design of IS-IS Protocol in BT Network.	16
3.2	Tracing IPv4 Routes between Laptops using <code>traceroute</code>	19
3.3	Tracing IPv6 Routes between Laptops using <code>traceroute</code>	20
3.4	Tracing IPv4 Routes from Laptop 2 (BT002) to Laptop 3 (BT003) when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.	21
3.5	Tracing IPv6 Routes from Laptop 2 (BT002) to Laptop 3 (BT003) when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.	21
3.6	IPv4 Routes to Other Subnets on All 3 Routers Respectively using <code>show ip route</code>	22
3.7	IPv6 Routes to Other Subnets on All 3 Routers Respectively using <code>show ipv6 route</code>	23
3.8	IP Routes to Other Subnets on Router 1 when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.	25
3.9	Design of BGP Protocol in BT Network.	26
4.1	Sucessful remote SSH access to all 3 routers from Laptop 1 (BT001).	36

LIST OF TABLES

List of Tables

2.1 Allocation of IPv4 and IPv6 Addresses to Subnets in BT Network.	9
2.2 Interfaces for Each Physical Connection and Corresponding IPv4 and IPv6 Addresses.	9
3.1 IP Loopback Addresses and NSAP for Routers in BT Network.	16

Chapter 1

Introduction

In this lab, our team set out to build BT Network, a small version of Tier-2 Internet Service Provider (ISP) located at Haslegrave Building, from scratch. Despite its limitations in terms of size and Internet access, we can proudly attest that BT Network is one of the leading providers at Haslegrave Building.

BT network is a Autonomous System (AS) as a whole and the AS Number is 2030. Its domain name is `bt.lbboro`.

1.1 Network Services

Our network provides the following services to each of our individual customers.

- IP addressing with a guaranteed range of 14 host addresses allocated from `23.0.0.0/8` (IPv4) and `2001:2300::/32` (IPv6) blocks.
- Intra-domain Internet connection with Intermediate System to Intermediate System (IS-IS) routing protocol.
- Inter-domain Internet connection with Border Gateway Protocol (BGP).
- A reliable Domain name System (DNS) service with duplicated servers under domain `bt.lbboro`.
- A World Wide Web (WWW) service located at `http://bt.lbboro/`.
- Email service at `bt.lbboro`.

For neighbouring ISPs who is a customer in our business relationships (see Section 1.2.3), we provide the following services.

- Internet connection to our domain as well as all the others'.

In addition, we provide secure remote access to our routers through Secure Shell (SSH) protocol on one of our laptops for administrative purposes.

1.2 Business Relationships with Neighbouring ISPs

BT Network has three immediate neighbouring ISPs and it's important to form business relationships with all three of them in order to gain economic benefits. The external routing policies of BGP protocol for each outside network are determined by the business relationship with which our network is connected to (see Section 3.2 for details). Our business relationships with neighbouring ISPs are shown in Figure 1.1 and elaborated in the following.

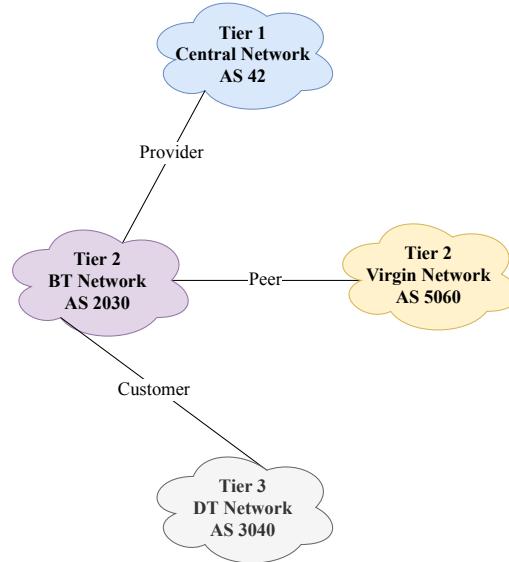


Figure 1.1: Business Relationships of BT Network with Neighbouring ISPs.

1.2.1 Provider: Central Network

Since BT Network is a Tier-2 ISP, it needs to be connected to a Tier-1 ISP to gain wider Internet connection. Therefore, BT is connected to Central Network as a customer, a Tier-1 ISP, which makes Central Network a network provider for BT.

1.2.2 Peer: Virgin Network

BT Network forms a Peer relationship with Virgin Network, which allows Virgin Network to connect to BT Network at zero cost and vice versa.

1.2.3 Customer: DT Network

BT Network forms a Provider-Customer relationship with DT Network, in which BT is the provider and DT is the customer. In other words, DT gains access to the border Internet through BT at a cost.

1.3 Roles of Network Components

There are 6 physical components in our network in total, of which 3 are Cisco routers and the other 3 are TOSHIBA laptops. Each component plays an important role in the network.

1.3.1 Routers

In terms of connection, each router is attached with one customer subnet and thus providing Internet service to one customer. Router 1 (BT-R001) is not physically connected to any outside network, while Router 2 (BT-R002) is connected to DT Network and Router 3 (BT-R003) is connected to Virgin Network and Central Network through cables.

In terms of routing, all routers are Level-1 routers in intra-domain IS-IS routing protocol. In BGP routing protocol, Router 1 (BT-R001) acts as an Internal BGP (IBGP) router while Router 2 (BT-R002) and Router 3 (BT-R003) act as External BGP (EBGP) routers.

1.3.2 Laptops

All laptops are running a Ubuntu 16.04 system. Each of them is connected to a customer subnet through a cable. In terms of services, Laptop 1 (BT001) provides DNS service for `bt.1boro` as a secondary DNS server and WWW service at `http://bt.1boro`. It also acts as a secure SSH access point to routers for administrative purposes. Laptop 2 (BT002) doesn't provide any service and thus acts as a normal user in the network. Laptop 3 (BT003) provides a DNS service for `bt.1boro` as a primary DNS server. In addition, it provides an Email service at `bt.1boro`.

1.4 Organisation of the Report

The report is organised as follows. We describe the architecture of BT Network on the network layer in Chapter 2. A Network Diagram involving all physical components and connections is drawn in the chapter. Then, IP addresses for interfaces in the network are carefully allocated and configured.

In order to allow packets to be forwarded within and outside the network, proper intra-domain and inter-domain routing protocols are set up and tested in Chapter 3.

In Chapter 4, we move up to the application layer and set up various services in the network as listed in Section 1.1.

Main conclusions drawn from the building process and possible further work are discussed in Chapter 5. At last, a summary of contributions for each group member is presented in Chapter 6.

Although the report does not necessarily reflect the actual order of steps in our building process (eg. remote SSH access was set up before BGP), readers can be assured that all results presented can be reproduced by following the natural order of the report.

To ensure readability, rationale behind important decisions made, problems we encountered and their respective solutions, alternative ways of configurations (if any) as well as reflective commentary for each step of implementation are documented in the report.

Chapter 2

Network Architecture

2.1 Network Diagram

2.1.1 Description

A full diagram of BT network is shown in Figure 2.1. There are 3 routers in the network, whose names are BT-R001, BT-R002 and BT-R003 respectively, connected to each other. Each connection forms a Router-Router subnet with only 2 interfaces.

On the other hand, each router is connected with a laptop separately named as BT001, BT002 and BT003 and thus forms a Router-Laptop subnet. A customer of BT Network is assigned with a Router-Laptop subnet and has a minimum of 10 host IP addresses.

To connect to neighbouring ISPs, a Router-Neighbour subnet is formed for each connection. Concretely, Router 2 (BT-R002) is connected to one of DT Network's routers while Router 3 (BT-R003) is connected to one of Virgin Network's and Central Network's routers separately.

All of the above connections are through physical cables.

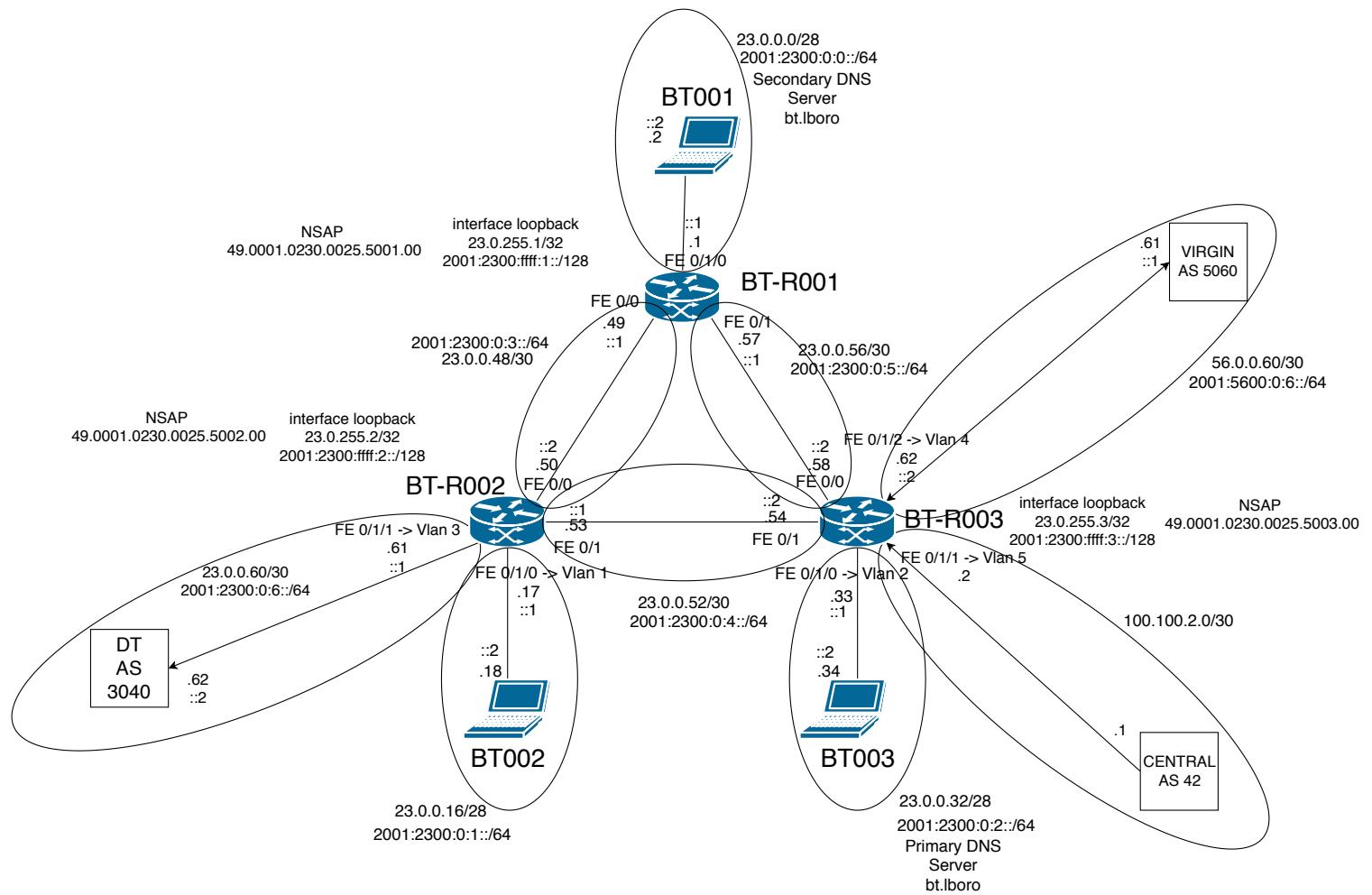


Figure 2.1: Full Network Diagram of BT Network.

