Lab 6 - OSPF Conceptual Notes and Configuration Exercise – Dynamic Routing

OSPF Fundamental Terminology

OSPF stands for Open Shortest Path First. OSPF is a link state open standard based routing protocol. It was created in mid-1980. Since it is based on open standard, we can use it with any vendor's router.

Features and advantage of OSPF

- It supports both IPv4 and IPv6 routed protocols.
- It supports load balancing with equal cost routes for same destination.
- Since it is based on open standards, it will run on most routers.
- It provides a loop free topology using SPF algorithm.
- It is a classless protocol.
- It supports VLSM and route summarization.
- It supports unlimited hop counts.
- It scales enterprise size network easily with area concept.
- It supports trigger updates for fast convergence.
- Just like other routing protocols, OSPF also has its negatives.

Disadvantage of OSPF

- It requires extra CPU process to run SPF algorithm.
- It requires more RAM to store adjacency topology.
- It is more complex to setup and hard to troubleshoot.

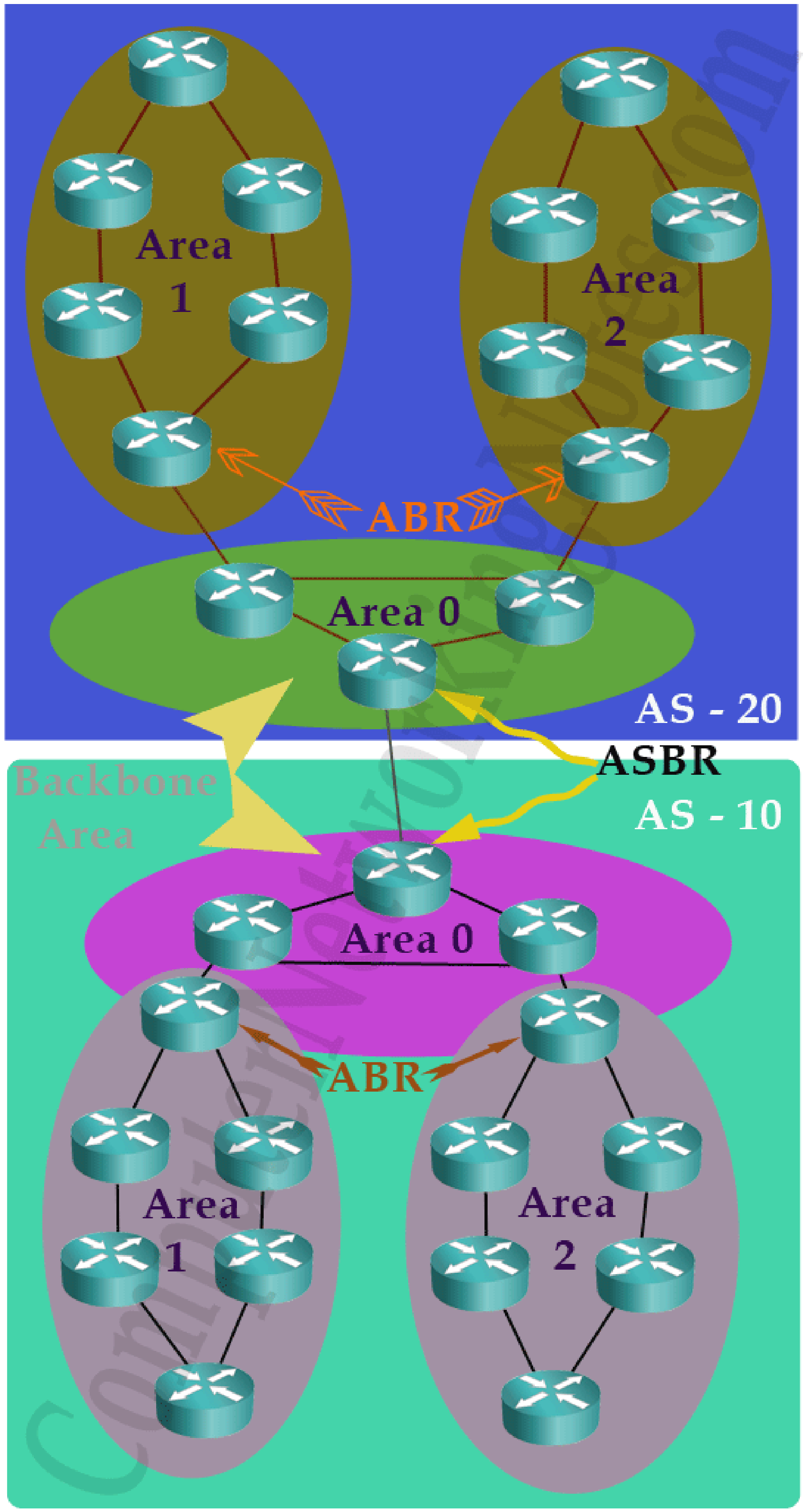
Basically OPSF was created to fulfill the requirement of enterprise size network. To scale a large size network it uses area concept. Area concept is similar to Subnetting. It allows us to separate the large internetwork into smaller networks known as areas.

Along with Area concept OSPF also supports Autonomous System (AS). Just like area, AS also divide a large network into smaller networks.

Difference between AS and Area concept

Area concept is a feature of OSPF. It is limited only with OSPF. We cannot use it with other routing protocol.

AS is an independent concept originally defined in RFC 1771. We can use it with any routing protocols which understand its concept.



Area 1
Area 2
ABR
Area 0
AS - 20
ASBR
Backbone Area
AS - 10
Area 0
ABR
Area 1
Area 2

AS

An AS is a group of networks running under a single administrative control. This could be our company or a branch of company. Just like Subnetting AS is also used to break a large network in smaller networks.

AS creates a boundary for routing protocol which allow us to control how far routing information should be propagated. Beside this we can also filter the routing information before sharing it with other AS system. These features enhance security and scalability of overall network.

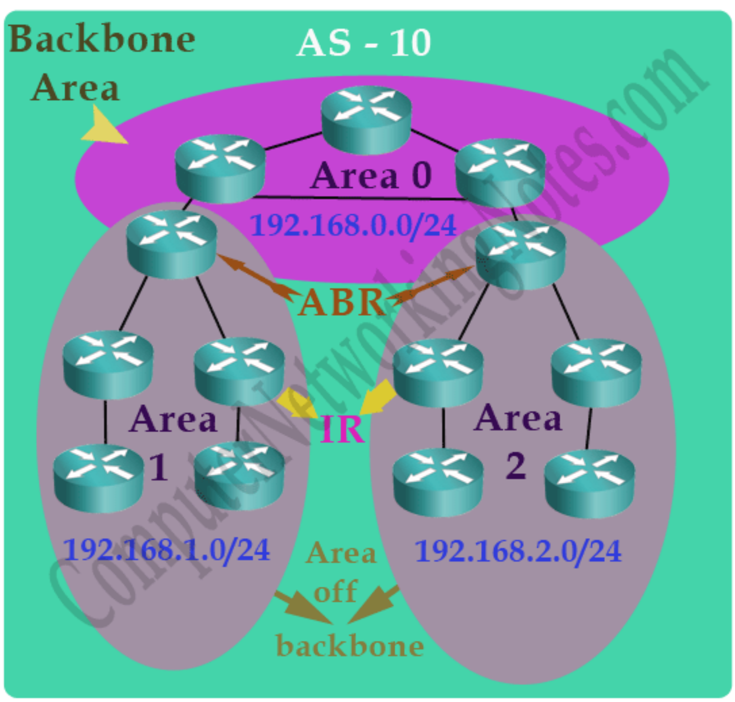
Basically AS concept was developed for large networks. Routing protocols which were developed for small networks such as RIP do not understand the concept of AS systems.

There are two types of routing protocols IGP and EGP.

IGP (Interior Gateway Protocol) is a routing protocol that runs in a single AS such as RIP, IGRP, EIGRP, OSPF and IS-IS.

EGP (Exterior Gateway Protocol) is a routing protocol that performs routing between different AS systems. Nowadays only BGP (Border Gateway Protocol) is an active EGP protocol.

In OSPF implementation, routers which connect two different ASes are known as autonomous system boundary router (ASBR). In an OSPF network any router can become ASBR.



Area

OSPF implements two levels hierarchy with areas: backbone and area off backbone.

Backbone

Backbone is the central point of this implementation. Routers running in this area required to maintain a complete database of entire network. All areas need to connect with this area through a physical link or via a virtual link if physical link is not possible.

Area off backbone

Area off backbone is the extension of backbone. Routes running in this area required to maintain an area specific database instead of complete database. This is a cool feature. It will speed-up the convergence time.

ABR

Area Border Router (ABR) is a bridge between Backbone and Area off backbone. With correct IP addressing we can summarize routes information on this router.

IR

IR (Internal Router) is a router running in area off backbone. IR only needs to maintain an area centric local database.

Link

Link is an interface running OSPF routing protocol. When we add an interface in OSPF process, it will be considered as a link.

State

State is the information associated with a link (interface). A link (interface) contains several information such as IP address, up/down status, subnet mask, type of interface, type of network , bandwidth and delay. OSFP consider this information as state.

LSA

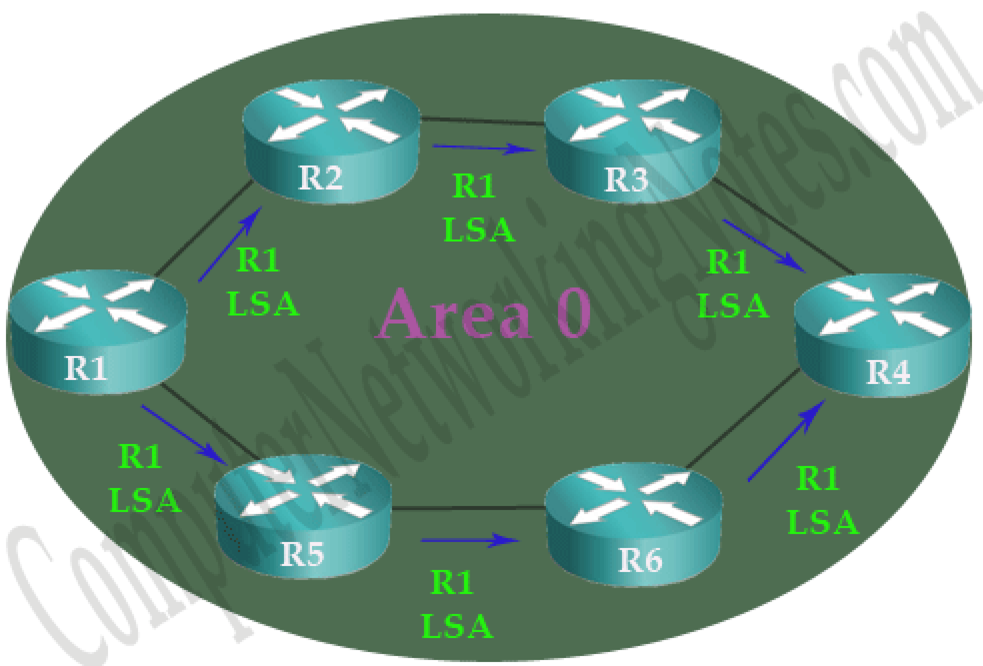
Link state advertisement (LSA) is data packet. It contains link-state and routing information. OSPF uses it to share and learn network information.

