Open Shortest Path First OSPF

Presented by
Jack Crowder, CCIE

Course Outline

- Prerequisites
- Routing Protocol Review
- Open Shortest Path First
  - Overview
  - Configuration
  - Troubleshooting
  - Design

Prerequisites

- Familiarity with
  - Cisco IOS command line
  - IP addressing and subnetting
  - Routing Protocols

Introduction to Routing & Routing Protocols

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Routing Intro: Agenda

- Purpose
- Considerations
- Routed Protocol vs. Routing Protocol
- Protocol Table vs. Routing Table
- Distance Vector vs. Link State Protocols
- Comparison Matrix
- Building a Routing Table

Routing Protocol Purpose

- Provide L3 guidance across [public and/or private] networks (WANs and/or LANs) for datagrams to reach devices not connected to the sources' directly attached media.
- Routing Protocols build Routing Tables which in turn are used for Forwarding decisions.
- Design goals:
  - Accuracy, Simplicity/low overhead, Robustness, Convergence, Flexibility, Stability

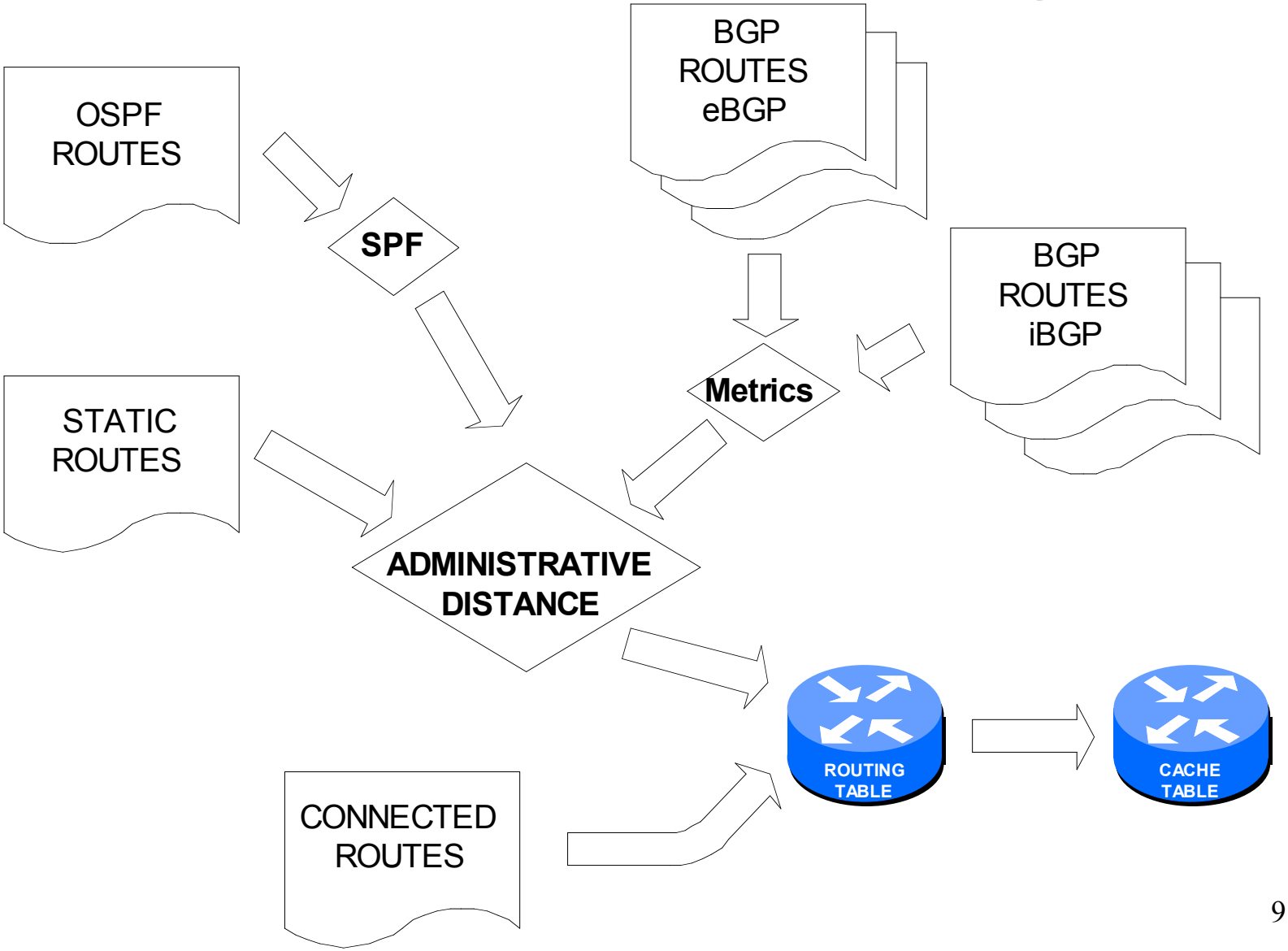
Routing Protocol Considerations

- Servers serve and Routers route.
- Router to Router communication
- Autonomous System
  - Extent of routing protocol(s) within your control
- Routing Domain (Routing Autonomous System)
  - Extent of a routing protocol
- AS to AS communication - Routing Domain
  - Peering
- AS to AS communication - Routing Protocol
  - Redistribution

Routed vs. Routing Protocols

- Routed Protocols
  - Can be routed using routing
  - Carry Routing Protocol information
    - RIF: Routing Information Field
  - Examples: TCP, UDP, IP
- Routing Protocols
  - Routes a routed protocol
  - IGP vs. EGP
  - Examples: RIP, OSPF, BGP

Protocol Table vs. Routing Table



Routing Concepts

- Destination/Next Hop Association
  - To reach a destination, send packet to next hop
- Destination/Metric Association
  - To reach a destination, send packet to next hop with lowest metric
- Destination/Path Association
  - To reach a destination, send packet along a certain path
- Metrics: Reliability, Delay, Bandwidth, Load, MTU, Communication cost

Distance Vector

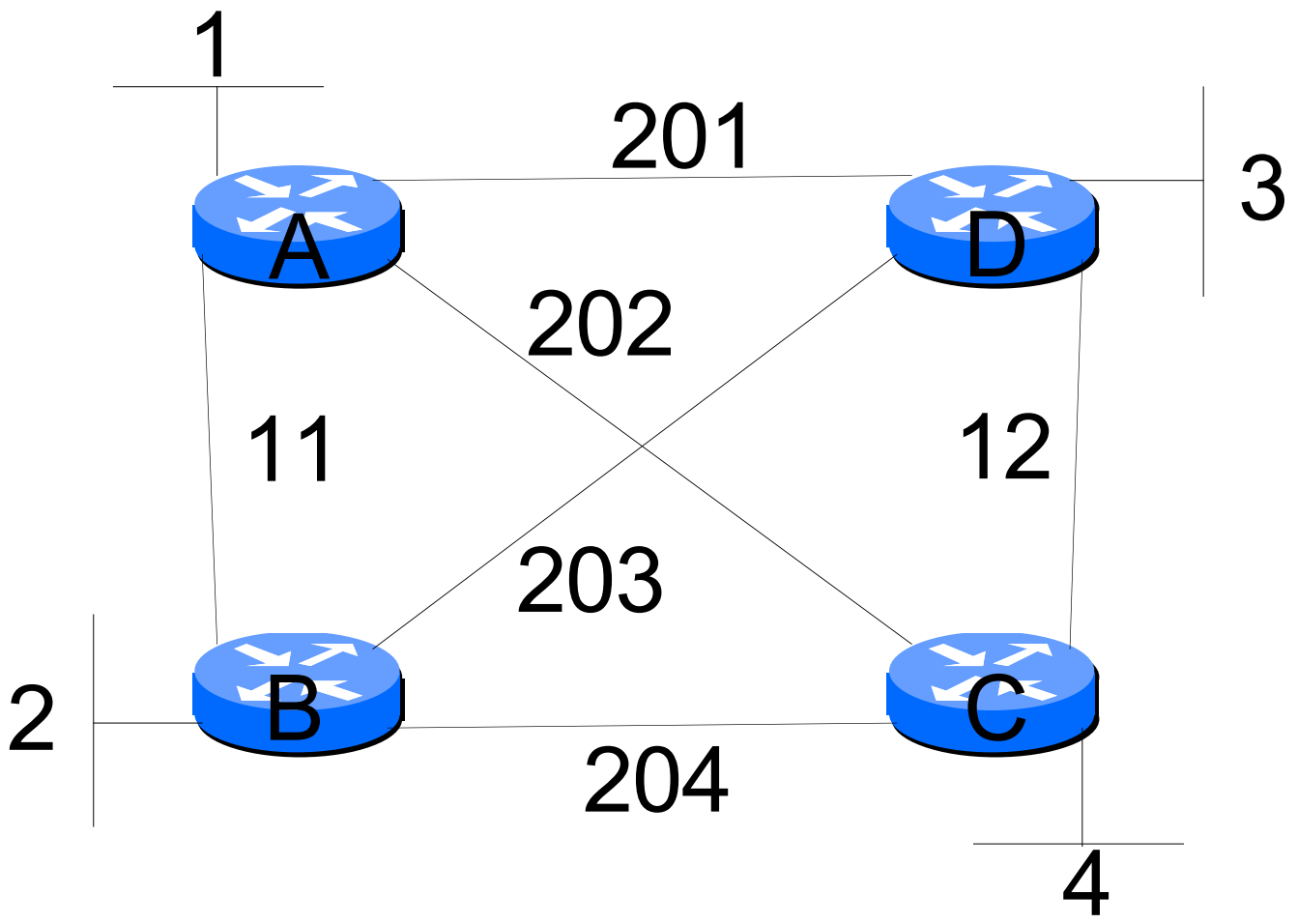
- Distance: Cost based on metrics
- Vector: Path to follow
- Bellman-Ford Algorithm
- Router sends its full table to direct neighbors
- Hop count (loop avoidance)
- Update on timers
- (EIGRP has added update on network change).

