EINTE lab 2 - OSPF
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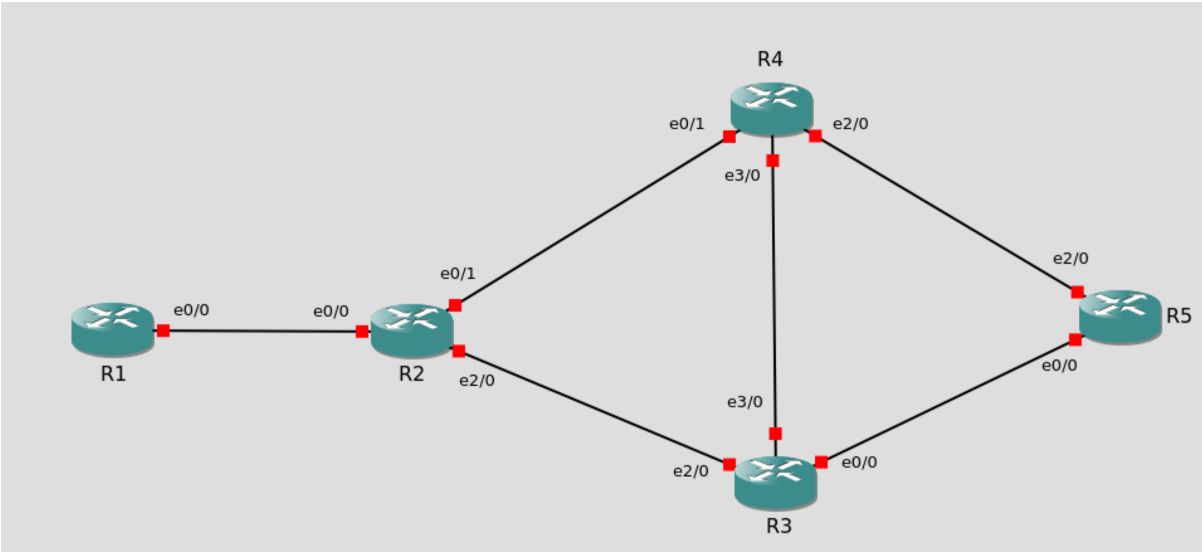
Task A - Basic device configuration

Introduction

For this task, we will need to perform basic router configuration in the network. To remind, this is how the network looks like:



Note that ex/y are FastEthernet interfaces. x stands for the card number, y stands for the port number. In this picture, the interfaces are named 'e'. This is most likely a result of a typo. They should be labeled fx/y. x and y remains unchanged.

IP addressing task prerequisites

From the task description, we show prerequisites regarding IP address allocation:

- IP Addresses for R1-R2 link should be addressed using the range
  - `192.168.11.0/30`
- IP addresses for any other link should be addressed using the range:
  - `192.168.10.0/27`
- IP addresses for loopback should be addressed using the range:
  - `192.168.0.0/29`

So, the actual available IP addresses for a given range can be obtained as follows:
(32 - netmask) tells us how many rightmost bits we can modify in an ip address.
So for example, in `192.168.11.0/30` we can modify only two of the rightmost bits.
That is, two rightmost bits in the last (rightmost) octet.
With the knowledge regarding binary system, we know that the biggest number made from two binary bits is = 3
Then from the obtained number we must subtract one, as one of the IP addresses is reserved for broadcast. The broadcast IP is the one for which every bit is set to 1 that is not a part of the mask.

IP address range calculations

Below we show theoretical calculations for the available IPs for a given IP/mask. Broadcast IP is omitted:

`192.168.11.0/30:`

`192.168.11.1 ; 192.168.11.2`

Since the highest number we can write in binary 32 - 30 = 2 bits is 3. So we got a maximum of 3 addresses, -1 for broadcast addresses. In total 2 addresses

`192.168.10.0/27:`

`192.168.10.1 ; 192.168.10.2 ; … ; 192.168.10.29 ; 192.168.10.30`

Since 32 - 27 = 5 and in 5 bits we can write the highest number 31. -1 for broadcast gives us 30 possible addresses.

`192.168.0.0/29:`

`192.168.0.1 ; 192.168.0.2 ; … ; 192.168.0.5 ; 192.168.0.6`

Analogical: 32 - 29 = 3. Highest binary for 3 bits is 7. -1 addr for broadcast, we end up with 6 possible addresses.

IP addressing - subnetting

Before showing the table, it should be noted that since we need to define a separate subnet for every link in the network (this is per task description), we will need to divide our `192.168.10.0/27` pool into smaller subnets. We will need 5 subnets, since there are 5 links between every router except R1. The above-mentioned scope can be divided into the following subnets:

`192.168.10.0/30`

`192.168.10.4/30`

…

`192.168.10.24/30`

`192.168.10.28/30`

This is from the fact that `192.168.10.0/27` netmask in binary is:

`11111111.11111111.11111111.111000 00`

So we can theoretically take some of the 0 bits (leftmost) and make subnets. The amount of subnets is from the amount of bits taken. Unfortunately, since we need 5 subnets, we need to take 3 bits, as for 2 bits we could only make 4 subnets.

For the task, we will use the first 5 subnets, that being:

`192.168.10.0/30 ; 192.168.10.4/30 ; 192.168.10.8/30 ;`

`192.168.10.12/30 and 192.168.10.16/30`

`192.168.10.20/30 ; 192.168.10.24/30 and 192.168.10.28/30` are available, but are unused

IP addressing - table

Below we show a table showing our planning for the IP address assignment for every router in our network:

Link no.	Routers	Interface	Assigned address	Address pool	Netmask
1	R1	f0/0	192.168.11.1	192.168.11.0/30	255.255.255.252
	R2		192.168.11.2		
2	R2	f2/0	192.168.10.1	192.168.10.0/30	
	R3		192.168.10.2		
3	R2	f0/1	192.168.10.5	192.168.10.4/30	
	R4		192.168.10.6		
4	R3	f3/0	192.168.10.9	192.168.10.8/30	
	R4		192.168.10.10		
5	R3	f0/0	192.168.10.13	192.168.10.12/30	
	R5		192.168.10.14		
6	R4	f2/0	192.168.10.17	192.168.10.16/30	
	R5		192.168.10.18		

And for loopback addresses:

Routers	Loopback address	Address pool	Netmask
R1	192.168.0.1	192.168.0.0/29	255.255.255.255
R2	192.168.0.2		
R3	192.168.0.3		
R4	192.168.0.4		
R5	192.168.0.5		

IP addressing - lab devices configuration in GNS3 environment

The next part of the task is to actually configure the routers. The network topology was given in the task as a GNS3 project file. Emulated routers are in total 5 routers of a cisco 1600 type. The following commands will be used to configure the routers. Step by step we will explain the purpose of the commands.

First of all, we need to turn on every router in our topology.
Then, opening a console for a router by right clicking a router and choosing ‘console’
After that, the following commands should be used:

This invokes a configuration option for the router. ‘t’ indicates that the terminal will be used to configure the router.

```
R1#config
Configuring from terminal, memory, or network [terminal]? t
```

This command enters the configuration for the interface (f0/0 for this picture). The R1(config) changes into R1(config-if), indicating we are configuring an interface.

```
R1(config)#interface f0/0
R1(config-if)#_
```

Then, we set up the ip address for the interface using the `ip address <address> <mask>` command. After that, `no shut` is used so that the interface is set to running mode (by default it is in shutdown mode). Full command is `no shutdown`. After that, `exit` leaves the interface configuration. We go back into R1(config)

```
R1(config-if)#ip address 192.168.11.1 255.255.255.252
R1(config-if)#no shut
R1(config-if)#exit
*Mar  1 00:08:44.235: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to up
*Mar  1 00:08:45.235: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/0, ch
anged state to up
```

Then, analogically to the setup of the fastethernet, we will setup loopback address:

```
R1(config)#interface l0
R1(config-if)#
*Mar  1 00:43:07.663: %LINEPROTO-5-UPDOWN: Line protocol on Interface Loopback0, changed
state to up
R1(config-if)#ip address 192.168.0.1 255.255.255.255
R1(config-if)#no shut
R1(config-if)#exit
R1(config)#_
```

After that, we will check if the configuration was done properly by running:

```
R1#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.1 is directly connected, Loopback0
```

And as it can be seen, configuration was successful.

We need to do one more very important thing - save the configuration. It copies the current config into the config that the router will start with.:

```
R1#copy running-config startup-config
Destination filename [startup-config]?
Building configuration...
[OK]
```

So, all routers will be configured as above-mentioned, with the difference of interface names and IP address assigned to the interfaces.