LSDB

Every OSPF router maintains a Link state database (LSDB). LSDB is collection of all LSAs received by a router. Every LSA has a unique sequence number. OSPF stores LSA in LADB with this sequence number.

Upon initialization or due to any change in network information, an OSPF speaking router generates a LSA. This LSA includes the collection of all link-states or link state updates. All routers exchange LSA by flooding. Each router that receives a LSA will store a copy of it in its LSDB then propagate the LSA to other routers.

For example figure display a basic flooding process where R1 is generating LSA and flooding it to the other routers of network.



R2 and R5 are the first clients who receive this LSA. They will update their LSDB and then forward it to R3 and R6 respectively. R3 and R6 will update their database with this LSA and then forward it to R4. From here only one router either R3 or R6 will be able to forward this LSA to R4. Why does this happen?

Because flooding process has a mechanism to prevent the loops. Before sending a LSA to neighbors, it asks them "Do you have this LSA?" If neighbor reply with yes, it will avoid flooding that LSA to this neighbor. If neighbor reply with no, it will flood that LSA to this neighbor. Thus R4 will only receive this LSA only from one neighbor; either R3 or R6.

OSPF routers share LSA only with neighbors. To become an OSPF neighbor, certain conditions need to be matched.

OSPF Neighborship Condition and Requirement

OSPF routers share routing information only with neighbors. OSPF uses hello packets to discover neighbors in segments. A hello packet contains some essential configuration values that must be same on both routers who want to build an OSPF neighborship.

OSPF Neighborship Requirement

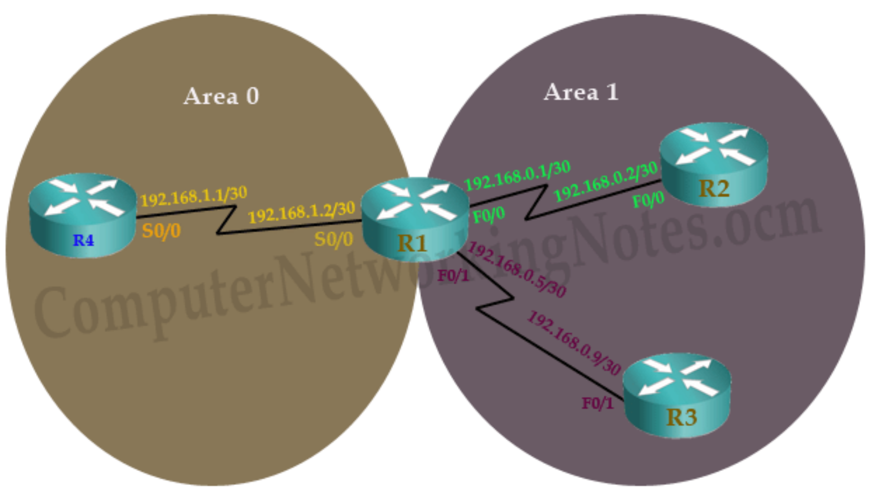
In order to become OSPF neighbor following values must be match on both routers.

- Area ID
- Authentication
- Hello and Dead Intervals
- Stub Flag
- MTU Size

Area ID

OSPF uses area concept to scale an enterprise size network. OSPF areas create a logical boundary for routing information. By default routers do not share routing information beyond the area. So in order to become neighbor, two routers must belong to same area. Here one confusing fact needs to clear. Area is associated with specific interface, not with entire router. This allows us to configure the router in multiple areas. For example a router that has two interfaces; Serial interface and FastEthernet interface, can run Serial interface in one area and FastEthernet in another area. It means link which connects two routers need be in same area including its both ends interface. Beside this interfaces should have same network ID and subnet mask.

Following figure illustrate a simple OSPF network. In this network R1 is eligible to form neighborship with R4 and R2 respectively on S0/0 and F0/0.



Why neighborship cannot be built between R1 and R3?

Let’s find out the answer step by step.

Both interfaces should be in same area.

Yes both interfaces (R1’s Fo/1 and R3’s F0/1) are in same area.

Both interfaces should be in same segment.

Yes both interfaces (R1’s Fo/1 and R3’s F0/1) are connected with direct link.

Both interfaces should have same subnet mask.

Yes both interfaces have same subnet mask /30.

Both interfaces should have same network ID.

No both interfaces have different network ID. R1’s F0/1 has network ID 192.168.0.4/30 while R3’s F0/1 has network ID 192.168.0.8/30. This condition does not match. Thus these two routers on these interfaces cannot build neighborship.

Authentication

To enhance the security of network, OSPF allows us to configure the password for specific areas. Routers who have same password will be eligible for neighborship. If you want to use this facility, you need to configure password on all routers which you want to include in network. If you skip any router, that will not be able to form an OSPF neighborship.

Suppose that our network has two routers R1 and R2. Both routers are connected with direct link and meet all criteria mentioned in first requirement. What if I configure password in R1 and leave R2 as it is? Will it form neighborship with R2?

Well in this situation neighborship will not take place. Because when both routers see each other’s hello packet in segment, they try to match all configure values including password field. One packet has a value in password filed while other has nothing in it. In this case routers will simply ignore each other’s packet.

Hello packets and hello interval

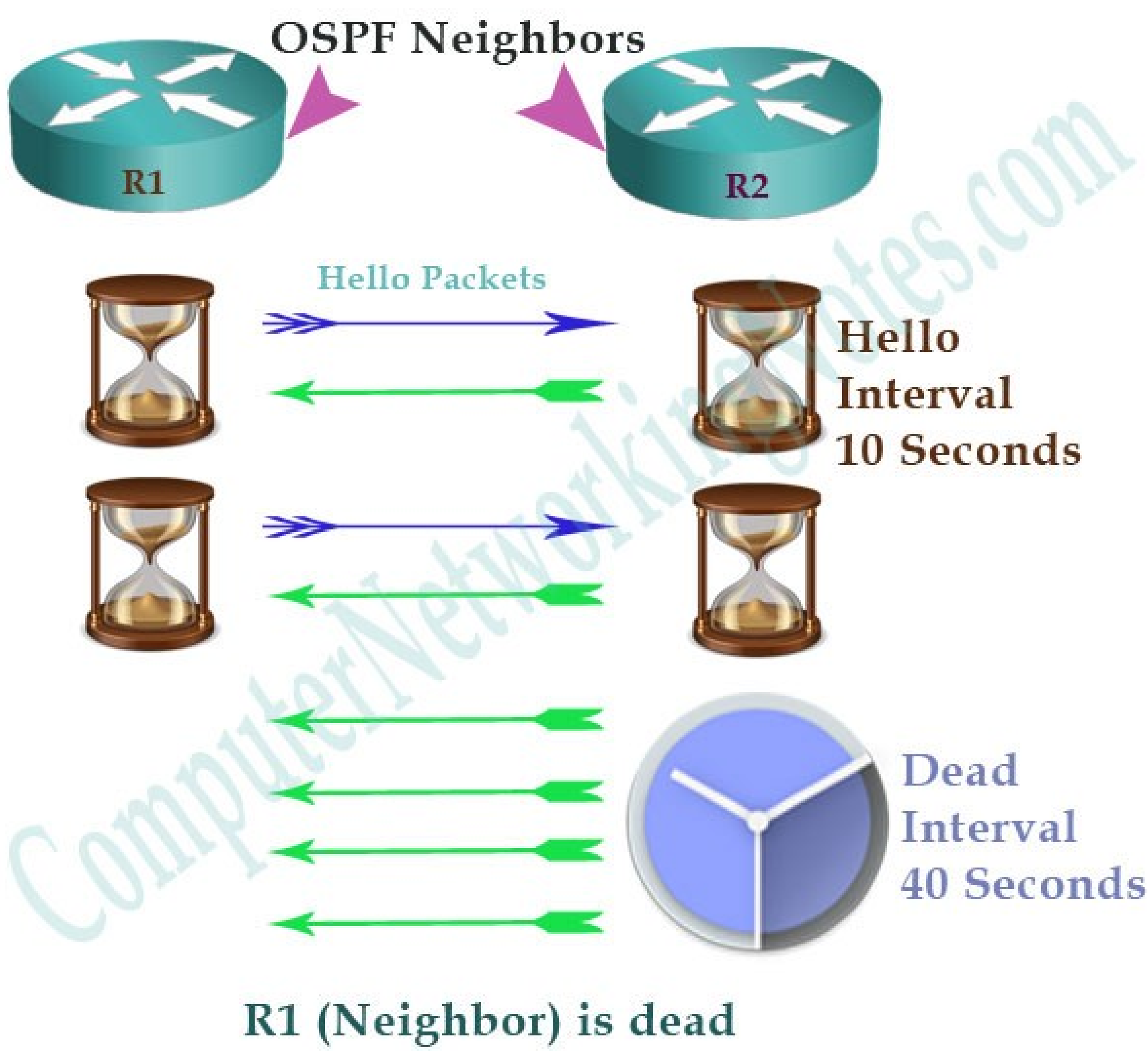
Hello packets are the special type of LSAs (Link State Advertisements) which are used to discover the neighbors in same segment. And once neighborship is built same hello packets are used to maintain the neighborship. Hello packets contain all necessary information that is required to form a neighborship. Hello packets are generated and distributed in hello interval via multicast. Hello interval is the length of time in seconds between the hello packets. Default hello interval is 10 seconds.

Dead Intervals

As we already know once neighborship is built, hello packets are used to maintain the neighborship.

So a router must see hello packets from neighbor in particular time interval. This time interval is known as dead interval. Dead interval is the number of seconds that a router waits for hello packet from neighbor, before declaring it as dead.

Default dead interval is 40 seconds. If a router does not receive hello packet in 40 seconds from neighbor it will declare that as dead. When this happens, router will propagate this information to other OSPF neighboring router via LSA message.



