Department of Computer and Communication Systems Engineering

Faculty of Engineering

Universiti Putra Malaysia

43400 UPM Serdang

Selangor

Course	:	ECC 3702 COMPUTER NETWORKS
Credit Hours	:	4 (3+1)
Lecturer	:	DR FAISUL ARIF B. AHMAD
Demonstrator	:	AMIRUL HUSSIN BIN MOHAMAD ANSAHARI
Assistant Engineer	:	EN. FATHULLAH B. HAKIM B. MD. MARHAM EN. MOHD HISHAM ALI
Laboratory	:	INTELLIGENT SYSTEMS LAB
Duration	:	3 HOURS
Experiment Date	:	3RD JANUARY 2023 - 13TH JANUARY 2023
Submission Date	:	20TH JANUARY 2023

LAB 6 [REPORT]

DYNAMIC ROUTING

Matric No.	Name
208651	TABINA KAMAL

1.0 Introduction

Dynamic routing is the mechanism by which information is exchanged between routers and remote routes are learned automatically to determine the optimal path between network devices [2]. A dynamic routing protocol is utilised to identify and announce the network paths. One of the first dynamic routing protocols used was the Routing Information Protocol (RIP) [1]. To accommodate for the current scale of networks, two advanced routing protocols were developed, namely; Open Shortest Path First (OSPF) and Intermediate System-to-Intermediate System (IS-IS). In addition, the different internetworks need to be connected to allow for routing between them. The Border Gateway Protocol (BGP) was developed for this purpose. It is used by internet service providers (ISPs) among themselves and larger clients in order to exchange routing information.

Dynamic routing protocols comprise three main components [1]:

- *Data structures* – Tables or databases are used in operations and are stored in the RAM.
- *Routing protocol messages* – Various messages are utilised to discover neighbouring routers, exchange routing information, and perform other tasks to learn about and maintain accurate information about the network.
- *Algorithm* – This is a finite list of steps that are executed to fulfil a task. Routing algorithms are used for facilitating routing information and determination of the best path.

Dynamic routing makes use of routing protocols that exchange information between routing devices. Routing protocols perform the following listed functions [2]:

- Discovers remote networks
- Uses the best path calculation to the remote networks
- Updating of the routing table
- Recalculation of a new best path in the event of failure of the current best path

There is very little administrator intervention required when using dynamic routing with protocols rather than static routing. The downside is that extra CPU and memory resources are required to run routing protocols. Routing protocols are compared using the following characteristics [2]; scalability, convergence speed, complexity, and resource usage.

2.0 Objectives

- Familiarisation with dynamic routing techniques with single and multiple routers
- Emulation of a dynamic routing configuration on GNS3 using Quagga router software
- Hardware implementation of a dynamic routing configuration with Linux routing appliance

3.0 List of Equipment

No.	Equipment	Quantity
1	GNS3 software	1
2	VirtualBox software	1
3	Wireshark software	1
4	Linux Quagga router image	1
5	Linux Router Appliance [NA-810C - 1U Rackmount Network Appliance Platform]	2
6	Desktop computer	4

4.0 Procedures

Before carrying out the laboratory tasks, two networks comprising four and eight subnets were designed. The network with four subnets was used for the emulation and hardware implementation of the star-topology configuration using a single router. The network with 8 subnets was used for the emulation of the topology with multiple routers. Figure 1 and Figure 2 show the calculations made for creating the networks with four and eight subnets respectively.

Block Address ⇒ 202.17.51.0 /24

/24 Netmask ⇒ 255.255.255.0
1111 1111 . 1111 1111 . 1111 1111 . 0000 0000

Since 3 new subnets are needed
↳ closest value ⇒ $4 = 2^2$ ∴ 2 bits need to be added to netmask

New netmask ⇒ 1111 1111 . 1111 1111 . 1111 1111 . 1100 0000 ⇒ /26
(128 64 32 16 8 4 2 1)

↳ Subnet divisions : 0, 64, 128, 192 ⟶ following least significant value of '1' in new netmask

Network Addresses	Broadcast Addresses	IP Address Ranges
202.17.51.0	202.17.51.63	202.17.51.1 – 202.17.51.62
202.17.51.64	202.17.51.127	202.17.51.65 – 202.17.51.126
202.17.51.128	202.17.51.191	202.17.51.129 – 202.17.51.190
202.17.51.192	202.17.51.255	202.17.51.193 – 202.17.51.254

Figure 1: Calculations for creating four subnets

Block Address ⇒ 202.17.51.0 / 24

/24 Netmask ⇒ 255.255.255.0
1111 1111 . 1111 1111 . 1111 1111 . 0000 0000

Since new subnets are needed
↳ closest value ⇒ 8 = 2^3 ∴ bits need to be added to netmask

New netmask ⇒ 1111 1111 . 1111 1111 . 1111 1111 . 1110 0000 ⇒ /27
128 64 32 16 8 4 2 1

↳ Subnet divisions : 0, 32, 64, 96, 128, 160, 192, 224

Network Addresses	Broadcast Addresses	IP Address Ranges
202.17.51.0	202.17.51.31	202.17.51.1 – 202.17.51.30
202.17.51.32	202.17.51.63	202.17.51.33 – 202.17.51.62
202.17.51.64	202.17.51.95	202.17.51.65 – 202.17.51.94
202.17.51.96	202.17.51.127	202.17.51.97 – 202.17.51.126
202.17.51.128	202.17.51.159	202.17.51.129 – 202.17.51.158
202.17.51.160	202.17.51.191	202.17.51.161 – 202.17.51.190
202.17.51.192	202.17.51.223	202.17.51.193 – 202.17.51.222
202.17.51.224	202.17.51.255	202.17.51.225 – 202.17.51.254

Figure 2: Calculations for creating eight subnets

1) Emulation of dynamic routing in star-topology configuration with a single router on GNS3

i. A star topology configuration was constructed on GNS3 using the Quagga router emulator as shown in Figure 2 below with straight-through cables connecting the VPCS (Virtual PC Simulator) with the router.

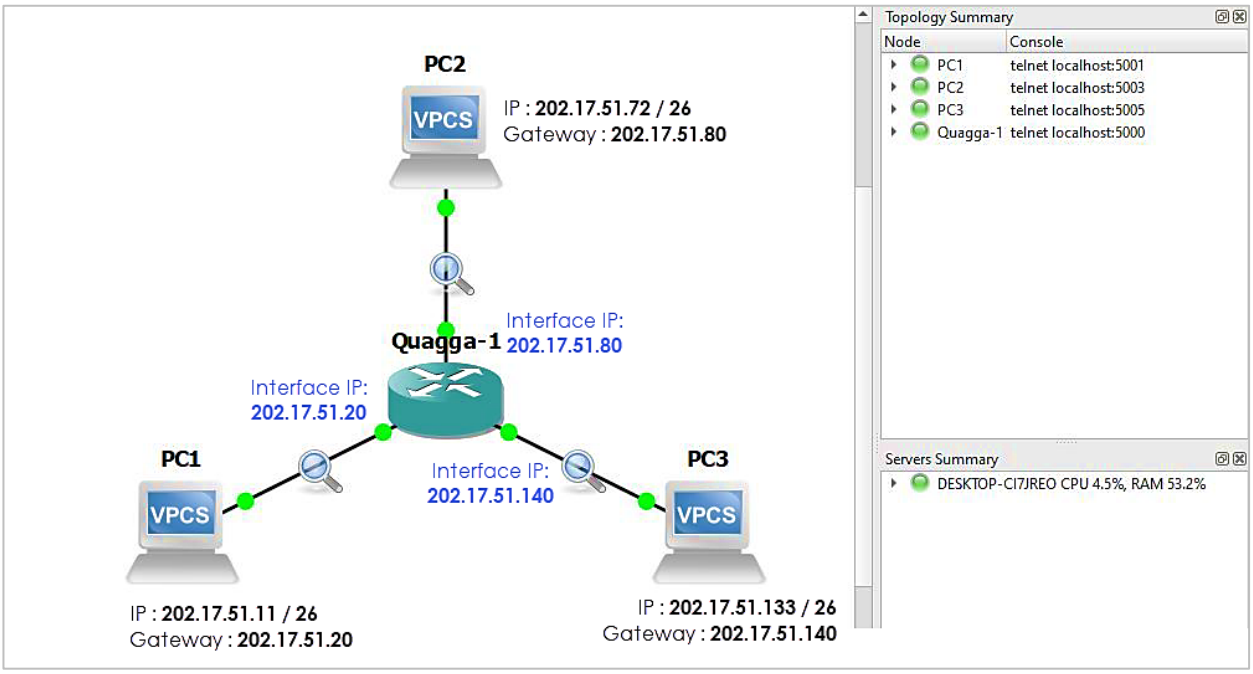

Figure 3: Star-topology configuration using Quagga router emulator on GNS3 for dynamic routing emulation

ii. The emulation was run and the console was opened. The Quagga router emulator was configured to have a different LAN at each interface as shown in Figure 4 below. The gateway of the VPCS should be set as the respective port IP addresses of the router. However, due to human error, the IP addresses of the VPCSs were set instead. The correct configuration is annotated in Figure 4 below. The Quagga router was also configured to run the OSPF protocol.

iii. The IP addresses for each of the VPCS were then set on the console window as well.

iv. The network configuration was tested using the *'traceroute'* command and recorded.

Quagga-1 | PC1 | PC2 | PC3

```
Booting Core 4.7.7

ogin to Core Linux
Username "tc", password is not set
box login: tc
 (|)-
 //\   Core is distributed with ABSOLUTELY NO WARRANTY.
 v_/_          www.tinycorelinux.com

tc@box:~$ vtysh

Hello, this is Quagga (version 0.99.22.4).
Copyright 1996-2005 Kunihiro Ishiguro, et al.

box# conf t
box(config)# interface eth0
box(config-if)# ip a 202.17.51.11/26
box(config-if)#
box(config-if)# interface eth1
box(config-if)# ip a 202.17.51.72/26
box(config-if)#
box(config-if)# interface eth2
box(config-if)# ip a 202.17.51.133/26
box(config-if)#
box(config-if)# exit
box(config)#
box(config)# router ospf
box(config-router)# network 202.17.51.0/26
% Command incomplete.
box(config-router)# network 202.17.51.0/26 area 0
box(config-router)# network 202.17.51.64/26 area 0
box(config-router)# network 202.17.51.128/26 area 0
box(config-router)# line vty
box(config-line)# no login
box(config-line)# enable password password
box(config)# exit
box#
box# show running-config
Building configuration...

Current configuration:
!
!
debug ospf6 lsa unknown
!
password quagga
enable password password
!
interface dummy0
 ipv6 nd suppress-ra
!
interface eth0
 ip address 202.17.51.11/26
 ipv6 nd suppress-ra
!
interface eth1
 ip address 202.17.51.72/26
 ipv6 nd suppress-ra
!
interface eth2
 ip address 202.17.51.133/26
 ipv6 nd suppress-ra
```

Erroneous IP Port Configuration

Correct IP Port Configuration

```
box(config)# interface eth0
box(config-if)# ip a 202.17.51.20/26
box(config-if)#
box(config)# interface eth1
box(config-if)# ip a 202.17.51.80/26
box(config-if)#
box(config)# interface eth2
box(config-if)# ip a 202.17.51.140/26
```

solarwinds | Solar-PuTTY *free tool*

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Figure 4(a): Configuration of Quagga router emulator on GNS3 for dynamic routing emulation (Part 1)

```
 ipv6 nd suppress-ra
!
interface eth2
 ip address 202.17.51.133/26
 ipv6 nd suppress-ra
!
interface eth3
 ipv6 nd suppress-ra
!
interface lo
!
router ospf
 network 202.17.51.0/26 area 0.0.0.0
 network 202.17.51.64/26 area 0.0.0.0
 network 202.17.51.128/26 area 0.0.0.0
!
ip forwarding
ipv6 forwarding
!
line vty
 no login
!
end
box# end
box# show ip route
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, A - Babel,
       > - selected route, * - FIB route

C>* 127.0.0.0/8 is directly connected, lo
K>* 127.0.0.1/32 is directly connected, lo
O   202.17.51.0/26 [110/10] is directly connected, eth0, 00:02:10
C>* 202.17.51.0/26 is directly connected, eth0
O   202.17.51.64/26 [110/10] is directly connected, eth1, 00:01:59
C>* 202.17.51.64/26 is directly connected, eth1
O   202.17.51.128/26 [110/10] is directly connected, eth2, 00:01:50
C>* 202.17.51.128/26 is directly connected, eth2
box#
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/26        [10] area: 0.0.0.0
                           directly attached to eth0
N    202.17.51.64/26       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.128/26      [10] area: 0.0.0.0
                           directly attached to eth2

============ OSPF router routing table =============

============ OSPF external routing table ===========

box#
box# show ip ospf database

       OSPF Router with ID (202.17.51.133)

                Router Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum  Link count
202.17.51.133   202.17.51.133    108 0x80000006 0xa80e 3
```

Figure 4(b): Configuration of Quagga router emulator on GNS3 for dynamic routing emulation (Part 2)

2) ***Hardware implementation of dynamic routing in star-topology configuration with a single router on Linux routing appliance***

i. Before setting up the NA-810C Linux routing hardware appliance, the PCs in use were all disconnected from any Internet connections and the firewall was turned off to allow all ingoing and outgoing connections.

ii. A monitor was connected to the Linux router appliance along with a mouse and keyboard to allow the configuration of the appliance. Straight-through cables were used to connect the PCs to the appliance.

iii. For each PC that was used, the following steps were carried out to change the IPV4 addresses of each PC: Control Panel > Network and Sharing Center > Change adapter settings > Ethernet (Select Linux router appliance connection) > Properties > Double click Internet Protocol Version 4 > Change IP addresses. Figure 5 below shows the process of changing the IP address of a PC.