`show ip route` - IP address allocation for every router

In this paragraph, as requested in the task description, we will show the output of the `show ip route` command, to verify proper configuration of every router. Furthermore, complete console log containing configuration commands executed for every router are attached with the report

We also decided to add `show ip interface brief` command to show that the IPs were properly assigned. `show ip route` shows only subnet connections

Router R1:

```
R1#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.1 is directly connected, Loopback0
```

```
R1#show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
FastEthernet0/0            192.168.11.1    YES manual up                    up
FastEthernet0/1            unassigned      YES unset  administratively down down
FastEthernet1/0            unassigned      YES unset  administratively down down
FastEthernet2/0            unassigned      YES unset  administratively down down
FastEthernet3/0            unassigned      YES unset  administratively down down
Loopback0                  192.168.0.1     YES manual up                    up
```

R2:

```
R2#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 2 subnets
C       192.168.10.0 is directly connected, FastEthernet2/0
C       192.168.10.4 is directly connected, FastEthernet0/1
     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.2 is directly connected, Loopback0
```

```
R2#show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
FastEthernet0/0            192.168.11.2    YES manual up                    up
FastEthernet0/1            192.168.10.5    YES manual up                    up
FastEthernet1/0            unassigned      YES unset  administratively down down
FastEthernet2/0            192.168.10.1    YES manual up                    up
FastEthernet3/0            unassigned      YES unset  administratively down down
Loopback0                  192.168.0.2     YES manual up                    up
```

R3:

```
R3#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 3 subnets
C       192.168.10.0 is directly connected, FastEthernet2/0
C       192.168.10.8 is directly connected, FastEthernet3/0
C       192.168.10.12 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.3 is directly connected, Loopback0
```

```
R3#show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
FastEthernet0/0            192.168.10.13   YES manual up                    up
FastEthernet0/1            unassigned      YES unset  administratively down down
FastEthernet1/0            unassigned      YES unset  administratively down down
FastEthernet2/0            192.168.10.2    YES manual up                    up
FastEthernet3/0            192.168.10.9    YES manual up                    up
Loopback0                  192.168.0.3     YES manual up                    up
```

R4:

```
R4#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 3 subnets
C       192.168.10.4 is directly connected, FastEthernet0/1
C       192.168.10.8 is directly connected, FastEthernet3/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.4 is directly connected, Loopback0
R4#show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
FastEthernet0/0            unassigned      YES unset  administratively down down
FastEthernet0/1            192.168.10.6    YES manual up                    up
FastEthernet1/0            unassigned      YES unset  administratively down down
FastEthernet2/0            192.168.10.17   YES manual up                    up
FastEthernet3/0            192.168.10.10   YES manual up                    up
Loopback0                  192.168.0.4     YES manual up                    up
```

R5:

```
R5#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 2 subnets
C       192.168.10.12 is directly connected, FastEthernet0/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.5 is directly connected, Loopback0
R5#show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
FastEthernet0/0            192.168.10.14   YES manual up                    up
FastEthernet0/1            unassigned      YES unset  administratively down down
FastEthernet1/0            unassigned      YES unset  administratively down down
FastEthernet2/0            192.168.10.18   YES manual up                    up
FastEthernet3/0            unassigned      YES unset  administratively down down
Loopback0                  192.168.0.5     YES manual up                    up
R5#
```

Task A - conclusions

As it can be seen, the interfaces have been correctly configured. That can be confirmed by `show ip route` and `show ip interface brief` commands.
But, prior to enabling the OSPF protocol we can see that the routers only connect to its neighbours.
For example Router 5 doesn't have any information on how to connect to router 1 or router 2. This can be seen by only two direct connections existing for router 5 (apart from loopback). If router 5 would know about R2 and R1, it would have had information about such connections with the letter O next to it (refer to the codes shown just after running the command).
But there only exist two C - connections (direct)
Same for other routers. There only exists the number of direct connections corresponding to the amount of links directly connected to the router.

Task B - initial OSPF configuration

In this task, we are going to perform basic OSPF configuration for our routers. All will be done according to the provided guide in the task .pdf. Below we show used commands to set up basic OSPF for our routers. The process is similar to the configuration of interfaces earlier, but there are some differences:

First we need to go into a console of a router, and invoke the config t command.

Then, we need to create an ospf process in our router, the command for this is:
router ospf <PID> ; PID being some process ID. 1 was chosen for every router.

That way, we enter ospf interface configuration. From now on, we need to do:
network <prefix> <wildcard-mask> area <area-id>

There are different ways to properly invoke this command. One can use wildcard-masks, but we have chosen to invoke a single command for every interface. <prefix> is the interface IP. <wildcard-mask> for our case should be 0.0.0.0 and area-id should be 0 - meaning BACKBONE network.

Take this example for R4 to demonstrate:

```
R4#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 3 subnets
C       192.168.10.4 is directly connected, FastEthernet0/1
C       192.168.10.8 is directly connected, FastEthernet3/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.4 is directly connected, Loopback0
R4#show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
FastEthernet0/0            unassigned      YES unset  administratively down down
FastEthernet0/1            192.168.10.6    YES manual up                    up
FastEthernet1/0            unassigned      YES unset  administratively down down
FastEthernet2/0            192.168.10.17   YES manual up                    up
FastEthernet3/0            192.168.10.10   YES manual up                    up
Loopback0                  192.168.0.4     YES manual up                    up
```

The following commands should be executed for our configuration procedure:

```
config t
router ospf 1
network 192.168.10.6 0.0.0.0 area 0
network 192.168.10.17 0.0.0.0 area 0
network 192.168.10.10 0.0.0.0 area 0
exit
exit
copy running-config startup-config
```

Initial OSPF configuration for all routers

Here we shot all necessary screenshots regarding initial OSPF config for our routers:

R1 OSPF config:

```
R1#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O       192.168.10.0 [110/11] via 192.168.11.2, 00:00:11, FastEthernet0/0
O       192.168.10.4 [110/20] via 192.168.11.2, 00:00:11, FastEthernet0/0
O       192.168.10.8 [110/12] via 192.168.11.2, 00:00:11, FastEthernet0/0
O       192.168.10.12 [110/21] via 192.168.11.2, 00:00:11, FastEthernet0/0
O       192.168.10.16 [110/13] via 192.168.11.2, 00:00:11, FastEthernet0/0
     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.1 is directly connected, Loopback0
```

```
R1#show ip ospf
 Routing Process "ospf 1" with ID 192.168.0.1
 Start time: 00:00:09.440, Time elapsed: 00:35:30.104
 Supports only single TOS(TOS0) routes
 Supports opaque LSA
 Supports Link-local Signaling (LLS)
 Supports area transit capability
 Router is not originating router-LSAs with maximum metric
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Incremental-SPF disabled
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of opaque AS LSA 0. Checksum Sum 0x000000
 Number of DCbitless external and opaque AS LSA 0
 Number of DoNotAge external and opaque AS LSA 0
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Number of areas transit capable is 0
 External flood list length 0
    Area BACKBONE(0)
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm last executed 00:21:14.616 ago
        SPF algorithm executed 9 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x04B2A7
        Number of opaque link LSA 0. Checksum Sum 0x000000
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0
```

R2:

```
R2#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
C       192.168.10.0 is directly connected, FastEthernet2/0
C       192.168.10.4 is directly connected, FastEthernet0/1
O       192.168.10.8 [110/2] via 192.168.10.2, 00:00:18, FastEthernet2/0
O       192.168.10.12 [110/11] via 192.168.10.2, 00:00:18, FastEthernet2/0
O       192.168.10.16 [110/3] via 192.168.10.2, 00:00:18, FastEthernet2/0
     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.2 is directly connected, Loopback0
```

```
R2#show ip ospf
 Routing Process "ospf 1" with ID 192.168.0.2
 Start time: 00:00:08.948, Time elapsed: 00:35:41.648
 Supports only single TOS(TOS0) routes
 Supports opaque LSA
 Supports Link-local Signaling (LLS)
 Supports area transit capability
 Router is not originating router-LSAs with maximum metric
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Incremental-SPF disabled
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of opaque AS LSA 0. Checksum Sum 0x000000
 Number of DCbitless external and opaque AS LSA 0
 Number of DoNotAge external and opaque AS LSA 0
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Number of areas transit capable is 0
 External flood list length 0
    Area BACKBONE(0)
        Number of interfaces in this area is 3
        Area has no authentication
        SPF algorithm last executed 00:21:25.424 ago
        SPF algorithm executed 9 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x04B2A7
        Number of opaque link LSA 0. Checksum Sum 0x000000
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0
```