Link State

- Shortest Path First
- Dijkstra Algorithm
- Each router sends its state to all other routers
- Every router has topology (database) of entire network
- Update on link change
- Faster convergence/Higher CPU requirements

	RIP	EIGR	OSP	IS-IS	static	BGP
Link State			X	X	X	X
Distance Vector	X	X			X	X
IGP	X	X	X	X	X	**iBGP**
EGP					X	**eBGP**
Admin Distance	**120**	summ: **5** int: **90** ext: **170**	**110**	**115**	interface: **0** next hop: **1** floating: **?**	

Topology



Routing Table: Router A

Route	Known via	Type
1	direct	connected
2	rtr **B**, C, D	protocol
3	rtr B, C, **D**	protocol
4	rtr B, **C**, D	protocol
11	direct	connected
12	rtr B, **C**, **D**	protocol
201	direct	connected
202	direct	connected
203	rtr **B**, C, **D**	protocol
204	rtr **B**, **C**, D	protocol

Routing Protocol: OSPF

- Overview
  - *what is it*
- Configuration
  - *how is it*
- Troubleshooting
  - *why is it*
- Design
  - *how, why and where to use it*

Part 1

Overview

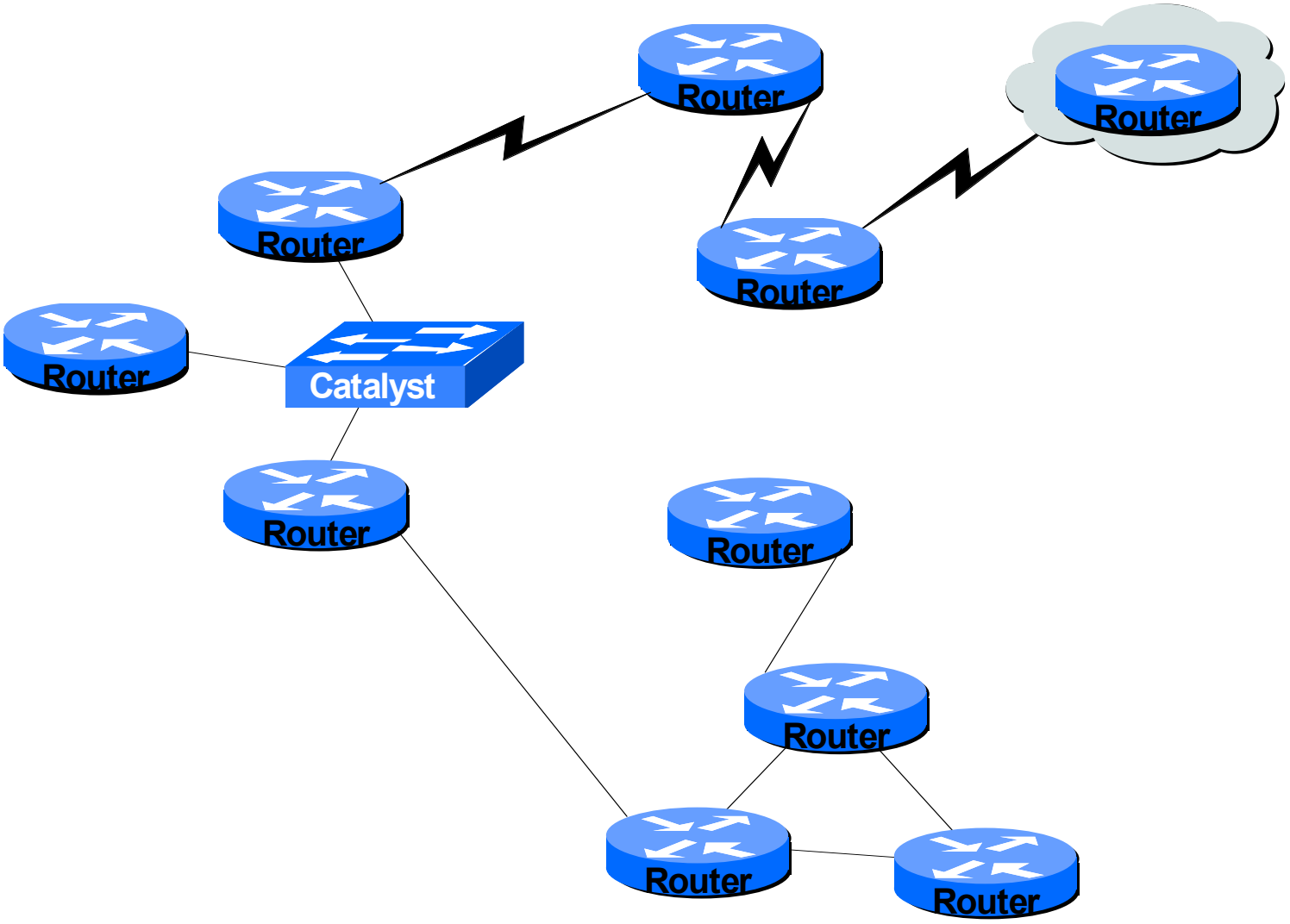
OSPF Overview

- Open Shortest Path First
  - RFC1131, J. Moy, Oct-1989
  - Cisco introduced in IOS v9.0 March-1990
- What is OSPF?
- Why you should use OSPF?
- Where would you use OSPF?

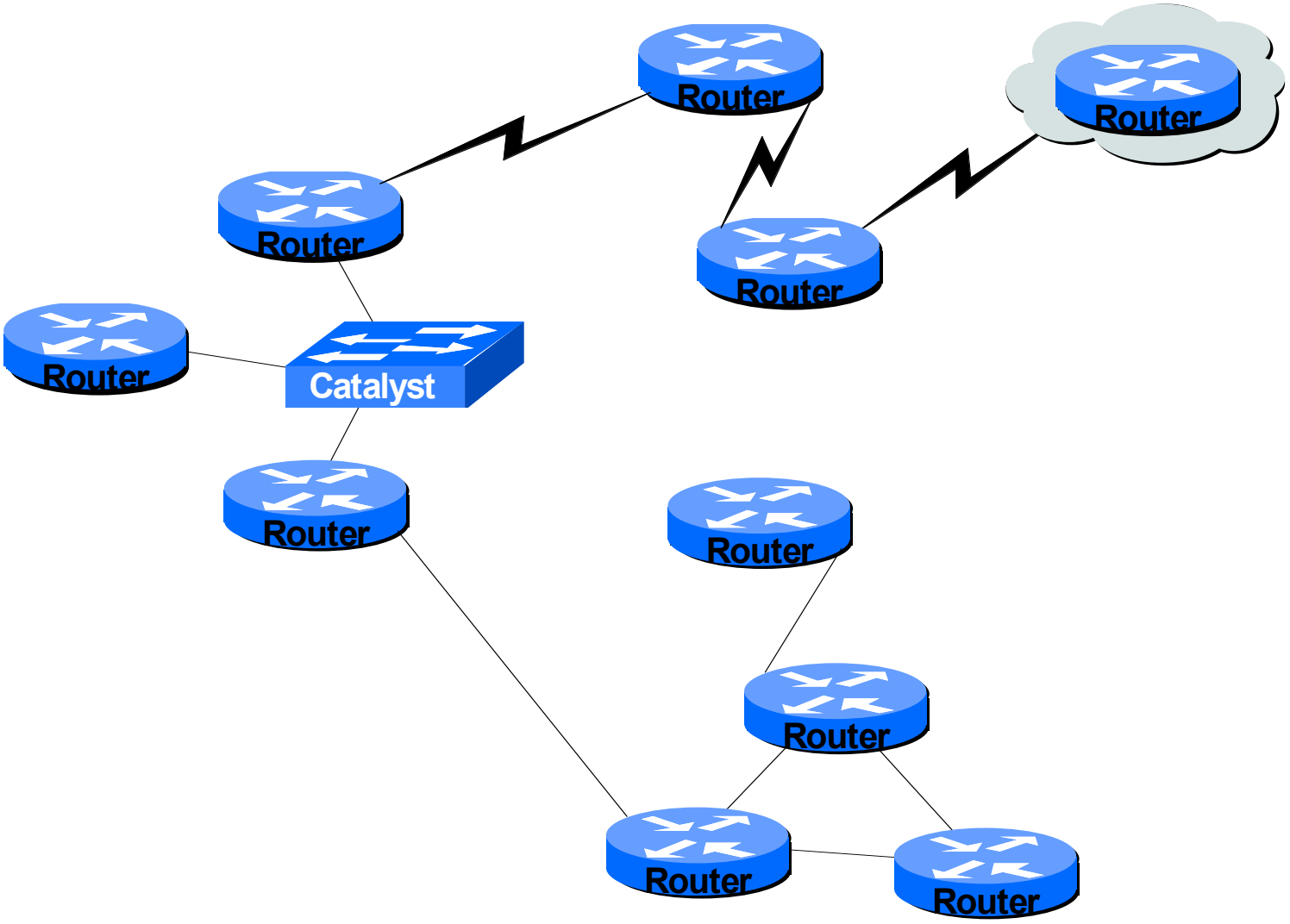
What is OSPF?

- IGP (Interior Gateway Protocol)
- Link State Protocol
  - Database (Topology)
  - Shortest Path First (SPF or Dijkstra) algorithm
  - Update on link state change
- Areas
- Neighbors
- Link State Advertisements (LSA)

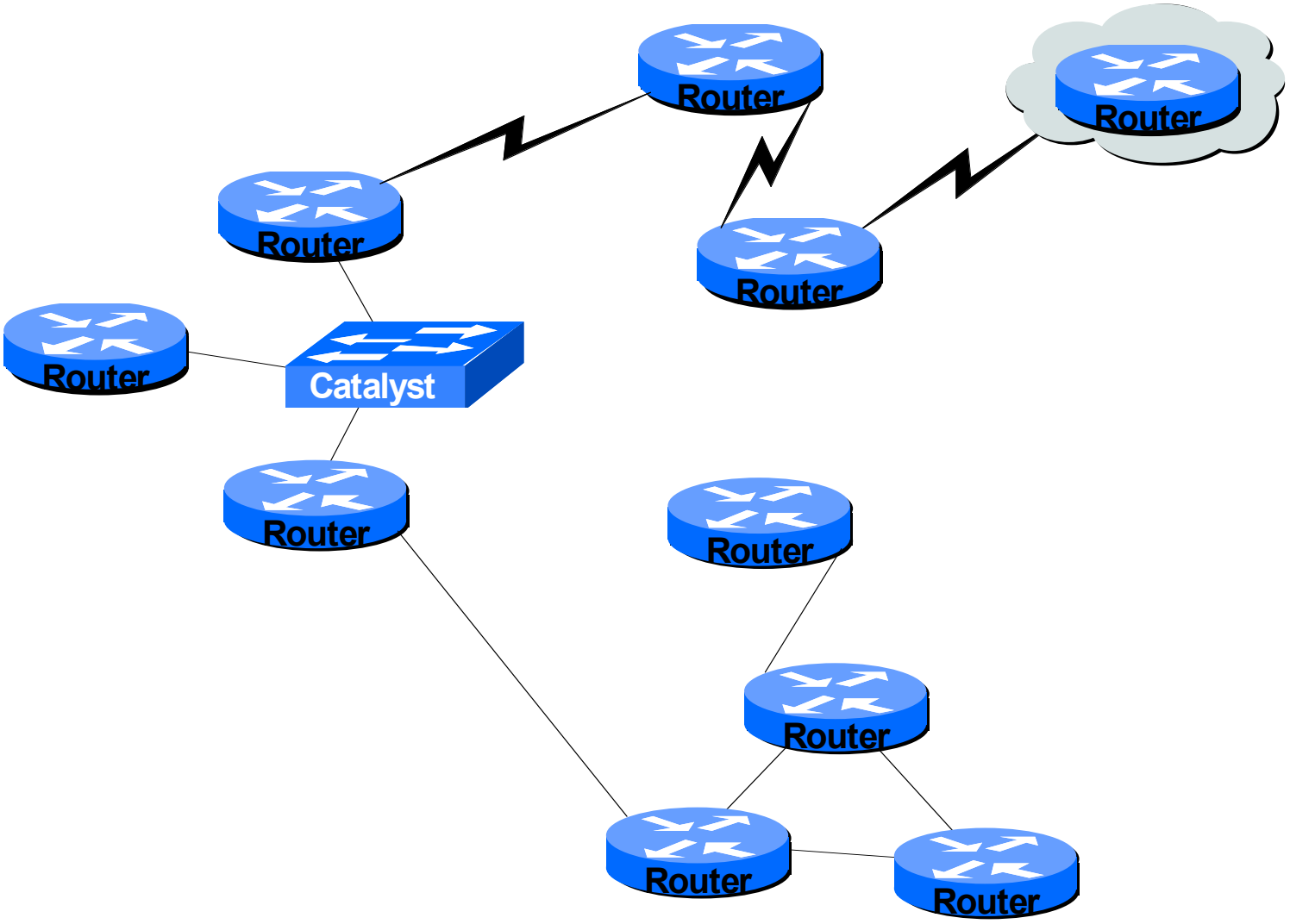
What is an OSPF Area?