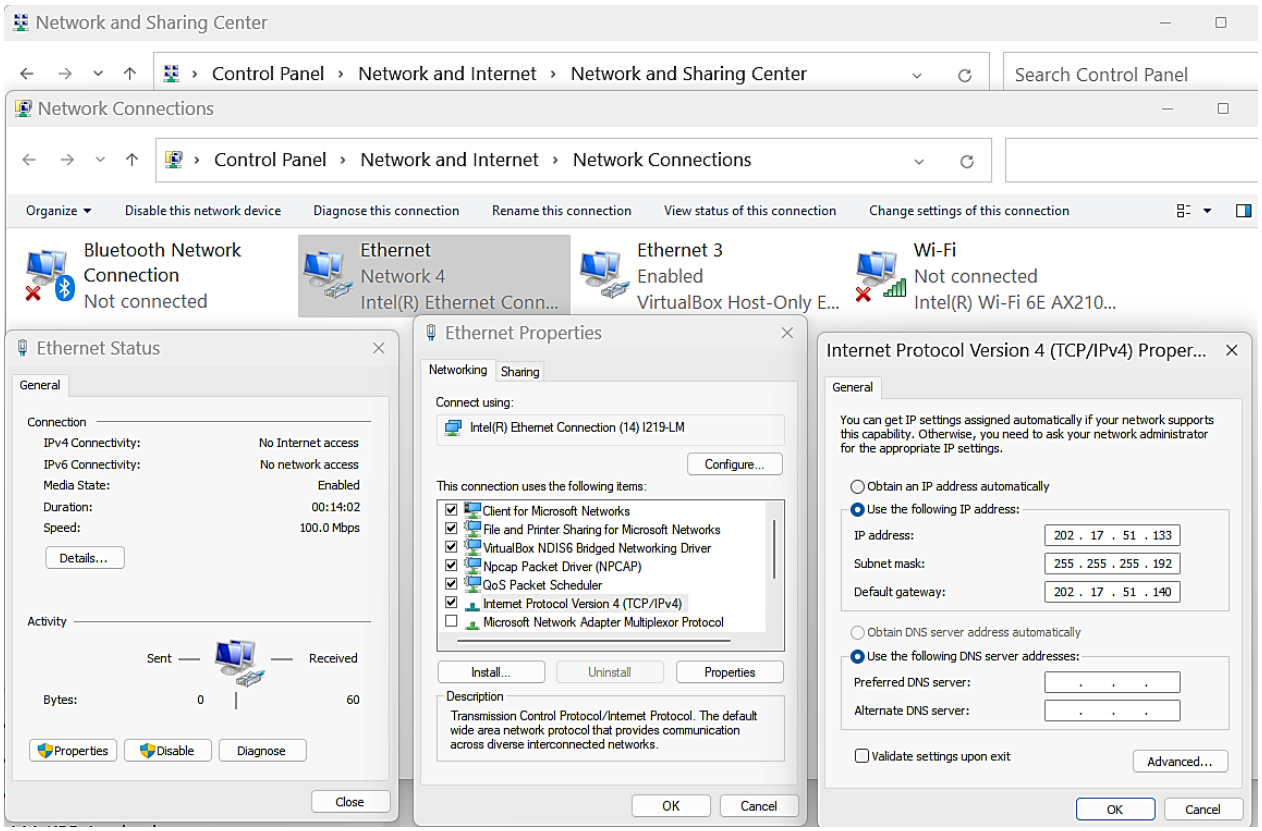

Figure 5: Process of changing IP address of the PCs (showing for PC3)

iv. After all the IP addresses were set for each PC, the Linux routing appliance was configured using the Terminal using the lines shown in Figure 6 below. The *'show interface'* command was used to check if the port connections were configured correctly.

v. The command prompt was opened on all PCs and the *'traceroute'* command was carried out between the PCs.

```
1  [router15@Router15 ~]$ su
2  Password:
3  [root@Router15 router15]# vtysh
4
5  Hello, this is Quagga (version 0.99.15).
6  Copyright 1996-2005 Kunihiro Ishiguro, et al.
7
8  Router15# conf t
9  Router15(config)# interface eth1
10 Router15(config-if)# ip a 202.17.51.2/26        → Port Interface IP for PC1
11 Router15(config-if)# interface eth2
12 Router15(config-if)# ip a 202.17.51.80/26       → Port Interface IP for PC2
13 Router15(config-if)# interface eth3
14 Router15(config-if)# ip a 202.17.51.140/26      → Port Interface IP for PC3
15 Router15(config-if)# exit
16 Router15(config)# router ospf
17 Router15(config-router)# network 202.17.51.0/26 area 0
18 Router15(config-router)# network 202.17.51.64/26 area 0
19 Router15(config-router)# network 202.17.51.128/26 area 0
20 Router15(config-router)# line vty
21 Router15(config-line)# no login
22 Router15(config-line)# enable password password
23 Router15(config)# exit
24 Router15# show running-config
25 Building configuration...
26
27 Current configuration:
28 !
29 hostname Router
30 hostname ospfd
31 log stdout
32 !
33 password zebra
34 enable password password
35 !
36 interface 0
37  ipv6 nd suppress-ra
38 !
39 interface 10
40  ipv6 nd suppress-ra
41  link-detect
42 !
43 interface eth0
44  description link to PC1
45  ip address 10.0.0.1/24
46  ip address 192.168.9.1/26
47  ipv6 nd suppress-ra
48  link-detect
49 !
50 interface eth1
51  description link to PC2
52  ip address 192.168.9.65/26
53  ip address 20.0.0.1/24
54  ip address 202.17.51.2/26
55  ipv6 nd suppress-ra
56  link-detect
57 !
58 interface eth01
59  ipv6 nd suppress-ra
60 !
61 interface eth2
62  description link to PC3
63  ip address 192.168.9.129/26
64  ip address 202.17.51.80/26
65  ip address 30.0.0.1/24
66  ipv6 nd suppress-ra
67  link-detect
68 !
```

Configuring Hardware appliance to run OSPF protocol

Figure 6(a): Configuration of the Linux routing appliance on the Terminal for star-topology for dynamic (Lines 1 to 68)

```
69  interface eth3
70   ip address 202.17.51.140/26
71   ipv6 nd suppress-ra
72  !
73  interface lo
74   ip address 10.200.1.2/32
75   link-detect
76  !
77  router ospf
78   network 10.0.0.0/24 area 0.0.0.0
79   network 10.200.1.2/32 area 0.0.0.0
80   network 20.0.0.0/24 area 0.0.0.0
81   network 30.0.0.0/24 area 0.0.0.0
82   network 192.168.9.1/26 area 0.0.0.0
83   network 192.168.9.65/26 area 0.0.0.0
84   network 192.168.9.129/26 area 0.0.0.0
85   network 202.17.51.0/26 area 0.0.0.0
86   network 202.17.51.64/26 area 0.0.0.0
87   network 202.17.51.128/26 area 0.0.0.0
88  !
89  ip forwarding
90  !
91  line vty
92   no login
93  !
94  end
95  Router15# end
96  Router15# show ip route
97  Codes: K - kernel route, C - connected, S - static, R - RIP, O - OSPF,
98         I - ISIS, B - BGP, > - selected route, * - FIB route
99
100 O   10.200.1.2/32 [110/10] is directly connected, lo, 00:04:04
101 C>* 10.200.1.2/32 is directly connected, lo
102 C>* 127.0.0.0/8 is directly connected, lo
103 O   202.17.51.0/26 [110/10] is directly connected, eth1, 00:01:17
104 C>* 202.17.51.0/26 is directly connected, eth1
105 O   202.17.51.64/26 [110/10] is directly connected, eth2, 00:01:10
106 C>* 202.17.51.64/26 is directly connected, eth2
107 O   202.17.51.128/26 [110/10] is directly connected, eth3, 00:01:03
108 C>* 202.17.51.128/26 is directly connected, eth3
109 Router15# show ip ospf route
110 ============ OSPF network routing table ============
111 N    10.200.1.2/32         [10] area: 0.0.0.0
112                            directly attached to lo
113 N    202.17.51.0/26        [10] area: 0.0.0.0
114                            directly attached to eth1
115 N    202.17.51.64/26       [10] area: 0.0.0.0
116                            directly attached to eth2
117 N    202.17.51.128/26      [10] area: 0.0.0.0
118                            directly attached to eth3
119
120 ============ OSPF router routing table =============
121
122 ============ OSPF external routing table ===========
123
124 Router15# show ip ospf database
125
126        OSPF Router with ID (10.200.1.2)
127
128                Router Link States (Area 0.0.0.0)
129
130 Link ID         ADV Router      Age  Seq#       CkSum  Link count
131 10.200.1.2      10.200.1.2        39 0x80000008 0x5ce5 4
132
```

Figure 6(a): Configuration of the Linux routing appliance on the Terminal for star-topology for dynamic (Lines 69 to 132)

3) *Emulation of dynamic routing in star-topology configuration with multiple routers on GNS3*

i. The multiple router configuration was constructed on GNS3 using the Quagga router emulator as shown in Figure 7 below with straight-through cables connecting the VPCS (Virtual PC Simulator) with the router and crossover cables connecting the routers.