R3:

```
R3#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
C       192.168.10.0 is directly connected, FastEthernet2/0
O       192.168.10.4 [110/11] via 192.168.10.10, 00:01:07, FastEthernet3/0
                     [110/11] via 192.168.10.1, 00:01:07, FastEthernet2/0
C       192.168.10.8 is directly connected, FastEthernet3/0
C       192.168.10.12 is directly connected, FastEthernet0/0
O       192.168.10.16 [110/2] via 192.168.10.10, 00:01:07, FastEthernet3/0
     192.168.11.0/30 is subnetted, 1 subnets
O       192.168.11.0 [110/11] via 192.168.10.1, 00:01:09, FastEthernet2/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.3 is directly connected, Loopback0
```

```
R3#show ip ospf
 Routing Process "ospf 1" with ID 192.168.0.3
 Start time: 00:09:52.804, Time elapsed: 00:24:29.292
 Supports only single TOS(TOS0) routes
 Supports opaque LSA
 Supports Link-local Signaling (LLS)
 Supports area transit capability
 Router is not originating router-LSAs with maximum metric
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Incremental-SPF disabled
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of opaque AS LSA 0. Checksum Sum 0x000000
 Number of DCbitless external and opaque AS LSA 0
 Number of DoNotAge external and opaque AS LSA 0
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Number of areas transit capable is 0
 External flood list length 0
    Area BACKBONE(0)
        Number of interfaces in this area is 3
        Area has no authentication
        SPF algorithm last executed 00:21:32.360 ago
        SPF algorithm executed 8 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x04B2A7
        Number of opaque link LSA 0. Checksum Sum 0x000000
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0
```

R4:

```
R4#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O       192.168.10.0 [110/2] via 192.168.10.9, 00:01:15, FastEthernet3/0
C       192.168.10.4 is directly connected, FastEthernet0/1
C       192.168.10.8 is directly connected, FastEthernet3/0
O       192.168.10.12 [110/11] via 192.168.10.18, 00:01:15, FastEthernet2/0
                      [110/11] via 192.168.10.9, 00:01:15, FastEthernet3/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.11.0/30 is subnetted, 1 subnets
O       192.168.11.0 [110/12] via 192.168.10.9, 00:01:17, FastEthernet3/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.4 is directly connected, Loopback0
```

```
R4#show ip ospf
 Routing Process "ospf 1" with ID 192.168.0.4
 Start time: 00:11:08.212, Time elapsed: 00:23:23.656
 Supports only single TOS(TOS0) routes
 Supports opaque LSA
 Supports Link-local Signaling (LLS)
 Supports area transit capability
 Router is not originating router-LSAs with maximum metric
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Incremental-SPF disabled
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of opaque AS LSA 0. Checksum Sum 0x000000
 Number of DCbitless external and opaque AS LSA 0
 Number of DoNotAge external and opaque AS LSA 0
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Number of areas transit capable is 0
 External flood list length 0
    Area BACKBONE(0)
        Number of interfaces in this area is 3
        Area has no authentication
        SPF algorithm last executed 00:21:39.700 ago
        SPF algorithm executed 6 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x04B2A7
        Number of opaque link LSA 0. Checksum Sum 0x000000
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0
```

R5:

```
R5#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O       192.168.10.0 [110/3] via 192.168.10.17, 00:01:27, FastEthernet2/0
O       192.168.10.4 [110/11] via 192.168.10.17, 00:01:27, FastEthernet2/0
O       192.168.10.8 [110/2] via 192.168.10.17, 00:01:27, FastEthernet2/0
C       192.168.10.12 is directly connected, FastEthernet0/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.11.0/30 is subnetted, 1 subnets
O       192.168.11.0 [110/13] via 192.168.10.17, 00:01:27, FastEthernet2/0
     192.168.0.0/32 is subnetted, 1 subnets
C       192.168.0.5 is directly connected, Loopback0
```

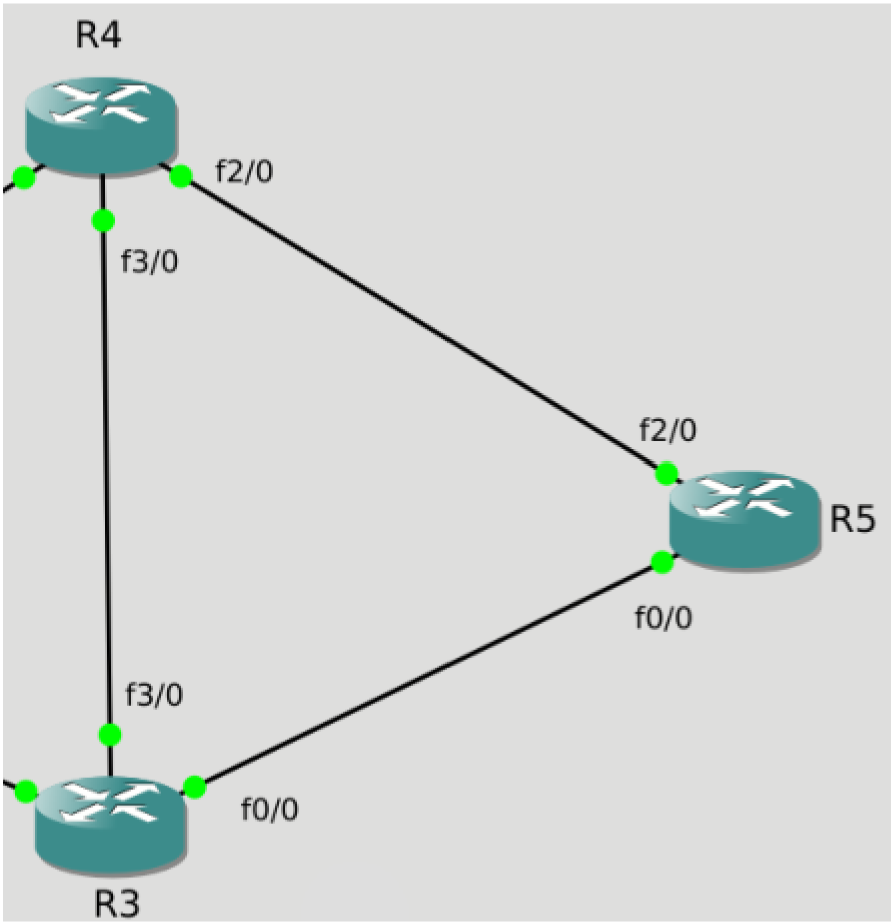
```
R5#show ip ospf
 Routing Process "ospf 1" with ID 192.168.0.5
 Start time: 00:11:55.348, Time elapsed: 00:22:19.752
 Supports only single TOS(TOS0) routes
 Supports opaque LSA
 Supports Link-local Signaling (LLS)
 Supports area transit capability
 Router is not originating router-LSAs with maximum metric
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Incremental-SPF disabled
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of opaque AS LSA 0. Checksum Sum 0x000000
 Number of DCbitless external and opaque AS LSA 0
 Number of DoNotAge external and opaque AS LSA 0
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Number of areas transit capable is 0
 External flood list length 0
    Area BACKBONE(0)
        Number of interfaces in this area is 2
        Area has no authentication
        SPF algorithm last executed 00:21:55.676 ago
        SPF algorithm executed 2 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x04B2A7
        Number of opaque link LSA 0. Checksum Sum 0x000000
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0
```

Task B - conclusions

Looking at the show ip route command now, compared to task 1, we see a huge difference. OSPF configuration has been successful. Every router in the network is connected to every defined subnet, even the subnets that require for the data to traverse through one router to get to the other. This is the task of OSPF - to route the data through different routers, making non-neighbouring routers (interfaces) available to every router in the network. Generally the correctness of the OSPF configuration can be noticed by the fact that every router knows every subnet in the network (of course excluding individual loopback interfaces).

It should be noted that for some routers, there exist two ways to connect to one interface. It is normal.

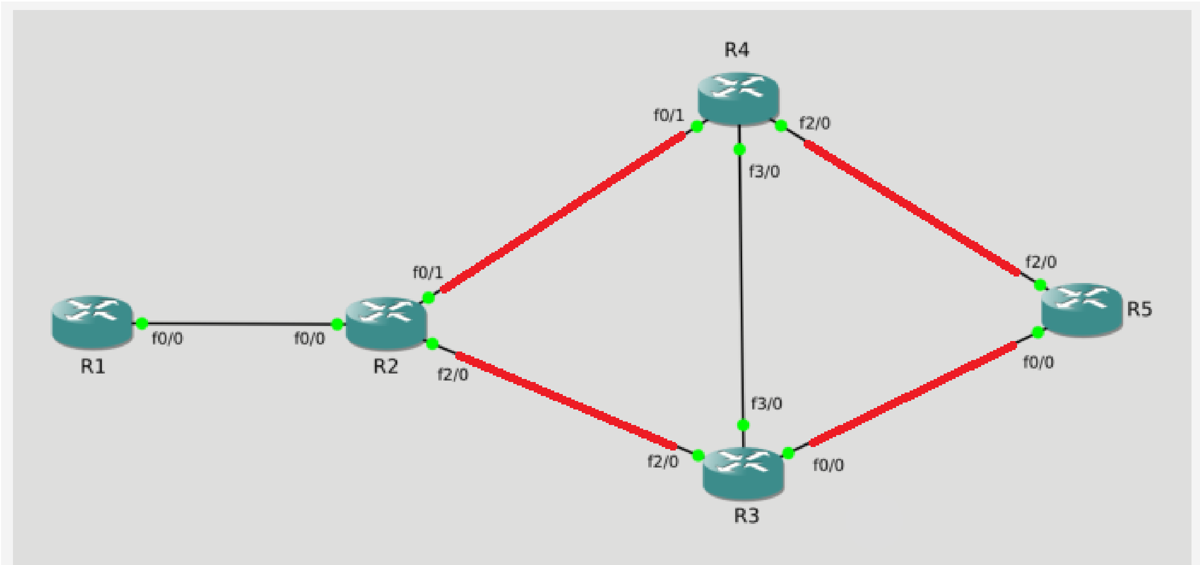
Let's consider the R4 router for example. There are two routes recorded to the `192.168.10.12` subnetwork. One is via `192.168.10.18`, second via `192.168.10.9`. But if we look at the network topology, it is due to the fact that data from R4 can reach the f0/0 interface either through R3 router, or R5 router.
Which is correct if we look at our network topology and addressing table:
`R3 f3/0 is 192.168.10.9`
`R5 f2/0 is 192.168.10.18`