2.1.2 IP Addresses and Interfaces

An IPv4 address range of $23.0.0.0/8$ and IPv6 address range of $2001:2300::/32$ are allocated to BT Network, which are further divided into sub-ranges to be allocated to each subnet.

For IPv4 addressing, a prefix of n is needed for a subnet that demands X host addresses, where n is an integer that satisfies $2^{32-n} - 2 \geq X$ and $n \leq 32$. For our lab, the maximum value for prefix is used in order to minimize the size of each subnet and reserve address space for future customers. However, it's also possible to use a larger value for each Router-Laptop subnet in order to maximize the size of the subnet, given that the number of customers (in this case, 3) is fixed.

In BT Network, the prefix for each Router-Router and Router-Neighbour subnet is 30 while the prefix for each Router-Laptop subnet is 28. In other words, each Router-Router and Router-Neighbour subnet has 2 guaranteed IPv4 host addresses while each Router-Laptop subnet has 14 guaranteed IPv4 host addresses. During address block allocation, larger subnet is being considered before smaller one reduce the number of block segments.

For IPv6 addressing, however, each subnet has a fixed prefix of 64 to ensure that each interface in the subnet has a unique address. The full details of IP address allocation is shown in Table 2.1.

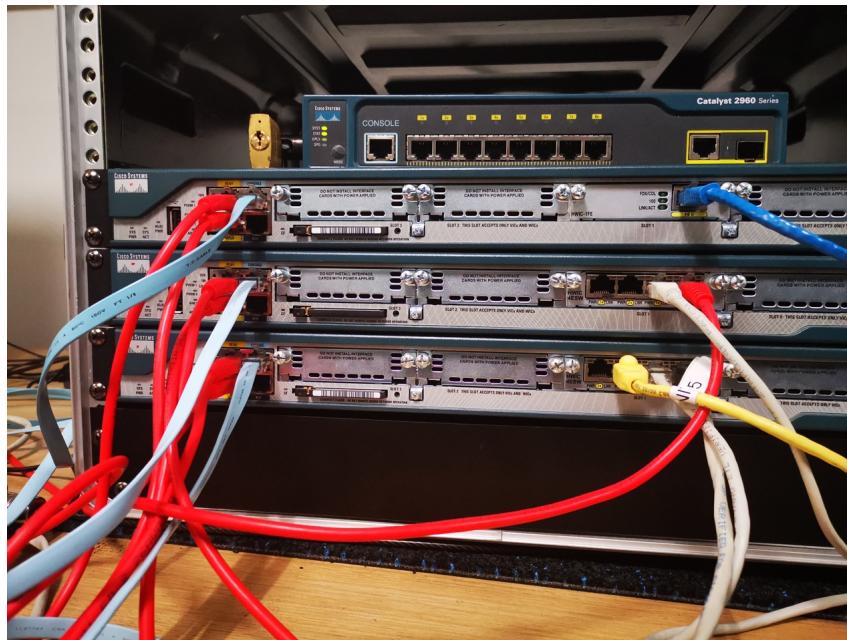


Figure 2.2: Physical Connections within BT Network.

CHAPTER 2. NETWORK ARCHITECTURE

In terms of interfaces, there are 3 Ethernet interfaces (**FastEthernet0/0**, **FastEthernet0/1** and **FastEthernet0/1/0**) on Router 1, each of which can be assigned with an IP address. On Router 2 and 3, however, there are 6 Ethernet interfaces each and only 2 of them (**FastEthernet0/0** and **FastEthernet0/1**) can be directly assigned with IP addresses. The remaining 4 interfaces are link layer interfaces and thus does not possess any IP address. To be assigned with an IP address, such an interface need to be assigned to an Virtual LAN (VLAN) to which the address is actually assigned.

Router-Router connections are established through either **FastEthernet0/0** or **FastEthernet0/1** interfaces on both ends while Router-Laptop and Router-Neighbour are through one of the remaining interfaces on the router end. Since both interfaces are on the left-hand side of each router and such arrangement helps distinguishing between Router-Router connections and others easily as shown in Figure 2.2. Interfaces of both ends for each connection as well as their corresponding IP addresses are detailed in Table 2.2.

Subnet	IPv4 Address / Prefix	IPv4 Address Range	IPv6 Address / Prefix	IPv6 Address Range
BT-R001 - BT001	23.0.0.0/28	23.0.0.1 - 23.0.0.14	2001:2300:0:0::/64	2001:2300:0:0::1 - 2001:2300:0:0:ffff:ffff:ffff:fffe
BT-R002 - BT002	23.0.0.16/28	23.0.0.17 - 23.0.0.30	2001:2300:0:1::/64	2001:2300:0:1::1 - 2001:2300:0:1:ffff:ffff:ffff:fffe
BT-R003 - BT003	23.0.0.32/28	23.0.0.33 - 23.0.0.62	2001:2300:0:2::/64	2001:2300:0:2::1 - 2001:2300:0:2:ffff:ffff:ffff:fffe
BT-R001 - BT-R002	23.0.0.48/30	23.0.0.49 - 23.0.0.50	2001:2300:0:3::/64	2001:2300:0:3::1 - 2001:2300:0:3:ffff:ffff:ffff:fffe
BT-R002 - BT-R003	23.0.0.52/30	23.0.0.53 - 23.0.0.54	2001:2300:0:4::/64	2001:2300:0:4::1 - 2001:2300:0:4:ffff:ffff:ffff:fffe
BT-R001 - BT-R003	23.0.0.56/30	23.0.0.57 - 23.0.0.58	2001:2300:0:5::/64	2001:2300:0:5::1 - 2001:2300:0:5:ffff:ffff:ffff:fffe
BT-R002 - DT	23.0.0.60/30	23.0.0.61 - 23.0.0.62	2001:2300:0:6::/64	2001:2300:0:6::1 - 2001:2300:0:6:ffff:ffff:ffff:fffe
BT-R003 - Virgin	56.0.0.60/30	56.0.0.61 - 56.0.0.62	2001:5600:0:6::/64	2001:5600:0:6::1 - 2001:5600:0:6:ffff:ffff:ffff:fffe
BT-R003 - Central	100.100.2.0/30	100.100.2.1 - 100.100.2.2		

Table 2.1: Allocation of IPv4 and IPv6 Addresses to Subnets in BT Network.

Connection	Interface 1	IPv4 Address	IPv6 Address	Interface 2	IPv4 Address	IPv6 Address
BT-R001 - BT001	BT-R001: FastEthernet0/1/0	23.0.0.1	2001:2300:0:0::1	BT001: eth0	23.0.0.2	2001:2300:0:0::2
BT-R002 - BT002	BT-R002: FastEthernet0/1/0 -> Vlan 1	23.0.0.17	2001:2300:0:1::1	BT002: eth0	23.0.0.18	2001:2300:0:1::2
BT-R003 - BT003	BT-R003: FastEthernet0/1/0 -> Vlan 2	23.0.0.33	2001:2300:0:2::1	BT003: eth0	23.0.0.34	2001:2300:0:2::2
BT-R001 - BT-R002	BT-R001: FastEthernet0/0	23.0.0.49	2001:2300:0:3::1	BT-R002: FastEthernet0/0	23.0.0.50	2001:2300:0:3::2
BT-R002 - BT-R003	BT-R002: FastEthernet0/1	23.0.0.53	2001:2300:0:4::1	BT-R003: FastEthernet0/1	23.0.0.54	2001:2300:0:4::2
BT-R001 - BT-R003	BT-R001: FastEthernet0/1	23.0.0.57	2001:2300:0:5::1	BT-R003: FastEthernet0/0	23.0.0.58	2001:2300:0:5::2
BT-R002 - DT	BT-R002: FastEthernet0/1/1 -> Vlan 3	23.0.0.61	2001:2300:0:6::1	DT	23.0.0.62	2001:2300:0:6::2
BT-R003 - Virgin	BT-R003: FastEthernet0/1/2 -> Vlan 4	56.0.0.62	2001:5600:0:6::2	Virgin	56.0.0.61	2001:5600:0:6::1
BT-R003 - Central	BT-R003: FastEthernet0/1/1 -> Vlan 5	100.100.2.2		Central	100.100.2.1	

Table 2.2: Interfaces for Each Physical Connection and Corresponding IPv4 and IPv6 Addresses.

2.2 IP Addresses of Interfaces

Assigning IP addresses to interfaces should be the first step in building BT Network since all network services listed in 1.1 cannot operate without IP addresses. The assignment of IP addresses in Table 2.1 and 2.2 is implemented.

