

Building BT Network

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Abstract

TODO

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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 neighbor 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 Neighbor ISPs

BT Network has three immediate neighbor 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 neighbor ISPs are shown in Figure 1.1 and elaborated in the following.

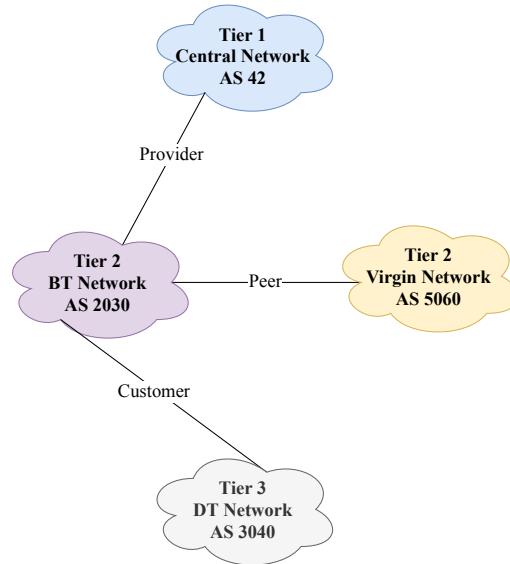


Figure 1.1: Business Relationships of BT Network with Neighbor ISPs.

1.2.1 Provider: Central Network

Since BT Network is a Tier-2 ISP, it need 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 neighbor ISPs, a Router-Neighbor 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.