Task C - OSPF database

In this task we are going to set OSPF network type to point-to-point rather than broadcast. We will check the ospf database for each router to see how it influences the OSPF protocol for our network.

First, notice below the links the modification will be done on:



Interfaces on the links marked on red will have the following command run, so that the OSPF network type will be changed to point-to-point:
`ip ospf network point-to-point`

How it will be done is presented below. Example for a single router:
Knowing from the picture which interfaces need change, we don't need `show ip interface` nor `show ip route` command.

First, naturally, we run `config t` command:

```
R2#config
Configuring from terminal, memory, or network [terminal]? t
Enter configuration commands, one per line.  End with CNTL/Z.
```

Then for every interface that needs to be modified (seen from the picture), we enter the interface, and then execute the command shown earlier, and exit the interface. Some OSPF information messages should show up as in the picture. :

```
R2(config)#interface fastEthernet0/1
R2(config-if)#ip os
R2(config-if)#ip ospf ne
R2(config-if)#ip ospf network  po
R2(config-if)#ip ospf network  point-to-po
R2(config-if)#ip ospf network point-to-point
R2(config-if)#
*Mar  1 00:04:26.399: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.0.4 on FastEthernet0/1 from FULL to DOWN, Neighbor Down: Interface down or deta
ched
*Mar  1 00:04:26.475: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.0.4 on FastEthernet0/1 from LOADING to FULL, Loading Done
R2(config-if)#exit
```

Then, the process is repeated for every necessary interface, for every router.
Naturally, if the configuration is deemed correct, we run `copy running-config startup-config` to save our router configuration.

Router 5 - checking OSPF database

Per task description, we executed 3 commands on router 5 to check the contents of its OSPF database. The results are shown below:

```
R5#show ip ospf database

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.0.1     192.168.0.1     74          0x80000004 0x008ADB 1
192.168.0.2     192.168.0.2     1814        0x80000007 0x00E081 5
192.168.0.3     192.168.0.3     58          0x80000007 0x0054F6 5
192.168.0.4     192.168.0.4     92          0x80000007 0x003701 5
192.168.0.5     192.168.0.5     53          0x80000006 0x00F937 4

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.10.10   192.168.0.4     92          0x80000002 0x00EF87
192.168.11.2    192.168.0.2     38          0x80000002 0x001173
```

One link will be shown per page:

```
R5#show ip ospf database router

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Router Link States (Area 0)

  LS age: 92
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 192.168.0.1
  Advertising Router: 192.168.0.1
  LS Seq Number: 80000004
  Checksum: 0x8ADB
  Length: 36
  Number of Links: 1

    Link connected to: a Transit Network
     (Link ID) Designated Router address: 192.168.11.2
     (Link Data) Router Interface address: 192.168.11.1
      Number of TOS metrics: 0
       TOS 0 Metrics: 10
```

```
LS age: 1832
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 192.168.0.2
Advertising Router: 192.168.0.2
LS Seq Number: 80000007
Checksum: 0xE081
Length: 84
Number of Links: 5

  Link connected to: a Transit Network
   (Link ID) Designated Router address: 192.168.11.2
   (Link Data) Router Interface address: 192.168.11.2
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.4
   (Link Data) Router Interface address: 192.168.10.5
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.4
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.3
   (Link Data) Router Interface address: 192.168.10.1
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.0
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 1
```

```
LS age: 79
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 192.168.0.3
Advertising Router: 192.168.0.3
LS Seq Number: 80000007
Checksum: 0x54F6
Length: 84
Number of Links: 5

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.5
   (Link Data) Router Interface address: 192.168.10.13
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.12
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Transit Network
   (Link ID) Designated Router address: 192.168.10.10
   (Link Data) Router Interface address: 192.168.10.9
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.2
   (Link Data) Router Interface address: 192.168.10.2
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.0
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 1
```

```
LS age: 117
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 192.168.0.4
Advertising Router: 192.168.0.4
LS Seq Number: 80000007
Checksum: 0x3701
Length: 84
Number of Links: 5

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.5
   (Link Data) Router Interface address: 192.168.10.17
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.16
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Transit Network
   (Link ID) Designated Router address: 192.168.10.10
   (Link Data) Router Interface address: 192.168.10.10
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.2
   (Link Data) Router Interface address: 192.168.10.6
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.4
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 10
```

```
LS age: 84
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 192.168.0.5
Advertising Router: 192.168.0.5
LS Seq Number: 80000006
Checksum: 0xF937
Length: 72
Number of Links: 4

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.4
   (Link Data) Router Interface address: 192.168.10.18
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.16
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.3
   (Link Data) Router Interface address: 192.168.10.14
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.12
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 10
```

```
R5#show ip ospf database network

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Net Link States (Area 0)

  Routing Bit Set on this LSA
  LS age: 146
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 192.168.10.10 (address of Designated Router)
  Advertising Router: 192.168.0.4
  LS Seq Number: 80000002
  Checksum: 0xEF87
  Length: 32
  Network Mask: /30
        Attached Router: 192.168.0.4
        Attached Router: 192.168.0.3

  Routing Bit Set on this LSA
  LS age: 92
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 192.168.11.2 (address of Designated Router)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000002
  Checksum: 0x1173
  Length: 32
  Network Mask: /30
        Attached Router: 192.168.0.2
        Attached Router: 192.168.0.1
```

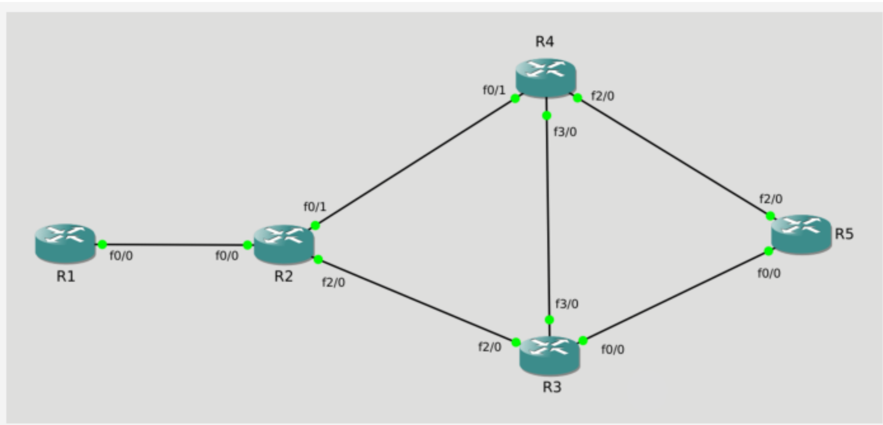
Task C - conclusions

Why are there exactly 5 router LSAs and 2 network LSAs in the OSPF database?

Every router LSA corresponds to the router, more precisely - to the router's loopback. We got 5 router LSA because we got 5 routers in the network.
There are two network LSA due to the fact that two subnetworks exist. One for the R1 and R2 router, the other subnet for all other routers.

