ECCS-3631
Networks and Data Communications

Module 2-5
Open Shortest Path First (OSPF)

Dr. Ajmal Khan

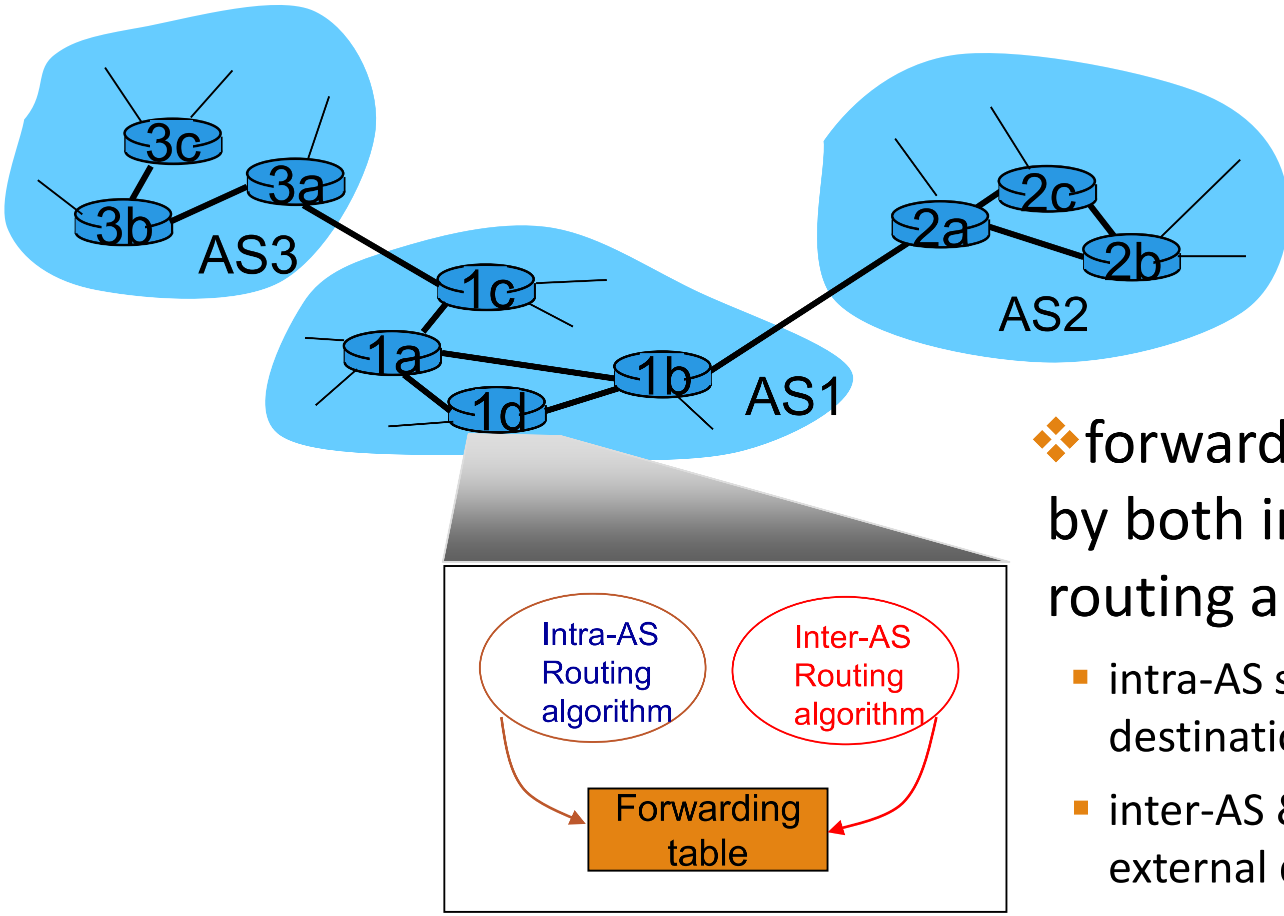
Hierarchical Routing - Motivation

- In the study of Link-State and Distance-Vector routing algorithms, you have noticed that all routers executed the same routing algorithm to compute the routing paths through the entire network.
- In practice, this model is simple for at least two reasons:
  - Scale: As the number of routers becomes large, the overhead involved in computing, storing, and communicating routing information.
  - Administrative Autonomy: An organization should be able to run and administer its network as it wishes, while still being able to connect its network to other outside networks.
- Both of these problems can be solved by organizing routers into Autonomous Systems (AS).

Hierarchical Routing

- Each Autonomous System (AS) consists of a group of routers that are typically under the same administrative control.
- Routers within the same AS all run the same routing protocol.
- The routing protocol running within an Autonomous System is called an Intra-Autonomous System Routing Protocol.
- As each AS connect to the outside World, each AS has routers, called Gateway Routers, to forward packets to destinations outside the AS.
- Gateway router has link to router in another AS.