2.2.1 Implementation

2.2.1.1 Routers

For Router 1 (BT-R001), IP addresses are assigned directly to physical interfaces as all interfaces are network layer interfaces.

```
1 int fa0/0
2 ip address 23.0.0.49 255.255.255.252
3 ipv6 address 2001:2300:0:3::1/64
4 no shutdown
5
6 int fa0/1
7 ip address 23.0.0.57 255.255.255.252
8 ipv6 address 2001:2300:0:5::1/64
9 no shutdown
10
11 int fa0/1/0
12 ip address 23.0.0.1 255.255.255.240
13 ipv6 address 2001:2300:0:0::1/64
14 no shutdown
```

For Router 2 (BT-R002), however, only 2 interfaces (`FastEthernet0/0` and `FastEthernet0/1`) each are network layer interfaces. The remaining 4 interfaces are link layer interfaces and need to be assigned to an VLAN separately so where an IP address can be assigned.

```
1 int fa0/0
2 ip address 23.0.0.50 255.255.255.252
3 ipv6 address 2001:2300:0:3::2/64
4 no shutdown
5
6 int fa0/1
7 ip address 23.0.0.53 255.255.255.252
8 ipv6 address 2001:2300:0:4::1/64
9 no shutdown
10
11 vlan 1
12 int fa0/1/0
13 switchport mode access
14 switchport access vlan 1
```

CHAPTER 2. NETWORK ARCHITECTURE

```
15 int vlan 1
16 ip address 23.0.0.17 255.255.255.240
17 ipv6 address 2001:2300:0:1::1/64
18 no shutdown
19
20 vlan 3
21 int fa0/1/1
22 switchport mode access
23 switchport access vlan 3
24 int vlan 3
25 ip address 23.0.0.61 255.255.255.252
26 ipv6 address 2001:2300:0:6::1/64
27 no shutdown
```

Similarly, IP addresses are assigned to Router 3 (BT-R003).

```
1 int fa0/0
2 ip address 23.0.0.58 255.255.255.252
3 ipv6 address 2001:2300:0:5::2/64
4 no shutdown
5
6 int fa0/1
7 ip address 23.0.0.54 255.255.255.252
8 ipv6 address 2001:2300:4::2/64
9 no shutdown
10
11 vlan 2
12 int fa0/1/0
13 switchport mode access
14 switchport access vlan 2
15 int vlan 2
16 ip address 23.0.0.33 255.255.255.240
17 ipv6 address 2001:2300:0:2::1/64
18 no shutdown
19
20 vlan 4
21 int fa0/1/2
22 switchport mode access
23 switchport access vlan 4
24 int vlan 4
25 ip address 56.0.0.62 255.255.255.252
26 ipv6 address 2001:5600:0:6::2/64
27 no shutdown
28
29 vlan 5
30 int fa0/1/1
31 switchport mode access
32 switchport access vlan 5
```

```
33 int vlan 5
34 ip address 100.100.2.2 255.255.255.252
35 no shutdown
```

2.2.1.2 Laptops

Unlike routers, the IP assignment of laptops' interfaces are more aligned since all laptops are of the same model. On Laptop 1 (BT001), the file `/etc/network/interface` is edited as follows before rebooting to apply changes. Similarly, IP address can be assigned to Laptop 2's (BT002) and Laptop 3's interfaces respectively.

```
1 auto lo
2 iface lo inet loopback
3 auto eth0
4 ifacce eth0 inet static
5 address 23.0.0.2
6 netmask 255.255.255.240
7 gateway 23.0.0.1
8
9 ifacce eth0 inet6 static
10 address 2001:2300::2
11 netmask 64
12 gateway 2001:2300::1
```

2.2.2 Evaluation

On all 3 routers, the implementation of IP assignments is evaluated using `show ip int brief` and `show ipv6 int brief`. These 2 commands show IPv4 and IPv6 addresses of interfaces on routers respectively. Successful assignment of IP addresses to routers' interfaces is evident from Figure 2.3 and 2.4.

On the laptops' side, the implementation of IP assignments is evaluated using `ifconfig` command. Successful assignment of IP addresses to laptops' interfaces is evident from Figure 2.5.

CHAPTER 2. NETWORK ARCHITECTURE

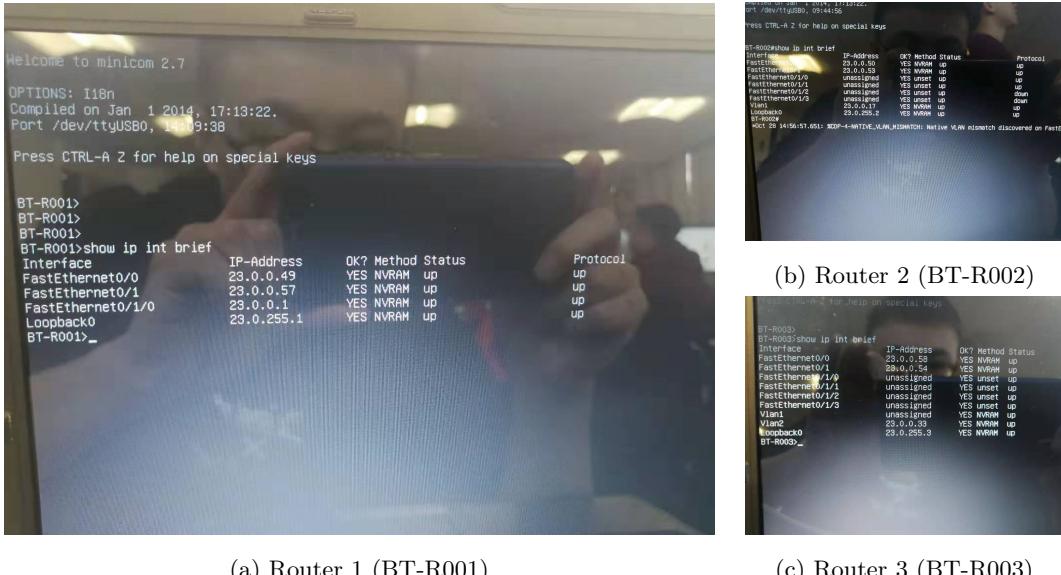
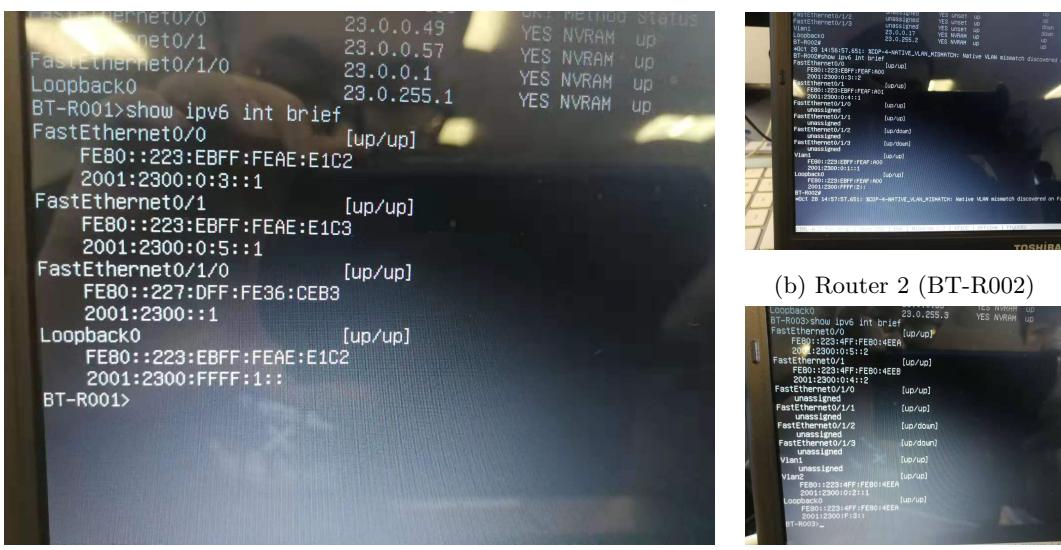


Figure 2.3: Successful Assignment of IPv4 Addresses to Routers' Interfaces.



CHAPTER 2. NETWORK ARCHITECTURE



(a) Laptop 1 (BT001)

```

root@BT001:/home/bt001# ifconfig
eth0      Link encap:Ethernet HWaddr 00:1e:68:d0:d5:18
          inet addr:23.0.0.2 Bcast:23.0.0.15 Mask:255.255.255.240
          inet6 addr: 2001:2300:10::1:2/64 Scope:Global
                  fe80::21e:68ff:fed0:d51a/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
          RX packets:407 errors:0 dropped:0 overruns:0 frame:0
          TX packets:646 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:41002 (41.0 KB) TX bytes:51773 (51.7 KB)
          Interrupt:16

lo       Link encap:Local Loopback
          inet addr:127.0.0.1 Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING MTU:65536 Metric:1
          RX packets:139 errors:0 dropped:0 overruns:0 frame:0
          TX packets:139 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:9727 (9.7 KB) TX bytes:9727 (9.7 KB)

root@BT001:/home/bt001#

```

(b) Laptop 2 (BT002)

```

root@BT002:/home/bt002# ifconfig
eth0      Link encap:Ethernet HWaddr 00:1e:68:d0:d5:24
          inet addr:23.0.0.3 Bcast:23.0.0.15 Mask:255.255.255.240
          inet6 addr: 2001:2300:10::1:3/64 Scope:Global
                  fe80::21e:68ff:fed0:d524/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
          RX packets:103 errors:0 dropped:0 overruns:0 frame:0
          TX packets:103 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:1036 (3.0 KB) TX bytes:7240 (7.2 KB)
          Interrupt:16

lo       Link encap:Local Loopback
          inet addr:127.0.0.1 Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING MTU:65536 Metric:1
          RX packets:222 errors:0 dropped:0 overruns:0 frame:0
          TX packets:222 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:22970 (22.5 KB) TX bytes:19970 (19.5 KB)
root@BT002:/home/bt002#

```

(c) Laptop 3 (BT003)

```

root@BT003:/home/bt003# ifconfig
eth0      Link encap:Ethernet HWaddr 00:1e:68:d0:d5:24
          inet addr:23.0.0.4 Bcast:23.0.0.15 Mask:255.255.255.240
          inet6 addr: 2001:2300:10::1:4/64 Scope:Global
                  fe80::21e:68ff:fed0:d524/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
          RX packets:107 errors:0 dropped:17 overruns:0 frame:0
          TX packets:107 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:10789 (10.7 KB) TX bytes:11699 (11.6 KB)
          Interrupt:16

lo       Link encap:Local Loopback
          inet addr:127.0.0.1 Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING MTU:65536 Metric:1
          RX packets:227 errors:0 dropped:0 overruns:0 frame:0
          TX packets:227 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:20202 (20.2 KB) TX bytes:20202 (20.2 KB)
root@BT003:/home/bt003#

```

Figure 2.5: Successful Assignment of IPv4 and IPv6 Addresses to Laptops' Interfaces.

Chapter 3

Routing Protocols in the Network

3.1 Intra-domain Routing Protocol: IS-IS

3.1.1 Design

IS-IS is short for Intermediate System to Intermediate System Routing Protocol. In this lab, the IS-IS is used as the Interior Gateway Protocol (IGP). By using this protocol, each router maintains a database which has a map of the whole topology and all routers have the same information. The best path to every destination is computed by all routers. Figure 3.1 shows the design of IS-IS protocol in BT Network. As the figure shows, the network only has level-1 routers for internal routing.

3.1.2 Loopback Addresses and NSAP for Routers

To set up IS-IS, an unique loopback address is needed for each router. An IPv4 address block of 23.0.255.0/24 and IPv6 address block of 2001:2300:ffff::/48 is allocated for loopback addresses.

Following the CLNS addressing convention, each router is then assigned with a NSAP. A NSAP has 3 main components.

According to the convention, the leading Area ID is composed of AFI (49) and Area Address (0001). The System ID followed is set to the IPv4 loopback address of the router. If the loopback address is *ABC.DEF.GHI.JKL*, then System ID should be *ABCD.EFGH.IJKL*. The last main component is N-Selector (NSEL) and set to 00.

The assignment of addresses and NSAP to routers are detailed in Table 3.1.