What is an OSPF Neighbor?



What is an OSPF LSA?



Why you should use OSPF?

- Mostly widely deployed on the Enterprise and Tier 2/3 Service Providers
  - Deployed in networks
  - Deployed by vendors
- Hardware supportability
  - Memory and processors are cheap
  - Each router knows about the entire topology
- Scalability
  - Recalculation upon change
  - Change restricted to Area

Where would you use OSPF?

- Clearly define the backbone Area 0
  - Think Hub and spoke
- Areas based on traffic flows
  - Therein lies it's one scalability issue
- Consider stability of links
  - Not for Remote Access Servers
  - (There is an OSPF DDR mechanism).

LAB 1:

Setup and Familiarization

Purpose:

Review Physical connectivity

Part 2

Configuration

OSPF Configuration

- Global
  - Router OSPF <**process-id**>
- Interface
  - LAN, WAN, Dial-up
- Protocol
  - Area
  - Neighbor
  - Link State Advertisements
  - Network Announcements

OSPF Protocol Configuration

- Area
  - Backbone (0)
  - Types: Intra, Inter, Stub, NSSA, TSA
- Neighbor
  - Adjacencies
    - Non-Broadcast Multi Access (NBMA)
    - Point-to-Point
- Link State Advertisements
  - Network, Router, Summary, External
- Network Announcements
  - Aggregation

Global Configuration

router OSPF <**1-65535**> (Process ID)

area	OSPF area parameters
auto-cost	Calculate interface cost according to bandwidth
capability	Enable specific OSPF feature
default	Set a command to its defaults
default-information	Control distribution of default information
default-metric	Set metric of redistributed routes
distance	Define an administrative distance
distribute-list	Filter networks in routing updates
ignore	Do not complain about specific event
log-adjacency-changes	Log changes in adjacency state

Global Configuration

router OSPF <**1-65535**> (Process ID)

maximum-paths	Forward packets over multiple paths
neighbor	Specify a neighbor router
network	Enable routing on an IP network
passive-interface	Suppress routing updates on an interface
redistribute	Redistribute information from another routing protocol
router-id	router-id for this OSPF process
summary-address	Configure IP address summaries
timers	Adjust routing timers
traffic-share	How to compute traffic share over alternate paths

Network Configuration

- Format
  - Network **X.X.X.X <inverse-mask>** Area **Z.Z.Z.Z**
- Example
  - Network **10.0.0.0 0.255.255.255** Area **0**
- Considerations
  - Interfaces brought in if address is within “network”
  - Order dependent

Network Configuration Example

- Example 1

Network 10.20.204.0 0.0.0.255 Area 5

Network 10.20.0.0 0.0.255.255 Area 18

Network 0.0.0.0 255.255.255.255 Area 0

- Example 2

Network 209.15.0.0 0.0.255.255 Area 209.15.0.0

Network 0.0.0.0 255.255.255.255 Area 0.0.0.0

Example Configuration

- **COR1.pdx**
- router ospf 4540
- network 207.170.192.50 0.0.0.0 area 0
- network 207.170.193.1 0.0.0.0 area 0
- **network 207.170.193.161 0.0.0.0 area 1**
- **network 207.170.193.177 0.0.0.0 area 1**
- network 207.170.198.1 0.0.0.0 area 0
- network 207.170.198.89 0.0.0.0 area 0
- network 207.170.198.93 0.0.0.0 area 0
- network 207.170.198.97 0.0.0.0 area 0
- network 207.170.198.101 0.0.0.0 area 0
- network 207.170.198.105 0.0.0.0 area 0
- network 207.170.198.109 0.0.0.0 area 0
- network 207.170.198.125 0.0.0.0 area 0
- network 207.170.198.133 0.0.0.0 area 0
- log-adjacency-changes

- **AGR4.pdx**
- router ospf 4540
- network 206.169.236.1 0.0.0.0 area 1
- **network 207.170.193.164 0.0.0.0 area 1**
- **network 207.170.193.180 0.0.0.0 area 1**
- network 207.170.192.46 0.0.0.0 area 1
- log-adjacency-changes

LAB 2a:
Global Configuration

Purpose:

Configure initial connectivity

Neighbor Adjacency

- Two neighbors must be configured:
  - On same IP subnet (even though multicast is used)
    - Multicast address 224.0.0.5 and 224.0.0.6 is used
  - Same area number
  - Timers (HelloInterval and DeadInterval) must match
    - Timer information is sent in packet

Interface Configuration

IP OSPF

authentication-key	Authentication password (key)
cost	Interface cost
database-filter	Filter LSA during synchronization / flooding
dead-interval	Interval after which neighbor is declared dead
demand-circuit	OSPF demand circuit
hello-interval	Time between HELLO packets
message-digest-key	Message digest authentication password
network	Network type
priority	Router priority
retransmit-interval	Time between retransmitting lost link state advertisements
transmit-delay	Link state transmit delay

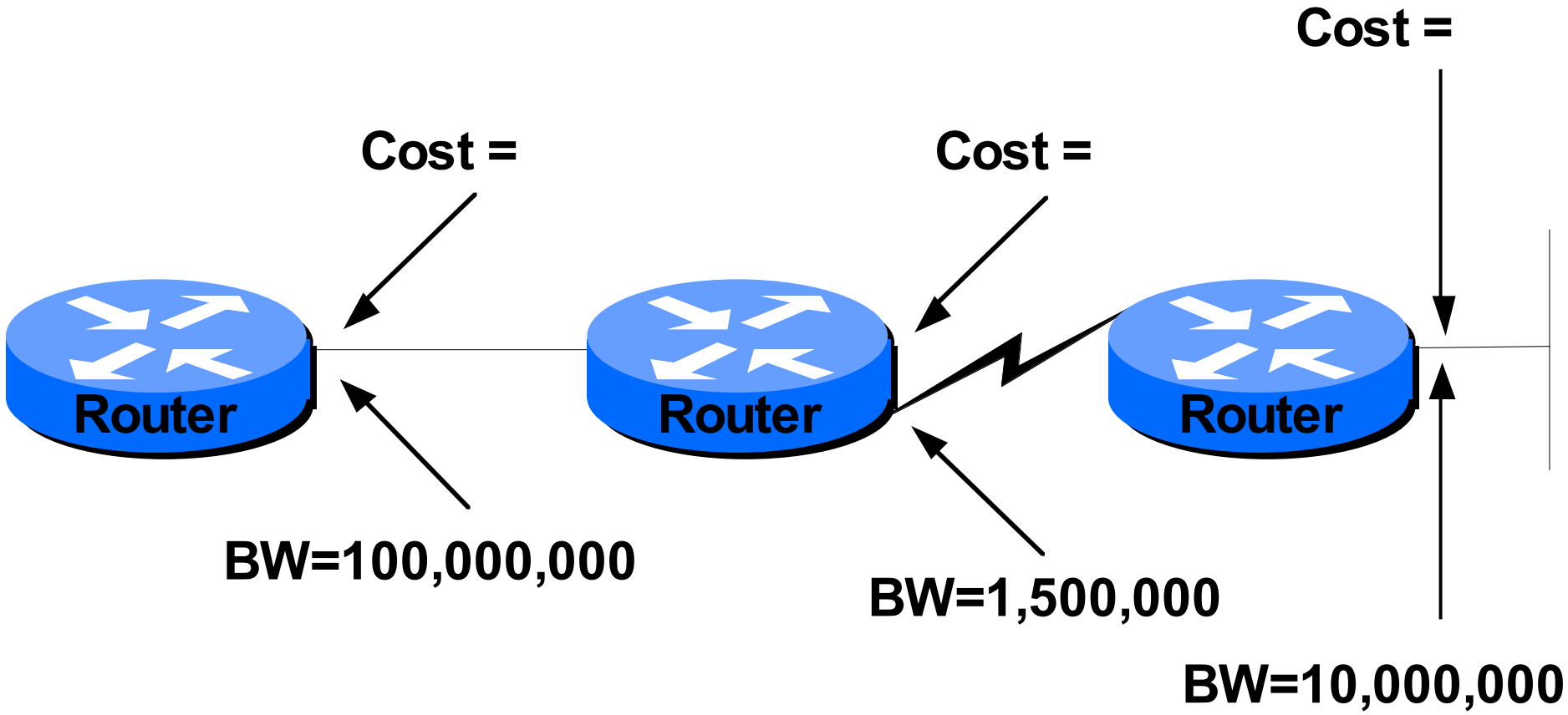
OSPF Metric Calculation

cor1.pdx> sh ip route ospf

```
O IA    207.170.192.25/32 [110/30] via 207.170.198.94, 01:00:33, ATM1/0/0.101
O        207.170.192.26/32 [110/2] via 207.170.193.163, 3w2d, FastEthernet1/1/0
O E2    209.234.154.0/24 [110/20] via 207.170.198.94, 01:00:33, ATM1/0/0.101
```

- Default Metric (Cost) = 100,000,000/bandwidth
  - bandwidth shown on interface (default can be changed)
- Cost can be changed
  - Manually configured on an interface: **ip ospf cost xx**
  - Globally configured: **ospf auto-cost reference-bandwidth**