Explain the content of the router LSA advertised by router R3 (check if the obtained output agrees with the network topology you have)

Let's recall network topology:



This is advertised LSA by R3:

```
LS age: 79
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 192.168.0.3
Advertising Router: 192.168.0.3
LS Seq Number: 80000007
Checksum: 0x54F6
Length: 84
Number of Links: 5

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.5
   (Link Data) Router Interface address: 192.168.10.13
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.12
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 10

  Link connected to: a Transit Network
   (Link ID) Designated Router address: 192.168.10.10
   (Link Data) Router Interface address: 192.168.10.9
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: another Router (point-to-point)
   (Link ID) Neighboring Router ID: 192.168.0.2
   (Link Data) Router Interface address: 192.168.10.2
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Stub Network
   (Link ID) Network/subnet number: 192.168.10.0
   (Link Data) Network Mask: 255.255.255.252
    Number of TOS metrics: 0
     TOS 0 Metrics: 1
```

So we got 3 direct connections labeled as another Router (point-to-point), transit network and a 2nd another Router (point-to-point).
We see for 1st point-to-point the following data:
`Neighbouring Router ID: 192.168.0.5`
`Router Interface addr.: 192.168.10.13`
2nd point-to-point:
`Neighbouring Router ID: 192.168.0.2`
`Router Interface addr.: 192.168.10.2`
And for transit network:
`Designated router addr.: 192.168.10.10`
`Router interface addr.: 192.168.10.9`

And all of it is correct:

- 1st point-to-point data indicates that neighbor router ID is R5 (loopback address of R5 is `192.168.0.5`), using our interface address `192.168.10.13`, which is the address of f0/0 interface for router R3 that is used for connection to router R5 on `192.168.10.14`
- 2nd point-to-point data analogically:
    - Neighbor ID is R2 (loopback `192.168.0.2`)
    - Interface address being `192.168.10.2`, which is address of interface f2/0 for R3 used for to connect to R2 on `192.168.10.1`
- Transit network shows that we connect using R3 interface IP `192.168.10.9` to the designed router's interface IP `192.168.10.10`, that is R4. Both IP addresses are for the f3/0 interface. The connection can be seen from the address table and the network topology

Then we can notice stub networks basically cover our interface address pool from the point-to-point networks:

- 1st point-to-point indicates a connection from R3 to R5 on f0/0, which means a connection from `192.168.10.13 to 192.168.10.14`. The stub network of `192.168.10.12` with mask `255.255.255.252` is equal to `192.168.10.12/30`. This network has the above-mentioned R3 and R5 IP addresses used for con.
- Analogically for 2nd point-to-point connection. We got a connection from R3 to R2 over f2/0 - a connection from `192.168.10.2 to 192.168.10.1.` The stub network of `192.168.10.2` with mask `255.255.255.252` is equal to `192.168.10.0/30`. This network has above-mentioned R3 and R2 IP addresses used for connection.

All of this can be seen also by looking at the addressing table provided in task A

Explain the content of the network LSAs (check if the obtained output agrees with the network topology you have)

```
R5#show ip ospf database network

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Net Link States (Area 0)

  Routing Bit Set on this LSA
  LS age: 146
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 192.168.10.10 (address of Designated Router)
  Advertising Router: 192.168.0.4
  LS Seq Number: 80000002
  Checksum: 0xEF87
  Length: 32
  Network Mask: /30
        Attached Router: 192.168.0.4
        Attached Router: 192.168.0.3

  Routing Bit Set on this LSA
  LS age: 92
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 192.168.11.2 (address of Designated Router)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000002
  Checksum: 0x1173
  Length: 32
  Network Mask: /30
        Attached Router: 192.168.0.2
        Attached Router: 192.168.0.1
```

First it should be noted that we did check every router, and the output of the command is the same regardless of the router we check (even for R1).

The content is correct due to the fact that it shows every broadcast network with the attached routers (IDs) to them. So we see that the broadcast network is made between R1 and R2, R2 being the Designated Router (DR). Then a 2nd broadcast network between R3 and R4, for which R4 is the Designated Router (DR)

Which routers were elected as DRs and why?

Router 2 and Router 4 were chosen as DR, as it can be seen from the screenshots in the previous question. Advertising router: <router_ID>, where router_ID is taken as the loopback IP for the router.

The general idea of picking a DR is the following:

- Pick the router with the highest priority
- If there is more than router with the same, highest priority, pick a router with bigger Id

Then, let's apply this logic to R1R2 network:

```
R1#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.0.2       1   FULL/DR         00:00:32    192.168.11.2    FastEthernet0/0
```

```
R2#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.0.1       1   FULL/BDR        00:00:30    192.168.11.1    FastEthernet0/0
192.168.0.4       0   FULL/  -        00:00:36    192.168.10.6    FastEthernet0/1
192.168.0.3       0   FULL/  -        00:00:32    192.168.10.2    FastEthernet2/0
```

So we see both routers are of priority 1 on the f0/0 interface. That means, the router with the bigger ID was chosen, which is R2.

Now for the other network:

```
R3#show ip ospf  neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.0.5       0   FULL/  -        00:00:37    192.168.10.14   FastEthernet0/0
192.168.0.4       1   FULL/DR         00:00:33    192.168.10.10   FastEthernet3/0
192.168.0.2       0   FULL/  -        00:00:37    192.168.10.1    FastEthernet2/0
```

```
R4#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.0.5       0   FULL/  -        00:00:34    192.168.10.18   FastEthernet2/0
192.168.0.3       1   FULL/BDR        00:00:33    192.168.10.9    FastEthernet3/0
192.168.0.2       0   FULL/  -        00:00:34    192.168.10.5    FastEthernet0/1
```

```
R5#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.0.4       0   FULL/  -        00:00:38    192.168.10.17   FastEthernet2/0
192.168.0.3       0   FULL/  -        00:00:33    192.168.10.13   FastEthernet0/0
```

So we see that on interface 3/0, R3 and R4 have priority 1, where for the other interfaces priority is 0. Then R4 was chosen as DR, because the ID of R4 is bigger than R3.

Note that the second highest priority/second highest ID is chosen as BDR (backup designated router)

Explain how router R5 can discover network topology using information from LSAs

Establish a connection to the advertising routers that will provide neighbor information and data about the network topology

Task D - multi-area OSPF

For this task we are going to change the area of our R1R2 subnetwork to 1 instead of the default 0 backbone area. For task C, the area was 0 for every router. We will check the influence of this change by executing some commands given in the task description.

So first, we will show how to change the area of our R1R2 network:
We need to enter ospf1 configuration:

```
R1#config
Configuring from terminal, memory, or network [terminal]? t
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)#router ospf 1
```

Then we execute the following. It is the same command as in task C, but with changed area_id parameter:

```
R1(config-router)#network 192.168.11.1 0.0.0.0 area 1
R1(config-router)#
*Mar  1 00:05:08.047: %OSPF-5-ADJCHG: Process 1, Nbr
R1(config-router)#ex
*Mar  1 00:05:08.059: %OSPF-6-AREACHG: 192.168.11.1/3
R1(config-router)#exit
*Mar  1 00:05:09.903: %OSPF-4-ERRRCV: Received invali
R1(config-router)#exit
R1(config)#
*Mar  1 00:05:19.891: %OSPF-4-ERRRCV: Received invali
R1(config)#exit
```

We also get some errors that are caused by misconfiguration of the area on the R2 router. This was simply fixed by properly reconfiguring router R2 to area 1 in the same way as the demonstrated example for router R1. Note that the loopback interfaces also had the command run. So in total we've run
`network <IP> 0.0.0.0 area 1` command for the following <IP>s:

```
In R1 console:
192.168.11.1
192.168.0.1
In R2 console:
192.168.11.2
192.168.0.2
```

Influence of R1R2 area change

Per task description, we will execute the following commands on routers R1 and R5:

```
show ip ospf database
show ip ospf database summary
```

And on each router, the following:

```
show ip route
```

Before the above-mentioned were run, we also used the `clear ip ospf process` to clear outdated records from the ospf database.

`show ip ospf database` command output for R1 and R5:

```
R1#show ip ospf database

            OSPF Router with ID (192.168.0.1) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.0.1     192.168.0.1     5           0x80000001 0x0022CB 2
192.168.0.2     192.168.0.2     6           0x80000006 0x002FB4 2

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.11.2    192.168.0.2     6           0x80000001 0x001372

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.10.0    192.168.0.2     945         0x80000004 0x00431A
192.168.10.4    192.168.0.2     945         0x80000004 0x0075DA
192.168.10.8    192.168.0.2     945         0x80000004 0x00FC57
192.168.10.12   192.168.0.2     945         0x80000004 0x002F18
192.168.10.16   192.168.0.2     945         0x80000004 0x00B694
```

```
R5#show ip ospf database

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.0.2     192.168.0.2     571         0x80000007 0x009FC7 4
192.168.0.3     192.168.0.3     86          0x80000009 0x0050F8 5
192.168.0.4     192.168.0.4     96          0x80000009 0x003303 5
192.168.0.5     192.168.0.5     837         0x80000006 0x00F937 4

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.10.10   192.168.0.4     96          0x80000001 0x00F186

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.0.1     192.168.0.2     571         0x80000004 0x001E3B
192.168.0.2     192.168.0.2     571         0x80000005 0x00ADB3
192.168.11.0    192.168.0.2     571         0x80000006 0x008EC2
```