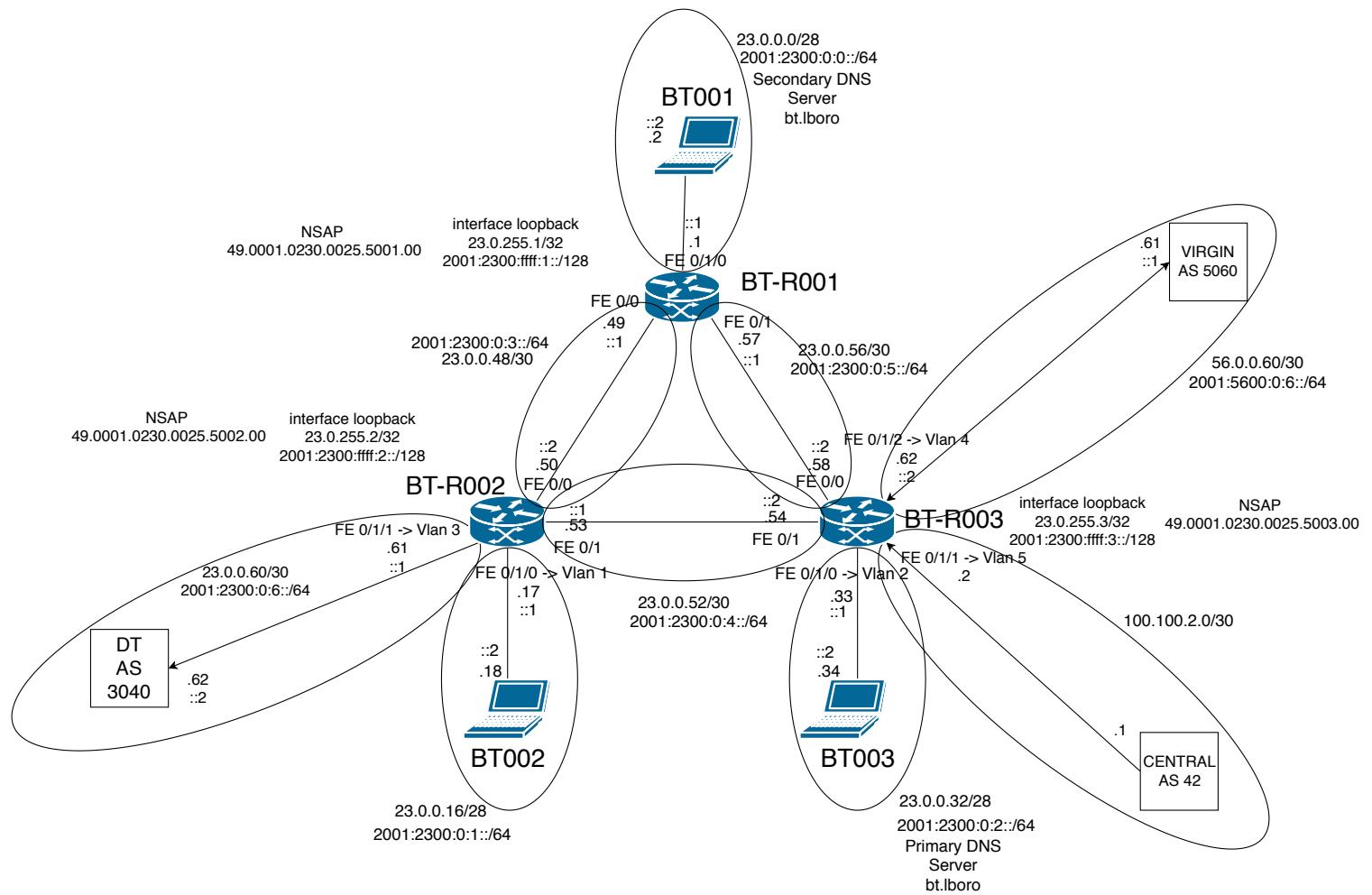


Figure 2.1: Full Network Diagram of BT Network.

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-Neighbor subnet is 30 while the prefix for each Router-Laptop subnet is 28. In other words, each Router-Router and Router-Neighbor 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.

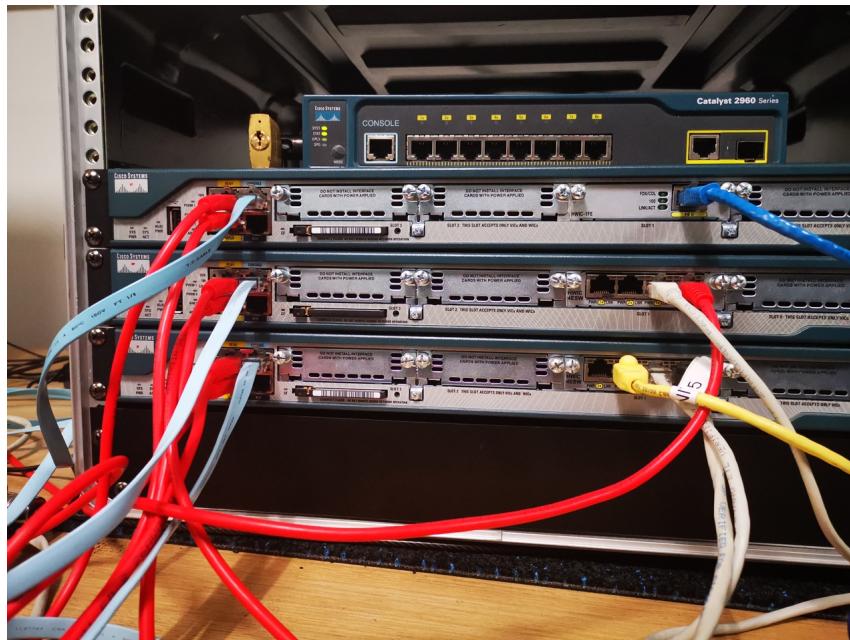


Figure 2.2: Physical Connections within BT Network.

