Routing Workshop I

Contact: training@apnic.net

Overview

Routing Workshop (3 Days)

- Introduction to IP Routing
- Routing Protocol Basic
- IPv6 Address Structure
- Routing Lab Topology Overview
- Operation of OSPF Routing Protocol
- Lab Exercise on Basic Router and OSPF Dynamic Routing Configuration
- Basic BGP Operation
- BGP Attributes and Path Selection Process
- BGP Scaling Techniques
- Lab Exercise on iBGP, eBGP, RR, Peer group etc
- Internet Exchange [IX] Policy Overview and Configuration requirement

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IPv4

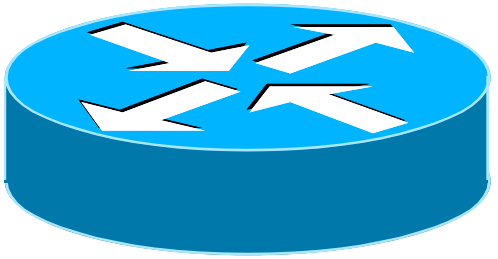
- Internet uses IPv4
  - Addresses are 32 bits long
  - Range from 1.0.0.0 to 223.255.255.255
  - 0.0.0.0 to 0.255.255.255 and 224.0.0.0 to 255.255.255.255 have “special” uses
- IPv4 address has a network portion and a host portion

IPv4 address format

- Address and subnet mask
  - written as
  - 12.34.56.78 255.255.255.0 or
  - 12.34.56.78/24
  - mask represents the number of network bits in the 32 bit address
  - the remaining bits are the host bits

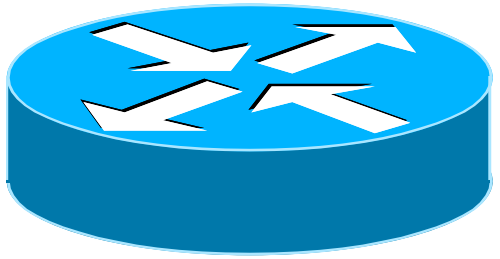
What does a router do?

- ?



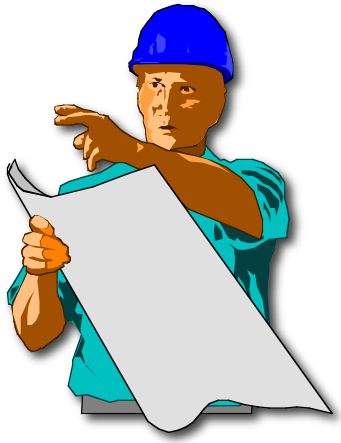
A day in a life of a router

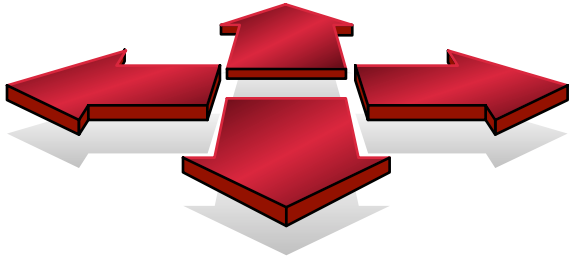
- find path
- forward packet, forward packet, forward packet, forward packet...
- find alternate path
- forward packet, forward packet, forward packet, forward packet…
- repeat until powered off



Routing versus Forwarding

- Routing = building maps and giving directions
- Forwarding = moving packets between interfaces according to the "directions"





IP Routing – finding the path

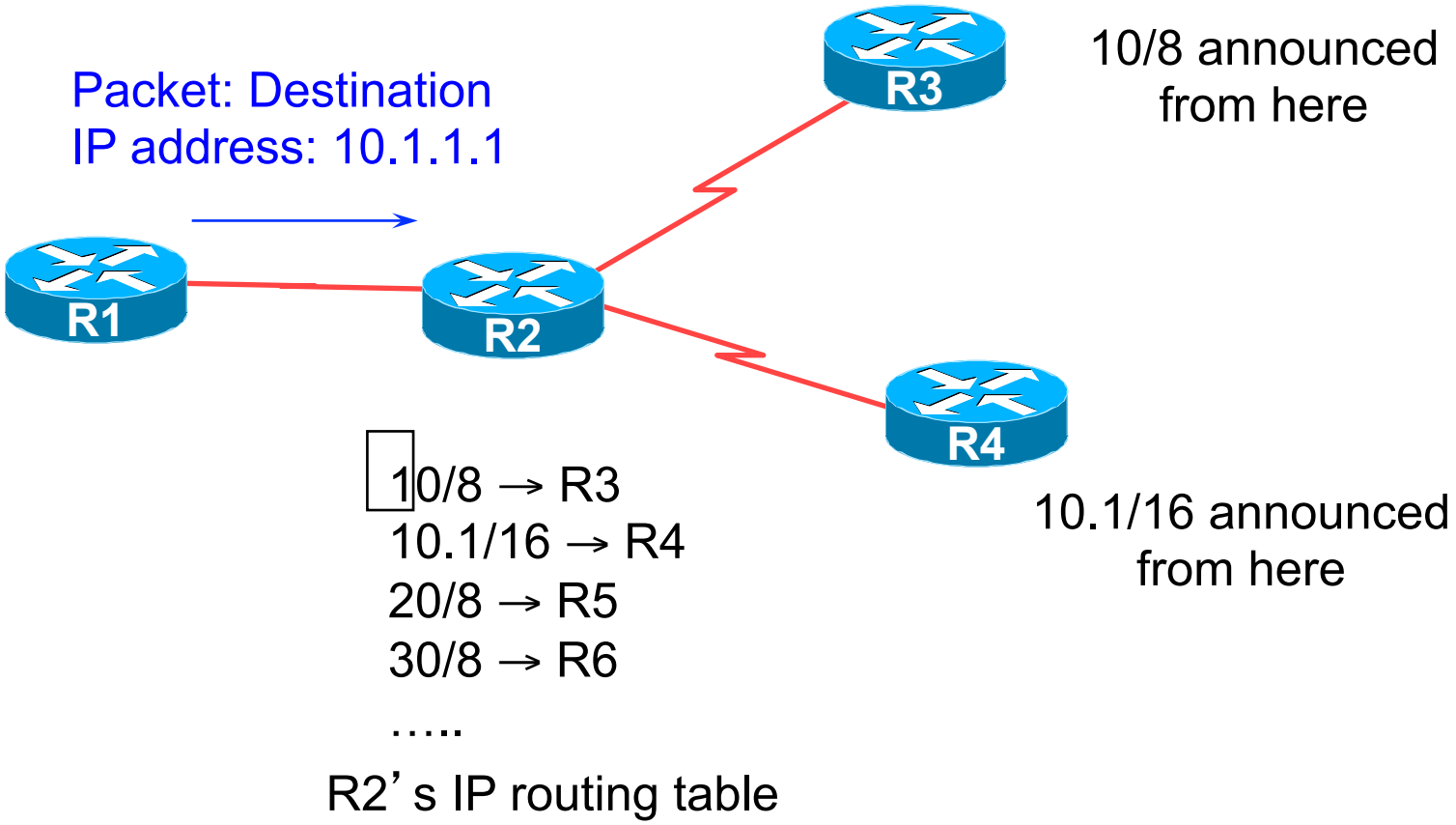
- Path derived from information received from a routing protocol
- Several alternative paths may exist
  - best path stored in forwarding table
- Decisions are updated periodically or as topology changes (event driven)
- Decisions are based on:
  - topology, policies and metrics (hop count, filtering, delay, bandwidth, etc.)

IP route lookup

- Based on destination IP address
- “longest match” routing
  - More specific prefix preferred over less specific prefix
  - Example: packet with destination of 10.1.1.1/32 is sent to the router announcing 10.1/16 rather than the router announcing 10/8.

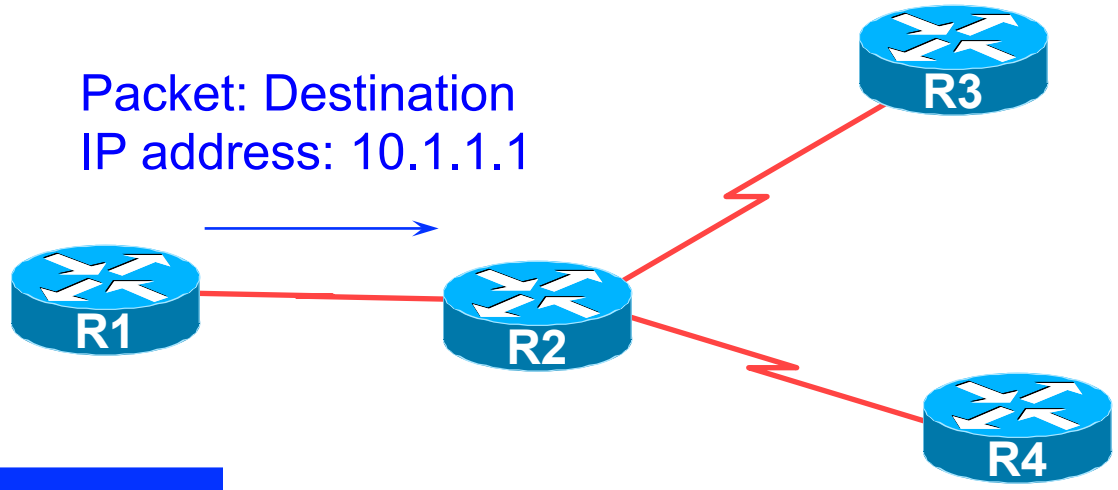
IP route lookup

- Based on destination IP address



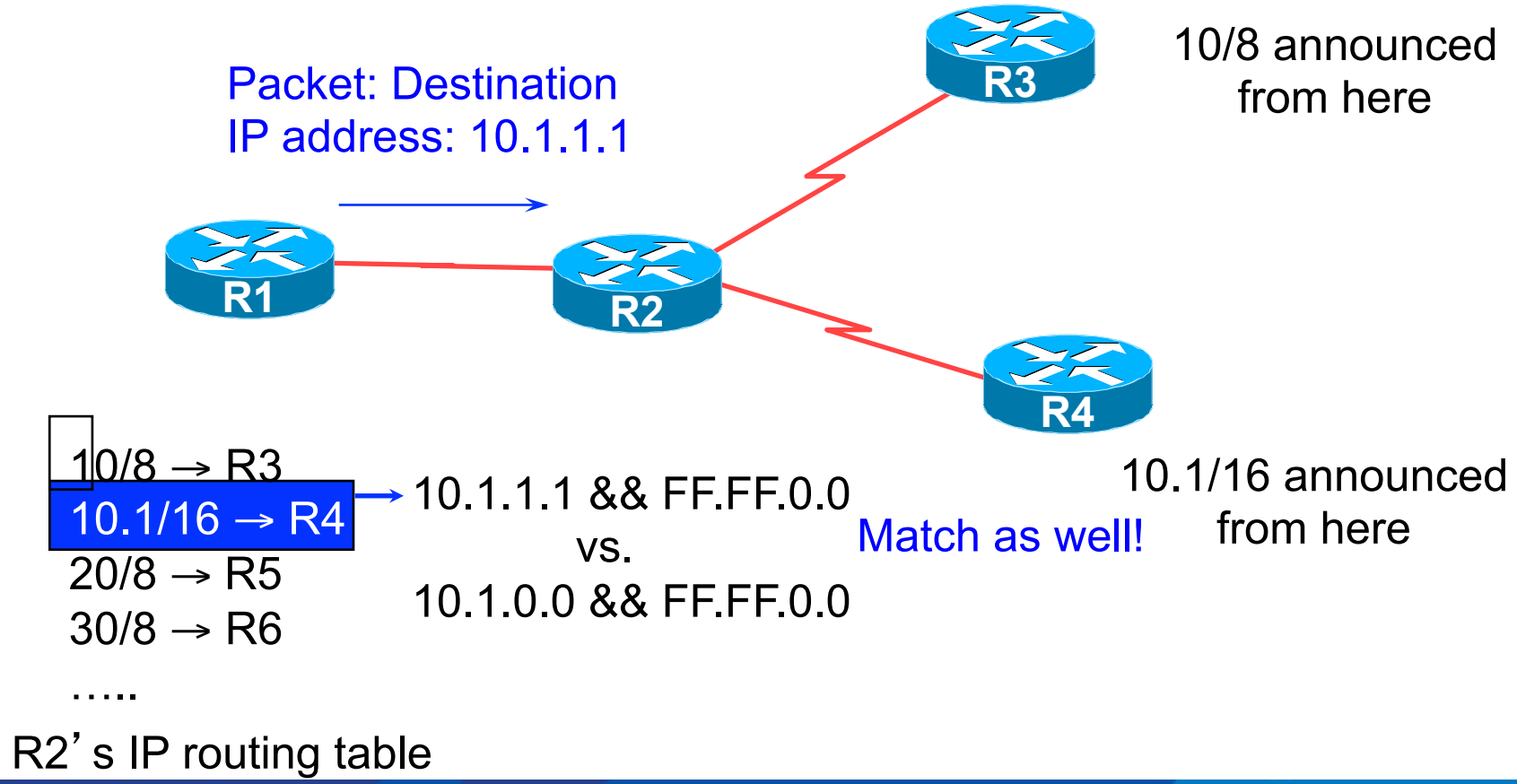
IP route lookup: Longest match routing

- Based on destination IP address



IP route lookup: Longest match routing

- Based on destination IP address



IP route lookup: Longest match routing

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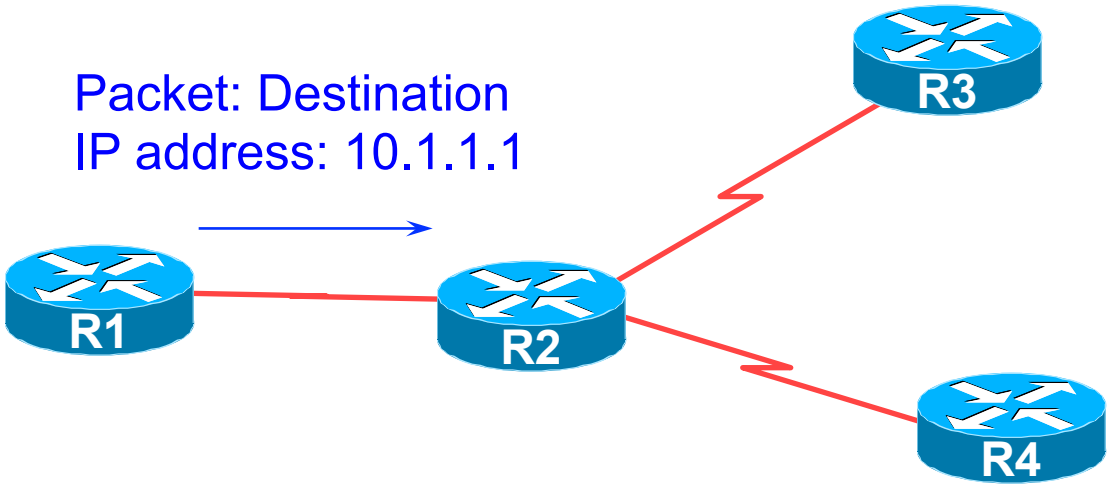


10/8 → R3
10.1/16 → R4
20/8 → R5
30/8 → R6
…..

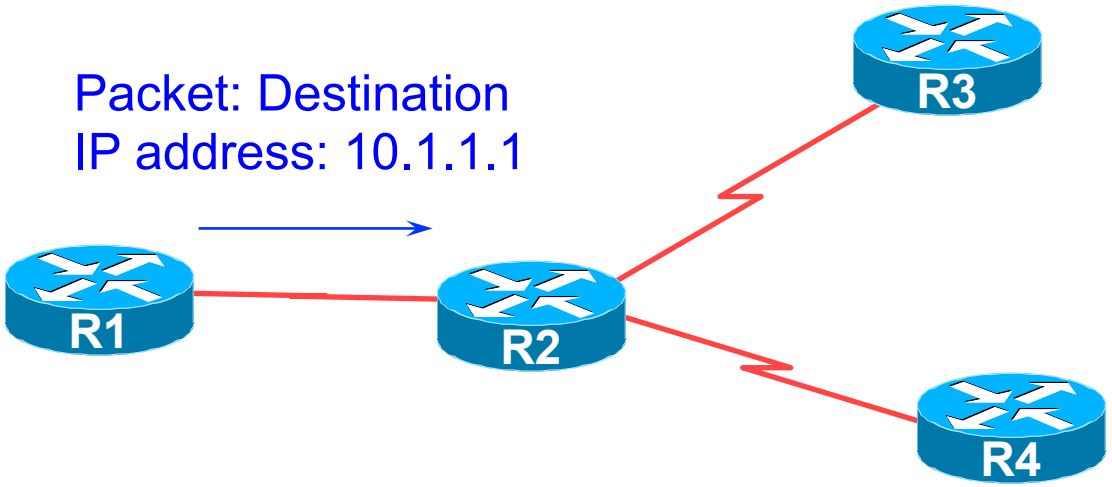
10.1.1.1 && FF.0.0.0
vs.
20.0.0.0 && FF.0.0.0

Does not match!

R2's IP routing table

IP route lookup: Longest match routing

- Based on destination IP address



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R2's IP routing table

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IP route lookup: Longest match routing

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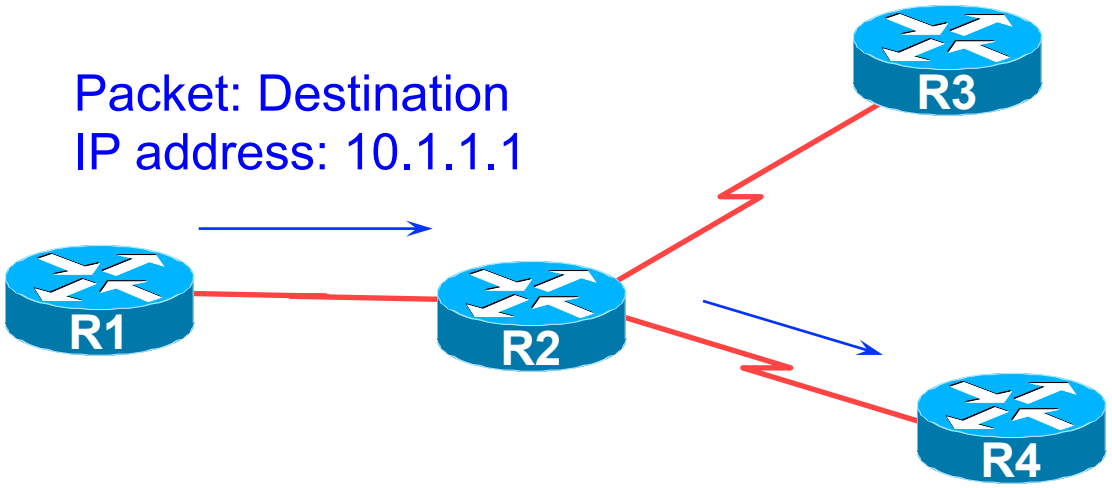


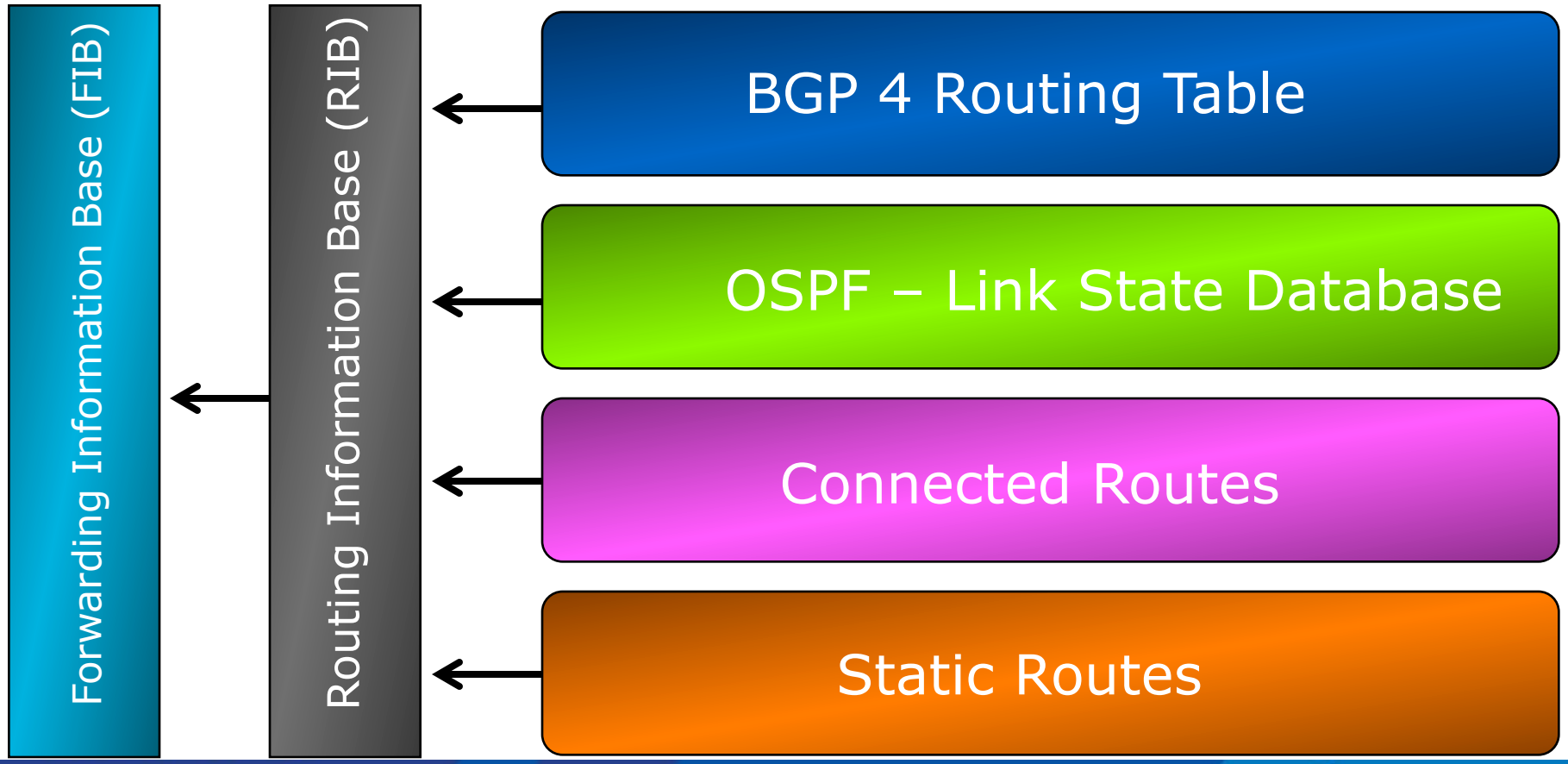
10/8 → R3
10.1/16 → R4 ← Longest match, 16 bit netmask
20/8 → R5
30/8 → R6
…..