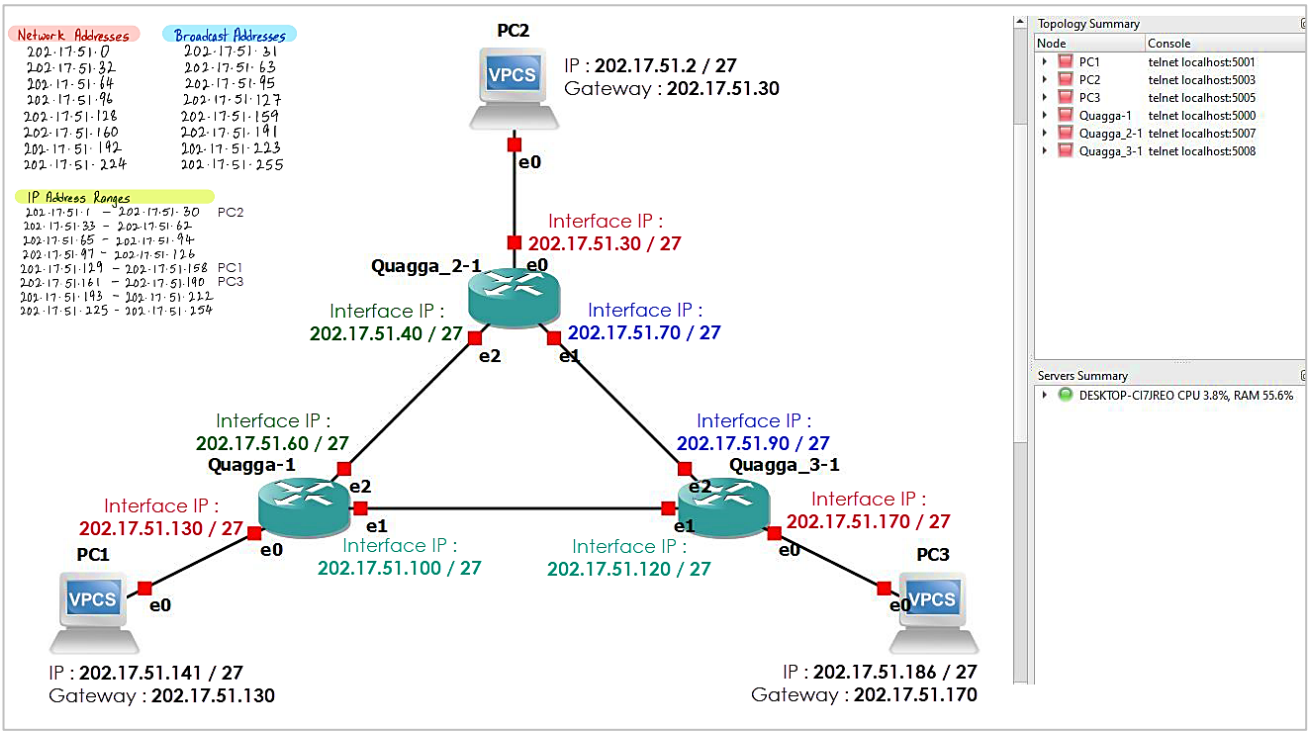

Figure 7: Star-topology configuration using multiple Quagga router emulators on GNS3 for dynamic routing emulation

ii. The emulation was run and the console was opened. The Quagga router emulators were configured to have a different LAN at each interface as shown in Figure 8, Figure 9, and Figure 10 below. The gateway of the VPCS should be set as the respective port IP addresses of the router. However, due to human error, the IP addresses of the VPCSs were set instead. The correct configuration is annotated in the respective figures. The Quagga routers were also configured to run the OSPF protocol.

iii. The IP addresses for each of the VPCS were then set on the console window as well

iv. The network configuration was tested using the *'traceroute'* command and recorded.

```
Login to Core Linux
Username "tc", password is not set
box login: tc
 (|)-
 //\   Core is distributed with ABSOLUTELY NO WARRANTY.
 v_/_          www.tinycorelinux.com

tc@box:~$ conf t
-sh: conf: not found
tc@box:~$ vtysh

Hello, this is Quagga (version 0.99.22.4).
Copyright 1996-2005 Kunihiro Ishiguro, et al.

box# conf t
box(config)# interface eth0
box(config-if)# ip a 202.17.51.141/27
box(config-if)#
box(config-if)# interface eth1
box(config-if)# ip a 202.17.51.100/27
box(config-if)#
box(config-if)# interface eth2
box(config-if)# ip a 202.17.51.60/27
box(config-if)#
box(config-if)# exit
box(config)#
box(config)# router ospf
box(config-router)#
box(config-router)# network 202.17.51.128/27 area 0
box(config-router)# network 202.17.51.96/27 area 0
box(config-router)# network 202.17.51.32/27 area 0
box(config-router)# line vty
box(config-line)# no login
box(config-line)# enable password password
box(config)# exit
box#
box# show running-config
Building configuration...

Current configuration:
!
!
debug ospf6 lsa unknown
!
password quagga
enable password password
!
interface dummy0
 ipv6 nd suppress-ra
!
interface eth0
 ip address 202.17.51.141/27
 ipv6 nd suppress-ra
!
interface eth1
 ip address 202.17.51.100/27
 ipv6 nd suppress-ra
!
interface eth2
 ip address 202.17.51.60/27
 ipv6 nd suppress-ra
```

Erroneous IP Configuration for PC1 and Quagga-1 interface

Corrected IP Configuration for PC1 and Quagga-1 interface

```
box(config)# interface eth0
box(config-if)# ip a 202.17.51.130/27
```

Configuration of Quagga emulator to run OSPF protocol

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Figure 8(a): Configuration of Quagga-1 router emulator on GNS3 for dynamic routing emulation (Part 1)

```
interface eth2
 ip address 202.17.51.60/27
 ipv6 nd suppress-ra
!
interface eth3
 ipv6 nd suppress-ra
!
interface lo
!
router ospf
 network 202.17.51.32/27 area 0.0.0.0
 network 202.17.51.96/27 area 0.0.0.0
 network 202.17.51.128/27 area 0.0.0.0
!
ip forwarding
ipv6 forwarding
!
line vty
 no login
!
end
box# end
box# show ip route
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, A - Babel,
       > - selected route, * - FIB route

C>* 127.0.0.0/8 is directly connected, lo
K>* 127.0.0.1/32 is directly connected, lo
O>* 202.17.51.0/27 [110/30] via 202.17.51.120, eth1, 00:02:15
O   202.17.51.32/27 [110/10] is directly connected, eth2, 00:12:17
C>* 202.17.51.32/27 is directly connected, eth2
O>* 202.17.51.64/27 [110/20] via 202.17.51.120, eth1, 00:02:33
O   202.17.51.96/27 [110/10] is directly connected, eth1, 00:12:38
C>* 202.17.51.96/27 is directly connected, eth1
O   202.17.51.128/27 [110/10] is directly connected, eth0, 00:13:02
C>* 202.17.51.128/27 is directly connected, eth0
O>* 202.17.51.160/27 [110/20] via 202.17.51.120, eth1, 00:02:45
box#
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/27        [30] area: 0.0.0.0
                           via 202.17.51.120, eth1
N    202.17.51.32/27       [10] area: 0.0.0.0
                           directly attached to eth2
N    202.17.51.64/27       [20] area: 0.0.0.0
                           via 202.17.51.120, eth1
N    202.17.51.96/27       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.128/27      [10] area: 0.0.0.0
                           directly attached to eth0
N    202.17.51.160/27      [20] area: 0.0.0.0
                           via 202.17.51.120, eth1

============ OSPF router routing table =============

============ OSPF external routing table ===========

box# show ip ospf database

       OSPF Router with ID (202.17.51.141)
```

Figure 8(b): Configuration of Quagga-1 router emulator on GNS3 for dynamic routing emulation (Part 2)

```
Quagga  Quagga_2  Quagga_3  PC1  PC2  PC3

      > - selected route, * - FIB route

C>* 127.0.0.0/8 is directly connected, lo
K>* 127.0.0.1/32 is directly connected, lo
O>* 202.17.51.0/27 [110/30] via 202.17.51.120, eth1, 00:02:15
O   202.17.51.32/27 [110/10] is directly connected, eth2, 00:12:17
C>* 202.17.51.32/27 is directly connected, eth2
O>* 202.17.51.64/27 [110/20] via 202.17.51.120, eth1, 00:02:33
O   202.17.51.96/27 [110/10] is directly connected, eth1, 00:12:38
C>* 202.17.51.96/27 is directly connected, eth1
O   202.17.51.128/27 [110/10] is directly connected, eth0, 00:13:02
C>* 202.17.51.128/27 is directly connected, eth0
O>* 202.17.51.160/27 [110/20] via 202.17.51.120, eth1, 00:02:45
box#
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/27        [30] area: 0.0.0.0
                           via 202.17.51.120, eth1
N    202.17.51.32/27       [10] area: 0.0.0.0
                           directly attached to eth2
N    202.17.51.64/27       [20] area: 0.0.0.0
                           via 202.17.51.120, eth1
N    202.17.51.96/27       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.128/27      [10] area: 0.0.0.0
                           directly attached to eth0
N    202.17.51.160/27      [20] area: 0.0.0.0
                           via 202.17.51.120, eth1

============ OSPF router routing table =============

============ OSPF external routing table ===========

box# show ip ospf database

       OSPF Router with ID (202.17.51.141)

                Router Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum  Link count
202.17.51.70    202.17.51.70     160 0x80000007 0x1f9b 3
202.17.51.141   202.17.51.141    182 0x80000007 0x551a 3
202.17.51.186   202.17.51.186    159 0x80000008 0x44ed 3

                Net Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum
202.17.51.70    202.17.51.70     161 0x80000001 0xf8b6
202.17.51.100   202.17.51.141    182 0x80000001 0xe81a
```

Figure 8(c): Configuration of Quagga-1 router emulator on GNS3 for dynamic routing emulation (Part 3)

Quagga-1 | Quagga | Quagga_3 | PC1 | PC2 | PC3

```
Possible swap partition(s) enabled.

udevadm settle - timeout of 5 seconds reached, the event queue contains:
  /sys/module/scsi_wait_scan (874)

Login to Core Linux
Username "tc", password is not set
box login: tc
 (|)-
 //\   Core is distributed with ABSOLUTELY NO WARRANTY.
 v_/_           www.tinycorelinux.com

tc@box:~$ vtysh

Hello, this is Quagga (version 0.99.22.4).
Copyright 1996-2005 Kunihiro Ishiguro, et al.

box# conf t
box(config)# interface eth0
box(config-if)# ip a 202.17.51.2/27
box(config-if)#
box(config-if)# interface eth1
box(config-if)# ip a 202.17.70/27
% Unknown command.
box(config-if)# ip a 202.17.70/27
% Unknown command.
box(config-if)# interface eth1
box(config-if)# ip a 202.17.51.70/27
box(config-if)#
box(config-if)# interface eth2
box(config-if)# ip a 202.17.51.40/27
box(config-if)# exit
box(config)#
box(config)# router ospf
box(config-router)# network 202.17.51.0/27
% Command incomplete.
box(config-router)# network 202.17.51.0/27 area 0
box(config-router)# network 202.17.51.64/27 area 0
box(config-router)# network 202.17.51.32/27 area 0
box(config-router)#
box(config-router)# line vty
box(config-line)# no login
box(config-line)# enable password password
box(config)# exit
box#
box# show running-config
Building configuration...

Current configuration:
!
!
debug ospf6 lsa unknown
!
password quagga
enable password password
!
interface dummy0
 ipv6 nd suppress-ra
!
interface eth0
 ip address 202.17.51.2/27
 ipv6 nd suppress-ra
```

Erroneous IP Configuration for PC2 and Quagga-2 interface

Corrected IP Configuration for PC2 and Quagga-2 interface

```
box(config)# interface eth0
box(config-if)# ip a 202.17.51.20/27
```

Configuration of Quagga emulator to run OSPF protocol

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Figure 8(d): Configuration of Quagga-2 router emulator on GNS3 for dynamic routing emulation (Part 1)

Quagga-1 | Quagga | Quagga_3 | PC1 | PC2 | PC3

Add new tab

```
!
interface eth1
 ip address 202.17.51.70/27
 ipv6 nd suppress-ra
!
interface eth2
 ip address 202.17.51.40/27
 ipv6 nd suppress-ra
!
interface eth3
 ipv6 nd suppress-ra
!
interface lo
!
router ospf
 network 202.17.51.0/27 area 0.0.0.0
 network 202.17.51.32/27 area 0.0.0.0
 network 202.17.51.64/27 area 0.0.0.0
!
ip forwarding
ipv6 forwarding
!
line vty
 no login
!
end
box# end
box# show ip route\
% Unknown command.
box# show ip route
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, A - Babel,
       > - selected route, * - FIB route

C>* 127.0.0.0/8 is directly connected, lo
K>* 127.0.0.1/32 is directly connected, lo
O   202.17.51.0/27 [110/10] is directly connected, eth0, 00:07:08
C>* 202.17.51.0/27 is directly connected, eth0
O   202.17.51.32/27 [110/10] is directly connected, eth2, 00:06:28
C>* 202.17.51.32/27 is directly connected, eth2
O   202.17.51.64/27 [110/10] is directly connected, eth1, 00:06:37
C>* 202.17.51.64/27 is directly connected, eth1
O>* 202.17.51.96/27 [110/20] via 202.17.51.90, eth1, 00:02:37
O>* 202.17.51.128/27 [110/30] via 202.17.51.90, eth1, 00:02:37
O>* 202.17.51.160/27 [110/20] via 202.17.51.90, eth1, 00:02:37
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/27        [10] area: 0.0.0.0
                           directly attached to eth0
N    202.17.51.32/27       [10] area: 0.0.0.0
                           directly attached to eth2
N    202.17.51.64/27       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.96/27       [20] area: 0.0.0.0
                           via 202.17.51.90, eth1
N    202.17.51.128/27      [30] area: 0.0.0.0
                           via 202.17.51.90, eth1
N    202.17.51.160/27      [20] area: 0.0.0.0
                           via 202.17.51.90, eth1

============ OSPF router routing table =============
```