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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-Neighbor 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
```

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```
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.

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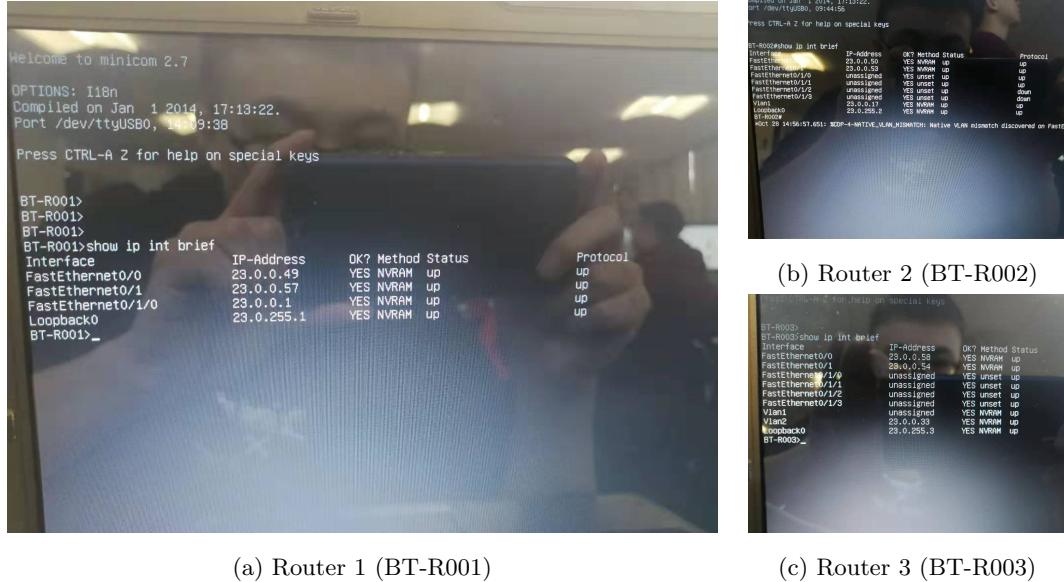


Figure 2.3: Sucessful Assignment of IPv4 Addresses to Routers' Interfaces.

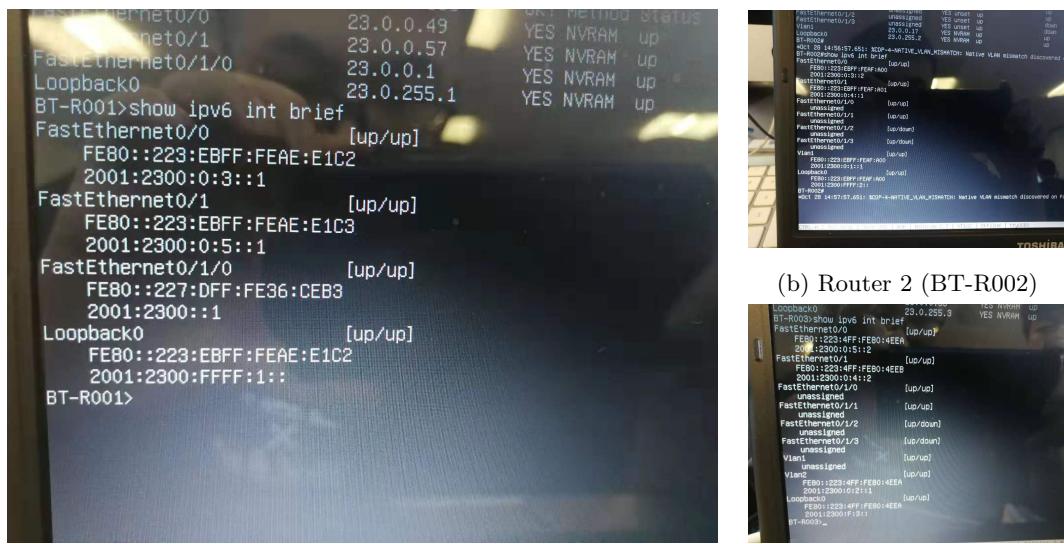


Figure 2.4: Sucessful Assignment of IPv6 Addresses to Routers' Interfaces.

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(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
            inet6 addr: 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
            inet6 addr: fe80::21e:68ff:fed0:d524/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
          RX packets:105 errors:0 dropped:0 overruns:0 frame:0
          TX packets:105 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:10536 (10.5 KB) TX bytes:1240 (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 (22.9 KB) TX bytes:19970 (19.9 KB)
          Interrupt:16

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
            inet6 addr: 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:10798 (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: Sucessful 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.

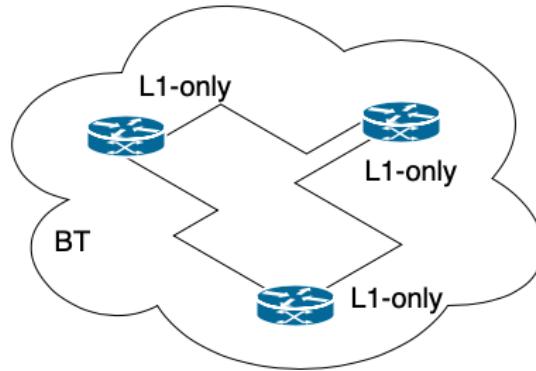


Figure 3.1: Design of IS-IS Protocol in BT Network.

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
```