R2's IP routing table

IP Forwarding

- Router decides which interface a packet is sent to
- Forwarding table populated by routing process
- Forwarding decisions:
  - destination address
  - class of service (fair queuing, precedence, others)
  - local requirements (packet filtering)
- Forwarding is usually aided by special hardware

Routing Tables Feed the Forwarding Table



RIBs and FIBs

- FIB is the Forwarding Table
  - It contains destinations and the interfaces to get to those destinations
  - Used by the router to figure out where to send the packet
  - Careful! Some people still call this a route!
- RIB is the Routing Table
  - It contains a list of all the destinations and the various next hops used to get to those destinations – and lots of other information too!
  - One destination can have lots of possible next-hops – only the best next-hop goes into the FIB

Explicit versus Default Routing

- Default:
  - simple, cheap (cycles, memory, bandwidth)
  - low granularity (metric games)
- Explicit (default free zone)
  - high overhead, complex, high cost, high granularity
- Hybrid
  - minimise overhead
  - provide useful granularity
  - requires some filtering knowledge

Egress Traffic

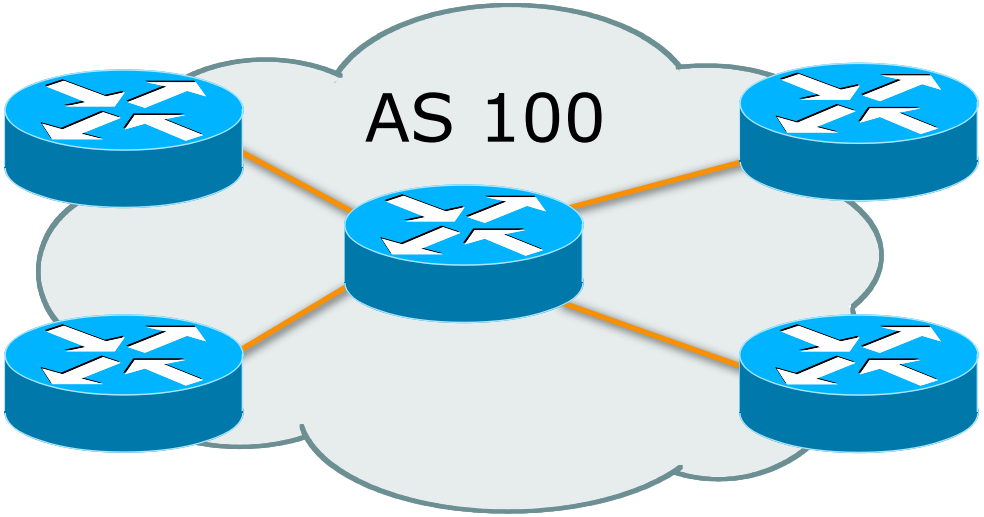
- How packets leave your network
- Egress traffic depends on:
  - route availability (what others send you)
  - route acceptance (what you accept from others)
  - policy and tuning (what you do with routes from others)
  - Peering and transit agreements

Ingress Traffic

- How packets get to your network and your customers' networks
- Ingress traffic depends on:
  - what information you send and to whom
  - based on your addressing and AS's
  - based on others' policy (what they accept from you and what they do with it)

Autonomous System (AS)

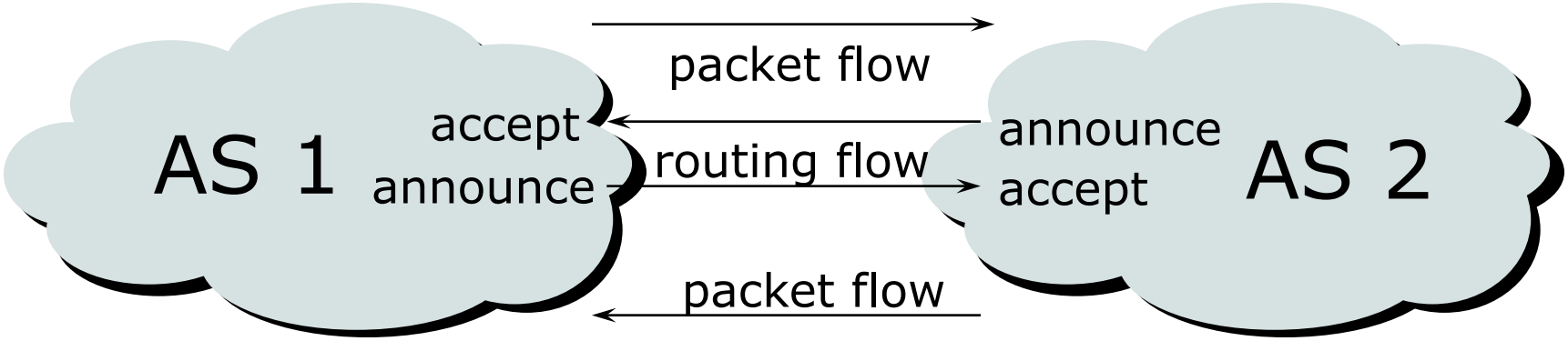
- Collection of networks with same routing policy
- Single routing protocol
- Usually under single ownership, trust and administrative control



Definition of terms

- Neighbours
  - AS's which directly exchange routing information
  - Routers which exchange routing information
- Announce
  - send routing information to a neighbour
- Accept
  - receive and use routing information sent by a neighbour
- Originate
  - insert routing information into external announcements (usually as a result of the IGP)
- Peers
  - routers in neighbouring AS's or within one AS which exchange routing and policy information

Routing flow and packet flow



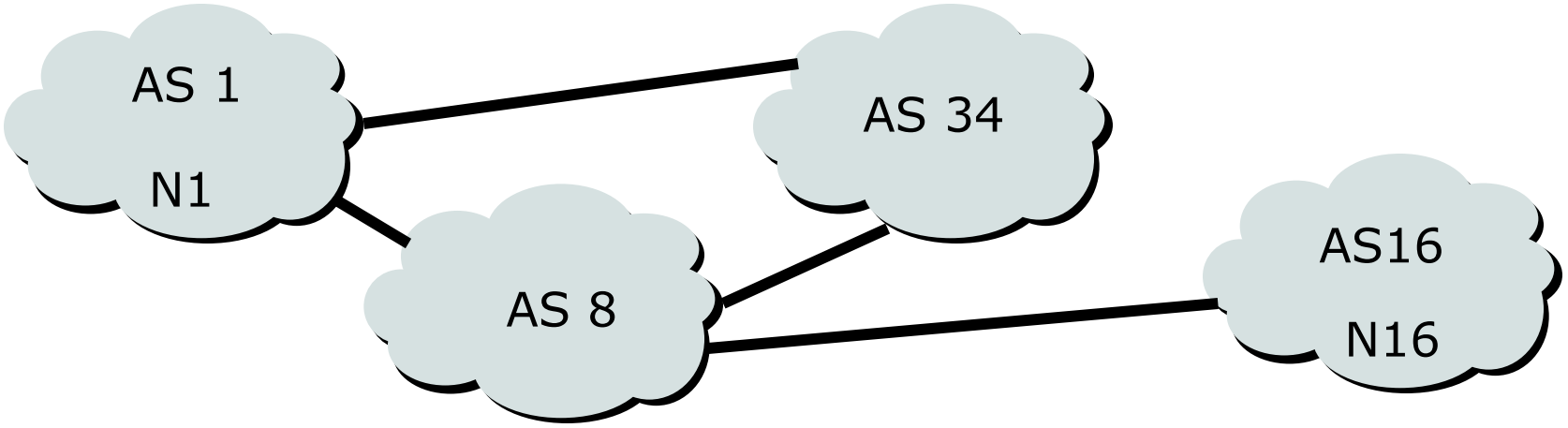
For networks in AS1 and AS2 to communicate:

- AS1 must announce to AS2
- AS2 must accept from AS1
- AS2 must announce to AS1
- AS1 must accept from AS2

Routing flow and Traffic flow

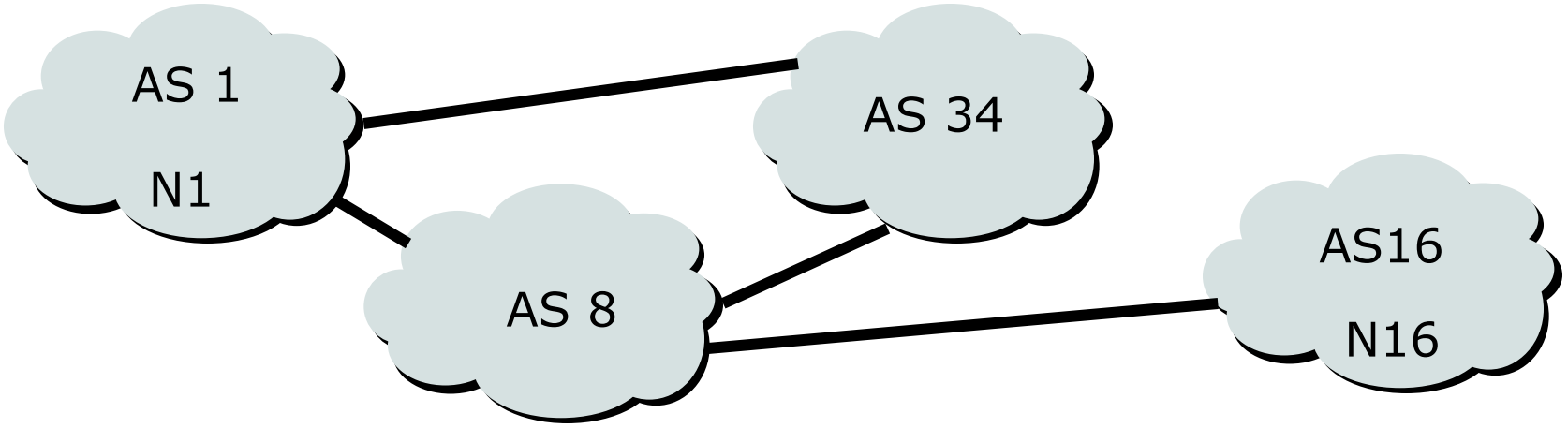
- Traffic flow is always in the opposite direction of the flow of Routing information
  - Filtering outgoing routing information inhibits traffic flow inbound
  - Filtering inbound routing information inhibits traffic flow outbound

Routing Flow/Packet Flow: With multiple ASes



- For net N1 in AS1 to send traffic to net N16 in AS16:
  - AS16 must originate and announce N16 to AS8.
  - AS8 must accept N16 from AS16.
  - AS8 must forward announcement of N16 to AS1 or AS34.
  - AS1 must accept N16 from AS8 or AS34.
- For two-way packet flow, similar policies must exist for N1

Routing Flow/Packet Flow: With multiple ASes

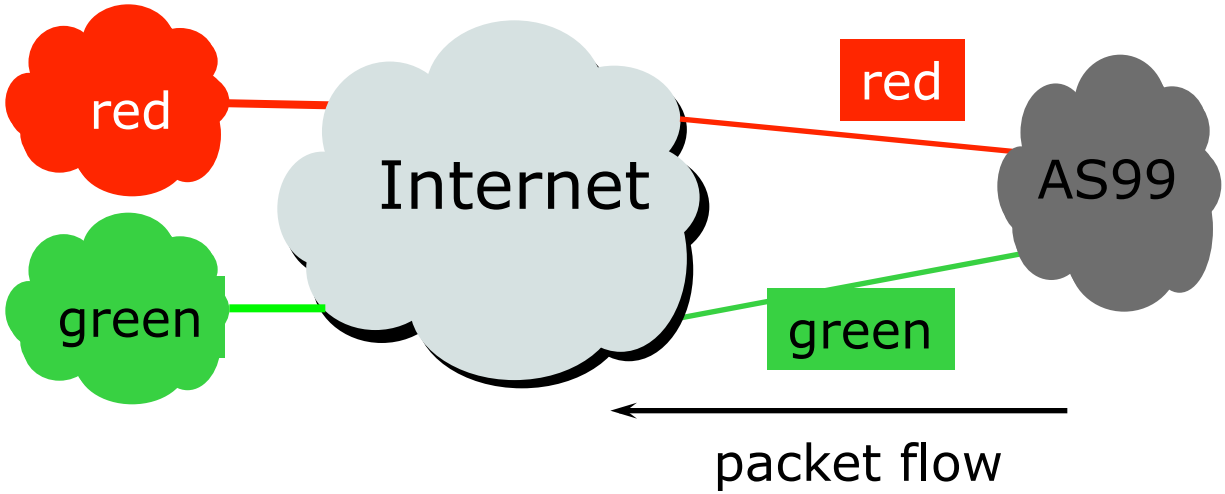


- As multiple paths between sites are implemented it is easy to see how policies can become quite complex.

Routing Policy

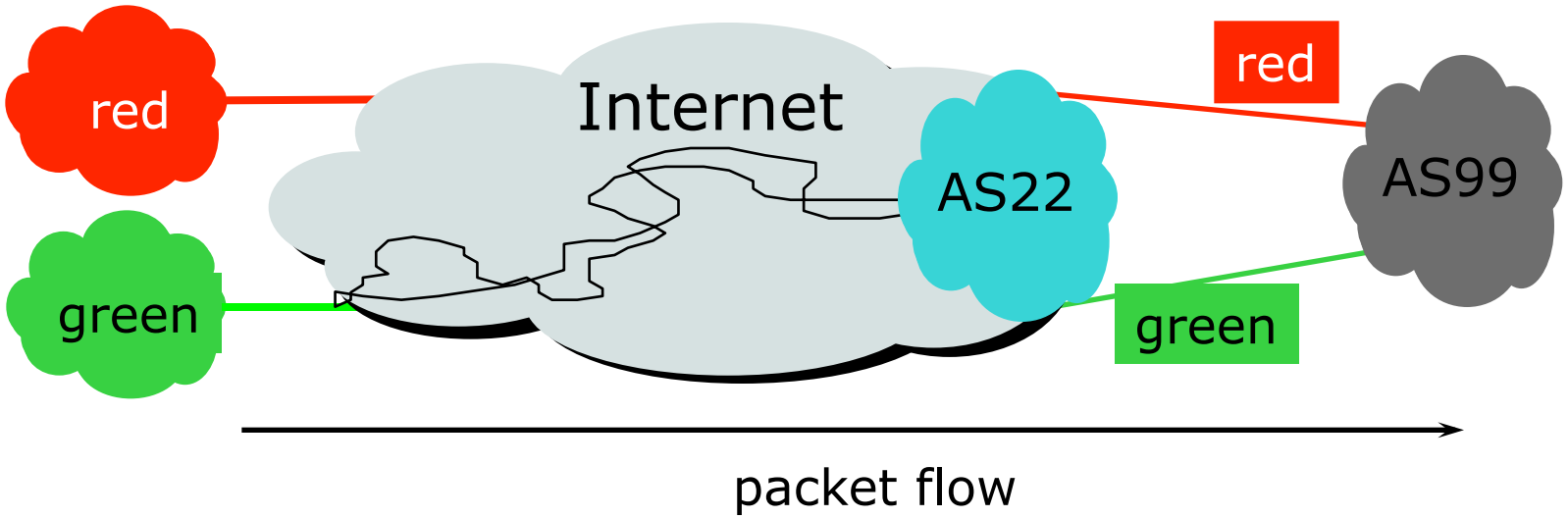
- Used to control traffic flow in and out of an ISP network
- ISP makes decisions on what routing information to accept and discard from its neighbours
  - Individual routes
  - Routes originated by specific ASes
  - Routes traversing specific ASes
  - Routes belonging to other groupings
    - Groupings which you define as you see fit

Routing Policy Limitations



- AS99 uses red link for traffic to the red AS and the green link for remaining traffic
- To implement this policy, AS99 has to:
  - Accept routes originating from the red AS on the red link
  - Accept all other routes on the green link

Routing Policy Limitations



- AS99 would like packets coming from the green AS to use the green link.
- But unless AS22 cooperates in pushing traffic from the green AS down the green link, there is very little that AS99 can do to achieve this aim

Routing Policy Issues

- End May 2012:
  - 400000+ prefixes
    - Not realistic to set policy on all of them individually
  - 40000 origin AS's
    - Too many to try and create individual policies for
- Routes tied to a specific AS or path may be unstable regardless of connectivity
- Solution: Groups of AS's are a natural abstraction for filtering purposes

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1: How Does Routing Work?

- Internet is made up of the ISPs who connect to each other's networks
- How does an ISP in Kenya tell an ISP in Japan what customers they have?
- And how does that ISP send data packets to the customers of the ISP in Japan, and get responses back
  - After all, as on a local ethernet, two way packet flow is needed for communication between two devices

2: How Does Routing Work?

- ISP in Kenya could buy a direct connection to the ISP in Japan
  - But this doesn't scale – thousands of ISPs, would need thousands of connections, and cost would be astronomical
- Instead, ISP in Kenya tells his neighbouring ISPs what customers he has
  - And the neighbouring ISPs pass this information on to their neighbours, and so on
  - This process repeats until the information reaches the ISP in Japan

3: How Does Routing Work?

- This process is called “Routing”
- The mechanisms used are called “Routing Protocols”
- Routing and Routing Protocols ensures that the Internet can scale, that thousands of ISPs can provide connectivity to each other, giving us the Internet we see today

4: How Does Routing Work?

- ISP in Kenya doesn't actually tell his neighbouring ISPs the names of the customers
  - (network equipment does not understand names)
- Instead, he has received an IP address block as a member of the Regional Internet Registry serving Kenya
  - His customers have received address space from this address block as part of their "Internet service"
  - And he announces this address block to his neighbouring ISPs – this is called announcing a "route"

Routing Protocols

- Routers use “routing protocols” to exchange routing information with each other
  - IGP is used to refer to the process running on routers inside an ISP’s network
  - EGP is used to refer to the process running between routers bordering directly connected ISP networks

What Is an IGP?

- Interior Gateway Protocol
- Within an Autonomous System
- Carries information about internal infrastructure prefixes
- Two widely used IGPs in service provider network:
  - OSPF
  - ISIS

Why Do We Need an IGP?

- ISP backbone scaling
  - Hierarchy
  - Limiting scope of failure
  - Only used for ISP's infrastructure addresses, not customers or anything else
  - Design goal is to minimise number of prefixes in IGP to aid scalability and rapid convergence

What Is an EGP?

- Exterior Gateway Protocol
- Used to convey routing information between Autonomous Systems
- De-coupled from the IGP
- Current EGP is BGP

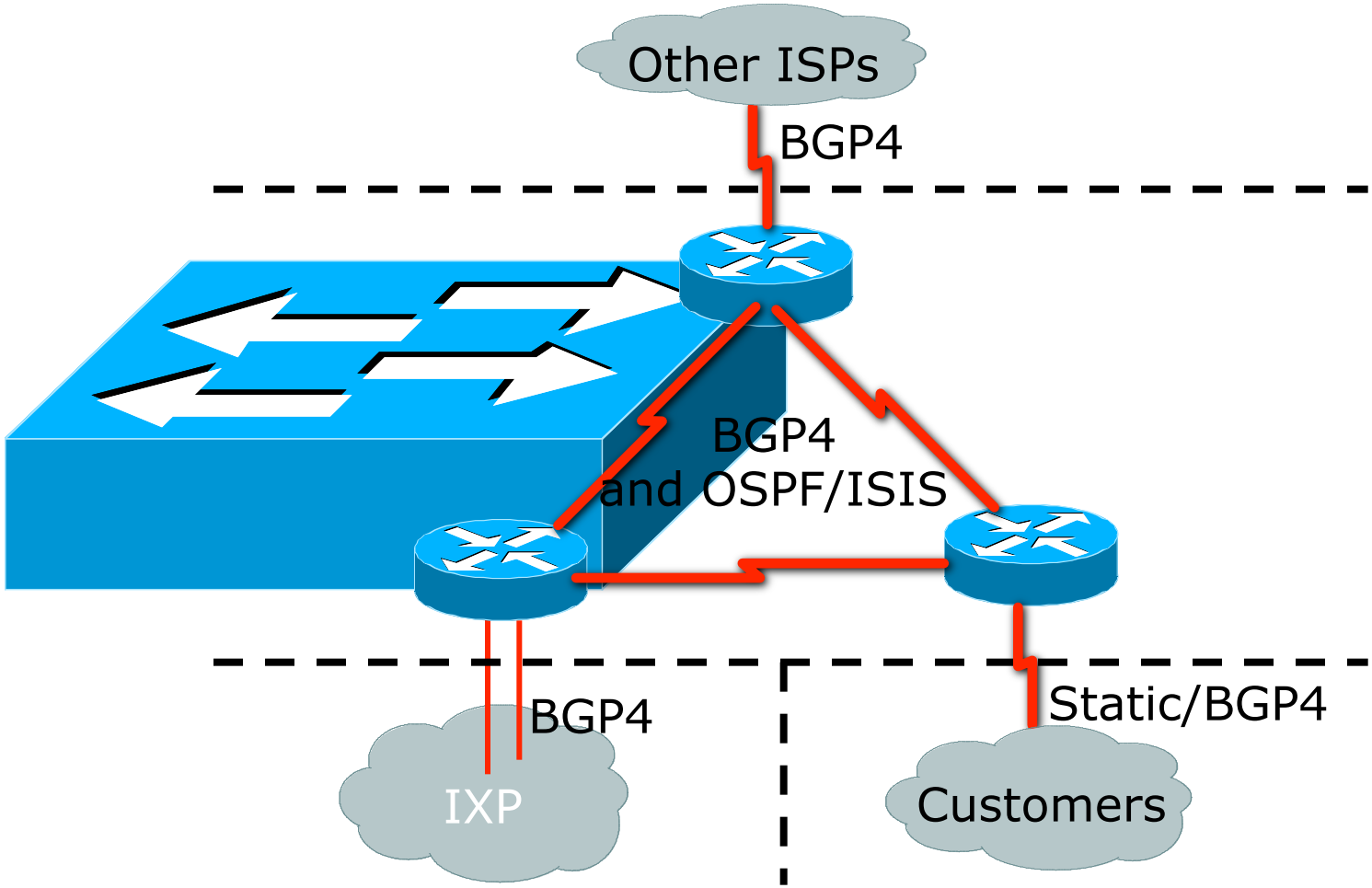
Why Do We Need an EGP?