Interconnected ASes



- forwarding table configured by both intra- and inter-AS routing algorithm
  - intra-AS sets entries for internal destinations
  - inter-AS & intra-AS sets entries for external destinations

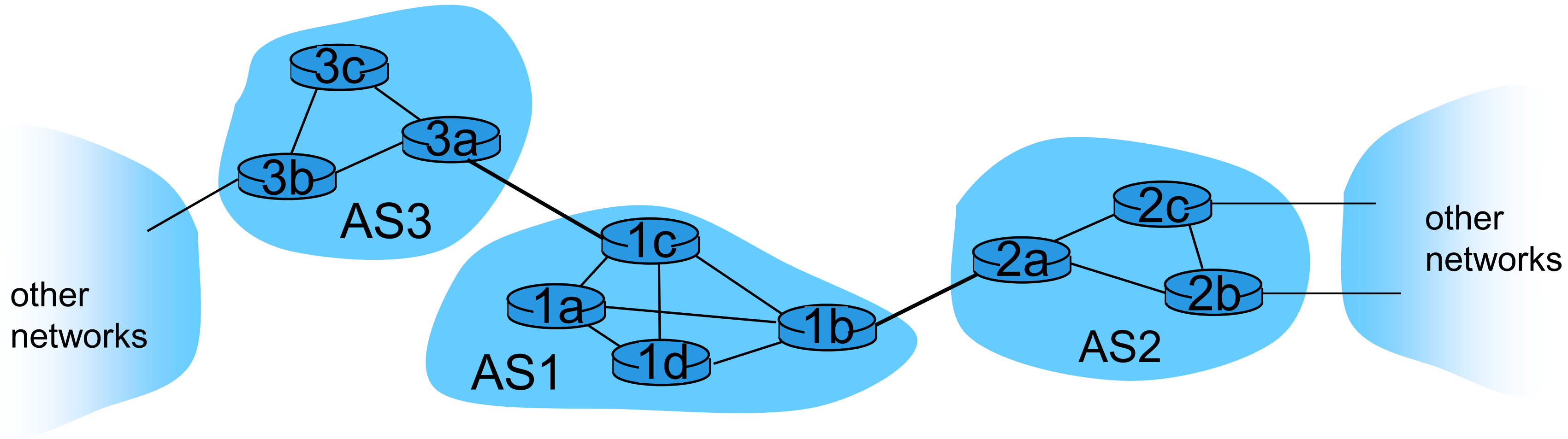
Inter-AS tasks

- suppose router in AS1 receives datagram destined outside of AS1:
  - router should forward packet to gateway router

AS1 must:

1. learn which destinations are reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1

job of inter-AS routing!



Intra-AS Routing

- also known as *interior gateway protocols (IGP)*
- most common intra-AS routing protocols:
  - RIP: Routing Information Protocol
  - OSPF: Open Shortest Path First
  - IGRP: Interior Gateway Routing Protocol (Cisco proprietary)
  - EIGRP: Enhanced Interior Gateway Routing Protocol (Cisco proprietary)

Inter-AS Routing

- Since the inter-AS routing protocol involves communication between two Ass, the two communicating ASes must run the same inter-AS routing protocol.
- There is only one Inter-AS routing protocol, that is BGP, Border Gateway routing Protocol.

OSPF Protocol

- OSPF – Open Shortest Path First routing protocol.
- OSPF is a link-state routing protocol that uses flooding of link-state information and a Dijkstra least-cost path algorithm.
- With OSPF, a router constructs a complete topological map of the entire AS.
- The router uses Dijkstra shortest-path algorithm to determine a shortest-path to all subnets.
- The link costs are configured by the network administrator. Administrator may choose to set all link costs to 1, or may choose to set the link weights to be inversely proportional to link capacity in order to discourage traffic from using low-bandwidth links.
- OSPF does not mandate a policy for how link weights are set, but instad provides the mechanism for determining least-cost path routing for the given set of link weights.

OSPF Protocol

- With OSPF, a router broadcasts routing information to all other routers in the AS, not just to its neighboring routers.
- A router broadcasts link-state information whenever there is a change in a link's state.
- **A router also broadcasts a link's state periodically at least once every 30 minutes,** even if the link's state has not changed.
- **OSPF protocol checks that links are operational via a HELLO message that is sent to an attached neighbor**, and allows an OSPF router to obtain a neighboring router's database.