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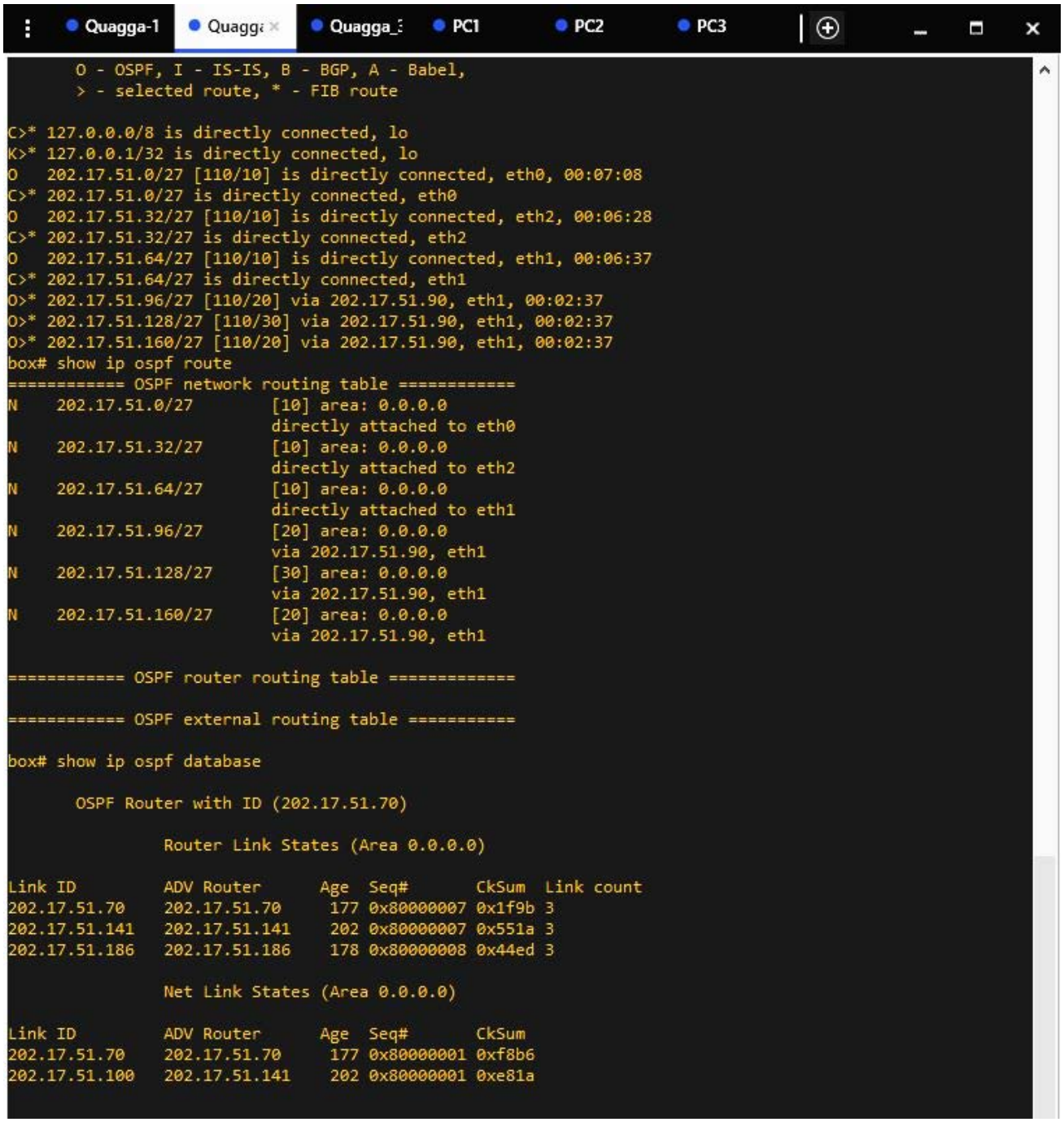
Figure 8(e): Configuration of Quagga-2 router emulator on GNS3 for dynamic routing emulation (Part 2)



```
Quagga-1   Quagga   Quagga_3   PC1   PC2   PC3

      O - OSPF, I - IS-IS, B - BGP, A - Babel,
      > - selected route, * - FIB route

C>* 127.0.0.0/8 is directly connected, lo
K>* 127.0.0.1/32 is directly connected, lo
O   202.17.51.0/27 [110/10] is directly connected, eth0, 00:07:08
C>* 202.17.51.0/27 is directly connected, eth0
O   202.17.51.32/27 [110/10] is directly connected, eth2, 00:06:28
C>* 202.17.51.32/27 is directly connected, eth2
O   202.17.51.64/27 [110/10] is directly connected, eth1, 00:06:37
C>* 202.17.51.64/27 is directly connected, eth1
O>* 202.17.51.96/27 [110/20] via 202.17.51.90, eth1, 00:02:37
O>* 202.17.51.128/27 [110/30] via 202.17.51.90, eth1, 00:02:37
O>* 202.17.51.160/27 [110/20] via 202.17.51.90, eth1, 00:02:37
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/27        [10] area: 0.0.0.0
                           directly attached to eth0
N    202.17.51.32/27       [10] area: 0.0.0.0
                           directly attached to eth2
N    202.17.51.64/27       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.96/27       [20] area: 0.0.0.0
                           via 202.17.51.90, eth1
N    202.17.51.128/27      [30] area: 0.0.0.0
                           via 202.17.51.90, eth1
N    202.17.51.160/27      [20] area: 0.0.0.0
                           via 202.17.51.90, eth1

============ OSPF router routing table =============

============ OSPF external routing table ===========

box# show ip ospf database

       OSPF Router with ID (202.17.51.70)

                Router Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum  Link count
202.17.51.70    202.17.51.70     177 0x80000007 0x1f9b 3
202.17.51.141   202.17.51.141    202 0x80000007 0x551a 3
202.17.51.186   202.17.51.186    178 0x80000008 0x44ed 3

                Net Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum
202.17.51.70    202.17.51.70     177 0x80000001 0xf8b6
202.17.51.100   202.17.51.141    202 0x80000001 0xe81a
```

Figure 8(f): Configuration of Quagga-2 router emulator on GNS3 for dynamic routing emulation (Part 3)

Quagga-1 | Quagga_2 | Quagga | PC1 | PC2 | PC3

```
devadm settle - timeout of 5 seconds reached, the event queue contains:
  /sys/module/scsi_wait_scan (874)

Login to Core Linux
Username "tc", password is not set
box login: tc
 (|)-
 //\   Core is distributed with ABSOLUTELY NO WARRANTY.
 v_/_           www.tinycorelinux.com

tc@box:~$ vtysh

Hello, this is Quagga (version 0.99.22.4).
Copyright 1996-2005 Kunihiro Ishiguro, et al.

box# conf t
box(config)# interface eth0
box(config-if)# ip a 202.17.51.186/27
box(config-if)#
box(config-if)# interface eth1
box(config-if)# ip a 202.17.51.120/27
box(config-if)#
box(config-if)# interface eth2
box(config-if)# ip a 202.17.51.90/27
box(config-if)#
box(config-if)# exit
box(config)#
box(config)# router ospf
box(config-router)# network 202.17.51.160 area 0
% Unknown command.
box(config-router)# network 202.17.51.160/27 area 0
box(config-router)# network 202.17.51.96/27 area 0
box(config-router)# network 202.17.51.64/27 area 0
box(config-router)#
box(config-router)# line vty
box(config-line)# no login
box(config-line)# enable password password
box(config)# exit
box#
box# show running-config
Building configuration...

Current configuration:
!
!
debug ospf6 lsa unknown
!
password quagga
enable password password
!
interface dummy0
 ipv6 nd suppress-ra
!
interface eth0
 ip address 202.17.51.186/27
 ipv6 nd suppress-ra
!
interface eth1
 ip address 202.17.51.120/27
 ipv6 nd suppress-ra
!
interface eth2
```

Erroneous IP Configuration for PC3 and Quagga-3 interface

Corrected IP Configuration for PC3 and Quagga-3 interface

```
box(config)# interface eth0
box(config-if)# ip a 202.17.51.170/27
```

Configuration of Quagga emulator to run OSPF protocol

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Figure 8(g): Configuration of Quagga-3 router emulator on GNS3 for dynamic routing emulation (Part 1)

```
!
interface eth2
 ip address 202.17.51.90/27
 ipv6 nd suppress-ra
!
interface eth3
 ipv6 nd suppress-ra
!
interface lo
!
router ospf
 network 202.17.51.64/27 area 0.0.0.0
 network 202.17.51.96/27 area 0.0.0.0
 network 202.17.51.160/27 area 0.0.0.0
!
ip forwarding
ipv6 forwarding
!
line vty
 no login
!
end
box# end
box# show ip route
Codes: K - kernel route, C - connected, S - static, R - RIP,
       O - OSPF, I - IS-IS, B - BGP, A - Babel,
       > - selected route, * - FIB route

C>* 127.0.0.0/8 is directly connected, lo
K>* 127.0.0.1/32 is directly connected, lo
O>* 202.17.51.0/27 [110/20] via 202.17.51.70, eth2, 00:02:53
O>* 202.17.51.32/27 [110/20] via 202.17.51.100, eth1, 00:02:53
  *                          via 202.17.51.70, eth2, 00:02:53
O   202.17.51.64/27 [110/10] is directly connected, eth2, 00:03:11
C>* 202.17.51.64/27 is directly connected, eth2
O   202.17.51.96/27 [110/10] is directly connected, eth1, 00:03:31
C>* 202.17.51.96/27 is directly connected, eth1
O>* 202.17.51.128/27 [110/20] via 202.17.51.100, eth1, 00:03:16
O   202.17.51.160/27 [110/10] is directly connected, eth0, 00:04:03
C>* 202.17.51.160/27 is directly connected, eth0
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/27        [20] area: 0.0.0.0
                           via 202.17.51.70, eth2
N    202.17.51.32/27       [20] area: 0.0.0.0
                           via 202.17.51.100, eth1
                           via 202.17.51.70, eth2
N    202.17.51.64/27       [10] area: 0.0.0.0
                           directly attached to eth2
N    202.17.51.96/27       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.128/27      [20] area: 0.0.0.0
                           via 202.17.51.100, eth1
N    202.17.51.160/27      [10] area: 0.0.0.0
                           directly attached to eth0

============ OSPF router routing table =============

============ OSPF external routing table ===========

box# show ip ospf database
```