- Scaling to large network
  - Hierarchy
  - Limit scope of failure
- Define Administrative Boundary
- Policy
  - Control reachability of prefixes
  - Merge separate organisations
  - Connect multiple IGPs

Interior versus Exterior Routing Protocols

- Interior
  - Automatic neighbour discovery
  - Generally trust your IGP routers
  - Prefixes go to all IGP routers
  - Binds routers in one AS together
  - Carries ISP infrastructure addresses only
  - ISPs aim to keep the IGP small for efficiency and scalability
- Exterior
  - Specifically configured peers
  - Connecting with outside networks
  - Set administrative boundaries
  - Binds AS's together
  - Carries customer prefixes
  - Carries Internet prefixes
  - EGPs are independent of ISP network topology

Hierarchy of Routing Protocols



FYI: Cisco IOS Default Administrative Distances

Route Source	Default Distance
Connected Interface	0
Static Route	1
Enhanced IGRP Summary Route	5
External BGP	20
Internal Enhanced IGRP	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EGP	140
External Enhanced IGRP	170
Internal BGP	200
Unknown	255

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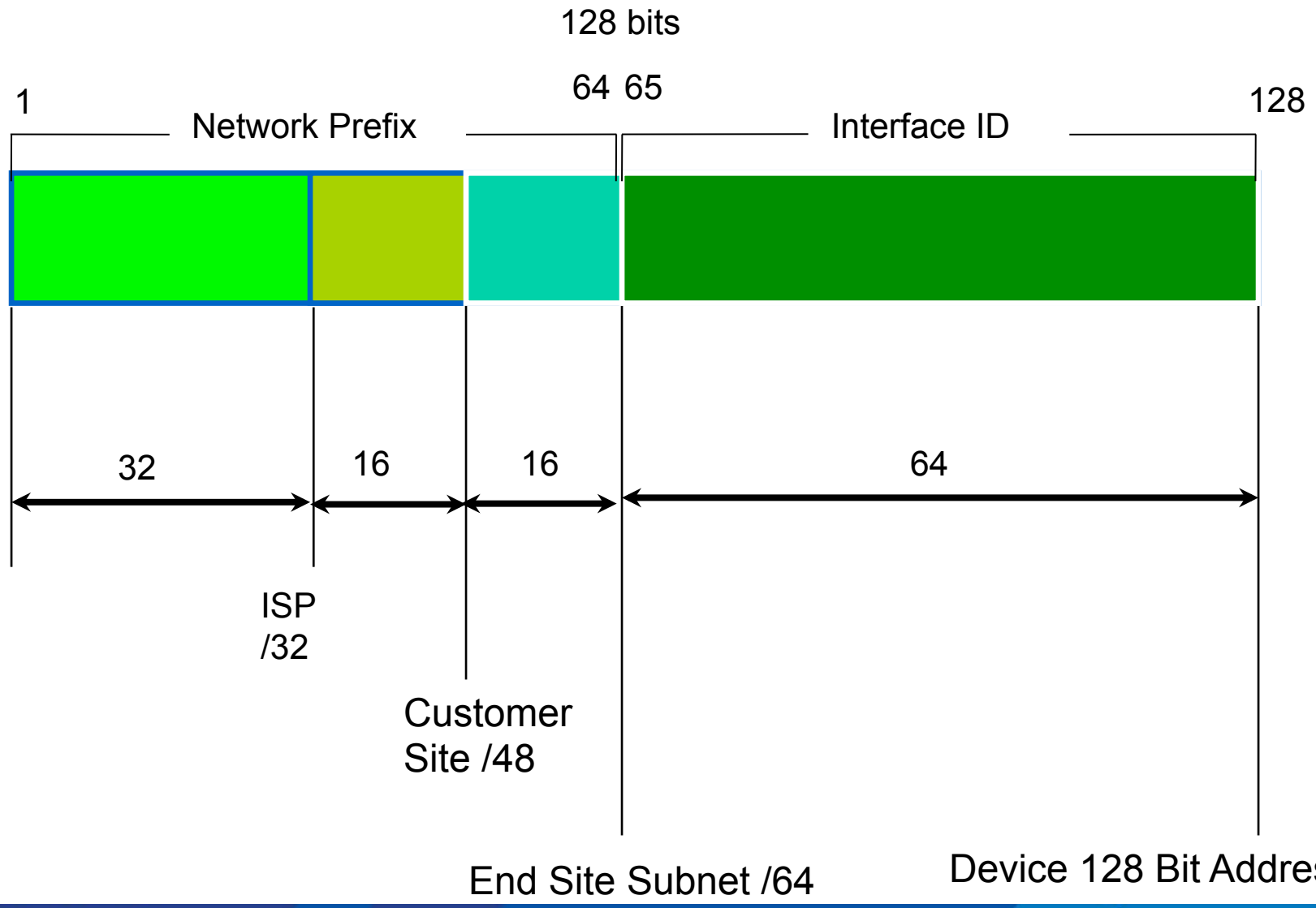
IPv6 Addressing

- An IPv6 address is 128 bits long
- So the number of addresses are 2^128
  =340282366920938463463374607431768211455
  (39 decimal digits)
  =0xffffffffffffffffffffffffffffffff (32 hexadecimal digits)
- In hex 4 bit (nibble) is represented by a hex digit
- So 128 bit is reduced down to 32 hex digit

IPv6 Address Representation

- Hexadecimal values of eight 16 bit fields
  - X:X:X:X:X:X:X:X (X=16 bit number, ex: A2FE)
  - 16 bit number is converted to a 4 digit hexadecimal number
- Example:
  - FE38:DCE3:124C:C1A2:BA03:6735:EF1C:683D
  - Abbreviated form of address
    - 4EED:0023:0000:0000:0000:036E:1250:2B00
    - →4EED:23:0:0:0:36E:1250:2B00
    - →4EED:23::36E:1250:2B00
    - (Null value can be used only once)

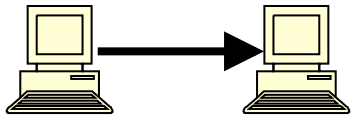
IPv6 addressing structure

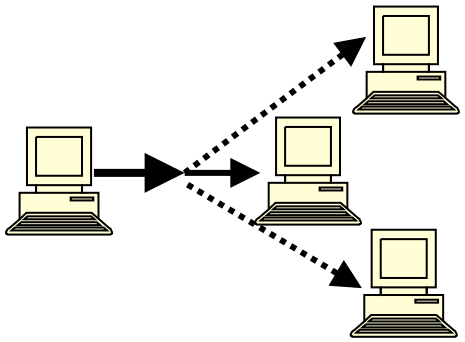


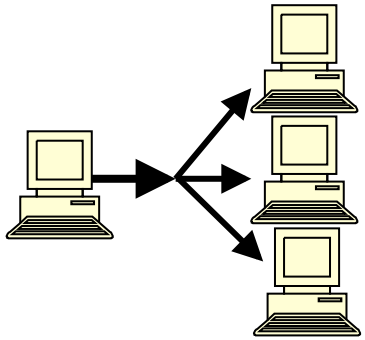
IPv6 addressing model

- **IPv6 Address type**
  - Unicast
    - An identifier for a single interface
  - Anycast
    - An identifier for a set of interfaces
  - Multicast
    - An identifier for a group of nodes

RFC 4291







Addresses Without a Network Prefix

- Localhost ::1/128
- Unspecified Address ::/128
- IPv4-mapped IPv6 address ::ffff/96 [a.b.c.d]
- IPv4-compatible IPv6 address ::/96 [a.b.c.d]

Local Addresses With Network Prefix

- Link Local Address
  - A special address used to communicate within the local link of an interface
  - i.e. anyone on the link as host or router
  - This address in packet destination that packet would never pass through a router
  - fe80::/10

Local Addresses With Network Prefix

- Unique Local IPv6 Unicast Address
  - Addresses similar to the RFC 1918 / private address like in IPv4 but will ensure uniqueness
  - A part of the prefix (40 bits) are generated using a pseudo-random algorithm and it's improbable that two generated ones are equal
  - fc00::/7
  - Example webtools to generate ULA prefix

    http://www.sixxs.net/tools/grh/ula/

    http://www.goebel-consult.de/ipv6/createLULA

Global Addresses With Network Prefix

- IPV6 Global Unicast Address
  - Global Unicast Range: 0010 2000::/3

    0011 3000::/3
  - All five RIRs are given a /12 from the /3 to further distribute within the RIR region
    - APNIC 2400:0000::/12
    - ARIN 2600:0000::/12
    - AfriNIC 2C00:0000::/12
    - LACNIC 2800:0000::/12
    - Ripe NCC 2A00:0000::/12

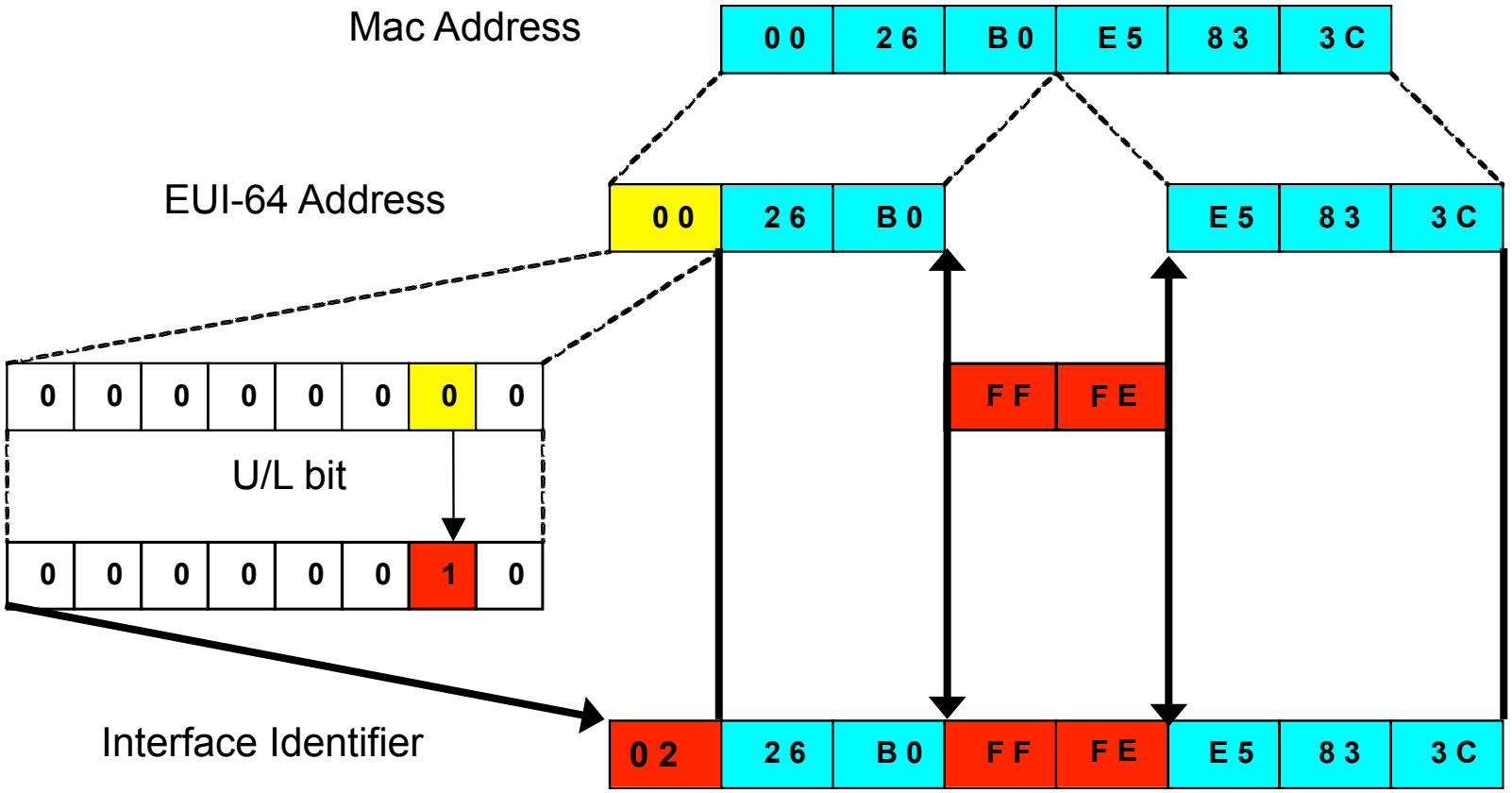
Examples and Documentation Prefix

- Two address ranges are reserved for examples and documentation purpose by RFC 3849
  - For example 3fff:ffff::/32
  - For documentation 2001:0DB8::/32

Interface ID

- The lowest-order 64-bit field addresses may be assigned in several different ways:
  - auto-configured from a 48-bit MAC address expanded into a 64-bit EUI-64
  - assigned via DHCP
  - manually configured
  - auto-generated pseudo-random number
  - possibly other methods in the future

EUI-64


Mac Address
00 26 B0 E5 83 3C
EUI-64 Address
00 26 B0 E5 83 3C
FF FE
0 0 0 0 0 0 0 0
U/L bit
0 0 0 0 0 0 1 0
Interface Identifier
02 26 B0 FF FE E5 83 3C

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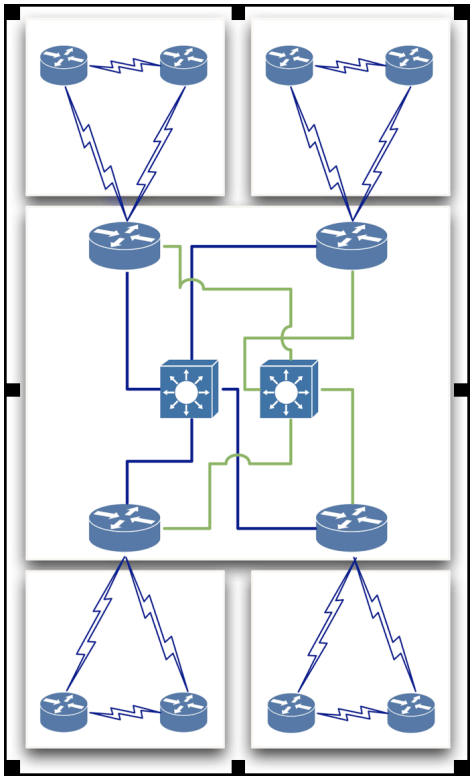
Training ISP Network Topology

- Scenario:
  - Training ISP has 4 main operating area or region
  - Each region has 2 small POP
  - Each region will have one datacenter to host content
  - Regional network are inter-connected with multiple link

Training ISP Network Topology



Training ISP Topology Diagram

Training ISP Network Topology

- Regional Network:
  - Each regional network will have 3 routers
  - 1 Core & 2 Edge Routers
  - 2 Point of Presence (POP) for every region
  - POP will use a router to terminate customer network i.e Edge Router
  - Each POP is an aggregation point of ISP customer

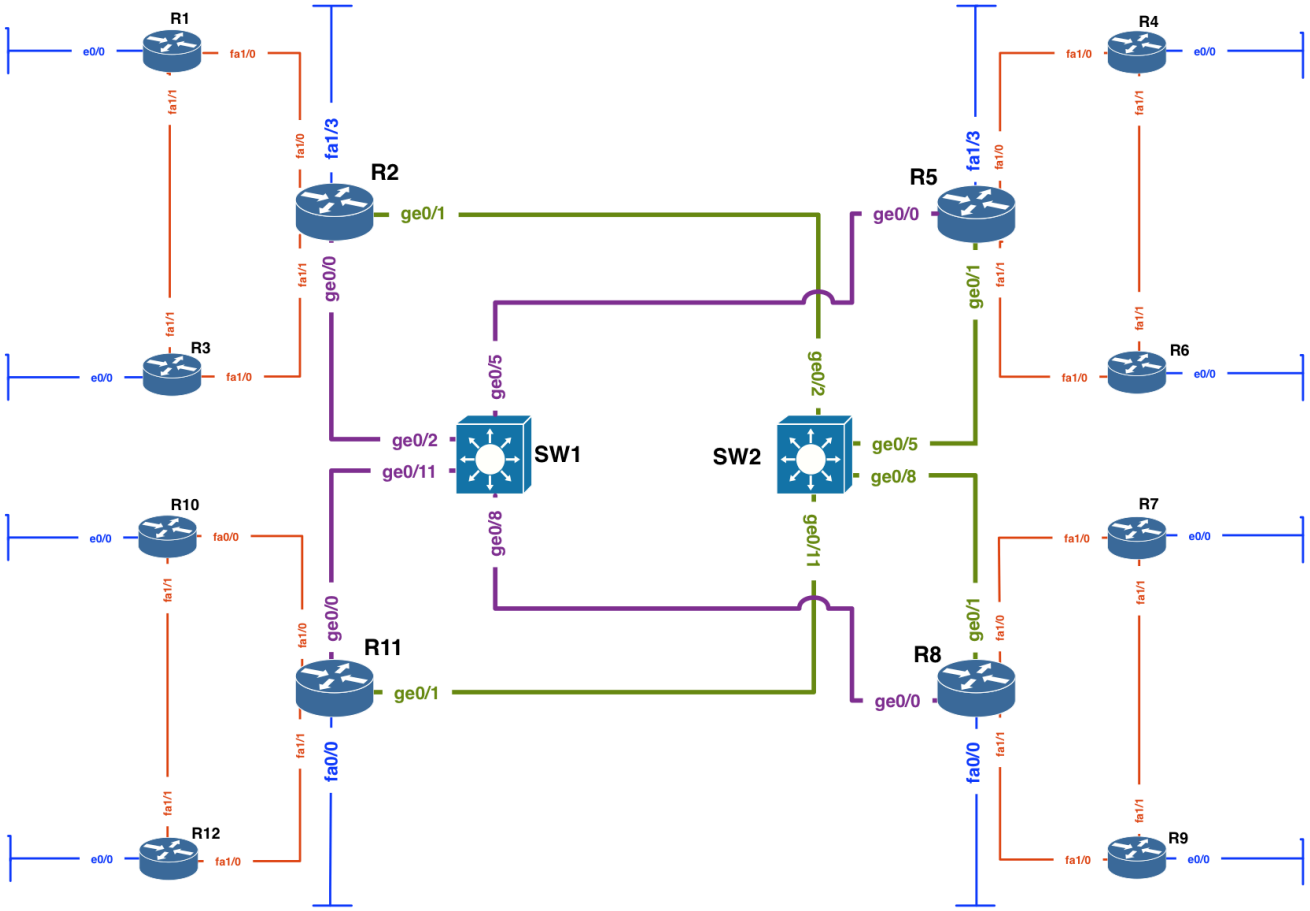
Training ISP Network Topology

- Access Network:
  - Connection between customer network & Edge router
  - Usually 10 to 100 MBPS link
  - Separate routing policy from most of ISP
  - Training ISP will connect them on edge router with separate customer IP prefix

Training ISP Network Topology

- Transport Link:
  - Inter-connection between regional core router
  - Higher data transmission capacity then access link
  - Training ISP has 2 transport link for link redundancy
  - 2 Transport link i.e Purple link & Green link are connected to two career grade switch

Training ISP Network Topology



Training ISP Core IP Backbone

Training ISP Network Topology

- Design Consideration:
  - Each regional network should have address summarization capability for customer block and CS link WAN.
  - Prefix planning should have scalability option for next couple of years for both customer block and infrastructure
  - No Summarization require for infrastructure WAN and loopback address

Training ISP Network Topology

- Design Consideration:
  - All WAN link should be ICMP reachable for link monitoring purpose (At least from designated host)
  - Conservation will get high preference for IPv4 address planning and aggregation will get high preference for IPv6 address planning.

Training ISP Network Topology

- Design Consideration:
  - OSPF is running in ISP network to carry infrastructure IP prefix
  - Each region is a separate OSPF area
  - Transport core is in OSPF area 0
  - Customer will connect on either static or eBGP (Not OSPF)
  - iBGP will carry external prefix within ISP core IP network

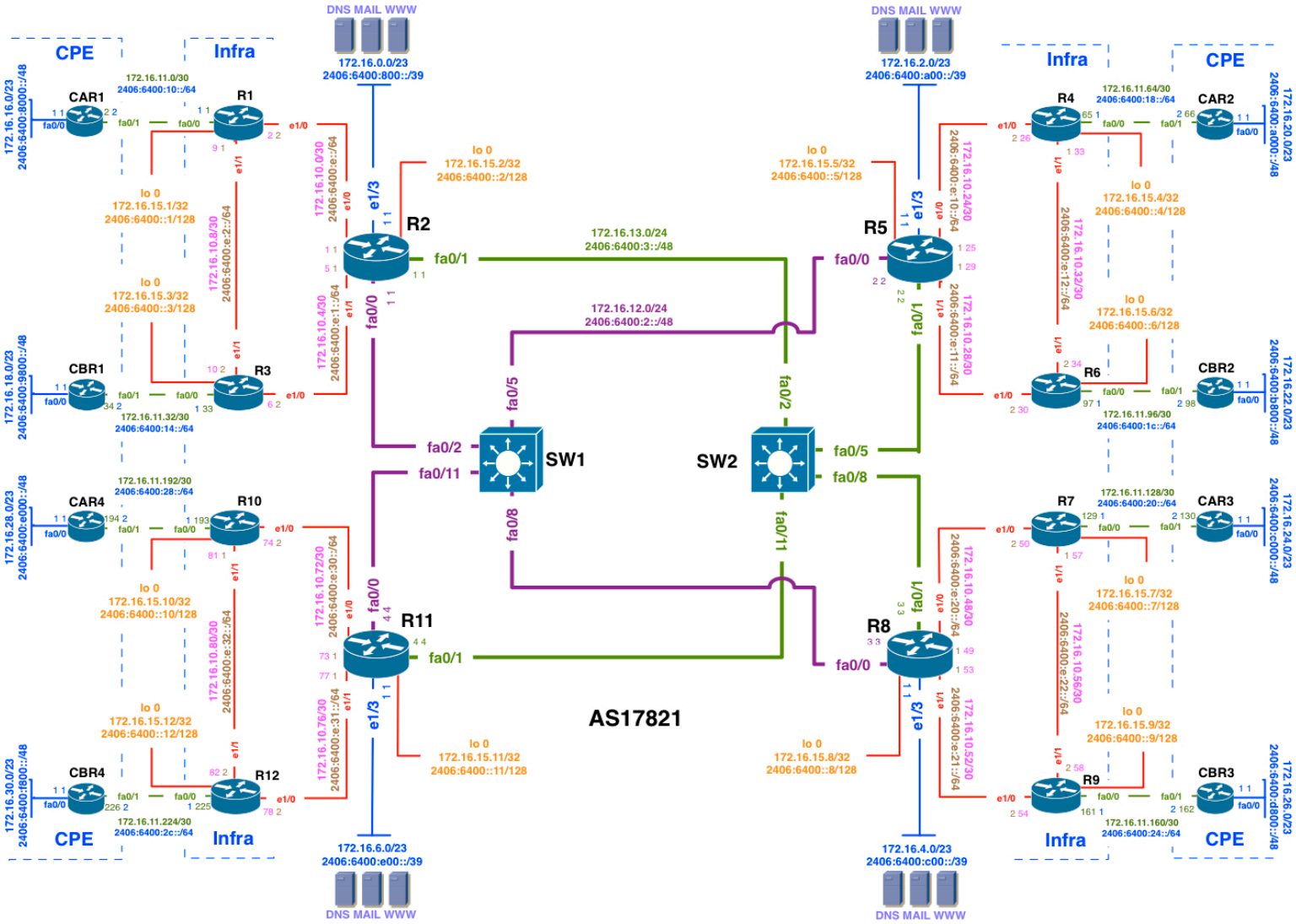
Training ISP IPV6 Addressing Plan

- IPv6 address plan consideration:
  - Big IPv6 address space can cause very very large routing table size
  - Most transit service provider apply IPv6 aggregation prefix filter (i.e. anything other then /48 & <=/32 prefix size
  - Prefix announcement need to send to Internet should be either /32 or /48 bit boundary