Hello and dead interval must be same between two neighbors. If any of these intervals are different, neighborship will not form.

Stub Area Flag

This value indicates that whether sending router belong to stub area or not. Routers who want to build OPSF neighborship must have same stub area flag.

For example we have two routers R1 and R2:-

- Both routers belong to same stub area, neighborship can be built
- Both routers belong to different stub area, neighborship cannot be built
- Both routers do not belong to any stub area, neighborship can be built
- Only one router belongs to a stub area, neighborship cannot be built

Just like another areas, Stub area also has some specific meanings in OSPF hierarchal design.

A stub area has following requirements:-

- A stub area can have only single exit point from that area.
- Stub area cannot be used as a transit area for virtual links.
- Routing from stub area to outside of the area should not have to take an optimal path.
- Any external networks (redistributed from other protocols into OSPF) should not be flooded in stub area.

Configuring a stub area reduces the size of topology table inside that area. Thus routers running in this area require less memory.

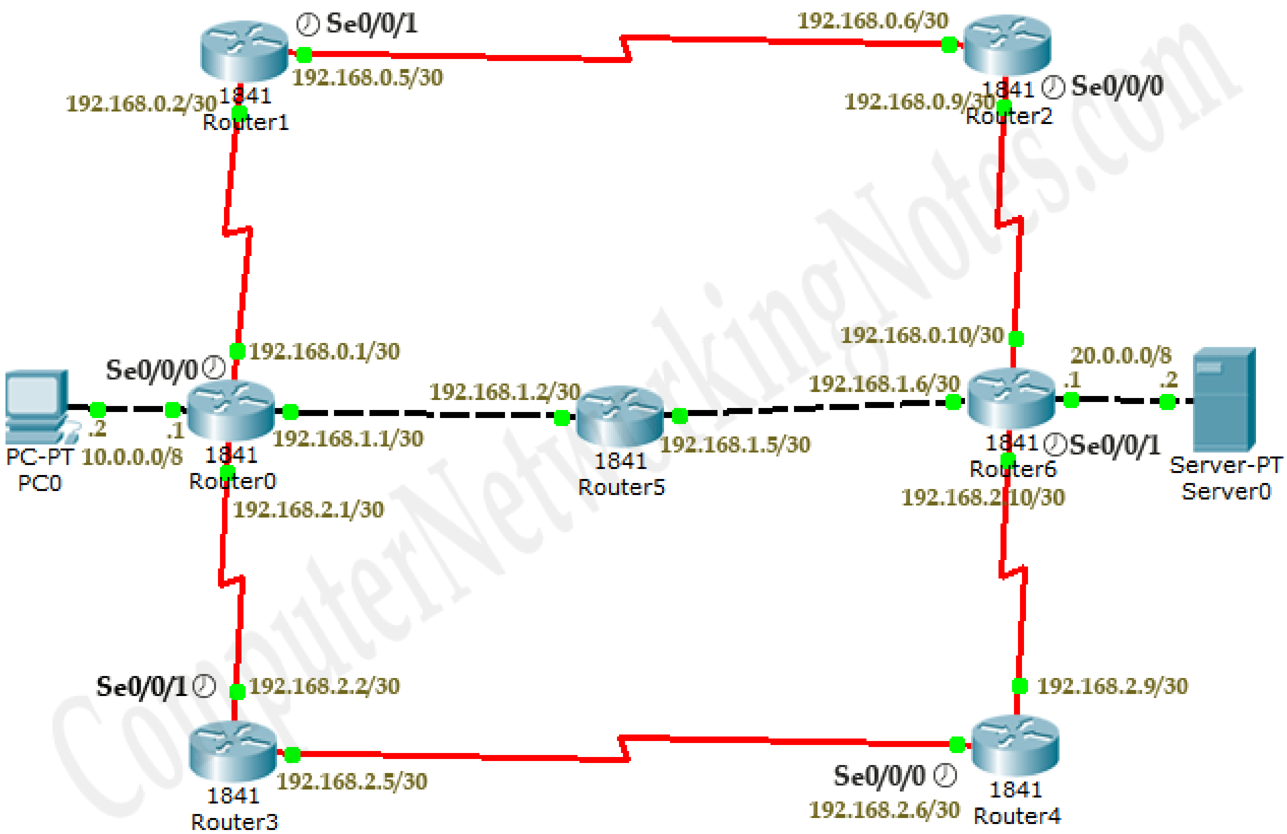
MTU

Technically MTU (Maximum Transmission Unit) is not a part of compulsory matching conditions. Still we should match this value. If this value does not match routers may stuck in Exstart/Exchange exchange stage.

Consider a situation where MTU setting between two OSPF routers does not match. If the router with the higher MTU sends a packet larger than the MTU set on the neighboring router, the neighboring router will ignores this packet. This function creates serious problem for database updates. Database updates are heavier in nature. Once an update becomes larger than the configured MTU setting, it needs to be spilt. In a case of miss match MTU, database update may lost few bytes. Due to this, OSPF will ignore that update and cannot sync with database. It will be stuck in Exstart/Exchange stage.

It is always worth to spend a little extra time in matching optional values along with compulsory values. Matching configuration values will make troubleshooting easier.

OSPF Configuration

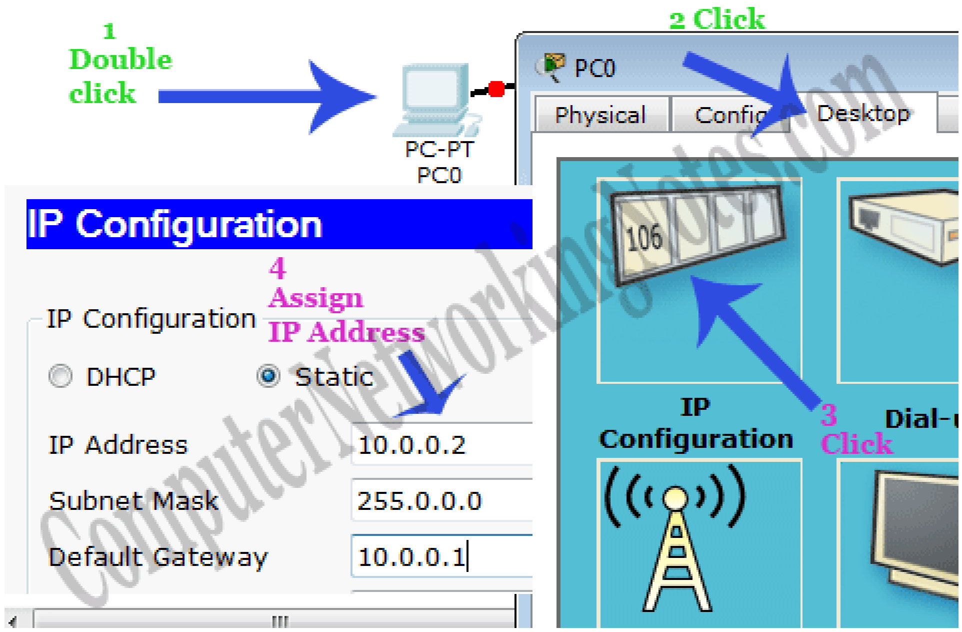


Initial IP Configuration

Device	Interface	IP Configuration	Connected with
PC0	Fa0/0	10.0.0.2/8	Router0's Fa0/0
Router0	Fa0/0	10.0.0.1/8	PC0's Fa0/0
Router0	Fa0/1	192.168.1.1/30	Router5's Fa0/1
Router5	Fa0/1	192.168.1.2/30	Router0's Fa0/1
Router5	Fa0/0	192.168.1.5/30	Router6's F0/0
Router6	Fa0/0	192.168.1.6/30	Router5's Fa0/0
Router6	Fa0/1	20.0.0.1/8	Server0's Fa0/0
Server0	Fa0/0	20.0.0.2/8	Router6's Fa0/1
Router0	Serial 0/0/0 (DCE)	192.168.0.1/30	Router1's Se0/0/0
Router1	Serial 0/0/0	192.168.0.2/30	Router0's Se0/0/0
Router1	Serial 0/0/1 (DCE)	192.168.0.5/30	Router2's Se0/0/1
Router2	Serial0/0/1	192.168.0.6/30	Router1's Se0/0/1
Router2	Serial 0/0/0 (DCE)	192.168.0.9/30	Router6's Se0/0/0
Router6	Serial 0/0/0	192.168.0.10/30	Router2's Se0/0/0
Router0	Serial 0/0/1	192.168.2.1/30	Router3's Se0/0/1
Router3	Serial 0/0/1 (DCE)	192.168.2.2/30	Router0's Se0/0/1
Router3	Serial 0/0/0	192.168.2.5/30	Router4's Se0/0/0
Router4	Serial 0/0/0 (DCE)	192.68.2.6/30	Router3's Se0/0/0
Router4	Serial 0/0/1	192.168.2.9/30	Router6's Se0/0/1
Router6	Serial0/0/1 (DCE)	192.168.2.10/30	Router4's Se0/0/1

Assign IP address to PC

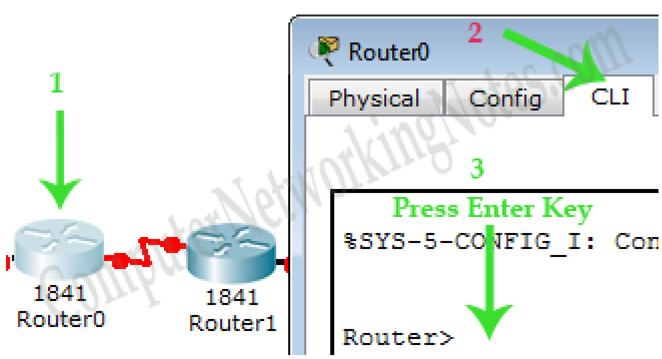
Double click PC0 and click Desktop menu item and click IP Configuration. Assign IP address 10.0.0.2/8 to PC0.



Repeat same process for Server0 and assign IP address 20.0.0.2/8.

Assign IP address to interfaces of routers

Double click Router0 and click CLI and press Enter key to access the command prompt of Router0.



Four interfaces FastEthernet0/0, FastEthernet0/1, Serial 0/0/0 and Serial0/0/1 of Router0 are used in this topology. By default interfaces on router are remain administratively down during the start up.