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Figure 8(h): Configuration of Quagga-3 router emulator on GNS3 for dynamic routing emulation (Part 2)

```
Quagga-1   Quagga_2   Quagga   PC1   PC2   PC3

K>* 127.0.0.1/32 is directly connected, lo
O>* 202.17.51.0/27 [110/20] via 202.17.51.70, eth2, 00:02:53
O>* 202.17.51.32/27 [110/20] via 202.17.51.100, eth1, 00:02:53
  *                          via 202.17.51.70, eth2, 00:02:53
O   202.17.51.64/27 [110/10] is directly connected, eth2, 00:03:11
C>* 202.17.51.64/27 is directly connected, eth2
O   202.17.51.96/27 [110/10] is directly connected, eth1, 00:03:31
C>* 202.17.51.96/27 is directly connected, eth1
O>* 202.17.51.128/27 [110/20] via 202.17.51.100, eth1, 00:03:16
O   202.17.51.160/27 [110/10] is directly connected, eth0, 00:04:03
C>* 202.17.51.160/27 is directly connected, eth0
box# show ip ospf route
============ OSPF network routing table ============
N    202.17.51.0/27        [20] area: 0.0.0.0
                           via 202.17.51.70, eth2
N    202.17.51.32/27       [20] area: 0.0.0.0
                           via 202.17.51.100, eth1
                           via 202.17.51.70, eth2
N    202.17.51.64/27       [10] area: 0.0.0.0
                           directly attached to eth2
N    202.17.51.96/27       [10] area: 0.0.0.0
                           directly attached to eth1
N    202.17.51.128/27      [20] area: 0.0.0.0
                           via 202.17.51.100, eth1
N    202.17.51.160/27      [10] area: 0.0.0.0
                           directly attached to eth0

============ OSPF router routing table =============

============ OSPF external routing table ===========

box# show ip ospf database

       OSPF Router with ID (202.17.51.186)

                Router Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum  Link count
202.17.51.70    202.17.51.70     194 0x80000007 0x1f9b 3
202.17.51.141   202.17.51.141    218 0x80000007 0x551a 3
202.17.51.186   202.17.51.186    194 0x80000008 0x44ed 3

                Net Link States (Area 0.0.0.0)

Link ID         ADV Router      Age  Seq#       CkSum
202.17.51.70    202.17.51.70     195 0x80000001 0xf8b6
202.17.51.100   202.17.51.141    218 0x80000001 0xe81a
```

Figure 8(h): Configuration of Quagga-3 router emulator on GNS3 for dynamic routing emulation (Part 3)

5.0 Results and Observations

1) Emulation of dynamic routing in star-topology configuration with a single router on GNS3

Figure 9, Figure 10, and Figure 11 show the console windows for PC1, PC2 and PC3 respectively. For each PC, the IP address was configured, the 'trace' command was carried out between the PCs to trace for the routes. Figure 12 shows the 'traceroute' command being executed from the Quagga router emulator. Table 1 below shows a summary of the PC IP address configurations.

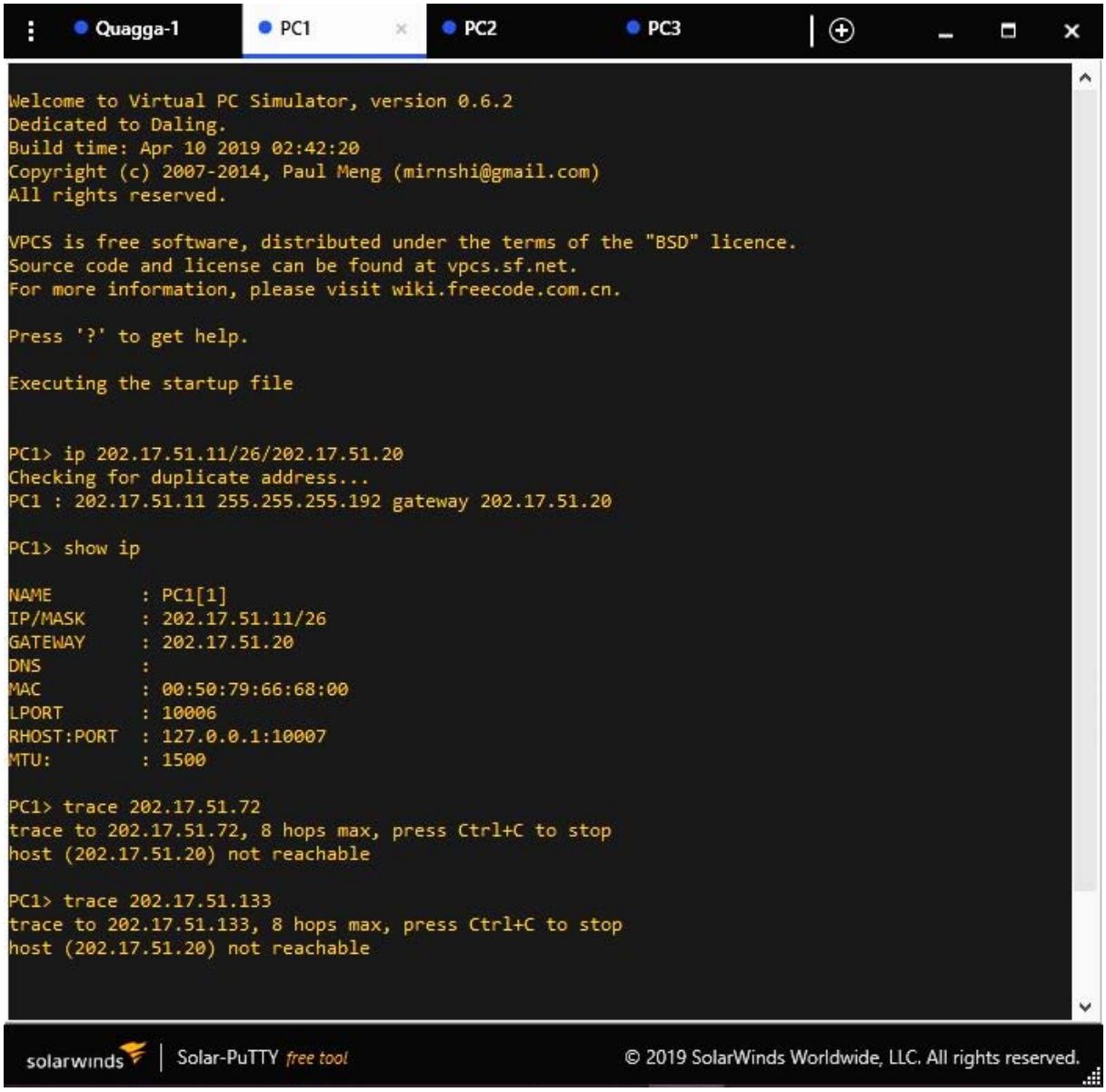

Figure 9: Setting up the IP address for PC1 and execution of trace command for GNS3 dynamic routing emulation

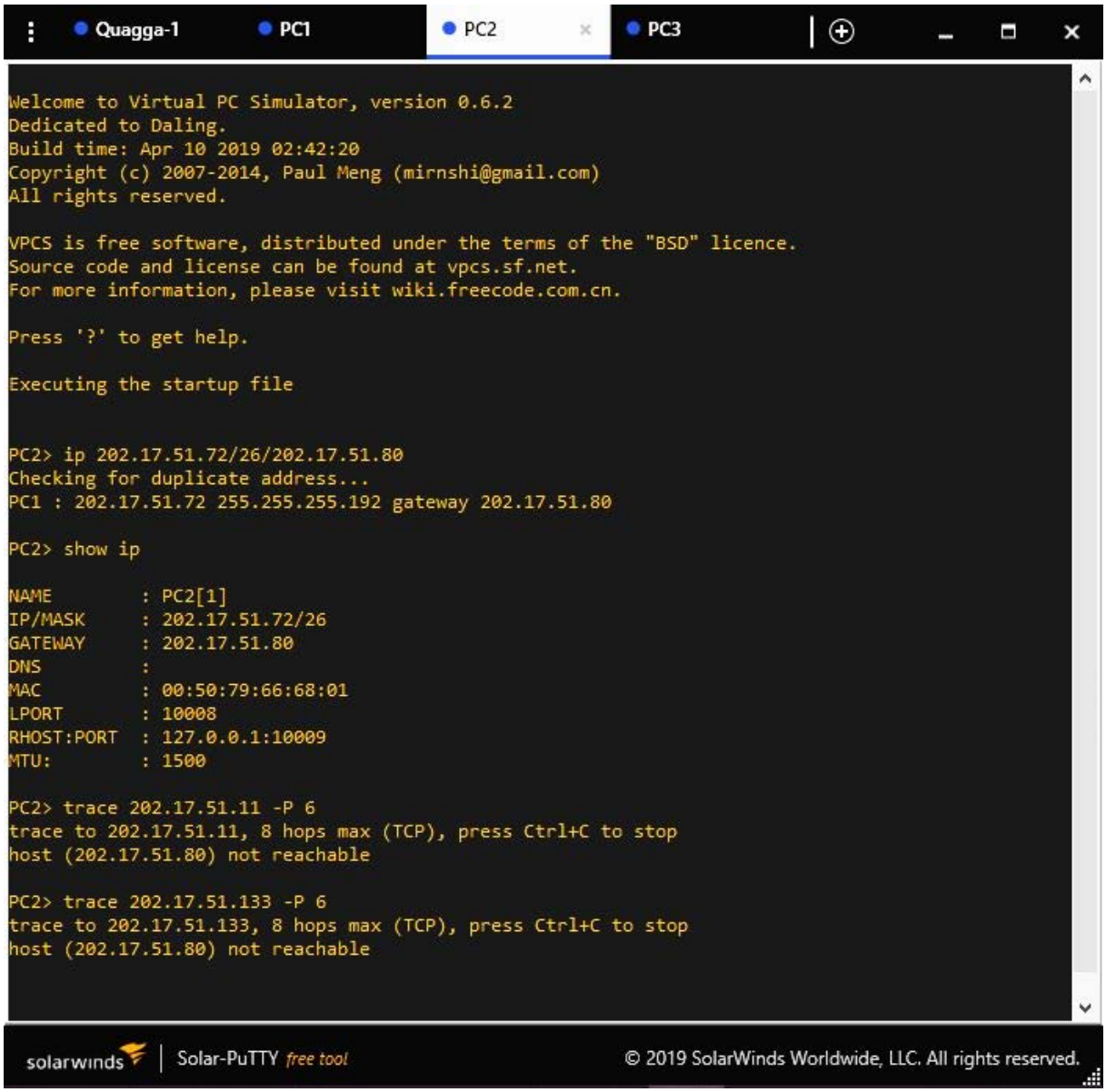

Figure 10: Setting up the IP address for PC2 and execution of trace command for GNS3 dynamic routing emulation

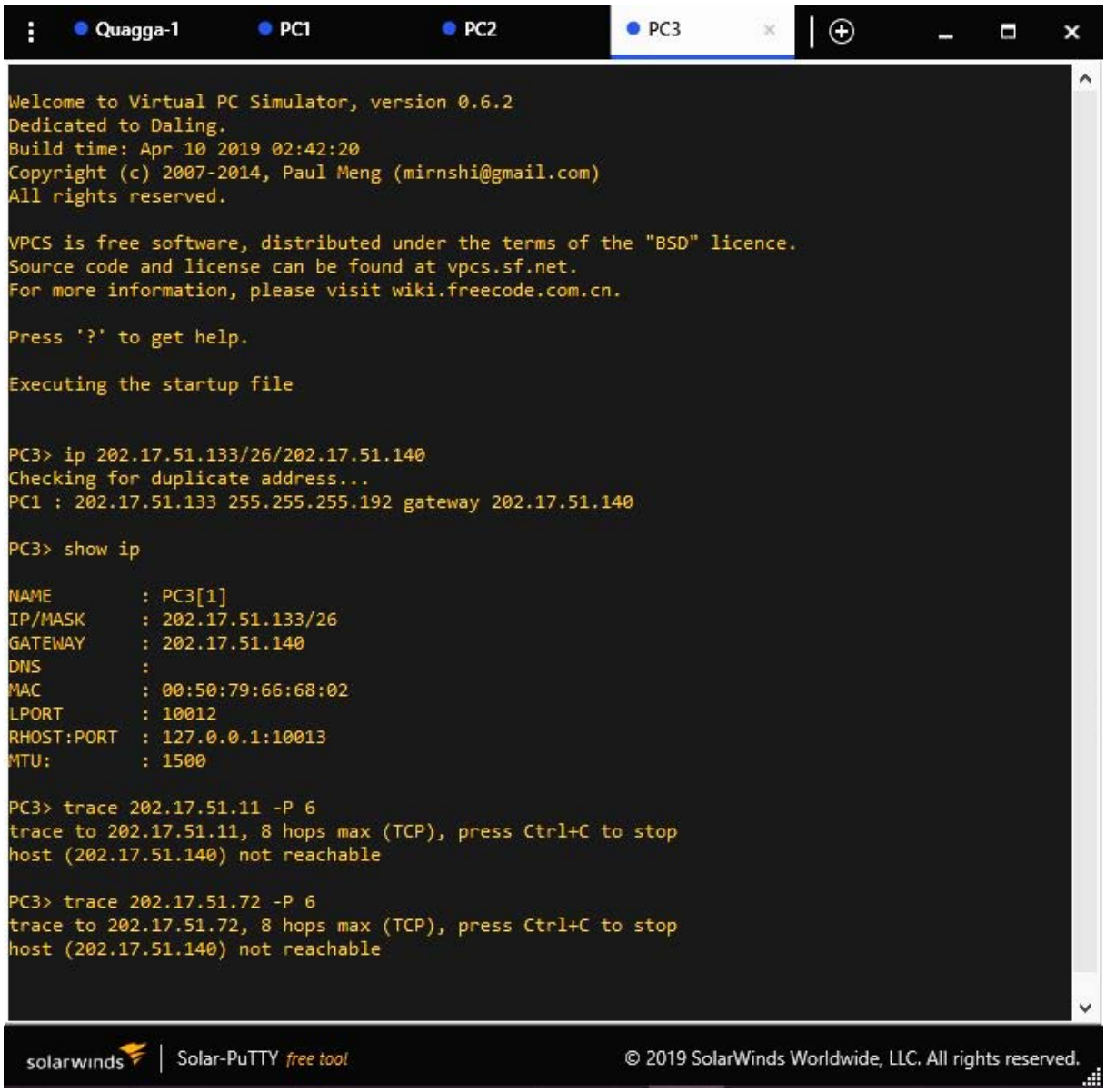

Figure 11: Setting up the IP address for PC3 and execution of trace command for GNS3 dynamic routing emulation