Now the `show ip ospf database summary` command for R1 and R5:

```
R1#show ip ospf database summary

            OSPF Router with ID (192.168.0.1) (Process ID 1)

                Summary Net Link States (Area 1)

  Routing Bit Set on this LSA
  LS age: 887
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.10.0 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000003
  Checksum: 0x4519
  Length: 28
  Network Mask: /30
        TOS: 0  Metric: 1

  Routing Bit Set on this LSA
  LS age: 887
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.10.4 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000004
  Checksum: 0x75DA
  Length: 28
  Network Mask: /30
        TOS: 0  Metric: 10

  Routing Bit Set on this LSA
  LS age: 873
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.10.8 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000001
  Checksum: 0x354
  Length: 28
  Network Mask: /30
        TOS: 0  Metric: 2
```

```
  Routing Bit Set on this LSA
  LS age: 889
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.10.12 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000004
  Checksum: 0x2F18
  Length: 28
  Network Mask: /30
        TOS: 0  Metric: 11

  Routing Bit Set on this LSA
  LS age: 875
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.10.16 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000007
  Checksum: 0xB097
  Length: 28
  Network Mask: /30
        TOS: 0  Metric: 3
```

R5:

```
R5#show ip ospf database summary

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Summary Net Link States (Area 0)

  Routing Bit Set on this LSA
  LS age: 1046
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.0.1 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000002
  Checksum: 0x2239
  Length: 28
  Network Mask: /32
        TOS: 0  Metric: 11

  Routing Bit Set on this LSA
  LS age: 1045
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.0.2 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000003
  Checksum: 0xB1B1
  Length: 28
  Network Mask: /32
        TOS: 0  Metric: 1

  Routing Bit Set on this LSA
  LS age: 1048
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 192.168.11.0 (summary Network Number)
  Advertising Router: 192.168.0.2
  LS Seq Number: 80000004
  Checksum: 0x92C0
  Length: 28
  Network Mask: /30
        TOS: 0  Metric: 10
```

`Show ip route` command. R1:

```
R1#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O IA    192.168.10.0 [110/11] via 192.168.11.2, 00:17:55, FastEthernet0/0
O IA    192.168.10.4 [110/20] via 192.168.11.2, 00:17:55, FastEthernet0/0
O IA    192.168.10.8 [110/12] via 192.168.11.2, 00:17:45, FastEthernet0/0
O IA    192.168.10.12 [110/21] via 192.168.11.2, 00:17:55, FastEthernet0/0
O IA    192.168.10.16 [110/13] via 192.168.11.2, 00:17:45, FastEthernet0/0
     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 2 subnets
C       192.168.0.1 is directly connected, Loopback0
O       192.168.0.2 [110/11] via 192.168.11.2, 00:17:57, FastEthernet0/0
```

R2:

```
R2#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
C       192.168.10.0 is directly connected, FastEthernet2/0
C       192.168.10.4 is directly connected, FastEthernet0/1
O       192.168.10.8 [110/2] via 192.168.10.2, 00:18:03, FastEthernet2/0
O       192.168.10.12 [110/11] via 192.168.10.2, 00:18:03, FastEthernet2/0
O       192.168.10.16 [110/3] via 192.168.10.2, 00:18:03, FastEthernet2/0
     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 2 subnets
O       192.168.0.1 [110/11] via 192.168.11.1, 00:18:35, FastEthernet0/0
C       192.168.0.2 is directly connected, Loopback0
```

R3:

```
R3#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
C       192.168.10.0 is directly connected, FastEthernet2/0
O       192.168.10.4 [110/11] via 192.168.10.10, 00:19:39, FastEthernet3/0
                     [110/11] via 192.168.10.1, 00:19:39, FastEthernet2/0
C       192.168.10.8 is directly connected, FastEthernet3/0
C       192.168.10.12 is directly connected, FastEthernet0/0
O       192.168.10.16 [110/2] via 192.168.10.10, 00:19:39, FastEthernet3/0
     192.168.11.0/30 is subnetted, 1 subnets
O IA    192.168.11.0 [110/11] via 192.168.10.1, 00:19:40, FastEthernet2/0
     192.168.0.0/32 is subnetted, 3 subnets
O IA    192.168.0.1 [110/12] via 192.168.10.1, 00:19:40, FastEthernet2/0
O IA    192.168.0.2 [110/2] via 192.168.10.1, 00:19:40, FastEthernet2/0
C       192.168.0.3 is directly connected, Loopback0
```

R4:

```
R4#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O       192.168.10.0 [110/2] via 192.168.10.9, 00:21:35, FastEthernet3/0
C       192.168.10.4 is directly connected, FastEthernet0/1
C       192.168.10.8 is directly connected, FastEthernet3/0
O       192.168.10.12 [110/11] via 192.168.10.18, 00:21:35, FastEthernet2/0
                      [110/11] via 192.168.10.9, 00:21:35, FastEthernet3/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.11.0/30 is subnetted, 1 subnets
O IA    192.168.11.0 [110/12] via 192.168.10.9, 00:21:36, FastEthernet3/0
     192.168.0.0/32 is subnetted, 3 subnets
O IA    192.168.0.1 [110/13] via 192.168.10.9, 00:21:36, FastEthernet3/0
O IA    192.168.0.2 [110/3] via 192.168.10.9, 00:21:36, FastEthernet3/0
C       192.168.0.4 is directly connected, Loopback0
```

And finally, R5:

```
R5#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O       192.168.10.0 [110/3] via 192.168.10.17, 00:35:29, FastEthernet2/0
O       192.168.10.4 [110/11] via 192.168.10.17, 00:35:29, FastEthernet2/0
O       192.168.10.8 [110/2] via 192.168.10.17, 00:35:29, FastEthernet2/0
C       192.168.10.12 is directly connected, FastEthernet0/0
C       192.168.10.16 is directly connected, FastEthernet2/0
     192.168.11.0/30 is subnetted, 1 subnets
O IA    192.168.11.0 [110/13] via 192.168.10.17, 00:35:29, FastEthernet2/0
     192.168.0.0/32 is subnetted, 3 subnets
O IA    192.168.0.1 [110/14] via 192.168.10.17, 00:35:30, FastEthernet2/0
O IA    192.168.0.2 [110/4] via 192.168.10.17, 00:35:30, FastEthernet2/0
C       192.168.0.5 is directly connected, Loopback0
```

Explain the obtained output (note any observed difference from the expected result) in `show ospf database` command

The difference from the previous task is that now a new category of LS appeared - Summary Net Link States.

This category basically shows inter-area connections. e.g. for R1 we got:

```
R1#show ip ospf database

            OSPF Router with ID (192.168.0.1) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.0.1     192.168.0.1     5           0x80000001 0x0022CB 2
192.168.0.2     192.168.0.2     6           0x80000006 0x002FB4 2

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.11.2    192.168.0.2     6           0x80000001 0x001372

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.10.0    192.168.0.2     945         0x80000004 0x00431A
192.168.10.4    192.168.0.2     945         0x80000004 0x0075DA
192.168.10.8    192.168.0.2     945         0x80000004 0x00FC57
192.168.10.12   192.168.0.2     945         0x80000004 0x002F18
192.168.10.16   192.168.0.2     945         0x80000004 0x00B694
```

We see the above-mentioned category having every ID link for interfaces outside the R1R2 link. In other words - it has the address pool of every interface outside the R1R2 link. Refer to the provided addressing table earlier in the report.

We also can see loopback for R1 and R2 present in router LS's, as well as the connection to R2 as the net LS. Everything in area 1.

For R5:

```
R5#show ip ospf database

            OSPF Router with ID (192.168.0.5) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.0.2     192.168.0.2     571         0x80000007 0x009FC7 4
192.168.0.3     192.168.0.3     86          0x80000009 0x0050F8 5
192.168.0.4     192.168.0.4     96          0x80000009 0x003303 5
192.168.0.5     192.168.0.5     837         0x80000006 0x00F937 4

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.10.10   192.168.0.4     96          0x80000001 0x00F186

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.0.1     192.168.0.2     571         0x80000004 0x001E3B
192.168.0.2     192.168.0.2     571         0x80000005 0x00ADB3
192.168.11.0    192.168.0.2     571         0x80000006 0x008EC2
```

In router LS's we see every router belonging to the area 0. For Summary Net LS's we see every router ID in the area 1 network, and also the address pool of interface addressing in R1R2 link (192.168.11.0).
Net LS correctly shows DR router ID (R4). This router works on link ID 192.168.10.10, which is interface f3/0 between R4 and R3 (that being the broadcast network). 192.168.10.10 is R4 IP addr. for the interface (refer to address table).

Explain the provided information from execution of `show ip ospf database summary` command.
What type of information can be obtained from summary LSAs? Compare the content of the output observed for routers R1 and R5, explain the differences etc.