We need to configure IP address and other parameters on interfaces before we could actually use them for routing. Interface mode is used to assign the IP address and other parameters. Interface mode can be accessed from global configuration mode. Following commands are used to access the global configuration mode.

```
Router>enable
Router# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#
```

From global configuration mode we can enter in interface mode. From there we can configure the interface. Following commands will assign IP address on FastEthernet0/0 and FastEthernet0/1.

```
Router(config)#interface fastEthernet 0/0
Router(config-if)#ip address 10.0.0.1 255.0.0.0
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface fastEthernet 0/1
Router(config-if)#ip address 192.168.1.1 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#
```

interface fastEthernet 0/0 command is used to enter in interface mode.

ip address 10.0.0.1 255.0.0.0 command would assign IP address to interface.

no shutdown command would bring the interface up.

exit command is used to return in global configuration mode.

Serial interface needs two additional parameters **clock rate** and **bandwidth**. Every serial cable has two ends DTE and DCE. These parameters are always configured at DCE end.

We can use **show controllers *interface*** command from privilege mode to check the cable's end.

```
Router#show controllers serial 0/0/0
Interface Serial0/0/0
Hardware is PowerQUICC MPC860
DCE V.35, clock rate 2000000
[Output omitted]
```

Fourth line of output confirms that DCE end of serial cable is attached. If you see DTE here instead of DCE skip these parameters.

Now we have necessary information let's assign IP address to serial interfaces.

```
Router# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface serial 0/0/0
Router(config-if)#ip address 192.168.0.1  255.255.255.252
Router(config-if)#clock rate 64000
Router(config-if)#bandwidth 64
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface serial 0/0/1
Router(config-if)#ip address 192.168.2.1  255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
```

Router#configure terminal Command is used to enter in global configuration mode.

Router(config)#interface serial 0/0/0 Command is used to enter in interface mode.

Router(config-if)#ip address 192.168.0.1 255.255.255.252 Command assigns IP address to interface. For serial link we usually use IP address from /30 subnet.

Router(config-if)#clock rate 64000 In real life environment this parameter controls the data flow between serial links and need to be set at service provider's end. In lab environment we need not to worry about this value. We can use any valid clock rate here.

Router(config-if)#bandwidth 64 Bandwidth works as an influencer. It is used to influence the metric calculation of OSPF or any other routing protocol which uses bandwidth parameter in route selection process. Serial interface has default bandwidth of 1544Kbps. To explain, how bandwidth influence route selection process we will configure (64Kbps) bandwidth on three serial DCE interfaces of our network; R0's Se0/0/0, R1's Se0/0/1 and R2's Se0/0/0.

Router(config-if)#no shutdown Command brings interface up.

Router(config-if)#exit Command is used to return in global configuration mode.

We will use same commands to assign IP addresses on interfaces of remaining routers.

Router1

Router1

Physical | Config | CLI

IOS Command Line Interface

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface serial 0/0/0
Router(config-if)#ip address 192.168.0.2 255.255.255.252
Router(config-if)#exit
Router(config)#interface serial 0/0/1
Router(config-if)#ip address 192.168.0.5 255.255.255.252
Router(config-if)#clock rate 64000
Router(config-if)#bandwidth 64
Router(config-if)#no shutdown
Router(config-if)#exit
```

Router2

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface serial 0/0/0
Router(config-if)#ip address 192.168.0.9 255.255.255.252
Router(config-if)#clock rate 64000
Router(config-if)#bandwidth 64
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config-if)#
Router(config)#interface serial 0/0/1
Router(config-if)#ip address 192.168.0.6 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#
```


Serial interface has a default bandwidth of 1544Kbps. If we don't assign any custom bandwidth, router would use default bandwidth. To see this feature in action we will not assign bandwidth on remaining routers.

Router6

Physical | Config | CLI

IOS Command Line Interface

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface serial 0/0/0
Router(config-if)#ip address 192.168.0.10 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface serial 0/0/1
Router(config-if)#ip address 192.168.2.10 255.255.255.252
Router(config-if)#clock rate 64000
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface fastethernet 0/0
Router(config-if)#ip address 192.168.1.6 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface fastethernet 0/1
Router(config-if)#ip address 20.0.0.1 255.0.0.0
Router(config-if)#no shutdown
Router(config-if)#exit
```

Router5

Router5

Physical | Config | CLI

IOS Command Line Interface

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface fastethernet 0/0
Router(config-if)#ip address 192.168.1.5 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface fastethernet 0/1
Router(config-if)#ip address 192.168.1.2 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#
```

Router3

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface serial 0/0/0
Router(config-if)#ip address 192.168.2.5 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface serial 0/0/1
Router(config-if)#ip address 192.168.2.2 255.255.255.252
Router(config-if)#clock rate 64000
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#
```

Router4

Physical | Config | CLI

IOS Command Line Interface

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#interface serial 0/0/0
Router(config-if)#ip address 192.168.0.10 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface serial 0/0/1
Router(config-if)#ip address 192.168.2.10 255.255.255.252
Router(config-if)#clock rate 64000
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface fastethernet 0/0
Router(config-if)#ip address 192.168.1.6 255.255.255.252
Router(config-if)#no shutdown
Router(config-if)#exit
Router(config)#interface fastethernet 0/1
Router(config-if)#ip address 20.0.0.1 255.0.0.0
Router(config-if)#no shutdown
Router(config-if)#exit
```

Now routers have information about the networks that they have on their own interfaces. Routers will not exchange this information between them on their own. We need to implement OSPF routing protocol that will insist them to share this information.

Configure OSPF routing protocol

Enabling OSPF is a two steps process:-

- Enable OSPF routing protocol from global configuration mode.
- Tell OSPF which interfaces we want to include.

For these steps following commands are used respectively.

```
Router(config)# router ospf process_ID
Router(config-router)# network IP_network_# [wild card mask] Area Number area number
```

Router(config)# router ospf process ID

This command will enable OSPF routing protocol in router. Process ID is a positive integer. We can use any number from 1 to 65,535. Process ID is locally significant. We can run multiple OSPF process on same router. Process ID is used to differentiate between them. Process ID need not to match on all routers.

Router(config-router)# network IP_network_# [wildcard_mask] area [area number]

Network command allows us to specify the interfaces which we want to include in OSPF process. This command accepts three arguments network number, wildcard mask and area number.

Network number

Network number is network ID. We can use any particular host IP address or network IP address. For example we can use 192.168.1.1 (host IP address) or we can use 192.168.1.0 (Network IP address). While targeting a specific interface usually we use host IP address (configured on that interface).

While targeting multiple interfaces, we use network IP address. So any interface that belongs to specified network ID will be selected.

Wildcard mask

Wildcard mask are used with network ID to filter the interfaces. Wildcard mask is different from subnet mask. Subnet mask is used to separate the network portion and host portion in IP address. While wildcard mask is used to match corresponding octet in network portion. Wildcard mask tells OSPF the part of network address that must be matched.

OSPF configuration

Router0

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 10
Router(config-router)#network 10.0.0.0 0.255.255.255 area 0
Router(config-router)#network 192.168.0.0 0.0.0.3 area 0
Router(config-router)#network 192.168.1.0 0.0.0.3 area 0
Router(config-router)#network 192.168.2.0 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

Router1

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 10
Router(config-router)#network 192.168.0.0 0.0.0.3 area 0
Router(config-router)#network 192.168.0.4 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

Router2

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 20
Router(config-router)#network 192.168.0.4 0.0.0.3 area 0
Router(config-router)#network 192.168.0.8 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

Router6

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 60
Router(config-router)#network 20.0.0.0 0.255.255.255 area 0
Router(config-router)#network 192.168.0.8 0.0.0.3 area 0
Router(config-router)#network 192.168.2.8 0.0.0.3 area 0
Router(config-router)#network 192.168.1.4 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

Router5

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 50
Router(config-router)#network 192.168.1.0 0.0.0.3 area 0
Router(config-router)#network 192.168.1.4 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

Router4

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 40
Router(config-router)#network 192.168.2.8 0.0.0.3 area 0
Router(config-router)#network 192.168.2.4 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