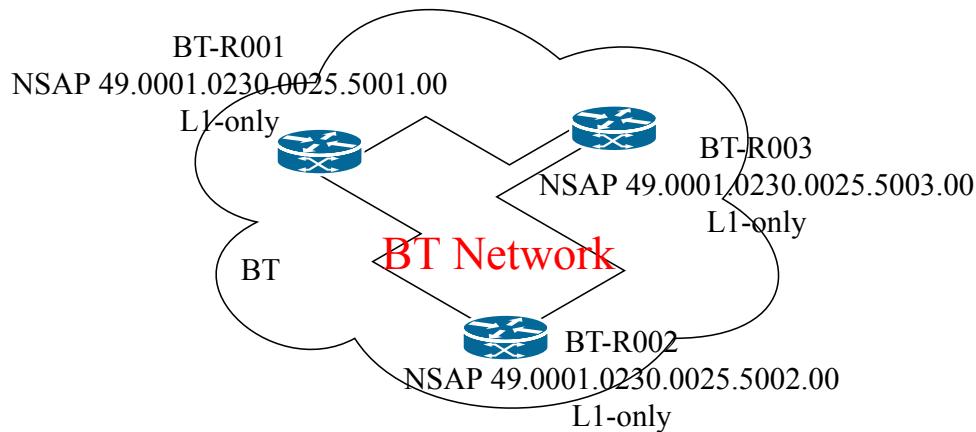


Figure 3.1: Design of IS-IS Protocol in BT Network.

Router	IPv4 Loopback Address	IPv6 Loopback Address	NSAP
BT-R001	23.0.255.1	2001:2300:ffff:1::	49.0001.0230.0025.5001.00
BT-R002	23.0.255.2	2001:2300:ffff:2::	49.0001.0230.0025.5002.00
BT-R003	23.0.255.3	2001:2300:ffff:3::	49.0001.0230.0025.5003.00

Table 3.1: IP Loopback Addresses and NSAP for Routers in BT Network.

3.1.3 Implementation

IS-IS is set up on Router 1 (BT-R001) using the following commands.

```
1 interface Loopback0
2 ip address 23.0.255.1 255.255.255.255
3 ipv6 address 2001:2300:FFFF:1::/128
4
5 router isis
6 net 49.0001.0230.0025.5001.00
7 is-type level-1
```

Then, IS-IS is turned on on all interfaces to internal routers.

```
1 interface FastEthernet0/0
2 ip router isis
3 ipv6 router isis
4
5 interface FastEthernet0/1
6 ip router isis
7 ipv6 router isis
8
9 interface FastEthernet0/1/0
10 ip router isis
11 ipv6 router isis
```

CHAPTER 3. ROUTING PROTOCOLS IN THE NETWORK

However, IS-IS routes should not be broadcasted nor received through the loopback interface (`Loopback0`) while the route to corresponding subnet should be broadcasted to other internal routers. Therefore, the loopback interface should be a passive interface in IS-IS protocol.

```
1 router isis
2 passive-interface Loopback0
```

For Router 2 (BT-R002) and Router 3 (BT-R002), IS-IS is set up similarly using the above commands. The main difference is that interfaces to external routers (VLAN 3 for Router 2 and VLAN 4 & 5 for Router 3) should be passive interfaces as well. Below is the configuration for Router 2.

```
1 interface Loopback0
2 ip address 23.0.255.2 255.255.255.255
3 ipv6 address 2001:2300:FFFF:2::/128
4
5 router isis
6 net 49.0001.0230.0025.5002.00
7 is-type level-1
8 passive-interface Vlan3
9 passive-interface Loopback0
10
11 interface FastEthernet0/0
12 ip router isis
13 ipv6 router isis
14
15 interface FastEthernet0/1
16 ip router isis
17 ipv6 router isis
18
19 interface Vlan1
20 ip router isis
21 ipv6 router isis
```

Below is the configuration for Router 3.

```
1 interface Loopback0
2 ip address 23.0.255.3 255.255.255.255
3 ipv6 address 2001:2300:FFFF:3::/128
4
5 router isis
6 net 49.0001.0230.0025.5003.00
7 is-type level-1
8 passive-interface Vlan4
9 passive-interface Vlan5
10 passive-interface Loopback0
```

```
11
12 interface FastEthernet0/0
13 ip router isis
14 ipv6 router isis
15
16 interface FastEthernet0/1
17 ip router isis
18 ipv6 router isis
19
20 interface Vlan2
21 ip router isis
22 ipv6 router isis
```

3.1.4 Evaluation

Once the IS-IS is set up, use **traceroute** command to check the IPv4 path from Laptop 1 (BT001, IPv4 Address: 23.0.0.2) to Laptop 2 (BT002, IPv4 Address: 23.0.0.18) in the network.

```
1 traceroute 23.0.0.34
```

Figure 3.2 shows the route taken is Laptop 1 (BT001, IPv4 Address: 23.0.0.2) -> Router 1 (BT-R001, IPv4 Address: 23.0.0.1) -> Router 2 (BT-R002, IPv4 Address: 23.0.0.50) -> Laptop 2 (BT002, IPv4 Address: 23.0.0.18), which is a correct route. Routes from Laptop 1 to Laptop 3 as well as from Laptop 2 to Laptop 3 are tested and shown in the figure as well.

Similiar results can be observed for IPv6 routes in Figure 3.3. The IPv6 Route taken from Laptop 1 to Laptop 2 is Laptop 1 (BT001, IPv6 Address: 2001:2300::2) -> Router 1 (BT-R001, IPv6 Address: 2001:2300::1) -> Router 2 (BT-R002, IPv6 Address: 2001:2300:3:2::2) -> Laptop 2 (BT002, IPv6 Address: 2001:2300:0:1::2), , which is also a correct route. Routes from Laptop 1 to Laptop 3 as well as from Laptop 2 to Laptop 3 are tested and shown in the figure as well.

```
root@BT001:/home/bt001# traceroute 23.0.0.18
traceroute to 23.0.0.18 (23.0.0.18), 30 hops max, 60 byte packets
 1  23.0.0.33 (23.0.0.33)  1.070 ms  1.643 ms  2.137 ms
 2  23.0.0.53 (23.0.0.53)  1.572 ms  1.980 ms  2.069 ms
 3  23.0.0.18 (23.0.0.18)  1.044 ms  1.023 ms  0.991 ms
root@BT001:/home/bt001# -
```

(a) traceroute from Laptop 1 (BT001) to Laptop 2 (BT002)

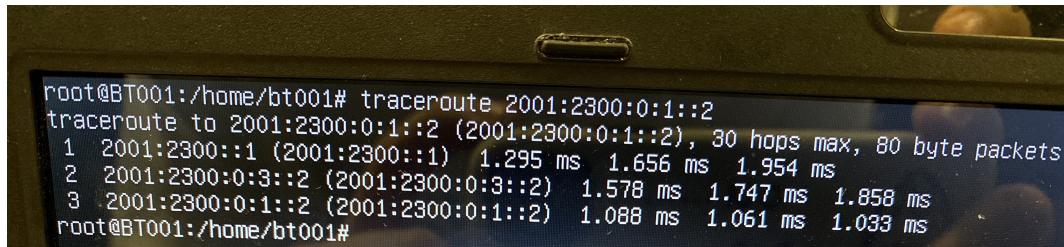
```
root@BT001:/home/bt001# traceroute 23.0.0.34
traceroute to 23.0.0.34 (23.0.0.34), 30 hops max, 60 byte packets
 1  23.0.0.1 (23.0.0.1)  1.073 ms  1.602 ms  1.840 ms
 2  23.0.0.58 (23.0.0.58)  1.208 ms  1.943 ms  2.264 ms
 3  23.0.0.34 (23.0.0.34)  1.850 ms  1.830 ms  1.809 ms
root@BT001:/home/bt001# -
```

(b) traceroute from Laptop 1 (BT001) to Laptop 3 (BT003)

```
root@BT002:/home/bt002# traceroute 23.0.0.34
traceroute to 23.0.0.34 (23.0.0.34), 30 hops max, 60 byte packets
 1  23.0.0.17 (23.0.0.17)  1.006 ms  1.542 ms  1.959 ms
 2  23.0.0.54 (23.0.0.54)  0.981 ms  2.216 ms  2.451 ms
 3  23.0.0.34 (23.0.0.34)  1.856 ms  1.843 ms  1.924 ms
root@BT002:/home/bt002# -
```

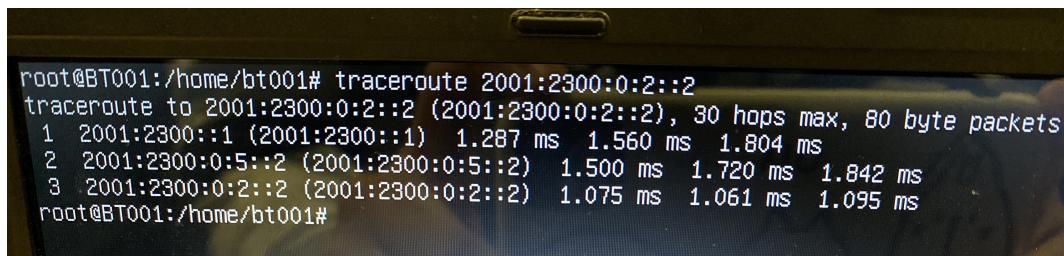
(c) traceroute from Laptop 2 (BT002) to Laptop 3 (BT003)

Figure 3.2: Tracing IPv4 Routes between Laptops using traceroute.