OSPF Advanced Features (not in RIP)

- **Security**: all OSPF messages authenticated (to prevent malicious intrusion). By default, OSPF packets are not authenticated.
- **Multiple Paths**: When multiple paths to a destination have the same cost, OSPF allows multiple paths to be used (that is, a single path need not be chosen for carrying all traffic when multiple equal-cost paths exist).
- **Support for hierarchy within a single routing domain**. Perhaps the most significant advance in OSPF is the ability to structure an autonomous system hierarchically.

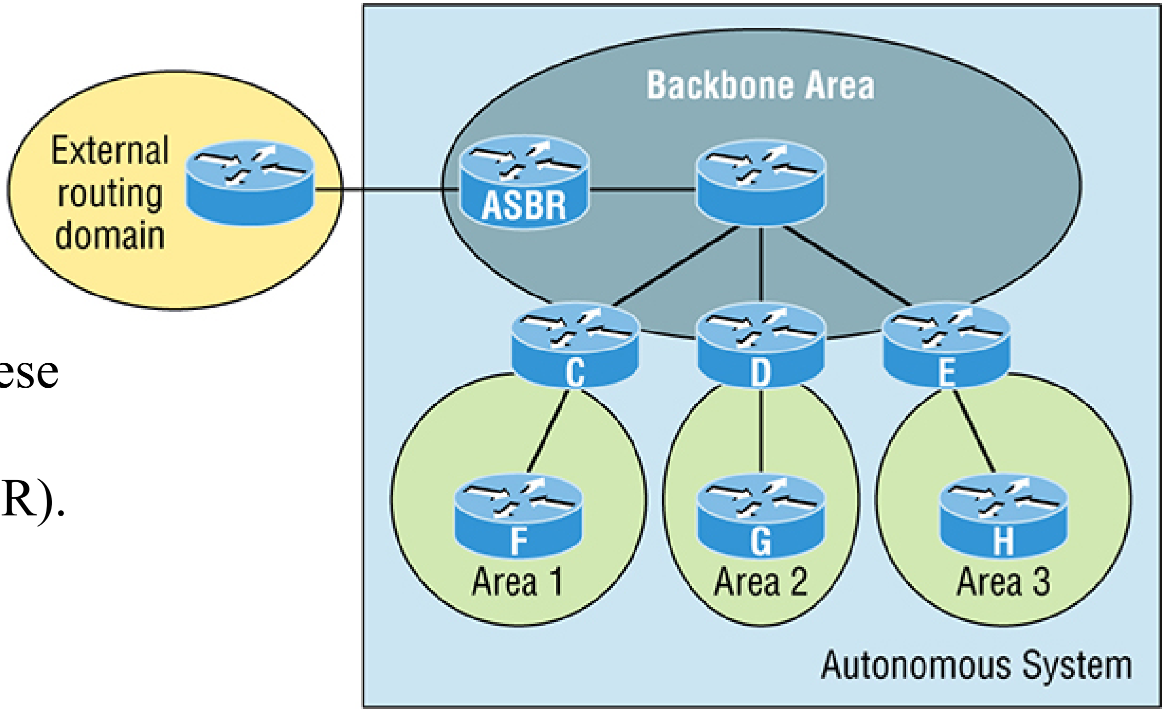
An OSPF autonomous system can be configured hierarchically into areas. Each area runs its own OSPF link-state routing algorithm, with each router in an area broadcasting its link state to all other routers in that area.

OSPF Features

- Allows for the creation of areas and autonomous systems
- Minimizes routing update traffic
- Is highly flexible, versatile, and scalable
- Supports VLSM/CIDR
- Offers an unlimited hop count
- Is open standard and supports multi-vendor deployment
- Speed up convergence if configured with areas
- Confine network instability to single areas of the network

OSPF Area

- An OSPF area is a grouping of contiguous networks and routers. All routers in the same area share a common area ID. Because a router can be a member of more than one area at a time, the area ID is associated with specific interfaces on the router. This allows some interfaces to belong to area 1 while the remaining interfaces can belong to area 0. There must be an area 0, and this is typically considered the backbone area. Areas also play a role in establishing a hierarchical network organization, enhancing the scalability of OSPF.



- The router that connects these ASs is called an autonomous system boundary router (ASBR).