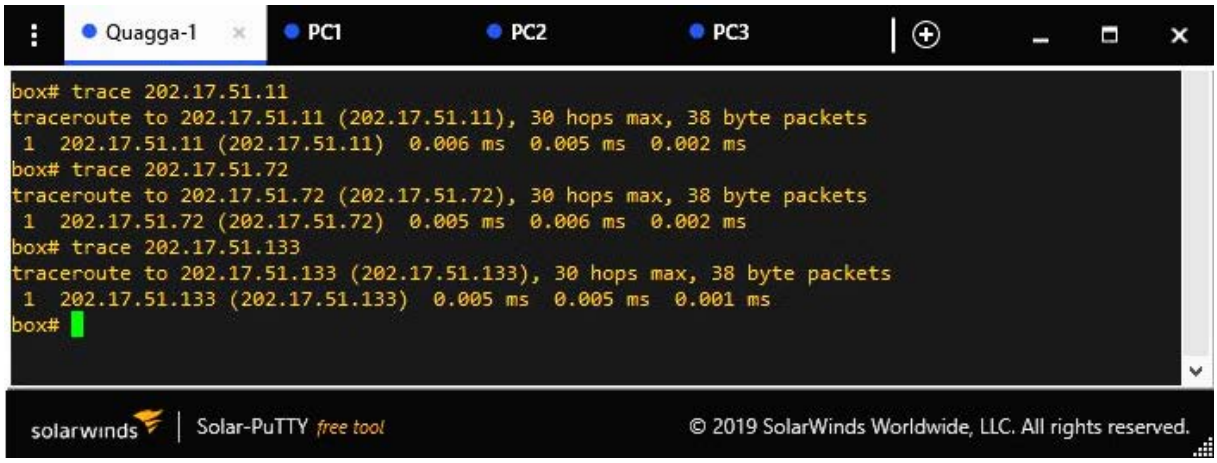

Figure 12: Execution of traceroute command from Quagga router emulator for GNS3 dynamic routing emulation

Table 1: Summary of LAN and PC IP address configuration for dynamic routing emulation with single Quagga router in star-topology

Computer	**IP Address**	**Netmask** [/26]	**Gateway Address**
PC1	202.17.51.11	255.255.255.192	202.17.51.20
PC2	202.17.51.72	255.255.255.192	202.17.51.80
PC3	202.17.51.133	255.255.255.192	202.17.51.140

2) ***Hardware implementation of dynamic routing in star-topology configuration with a single router on Linux routing appliance***

Figure 13, Figure 14, and Figure 15 below show the command windows for PC1, PC2, and PC3 respectively after carrying out the 'ipconfig' command to view the newly configured IP addresses. Figure 16, Figure 17, and Figure 18 show the 'tracert' command that was carried out between the PCs to trace the routes for PC1, PC2, and PC3 respectively. Figure 19, Figure 20, and Figure 21 show the 'ping' command that was carried out between PC1, PC2, and PC3 respectively. Table 2 below shows a summary of the PC IP address configurations.

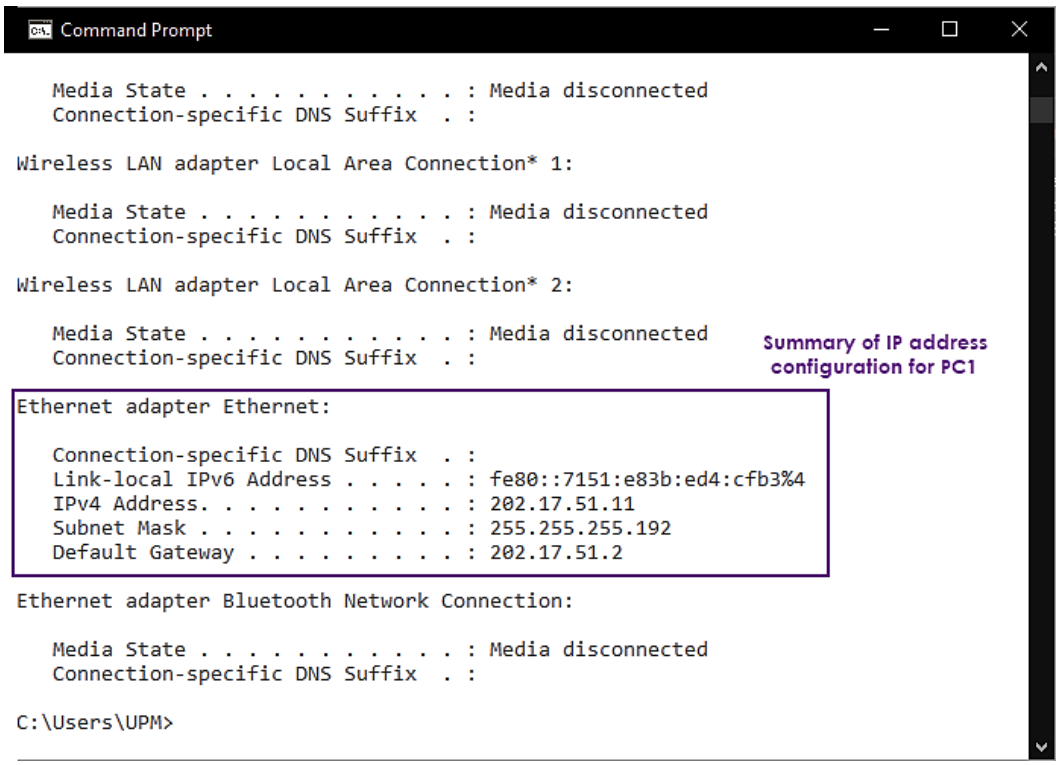

Figure 13: IP configuration summary of PC1 for the hardware implementation of dynamic routing in star-topology configuration

```
Select Command Prompt
Microsoft Windows [Version 10.0.19044.2486]
(c) Microsoft Corporation. All rights reserved.

C:\Users\ASUS>ipconfig

Windows IP Configuration


Unknown adapter Local Area Connection:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

Ethernet adapter VirtualBox Host-Only Network:

   Connection-specific DNS Suffix  . :
   Link-local IPv6 Address . . . . . : fe80::a569:d05e:f69c:2de0%8
   IPv4 Address. . . . . . . . . . . : 192.168.56.1
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . :

Wireless LAN adapter Local Area Connection* 3:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

Ethernet adapter Ethernet 2:

   Connection-specific DNS Suffix  . :
   Link-local IPv6 Address . . . . . : fe80::20e5:a2c2:4bca:1069%1
   IPv4 Address. . . . . . . . . . . : 202.17.51.72
   Subnet Mask . . . . . . . . . . . : 255.255.255.192
   Default Gateway . . . . . . . . . : 202.17.51.80

Wireless LAN adapter Wi-Fi:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . : upm.edu.my
```

Summary of IP address configuration for PC2

Figure 14: IP configuration summary of PC2 for the hardware implementation of dynamic routing in star-topology configuration

```
Command Prompt

Wireless LAN adapter Local Area Connection* 3:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

Wireless LAN adapter Local Area Connection* 12:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

Ethernet adapter Ethernet:

   Connection-specific DNS Suffix  . :
   Link-local IPv6 Address . . . . . : fe80::8871:754c:2438:76bb%3
   IPv4 Address. . . . . . . . . . . : 202.17.51.133
   Subnet Mask . . . . . . . . . . . : 255.255.255.192
   Default Gateway . . . . . . . . . : 202.17.51.140

Wireless LAN adapter Wi-Fi:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

Ethernet adapter Bluetooth Network Connection:

   Media State . . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :

C:\Users\Dell>
```

Summary of IP address configuration for PC3

Figure 15: IP configuration summary of PC3 for the hardware implementation of dynamic routing in star-topology configuration

```
Select Command Prompt
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 1ms

C:\Users\UPM>tracert 202.17.51.72          Traceroute to PC2

Tracing route to LAPTOP-O3M7UR09 [202.17.51.72]
over a maximum of 30 hops:

  1    <1 ms    <1 ms    <1 ms  202.17.51.2
  2     1 ms     1 ms    <1 ms  LAPTOP-O3M7UR09 [202.17.51.72]

Trace complete.

C:\Users\UPM>tracert 202.17.51.133         Traceroute to PC3

Tracing route to DESKTOP-ILRJG13 [202.17.51.133]
over a maximum of 30 hops:

  1    <1 ms    <1 ms    <1 ms  202.17.51.2
  2     2 ms     1 ms     1 ms  DESKTOP-ILRJG13 [202.17.51.133]

Trace complete.

C:\Users\UPM>
```

Figure 16: 'tracert' command executed from PC1 on the hardware implementation of dynamic routing in star-topology configuration

```
Select Command Prompt
C:\Users\ASUS>tracert 202.17.51.11         Traceroute to PC1

Tracing route to DESKTOP-CI7JREO [202.17.51.11]
over a maximum of 30 hops:

  1    <1 ms    <1 ms    <1 ms  202.17.51.80
  2     1 ms     1 ms    <1 ms  DESKTOP-CI7JREO [202.17.51.11]

Trace complete.

C:\Users\ASUS>tracert 202.17.51.133        Traceroute to PC3

Tracing route to DESKTOP-ILRJG13 [202.17.51.133]
over a maximum of 30 hops:

  1     1 ms    <1 ms    <1 ms  202.17.51.80
  2     1 ms     1 ms     1 ms  DESKTOP-ILRJG13 [202.17.51.133]

Trace complete.
```

Figure 17: 'tracert' command executed from PC2 on the hardware implementation of dynamic routing in star-topology configuration

```
Command Prompt

C:\Users\Dell>tracert 202.17.51.11        <- Traceroute to PC1

Tracing route to DESKTOP-CI7JREO [202.17.51.11]
over a maximum of 30 hops:

  1    <1 ms    <1 ms    <1 ms  202.17.51.140
  2    <1 ms    <1 ms    <1 ms  DESKTOP-CI7JREO [202.17.51.11]

Trace complete.

C:\Users\Dell>tracert 202.17.51.72        <- Traceroute to PC2

Tracing route to LAPTOP-O3M7UR09 [202.17.51.72]
over a maximum of 30 hops:

  1    <1 ms    <1 ms    <1 ms  202.17.51.140
  2     1 ms    <1 ms     1 ms  LAPTOP-O3M7UR09 [202.17.51.72]

Trace complete.

C:\Users\Dell>
```