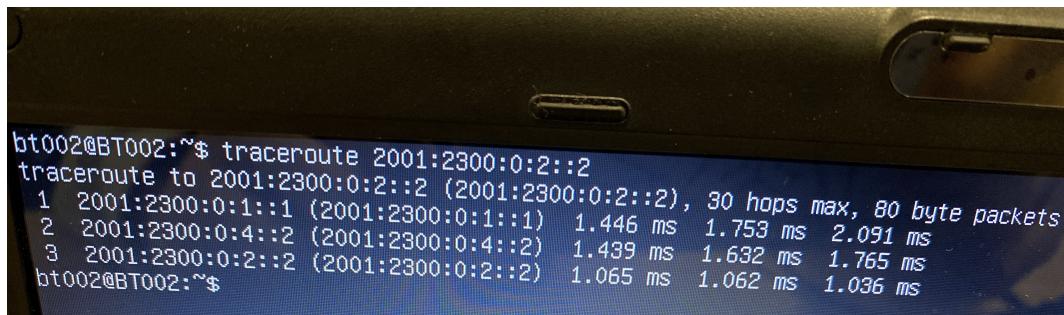
```
root@BT001:/home/bt001# traceroute 2001:2300:0:1::2
traceroute to 2001:2300:0:1::2 (2001:2300:0:1::2), 30 hops max, 80 byte packets
 1  2001:2300::1 (2001:2300::1)  1.295 ms  1.656 ms  1.954 ms
 2  2001:2300:0:3::2 (2001:2300:0:3::2)  1.578 ms  1.747 ms  1.858 ms
 3  2001:2300:0:1::2 (2001:2300:0:1::2)  1.088 ms  1.061 ms  1.033 ms
root@BT001:/home/bt001#
```

(a) traceroute from Laptop 1 (BT001) to Laptop 2 (BT002)



```
root@BT001:/home/bt001# traceroute 2001:2300:0:2::2
traceroute to 2001:2300:0:2::2 (2001:2300:0:2::2), 30 hops max, 80 byte packets
 1  2001:2300::1 (2001:2300::1)  1.287 ms  1.560 ms  1.804 ms
 2  2001:2300:0:5::2 (2001:2300:0:5::2)  1.500 ms  1.720 ms  1.842 ms
 3  2001:2300:0:2::2 (2001:2300:0:2::2)  1.075 ms  1.061 ms  1.095 ms
root@BT001:/home/bt001#
```

(b) traceroute from Laptop 1 (BT001) to Laptop 3 (BT003)



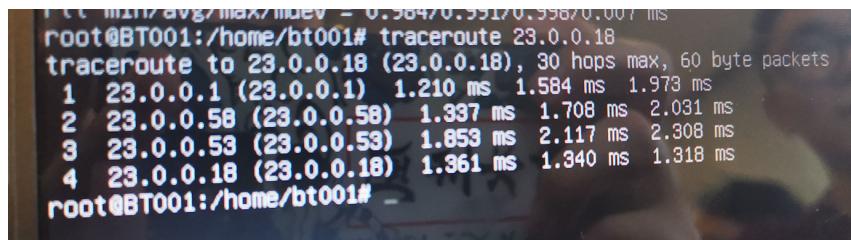
```
bt002@BT002:~$ traceroute 2001:2300:0:2::2
traceroute to 2001:2300:0:2::2 (2001:2300:0:2::2), 30 hops max, 80 byte packets
 1  2001:2300:0:1::1 (2001:2300:0:1::1)  1.446 ms  1.753 ms  2.091 ms
 2  2001:2300:0:4::2 (2001:2300:0:4::2)  1.439 ms  1.632 ms  1.765 ms
 3  2001:2300:0:2::2 (2001:2300:0:2::2)  1.065 ms  1.062 ms  1.036 ms
bt002@BT002:~$
```

(c) traceroute from Laptop 2 (BT002) to Laptop 3 (BT003)

Figure 3.3: Tracing IPv6 Routes between Laptops using traceroute.

To further evaluate the correctness of our implementation, we check the path from Laptop 1 to Laptop 2 under the condition that the physical connection between Router 1 and Router 2 is broken. The IS-IS protocol on Router 1 should be able to find route to Router 2 through Router 3.

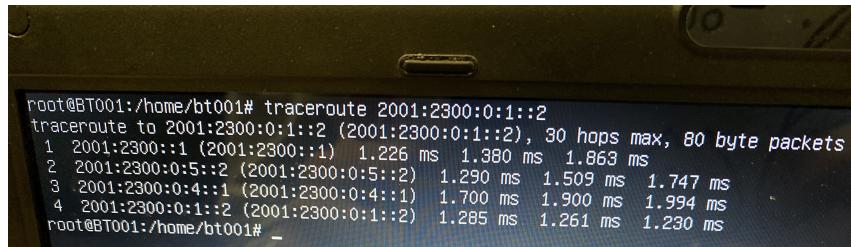
Figure 3.4 shows the IPv4 route taken is Laptop 1 (BT001, IPv6 Address: 23.0.0.2) -> Router 1 (BT-R001, IPv4 Address: 23.0.0.1) -> Router 3 (BT-R003, IPv4 Address: 23.0.0.58) -> Router 2 (BT-R002, IPv4 Address: 23.0.0.53) -> Laptop 2 (BT002, IPv4 Address: 23.0.0.18), which is a correct route.



```
root@BT001:/home/bt001# traceroute 23.0.0.18
traceroute to 23.0.0.18 (23.0.0.18), 30 hops max, 60 byte packets
 1  23.0.0.1 (23.0.0.1)  1.210 ms  1.584 ms  1.973 ms
 2  23.0.0.58 (23.0.0.58)  1.337 ms  1.708 ms  2.031 ms
 3  23.0.0.53 (23.0.0.53)  1.853 ms  2.117 ms  2.308 ms
 4  23.0.0.18 (23.0.0.18)  1.361 ms  1.340 ms  1.318 ms
root@BT001:/home/bt001#
```

Figure 3.4: Tracing IPv4 Routes from Laptop 2 (BT002) to Laptop 3 (BT003) when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.

Figure 3.5 shows the IPv6 route taken is Laptop 1 (BT001, IPv6 Address: 2001:2300::2) -> Router 1 (BT-R001, IPv6 Address: 2001:2300::1) -> Router 3 (BT-R003, IPv6 Address: 2001:2300:0:5::2) -> Router 2 (BT-R002, IPv6 Address: 2001:2300:0:4::1) -> Laptop 2 (BT002, IPv6 Address: 2001:2300:0:1::2), which is also a correct route.

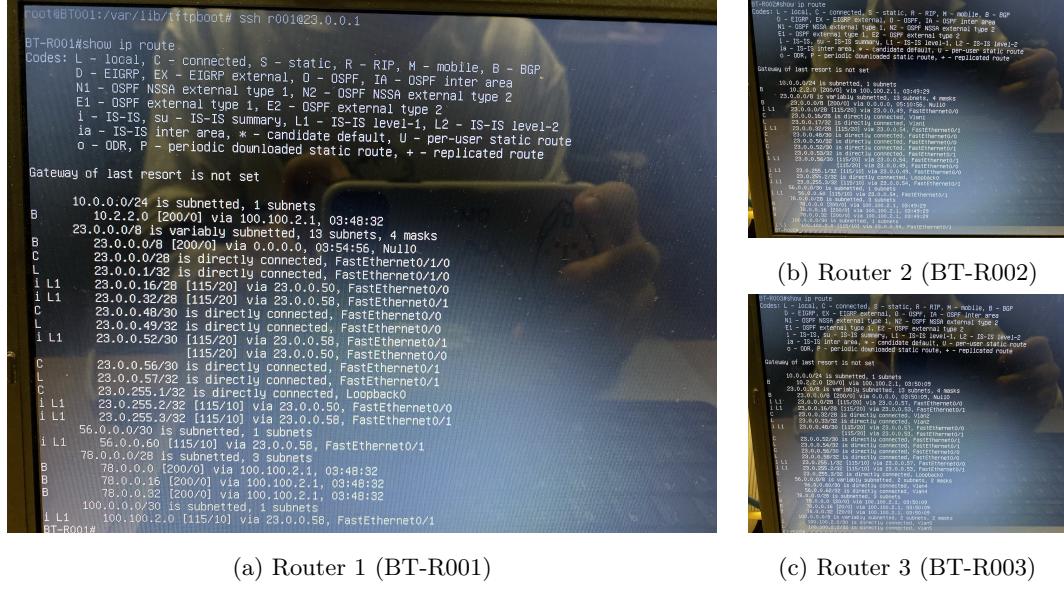


```
root@BT001:/home/bt001# traceroute 2001:2300:0:1::2
traceroute to 2001:2300:0:1::2 (2001:2300:0:1::2), 30 hops max, 80 byte packets
 1  2001:2300::1 (2001:2300::1)  1.226 ms  1.380 ms  1.863 ms
 2  2001:2300:0:5::2 (2001:2300:0:5::2)  1.290 ms  1.509 ms  1.747 ms
 3  2001:2300:0:4::1 (2001:2300:0:4::1)  1.700 ms  1.900 ms  1.994 ms
 4  2001:2300:0:1::2 (2001:2300:0:1::2)  1.285 ms  1.261 ms  1.230 ms
root@BT001:/home/bt001#
```

Figure 3.5: Tracing IPv6 Routes from Laptop 2 (BT002) to Laptop 3 (BT003) when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.

CHAPTER 3. ROUTING PROTOCOLS IN THE NETWORK

On the router's side, `show ip route` and `show ipv6 route` is used to inspect the routes discovered by IS-IS protocol. In Figure 3.6 and 3.7, such routes to other subnets inside BT Network on each router are shown.



(a) Router 1 (BT-R001)

```

root@BT-R001:/var/lib/tftpboot# ssh r001@23.0.0.1
BT-R001#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
      N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
      E1 - OSPF external type 1, E2 - OSPF external type 2
      L1 - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
      ia - IS-IS inter area, * - candidate default, U - per-user static route
      o - ODR, P - periodic downloaded static route, + - replicated route
Gateway of last resort is not set

10.0.0.0/24 is subnetted, 1 subnets
B 10.2.2.0 [200/0] via 100.100.2.1, 03:48:32
23.0.0.0/8 is variably subnetted, 13 subnets, 4 masks
B 23.0.0.0/8 [200/0] via 0.0.0.0, 03:54:56, Null0
C 23.0.0.0/28 is directly connected, FastEthernet0/1/0
L 23.0.0.1/32 is directly connected, FastEthernet0/1/0
I L1 23.0.0.16/28 [115/20] via 23.0.0.50, FastEthernet0/0
I L1 23.0.0.32/28 [115/20] via 23.0.0.58, FastEthernet0/1
C 23.0.0.48/30 is directly connected, FastEthernet0/0
L 23.0.0.49/32 is directly connected, FastEthernet0/0
I L1 23.0.0.52/30 [115/20] via 23.0.0.58, FastEthernet0/1
C 23.0.0.56/30 is directly connected, FastEthernet0/1
L 23.0.0.57/32 is directly connected, FastEthernet0/1
C 23.0.255.1/32 is directly connected, Loopback0
I L1 23.0.255.2/32 [115/10] via 23.0.0.50, FastEthernet0/0
I L1 23.0.255.3/32 [115/10] via 23.0.0.58, FastEthernet0/1
56.0.0.0/30 is subnetted, 1 subnets
I L1 56.0.0.60 [115/10] via 23.0.0.58, FastEthernet0/1
78.0.0.0/28 is subnetted, 3 subnets
B 78.0.0.0 [200/0] via 100.100.2.1, 03:48:32
B 78.0.0.16 [200/0] via 100.100.2.1, 03:48:32
B 78.0.0.32 [200/0] via 100.100.2.1, 03:48:32
    100.0.0.30 is subnetted, 1 subnets
I L1 100.100.2.0 [115/10] via 23.0.0.58, FastEthernet0/1
BT-R001#