Route Cost Calculation



Total Cost =

LAB 2b:
Interface Configuration

Purpose:

Observe the effect of
changing interface parameters

Areas

- Backbone - Area 0
  - Contiguous
  - No full-mesh requirements
- All AREAs touch Area 0 and *NO* other area
  - Virtual links can “heal” this
- All AREAs are contiguous
  - Virtual links can “heal” this
- Area types:
  - Normal (default) - Stub
  - NSSA - TSA

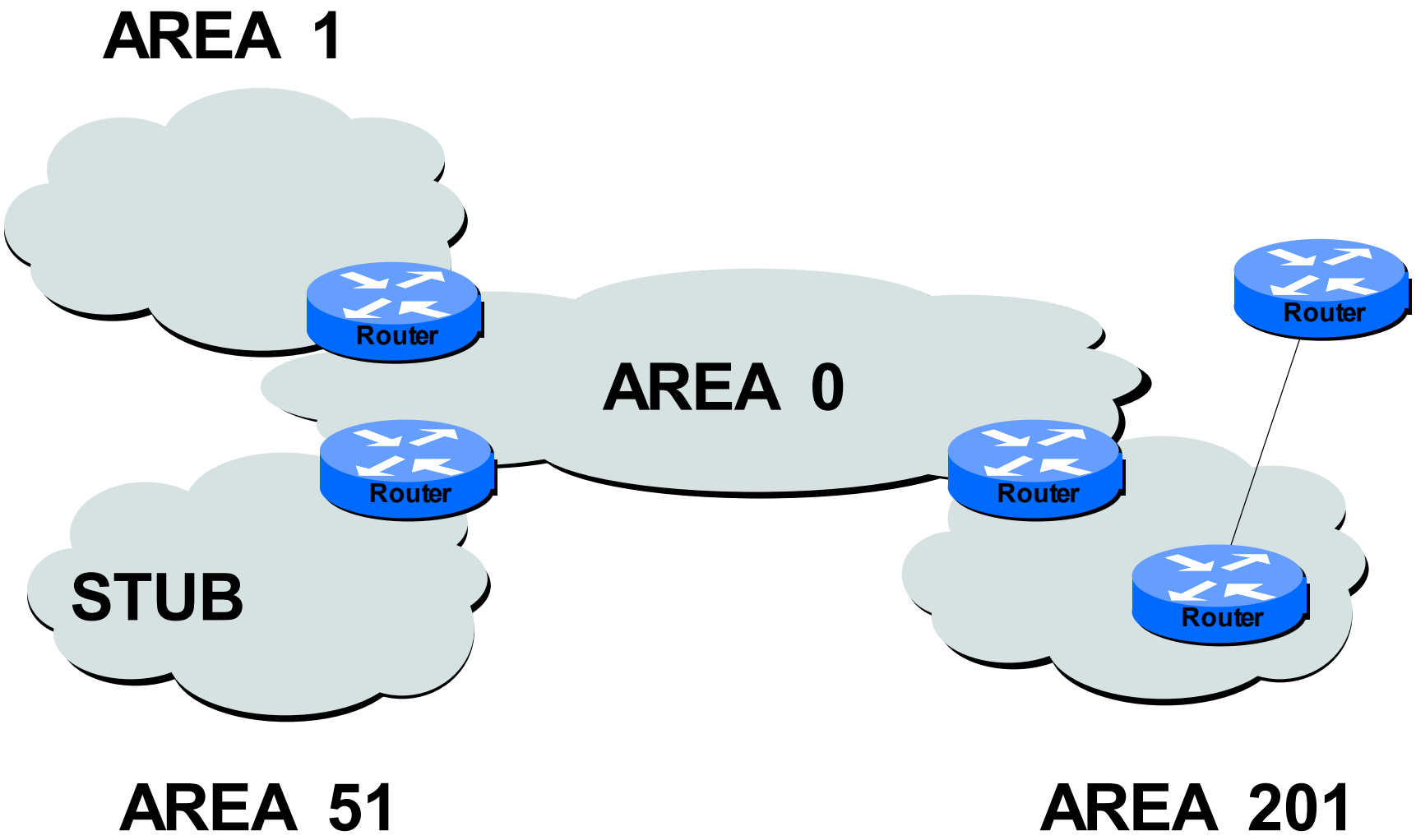
Area Configuration

Router OSPF <**1-65535**> (Process ID)

area <**0-4294967295**> or **A.B.C.D**

authentication	Enable authentication
default-cost	Set summary default-cost of NSSA/stub area
nssa	Specify a NSSA area
range	Summarize routes matching address/mask (border routers only)
stub	Specify a Stub Area
no-summary	Specify a Totally Stubby Area
virtual-link	Define a virtual link and its parameters

Backbone Area 0 / Normal Area X



Route Types: Internal

- Intra Area
  - Designated “O”
  - Flows within an area
  - Is converted to type Inter-Area upon area exit
- Inter Area
  - Designated “O IA”
  - Can be summarized at Area Boundary (on ABR)

Route Types: External

- Redistributed into an OSPF process
  - From other routing protocols
  - From another OSPF process (not automatic)
- External Type 1
  - Designated “O E1”
  - **Cost**: Internal OSPF cost metric + External route metric
- External Type 2 (default)
  - Designated “O E2”
  - Cost: External route metric

LAB 2c:

Area X Configuration

Purpose:

Configure multiple [NORMAL] Areas

Stub Area

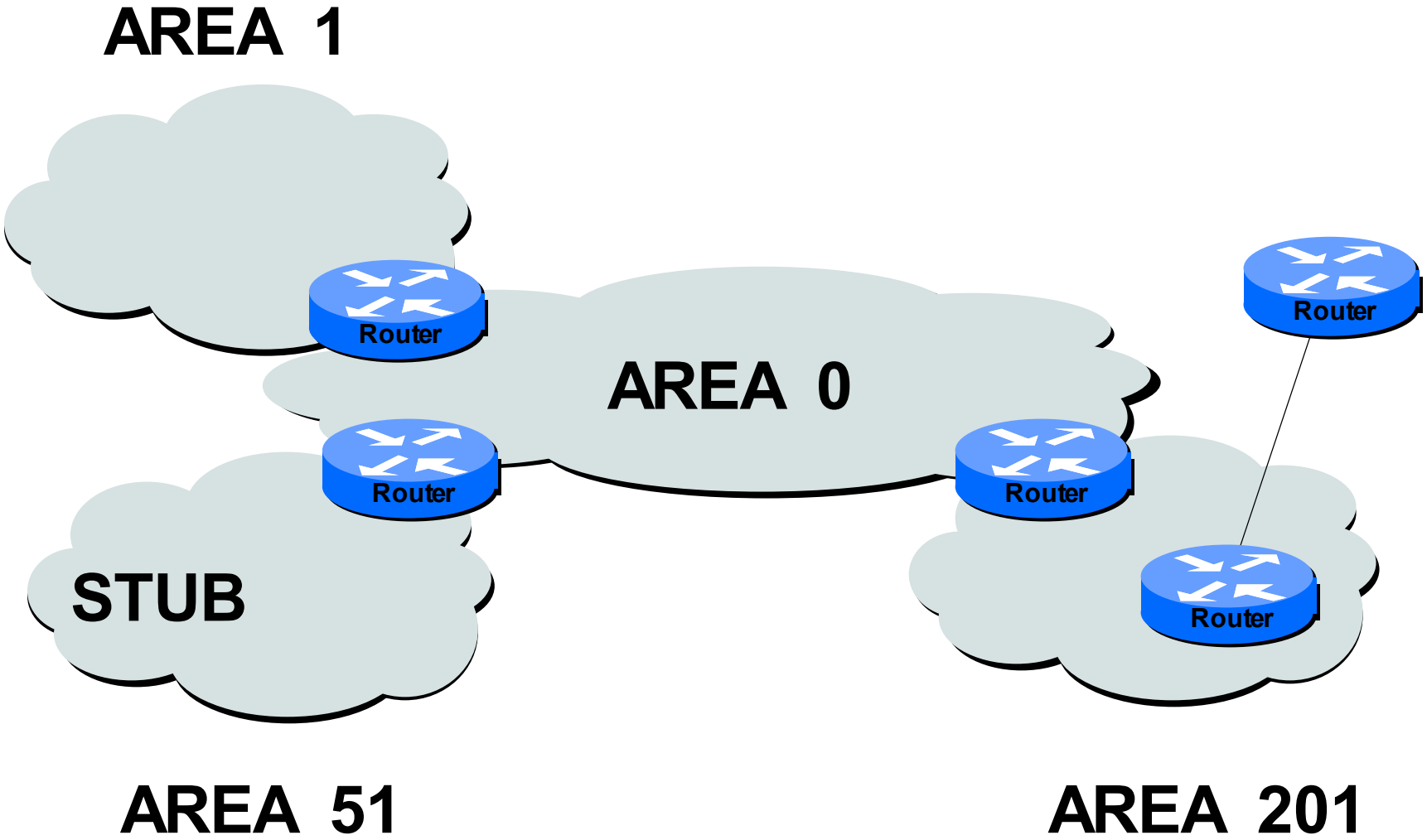
LAB 2d:

Area X Configuration

Purpose:

Configure multiple [STUB] Areas

Not-So-Stubby Area (NSSA)