Training ISP IPV6 Addressing Plan

- IPv6 address plan consideration (RFC3177):
  - WAN link can be used on /64 bit boundary
  - End site/Customer sub allocation can be made between /48~/64 bit boundary
  - APNIC Utilization/HD ratio will be calculated based on /56 end site assignment/sub-allocation

Training ISP IPV6 Addressing Plan



Addressing Plans – ISP Infrastructure

- What about LANs?
  - /64 per LAN
- What about Point-to-Point links?
  - Protocol design expectation is that /64 is used
  - /127 now recommended/standardised
    - http://www.rfc-editor.org/rfc/rfc6164.txt
    - (reserve /64 for the link, but address it as a /127)
  - Other options:
    - /126s are being used (mirrors IPv4 /30)
    - /112s are being used
      - Leaves final 16 bits free for node IDs
    - Some discussion about /80s, /96s and /120s too

Addressing Plans – ISP Infrastructure

- ISPs should receive /32 from their RIR
- Address block for router loop-back interfaces
  - Generally number all loopbacks out of one /48
  - /128 per loopback
- Address block for infrastructure
  - /48 allows 65k subnets
  - /48 per region (for the largest international networks)
  - /48 for whole backbone (for the majority of networks)
  - Summarise between sites if it makes sense

Addressing Plans – Customer

- Customers get one /48
  - Unless they have more than 65k subnets in which case they get a second /48 (and so on)
- In typical deployments today:
  - Several ISPs give small customers a /56 or single LAN end-sites a /64, e.g.:
  - /64 if end-site will only ever be a LAN
  - /56 for medium end-sites (e.g. small business)
  - /48 for large end-sites
  - (This is another very active discussion area)

Addressing Plans – Advice

- Customer address assignments should not be reserved or assigned on a per PoP basis
  - Same principle as for IPv4
  - ISP iBGP carries customer nets
  - Aggregation within the iBGP not required and usually not desirable
  - Aggregation in eBGP is very necessary
- Backbone infrastructure assignments:
  - Number out of a single /48
    - Operational simplicity and security
  - Aggregate to minimise size of the IGP

Addressing Plans
Planning

- Registries will usually allocate the next block to be contiguous with the first allocation
  - Minimum allocation is /32
  - Very likely that subsequent allocation will make this up to a /31
  - So plan accordingly

Example Address Plan

- IPv6 Allocation Form Registry is
  - 2406:6400::/32
- IPv4 Allocation From Registry is
  - 172.16.0.0/19

Training ISP IPV6 Addressing Plan

- **Table 1: Top level distribution infrastructure & customer**

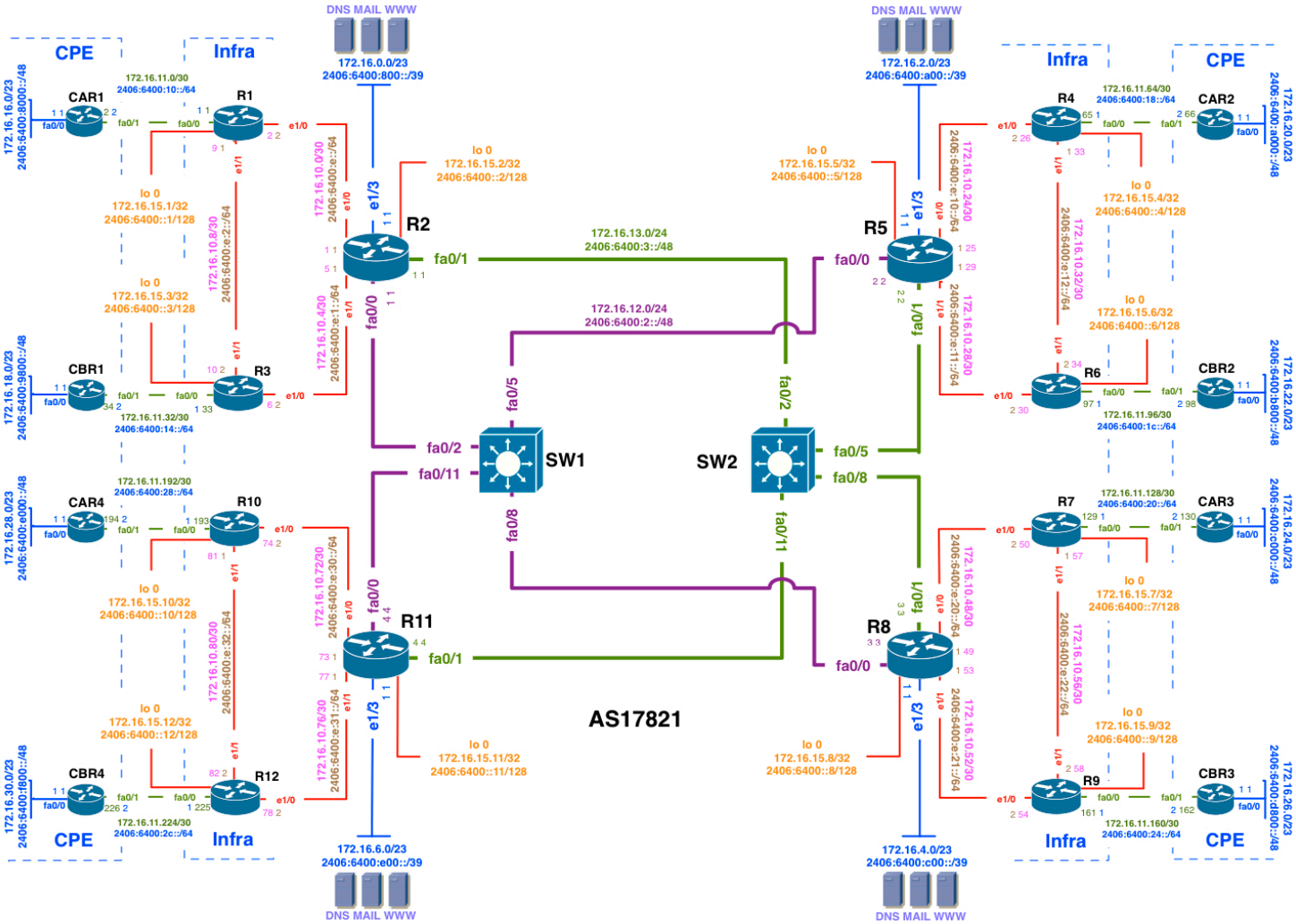
Block#	Prefix	Description	Reverse Domain	SOR	Registration
1	**2406:6400::/32**	***Parent Block***	0.0.4.6.6.0.4.2.ip6.arpa.	N/A	APNIC
2	2406:6400:0000:0000::/36	Infrastructure	0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Optional
	2406:6400:1000:0000::/36				
	2406:6400:2000:0000::/36				
	2406:6400:3000:0000::/36				
	2406:6400:4000:0000::/36				
	2406:6400:5000:0000::/36				
	2406:6400:6000:0000::/36				
	2406:6400:7000:0000::/36				
3	2406:6400:8000:0000::/36	Customer network Region 1	8.0.0.4.6.6.0.4.2.ip6.arpa.	Not yet	Optional
	2406:6400:9000:0000::/36				
4	2406:6400:a000:0000::/36	Customer network Region 2	a.0.0.4.6.6.0.4.2.ip6.arpa.	Not yet	Optional
	2406:6400:b000:0000::/36				
5	2406:6400:c000:0000::/36	Customer network Region 3	c.0.0.4.6.6.0.4.2.ip6.arpa.	Not yet	Optional
	2406:6400:d000:0000::/36				
6	2406:6400:e000:0000::/36	Customer network Region 4	e.0.0.4.6.6.0.4.2.ip6.arpa.	Not yet	Optional
	2406:6400:f000:0000::/36				

Training ISP IPV6 Addressing Plan

Table 2: Top level summarization option infrastructure & customer

Block#	Prefix	Description	Reverse Domain
7	2406:6400:8000:0000::/35	CS net summary region1 [R2]	2x/36 arpa domain
8	2406:6400:a000:0000::/35	CS net summary region2 [R5]	2x/36 arpa domain
9	2406:6400:c000:0000::/35	CS net summary region3 [R8]	2x/36 arpa domain
10	2406:6400:e000:0000::/35	CS net summary region4 [R11]	2x/36 arpa domain

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

Table 3: Detail distribution infrastructure

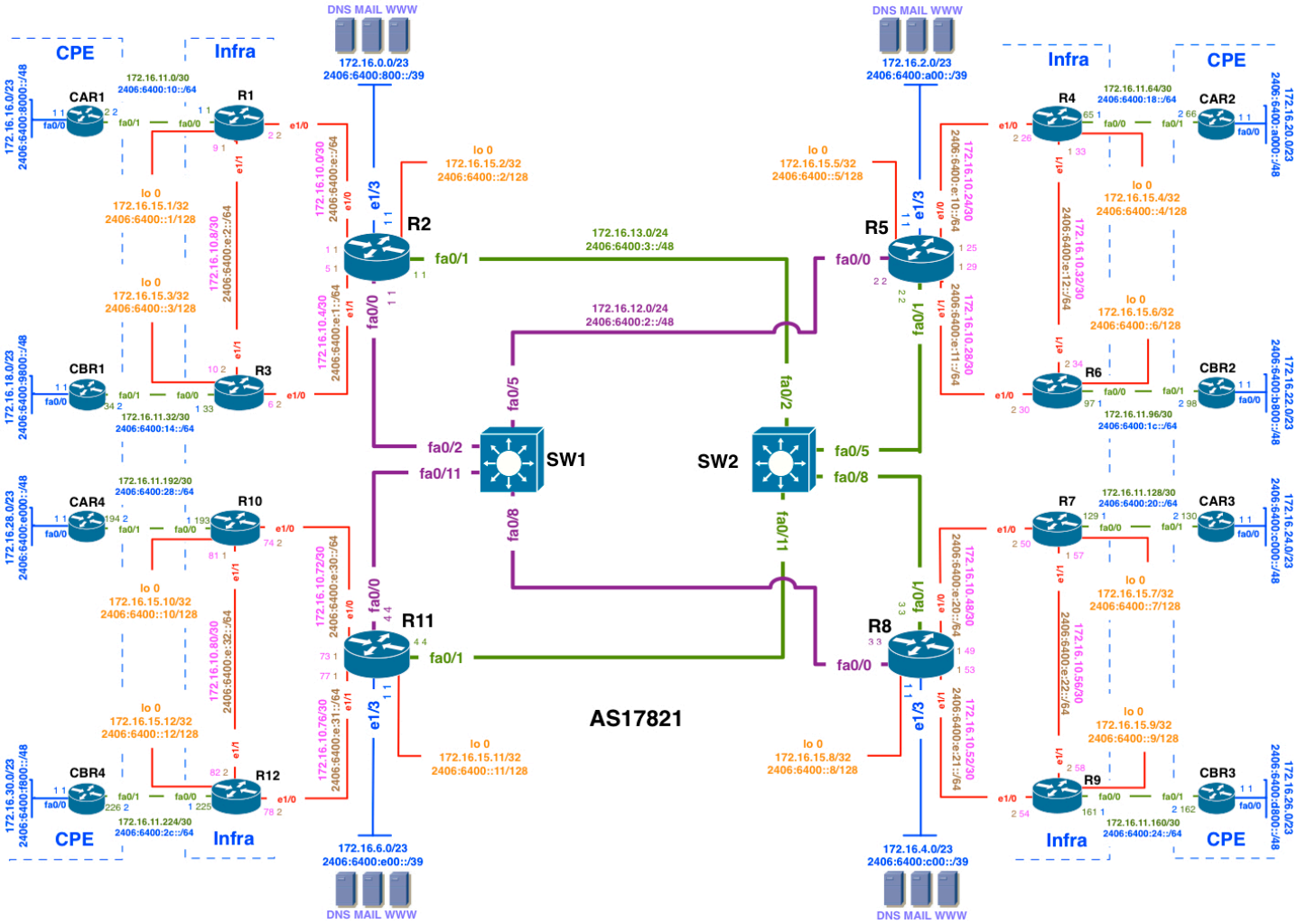
Block#	Prefix	Description	Reverse Domain	SOR	Registration
2	***2406:6400:0000:0000::/36***	***Infrastructure***	0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Optional
11	2406:6400:0000:0000::/40	Loopback, Transport & WAN [Infra+CS]	0.0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Optional
	2406:6400:0100:0000::/40				
	2406:6400:0200:0000::/40				
	2406:6400:0300:0000::/40				
	2406:6400:0400:0000::/40				
	2406:6400:0500:0000::/40				
	2406:6400:0600:0000::/40				
	2406:6400:0700:0000::/40				
16	2406:6400:0800:0000::/40	R2 DC	8.0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Recommeded
	2406:6400:0900:0000::/40				
17	2406:6400:0a00:0000::/40	R5 DC	a.0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Recommeded
	2406:6400:0b00:0000::/40				
18	2406:6400:0c00:0000::/40	R8 DC	c.0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Recommeded
	2406:6400:0d00:0000::/40				
19	2406:6400:0e00:0000::/40	R11 DC	e.0.0.0.4.6.6.0.4.2.ip6.arpa.	No	Recommeded
	2406:6400:0f00:0000::/40				

Training ISP IPV6 Addressing Plan

Table 4: Datacenter prefix summarization options

Block#	Prefix	Description	Reverse Domain
12	2406:6400:0800:0000::/39	Region 1 DC Summary [R2]	
13	2406:6400:0a00:0000::/39	Region 2 DC Summary [R5]	
14	2406:6400:0c00:0000::/39	Region 3 DC Summary [R8]	
15	2406:6400:0e00:0000::/39	Region 4 DC Summary [R11]	

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

Table 5: Further detail loopback, transport & infrastructure WAN

Block#	Prefix	Description	Reverse Domain	SOR	Registration
11	***2406:6400:0000:0000::/40***	***Loopback, Transport & Infra WAN***	*0.0.0.0.4.6.6.0.4.2.ip6.arpa.*		
20	2406:6400:0000:0000::/48	Loopback		No	Recommeded
	2406:6400:0001:0000::/48				
21	2406:6400:0002:0000::/48	Purple Transport		No	Recommeded
22	2406:6400:0003:0000::/48	Green Transport		No	Recommeded
	2406:6400:0004:0000::/48				
	2406:6400:0005:0000::/48				
	2406:6400:0006:0000::/48				
	2406:6400:0007:0000::/48				
	2406:6400:0008:0000::/48				
	2406:6400:0009:0000::/48				
	2406:6400:000A:0000::/48				
	2406:6400:000B:0000::/48				
	2406:6400:000C:0000::/48				
	2406:6400:000D:0000::/48				
23	2406:6400:000E:0000::/48	WAN Prefix Infra Link		No	Recommeded
	2406:6400:000F:0000::/48				

Training ISP IPV6 Addressing Plan

Table 6: Further detail CS link WAN

Block#	Prefix	Description	Reverse Domain	SOR	Registration
27	2406:6400:0010:0000::/48	WAN Prefix CS Link R1 Region1		No	Recommeded
	2406:6400:0011:0000::/48				
	2406:6400:0012:0000::/48				
	2406:6400:0013:0000::/48				
28	2406:6400:0014:0000::/48	WAN Prefix CS Link R3 Region1		No	Recommeded
	2406:6400:0015:0000::/48				
	2406:6400:0016:0000::/48				
	2406:6400:0017:0000::/48				
32	2406:6400:0018:0000::/48	WAN Prefix CS Link R4 Region2		No	Recommeded
	2406:6400:0019:0000::/48				
	2406:6400:001A:0000::/48				
	2406:6400:001B:0000::/48				
33	2406:6400:001C:0000::/48	WAN Prefix CS Link R6 Region2		No	Recommeded
	2406:6400:001D:0000::/48				
	2406:6400:001E:0000::/48				
	2406:6400:001F:0000::/48				
37	2406:6400:0020:0000::/48	WAN Prefix CS Link R7 Region3		No	Recommeded
	2406:6400:0021:0000::/48				
	2406:6400:0022:0000::/48				
	2406:6400:0023:0000::/48				
38	2406:6400:0024:0000::/48	WAN Prefix CS Link R9 Region3		No	Recommeded
	2406:6400:0025:0000::/48				
	2406:6400:0026:0000::/48				
	2406:6400:0027:0000::/48				
42	2406:6400:0028:0000::/48	WAN Prefix CS Link R10 Region4		No	Recommeded
	2406:6400:0029:0000::/48				
	2406:6400:002A:0000::/48				
	2406:6400:002B:0000::/48				
43	2406:6400:002C:0000::/48	WAN Prefix CS Link R12 Region4		No	Recommeded
	2406:6400:002D:0000::/48				
	2406:6400:002E:0000::/48				
	2406:6400:002F:0000::/48				

Training ISP IPV6 Addressing Plan

Table 7: CS link WAN summarization options

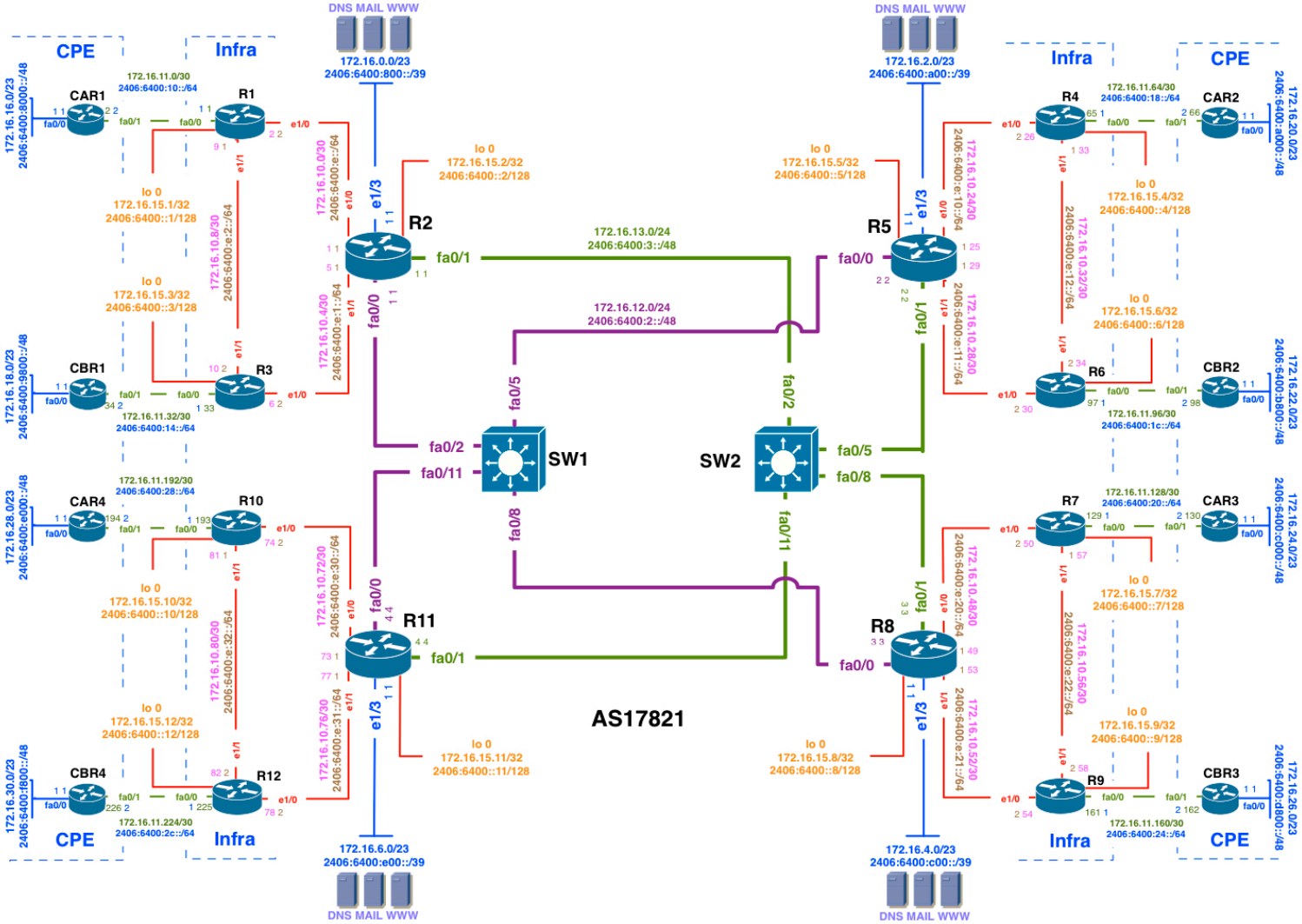
Block#	Prefix	Description	Reverse Domain
24	2406:6400:0010:0000::/45	WAN CS Link Region1 Summary [R2]	
25	2406:6400:0010:0000::/46	WAN CS Link Region1 POP1 Summary [R1]	
26	2406:6400:0014:0000::/46	WAN CS Link Region1 POP2 Summary [R3]	

Block#	Prefix	Description	Reverse Domain
29	2406:6400:0018:0000::/45	WAN Prefix CS Link Region2 Summary [R5]	
30	2406:6400:0018:0000::/46	WAN CS Link Region2 POP1 Summary [R4]	
31	2406:6400:001C:0000::/46	WAN CS Link Region2 POP2 Summary [R6]	

Block#	Prefix	Description	Reverse Domain
34	2406:6400:0020:0000::/45	WAN Prefix CS Link Region3 Summary [R8]	
35	2406:6400:0020:0000::/46	WAN CS Link Region3 POP1 Summary [R7]	
36	2406:6400:0024:0000::/46	WAN CS Link Region3 POP2 Summary [R9]	

Block#	Prefix	Description	Reverse Domain
39	2406:6400:0028:0000::/45	WAN Prefix CS Link Region4 Summary [R11]	
40	2406:6400:0028:0000::/46	WAN CS Link Region4 POP1 Summary [R10]	
41	2406:6400:002C:0000::/46	WAN CS Link Region4 POP2 Summary [R12]	