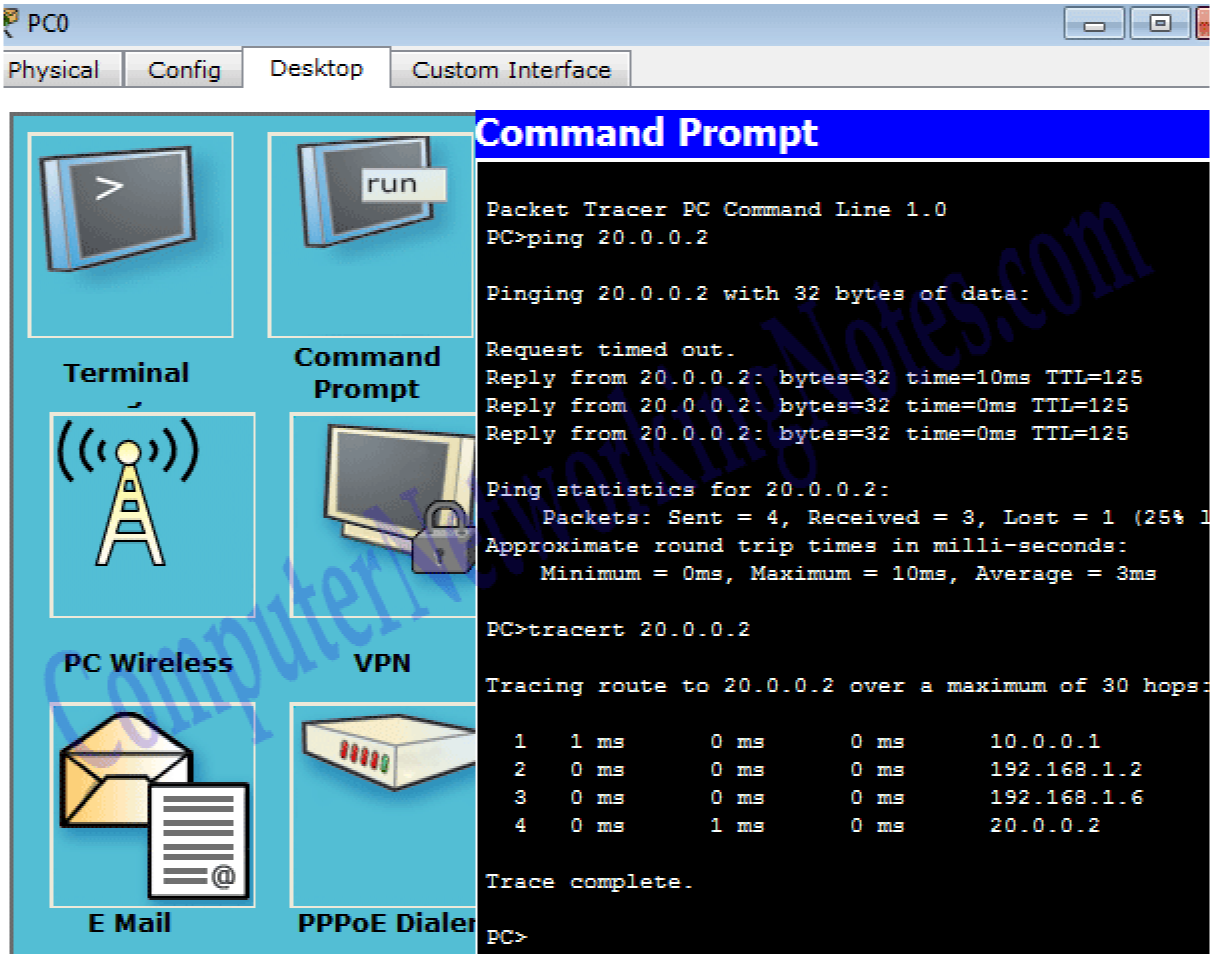
Router3

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)#router ospf 30
Router(config-router)#network 192.168.2.0 0.0.0.3 area 0
Router(config-router)#network 192.168.2.4 0.0.0.3 area 0
Router(config-router)#exit
Router(config)#
```

Our network is ready to take the advantage of OSPF routing. To verify the setup we will use ping command. **ping** command is used to test the connectivity between two devices.

We have two routes between source and destination. **tracert** command is used to know the route which is used to get the destination.

Access the command prompt of PC1 and use ping command to test the connectivity from Server0. After that use tracert command to print the taken path.


PC0
Physical
Config
Desktop
Custom Interface
Terminal
Command Prompt
PC Wireless
VPN
E Mail
PPPoE Dialer
Command Prompt
Packet Tracer PC Command Line 1.0
PC>ping 20.0.0.2
Pinging 20.0.0.2 with 32 bytes of data:
Request timed out.
Reply from 20.0.0.2: bytes=32 time=10ms TTL=125
Reply from 20.0.0.2: bytes=32 time=0ms TTL=125
Reply from 20.0.0.2: bytes=32 time=0ms TTL=125
Ping statistics for 20.0.0.2:
Packets: Sent = 4, Received = 3, Lost = 1 (25%
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 10ms, Average = 3ms
PC>tracert 20.0.0.2
Tracing route to 20.0.0.2 over a maximum of 30 hops:
1 1 ms 0 ms 0 ms 10.0.0.1
2 0 ms 0 ms 0 ms 192.168.1.2
3 0 ms 0 ms 0 ms 192.168.1.6
4 0 ms 1 ms 0 ms 20.0.0.2
Trace complete.
PC>
ComputerNetworkingNotes.com

Summary

Command	Description
Router(config)#router opsf 10	Enable OSPF routing protocol under process ID 10.
Router(config-router)#network 10.10.0.0 0.0.255.255 area 0	Enable OSPF with area 0 on matching interface.
Router(config)#interface loopback 0	Create a Loopback interface and move in sub interface configuration mode
Router(config-if)#ip address 192.168.250.250 255.255.255.0	Assign IP address to loopback interface.
Router(config-router)#router-id 1.1.1.1	Set 1.1.1.1 as router ID
Router(config)#interface serial 0/0	Inter in sub interface configuration mode
Router(config-if)#ip ospf priority 100	Used to influence DR/BDR selection process. Valid range is 0 to 255. 0 makes router ineligible for DR/BDR while 255 makes router guaranteed DR/BDR. Higher priority value means higher chance of becoming DR/BDR.
Router(config-if)#bandwidth 256	Used to influence route metric cost. Cost is the inverse of bandwidth. Higher bandwidth has lower cost. Bandwidth is defined in Kbps. 256 means 256 Kbps.
Router(config-if)#ip ospf hello-interval timer 15	Set hello interval timer to 15 seconds. Hello timer must be match on both routers in order become neighbors.
Router(config-if)#ip ospf dead-interval 60	Set dead interval timer to 60 seconds. Dead interval timer must be match on both routers in order to become neighbor
Router#show ip route	Display all routes from routing table
Router#show ip route ospf	Display all routers learned through OSPF from routing table
Router#show ip ospf	Display basic information about OSPF
Router#show ip ospf interface	Display information about all OSPF active interfaces
Router#show ip ospf interface serial 0/0/0	Display OSPF information about serial 0/0/0 interface
Router#show ip ospf neighbor List all	OSPF neighbors with basic info
Router#show ip ospf neighbor detail	List OSPF neighbors with detail info
Router#show ip ospf database	Display data for OSPF database
Router#clear ip route *	Clear all routes from routing table.
Router#clear ip route 10.0.0.0/8	Clear particular route from routing table
Router#clear ip ospf counters	Clear OSPF counters
Router#debug ip ospf events	Display all ospf events
Router#debug ip ospf packets	Display exchanged OSPF packets
Router#debug ip ospf adjacency	Display DR/BDR election process state

OSPF Metric cost Calculation Formula

Shortest Path First (SPF) Algorithm

As we know upon initialization or due to any change in routing information an OSPF router generates a LSA. This LSA (Link State Advertisement) contains the collection of all link-states on that router. Router propagates this LSA in network. Each router that receives this LSA would store a copy of it in its LSA database then flood this LSA to other routers.

After database is updated, router selects a single best route for each destination from all available routes. Router uses SPF algorithm to select the best route.

Just like other routing algorithm SPF also uses a metric component called cost to select the best route for routing table.