```

(b) Router 2 (BT-R002)

```

BT-R002#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
      N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
      E1 - OSPF external type 1, E2 - OSPF external type 2
      L1 - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
      ia - IS-IS inter area, * - candidate default, U - per-user static route
      o - ODR, P - periodic downloaded static route, + - replicated route
Gateway of last resort is not set

10.0.0.0/24 is subnetted, 1 subnets
B 10.2.2.0 [200/0] via 100.100.2.1, 03:49:23
23.0.0.0/8 is variably subnetted, 13 subnets, 4 masks
B 23.0.0.0/8 [200/0] via 0.0.0.0, 03:51:56, Null0
L 23.0.0.1/32 is directly connected, Vlan1
I L1 23.0.0.16/28 [115/20] via 23.0.0.50, FastEthernet0/0
I L1 23.0.0.32/28 [115/20] via 23.0.0.58, FastEthernet0/1
C 23.0.0.48/30 is directly connected, FastEthernet0/0
C 23.0.0.49/32 is directly connected, FastEthernet0/1
I L1 23.0.0.52/30 [115/20] via 23.0.0.58, FastEthernet0/1
I L1 23.0.0.56/30 [115/20] via 23.0.0.58, FastEthernet0/1
I L1 23.0.0.57/32 is directly connected, FastEthernet0/1
C 23.0.255.1/32 is directly connected, Loopback0
I L1 23.0.255.2/32 [115/10] via 23.0.0.50, FastEthernet0/0
I L1 23.0.255.3/32 [115/10] via 23.0.0.58, FastEthernet0/1
56.0.0.0/30 is subnetted, 1 subnets
I L1 56.0.0.60 [115/10] via 23.0.0.58, FastEthernet0/1
78.0.0.0/28 is subnetted, 3 subnets
B 78.0.0.0 [200/0] via 100.100.2.1, 03:48:32
B 78.0.0.16 [200/0] via 100.100.2.1, 03:48:32
B 78.0.0.32 [200/0] via 100.100.2.1, 03:48:32
    100.0.0.30 is subnetted, 1 subnets
I L1 100.100.2.0 [115/10] via 23.0.0.58, FastEthernet0/1
BT-R002#

```

(c) Router 3 (BT-R003)

```

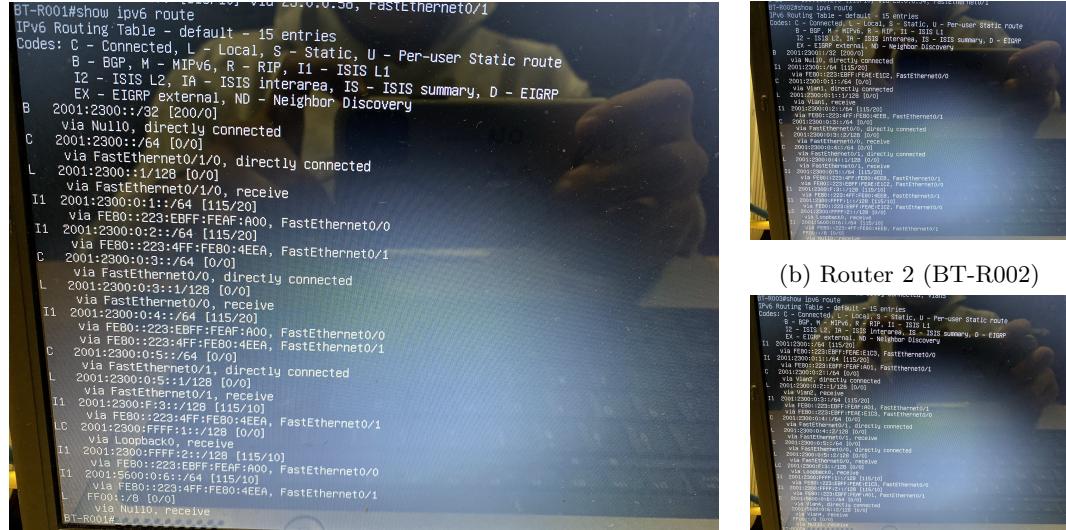
BT-R003#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
      N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
      E1 - OSPF external type 1, E2 - OSPF external type 2
      L1 - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
      ia - IS-IS inter area, * - candidate default, U - per-user static route
      o - ODR, P - periodic downloaded static route, + - replicated route
Gateway of last resort is not set

10.0.0.0/24 is subnetted, 1 subnets
B 10.2.2.0 [200/0] via 100.100.2.1, 03:49:23
23.0.0.0/8 is variably subnetted, 13 subnets, 4 masks
B 23.0.0.0/8 [200/0] via 0.0.0.0, 03:51:56, Null0
L 23.0.0.1/32 is directly connected, Vlan1
I L1 23.0.0.16/28 [115/20] via 23.0.0.50, FastEthernet0/0
I L1 23.0.0.32/28 [115/20] via 23.0.0.58, FastEthernet0/1
C 23.0.0.48/30 is directly connected, FastEthernet0/0
C 23.0.0.49/32 is directly connected, FastEthernet0/1
I L1 23.0.0.52/30 [115/20] via 23.0.0.58, FastEthernet0/1
I L1 23.0.0.56/30 [115/20] via 23.0.0.58, FastEthernet0/1
I L1 23.0.0.57/32 is directly connected, FastEthernet0/1
C 23.0.255.1/32 is directly connected, Loopback0
I L1 23.0.255.2/32 [115/10] via 23.0.0.50, FastEthernet0/0
I L1 23.0.255.3/32 [115/10] via 23.0.0.58, FastEthernet0/1
56.0.0.0/30 is subnetted, 1 subnets
I L1 56.0.0.60 [115/10] via 23.0.0.58, FastEthernet0/1
78.0.0.0/28 is subnetted, 3 subnets
B 78.0.0.0 [200/0] via 100.100.2.1, 03:48:32
B 78.0.0.16 [200/0] via 100.100.2.1, 03:48:32
B 78.0.0.32 [200/0] via 100.100.2.1, 03:48:32
    100.0.0.30 is subnetted, 1 subnets
I L1 100.100.2.0 [115/10] via 23.0.0.58, FastEthernet0/1
BT-R003#

```

Figure 3.6: IPv4 Routes to Other Subnets on All 3 Routers Respectively using `show ip route`.

CHAPTER 3. ROUTING PROTOCOLS IN THE NETWORK



(a) Router 1 (BT-R001)

```

BT-R001#show ipv6 route
IPv6 Routing Table - default - 15 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
      B - BGP, M - MIPv6, R - RIP, I1 - ISIS L1
      I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
      EX - EIGRP external, ND - Neighbor Discovery
B  2001:2300::/32 [200/0]
  via Null0, directly connected
C  2001:2300::/64 [0/0]
  via FastEthernet0/1, directly connected
L  2001:2300::1/128 [0/0]
  via FastEthernet0/1/0, receive
I1  2001:2300:0:1::64 [115/20]
  via FE80::223:EBFF:FEAF:A00, FastEthernet0/0
I1  2001:2300:0:2::64 [115/20]
  via FE80::223:FF:FE80:4EEA, FastEthernet0/1
C  2001:2300:0:3::64 [0/0]
  via FastEthernet0/0, directly connected
L  2001:2300:0:3::1/128 [0/0]
  via FastEthernet0/0, receive
I1  2001:2300:0:4::64 [115/20]
  via FE80::223:EBFF:FEAF:A00, FastEthernet0/0
C  2001:2300:0:5::64 [0/0]
  via FE80::223:FF:FE80:4EEA, FastEthernet0/1
L  2001:2300:0:5::1/128 [0/0]
  via FastEthernet0/0, directly connected
I1  2001:2300:0:f3::1/128 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
I1  2001:2300:0:FFF1::1/128 [0/0]
  via Null0, receive
I1  2001:2300:0:12::1/15/10
  via FE80::223:EBFF:FEAF:F000, FastEthernet0/0
I1  2001:5600:0:6::64 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
L  FF00::/8 [0/0]
  via Null0, receive
BT-R001#

```

(b) Router 2 (BT-R002)

```

BT-R002#show ipv6 route
IPv6 Routing Table - default - 15 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
      B - BGP, M - MIPv6, R - RIP, I1 - ISIS L1
      I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
      EX - EIGRP external, ND - Neighbor Discovery
B  2001:2300::/32 [200/0]
  via Null0, directly connected
C  2001:2300::/64 [0/0]
  via FastEthernet0/1, directly connected
L  2001:2300::1/128 [0/0]
  via FastEthernet0/1/0, receive
I1  2001:2300:0:1::64 [115/20]
  via FE80::223:EBFF:FEAF:A00, FastEthernet0/0
I1  2001:2300:0:2::64 [115/20]
  via FE80::223:FF:FE80:4EEA, FastEthernet0/1
C  2001:2300:0:3::64 [0/0]
  via FastEthernet0/0, directly connected
L  2001:2300:0:3::1/128 [0/0]
  via FastEthernet0/0, receive
I1  2001:2300:0:4::64 [115/20]
  via FE80::223:EBFF:FEAF:A00, FastEthernet0/0
C  2001:2300:0:5::64 [0/0]
  via FE80::223:FF:FE80:4EEA, FastEthernet0/1
L  2001:2300:0:5::1/128 [0/0]
  via FastEthernet0/0, directly connected
I1  2001:2300:0:f3::1/128 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
I1  2001:2300:0:FFF1::1/128 [0/0]
  via Null0, receive
I1  2001:2300:0:12::1/15/10
  via FE80::223:EBFF:FEAF:F000, FastEthernet0/0
I1  2001:5600:0:6::64 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
L  FF00::/8 [0/0]
  via Null0, receive
BT-R002#

```

(c) Router 3 (BT-R003)

```

BT-R003#show ipv6 route
IPv6 Routing Table - default - 15 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
      B - BGP, M - MIPv6, R - RIP, I1 - ISIS L1
      I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
      EX - EIGRP external, ND - Neighbor Discovery
B  2001:2300::/32 [200/0]
  via Null0, directly connected
C  2001:2300::/64 [0/0]
  via FastEthernet0/1, directly connected
L  2001:2300::1/128 [0/0]
  via FastEthernet0/1/0, receive
I1  2001:2300:0:1::64 [115/20]
  via FE80::223:EBFF:FEAF:A00, FastEthernet0/0
I1  2001:2300:0:2::64 [115/20]
  via FE80::223:FF:FE80:4EEA, FastEthernet0/1
C  2001:2300:0:3::64 [0/0]
  via FastEthernet0/0, directly connected
L  2001:2300:0:3::1/128 [0/0]
  via FastEthernet0/0, receive
I1  2001:2300:0:4::64 [115/20]
  via FE80::223:EBFF:FEAF:A00, FastEthernet0/0
C  2001:2300:0:5::64 [0/0]
  via FE80::223:FF:FE80:4EEA, FastEthernet0/1
L  2001:2300:0:5::1/128 [0/0]
  via FastEthernet0/0, directly connected
I1  2001:2300:0:f3::1/128 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
I1  2001:2300:0:FFF1::1/128 [0/0]
  via Null0, receive
I1  2001:2300:0:12::1/15/10
  via FE80::223:EBFF:FEAF:F000, FastEthernet0/0
I1  2001:5600:0:6::64 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
L  FF00::/8 [0/0]
  via Null0, receive
BT-R003#

```

Figure 3.7: IPv6 Routes to Other Subnets on All 3 Routers Respectively using `show ipv6 route`.