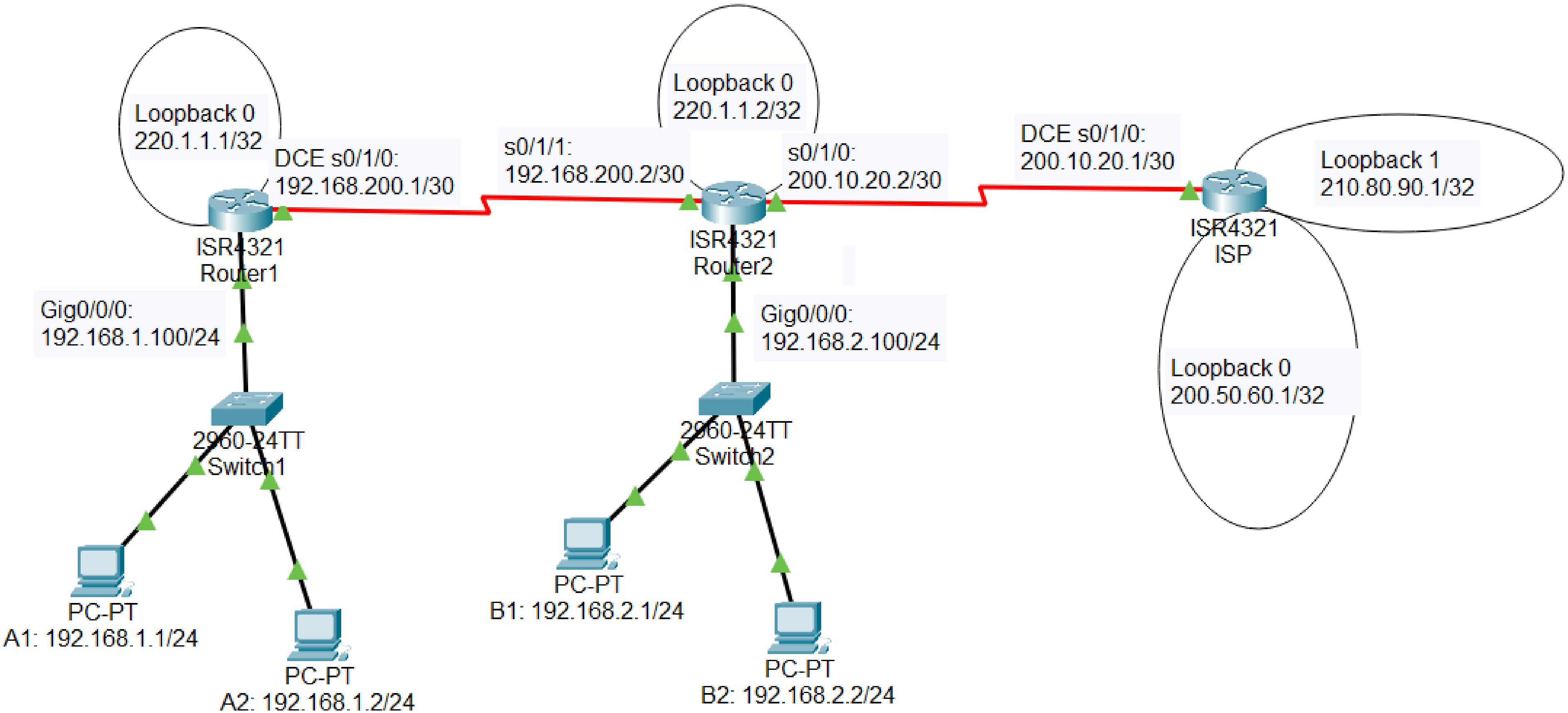
Process ID

- Process_ID is a positive integer. Any number from 1 to 65535 can be used as process_ID. Process_ID is locally significant, and we can run multiple OSPF processes on the same router. The Process ID is used to differentiate between different processes running on the same router. Process ID need not to match on all routers.

- The OSPF process number doesn't have to be the same on all routers to establish a neighbor relationship, but the Area ID has to be the same on all neighboring routers for routers to become neighbors.

OSPF Example

- Let's look at the following network and apply OSPF in this network



Loopback Interface

- Loopback interfaces are logical interfaces, which means they are virtual, software-only interfaces, not actual, physical router interfaces. A big reason we use loopback interfaces with router configurations is that they ensure an interface is always active and available.
- Loopback interfaces also come in very handy for diagnostic purposes. When you do not have the option to check beyond the router or cannot connect a device, a loopback interface is used to test connectivity.

```
ISP(config)#interface loopback 0
ISP(config-if)#ip address 200.10.20.1 255.255.255.255
ISP(config-if)#exit
```

- **Why we don't just use 255.255.255.0**: While it's true that either mask works, the /32 mask is called a host mask and works fine for loopback interfaces. It also allows us to save subnets.

OSPF Example – Enable OSPF

- The first command used to activate the OSPF routing process is:

  Router(config)#router ospf <Process_ID>

  Router1(config)#router ospf 1

- A value in the range from 1 to 65,535 identifies the OSPF process ID.

- The OSPF process ID number is irrelevant. It can be the same on every router on the network, or it can be different—doesn't matter. It's locally significant and just enables the OSPF routing on the router.