OSPF Metric cost

Logically a packet will face more overhead in crossing a 56Kbps serial link than crossing a 100Mbps Ethernet link. Respectively it will take less time in crossing a higher bandwidth link than a lower bandwidth link. OSPF uses this logic to calculate the cost. Cost is the inverse proportional of bandwidth. Higher bandwidth has a lower cost. Lower bandwidth has a higher cost.

OSPF uses following formula to calculate the cost

Cost = Reference bandwidth / Interface bandwidth in bps.

Reference bandwidth was defined as arbitrary value in OSPF documentation (RFC 2338). Vendors need to use their own reference bandwidth. Cisco uses 100Mbps (108) bandwidth as reference bandwidth. With this bandwidth, our equation would be

Cost = 10^8/interface bandwidth in bps

Key points

- Cost is a positive integer value.
- Any decimal value would be rounded back in nearest positive integer.
- Any value below 1 would be considered as 1.

Now we know the equation, let’s do some math and figure out the default cost of some essential interfaces.

Default cost of essential interfaces.

Interface Type	bandwidth	Metric Calculation	Cost
Ethernet Link	10Mbps	100000000/10000000 = 10	10
FastEthernet Link	100Mbps	100000000/100000000 = 1	1
Serial Link	1544Kbps(default)	100000000/1544000 = 64.76	64

Cost of common lines

Line	Bandwidth	Metric calculation	Cost
56 Kbps line	56Kbps	100000000/56000 = 1785.71	1785
64 Kbps line	64Kbps	100000000/64000 = 1562.5	1562
128 Kbps line	128Kbps	100000000/128000 = 781.25	781
512 Kbps line	512 Kbps	100000000/512000 = 195.31	195
1 Mbps line	1Mbps	100000000/1000000 = 100	100
10 Mbps line	10Mbps	100000000/10000000 = 10	10
100 Mbps line	100Mbps	100000000/100000000 = 1	1
1 Gbps line	1Gbps	100000000/100000000 0= 0.1	1
10 Gbps line	10Gbps	100000000/10000000000 = 0.01	1

SPT (Shortest Path Tree)

OSPF router builds a Shortest Path Tree. SPT is just like a family tree where router is the root and destination networks are the leaves. SPF algorithm calculates the branch cost between leaves and root. Branch with lowest cost will be used to reach at leaf. In technical language route that has lowest cumulative cost value between source and destination will be selected for routing table.

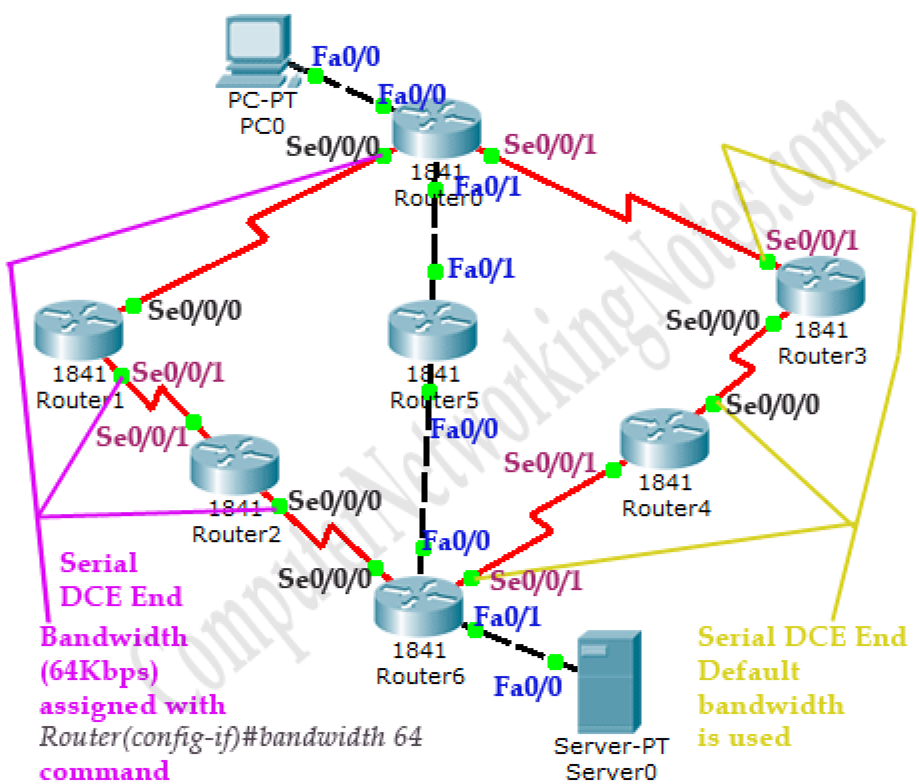
Cumulative cost = Sum of all outgoing interfaces cost in route

Best route for routing table = Route which has the lowest cumulative cost

Summary

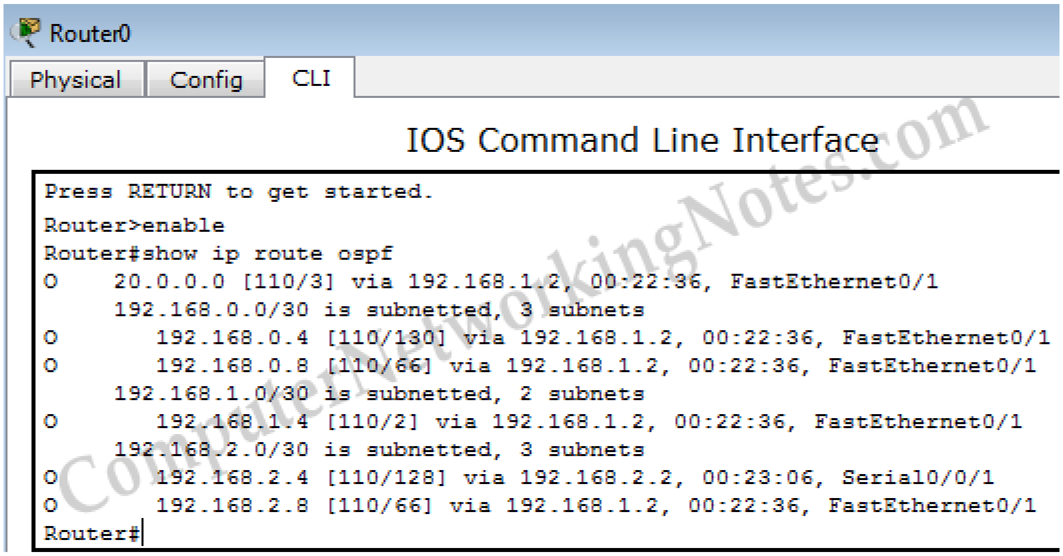
- OSPF uses SPT tree to calculate the best route for routing table.
- A SPT tree cannot grow beyond the area. So if a router has interfaces in multiple areas, it needs to build separate tree for each area.
- SPF algorithm calculates all possible routes from source router to destination network.
- Cumulative cost is the sum of the all costs of the outgoing OSPF interfaces in the path.
- While calculating cumulative cost, OSPF consider only outgoing interfaces in path. It does not add the cost of incoming interfaces in cumulative cost.
- If multiple routes exist, SPF compares the cumulative costs. Route which has the lowest cumulative cost will be chosen for routing table.

Now we have a basic understanding of SPF algorithm. In remaining part we will learn how SPF algorithm selects the best route from available routes.



Access CLI prompt of Router0.

Run **show ip route ospf** command from privilege mode to view all learned routes through the OSPF protocol.



As output shows, Router0 has six routes from OSPF in routing table. We will go through the each route and find out why it was chosen as the best route for routing table by OSPF

Route 20.0.0.0

We have three routes to get 20.0.0.0/8 network. Let's calculate the cumulative cost of each route.

Via Route R0-R1-R2-R6

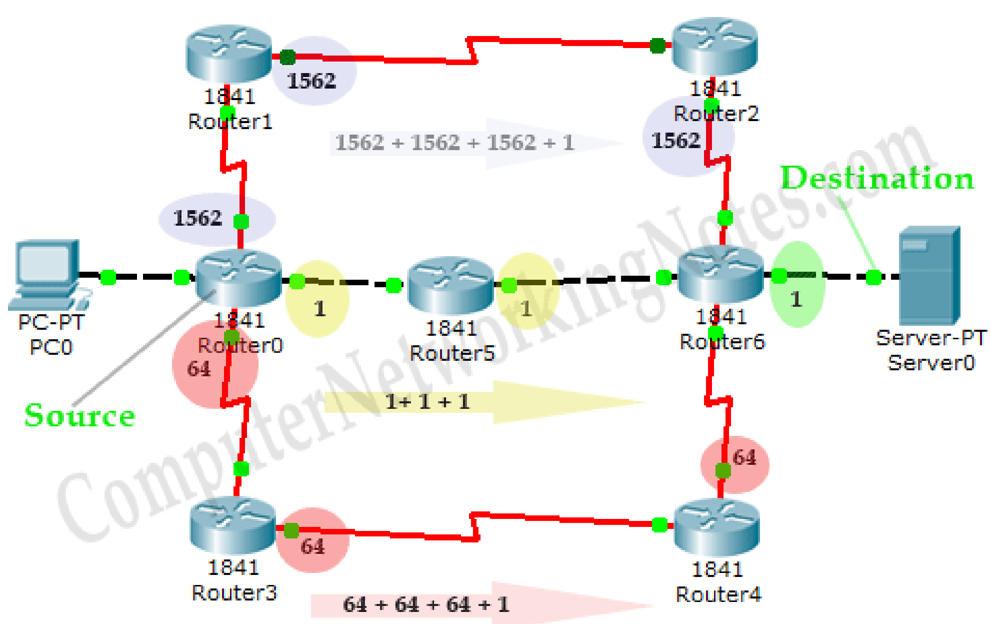
Router	Exit Interface	Bandwidth	Metric Calculation	Cost
R0	Se0/0/0	64Kbps (Manually Assigned)	100000000/64000 = 1562.5	1562
R1	Se0/0/1	64Kbps (Manually Assigned)	100000000/64000 = 1562.5	1562
R2	Se0/0/0	64Kbps (Manually Assigned)	100000000/64000 = 1562.5	1562
R6	Fa0/1	100Mbps	100000000/100000000 = 1	1
				Cumulative cost of route (1562 + 1562 + 1562 + 1) = 4687

Via route R0 – R3 – R4 – R6

Router	Exit Interface	Bandwidth	Metric Calculation	Cost
R0	Se0/0/1	1544Kbps (Default)	100000000/1544000 = 64.76	64
R3	Se0/0/0	1544Kbps (Default)	100000000/1544000 = 64.76	64
R2	Se0/0/1	1544Kbps (Default)	100000000/1544000 = 64.76	64