Figure 18: 'tracert' command executed from PC3 on the hardware implementation of dynamic routing in star-topology configuration

```
Select Command Prompt
Microsoft Windows [Version 10.0.19044.2486]
(c) Microsoft Corporation. All rights reserved.

C:\Users\UPM>ping 202.17.51.72            <- Ping to PC2

Pinging 202.17.51.72 with 32 bytes of data:
Reply from 202.17.51.72: bytes=32 time<1ms TTL=127
Reply from 202.17.51.72: bytes=32 time=2ms TTL=127
Reply from 202.17.51.72: bytes=32 time=2ms TTL=127
Reply from 202.17.51.72: bytes=32 time=2ms TTL=127

Ping statistics for 202.17.51.72:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 1ms

C:\Users\UPM>ping 202.17.51.133           <- Ping to PC3

Pinging 202.17.51.133 with 32 bytes of data:
Reply from 202.17.51.133: bytes=32 time=1ms TTL=127
Reply from 202.17.51.133: bytes=32 time=2ms TTL=127
Reply from 202.17.51.133: bytes=32 time=1ms TTL=127
Reply from 202.17.51.133: bytes=32 time=2ms TTL=127

Ping statistics for 202.17.51.133:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 2ms, Average = 1ms

C:\Users\UPM>
```

Figure 19: 'ping' command executed from PC1 on the hardware implementation of dynamic routing in star-topology configuration

```
Select Command Prompt
C:\Users\ASUS>ping 202.17.51.11          <- Ping to PC2

Pinging 202.17.51.11 with 32 bytes of data:
Reply from 202.17.51.11: bytes=32 time=1ms TTL=127
Reply from 202.17.51.11: bytes=32 time=1ms TTL=127
Reply from 202.17.51.11: bytes=32 time=2ms TTL=127
Reply from 202.17.51.11: bytes=32 time=3ms TTL=127

Ping statistics for 202.17.51.11:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 3ms, Average = 1ms

C:\Users\ASUS>ping 202.17.51.133         <- Ping to PC3

Pinging 202.17.51.133 with 32 bytes of data:
Reply from 202.17.51.133: bytes=32 time=1ms TTL=127
Reply from 202.17.51.133: bytes=32 time=2ms TTL=127
Reply from 202.17.51.133: bytes=32 time=1ms TTL=127
Reply from 202.17.51.133: bytes=32 time=2ms TTL=127

Ping statistics for 202.17.51.133:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
```

Figure 20: 'ping' command executed from PC2 on the hardware implementation of dynamic routing in star-topology configuration

```
Command Prompt

Trace complete.

C:\Users\Dell>ping 202.17.51.11          <- Ping to PC2

Pinging 202.17.51.11 with 32 bytes of data:
Reply from 202.17.51.11: bytes=32 time=489ms TTL=127
Reply from 202.17.51.11: bytes=32 time<1ms TTL=127
Reply from 202.17.51.11: bytes=32 time<1ms TTL=127
Reply from 202.17.51.11: bytes=32 time<1ms TTL=127

Ping statistics for 202.17.51.11:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 489ms, Average = 122ms

C:\Users\Dell>ping 202.17.51.72          <- Ping to PC3

Pinging 202.17.51.72 with 32 bytes of data:
Reply from 202.17.51.72: bytes=32 time=1ms TTL=127
Reply from 202.17.51.72: bytes=32 time=2ms TTL=127
Reply from 202.17.51.72: bytes=32 time=2ms TTL=127
Reply from 202.17.51.72: bytes=32 time=2ms TTL=127

Ping statistics for 202.17.51.72:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 2ms, Average = 1ms

C:\Users\Dell>
```

Figure 21: 'ping' command executed from PC3 on the hardware implementation of dynamic routing in star-topology configuration

Table 2: Summary of LAN and PC IP address configuration for dynamic routing hardware implementation with single router in star-topology

Computer	**IP Address**	**Netmask** [/26]	**Gateway Address**
PC1	202.17.51.11	255.255.255.192	202.17.51.2
PC2	202.17.51.72	255.255.255.192	202.17.51.80
PC3	202.17.51.133	255.255.255.192	202.17.51.140

3) ***Emulation of dynamic routing in star-topology configuration with multiple routers on GNS3***

Figure 21, Figure 22, and Figure 23 show the console windows for PC1, PC2 and PC3 respectively. For each PC, the IP address was configured, the 'trace' command was carried out between the PCs to trace for the routes. Figure 24, Figure 25 and Figure 26 shows the 'traceroute' command being executed from the Quagga-1, Quagga-2 and Quagga-3 router emulators respectively. Table 3 below shows a summary of the PC IP address configurations.

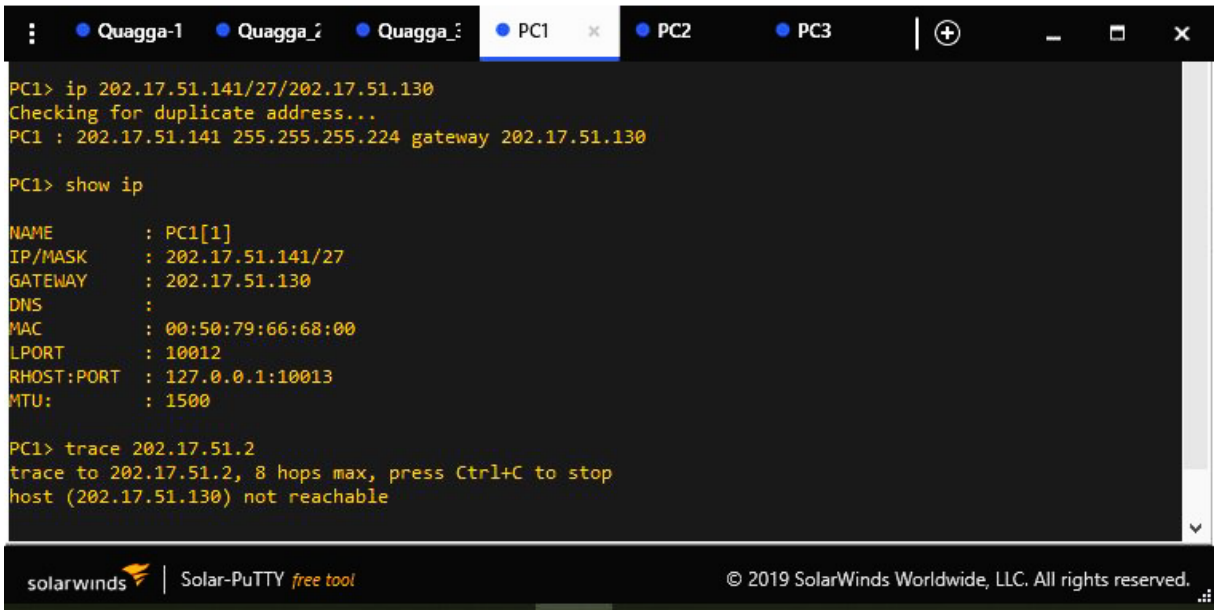

Figure 21: Setting up the IP address for PC1 and execution of trace command for GNS3 dynamic routing emulation with multiple routers

```
PC2> ip 202.17.51.2/27/202.17.51.30
Checking for duplicate address...
PC1 : 202.17.51.2 255.255.255.224 gateway 202.17.51.30

PC2> show ip

NAME        : PC2[1]
IP/MASK     : 202.17.51.2/27
GATEWAY     : 202.17.51.30
DNS         :
MAC         : 00:50:79:66:68:01
LPORT       : 10016
RHOST:PORT  : 127.0.0.1:10017
MTU:        : 1500

PC2>
```

Figure 22: Setting up the IP address for PC2 for GNS3 dynamic routing emulation with multiple routers

```
PC3> ip 202.17.51.186/27/202.17.51.170
Checking for duplicate address...
PC1 : 202.17.51.186 255.255.255.224 gateway 202.17.51.170

PC3> show ip

NAME        : PC3[1]
IP/MASK     : 202.17.51.186/27
GATEWAY     : 202.17.51.170
DNS         :
MAC         : 00:50:79:66:68:02
LPORT       : 10014
RHOST:PORT  : 127.0.0.1:10015
MTU:        : 1500

PC3>
```

Figure 23: Setting up the IP address for PC3 for GNS3 dynamic routing emulation with multiple routers

```
box# traceroute 202.17.51.141
traceroute to 202.17.51.141 (202.17.51.141), 30 hops max, 38 byte packets
 1  202.17.51.141 (202.17.51.141)  0.004 ms  0.005 ms  0.002 ms
box# traceroute 202.17.51.2
traceroute to 202.17.51.2 (202.17.51.2), 30 hops max, 38 byte packets
 1  202.17.51.120 (202.17.51.120)  2.974 ms  0.583 ms  0.522 ms
 2  202.17.51.2 (202.17.51.2)  3.617 ms  0.700 ms  0.698 ms
box# traceroute 202.17.51.186
traceroute to 202.17.51.186 (202.17.51.186), 30 hops max, 38 byte packets
 1  202.17.51.186 (202.17.51.186)  0.350 ms  0.479 ms  0.462 ms
box#
```

Figure 24: Execution of traceroute command from Quagga-1 router emulator for GNS3 dynamic routing emulation with multiple routers

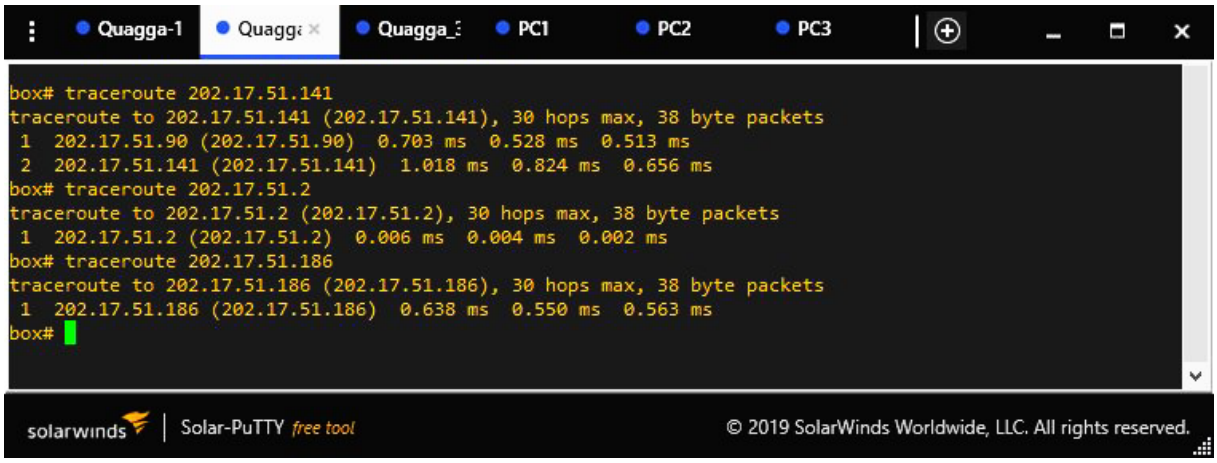

Figure 25: Execution of traceroute command from Quagga-2 router emulator for GNS3 dynamic routing emulation with multiple routers

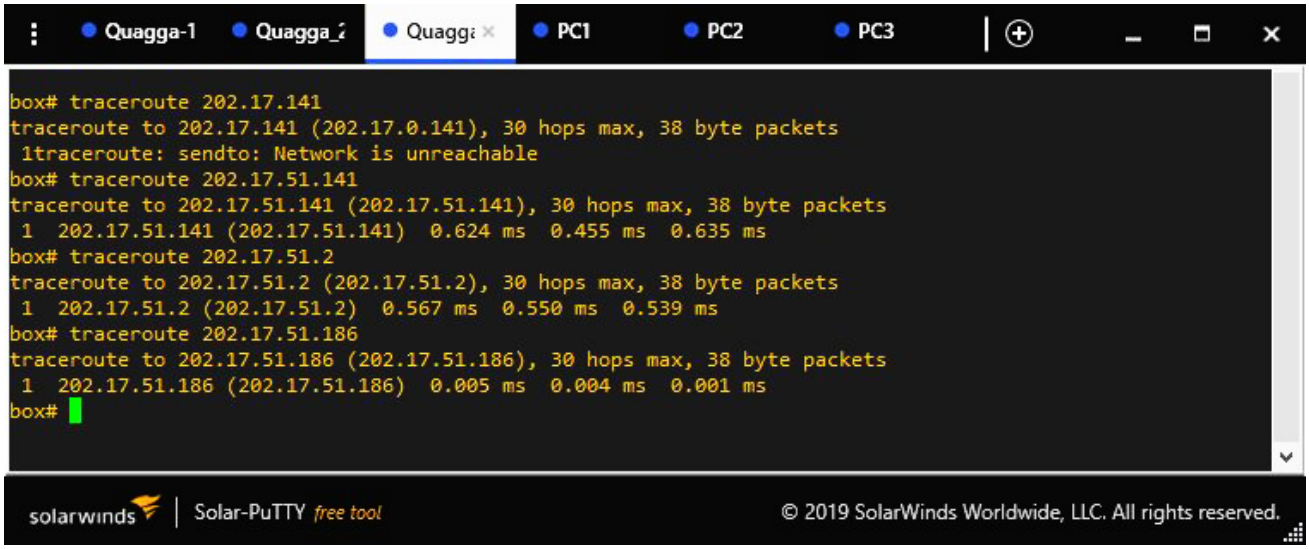

Figure 26: Execution of traceroute command from Quagga-3 router emulator for GNS3 dynamic routing emulation with multiple routers

Table 3: Summary of LAN and PC IP address configuration for dynamics routing emulation with multiple Quagga routers

Computer	**IP Address**	**Netmask** [/27]	**Gateway Address**
PC1	202.17.51.141	255.255.255.224	202.17.51.130
PC2	202.17.51.2	255.255.255.224	202.17.51.30
PC3	202.17.51.186	255.255.255.224	202.17.51.170

6.0 Discussion

a) What is the purpose of the routing algorithm?