Noticably, when the physical connection between Router 1 and Router 2 is broken, the route from Router 1 to Router 2 goes through Router 3 instead, as evident in Figure 3.8.

3.1.5 Commentary

3.1.5.1 Problem: IS-IS Not Set Up for Laptop-Router Interface

When initially setting up IS-IS on the interfaces, only the interfaces between routers have been turned on. This leads to laptop's failure to reach a router not directly connected. To solve this problem, IS-IS is set up on the interface between a laptop and a router.

CHAPTER 3. ROUTING PROTOCOLS IN THE NETWORK

```

Success rate is 80 percent (4/5), round-trip min/avg/max = 1/2/4 ms
BT-R001#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
      N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
      E1 - OSPF external type 1, E2 - OSPF external type 2
      i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
      ia - IS-IS inter area, * - candidate default, U - per-user static route
      o - ODR, P - periodic downloaded static route, + - replicated route
Gateway of last resort is not set

      10.0.0.0/24 is subnetted, 1 subnets
B        10.2.2.0 [200/0] via 100.100.2.1, 04:04:39
      23.0.0.0/8 is variably subnetted, 12 subnets, 4 masks
B          23.0.0.0/8 [200/0] via 0.0.0.0, 04:11:03, Null0
C          23.0.0.0/28 is directly connected, FastEthernet0/1/0
L          23.0.0.1/32 is directly connected, FastEthernet0/1/0
i L1        23.0.0.16/28 [115/30] via 23.0.0.58, FastEthernet0/1
i L1        23.0.0.32/28 [115/20] via 23.0.0.58, FastEthernet0/1
i L1        23.0.0.48/30 [115/30] via 23.0.0.58, FastEthernet0/1
i L1        23.0.0.52/30 [115/20] via 23.0.0.58, FastEthernet0/1
C          23.0.0.56/30 is directly connected, FastEthernet0/1
L          23.0.0.57/32 is directly connected, FastEthernet0/1
C          23.0.255.1/32 is directly connected, Loopback0
i L1        23.0.255.2/32 [115/20] via 23.0.0.58, FastEthernet0/1
i L1        23.0.255.3/32 [115/10] via 23.0.0.58, FastEthernet0/1
i L1        56.0.0.0/30 is subnetted, 1 subnets
i L1          56.0.0.60 [115/10] via 23.0.0.58, FastEthernet0/1
      78.0.0.0/28 is subnetted, 3 subnets
B          78.0.0.0 [200/0] via 100.100.2.1, 04:04:39
B          78.0.0.16 [200/0] via 100.100.2.1, 04:04:39
B          78.0.0.32 [200/0] via 100.100.2.1, 04:04:39
i L1        100.0.0.0/30 is subnetted, 1 subnets
i L1          100.100.2.0 [115/10] via 23.0.0.58, FastEthernet0/1
BT-R001#

```

(a) IPv4 Routes to Other Subnets on Router 1 using show ip route.

```

i L1        100.100.2.0 [115/10] via 23.0.0.58, FastEthernet0/1
BT-R001#sh ipv6 route
IPv6 Routing Table - default - 13 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
      B - BGP, M - MIPv6, R - RIP, I1 - ISIS L1
      I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
      EX - EIGRP external, ND - Neighbor Discovery
B  2001:2300::/32 [200/0]
  via Null0, directly connected
C  2001:2300::/64 [0/0]
  via FastEthernet0/1/0, directly connected
L  2001:2300::1/128 [0/0]
  via FastEthernet0/1/0, receive
I1 2001:2300:0:1::/64 [115/30]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
I1 2001:2300:0:2::/64 [115/20]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
I1 2001:2300:0:4::/64 [115/20]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
C  2001:2300:0:5::/64 [0/0]
  via FastEthernet0/1, directly connected
L  2001:2300:0:5::1/128 [0/0]
  via FastEthernet0/1, receive
I1 2001:2300:F:3::/128 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
LC 2001:2300:FFFF:1::128 [0/0]
  via Loopback0, receive
I1 2001:2300:FFFF:2::/128 [115/20]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
I1 2001:5600:0:6::/64 [115/10]
  via FE80::223:4FF:FE80:4EEA, FastEthernet0/1
L  FF00::/8 [0/0]
  via Null0, receive
BT-R001#

```

(b) IPv6 Routes to Other Subnets on Router 1 using show ip route.

Figure 3.8: IP Routes to Other Subnets on Router 1 when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.

3.2 Inter-domain Routing Protocol: BGP

3.2.1 Design

For inter-domain routing, Border Gateway Protocol (BGP) is applied in BT Network since it's the one and only External Gateway Protocol (EGP) in today's global Internet. BGP provides scalability to large networks, clear definitions of administrative boundary as well as flexible policy control, which allow business relationships with neighbouring ISPs to be expressed in terms of routing policies.

Figure 3.9 shows the design of BGP protocol in our network. The AS Number (ASN) of BT Network is 2030 while ASN of Central, Virgin, DT are 42, 5060, 3040 respectively.

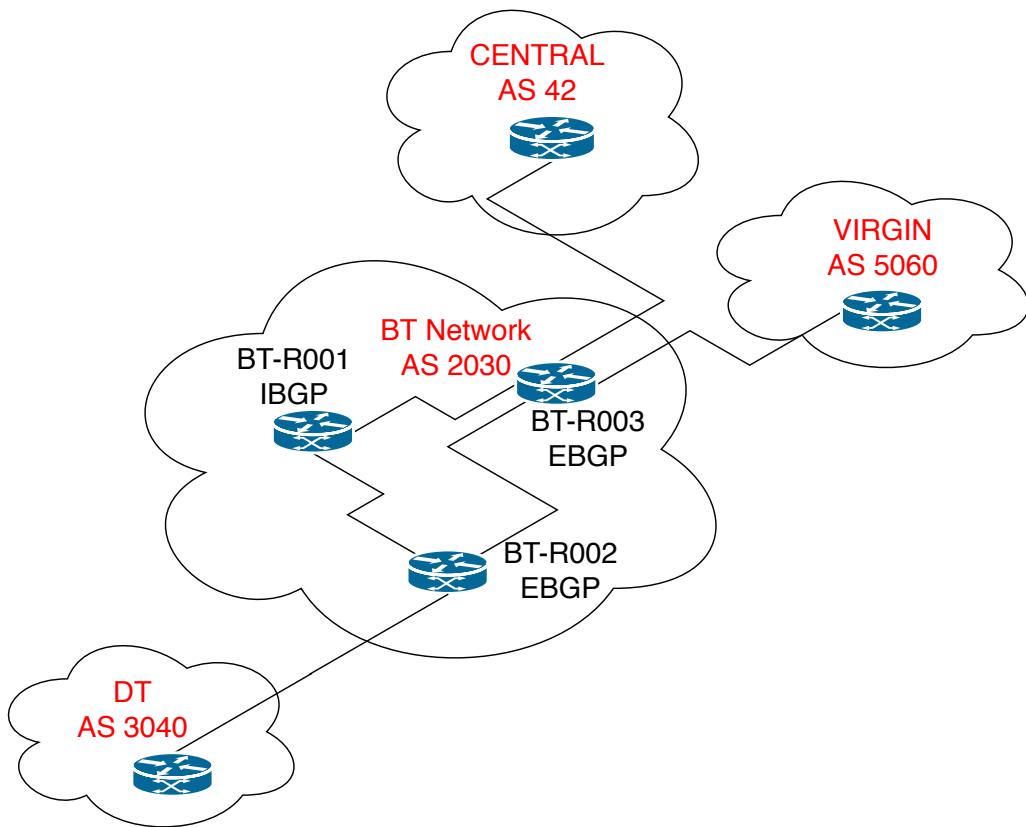


Figure 3.9: Design of BGP Protocol in BT Network.

Router 2 (BT-R002) and Router 3 (BT-R003) act as External BGP routers since they are directly connected to neighbouring ISPs. They receive routes announced by neighbouring ISPs' routers and announce routes originated from BT Network. Router 1 (BT-R001) acts

as an Internal BGP (IBGP) router only since it is not directly connected to any neighbouring ISP and only forwards and receives routes announced by EGBP routers.

3.2.2 Routing Policies

To enact business relationships with neighbouring ISPs, proper routing policies should be implemented for each different relationship in BGP protocol. Specifically, for customer ISPs, all routes announced by such ISP should be accepted and all routes received should be announced to it as well. This allows customers to connect to BT Network as well as connect to other networks through BT Network.

For non-customer neighbouring ISPs (peers and providers), all routes announced by such ISP should be accepted in order for BT Network to connect to it. Meanwhile, only routes originated from either BT Network or BT's customers are announced to such ISP.