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

Table 8: Further detail loopback

Block#	Prefix	Description	PTR Record	SOR	Registration
20	2406:6400:0000:0000::/48	Loopback		No	Recommeded
			YES		
43	2406:6400:0000:0000::1/128	Router1 loopback 0	YES	No	No
44	2406:6400:0000:0000::2/128	Router2 loopback 0	YES	No	No
45	2406:6400:0000:0000::3/128	Router3 loopback 0	YES	No	No
46	2406:6400:0000:0000::4/128	Router4 loopback 0	YES	No	No
47	2406:6400:0000:0000::5/128	Router5 loopback 0	YES	No	No
48	2406:6400:0000:0000::6/128	Router6 loopback 0	YES	No	No
49	2406:6400:0000:0000::7/128	Router7 loopback 0	YES	No	No
50	2406:6400:0000:0000::8/128	Router8 loopback 0	YES	No	No
51	2406:6400:0000:0000::9/128	Router9 loopback 0	YES	No	No
52	2406:6400:0000:0000::10/128	Router10 loopback 0	YES	No	No
53	2406:6400:0000:0000::11/128	Router11 loopback 0	YES	No	No
54	2406:6400:0000:0000::12/128	Router12 loopback 0	YES	No	No

Training ISP IPV6 Addressing Plan

Table 9: Further detail transport

Block#	Prefix	Description	PTR Record	SOR	Registration
21	2406:6400:0002:0000::/48	Purple Transport		No	Recommeded
	2406:6400:0002:0000::1/48	Router2 fa0/0	YES	No	No
	2406:6400:0002:0000::2/48	Router5 fa0/0	YES	No	No
	2406:6400:0002:0000::3/48	Router8 fa0/0	YES	No	No
	2406:6400:0002:0000::4/48	Router11 fa0/0	YES	No	No
Block#	**Prefix**	**Description**	**PTR Record**	**SOR**	**Registration**
22	2406:6400:0003:0000::/48	Green Transport		No	Recommended
	2406:6400:0003:0000::1/48	Router2 fa0/1	YES	No	No
	2406:6400:0003:0000::2/48	Router5 fa0/1	YES	No	No
	2406:6400:0003:0000::3/48	Router8 fa0/1	YES	No	No
	2406:6400:0003:0000::4/48	Router11 fa0/1	YES	No	No

Training ISP IPV6 Addressing Plan

Table 10: Further detail Infra WAN

Block#	Prefix	Description	PTR Record	SOR	Registration
23	2406:6400:000E:0000::/48	WAN Prefix Infra Link		No	Recommeded
55	2406:6400:000E:0000::/64	R2[::1]-R1[::2]	YES	No	No
56	2406:6400:000E:0001::/64	R2[::1]-R3[::2]	YES	No	No
57	2406:6400:000E:0002::/64	R1[::1]-R3[::2]	YES	No	No
	2406:6400:000E:0003::/64				
	2406:6400:000E:0004::/64				
	2406:6400:000E:0005::/64				
	2406:6400:000E:0006::/64				
	2406:6400:000E:0007::/64				
	2406:6400:000E:0008::/64				
	2406:6400:000E:0009::/64				
	2406:6400:000E:000A::/64				
	2406:6400:000E:000B::/64				
	2406:6400:000E:000C::/64				
	2406:6400:000E:000D::/64				
	2406:6400:000E:000E::/64				
	2406:6400:000E:000F::/64				
58	2406:6400:000E:0010::/64	R5[::1]-R4[::2]	YES	No	No
59	2406:6400:000E:0011::/64	R5[::1]-R6[::2]	YES	No	No
60	2406:6400:000E:0012::/64	R4[::1]-R6[::2]	YES	No	No
	2406:6400:000E:0013::/64				
	2406:6400:000E:0014::/64				
	2406:6400:000E:0015::/64				
	2406:6400:000E:0016::/64				
	2406:6400:000E:0017::/64				
	2406:6400:000E:0018::/64				
	2406:6400:000E:0019::/64				
	2406:6400:000E:001A::/64				
	2406:6400:000E:001B::/64				
	2406:6400:000E:001C::/64				
	2406:6400:000E:001D::/64				
	2406:6400:000E:001E::/64				
	2406:6400:000E:001F::/64				
61	2406:6400:000E:0020::/64	R8[::1]-R7[::2]	YES	No	No
62	2406:6400:000E:0021::/64	R8[::1]-R9[::2]	YES	No	No
63	2406:6400:000E:0022::/64	R7[::1]-R9[::2]	YES	No	No
	2406:6400:000E:0023::/64				
	2406:6400:000E:0024::/64				
	2406:6400:000E:0025::/64				
	2406:6400:000E:0026::/64				
	2406:6400:000E:0027::/64				
	2406:6400:000E:0028::/64				
	2406:6400:000E:0029::/64				
	2406:6400:000E:002A::/64				
	2406:6400:000E:002B::/64				
	2406:6400:000E:002C::/64				
	2406:6400:000E:002D::/64				
	2406:6400:000E:002E::/64				
	2406:6400:000E:002F::/64				
64	2406:6400:000E:0030::/64	R11[::1]-R10[::2]	YES	No	No
65	2406:6400:000E:0031::/64	R11[::1]-R12[::2]	YES	No	No
66	2406:6400:000E:0032::/64	R10[::1]-R12[::2]	YES	No	No
	2406:6400:000E:0033::/64				
	2406:6400:000E:0034::/64				
	2406:6400:000E:0035::/64				
	2406:6400:000E:0036::/64				
	2406:6400:000E:0037::/64				
	2406:6400:000E:0038::/64				
	2406:6400:000E:0039::/64				
	2406:6400:000E:003A::/64				

Training ISP IPV6 Addressing Plan

Table 11: Detail CS link WAN Region 1					
Block#	**Prefix**	**Description**	**PTR Record**	**SOR**	**Registration**
27	2406:6400:0010:0000::/48	WAN Prefix CS Link R1 Region1		No	Recommeded
	2406:6400:0010:0000::/64	R1[::1]-CAR1[::2]	Yes	No	No
	2406:6400:0010:0001::/64		Yes	No	No
	2406:6400:0010:0002::/64		Yes	No	No
	2406:6400:0010:0003::/64		Yes	No	No
	2406:6400:0010:0004::/64		Yes	No	No
	2406:6400:0010:0005::/64		Yes	No	No
	2406:6400:0010:0006::/64		Yes	No	No
	2406:6400:0010:0007::/64		Yes	No	No
	2406:6400:0010:0008::/64		Yes	No	No
	2406:6400:0010:0009::/64		Yes	No	No
	2406:6400:0010:000A::/64		Yes	No	No
	2406:6400:0010:000B::/64		Yes	No	No
	2406:6400:0010:000C::/64		Yes	No	No
	2406:6400:0010:000D::/64		Yes	No	No
	2406:6400:0010:000E::/64		Yes	No	No
	2406:6400:0010:000F::/64		Yes	No	No
Block#	**Prefix**	**Description**	**PTR Record**	**SOR**	**Registration**
28	2406:6400:0014:0000::/48	WAN Prefix CS Link R3 Region1		No	Recommeded
	2406:6400:0014:0000::/64	R3[::1]-CBR1[::2]	Yes	No	No
	2406:6400:0014:0001::/64		Yes	No	No
	2406:6400:0014:0002::/64		Yes	No	No
	2406:6400:0014:0003::/64		Yes	No	No
	2406:6400:0014:0004::/64		Yes	No	No
	2406:6400:0014:0005::/64		Yes	No	No
	2406:6400:0014:0006::/64		Yes	No	No
	2406:6400:0014:0007::/64		Yes	No	No
	2406:6400:0014:0008::/64		Yes	No	No
	2406:6400:0014:0009::/64		Yes	No	No
	2406:6400:0014:000A::/64		Yes	No	No
	2406:6400:0014:000B::/64		Yes	No	No
	2406:6400:0014:000C::/64		Yes	No	No
	2406:6400:0014:000D::/64		Yes	No	No
	2406:6400:0014:000E::/64		Yes	No	No
	2406:6400:0014:000F::/64		Yes	No	No

Training ISP IPV6 Addressing Plan

Table 12: Detail CS link WAN Region 2

Block#	Prefix	Description	PTR Record	SOR	Registration
32	2406:6400:0018:0000::/48	WAN Prefix CS Link R4 Region2		No	Recommeded
	2406:6400:0018:0000::/64	R4[::1]-CAR2[::2]	Yes	No	No
	2406:6400:0018:0001::/64		Yes	No	No
	2406:6400:0018:0002::/64		Yes	No	No
	2406:6400:0018:0003::/64		Yes	No	No
	2406:6400:0018:0004::/64		Yes	No	No
	2406:6400:0018:0005::/64		Yes	No	No
	2406:6400:0018:0006::/64		Yes	No	No
	2406:6400:0018:0007::/64		Yes	No	No
	2406:6400:0018:0008::/64		Yes	No	No
	2406:6400:0018:0009::/64		Yes	No	No
	2406:6400:0018:000A::/64		Yes	No	No
	2406:6400:0018:000B::/64		Yes	No	No
	2406:6400:0018:000C::/64		Yes	No	No
	2406:6400:0018:000D::/64		Yes	No	No
	2406:6400:0018:000E::/64		Yes	No	No
	2406:6400:0018:000F::/64		Yes	No	No
Block#	**Prefix**	**Description**	**PTR Record**	**SOR**	**Registration**
33	2406:6400:001C:0000::/48	WAN Prefix CS Link R6 Region2		No	Recommeded
	2406:6400:001C:0000::/64	R6[::1]-CBR2[::2]	Yes	No	No
	2406:6400:001C:0001::/64		Yes	No	No
	2406:6400:001C:0002::/64		Yes	No	No
	2406:6400:001C:0003::/64		Yes	No	No
	2406:6400:001C:0004::/64		Yes	No	No
	2406:6400:001C:0005::/64		Yes	No	No
	2406:6400:001C:0006::/64		Yes	No	No
	2406:6400:001C:0007::/64		Yes	No	No
	2406:6400:001C:0008::/64		Yes	No	No
	2406:6400:001C:0009::/64		Yes	No	No
	2406:6400:001C:000A::/64		Yes	No	No
	2406:6400:001C:000B::/64		Yes	No	No
	2406:6400:001C:000C::/64		Yes	No	No
	2406:6400:001C:000D::/64		Yes	No	No
	2406:6400:001C:000E::/64		Yes	No	No
	2406:6400:001C:000F::/64		Yes	No	No

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Table 13: Detail CS link WAN Region3

Block#	Prefix	Description	PTR Record	SOR	Registration
37	2406:6400:0020:0000::/48	WAN Prefix CS Link R7 Region3		No	Recommeded
	2406:6400:0020:0000::/64	R7[::1]-CAR3[::2]	Yes	No	No
	2406:6400:0020:0001::/64		Yes	No	No
	2406:6400:0020:0002::/64		Yes	No	No
	2406:6400:0020:0003::/64		Yes	No	No
	2406:6400:0020:0004::/64		Yes	No	No
	2406:6400:0020:0005::/64		Yes	No	No
	2406:6400:0020:0006::/64		Yes	No	No
	2406:6400:0020:0007::/64		Yes	No	No
	2406:6400:0020:0008::/64		Yes	No	No
	2406:6400:0020:0009::/64		Yes	No	No
	2406:6400:0020:000A::/64		Yes	No	No
	2406:6400:0020:000B::/64		Yes	No	No
	2406:6400:0020:000C::/64		Yes	No	No
	2406:6400:0020:000D::/64		Yes	No	No
	2406:6400:0020:000E::/64		Yes	No	No
	2406:6400:0020:000F::/64		Yes	No	No
Block#	**Prefix**	**Description**	**PTR Record**	**SOR**	**Registration**
38	2406:6400:0024:0000::/48	WAN Prefix CS Link R9 Region3		No	Recommeded
	2406:6400:0024:0000::/64	R9[::1]-CBR3[::2]	Yes	No	No
	2406:6400:0024:0001::/64		Yes	No	No
	2406:6400:0024:0002::/64		Yes	No	No
	2406:6400:0024:0003::/64		Yes	No	No
	2406:6400:0024:0004::/64		Yes	No	No
	2406:6400:0024:0005::/64		Yes	No	No
	2406:6400:0024:0006::/64		Yes	No	No
	2406:6400:0024:0007::/64		Yes	No	No
	2406:6400:0024:0008::/64		Yes	No	No
	2406:6400:0024:0009::/64		Yes	No	No
	2406:6400:0024:000A::/64		Yes	No	No
	2406:6400:0024:000B::/64		Yes	No	No
	2406:6400:0024:000C::/64		Yes	No	No
	2406:6400:0024:000D::/64		Yes	No	No
	2406:6400:0024:000E::/64		Yes	No	No
	2406:6400:0024:000F::/64		Yes	No	No

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Table 14: Detail CS link WAN Region 4

Block#	Prefix	Description	PTR Record	SOR	Registration
42	2406:6400:0028:0000::/48	WAN Prefix CS Link R10 Region4		No	Recommeded
	2406:6400:0028:0000::/64	R10[::1]-CAR4[::2]	Yes	No	No
	2406:6400:0028:0001::/64		Yes	No	No
	2406:6400:0028:0002::/64		Yes	No	No
	2406:6400:0028:0003::/64		Yes	No	No
	2406:6400:0028:0004::/64		Yes	No	No
	2406:6400:0028:0005::/64		Yes	No	No
	2406:6400:0028:0006::/64		Yes	No	No
	2406:6400:0028:0007::/64		Yes	No	No
	2406:6400:0028:0008::/64		Yes	No	No
	2406:6400:0028:0009::/64		Yes	No	No
	2406:6400:0028:000A::/64		Yes	No	No
	2406:6400:0028:000B::/64		Yes	No	No
	2406:6400:0028:000C::/64		Yes	No	No
	2406:6400:0028:000D::/64		Yes	No	No
	2406:6400:0028:000E::/64		Yes	No	No
	2406:6400:0028:000F::/64		Yes	No	No
Block#	**Prefix**	**Description**	**PTR Record**	**SOR**	**Registration**
43	2406:6400:002C:0000::/48	WAN Prefix CS Link R12 Region4		No	Recommeded
	2406:6400:002C:0000::/64	R12[::1]-CBR4[::2]	Yes	No	No
	2406:6400:002C:0001::/64		Yes	No	No
	2406:6400:002C:0002::/64		Yes	No	No
	2406:6400:002C:0003::/64		Yes	No	No
	2406:6400:002C:0004::/64		Yes	No	No
	2406:6400:002C:0005::/64		Yes	No	No
	2406:6400:002C:0006::/64		Yes	No	No
	2406:6400:002C:0007::/64		Yes	No	No
	2406:6400:002C:0008::/64		Yes	No	No
	2406:6400:002C:0009::/64		Yes	No	No
	2406:6400:002C:000A::/64		Yes	No	No
	2406:6400:002C:000B::/64		Yes	No	No
	2406:6400:002C:000C::/64		Yes	No	No
	2406:6400:002C:000D::/64		Yes	No	No
	2406:6400:002C:000E::/64		Yes	No	No
	2406:6400:002C:000F::/64		Yes	No	No

Training ISP IPV6 Addressing Plan

Table 15: Customer block Region 1

Block#	Prefix	Description	Reverse DNS	SOR	Registration
7	2406:6400:8000:0000::/35	Customer block Region 1			
	2406:6400:8000:0000::/40	Customer block POP1 [R1]		>= /48 Yes	Yes
	2406:6400:8100:0000::/40				
	2406:6400:8200:0000::/40				
	2406:6400:8300:0000::/40				
	2406:6400:8400:0000::/40				
	2406:6400:8500:0000::/40				
	2406:6400:8600:0000::/40				
	2406:6400:8700:0000::/40				
	2406:6400:8800:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:8900:0000::/40				
	2406:6400:8A00:0000::/40				
	2406:6400:8B00:0000::/40				
	2406:6400:8C00:0000::/40				
	2406:6400:8D00:0000::/40				
	2406:6400:8E00:0000::/40				
	2406:6400:8F00:0000::/40				
	2406:6400:9000:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:9100:0000::/40				
	2406:6400:9200:0000::/40				
	2406:6400:9300:0000::/40				
	2406:6400:9400:0000::/40				
	2406:6400:9500:0000::/40				
	2406:6400:9600:0000::/40				
	2406:6400:9700:0000::/40				
	2406:6400:9800:0000::/40	Customer block POP2 [R3]		>= /48 Yes	Yes
	2406:6400:9900:0000::/40				
	2406:6400:9A00:0000::/40				
	2406:6400:9B00:0000::/40				
	2406:6400:9C00:0000::/40				
	2406:6400:9D00:0000::/40				
	2406:6400:9E00:0000::/40				
	2406:6400:9F00:0000::/40				

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Table 16: Summarization oprions customer block Region 1			
Block#	**Prefix**	**Description**	**Reverse Domain**
	2406:6400:8000:0000::/35	Customer block Region 1 [R2]	
	2406:6400:8000:0000::/37	Customer block POP1 [R1]	
	2406:6400:8800:0000::/37	Customer block future use/POP	
	2406:6400:9000:0000::/37	Customer block future use/POP	
	2406:6400:9800:0000::/37	Customer block POP2 [R3]	

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Table 17: Detail customer block Region 1					
Block#	**Prefix**	**Description**	**Reverse DNS**	**SOR**	**Registration**
	2406:6400:8000:0000::/40	1st Customer block POP1 [R1]			
	2406:6400:8000:0000::/48	1st Customer prefix POP1 [R1]		Yes	Yes
	2406:6400:8001:0000::/48				
	2406:6400:8002:0000::/48				
	2406:6400:8003:0000::/48				
	2406:6400:8004:0000::/48				
	2406:6400:8005:0000::/48				
	2406:6400:8006:0000::/48				
	2406:6400:8007:0000::/48				
	2406:6400:9800:0000::/40	1st Customer block POP2 [R3]			
	2406:6400:9800:0000::/48	1st Customer prefix POP2 [R3]		Yes	Yes
	2406:6400:9801:0000::/48				
	2406:6400:9802:0000::/48				
	2406:6400:9803:0000::/48				
	2406:6400:9804:0000::/48				
	2406:6400:9805:0000::/48				
	2406:6400:9806:0000::/48				
	2406:6400:9807:0000::/48				

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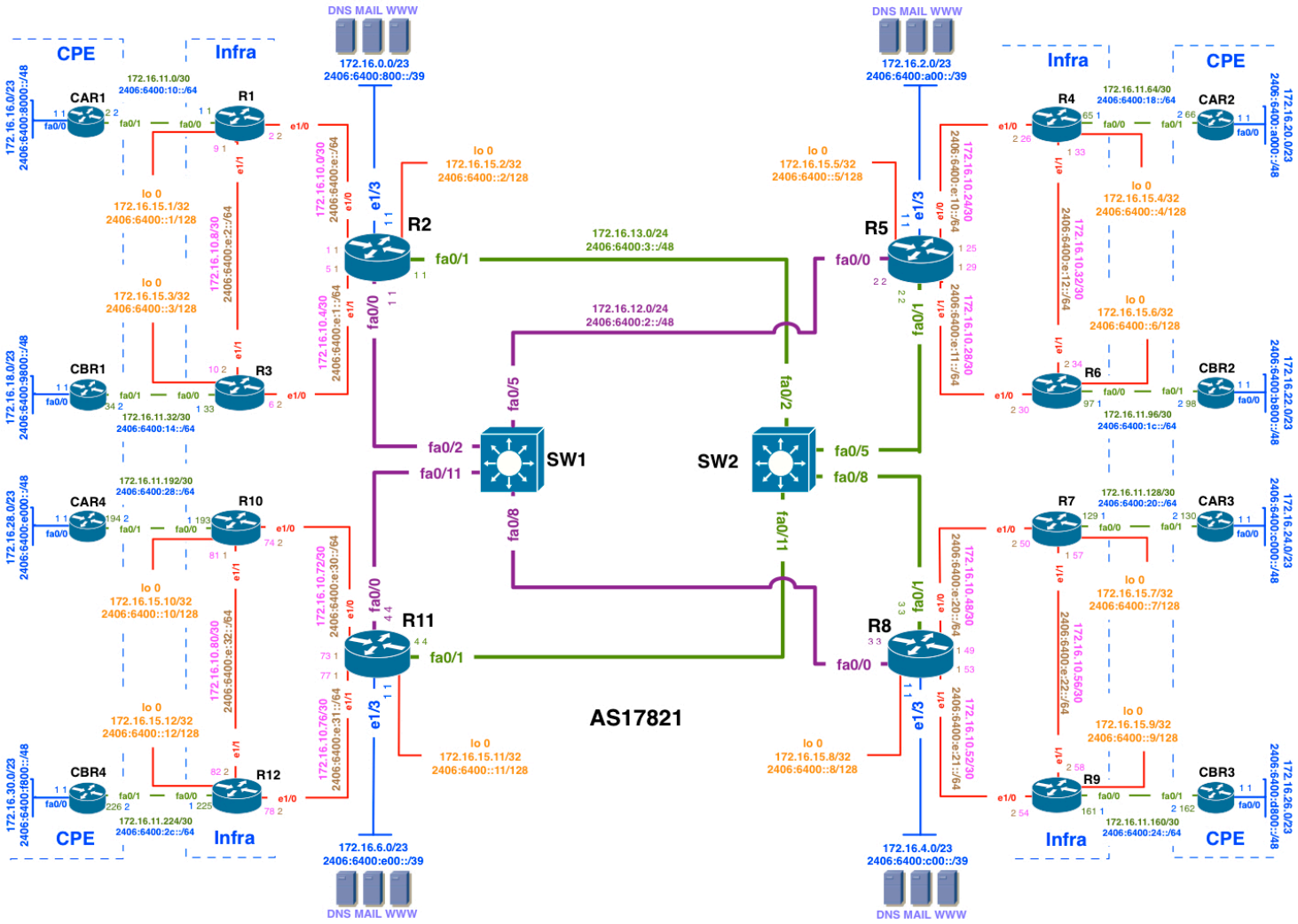