First, let's look at R1. Looking back into earlier provided screenshots, we can basically see 5 entries.
For every entry, advertising router is `192.168.0.2`, and the mask is `/30`:
Link state IDs (Summary network numbers) reported with above-mentioned:
`192.168.10.0`
`192.168.10.4`
`192.168.10.8`
`192.168.10.12`
`192.168.10.16`
Which generally means that the R1 router has information about the above-mentioned networks shown in the summary network numbers. These networks have the mentioned mask `/30,` and this information originates from the Router R2 identifying with `192.168.0.2` ID.

Now let's consider R5. Also looking back at the screenshot provided earlier, we see that the advertising router is the same for each entry `192.168.0.2.`
Link state IDs (Summary network numbers) are reported with following mask:
`192.168.0.1/32`
`192.168.0.2/32`
`192.168.11.0/30`

So R5 correctly sees the information provided by ABR (R2). It sees the whole network of R1R2, which is `192.168.11.0/30.` It also sees the loopback interfaces of R1 and R2, as they were added to the OSPF (`192.168.0.1` is R1 loopback, `192.168.0.2` is R2 loopback)

Show ip route - analysis

We see that new connections labeled IA, which means OSPF inter area, have appeared.
What should be noticed is that R2 sees 0 IA connections. It is due to the fact that R2 is the ABR. The R2 is the area border itself, so it is natural that the border router sees no inter-area connections.

Now looking at the R1 router, we see 5 IA connections through the R2 router. 5 connections are due to the fact that there are 5 links in the area 0. Topology image confirms it.

Now looking at R3, R4 or R5 router, we see 3 IA connections:
`192.168.11.0/30`
`192.168.0.1/32`
`192.168.0.2/32`

The conclusion to this is the same as in the previous paragraph:

"So [R3, R4 and R5] correctly see the information provided by ABR (R2). It sees the whole network of R1R2, which is `192.168.11.0/30`. It also sees the loopback interfaces of R1 and R2, as they were added to the OSPF (`192.168.0.1` is R1 loopback, `192.168.0.2` is R2 loopback)"

Task E - OSPF link costs

In this task we are going to see the influence of OSPF link costs, but also generally test the OSPF protocol with the use of `ping` and `traceroute` commands.

Pinging and tracerouting f0/0 of R1 from R4 - results

Below we show and explain the execution of ping and traceroute command from R1. Interface f0/0 of R1 has the following IP addr.: `192.168.11.1`

```
R4#ping 192.168.11.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.11.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 192/292/640 ms
R4#traceroute 192.168.11.1

Type escape sequence to abort.
Tracing the route to 192.168.11.1

  1 192.168.10.9 324 msec 196 msec 140 msec
  2 192.168.10.1 320 msec 196 msec 192 msec
  3 192.168.11.1 440 msec 192 msec 204 msec
```

So we see that all packets reach the destination. with RTT min/avg/max shown in the screenshot. 5 ICMP 100-byte echos were sent to the f0/0 R1 interface.

Furthermore, from the traceroute we see that packet travels through the following:

`192.168.10.9` - R3 interface f3/0 address

`192.168.10.1` - R2 interface f2/0 address

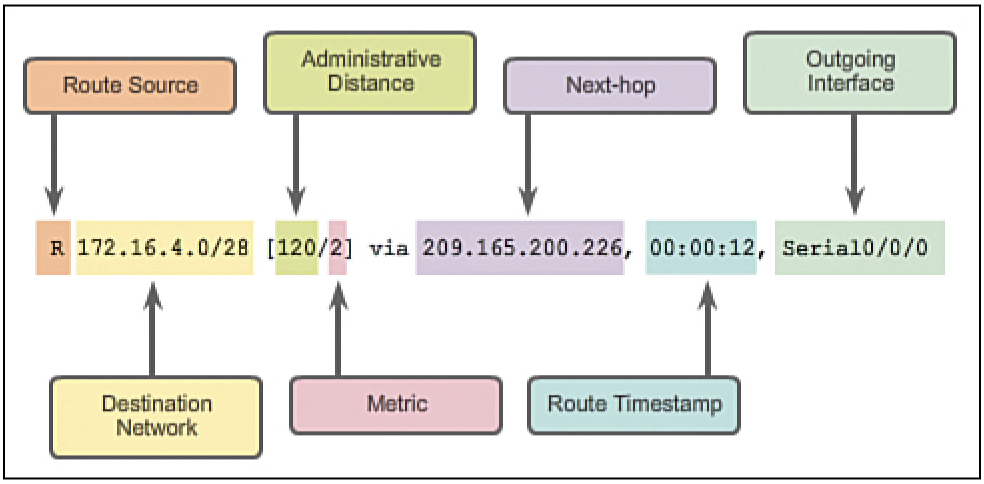
`192.168.11.1` - R1 interface f0/0 address (our destination)

The traceroute may seem a bit weird, given the fact that there is a shortest path. We could go directly into the R2 router rather than go to R3 first.

This behavior is probably due to the fact that there are link costs defined so that it’s cheaper to go through R3 into R2 rather than use the direct connection to R2.

Routing table for R1 - explanation

Per https://www.ciscopress.com/articles/article.asp?p=2180210&seqNum=12, we learned the following explanation of `show ip route` entries:



Source: above-mentioned link

To remind, this is the result of the commands for R1:

```
R1#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 5 subnets
O IA    192.168.10.0 [110/11] via 192.168.11.2, 03:16:39, FastEthernet0/0
O IA    192.168.10.4 [110/20] via 192.168.11.2, 03:16:39, FastEthernet0/0
O IA    192.168.10.8 [110/12] via 192.168.11.2, 03:16:39, FastEthernet0/0
O IA    192.168.10.12 [110/21] via 192.168.11.2, 03:16:39, FastEthernet0/0
O IA    192.168.10.16 [110/13] via 192.168.11.2, 03:16:29, FastEthernet0/0
     192.168.11.0/30 is subnetted, 1 subnets
C       192.168.11.0 is directly connected, FastEthernet0/0
     192.168.0.0/32 is subnetted, 2 subnets
C       192.168.0.1 is directly connected, Loopback0
O       192.168.0.2 [110/11] via 192.168.11.2, 03:16:44, FastEthernet0/0
```

Metric in this case shows us the route cost.

If we notice that:

```
R1#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     1               192.168.0.1/32     1     LOOP  0/0
Fa0/0        1     1               192.168.11.1/30    10    BDR   1/1
```

And:

```
R4#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa2/0        1     0               192.168.10.17/30   1     P2P   1/1
Fa3/0        1     0               192.168.10.10/30   1     DR    1/1
Fa0/1        1     0               192.168.10.6/30    10    P2P   1/1
```

Then for example, knowing that `192.168.10.4` is a subnet f0/1 between R2 and R4. The cost of this connection is 10 (seen in `show ip ospf interface brief` for R4) The cost of 20 is correct due to the fact that the cost of link f0/1 reported by R4 is also 10. Traceroute confirms this is indeed the path the packets take:

```
R1#traceroute 192.168.10.6

Type escape sequence to abort.
Tracing the route to 192.168.10.6

  1 192.168.11.2 68 msec 128 msec 140 msec
  2 192.168.10.6 636 msec 160 msec 200 msec
```

Furthermore, taking another example:

```
R3#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa0/0        1     0               192.168.10.13/30   10    P2P   1/1
Fa3/0        1     0               192.168.10.9/30    1     BDR   1/1
Fa2/0        1     0               192.168.10.2/30    1     P2P   1/1
```

That explains the highest cost of 21 reported for `192.168.10.12/30` . The address is for R3 and R5 interface f0/0.
So knowing f0/1 between R2 and R3 cost is 1, and R2 and R4 cost is 10, the packet will go from R2 to R3 after arriving at R2 from R1. In case the cost of R2->R3 was 10 instead, and R2->R4 1, but also R4->R3 being 1, then the better route would actually be R2->R4->R3 rather than the direct R2->R3 route.
So, the direct route R2->R3 has the lowest cost. There is no other way the packet could go through.
Then, since

```
R5#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa2/0        1     0               192.168.10.18/30   1     P2P   1/1
Fa0/0        1     0               192.168.10.14/30   10    P2P   1/1
```

f2/0 is R4R5, cost being 1, whereas f0/0 is R3R5, cost being 10. The packet goes R3->R5
The cost being 21 means the packet traverses R2->R3->R5. (10+1+10)