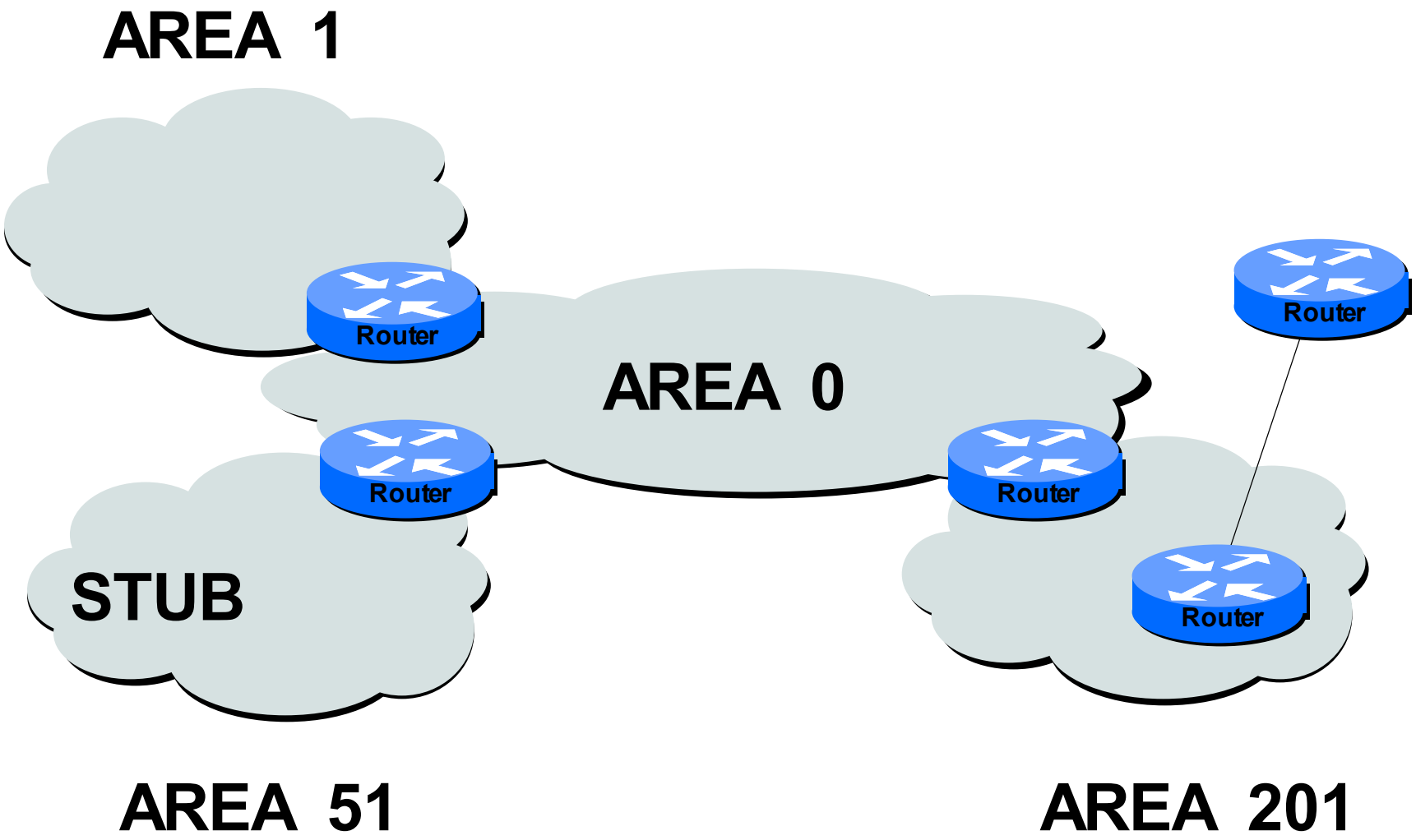
LAB 2e:

Area X Configuration

Purpose:

Configure multiple [NSSA] Areas

Totally-Stubby Area (TSA)



LAB 2f:

Area X Configuration

Purpose:

Configure multiple [TSA] Areas

Area Type Matrix

	Normal	Stub	NSSA	TSA
Intra Area	X	X	X	X
Inter Area	X	X		
External Type 1	X			
External Type 2	X			
Default	X	X	X	X
	ASBR	NO ASBR	ASBR	NO ASBR

Neighbors

- Adjacencies:
  - Rules
  - Timers
  - Sequence
- Media Types:
  - Broadcast Multi Access
  - Non-Broadcast Multi Access
    - Point to Multi-Point
  - Point to Point
- Link State Advertisements
  - Type 1 through 10

Neighbor Adjacency

- Two neighbors must be configured:
  - On same IP subnet (even though multicast is used)
  - Same area number
  - Timers (HelloInterval and DeadInterval) must match
    - Timer information is sent in packet
  - Multicast address 224.0.0.5 is used

Adjacency Sequence

1. **2way / INIT**
   - Hello discovery and DR election
2. **Exstart**
   - Master/Slave relationship
   - Database Description (DD) packets
3. **Exchange**
   - More DD packets from Master to Slave
   - OSPF considered operational because LSA's flow
4. **Loading**
   - Link-state requests sent asking for advertisements
   - Ensure all links up-to-date and properly acknowledged
5. **FULL**
   - Link-state databases fully synchronized

Neighbor Types

- FULL
  - Full adjacency established
- DR
- BDR
- DROTHER
  - Non DR or BDR
- 2Way

Show IP OSPF Neighbor

Neighbor ID	Pri	State	Dead Time	Address	Interface
207.170.220.65	1	FULL/ -	00:00:38	207.170.198.90	ATM1/0/0.100
207.170.192.37	128	FULL/ -	00:00:37	207.170.198.94	ATM1/0/0.101
207.170.192.4	1	FULL/ -	00:00:37	207.170.198.98	ATM1/0/0.102
207.170.192.59	1	FULL/ -	00:00:38	207.170.198.134	ATM1/0/0.103
207.170.192.46	1	FULL/DROTHER	00:00:33	207.170.193.164	FastEthernet1/1/0
207.170.192.26	1	FULL/BDR	00:00:30	207.170.193.163	FastEthernet1/1/0
207.170.192.13	**1**	**FULL/DROTHER**	**00:00:31**	**207.170.193.162**	**FastEthernet 1/1/0**
207.170.192.13	**1**	**FULL/DROTHER**	**00:00:39**	**207.170.193.178**	**FastEthernet 4/0/0**
207.170.192.51	1	FULL/DR	00:00:38	207.170.193.179	FastEthernet4/0/0
207.170.192.46	1	FULL/DROTHER	00:00:33	207.170.193.180	FastEthernet4/0/0
207.170.192.11	1	FULL/ -	00:00:38	207.170.198.106	ATM4/1/0.101

Neighbor ID	Pri	State	Dead Time	Address	Interface
207.170.192.46	1	2WAY/DROTHER	00:00:34	207.170.193.164	FastEthernet0/0
207.170.192.26	1	FULL/BDR	00:00:31	207.170.193.163	FastEthernet0/0
207.170.192.50	**1**	**FULL/DR**	**00:00:32**	**207.170.193.161**	**FastEthernet 0/0**
207.170.192.50	**1**	**FULL/BDR**	**00:00:32**	**207.170.193.177**	**FastEthernet 1/0**
207.170.192.46	1	2WAY/DROTHER	00:00:34	207.170.193.180	FastEthernet1/0
207.170.192.51	1	FULL/DR	00:00:39	207.170.193.179	FastEthernet1/0

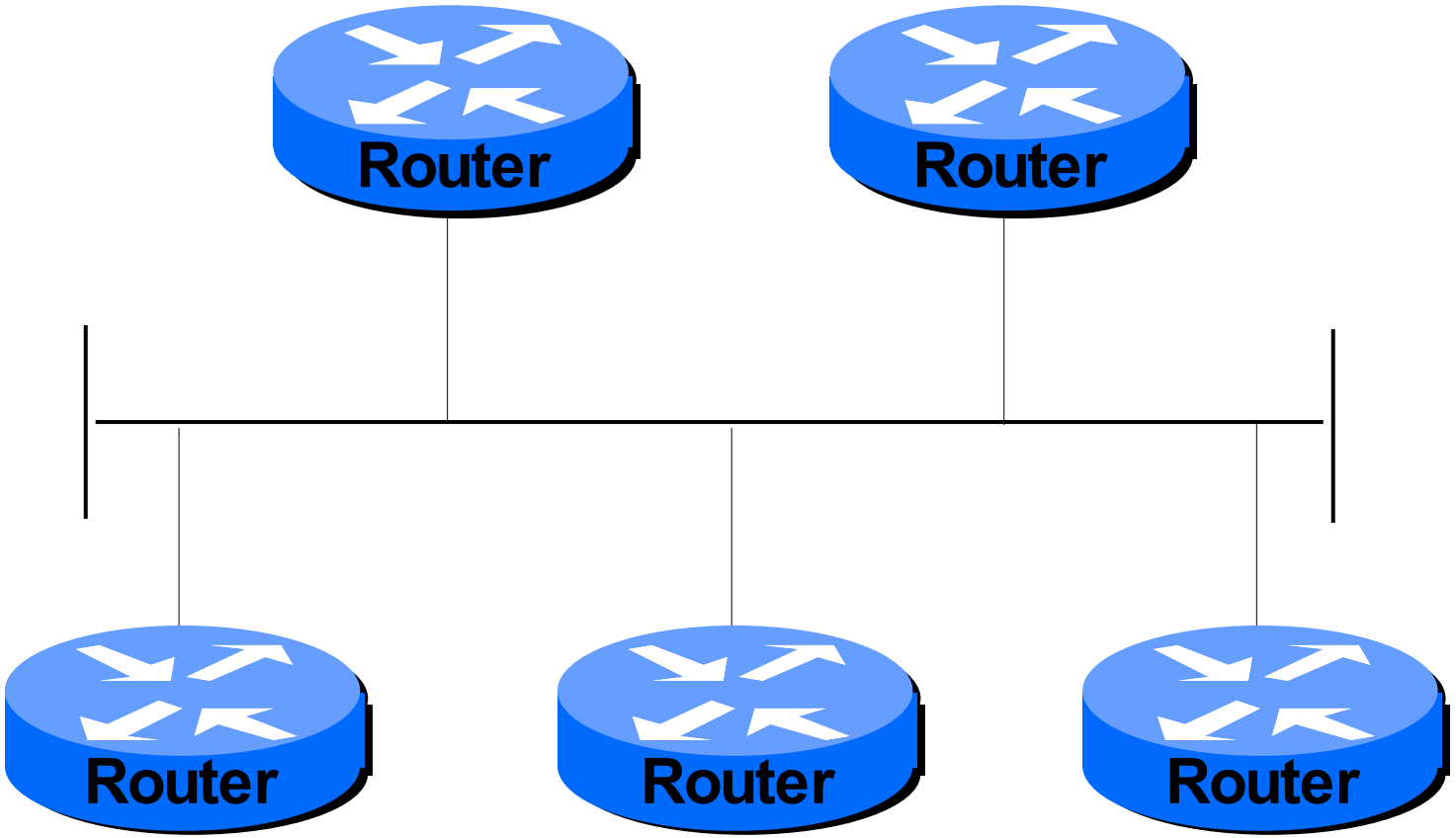
DR/BDR on Multi Access Network

- All routers form adjacencies with all other routers on each multi access media (network):
  - Meaning **N-1** hellos and updates
- Solution:
  - Designated and Backup Designated Router
- Highest and 2nd highest router-id become DR and BDR respectively.

DR/BDR on Multi Access Network

- If "ip ospf priority" interface command is used:
  - Highest and 2nd highest priorities win.
  - Priority o (zero) means router can never become DR or BDR on that media
- Multicast used for router to router exchange
  - 224.0.0.5 - all SPF routers
  - 224.0.0.6 - all B/DR routers

DR and BDR Election



LAB 2g:
DR and BDR Configuration

Purpose:

Configure DR and BDR on Multi Access media

Non-Broadcast Multi Access

- Point-to-Point
  - HDLC, PPP and SONET
  - No DR/BDR election
  - Frame-Relay and ATM sub-interfaces
- Point-to-Multipoint
  - Frame-Relay and ATM
  - Can be configured as Point-to-Point

Non-Broadcast Multi Access

- Multipoint can be made to look like Multi Access
  - "IP OSPF Network Broadcast" interface command
  - DR/BDR election then happens
  - Used primarily on Hub-and-Spoke configurations. (Hub should be DR).