OSPF Example – Area

- Define network with area. The areas can be any number from 0 to 4.2 billion.

  Router1(config)#router ospf 1

  Router1(config-router)#network 192.168.1.0 0.0.0.255 area 0

  Router1(config-router)#network 192.168.200.0 0.0.0.3 area 0

Wildcard Mask

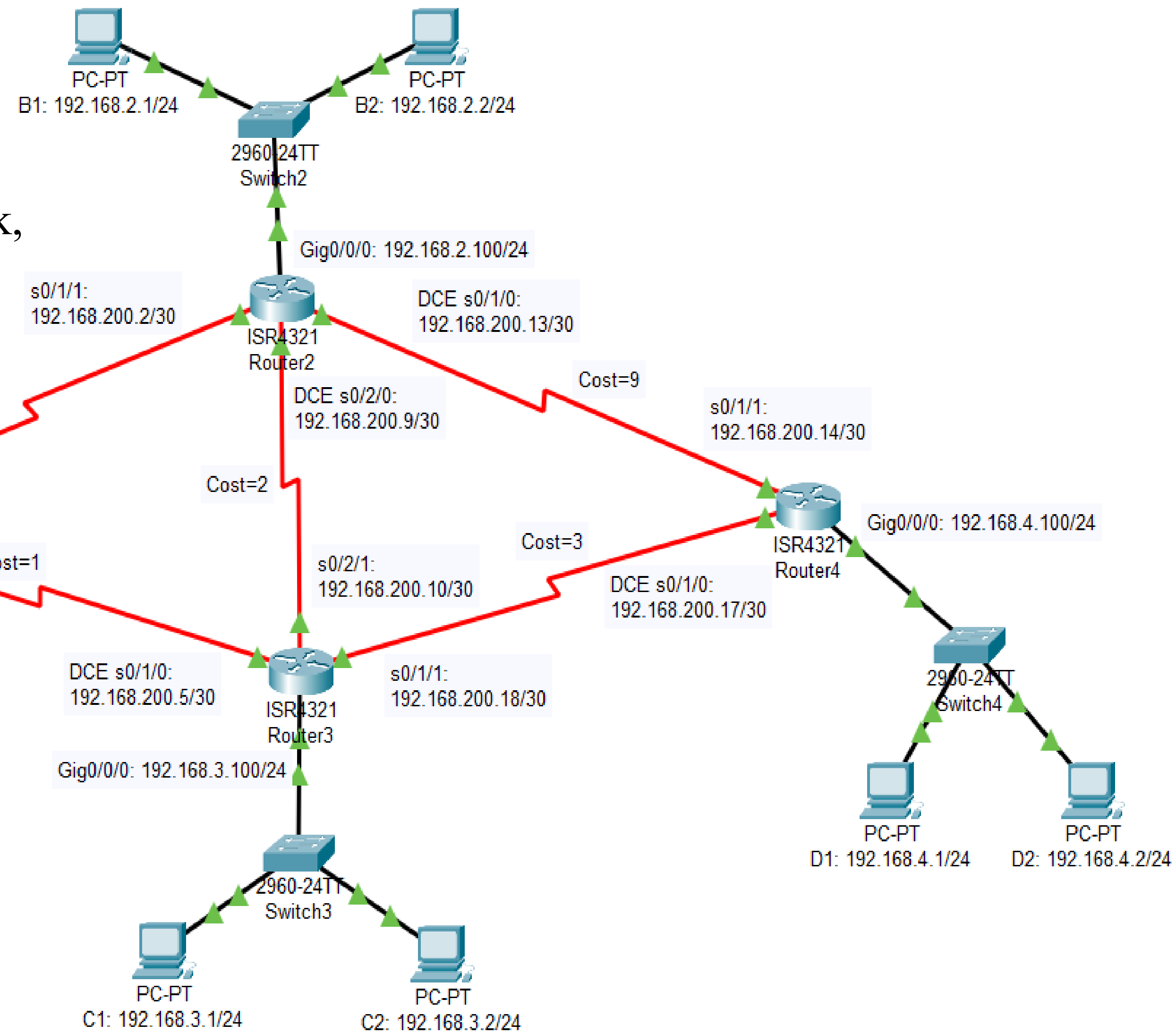
- A 0 octet in the wildcard mask indicates that the corresponding octet in the network must match exactly. On the other hand, a 255 indicates that you don't care what the corresponding octet is in the network number. A network and wildcard mask combination of 1.1.1.1 0.0.0.0 would match an interface configured exactly with 1.1.1.1 only, and nothing else. This is really useful if you want to activate OSPF on a specific interface in a very clear and simple way. If you want to match a range of networks, the network and wildcard mask combination of 1.1.0.0 0.0.255.255 would match any interface in the range of 1.1.0.0 to 1.1.255.255.