Cost map

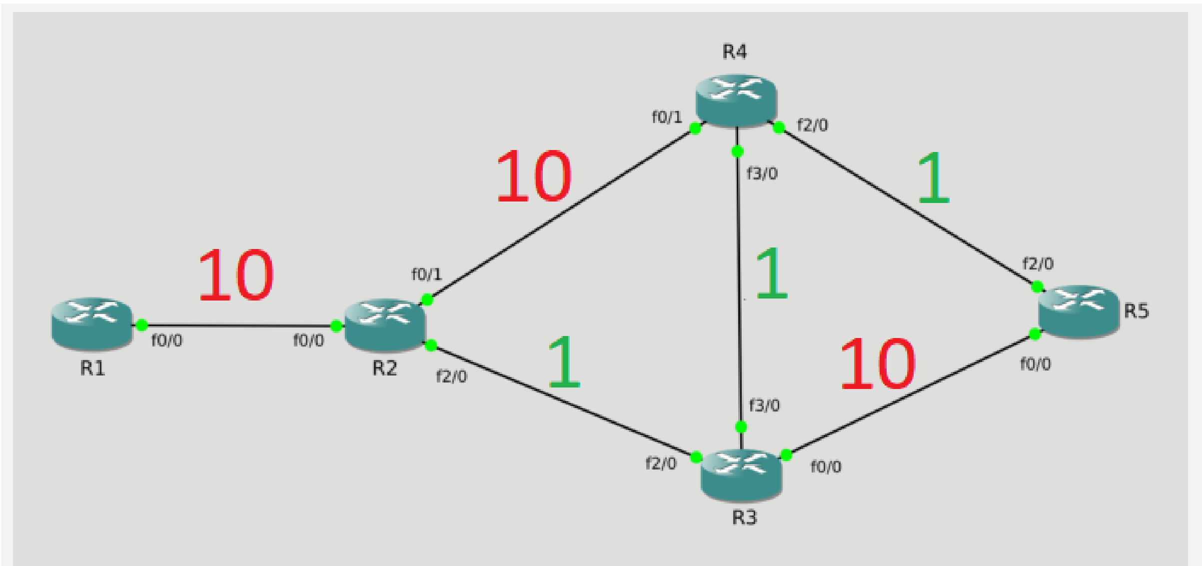
All of this can be more easily explained in the form of a graphic. We've run show ip ospf interface brief on some routers and were able to create the following 'cost map':

```
R1#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     1               192.168.0.1/32     1     LOOP  0/0
Fa0/0        1     1               192.168.11.1/30    10    BDR   1/1
```

```
R3#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa0/0        1     0               192.168.10.13/30   10    P2P   1/1
Fa3/0        1     0               192.168.10.9/30    1     BDR   1/1
Fa2/0        1     0               192.168.10.2/30    1     P2P   1/1
```

```
R4#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa2/0        1     0               192.168.10.17/30   1     P2P   1/1
Fa3/0        1     0               192.168.10.10/30   1     DR    1/1
Fa0/1        1     0               192.168.10.6/30    10    P2P   1/1
```

Results in the following map:



R2R4 link analysis

Now we will analyse the cost and bandwidth of the R2R4 link (f0/1 interface). Notice that the cost is already displayed in the picture above, and is equal to 10. Now to check the bandwidth, the following command was executed.:

```
R2#show interface fastEthernet0/1
FastEthernet0/1 is up, line protocol is up
  Hardware is Gt96k FE, address is c402.6504.0001 (bia c402.6504.0001)
  Internet address is 192.168.10.5/30
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Half-duplex, 10Mb/s, 100BaseTX/FX
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 00:00:05, output 00:00:01, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     2252 packets input, 294034 bytes
     Received 2251 broadcasts, 0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog
     0 input packets with dribble condition detected
     3445 packets output, 338565 bytes, 0 underruns
     0 output errors, 0 collisions, 0 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier
     0 output buffer failures, 0 output buffers swapped out
```

Bitrate is marked

For comparison, we check R3R4 link speed. The cost of this link is 1:

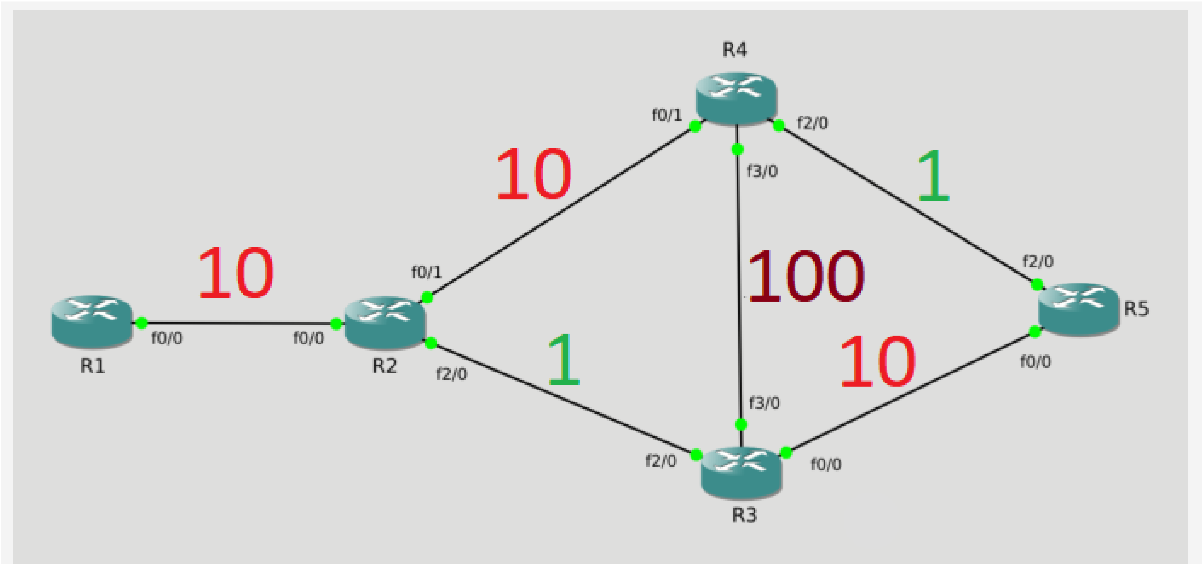
```
R3#show interface fastEthernet3/0
FastEthernet3/0 is up, line protocol is up
  Hardware is AmdFE, address is c403.656c.0030 (bia c403.656c.0030)
  Internet address is 192.168.10.9/30
  MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Full-duplex, 100Mb/s, 100BaseTX/FX
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 00:00:06, output 00:00:06, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     2476 packets input, 319704 bytes
     Received 2452 broadcasts, 0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog
     0 input packets with dribble condition detected
     3962 packets output, 389258 bytes, 0 underruns
     0 output errors, 0 collisions, 0 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier
     0 output buffer failures, 0 output buffers swapped out
```

The obtained values make sense, as the slower link has higher cost. This is proper behavior. Smaller cost means the link is better in the sense of speed.

The above-mentioned speeds might be related to duplex type. Half-duplex is slower than full-duplex (in general).

Further analysis of OSPF link costs

Now we are going to modify one of the OSPF link costs and check how that influences routing in our topology. Per task, it is said that we should set the cost of R3R4 link to 100. In that case, our ‘cost map’ changes and will look like this:



From that we can already see that the routes will change. Route that was among 3 cheapest routes has now become the single most expensive route in the network.

Setting the new cost of the link is done as follows:

```
R4#config t
Enter configuration commands, one per line.  End with CNTL/Z.
R4(config)#interface f3/0
R4(config-if)#ip ospf cost 100
R4(config-if)#exit
R4(config)#exit
R4#
```

This is done on R3 as well, with the same commands.

Then, this is how we check if the cost was changed. As we can see - it was:

```
R3#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa0/0        1     0               192.168.10.13/30   10    P2P   1/1
Fa3/0        1     0               192.168.10.9/30    100   BDR   1/1
Fa2/0        1     0               192.168.10.2/30    1     P2P   1/1
```

```
R4#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa2/0        1     0               192.168.10.17/30   1     P2P   1/1
Fa3/0        1     0               192.168.10.10/30   100   DR    1/1
Fa0/1        1     0               192.168.10.6/30    10    P2P   1/1
```

Then what we need to do next is to ping and traceroute from R4 to R1:

```
R4#ping 192.168.11.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.11.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/29/36 ms
```

```
R4#traceroute 192.168.11.1

Type escape sequence to abort.
Tracing the route to 192.168.11.1

  1 192.168.10.5 44 msec 12 msec 24 msec
  2 192.168.11.1 32 msec 36 msec 8 msec
```

So we see that changing the cost of the R4R3 link has changed the path to go directly into the f0/1 interface of R2, as `192.168.10.5` is the interface IP of R2 between R2 and R5, as written in the addressing table. And after that, from R2 to R1, which is the same route part before changing the cost of the link.
The ping times have significantly increased
min/avg/max `192/292/640 ms` has changed to `20/29/36 ms`. Of course - the lower ping the better, as it means faster travel times.
RTTs for the traceroute are also significantly lower.

Task G - closing remarks

As requested, the show running-config output from every router is attached in the *.zip.

End