LAB 2h:

Neighbor Configuration

Purpose:

Configure neighbors on NBMA media

LSA Packet Type

1. **Router LSA**
   - Generated by each router for each area it belongs
   - Describe the state of router's links
   - Flooded within area only
2. **Network LSA**
   - Generated by Designated Router
   - Flooded within area containing network
   - Link-state ID is the interface IP address of DR
3. **Summary LSA (ABR)**
   - Generated by Area Border Router
   - Describe Inter-Area (IA) routes
   - Can be used for aggregation
   - Link-state ID is the destination network number

LSA Packet Type

4. Summary LSA (ASBR)

- Generated by Autonomous System Border Routers
- Describe links to ASBRs
- Link-state ID is the Router-ID of described ASBR

5. AS External LSA

- Generated by Autonomous System Border Routers
- Describe routes external to OSPF AS
- Flooded everywhere except any STUB type areas

6. Multicast OSPF LSA

- Not currently used given other Multicast Routing Protocols currently available. (ie. PIM, DVMRP)

LSA Packet Type

7. Not-So-Stubby-Area LSA

- RFC 1587
- Generated by Autonomous System Border Routers
- Describe external routes within an NSSA
- Can be converted into **Type 5 LSA**

8.,9.,10. Reserved

Network Aggregation

- Occurs at Area Boundary on ABR
- Can be manually configured with:
  - **Summary-address A.B.C.D <mask>**

    not-advertise

    No advertise when translating Type-7 LSA.

    tag <value>

    Set 32 bit tag value

    <**cr**>
- IP address scheme must lend itself
  - Service Providers might find this difficult

LAB 2i:

Neighbor Configuration

Purpose:

Configure aggregation for area announcement.

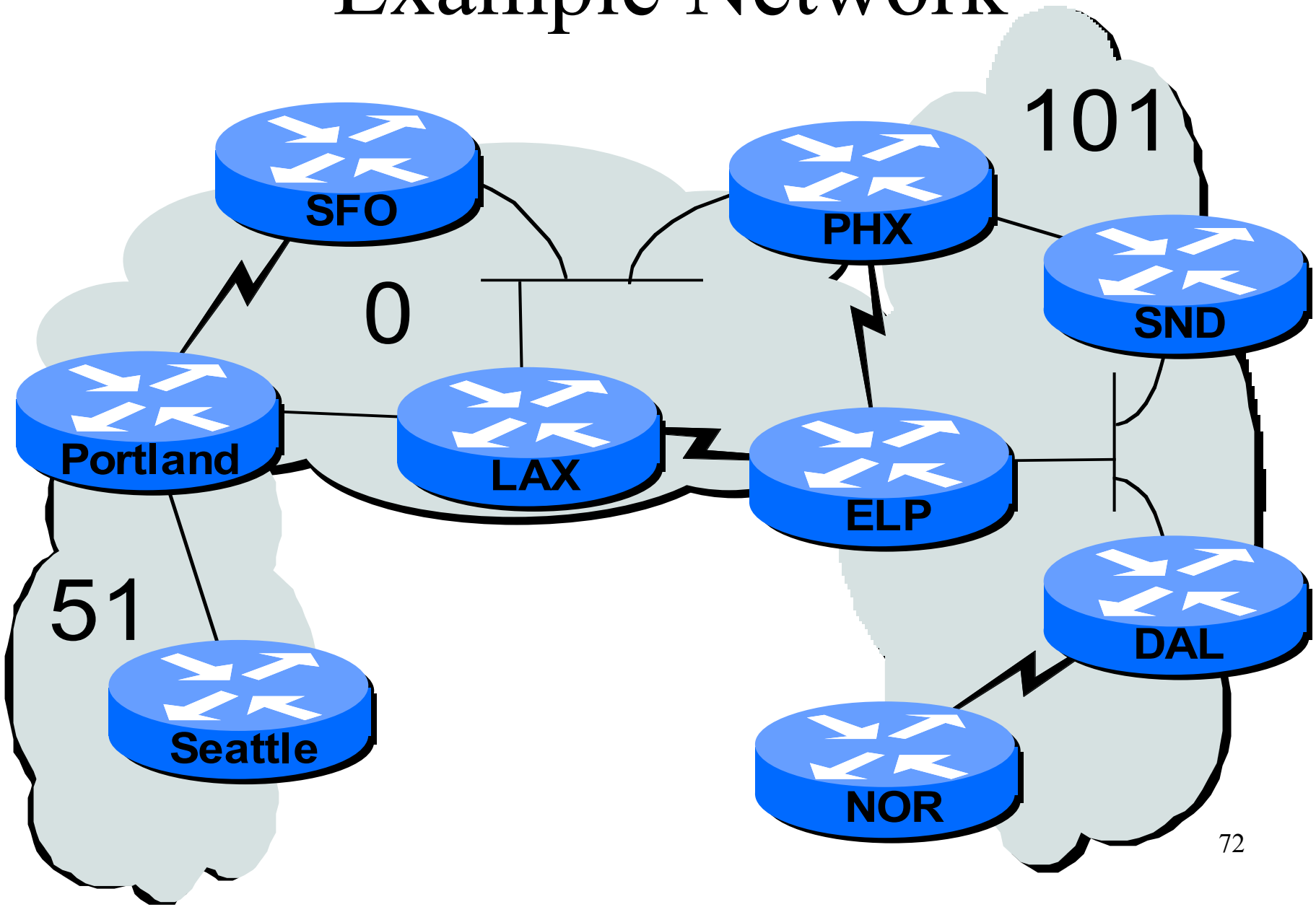
Part 3

Troubleshooting

OSPF Troubleshooting

- Example Network
- Show
  - Commands
  - Output
- Debug
  - Commands
  - Output

Example Network



Show IP OSPF Command

- **Show ip route ospf**
- **Show ip protocol**
- **Show ip ospf ?**
  - **<1-4294967295>** Process ID number
  - **border-routers** Border and Boundary Router Info
  - **database** Database summary
  - **flood-list** Link state flood list
  - **interface** Interface information
  - **neighbor** Neighbor list
  - **request-list** Link state request list
  - **retransmission-list** Link state retransmission list
  - **summary-address** Summary-address redistribution Info
  - **virtual-links** Virtual link information
  - **<cr>**

Show Output

Debug Commands

- **Debug IP OSPF ?**
  - **Adj** OSPF adjacency events
  - **database-timer** OSPF database timer
  - **Events** OSPF events
  - **Flood** OSPF flooding
  - **lsa-generation** OSPF lsa generation
  - **Packet** OSPF packets
  - **Retransmission** OSPF retransmission events
  - **Spf** OSPF spf
  - **Tree** OSPF database tree

Debug Output

LAB 3a:
Troubleshooting

Purpose:

Run through normal operations and various break-and-fix scenarios

Part 4

Design

OSPF Design

- Backbone
- Area X
- Traffic Flow
- Backup
- IGP / EGP Interaction
- Miscellaneous

Design - Backbone

- Area 0
  - All Inter-Area traffic flows through here
  - Bigger links and routers
- Area X
  - Aggregation
- EGP access
  - OSPF/BGP interaction
  - Security / VPN

Design - Area X

- To Stub or not to Stub?
- Boundary
  - ABR
- Virtual Links
  - “Healing” Areas
- Redistribution
  - ASBR
- Summarization

Example Network - Area 0 / Area X

LAB 4a:

Design

Purpose:

Initial Area 0 and Area X

Design - Traffic Flow

- 80/20 - Intra Area / Inter Area
- Core, Distribution, Access, Remote Access
- Services
  - Data
  - Multicast
    - MOSPF (at your own risk)
  - Voice
  - Video

Design - Backup

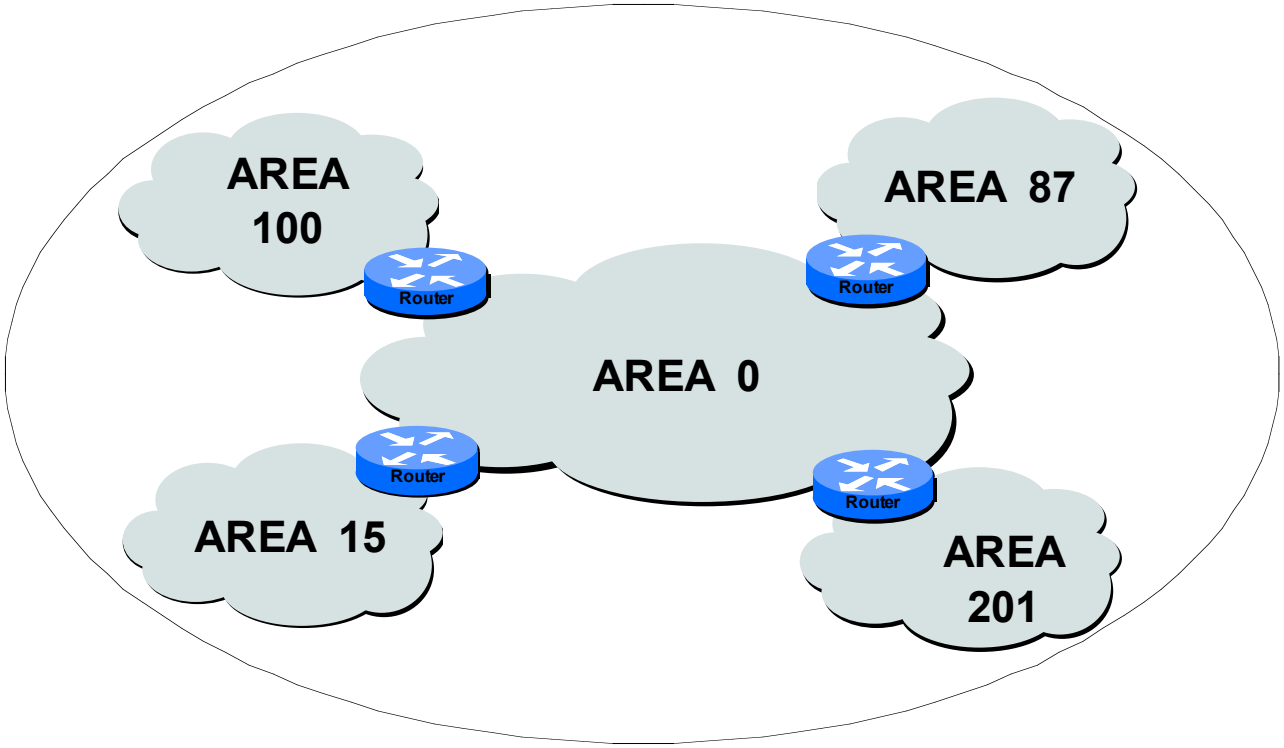
- Redundancy
- Load-share
- On Demand Circuit
- Concerns
  - Adding on top of existing install