OSPF Example – Default Route

- **`Router2(config)#ip route 0.0.0.0 0.0.0.0 s0/1/0`**
- Router2(config)#router ospf 1
  Router2(config-router)#default-information originate
- Add a default route to ISP
- View show ip route of Router2
- View show ip route of Router1

Configuring OSPF on R1

- Let's configure OSPF on Router1.
- First, identify only directly connected networks;
- Identify network's subnet mask, convert to Wildcard Mask
- Who are the networks in this system?



Identify Directly Connected Networks

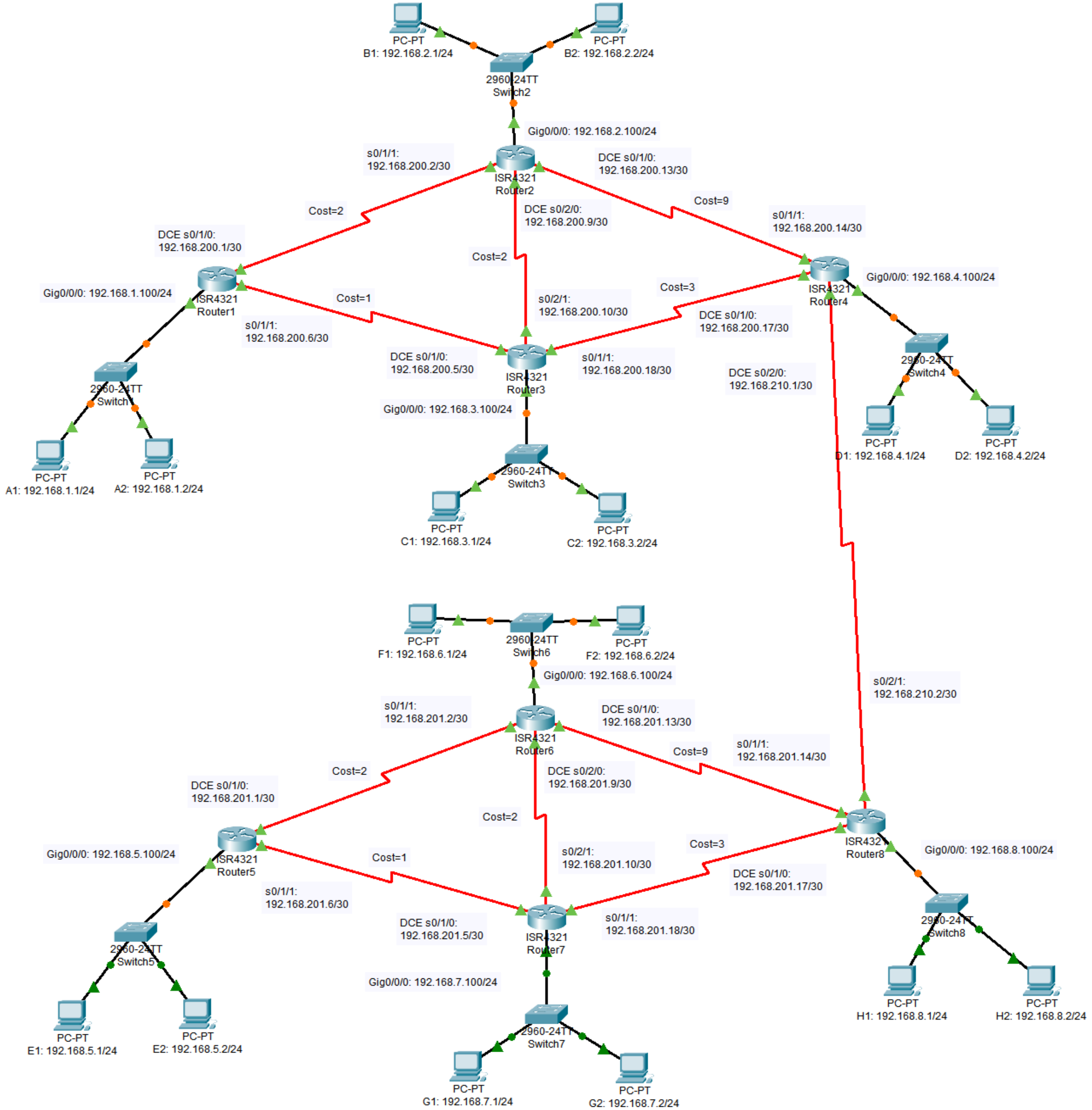
List Directly connected networks on Router1:

Network Address	Subnet Mask	Wildcard Mask
192.168.1.0	255.255.255.0	0.0.0.255
192.168.200.0	255.255.255.252	0.0.0.3
192.168.200.4	255.255.255.252	0.0.0.3

Configuring OSPF Routing on R1

Configuring OSPF on Router1:

```
Router1(config)#router ospf 1
Router1(config-router)#network 192.168.1.0 0.0.0.255 area 1
Router1(config-router)#network 192.168.200.0 0.0.0.3 area 1
Router1(config-router)#network 192.168.200.4 0.0.0.3 area 1
Router1(config-router)#exit
```



PC-PT
B1: 192.168.2.1/24
PC-PT
B2: 192.168.2.2/24
2960-24TT
Switch2
Gig0/0/0: 192.168.2.100/24
s0/1/1:
192.168.200.2/30
DCE s0/1/0:
192.168.200.13/30
ISR4321
Router2
Cost=2
DCE s0/2/0:
192.168.200.9/30
Cost=9
s0/1/1:
192.168.200.14/30
DCE s0/1/0:
192.168.200.1/30
Cost=2
Gig0/0/0: 192.168.4.100/24
Gig0/0/0: 192.168.1.100/24
ISR4321
Router1
Cost=1
s0/2/1:
192.168.200.10/30
Cost=3
ISR4321
Router4
s0/1/1:
192.168.200.6/30
DCE s0/1/0:
192.168.200.17/30
DCE s0/1/0:
192.168.200.5/30
ISR4321
Router3
s0/1/1:
192.168.200.18/30
DCE s0/2/0:
192.168.210.1/30
2960-24TT
Switch4
2960-24TT
Switch1
Gig0/0/0: 192.168.3.100/24
PC-PT
D1: 192.168.4.1/24
PC-PT
D2: 192.168.4.2/24
PC-PT
A1: 192.168.1.1/24
PC-PT
A2: 192.168.1.2/24
2960-24TT
Switch3
PC-PT
C1: 192.168.3.1/24
PC-PT
C2: 192.168.3.2/24
PC-PT
F1: 192.168.6.1/24
2960-24TT
Switch6
PC-PT
F2: 192.168.6.2/24
Gig0/0/0: 192.168.6.100/24
s0/2/1:
192.168.210.2/30
s0/1/1:
192.168.201.2/30
DCE s0/1/0:
192.168.201.13/30
ISR4321
Router6
s0/1/1:
192.168.201.14/30
Cost=9
Cost=2
DCE s0/2/0:
192.168.201.9/30
DCE s0/1/0:
192.168.201.1/30
Cost=2
Gig0/0/0: 192.168.5.100/24
ISR4321
Router5
Cost=1
s0/2/1:
192.168.201.10/30
Cost=3
ISR4321
Router8
Gig0/0/0: 192.168.8.100/24
s0/1/1:
192.168.201.6/30
DCE s0/1/0:
192.168.201.17/30
DCE s0/1/0:
192.168.201.5/30
ISR4321
Router7
s0/1/1:
192.168.201.18/30
2960-24TT
Switch8
2960-24TT
Switch5
Gig0/0/0: 192.168.7.100/24
PC-PT
H1: 192.168.8.1/24
PC-PT
H2: 192.168.8.2/24
PC-PT
E1: 192.168.5.1/24
PC-PT
E2: 192.168.5.2/24
2960-24TT
Switch7
PC-PT
G1: 192.168.7.1/24
PC-PT
G2: 192.168.7.2/24

Identify Directly Connected Networks

List Directly connected networks on Router4:

Network Address	Subnet Mask	Wildcard Mask
192.168.4.0	255.255.255.0	0.0.0.255
192.168.200.12	255.255.255.252	0.0.0.3
192.168.200.16	255.255.255.252	0.0.0.3
192.168.210.0	255.255.255.252	0.0.0.3

Configuring OSPF Routing on R4

Configuring OSPF on Router4:

```
Router4(config)#router ospf 1
Router4(config-router)#network 192.168.1.0 0.0.0.255 area 1
Router4(config-router)#network 192.168.200.12 0.0.0.3 area 1
Router4(config-router)#network 192.168.200.16 0.0.0.3 area 1
Router4(config-router)#network 192.168.210.0 0.0.0.3 area 0
Router4(config-router)#exit
```