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Table 18: Customer block Region 2					
Block#	**Prefix**	**Description**	**Reverse DNS**	**SOR**	**Registration**
8	2406:6400:a000:0000::/35	Customer block Region 2			
	2406:6400:A000:0000::/40	Customer block POP1 [R4]		>= /48 Yes	Yes
	2406:6400:A100:0000::/40				
	2406:6400:A200:0000::/40				
	2406:6400:A300:0000::/40				
	2406:6400:A400:0000::/40				
	2406:6400:A500:0000::/40				
	2406:6400:A600:0000::/40				
	2406:6400:A700:0000::/40				
	2406:6400:A800:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:A900:0000::/40				
	2406:6400:AA00:0000::/40				
	2406:6400:AB00:0000::/40				
	2406:6400:AC00:0000::/40				
	2406:6400:AD00:0000::/40				
	2406:6400:AE00:0000::/40				
	2406:6400:AF00:0000::/40				
	2406:6400:B000:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:B100:0000::/40				
	2406:6400:B200:0000::/40				
	2406:6400:B300:0000::/40				
	2406:6400:B400:0000::/40				
	2406:6400:B500:0000::/40				
	2406:6400:B600:0000::/40				
	2406:6400:B700:0000::/40				
	2406:6400:B800:0000::/40	Customer block POP2 [R6]		>= /48 Yes	Yes
	2406:6400:B900:0000::/40				
	2406:6400:BA00:0000::/40				
	2406:6400:BB00:0000::/40				
	2406:6400:BC00:0000::/40				
	2406:6400:BD00:0000::/40				
	2406:6400:BE00:0000::/40				
	2406:6400:BF00:0000::/40				

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Table 19: Summarization oprions customer block Region 2			
Block#	**Prefix**	**Description**	**Reverse Domain**
	2406:6400:A000:0000::/35	Customer block Region 2 [R5]	
	2406:6400:A000:0000::/37	Customer block POP1 [R4]	
	2406:6400:A800:0000::/37	Customer block future use/POP	
	2406:6400:B000:0000::/37	Customer block future use/POP	
	2406:6400:B800:0000::/37	Customer block POP2 [R6]	

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Table 20: Detail customer block Region 2					
Block#	**Prefix**	**Description**	**Reverse DNS**	**SOR**	**Registration**
	2406:6400:A000:0000::/40	1st Customer block POP1 [R4]			
	2406:6400:A000:0000::/48	1st Customer prefix POP1 [R4]		Yes	Yes
	2406:6400:A001:0000::/48				
	2406:6400:A002:0000::/48				
	2406:6400:A003:0000::/48				
	2406:6400:A004:0000::/48				
	2406:6400:A005:0000::/48				
	2406:6400:A006:0000::/48				
	2406:6400:A007:0000::/48				
	2406:6400:B800:0000::/40	1st Customer block POP2 [R6]			
	2406:6400:B800:0000::/48	1st Customer prefix POP2 [R6]		Yes	Yes
	2406:6400:B801:0000::/48				
	2406:6400:B802:0000::/48				
	2406:6400:B803:0000::/48				
	2406:6400:B804:0000::/48				
	2406:6400:B805:0000::/48				
	2406:6400:B806:0000::/48				
	2406:6400:B807:0000::/48				

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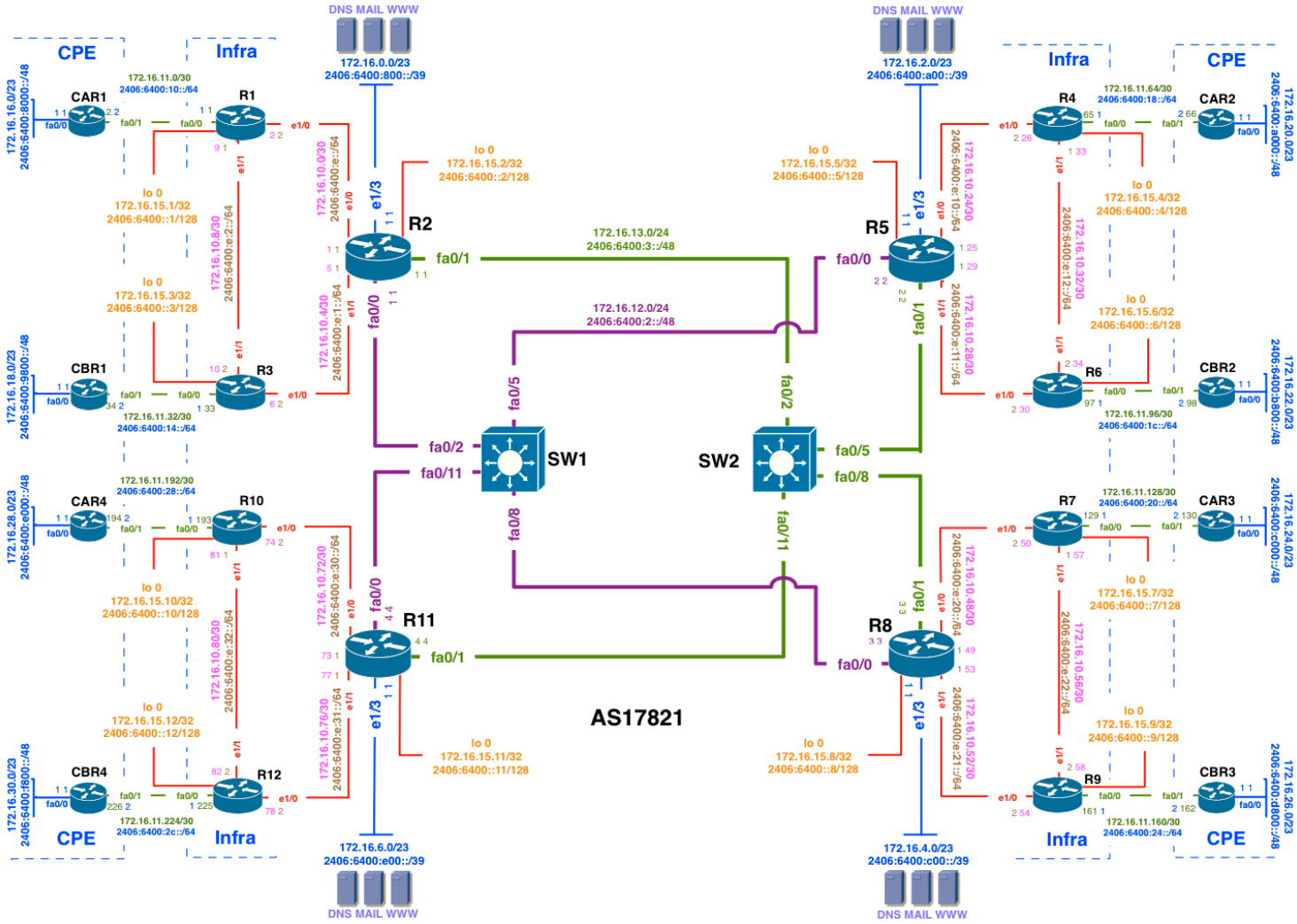

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Table 21: Customer block Region 3					
Block#	**Prefix**	**Description**	**Reverse DNS**	**SOR**	**Registration**
9	2406:6400:c000:0000::/35	Customer block Region 3			
	2406:6400:C000:0000::/40	Customer block POP1 [R7]		>= /48 Yes	Yes
	2406:6400:C100:0000::/40				
	2406:6400:C200:0000::/40				
	2406:6400:C300:0000::/40				
	2406:6400:C400:0000::/40				
	2406:6400:C500:0000::/40				
	2406:6400:C600:0000::/40				
	2406:6400:C700:0000::/40				
	2406:6400:C800:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:C900:0000::/40				
	2406:6400:CA00:0000::/40				
	2406:6400:CB00:0000::/40				
	2406:6400:CC00:0000::/40				
	2406:6400:CD00:0000::/40				
	2406:6400:CE00:0000::/40				
	2406:6400:CF00:0000::/40				
	2406:6400:D000:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:D100:0000::/40				
	2406:6400:D200:0000::/40				
	2406:6400:D300:0000::/40				
	2406:6400:D400:0000::/40				
	2406:6400:D500:0000::/40				
	2406:6400:D600:0000::/40				
	2406:6400:D700:0000::/40				
	2406:6400:D800:0000::/40	Customer block POP2 [R9]		>= /48 Yes	Yes
	2406:6400:D900:0000::/40				
	2406:6400:DA00:0000::/40				
	2406:6400:DB00:0000::/40				
	2406:6400:DC00:0000::/40				
	2406:6400:DD00:0000::/40				
	2406:6400:DE00:0000::/40				
	2406:6400:DF00:0000::/40				

Training ISP IPV6 Addressing Plan

Table 22: Summarization oprions customer block Region 3			
Block#	**Prefix**	**Description**	**Reverse Domain**
	2406:6400:c000:0000::/35	Customer block Region 3 [R8]	
	2406:6400:C000:0000::/37	Customer block POP1 [R7]	
	2406:6400:C800:0000::/37	Customer block future use/POP	
	2406:6400:D000:0000::/37	Customer block future use/POP	
	2406:6400:D800:0000::/37	Customer block POP2 [R9]	

Training ISP IPV6 Addressing Plan

Table 23: Detail customer block Region 3

Block#	Prefix	Description	Reverse DNS	SOR	Registration
	2406:6400:C000:0000::/40	1st Customer block POP1 [R7]			
	2406:6400:C000:0000::/48	1st Customer prefix POP1 [R7]		Yes	Yes
	2406:6400:C001:0000::/48				
	2406:6400:C002:0000::/48				
	2406:6400:C003:0000::/48				
	2406:6400:C004:0000::/48				
	2406:6400:C005:0000::/48				
	2406:6400:C006:0000::/48				
	2406:6400:C007:0000::/48				
	2406:6400:D800:0000::/40	1st Customer block POP2 [R9]			
	2406:6400:D800:0000::/48	1st Customer prefix POP2 [R9]		Yes	Yes
	2406:6400:D801:0000::/48				
	2406:6400:D802:0000::/48				
	2406:6400:D803:0000::/48				
	2406:6400:D804:0000::/48				
	2406:6400:D805:0000::/48				
	2406:6400:D806:0000::/48				
	2406:6400:D807:0000::/48				

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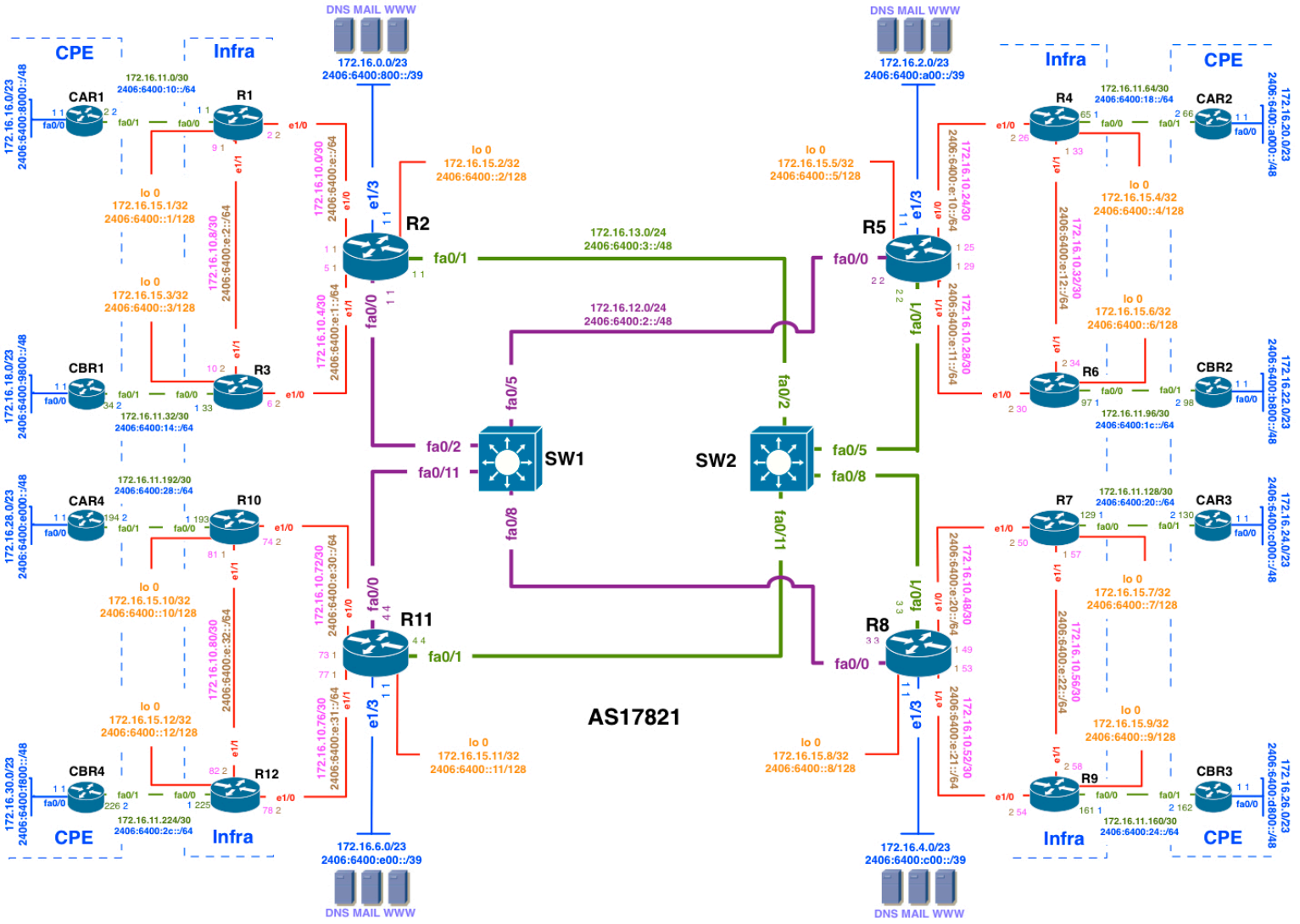

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Table 24: Customer block Region 4					
Block#	**Prefix**	**Description**	**Reverse DNS**	**SOR**	**Registration**
10	2406:6400:e000:0000::/35	Customer block Region 4			
	2406:6400:E000:0000::/40	Customer block POP1 [R10]		>= /48 Yes	Yes
	2406:6400:E100:0000::/40				
	2406:6400:E200:0000::/40				
	2406:6400:E300:0000::/40				
	2406:6400:E400:0000::/40				
	2406:6400:E500:0000::/40				
	2406:6400:E600:0000::/40				
	2406:6400:E700:0000::/40				
	2406:6400:E800:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:E900:0000::/40				
	2406:6400:EA00:0000::/40				
	2406:6400:EB00:0000::/40				
	2406:6400:EC00:0000::/40				
	2406:6400:ED00:0000::/40				
	2406:6400:EE00:0000::/40				
	2406:6400:EF00:0000::/40				
	2406:6400:F000:0000::/40	Customer block future use/POP		>= /48 Yes	Yes
	2406:6400:F100:0000::/40				
	2406:6400:F200:0000::/40				
	2406:6400:F300:0000::/40				
	2406:6400:F400:0000::/40				
	2406:6400:F500:0000::/40				
	2406:6400:F600:0000::/40				
	2406:6400:F700:0000::/40				
	2406:6400:F800:0000::/40	Customer block POP2 [R12]		>= /48 Yes	Yes
	2406:6400:F900:0000::/40				
	2406:6400:FA00:0000::/40				
	2406:6400:FB00:0000::/40				
	2406:6400:FC00:0000::/40				
	2406:6400:FD00:0000::/40				
	2406:6400:FE00:0000::/40				
	2406:6400:FF00:0000::/40				

Training ISP IPV6 Addressing Plan

Table 25: Summarization oprions customer block Region 4			
Block#	**Prefix**	**Description**	**Reverse Domain**
	2406:6400:e000:0000::/35	Customer block Region 4 [R11]	
	2406:6400:E000:0000::/37	Customer block POP1 [R10]	
	2406:6400:E800:0000::/37	Customer block future use/POP	
	2406:6400:F000:0000::/37	Customer block future use/POP	
	2406:6400:F800:0000::/37	Customer block POP2 [R12]	

Training ISP IPV6 Addressing Plan

Table 26: Detail customer block Region 4					
Block#	**Prefix**	**Description**	**Reverse DNS**	**SOR**	**Registration**
	2406:6400:E000:0000::/40	1st Customer block POP1 [R10]			
	2406:6400:E000:0000::/48	1st Customer prefix POP1 [R10]		Yes	Yes
	2406:6400:E001:0000::/48				
	2406:6400:E002:0000::/48				
	2406:6400:E003:0000::/48				
	2406:6400:E004:0000::/48				
	2406:6400:E005:0000::/48				
	2406:6400:E006:0000::/48				
	2406:6400:E007:0000::/48				
	2406:6400:F800:0000::/40	1st Customer block POP2 [R10]			
	2406:6400:F800:0000::/48	1st Customer prefix POP2 [R10]		Yes	Yes
	2406:6400:F801:0000::/48				
	2406:6400:F802:0000::/48				
	2406:6400:F803:0000::/48				
	2406:6400:F804:0000::/48				
	2406:6400:F805:0000::/48				
	2406:6400:F806:0000::/48				
	2406:6400:F807:0000::/48				

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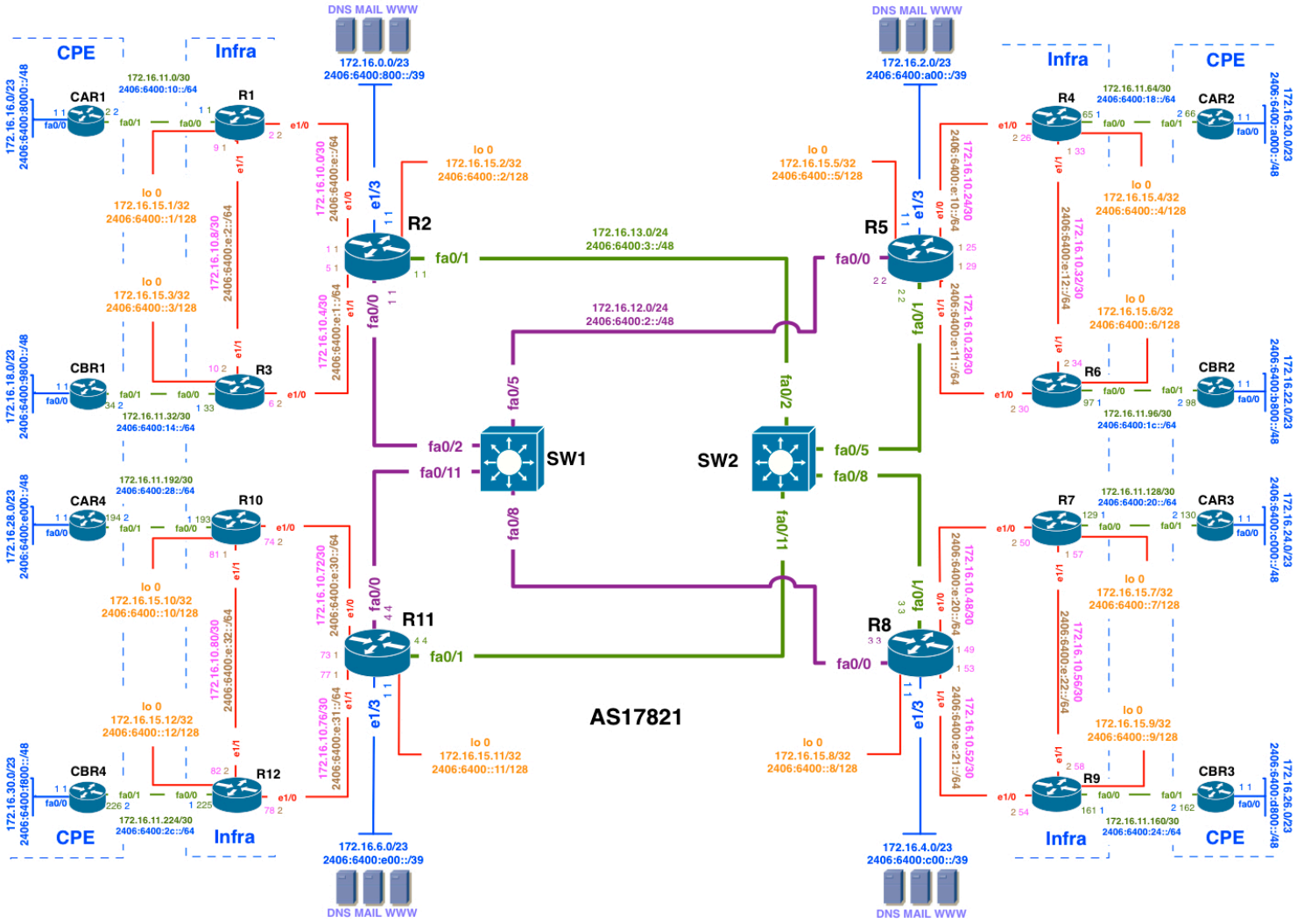


Training ISP IPV4 Addressing Plan

Summary parent block IPV4

Block#	Prefix	Size	Description
1	172.16.0.0	/19	Parent block
2	172.16.0.0	/20	Infrastructure
3	172.16.16.0	/20	Customer network

Training ISP IPV4 Addressing Plan

Detail DC infrastructure block IPV4

Block#	Prefix	Size	Description	SOR	Register
2	172.16.0.0	/20	Infrastructure		
4	172.16.0.0	/23	Router2 DC summary net		
5	172.16.0.0	/24	Router2 DC	No	Recommended
6	172.16.2.0	/23	Router5 DC summary net		
7	172.16.2.0	/24	Router5 DC	No	Recommended
8	172.16.4.0	/23	Router8 DC summary net		
9	172.16.4.0	/24	Router8 DC	No	Recommended
10	172.16.6.0	/23	Router11 DC summary net		
11	172.16.6.0	/24	Router11 DC	No	Recommended

Training ISP IPV4 Addressing Plan

Detail infrastructure WAN block IPV4

12	172.16.10.0	/24	WAN prefix		Optional
13	172.16.10.0	/30	Router2-1 WAN	No	
14	172.16.10.4	/30	Router2-3 WAN	No	
15	172.16.10.8	/30	Router1-3 WAN	No	
16	172.16.10.24	/30	Router5-4 WAN	No	
17	172.16.10.28	/30	Router5-6 WAN	No	
18	172.16.10.32	/30	Router4-6 WAN	No	
19	172.16.10.48	/30	Router8-7 WAN	No	
20	172.16.10.52	/30	Router8-9 WAN	No	
21	172.16.10.56	/30	Router7-9 WAN	No	
22	172.16.10.72	/30	Router11-10 WAN	No	
23	172.16.10.76	/30	Router11-12 WAN	No	
24	172.16.10.80	/30	Router10-12 WAN	No	