R6	Fa0/1	100Mbps	100000000/100000000 = 1	1
				Cumulative cost of route (64 + 64 + 64 + 1) = 193

Via route R0 – R5 – R6

Router	Exit Interface	Bandwidth	Metric Calculation	Cost
R0	Fa0/1	100Mbps	100000000/100000000 = 1	1
R5	Fa0/0	100Mbps	100000000/100000000 = 1	1
R0	Fa0/1	100Mbps	100000000/100000000 = 1	1
				Cumulative cost of route (1+ 1 + 1) = 3



Among these routes, route R0-R5-R6 has the lowest cumulative cost. So it was selected as the best route for routing table.

Route 192.168.0.4

Via Route R0 – R1

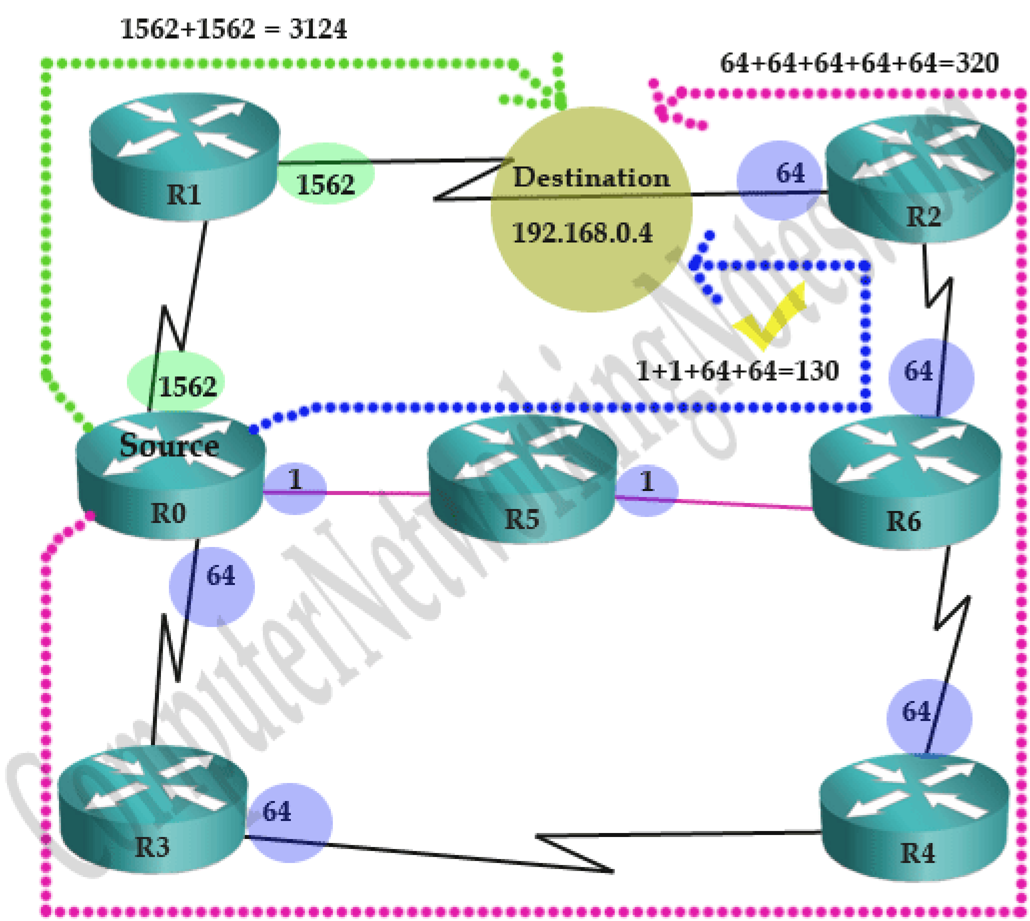
R0's Serial 0/0/0 cost (1562) + R1's Serial 0/0/1 cost (1562) = 3124 (Cumulative cost)

Via Route R0 – R3 – R4 – R6 – R2

R0's Serial 0/0/1 cost (64) + R3's Serial 0/0/0 cost (64) + R4's Serial 0/0/1 cost (64) + R6's Serial 0/0/0 cost (64) + R2's Serial 0/0/1 cost (64) = 320 (Cumulative cost)

Via Route R0 – R5 – R6 – R2

R0's FastEthernet 0/1 cost (1) + R5's FastEthernet 0/0 cost (1) + R6's Serial 0/0/0 cost (64) +R2's Serial 0/0/1 cost (64) = 130 (Cumulative cost)



Among these routes, Route R0 – R5 – R6 – R2 has the lowest cost so it was picked for routing table.

Route 192.168.0.8

Via Route R0 – R1

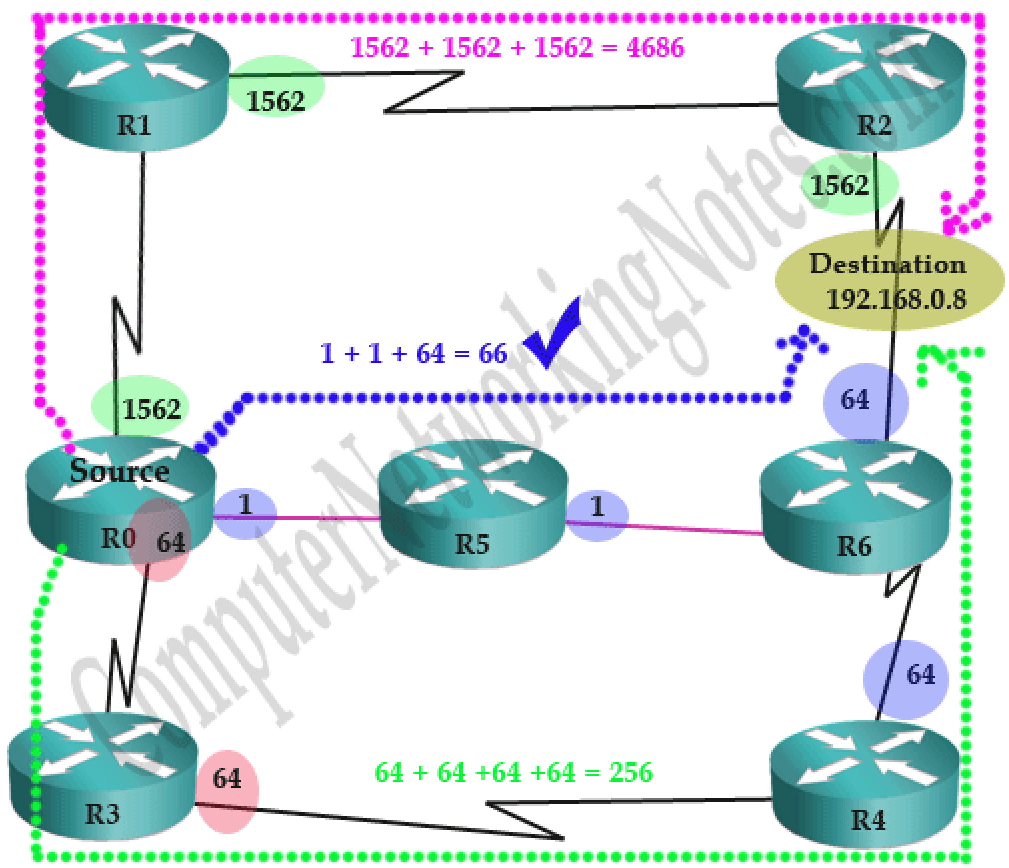
R0's Serial 0/0/0 cost (1562) + R1's Serial 0/0/1 cost (1562) + R2's Serial 0/0/0 (1562) = 4686 (Cumulative cost)

Via Route R0 – R3 – R4 – R6

R0's Serial 0/0/1 cost (64) + R3's Serial 0/0/0 cost (64) + R4's Serial 0/0/1 cost (64) + R6's Serial 0/0/0 cost (64) = 256 (Cumulative cost)

Via Route R0 – R5 – R6

Ro's FastEthernet 0/1 cost (1) + R5's FastEthernet 0/0 cost (1) + R6's Serial 0/0/0 cost (64) = 66 (Cumulative cost)



Among these routes, Route R0 – R5 – R6 has the lowest cost so it was picked for routing table.

Route 192.168.1.4

Via Route R0 – R1 – R2 – R6

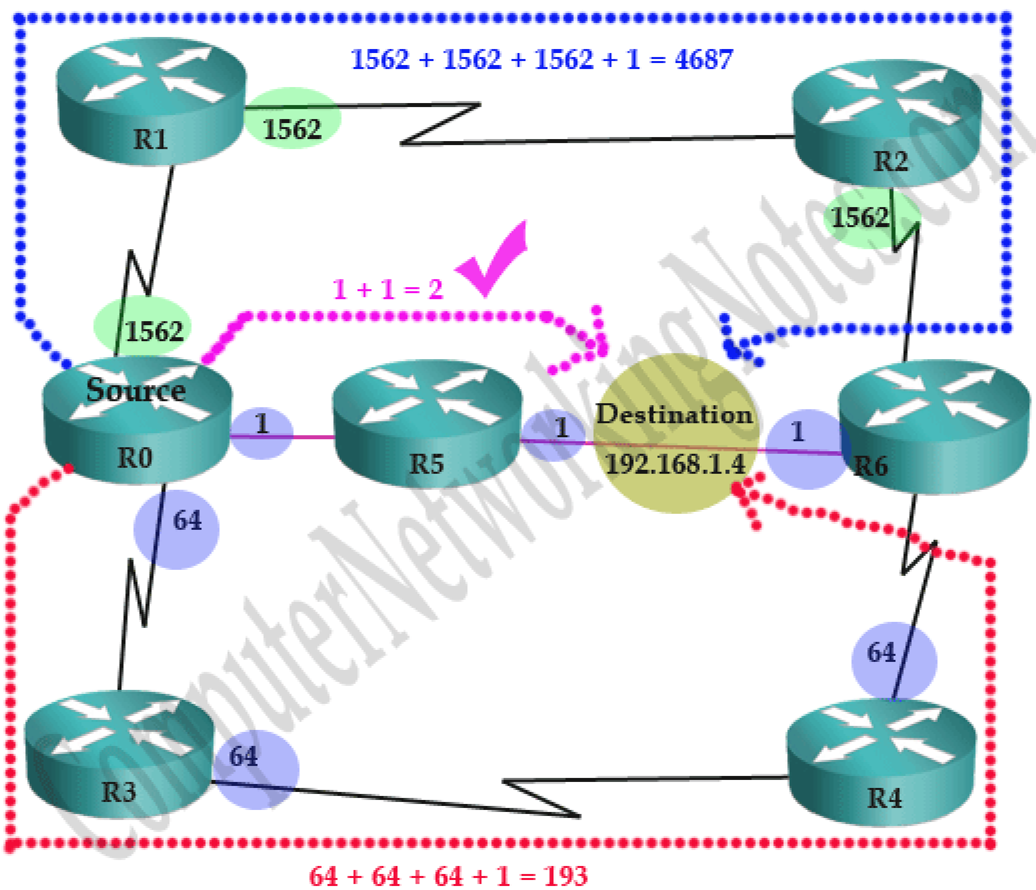
R0’s Serial 0/0/0 cost (1562) + R1’s Serial 0/0/1 (1562) + R2’s Serial 0/0/0 (1562) + R6’s FastEthernet 0/0 (1) = 4687 (Cumulative cost)

Via R0 – R3 – R4 – R6

R0’s Serial 0/0/1 cost (64) + R3’s Serial 0/0/0 cost (64) + R4’s Serial 0/0/1 cost (64) + R6’s FastEthernet 0/0 (1) = 193

Via R0 – R5

R0’s FastEthernet 0/1 cost (1) + R5’s FastEthernet 0/0 cost (1) = 2



Among these routes, Route R0 – R5 has the lowest cost so it was selected as the best route.

Route 192.168.2.4

Via Route R0 – R1 – R2 – R6 – R4

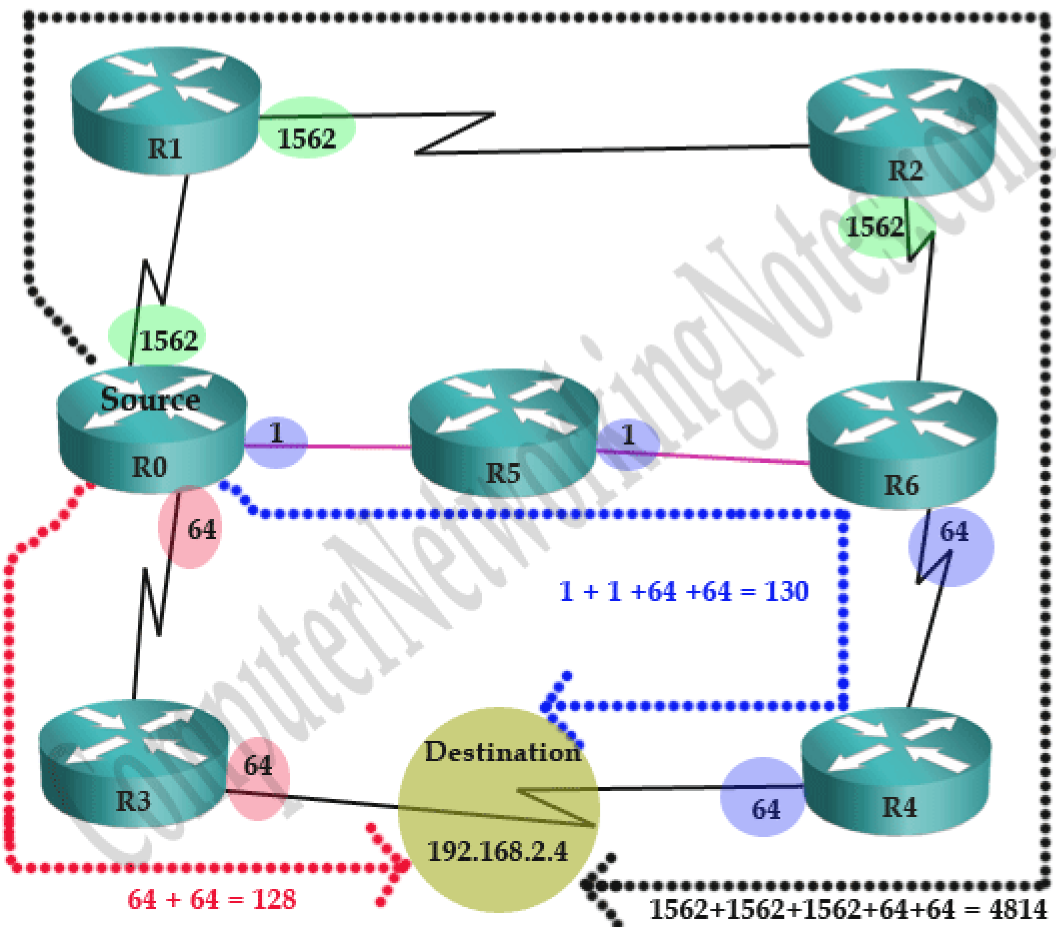
R0's Serial 0/0/0 cost (1562) + R1's Serial 0/0/1 cost (1562) + R2's Serial 0/0/0 cost (1562) + R6's Serial 0/0/1 cost (64) + R4's Serial 0/0/0 cost (64) = 4814

Via Route R0 – R5 – R6 – R4

R0's FastEthernet 0/1 cost (1) + R5's FastEthernet 0/0 cost (1) + R6's Serial 0/0/1 (64) + R4's Serial 0/0/0 cost (64) = 130

Via Route R0 – R3

R0's Serial 0/0/1 cost (64) + R3's serial 0/0/0 cost (64) = 128



Among these routes, Route R0 - R3 has the lowest cost for destination 192.168.2.4.

Route 192.168.2.8

Via Route R0 – R3 – R4

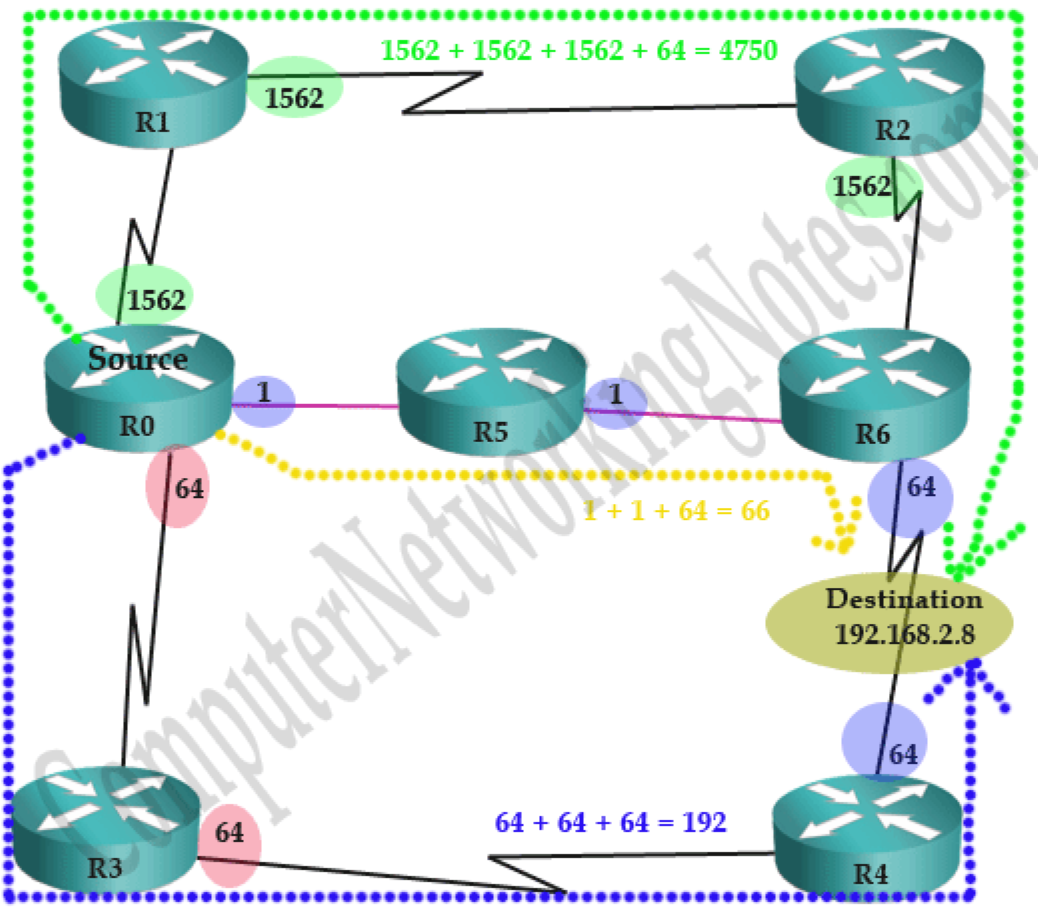
R0's Serial 0/0/1 cost (64) + R3's Serial 0/0/0 cost (64) + R4's Serial 0/0/1 cost (64) = 192

Via Route R0 – R1 – R2 – R6

Ro's Serial 0/0/0 cost (1562) + R1's Serial 0/0/1 cost (1562) + R2's Serial 0/0/0 cost (1562) + R6's Serial 0/0/1 cost (64) = 4750

Via Route R0 – R5 – R6

R0's FastEthernet 0/1 cost (1) + R5's FastEthernet 0/0 cost (1) + R6's Serial 0/0/1 cost (64) = 66



Route R0 – R5 – R6 has the lowest cost value.

OSPF Route cost Manipulation

We can manipulate OSPF route cost in two ways.

1. By changing bandwidth of interface
2. By changing reference bandwidth value

By changing bandwidth of interface

Sub interface mode command Bandwidth is used to set the bandwidth of supported interface.

If bandwidth is set through this command, OSPF will use it. If bandwidth is not set, it will use interface's default bandwidth.

When we enable an interface, router automatically assign a bandwidth value to it based on its type. For example serial interface has a default bandwidth value of 1544k. Until we change this value with bandwidth command, it will be used where it is required.

Let me clear one more thing about bandwidth. Changing default bandwidth with bandwidth command does not change actual bandwidth of interface. Neither default bandwidth nor bandwidth set by bandwidth command has anything to do with actual layer one link bandwidth.

Then what purpose does this command solve?