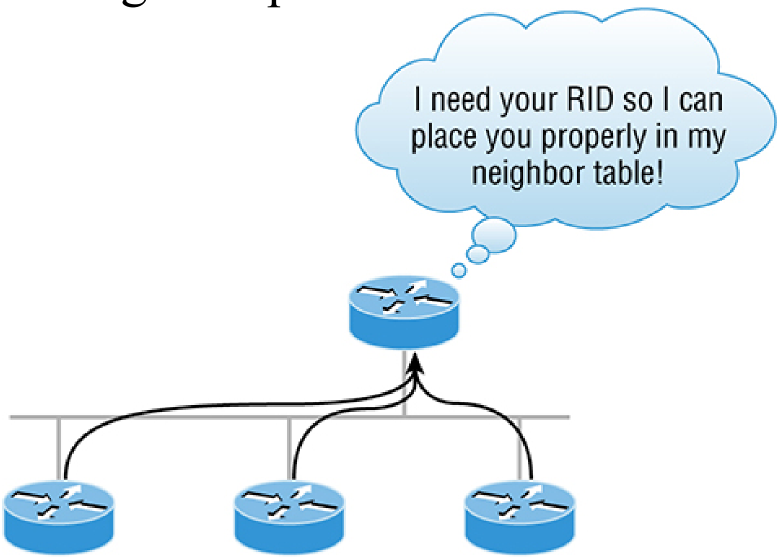
New Assignments

- Homework #7 Due Oct/11
- Lab-6 Report, due Oct/12
- Computer Assignment #4, due Oct/13
- Writing Assignment #2, due Oct/16

- Class on Wednesday, Oct/11
- No Lab on Thursday, Oct/12
- No Class on Friday, Oct/13

Router ID

- The router ID (RID) is an IP address that identifies the router.
- Cisco chooses the router ID by using the highest IP address of all configured loopback interfaces.
- If no loopback interfaces are configured with addresses, OSPF will choose the highest IP address out of all active physical interfaces.
- If you configure loopback before applying OSPF, loopback address will be chosen as Router ID
- If you configure loopback after applying OSPF, OSPF will choose the highest IP address. In this case, you can restart your router to get loopback as Router ID.



Router ID

- The show ip ospf command displays OSPF information for one or all OSPF processes running on the router. Information contained therein includes the router ID, and area information

```
Router1#show ip ospf
Routing Process "ospf 1" with ID 220.1.1.1

Router2#show ip ospf
Routing Process "ospf 1" with ID 220.1.1.2
```

show ip protocols

- The show ip protocols command is highly useful, whether you're running OSPF, EIGRP, RIP, BGP, IS-IS, or any other routing protocol that can be configured on your router. It provides an excellent overview of the actual operation of all currently running protocols!
- The show ip ospf protocols displays the OSPF process ID, OSPF router ID, type of OSPF area, networks and areas configured for OSPF, and the OSPF router IDs of neighbors.
- **`Router1#show ip protocols`**
- **`Router2#show ip protocols`**

Routing Protocol is "ospf 1"

show ip ospf database

- OSPF, as a link-state protocol, uses several different packets to exchange the information about network topology between routers. These packets are called link-state advertisements (LSAs), and they describe the network topology in great detail. Each router stores the received LSA packets in the link-state database (LSDB). After LSDBs are synced between the routers, OSPF uses the shortest path first (SPF) algorithm to calculate the best routes. The best intra-area routes are calculated individually by each OSPF router.
- The show ip ospf database command gives information about the number of routers in the internetwork (AS) plus the neighboring router's ID—the topology database
- The router output shows the link ID—remember that an interface is also a link—and the RID of the router on that link under the ADV router, or advertising router.
- **`Router1#show ip ospf database`**

show ip ospf database

- OSPF floods LSAs every 30 minutes. Each LSA (Link-State Advertisement) includes the link-state age variable, which counts the age of the LSA packet. When a network change occurs, the LSA's advertising router generates an updated LSA to reflect the change in the network topology.
- The output of the OSPF LSDB (Link-State Database) reveals the value of the current link-state age timer for all LSAs. In a normally operating network, you will not see the age variable with values higher than 1800 seconds.
- When an LSA reaches a max age of 60 minutes in the LSDB, it is removed from the LSDB, and the router will perform a new SPF (Shortest Path First) calculation.

show ip ospf interface

- The show ip ospf command displays OSPF information for one or all OSPF processes running on the router. Information contained therein includes the router ID, and area information

Router2#**show ip ospf interface serial 0/1/1**

Serial0/1/1 is up, line protocol is up

Internet address is 192.168.200.2/30, Area 0

Process ID 1, Router ID 220.1.1.2, Network Type POINT-TO-POINT, Cost: 64

Router2#**show ip ospf interface serial 0/1/0**

OSPF Cost Calculation

- **Cost = 10^8/interface bandwidth in bps**

512 Kbps	100000000/512000 = 195.31	195
1Mbps	100000000/1000000 = 100	100

- Cumulative Cost of a Route from R1 to R4

R1 to R3 cost is 98, R3 to R4 cost is 98, so the total cost to Network 192.168.4.0 from R1 is 98+98=196