A routing algorithm is a series of steps or procedures that is used to determine the best path or route to transfer data packets from source to destination using mathematical computations [3]. These algorithms hep to direct internet traffic efficiently. Once a data packet leaves the source or sender, it can choose from many different paths to reach the intended destination and routing algorithms ensure efficiency of this process.

b) Discuss link-state and distance-vector routing algorithms.

Algorithms that have the global state information of the entire network are called link-state (LS) algorithms as the algorithm must be aware of the cost of each link in the network [4]. The LS algorithm is a centralised routing algorithm and it is also dynamic whereby each router shares knowledge of its neighbouring routers with all other routers in the network. The LS algorithm makes use of the Dijkstra's algorithm to construct its routing tables [5]. The router shares its knowledge to the entire network using flooding whenever there is a change in the network. There are some problems with this method; there may be heavy traffic due to the flooding of data packets and the flooding may also result in infinite looping however this is resolved by using the TTL field.

The distance-vector (DV) algorithm is a decentralised routing algorithm as each node maintains a vector of estimated costs or distances to all the other nodes in the network [4], thus making it a dynamic algorithm [5]. The sharing of information among the routers is done at regular time intervals to its neighbours and the tables of each router are updated accordingly. The DV algorithm utilises the Bellman-Ford algorithm. There are some issues when using this algorithm; the count to infinity problem which can be resolved by split horizon protocol, persistent looping and the 'good news travels fast and bad news spreads slowly' issue.

c) Which routing technique is better; static or dynamic? Provide an explanation for your answer.

Static routing has a number of advantages such as being very predictable, very secure and not using resources such as memory and CPU however the drawbacks outweigh the benefits. Static routing is only suitable for small networks as manual configuration is required for each router which is not feasible for current networking systems [1]. Also, if a link failure occurs, the static route cannot reroute traffic which is wasteful of time and inefficient.

For the above reasons, dynamic routing is much more advantageous compared to static routing. Although dynamic routing requires additional resources such as CPU, memory and link bandwidth and also are costly at initial implementation [1], they are more versatile and suitable for the large and extensive modern networking topologies. Dynamic routing is suitable for all topology scales whereby multiple routers are required and since dynamic routing can automatically adapt the topology and reroute traffic in the event of a link failure or congestion, there is virtually no link failures [1].

d) What is the main difference between using RIP and OSPF routing servers?

The key differences between RIP (Routing Information Protocol) and OSPF (Open Shortest Path First) are listed in Table 4 below.

Table 4: Differences between RIP and OSPF protocols [6]

RIP	OSPF
Uses the Bellman-Ford algorithm	Uses the Dijkstra's algorithm
DV (distance-vector) algorithm and uses number of hops or distance to determine transmission path	LS (link-state) algorithm is used and the speed, cost and path congestion while identifying the shortest path
Used for smaller organisations	Used for larger organisations
Allows for a maximum of 15 hops	No restrictions on number of hops
Uses UDP (User Datagram Protocol) protocol	Works for IP (Internet Protocol)
Consumes more bandwidth due to sending the whole routing table	Consumes lesser bandwidth as only the required part of routing table is sent
Broadcasts to neighbouring routers every 30 seconds	Sends partial routing only when a change has been made

e) What is the main difference between using BGP and OSPF routing servers?

The key differences between BGP (Routing Information Protocol) and OSPF (Open Shortest Path First) are listed in Table 5 below.

Table 5: Differences between BGP and OSPF protocols [7]

	BGP	OSPF
Routing domain	Designed to be used to route between routing domains (inter-domain)	Is an interior gateway protocol and confined to a single domain (intra-domain)
Maximum network size	Can be scaled to the entire Internet	Suitable for mid-sized to large networks with several hundred routers
Implementation	Requires more effort and some advanced routing knowledge	Basic configuration in a single area with no complicated features
Network topology	Mesh topology but may be modified to star topology using a route reflector	Hierarchical topology used
Convergence	Slower reaction due to extensive scale	Reacts quicker to changes in network
Resource requirements	Memory and CPU requirements increase along with size of routing table	Intensive memory and CPU requirement
Metrics	BGP attributes used to determine best route	Bandwidth and cost used to determine best route

f) What is the main configuration file of the OSPF routing server and where is it located?

The main configuration file of the OSPF routing server in the Quagga routing software are the following [8]:

```
# cd /usr/local/etc/quagga
# cp /usr/local/share/examples/quagga/zebra.conf.sample zebra.conf
# cp /usr/local/share/examples/quagga/ospfd.conf.sample ospfd.conf
```

The `zebra.conf` file is the overall manager of the IP forwarding table which enables the routing functionality. The `ospfd.conf` file is a text file that is the daemon which runs the OSPF protocol. Both these files are located inside the Quagga router software.

g) What is the difference between the backbone area and the stub area in OSPF?

An OSPF network can be divides into sub-domains known as 'areas' [9]. A router that is within any area must maintain the topological database of that area which it belongs to. Since the router does not contain the information of the routers in other areas, the size of the database is reduced greatly. Areas limit the coverage of route information distribution. There are a few types of areas which are use to control link-state advertisements (LSAs) across the OSPF network; standard or normal area, backbone area, stub area, totally stubby area and 'not so stubby' area (NSSA).

The backbone area is similar to the standard area and is referred to as 'Area 0' [9]. LSAs of Type 1 and 2 are sent between the routers within an area which aids in preparing the shortest path tree for the particular area. Type 3 LSA shares the internal routes and LSA Type 5 shares the external routes flood through the area. The internal routes are by the OSPF router and the external routes are by the autonomous system boundary router (ASBR).

In a stub area, a default route is sent by the area border router (ABR) along with Type 3 LSA [9]. The default route allows reaching the external networks. All the routers in a given area must be configured as stub for the are to be a stub area.

h) Define internal router, backbone router, boundary router and area border router.

The following are OSPF router types and respective positions in the autonomous system (AS). An AS is a collection of IP networks under a common administration and share common routing strategy and run a single routing protocol [11].

- *Internal router* – These routers belong in the same OSPF region as they are directly connected networks and belong to only one area [10]. Internal routers have a single LSDB (link-state database).

- *Backbone router* – These routers exclusively connect to the backbone area as they do not have an interface with any of the other OSPF regions [10].

- *Boundary router* – Autonomous system boundary routers (ASBRs) are connected to many Ass to communicate with the routers in the other Ass to exchange routing information [10]. The transferred external routing information is advertised by the ASBRs throughout their particular AS.

- *Border router* – Area border routers (ABRs) are linked to the various OSPF areas and a single area may have several ABRs [10]. A router is in between an OSPF and a non-OSPF network and the routing information is redistributed between the networks using this protocol.

i) Discuss your achievements and problems encountered during the laboratory session.

The objectives of the laboratory session were fulfilled successfully as the desired results were obtained. Emulation and hardware implementation of dynamic routing was carried out using the OSPF protocol on two different topologies; single router topology and three-router topology. For both laboratory tasks, the traceroute command was carried out to trace the path taken by the network packets between the hosts. There were no notable issues encountered throughout the experiments and the expected results were obtained.

There was human error made during the emulation of the three-router topology. When configuring the Quagga routers, the gateway IP address of the PCs needed to be set as the port interface of the routers to allow packet forwarding. It was due to this mistake that the output from the traceroute command was not as expected. Supposedly, at least three hops should have been observed because in order to trace from one PC to another the packets need to be forwarded by two routers. Table 6 below shows the number of expected hops to be observed if the correct configuration was made. Since the OSPF protocol is used, the shortest path is counted.

Table 6: Expected number of hops from 'traceroute' command

Source to Destination	Number of hops
PC1 to PC2	3 hops as packets need to travel from PC then through two routers to reach another PC.
PC1 to PC3	
PC2 to PC1	
PC2 to PC3	
PC3 to PC1	
PC3 to PC2	
Quagga-1 to PC1	1 hop
Quagga-1 to PC2	2 hops
Quagga-1 to PC3	
Quagga_2-1 to PC2	1 hop
Quagga_2-1 to PC1	2 hops
Quagga_2-1 to PC3	

Quagga_3-1 to PC3	1 hop
Quagga_3-1 to PC2	2 hops
Quagga_3-1 to PC1	

Conclusion

The objectives of the laboratory session were fulfilled successfully as the desired results were obtained. Dynamic routing was carried out using a single router topology as well as a multiple router topology. Emulation of the single router topology was carried out on GNS3 using the Quagga router software as well as the multiple router topology using OSPF protocol. The single router topology was also implemented on hardware using the NA-810C Linux routing appliance.

References

[1] "Cisco networking academy's introduction to routing dynamically," *Ciscopress.com*. [Online]. Available: https://www.ciscopress.com/articles/article.asp?p=2180210&seqNum=4. [Accessed: 20-Jan-2023].

[2] "Dynamic routing protocols," *Catchpoint.com*. [Online]. Available: https://www.catchpoint.com/dynamic-routing-protocols. [Accessed: 20-Jan-2023].

[3] "What is a Routing Algorithm in Computer Network?," *Tutorialspoint.com*. [Online]. Available: https://www.tutorialspoint.com/what-is-a-routing-algorithm-in-computer-network. [Accessed: 20-Jan-2023].

[4] J. F. Kurose and K. W. Ross, "The Network Layer: Control Plane," in *Computer networking: A top-down approach: International edition*, 5th ed., Upper Saddle River, NJ: Pearson, 2010, pp. 409–480.

[5] "Difference between Distance vector routing and Link State routing," *GeeksforGeeks*, 30-Apr-2018. [Online]. Available: https://www.geeksforgeeks.org/difference-between-distance-vector-routing-and-link-state-routing/. [Accessed: 20-Jan-2023].

[6] "Difference between RIP and OSPF," *GeeksforGeeks*, 03-Jun-2020. [Online]. Available: https://www.geeksforgeeks.org/difference-between-rip-and-ospf/. [Accessed: 20-Jan-2023].

[7] "BGP vs OSPF," *Catchpoint.com*. [Online]. Available: https://www.catchpoint.com/dynamic-routing-protocols/bgp-vs-ospf. [Accessed: 20-Jan-2023].

[8] R. Bhardwaj, "OSPF Area types: Detailed explanation," *IP With Ease*, 20-Jul-2022. .

[9] R. Salunke, "OSPF Router Types," *EDUCBA*, 17-Jul-2021. [Online]. Available: https://www.educba.com/ospf-router-types/. [Accessed: 20-Jan-2023].

[10] "IBM documentation," *Ibm.com*, 08-Sep-2021. [Online]. Available: https://www.ibm.com/docs/en/i/7.3?topic=concepts-ospf-routing-domain-areas. [Accessed: 20-Jan-2023].