This command is only used to influence the routing protocol which uses bandwidth in route selection process such as OSPF and EIGRP.

We have already seen an example of this method in our example. We changed default bandwidth (1544Kbps) to custom (64kbps) bandwidth on R0's serial 0/0/0, R1's serial 0/0/1 and R2's serial 0/0/0. Due to this change R0 took another router for 192.168.0.4 network.

Let's understand this in more detail.

Current cost for destination 192.168.0.4 from R0

Via Route R0 – R1

R0's Serial 0/0/0 cost (1562) + R1's Serial 0/0/1 cost (1562) = 3124 (Cumulative cost)

Via Route R0 – R5 – R6 – R2

Ro's FastEthernet 0/1 cost (1) + R5's FastEthernet 0/0 cost (1) + R6's Serial 0/0/0 cost (64) +R2's Serial 0/0/1 cost (64) = 130 (Cumulative cost)

Via Route R0 – R3 – R4 – R6 – R2

R0's Serial 0/0/1 cost (64) + R3's Serial 0/0/0 cost (64) + R4's Serial 0/0/1 cost (64) + R6's Serial 0/0/0 cost (64) + R2's Serial 0/0/1 cost (64) = 320 (Cumulative cost)

Among these routes, Route R0 – R5 – R6 – R2 has the lowest cost so it was picked for routing table.

Well … Which route would have selected, if we had used default bandwidth?

Cost for destination 192.168.0.4 from R0 with default bandwidth.

Via Route R0 – R1

R0's Serial 0/0/0 cost (64) + R1's Serial 0/0/1 cost (64) = 128 (Cumulative cost)

Via Route R0 – R5 – R6 – R2

Ro's FastEthernet 0/1 cost (1) + R5's FastEthernet 0/0 cost (1) + R6's Serial 0/0/0 cost (64) +R2's Serial 0/0/1 cost (64) = 130 (Cumulative cost)

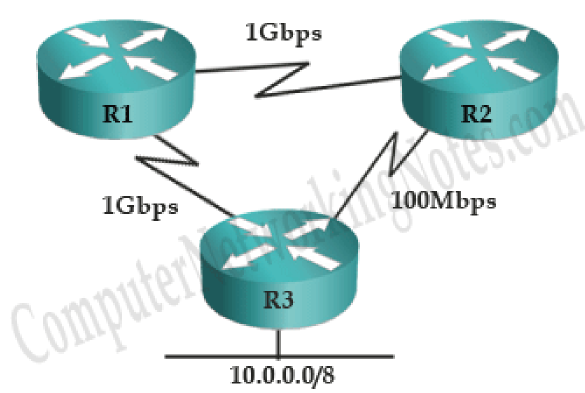
Via Route R0 – R3 – R4 – R6 – R2

R0's Serial 0/0/1 cost (64) + R3's Serial 0/0/0 cost (64) + R4's Serial 0/0/1 cost (64) + R6's Serial 0/0/0 cost (64) + R2's Serial 0/0/1 cost (64) = 320 (Cumulative cost)

Among these routes, Route R0 – R1 has the lowest cost value so it would be selected for routing table. Thus by changing interface bandwidth we actually influenced route selection process.

By changing reference bandwidth value

As I mention earlier, by default OSPF uses 100Mbps bandwidth as a reference bandwidth. Changing this value would also change the cost of route. If we use 1000Mbps as a reference bandwidth, cost of 100Mbps link would become 10. This sounds great, especially if we have higher bandwidth links in our network. For example have a look on following figure.



Which route will R2 take to get the network of 10.0.0.0/8?

Route R2 – R3

In this route we have two exit points. Both points have default 1oo Mbps speed.

R2's FastEthernet cost (100000000/100000000) = 1

R3's FastEthernet cost (100000000/100000000) = 1

Cost of this route 1 + 1 = 2

Route R2 – R1 – R3

In this route we have three exit points. Two exit points (R2 and R1) have 1 Gbps link.

R2's FastEthernet cost (100000000/1000000000) = .1 (Anything below 1 would be considered as 1)

R3's FastEthernet (100000000/1000000000) = .1 (Anything below 1 would be considered as 1)

R3's FastEthernet cost (100000000/100000000) = 1

Cost of this route 1 + 1 + 1 = 3

With default reference bandwidth R2 will choose Route R2 – R3, which is not good.

We can adjust reference bandwidth with **auto-cost reference-bandwidth *ref-band*** command.

We need to adjust reference bandwidth on all routers of network. Mismatched reference bandwidth can cause routers to run the SPF algorithm continually, which could create a serious performance issue.

Reference bandwidth is assigned in Mbps. Valid range is 1 to 4294967. Default reference bandwidth is 100Mbps.

Sadly packet tracer does not include this command. For the practice of this command please use other simulator software which support this command or use real router.

Let's change reference bandwidth to 1000Mbps on all three routers using following commands

```
Router# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router (config)#router ospf 1
Router (config-router)#auto-cost reference-bandwidth 1000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
Router (config-router)#exit
Router #
```

Route cost with new reference bandwidth

{module in_art_slot_10}

Route R2 – R3

R2’s FastEthernet cost (1000000000/100000000) = 10

R3’s FastEthernet cost (1000000000/100000000) = 10

Cost of this route 10 + 10 = 20

Route R2 – R1 – R3

R2’s FastEthernet cost (1000000000/1000000000) = 1

R3’s FastEthernet (1000000000/1000000000) = 1

R3’s FastEthernet cost (1000000000/100000000) = 10

Cost of this route 1 + 1 + 10 = 12

In this case Route R2-R1-R3 will be selected, which is the shortest route for destination.