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
```

3.1.4 Evaluation

Once the IS-IS is set up, use `traceroute` command to check the 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 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@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)  0.931 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# _
```

(b) `traceroute` from Laptop 2 (BT002) to Laptop 3 (BT003)

Figure 3.2: Running `traceroute` between Laptops in BT Network.

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 3.3 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 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 3.3: `traceroute` from Laptop 2 (BT002) to Laptop 3 (BT003) when Physical Connection between Router 1 (BT-R001) and Router 2 (BT-R002) is broken.

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.

3.2 Inter-domain Routing Protocol: BGP

- 3.2.1 Design
- 3.2.2 Implementation
- 3.2.3 Evaluation
- 3.2.4 Commentary

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.

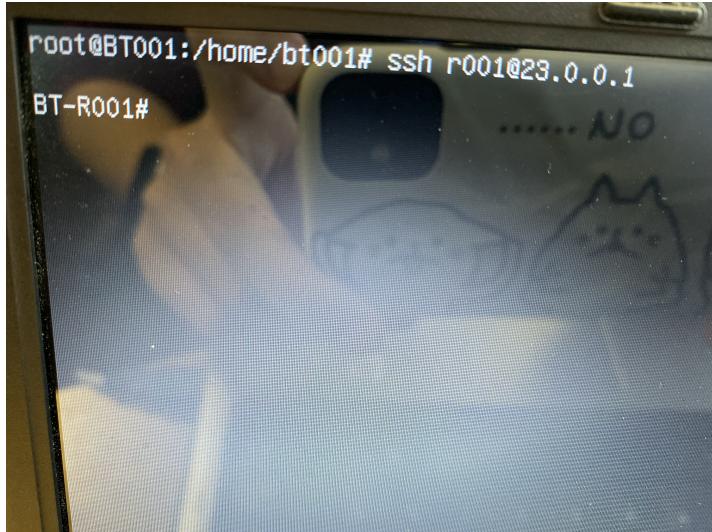
```
1 ip ssh pubkey-chain
2 username r001
3 key-string
```

4.1.3 Evaluation

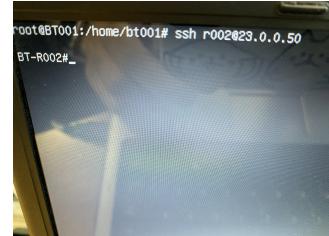
Once remote SSH access is set up on 3 routers, one should be able to access them on Laptop 1 (BT001) without entering the password using the following commands.

```
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
```

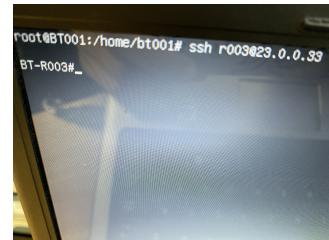
Screenshots of successful remote access to all 3 routers are shown in Figure 4.1.



(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

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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