3.2.3 Implementation

On Router 1 (BT-R001, IPv4 Loopback Address: 23.0.255.1, IPv6 Loopback Address: 2001:2300:FFFF:1::), both Router 2 (BT-R002, IPv4 Loopback Address: 23.0.255.2, IPv6 Loopback Address: 2001:2300:FFFF:2::) and Router 3 (BT-R003, IPv4 Loopback Address: 23.0.255.3, IPv6 Loopback Address: 2001:2300:FFFF:3::) are taken as neighbouring routers in the same AS. In addition, the source of BGP messages are set to be the loopback address of Router 1 to prevent physical disconnection to the 2 routers. Router 1 announces the subnet BT-R001 – BT001 (IPv4: 23.0.0.0/28, IPv6: 2001:2300:0:0::/64) to other routers.

```
1 router bgp 2030
2 network 23.0.0.0 mask 255.255.255.240
3 neighbor 23.0.255.2 remote-as 2030
4 neighbor 23.0.255.2 update-source Loopback0
5 neighbor 23.0.255.3 remote-as 2030
6 neighbor 23.0.255.3 update-source Loopback0
7 neighbor 2001:2300:FFFF:2:: remote-as 2030
8 neighbor 2001:2300:FFFF:2:: update-source Loopback0
9 neighbor 2001:2300:FFFF:3:: remote-as 2030
10 neighbor 2001:2300:FFFF:3:: update-source Loopback0
11
12 address-family ipv6
13 network 2001:2300::/64
14 neighbor 2001:2300:FFFF:2:: activate
15 neighbor 2001:2300:FFFF:3:: activate
```

On Router 2 (BT-R002), both Router 1 and Router 3 are taken as neighbouring routers in the same AS while the router from DT is taken as router from AS 3040. Router 2 announces

CHAPTER 3. ROUTING PROTOCOLS IN THE NETWORK

the subnet BT-R002 – BT002 (IPv4: 23.0.0.16/28, IPv6: 2001:2300:0:1::/64) to other routers. Since Router 2 is directly connected to customer DT Network, it applies no filter on inbound and outbound routes.

```
1 router bgp 2030
2 network 23.0.0.16 mask 255.255.255.240
3 neighbor 23.0.0.62 remote-as 3040
4 neighbor 23.0.255.1 remote-as 2030
5 neighbor 23.0.255.1 update-source Loopback0
6 neighbor 23.0.255.3 remote-as 2030
7 neighbor 23.0.255.3 update-source Loopback0
8 neighbor 2001:2300:0:6::2 remote-as 3040
9 neighbor 2001:2300:FFFF:1:: remote-as 2030
10 neighbor 2001:2300:FFFF:1:: update-source Loopback0
11 neighbor 2001:2300:FFFF:3:: remote-as 2030
12 neighbor 2001:2300:FFFF:3:: update-source Loopback0
13
14 address-family ipv6
15 network 2001:2300:0:1::/64
16 neighbor 2001:2300:0:6::2 activate
17 neighbor 2001:2300:FFFF:1:: activate
18 neighbor 2001:2300:FFFF:3:: activate
```

On Router 3 (BT-R003), both Router 1 and Router 2 are taken as neighbouring routers in the same AS while the routers from Central and Virgin are taken as router from AS 42 and AS 5060 respectively. Router 3 announces the subnet BT-R003 – BT003 (IPv4: 23.0.0.32/28, IPv6: 2001:2300:0:2::/64) to other routers.

```
1 router bgp 2030
2 network 23.0.0.32 mask 255.255.255.240
3 neighbor 23.0.255.1 remote-as 2030
4 neighbor 23.0.255.1 update-source Loopback0
5 neighbor 23.0.255.2 remote-as 2030
6 neighbor 23.0.255.2 update-source Loopback0
7 neighbor 2001:2300:FFFF:1:: remote-as 2030
8 neighbor 2001:2300:FFFF:1:: update-source Loopback0
9 neighbor 2001:2300:FFFF:2:: remote-as 2030
10 neighbor 2001:2300:FFFF:2:: update-source Loopback0
11 neighbor 2001:5600:0:6::1 remote-as 5060
12 neighbor 56.0.0.61 remote-as 5060
13 neighbor 100.100.2.1 remote-as 42
14
15 address-family ipv6
16 network 2001:2300:0:2::/64
17 aggregate-address 2001:2300::/32 summary-only
18 neighbor 2001:2300:FFFF:1:: activate
19 neighbor 2001:2300:FFFF:2:: activate
```

Since Router 3 is directly connected to non-customer ISPs, it applies a filter on outbound routes, which denies all routes that pass through either Central Network (ASN: 42) or Virgin Network (ASN: 5060).

```
1 ip as-path access-list 1 deny _42_
2 ip as-path access-list 1 deny _5060_
3 ip as-path access-list 1 permit .*
4 router bgp 2030
5 neighbor 56.0.0.61 filter-list 1 out
6 neighbor 100.100.2.1 filter-list 1 out
```

Address aggregation for 23.0.0.0/8 and 2001:2300::/32 is set up on all 3 routers, which aggregates routes destined for all addresses inside BT Network range into a single route.

```
1 aggregate-address 23.0.0.0 255.0.0.0 summary-only
2 address-family ipv6
3 aggregate-address 2001:2300::/32 summary-only
```

3.2.4 Evaluation

3.2.4.1 BGP Routes

Routes collected through BGP protocol on all 3 routers are shown in Figure ?? and ?? using commands `show bgp` and `show bgp ipv6`. Routes to DT Network (IPv4: 34.0.0.0/8, IPv6: 2001:3400::/32), Virgin Network (IPv4: 56.0.0.0/8, IPv6: 2001:5600::/32), Central Network (IPv4: 10.2.2.0/24) and other networks can be observed in the figure.

TODO

3.2.4.2 Connectivity to Provider Central Network

The connectivity to provider Central Network using BGP protocol is tested and evaluated by tracing routes to IP addresses 10.2.2.1 and 10.2.2.253 on Laptop 1 (BT001). As shown in Figure ??, connection to Central Network is successfully established through BGP routes.

TODO

3.2.4.3 Connectivity to Customer DT Network

TODO

3.2.4.4 Connectivity to Peer Virgin Network

TODO

3.2.4.5 Connectivity to Other Networks

TODO

3.2.5 Commentary

3.2.5.1 Problem: Filter List Not Working for Self-Originated Routes

The initial filter list for outbound routes on Router 3 only permits routes originated from BT Network (ASN 2030) and customer DT Network (ASN 3040).

```
1 ip as-path access-list 1 permit _2030$  
2 ip as-path access-list 1 permit _3040$
```

However, the filter list blocks all routes except those originated from customer DT Network to be announced. To solve this problem, a filter list where all routes except those go through provider Central Network (ASN 42) and peer Virgin Network (ASN 5060) are allowed. The new list should have the same effects as the previous list and indeed works as intended.

```
1 ip as-path access-list 1 deny _42_  
2 ip as-path access-list 1 deny _5060_  
3 ip as-path access-list 1 permit ..*
```

Chapter 4

Applications in the Network

4.1 Secure Remote Access to Routers through SSH

4.1.1 Design

Accessing the routers through the physical "console" port is inconvenient and dangerous. Thus, remote access through Secure Shell (SSH) protocol to routers is needed.

In BT network, remote SSH access is enabled on all 3 routers. Separate combinations of username and password on each router are used to ensure the independence of security of each router.

In addition, SSH public key authentication is set up on Laptop 1 (BT001), which allows the root user on the laptop to log in to all routers without entering passwords.

4.1.2 Implementation

We first set up Remote SSH access was first set up as instructed in Reference Guide on all 3 routers. Below is the configuration commands for Router 1 (BT-R001).

```

1 hostname BT-R001
2 ip domain name bt.lboro
3 username r001 priv 15 secret <secret>
4 line vty 0 4
5 transport input ssh telnet
6 login local
7
8 ip ssh version 2
9 crypto key generate rsa general-keys
10 ip ssh dh min size 4096

```

We then generate a pair of public and private keys on Laptop 1 (BT001).

```
1 ssh-keygen
```

After that, the pair of keys is written into files `~/.ssh/id_rsa` and `~/.ssh/id_rsa.pub`. We use the generated public key (`id_rsa.pub`) to set up SSH public key authentication on all 3 routers.

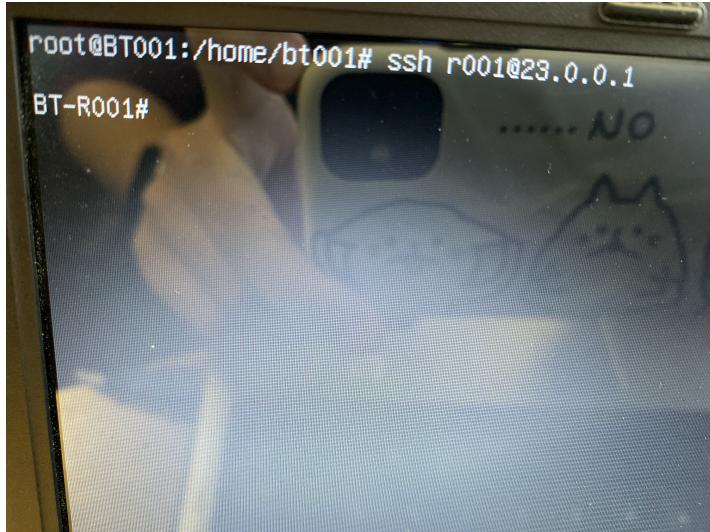
```
1 ip ssh pubkey-chain
2 username r001
3 key-string
```

4.1.3 Evaluation

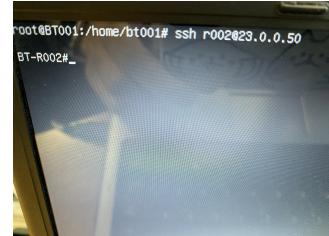
Once remote SSH access is set up on 3 routers, one should be able to access them on Laptop 1 (BT001) without entering the password using the following commands.

```
1 # access Router 1
2 ssh r001@23.0.0.1
3 # access Router 2
4 ssh r002@23.0.0.50
5 # access Router 3
6 ssh r003@23.0.0.33
```

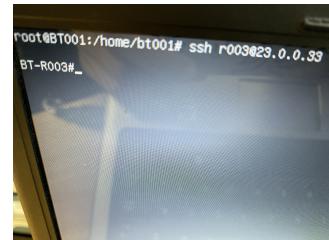
Screenshots of successful remote access to all 3 routers are shown in Figure 4.1.



(a) Router 1 (BT-R001)



(b) Router 2 (BT-R002)



(c) Router 3 (BT-R003)

Figure 4.1: Sucessful remote SSH access to all 3 routers from Laptop 1 (BT001).

4.1.4 Commentary

4.1.4.1 Problem: Maximum Limit of Characters per Line

When we tried to set up SSH public key authentication on routers, we failed at our initial attempt. It turned out that Cisco router has maximum limit of characters for each command line. Thus, a public key in a single long line was not accepted by the router.

To solve this problem, `fold` command is used to split the public key into multiple lines before re-uploading the key and SSH public key authentication was successfully set up on the router.

4.2 World Wide Web Service

- 4.2.1 Design
- 4.2.2 Implementation
- 4.2.3 Evaluation
- 4.2.4 Commentary

4.3 Domain Name System Service

4.3.1 Design

4.3.2 Implementation

4.3.3 Evaluation

4.3.4 Commentary

4.4 Email Service

4.4.1 Design

4.4.2 Implementation

4.4.3 Evaluation

4.4.4 Commentary

Chapter 5

Discussion

5.1 Conclusions

5.2 Further Work

Chapter 6

Contributions

6.1 Group Leader: Zhihao DAI

6.2 Technical Director: Yunsong ZHANG

6.3 Network Engineer: Huijing LEI

6.4 Network Engineer: Changrong CHEN

6.5 Network Engineer: Yan HUANG

REFERENCES

References

Appendix A

Routers Configuration

A.1 Router 1 Configuration

A.2 Router 2 Configuration

A.3 Router 3 Configuration

Appendix B

Laptops Configuration

B.1 Laptop 1 Configuration

B.2 Laptop 2 Configuration

B.3 Laptop 3 Configuration