Training ISP IPV4 Addressing Plan

Detail customer link WAN block

Block#	Prefix	Size	Description	SOR	Register
	172.16.11.0	/26	WAN CS Link Region1		
	172.16.11.0	/27	WAN CS Link POP1 [R1]		
	172.16.11.0	/30	R1[::1]-CAR1[::2]	No	No
	172.16.11.4	/30			
	172.16.11.32	/27	WAN CS Link POP2 [R3]		
	172.16.11.32	/30	R3[::33]-CBR1[::34]	No	No
	172.16.11.36	/30			
	172.16.11.64	/26	WAN CS Link Region2		
	172.16.11.64	/27	WAN CS Link POP1 [R4]		
	172.16.11.64	/30	R4[::65]-CAR2[::66]	No	No
	172.16.11.68	/30			
	172.16.11.96	/27	WAN CS Link POP2 [R6]		
	172.16.11.96	/30	R6[::97]-CBR2[::98]	No	No
	172.16.11.100	/30			
	172.16.11.128	/26	WAN CS Link Region3		
	172.16.11.128	/27	WAN CS Link POP1 [R7]		
	172.16.11.128	/30	R7[::129]-CAR3[::130]	No	No
	172.16.11.132	/30			
	172.16.11.160	/27	WAN CS Link POP2 [R9]		
	172.16.11.160	/30	R9[::161]-CBR3[::162]	No	No
	172.16.11.164	/30			
	172.16.11.192	/26	WAN CS Link Region4		
	172.16.11.192	/27	WAN CS Link POP1 [R10]		
	172.16.11.192	/30	R10[::193]-CAR4[::194]	No	No
	172.16.11.196	/30			
	172.16.11.224	/27	WAN CS Link POP2 [R12]		
	172.16.11.224	/30	R12[::225]-CBR4[::226]	No	No
	172.16.11.228	/30			

Training ISP IPV4 Addressing Plan

Detail infrastructure block Transport & Loopback IPV4

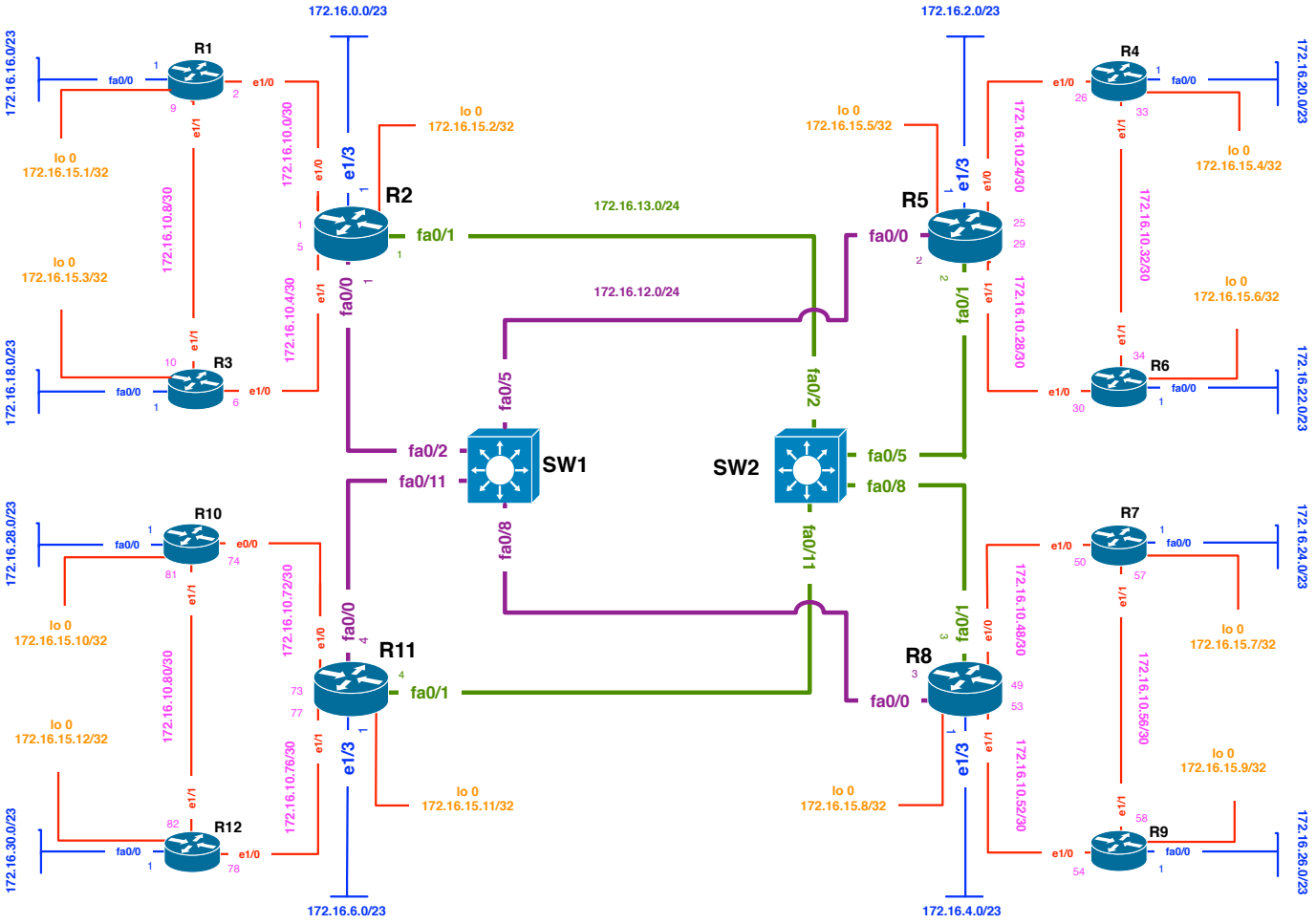
25	172.16.12.0	/24	Transport link PURPLE	No	
26	172.16.13.0	/24	Transport link GREEN	No	
27	172.16.15.0	/24	Loopback	No	

Training ISP IPV4 Addressing Plan

Detail customer block

Block#	Prefix	Size	Description	SOR	Register
28	172.16.6.0	/20	Customer network		
29	172.16.16.0	/22	Router2 summary net		
30	172.16.16.0	/23	Router1 CS network	Yes	Must
31	172.16.18.0	/23	Router3 CS network	Yes	Must
32	172.16.20.0	/22	Router5 summary net		
33	172.16.20.0	/23	Router4 CS network	Yes	Must
34	172.16.22.0	/23	Router6 CS network	Yes	Must
35	172.16.24.0	/22	Router8 summary net		
36	172.16.24.0	/23	Router7 CS network	Yes	Must
37	172.16.26.0	/23	Router9 CS network	Yes	Must
38	172.16.28.0	/22	Router11 summary net		
39	172.16.28.0	/23	Router10 CS network	Yes	Must
40	172.16.30.0	/23	Router12 CS network	Yes	Must

Training ISP IPV4 Addressing Plan



Training ISP IPv4 Address Plan

Questions?

APNIC

Overview

Routing Workshop (3 Days)

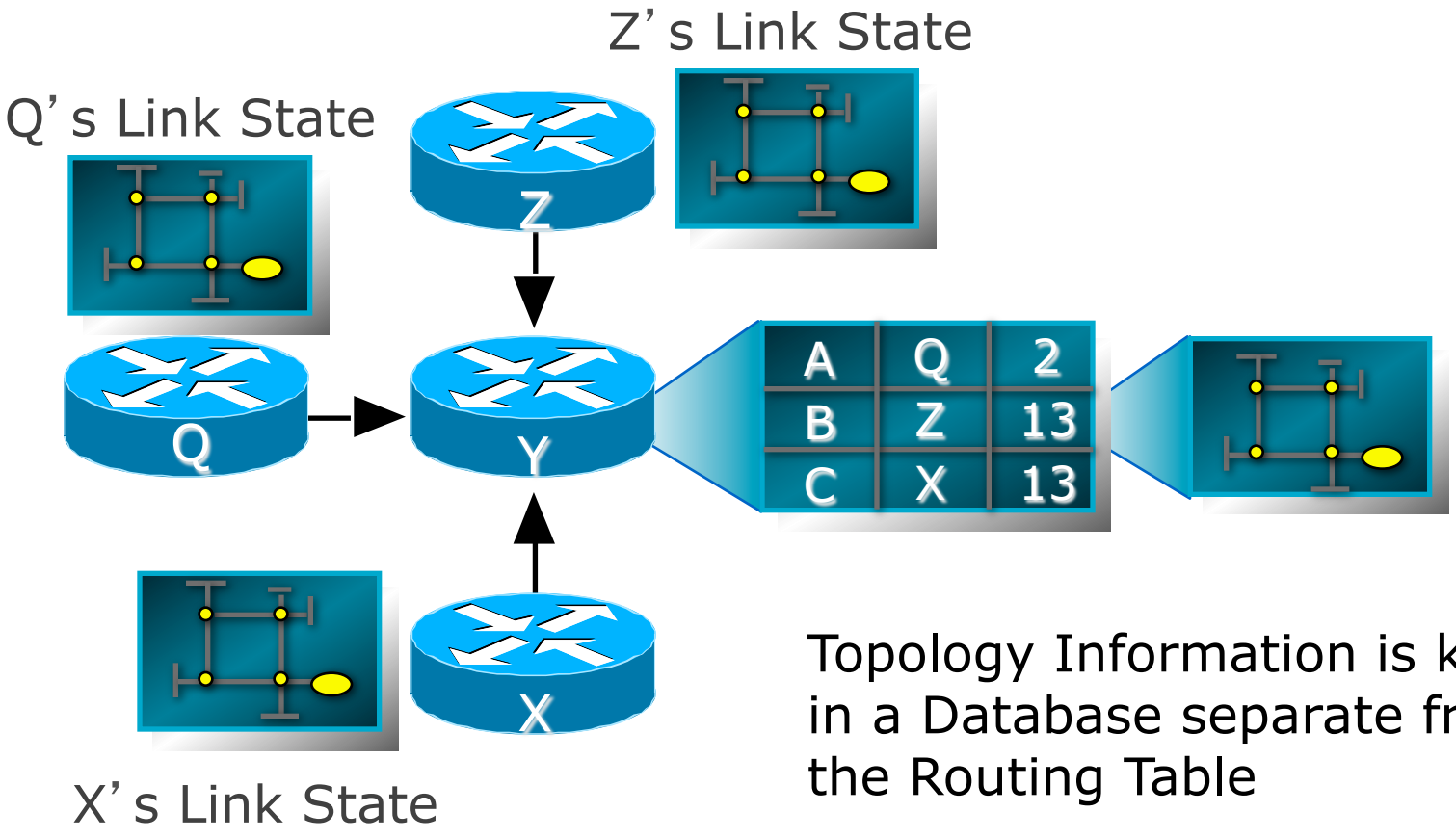
- Introduction to IP Routing
- Routing Protocol Basic
- IPv6 Address Structure
- Routing Lab Topology Overview
- **Operation of OSPF Routing Protocol**
- Lab Exercise on Basic Router and OSPF Dynamic Routing Configuration
- Basic BGP Operation
- BGP Attributes and Path Selection Process
- BGP Scaling Techniques
- Lab Exercise on iBGP, eBGP, RR, Peer group etc
- Internet Exchange [IX] Policy Overview and Configuration requirement

OSPF

- Open Shortest Path First
- Link state or SPF technology
- Developed by OSPF working group of IETF (RFC 1247)
- OSPFv2 (IPv4) standard described in RFC2328
- OSPFv3 (IPv6) standard described in RFC2740

- Designed for:
  - TCP/IP environment
  - Fast convergence
  - Variable-length subnet masks
  - Discontiguous subnets
  - Incremental updates
  - Route authentication
- Runs on IP, Protocol 89

Link State Routing Protocol



Topology Information is kept in a Database separate from the Routing Table

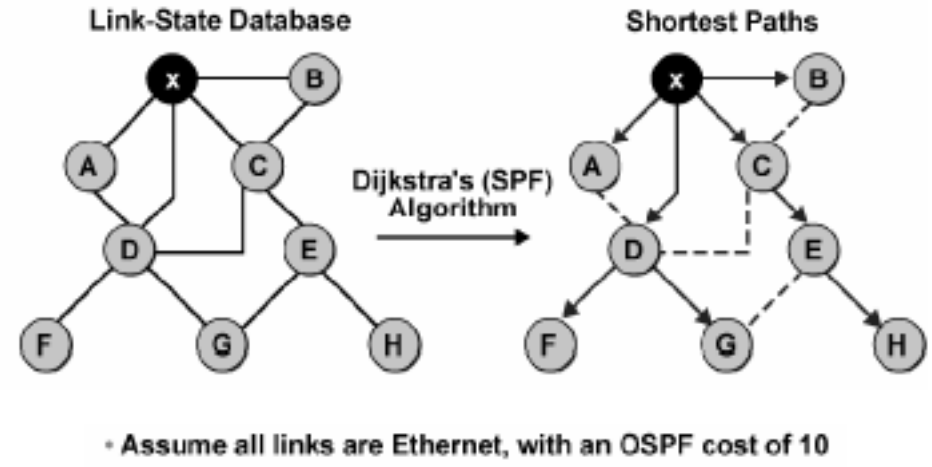
What is Link State Routing

- Do not send full routing table on periodic interval
- Maintain three tables to collect routing information
  - Neighbor table
  - Topology Table
  - Routing table
- Use Shortest Path First (SPF) algorithm to select best path from topology table
- Send very small periodic (Hello) message to maintain link condition
- Send triggered update instantly when network change occur

Link State Data Structure

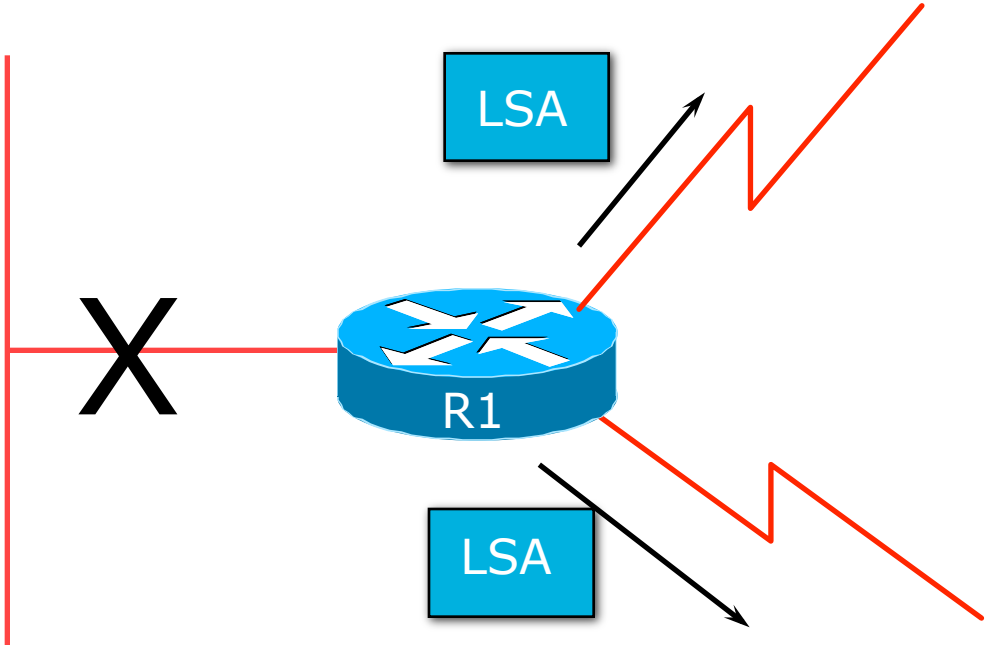
- Neighbor Table
  - List of all recognized neighboring router to whom routing information will be interchanged
- Topology Table
  - Also called LSDB which maintain list of routers and their link information i.e network destination, prefix length, link cost etc
- Routing table
  - Also called forwarding table contain only the best path to forward data traffic

Shortest Path First (SPF) Tree



- Every router in an OSPF network maintain an identical topology database
- Router place itself at the root of SPF tree when calculate the best path

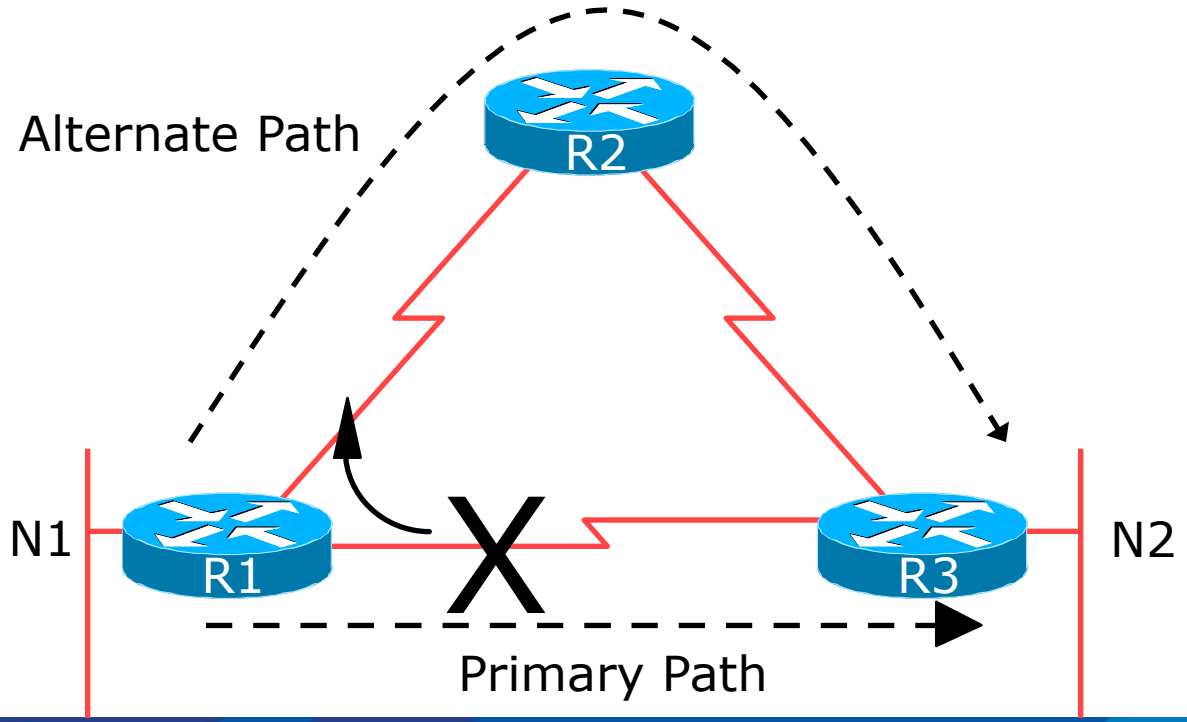
Low Bandwidth Utilisation



- Only changes propagated
- Uses multicast on multi-access broadcast networks

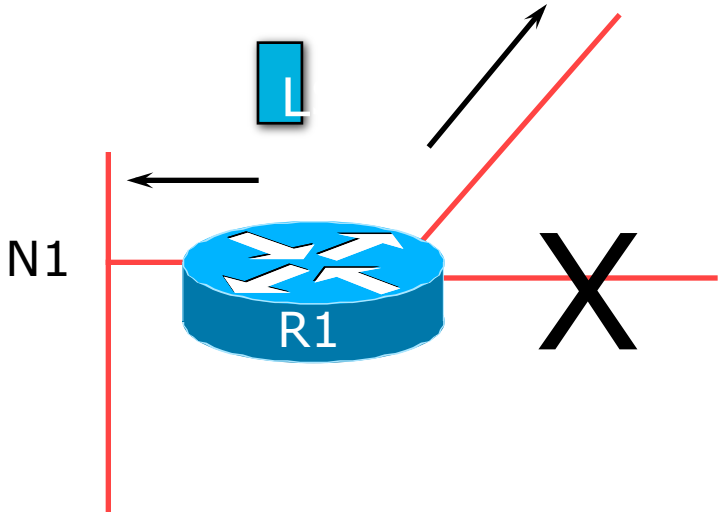
Fast Convergence

- Detection Plus LSA/SPF
  - Known as the Dijkstra Algorithm



Fast Convergence

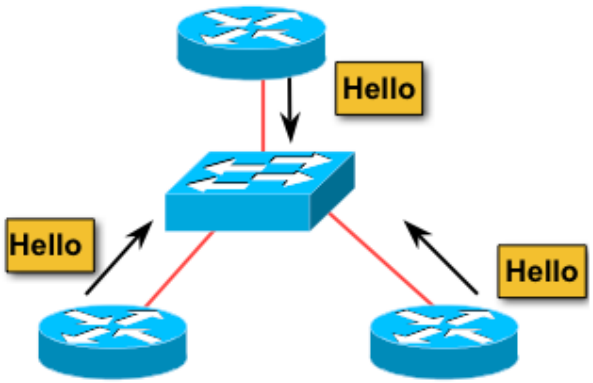
- Finding a new route
  - LSA flooded throughout area
  - Acknowledgement based
  - Topology database synchronised
  - Each router derives routing table to destination network



Basic OSPF Operation

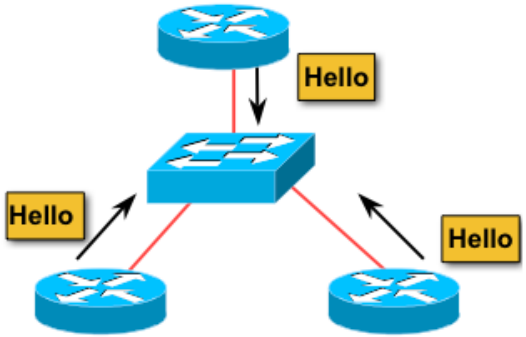
- Neighbor discovery
  - Send L3 multicast message (hello) to discover neighbors
- Exchanging topology table (LSDB)
  - Send L3 multicast message (DBD packets)
- Use SPF algorithm to select best path
  - Each router independently calculates best path from an identical topology database of an OSPF network or area
- Building up routing table
  - All the SPF selected best paths are installed in routing table for the traffic to be forwarded

OSPF Neighbor Discovery Process



- Use IP packet to send hello message. At start routers are at OSPF **Down State**
- Use multicast address 224.0.0.5/FF02::5 to make sure single IP packet will be forwarded to every router within OSPF network. Router now at OSPF **Init State**

OSPF Neighbor Discovery Process



- All neighboring router with OSPF enabled receive the hello packet
- Checks contents of the hello message and if certain information match it reply (Unicast) to that hello with sending its router ID in the neighbor list.
- This is OSPF **Two-way State**

Contents Of A Hello Packet

- Required information to build up adjacency:
  - Router ID of sending router
  - Hello and dead interval time *
  - List of neighbors
  - Network mask
  - Router priority
  - Area ID *
  - DR & BDR IP
  - Authentication information (If any) *

* Need to match to create neighbor relationship

Discovering Network Information

- After creating 2-way neighbor relationship neighboring routers will start exchanging network related information
- At this stage they will decide who will send network information first. Router with the highest router ID will start sending first. This stage is called OSPF **Exstart Stage**
- Then they will start exchanging link state database. This stage is **Exchange Stage**