Design - IGP / EGP Interaction

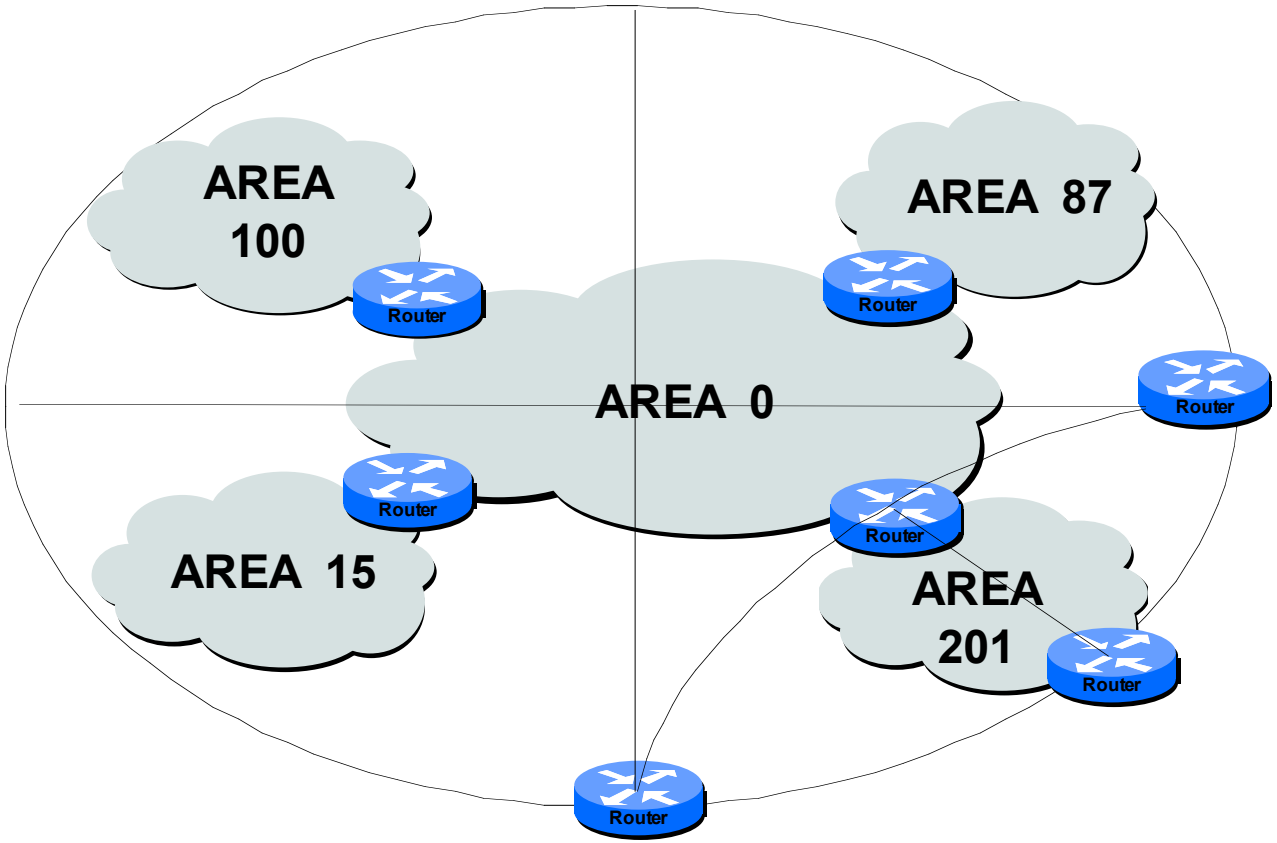
- Purpose
- Access
  - Services
- Redistribution
  - DON'T DO IT
- Security

Purpose of IGP - Interior

IGP/EGP interaction
Network Services
Customer to Customer



Purpose of IGP - Exterior



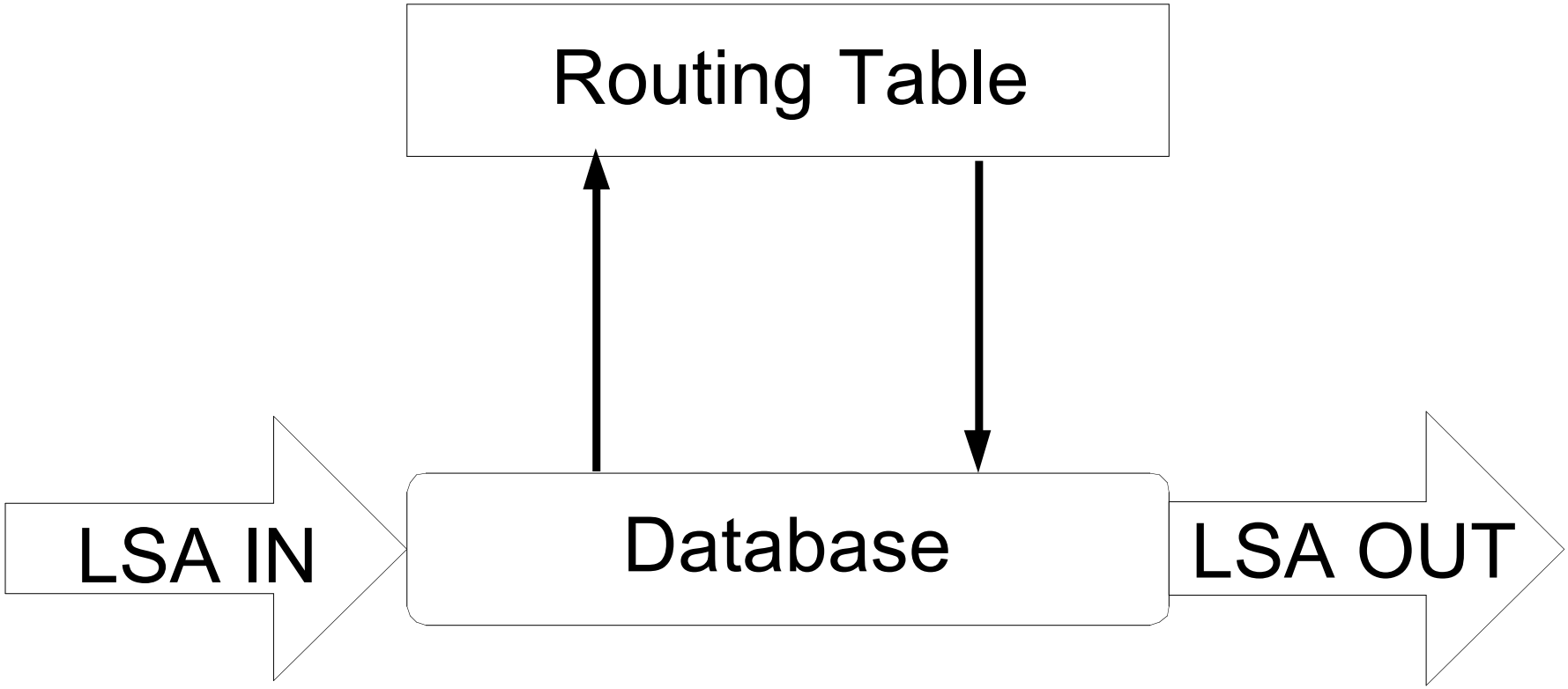
Design - Miscellaneous

- Security
  - NAT doesn't translate routing update
  - Firewalls can stop routing updates
- Filtering
- Virtual Links
- Redistribution
- Summarization
- ABR's

Filtering

- Usage
  - Affect LSA to Routing Table
  - Affect LSA distribution
- Interface
  - Database-filter
  - Access Control Lists
- OSPF process
  - Passive Interface
  - Distribute List (Access Control Lists)

Filtering - Usage



Filtering - Interface

- Database Filter

ip ospf database-filter

	Filter LSA during synchronization and flooding
all	Filter all LSA
out	Outgoing LSA
	<cr>

Filtering - Process

- Access Control Lists

access-list <**100-199**> permit|deny OSPF <**src**> <**dst**>

dscp	Match packets with given dscp value
log	Log matches against this entry
log-input	Log matches against this entry, including input intf
precedence	Match packets with given precedence value
time-range	Specify a time-range
tos	Match packets with given TOS value
<cr>	

Filtering - Process

- Distribute-list <type> [in|out]

  <1-199> IP access list number

  <1300-2699> IP expanded access list number

  Gateway <**prefix-list-name**> [in|out] [interface|<cr>]

  Filter incoming updates based on gateway

  Prefix <**prefix-list-name**> [in|out] [interface|<cr>]

  Filter prefixes in routing updates

Filtering - Process

- Denies sending LSA OUT-bound
- LSA's are still received
- Subnet of interface still advertised as stub
- Routing info not sent or received
- Passive-interface

BRI	ISDN Basic Rate Interface
Default	Suppress routing updates on all interfaces
Ethernet	IEEE 802.3
Loopback	Loopback interface
Null	Null interface

LAB 4b:

Design

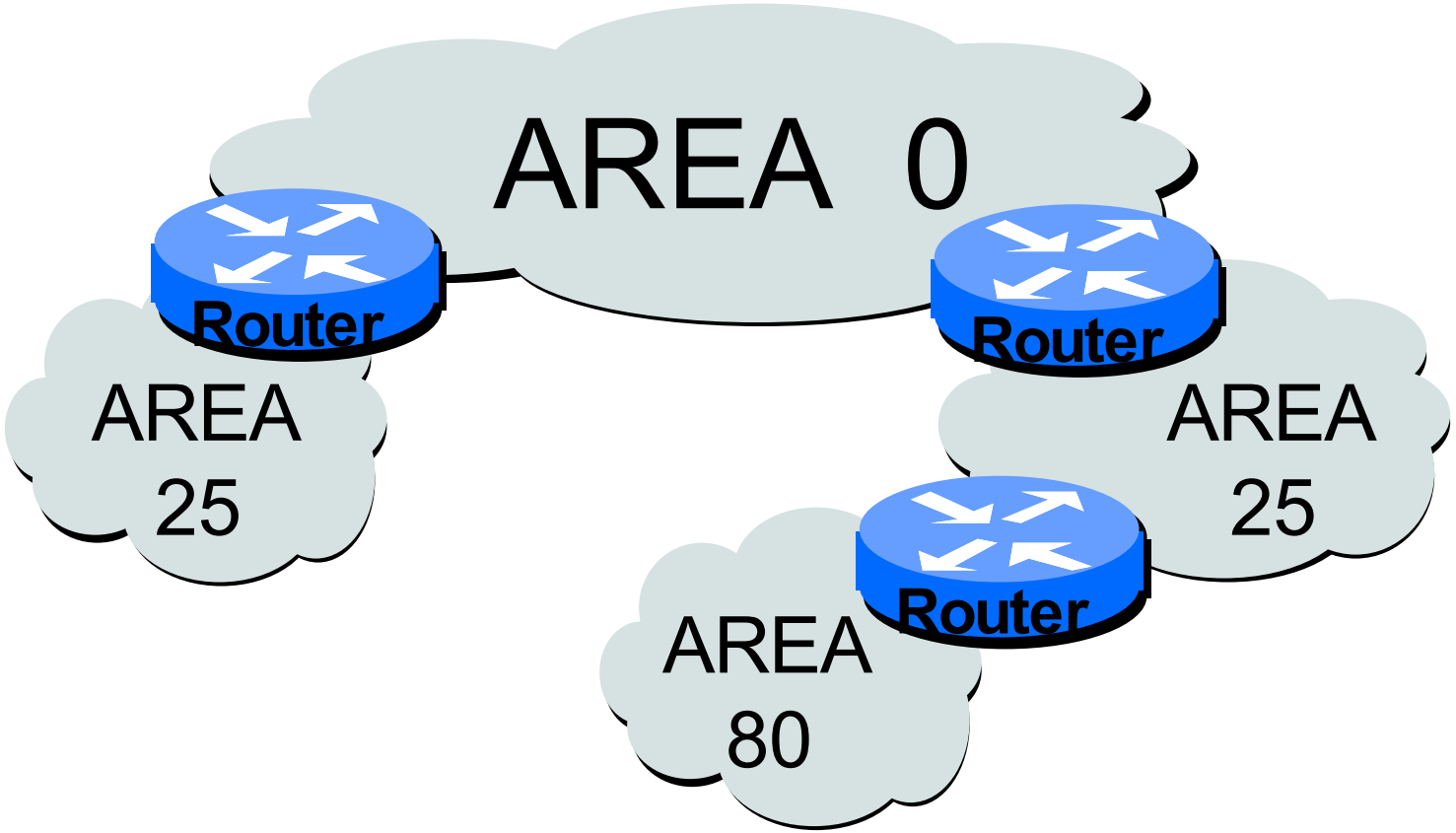
Purpose:

Understand filtering capabilities between areas.

Virtual Links

- Configurations
  - Uni-directional tunnels
- Used to “heal”
  - Discontinuous areas
  - Areas not touching Area 0
- Cannot be used across Stub Areas
- Use at your own risk
  - Design considerations
  - Troubleshooting considerations

Virtual Links



Virtual Links

- area [<**0-4294967295**> | **A.B.C.D**]

  virtual-link Define a virtual link and its parameters

  A.B.C.D ID (IP addr) associated with virtual link neighbor

authentication-key	Set authentication key
dead-interval	Dead router detection time
hello-interval	Hello packet interval
message-digest-key	Set message digest key
retransmit-interval	LSA retransmit interval
transmit-delay	LSA transmission delay
<cr>	

LAB 4c:
Design

Purpose:

Use Virtual Links to “heal” areas.

Redistribution

- Always tricky no matter the protocol
  - NEVER redistribute into BGP
  - Beware routing loops
  - Mutual redistribution
- ASBR can generate a default route into OSPF
  - Use default-information originate [always] …
- Each subnet is redistributed as an external
  - Use summary-address <**address**> <**mask**>

Redistribution

- Redistribute <**protocol**>

  Metric Metric for redistributed routes

  Metric-type Exterior metric type for redistributed routes

  Mobile Mobile routes

  ODR On Demand stub Routes

  Route-map Route map reference

  Static Static routes

  Subnets Consider subnets for redistribution into OSPF

  Tag Set tag for routes redistributed into OSPF

LAB 4d:

Design

Purpose:

Understand the effects of Redistribution and ASBR's.

Summarization

- Summary-address **A.B.C.D <mask>**

  not-advertise Do not advertise when translating OSPF type-7 LSA

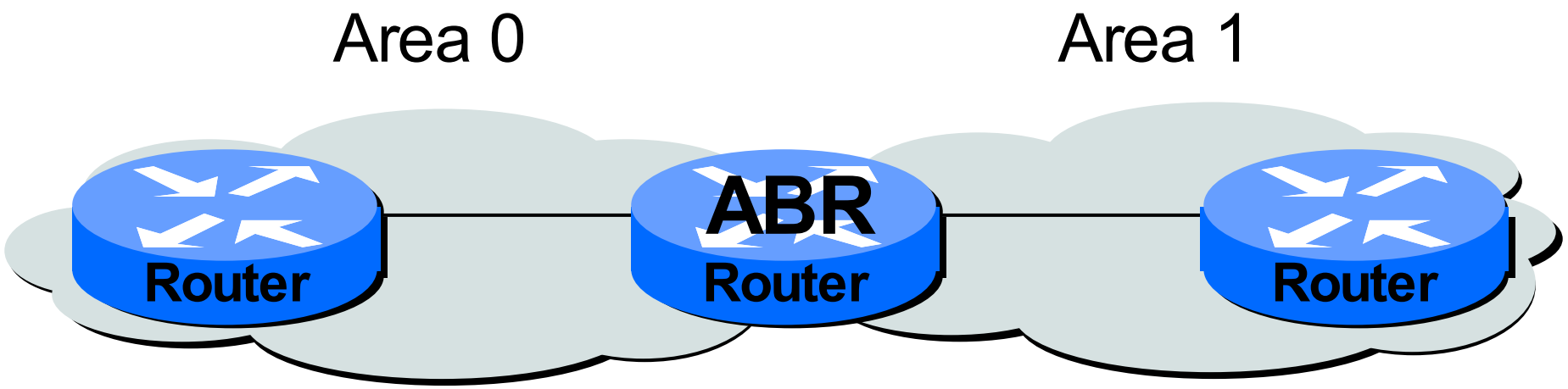
  tag Set tag

  <cr>

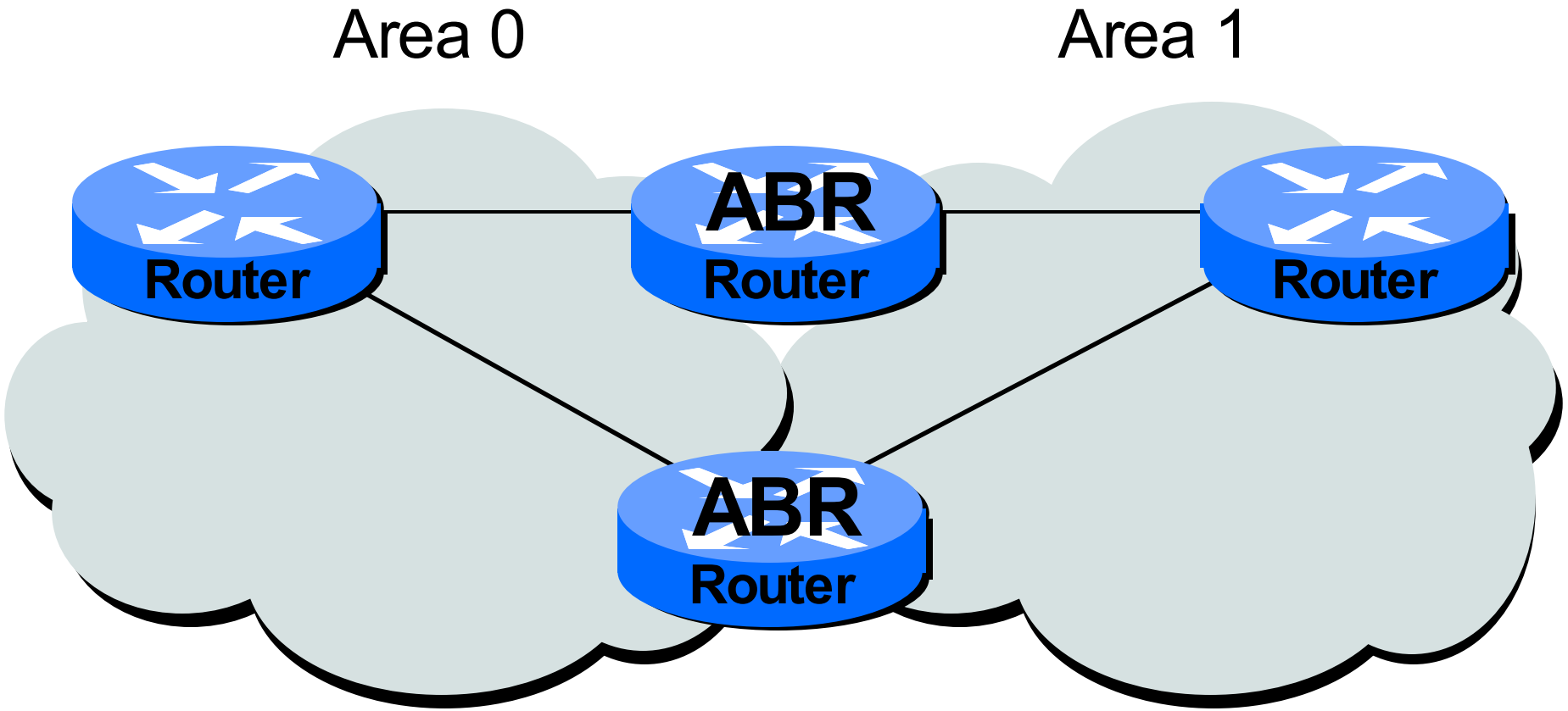
Area Boundary Routers

- 1 ABR
- 2+ ABR
- Type of Area: Intra, Stub, NSSA, TSA
  - Default route injected

ABR Configuration



ABR Configuration



LAB 4e:

Design

Purpose:

Understand the effects of multiple ABR's connecting Area 0 to Area X.

Part 5

References

References (RFC)

- **1245-6** Analysis and Experience
- **1584-5** Multicast extensions
- **1586** Running over Frame-Relay
- **1587** NSSA
- **1793** Support for On Demand Circuits
- **1850** MIB v2
- **2154** Digital Signatures
- **2328** OSPF v2
- **2370** Opaque LSA
- **2676** QoS
- **2740** IPv6
- **2844** Running over Asynchronous Transfer Mode

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  - /warp/public/104/index.shtml
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- Interconnections Second Edition
  - Radia Perlman (Addison Wesley)