Adding Network Information

- When router receive the LSDB it perform following action:
  - Acknowledge the receipt of DBD by sending Ack packet (LSAck)
  - Compare the information it received with the existing DB (if any)
  - If the new DB is more up to date the router send link state request (LSR) for detail information of that link. This is **Loading Stage**
- When all LSR have been satisfied and all routers has an identical LSDB this stage is OSPF **Full Stage**

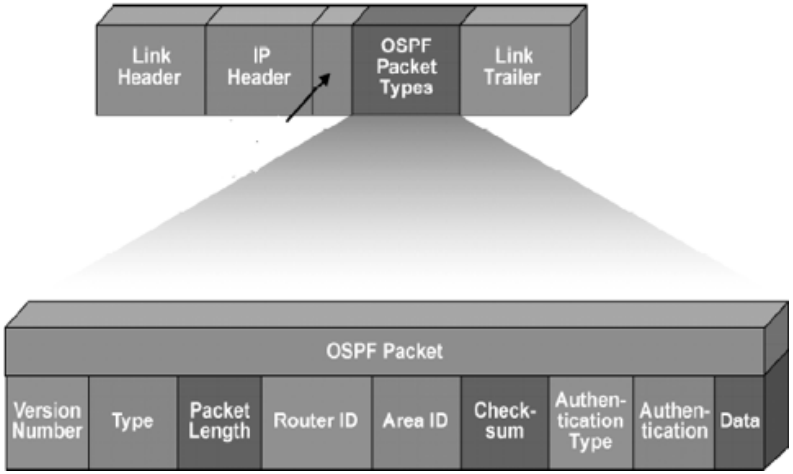
Maintaining Routing Information

- Send periodic updates (Hello) to all neighbors to make sure link with the neighbor is active. I.e 10 sec for LAN
- Send triggered (Instant) update if any network information changed
- Maintain link state sequence number to make sure all information are up-to-date
- Sequence number is 4-byte number that begins with 0x80000001 to 0x7fffffff

OSPF Packet Types

- OSPF use following five packet types to flow routing information between routers:
  - 1: hello [every 10 sec]
    - Hello Builds adjacencies between neighbors
  - 2: DBD [Database Descriptor Packet]
    - DBD for database synchronization between routers
  - 3: LSR [Link State Request Packet]
    - Requests specific link-state records from router to router
  - 4: LSU [Link State Update Packet]
    - Sends specifically requested link-state records
  - 5: LSAck [Link State Ack Packet]
    - Acknowledges the above packet types

Format of OSPF Packet



- All five OSPF packets encapsulated in IP payload (Not TCP)
- To ensure reliable deliver using IP packet OSPF use its own Ack packet (Type 5)

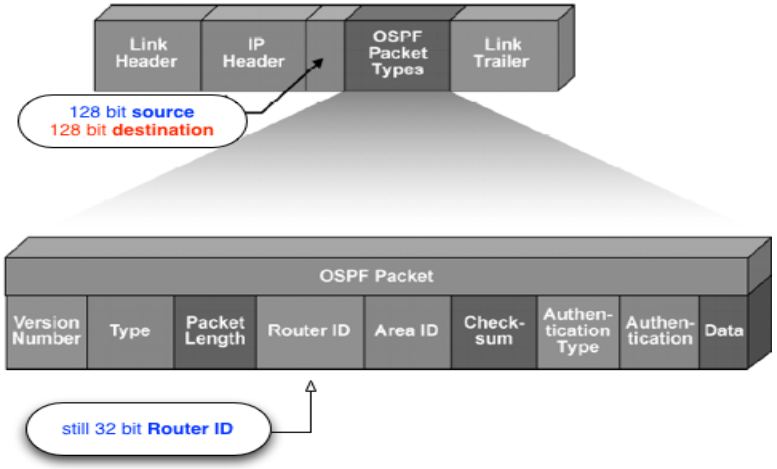
Format of OSPF Packet Header Field

- Version number
  - Either OSPF version 2 (IPv4) or version 3 (IPv6)
- Packet type
  - Differentiates the five OSPF packet types [Type 1 to Type 5]
- Packet length
  - Length of OSPF packet in bytes
- Router ID
  - Defines which router is the source of the packet [Not always source address of IP header]
- Area ID
  - Defines the area where the packet originated
- Checksum
  - Used for packet-header error-detection to ensure that the OSPF packet was not corrupted during transmission
- Authentication type
  - An option in OSPF that describes either clear-text passwords or encrypted Message Digest 5 (MD5) formats for router authentication

Content of OSPF Packet Data

- Data (for hello packet):
  - Contains a list of known neighbors
- Data (for DBD packet):
  - Contains a summary of the LSDB, which includes all known router IDs and their last sequence number, among a number of other fields
- Data (for LSR packet):
  - Contains the type of LSU needed and the router ID of the needed LSU
- Data (for LSU packet):
  - Contains the full LSA entry. Multiple LSA entries can fit in one OSPF update packet
- Data (for LSAck packet):
  - Is empty

Difference is OSPFv3 for IPv6



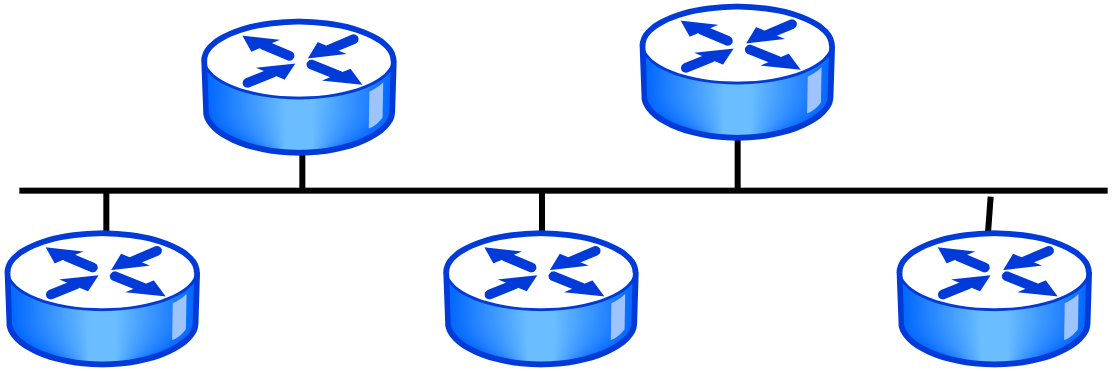
- OSPFv3 still use 32 bit number as router ID
- So OSPFv3 operation and packet types are same as OSPFv2
- Change will be in IP header where source address will be interface address and destination will be FF02::5 which is 128 bit address.
- Change will be in DBD [t2] and LSU packet [t4] to carry 128 bit prefix

OSPF Network Topology

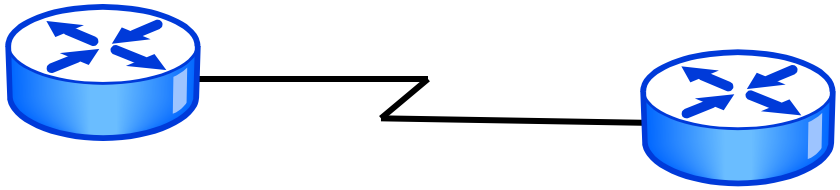
- OSPF network can made up of different types of network links
- Neighbor relationship behavior will also be different for each network type
- It is important for OSPF to be configured correctly based on its network types to be functioned properly
- Some network type create neighbor relationship automatically some need to create it manually

OSPF Network Topology

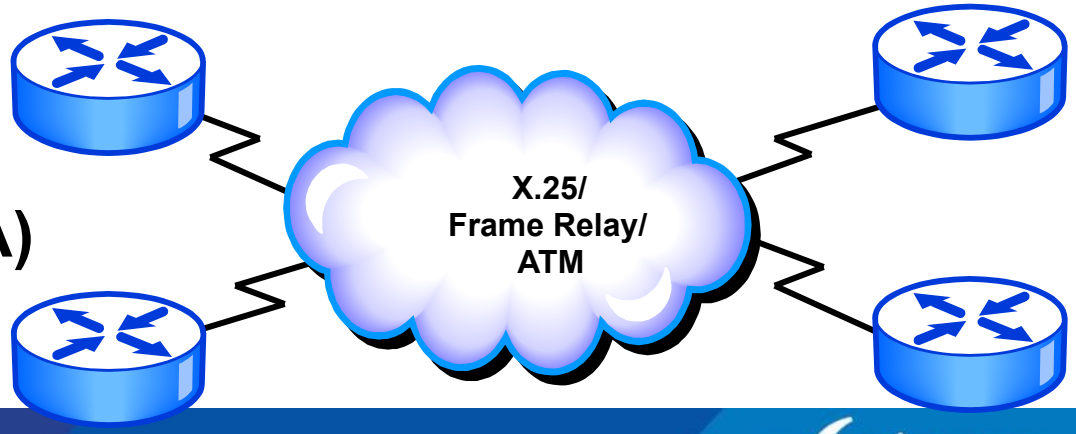
Broadcast Multi-access



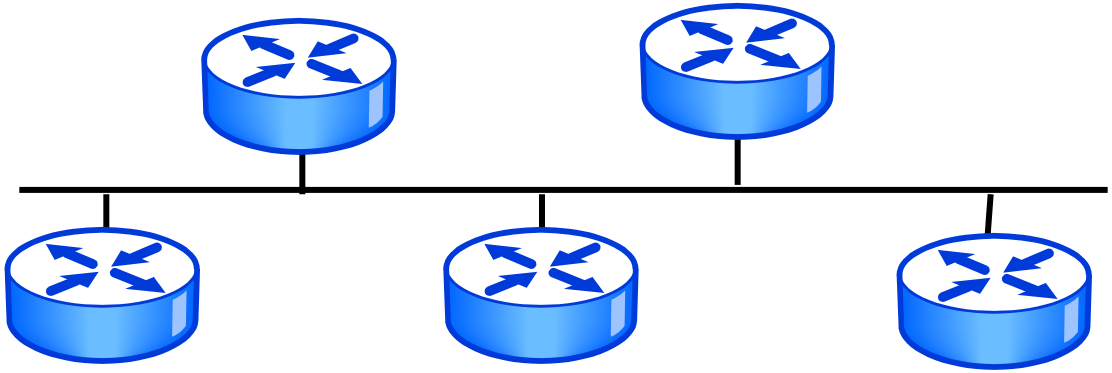
Point-to-Point



Non Broadcast Multi-access (NBMA)



Broadcast Multi-access Network



- Generally LAN type of technologies like Ethernet or Token Ring
- Neighbor relationship are created automatically
- DB/BDR election is required
- Default OSPF hello is 10 sec dead interval is 40 sec

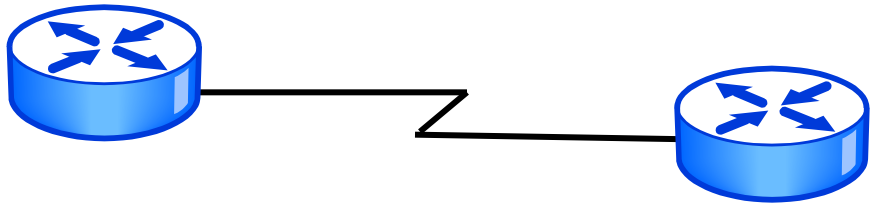
Broadcast Multi-access Network

- Broadcast network use flooding process to send routing update
- Broadcast network use DR/BDR concept to reduce routing update traffic in the LAN
- Packet sent to DR/BDR use 224.0.0.6/FF02::6 multicast address
- Packets from DR to all other routers use 224.0.0.5/FF02::5 multicast address
- All neighbor routers form full adjacencies relation with the DR and BDR only

DB/BDR Election Process

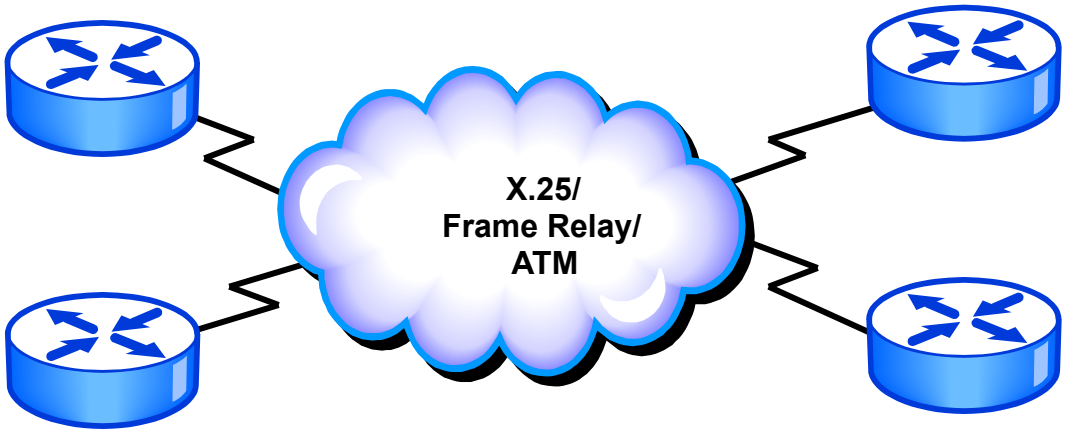
- Router with the highest priority value is the DR, Second highest is BDR
- In the event of tie router with the highest IP address on an interface become DR and second highest is BDR
- DR/BDR election can be manipulated by using router-ID command.
- In practice loopback IP address is used as router ID and the highest IP address will become DR, Second highest is BDR
- The DR/BDR election is non-preemptive
- Generates network link advertisements
- Assists in database synchronization

Point-to-Point Network



- Usually a serial interface running either PPP or HDLC
- Neighbor relationship are created automatically
- No DR or BDR election required
- Default OSPF hello is 10 sec and dead interval is 40 sec

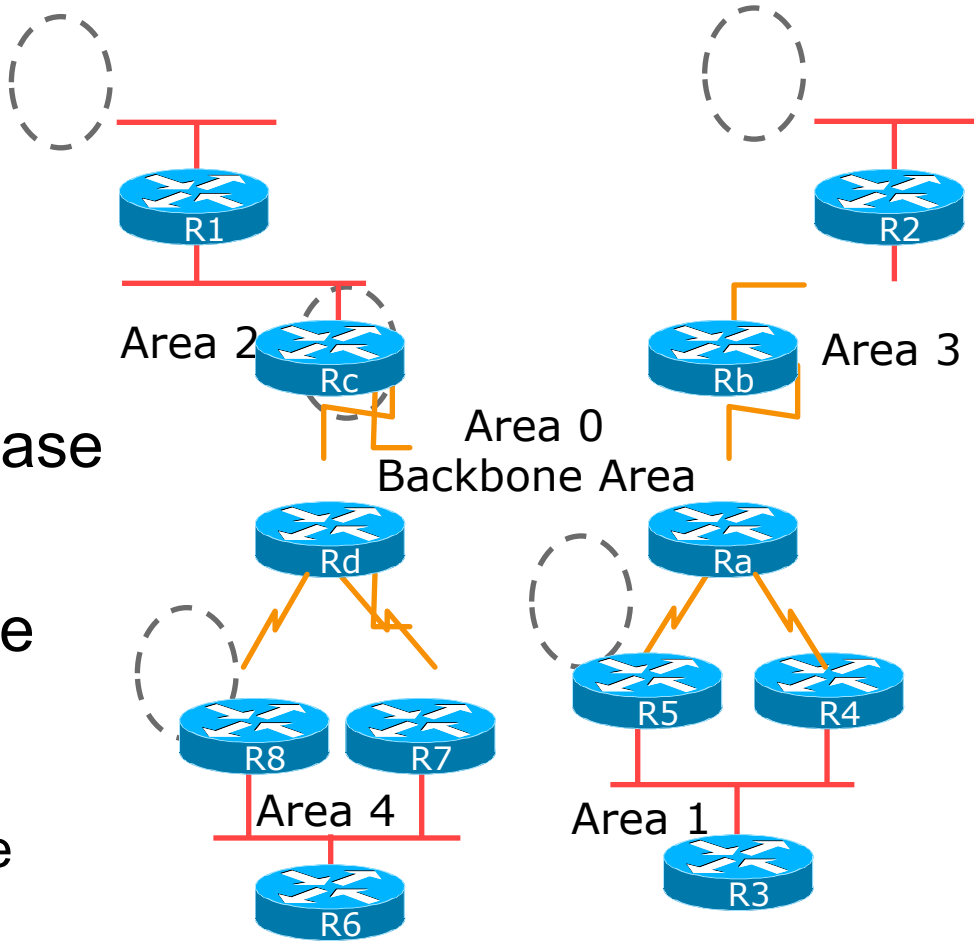
Non Broadcast Multi-access Network



- A single interface interconnects multiple sites like Frame Relay/ATM/X.25
- NBMA topologies support multiple routers, but without broadcasting capabilities
- OSPF neighbor relation need to create manually, DR/BDR will be elected
- Default OSPF hello is 30 sec and dead interval is 120 sec

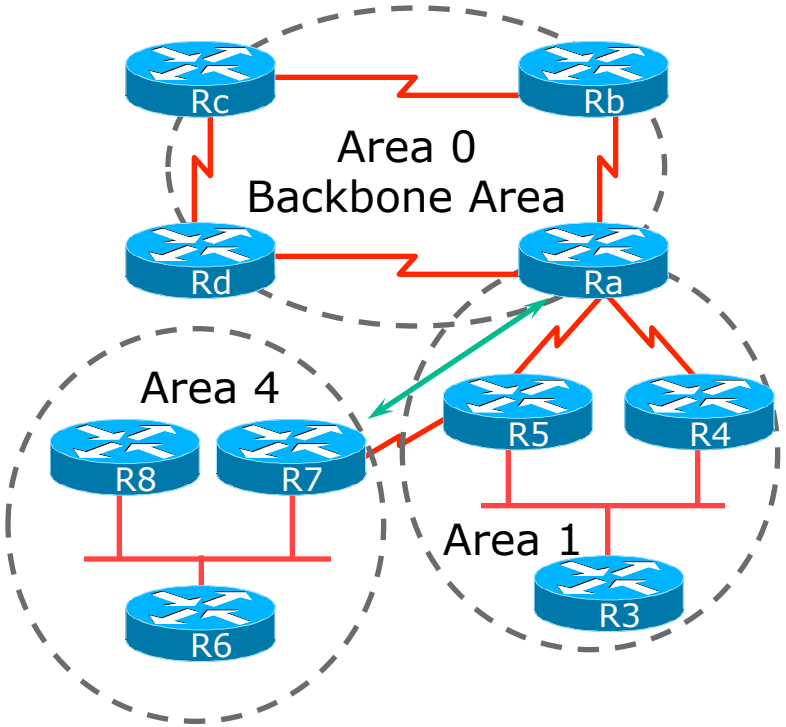
OSPF Areas

- Area is a group of contiguous hosts and networks
  - Reduces routing traffic
- Per area topology database
  - Invisible outside the area
- Backbone area MUST be contiguous
  - All other areas must be connected to the backbone

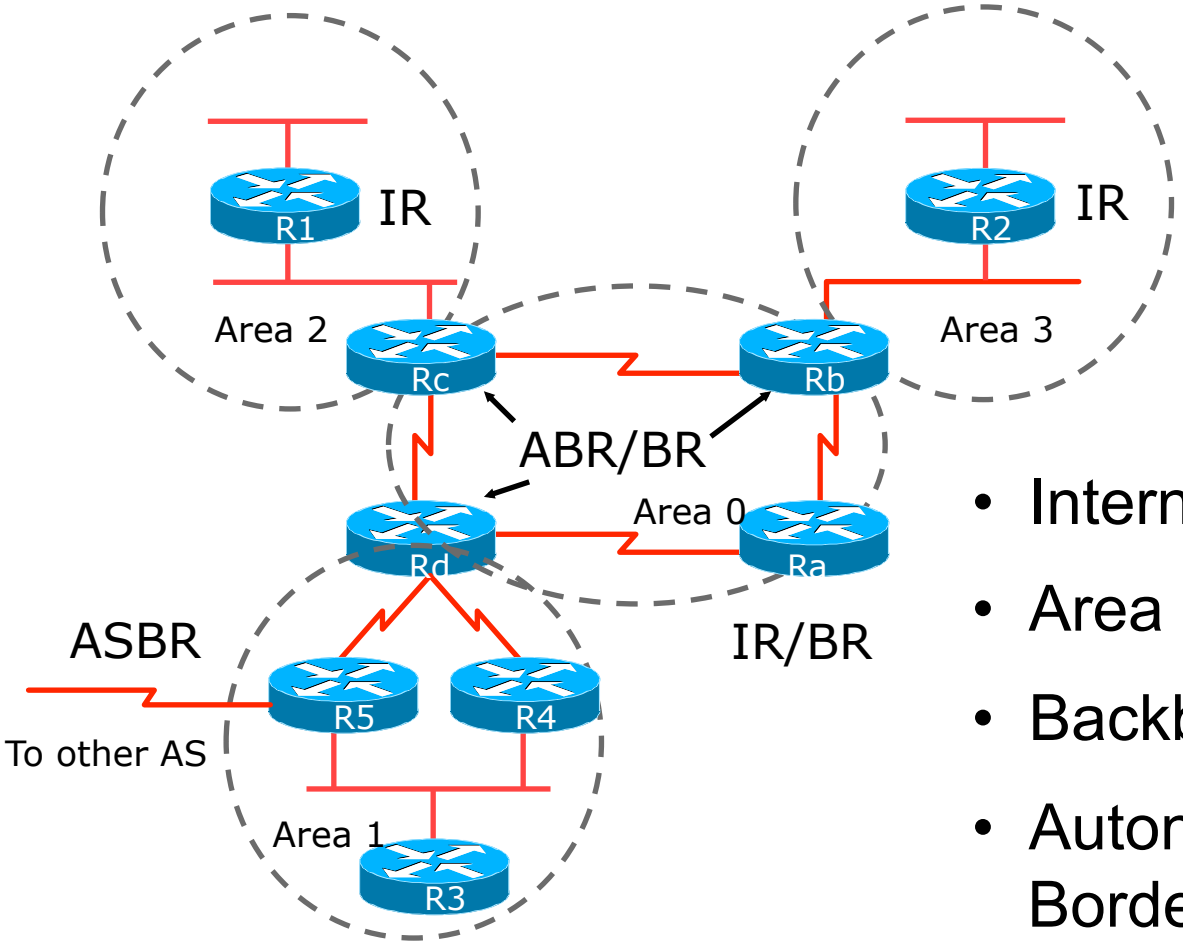


Virtual Links between OSPF Areas

- Virtual Link is used when it is not possible to physically connect the area to the backbone
- ISPs avoid designs which require virtual links
  - Increases complexity
  - Decreases reliability and scalability

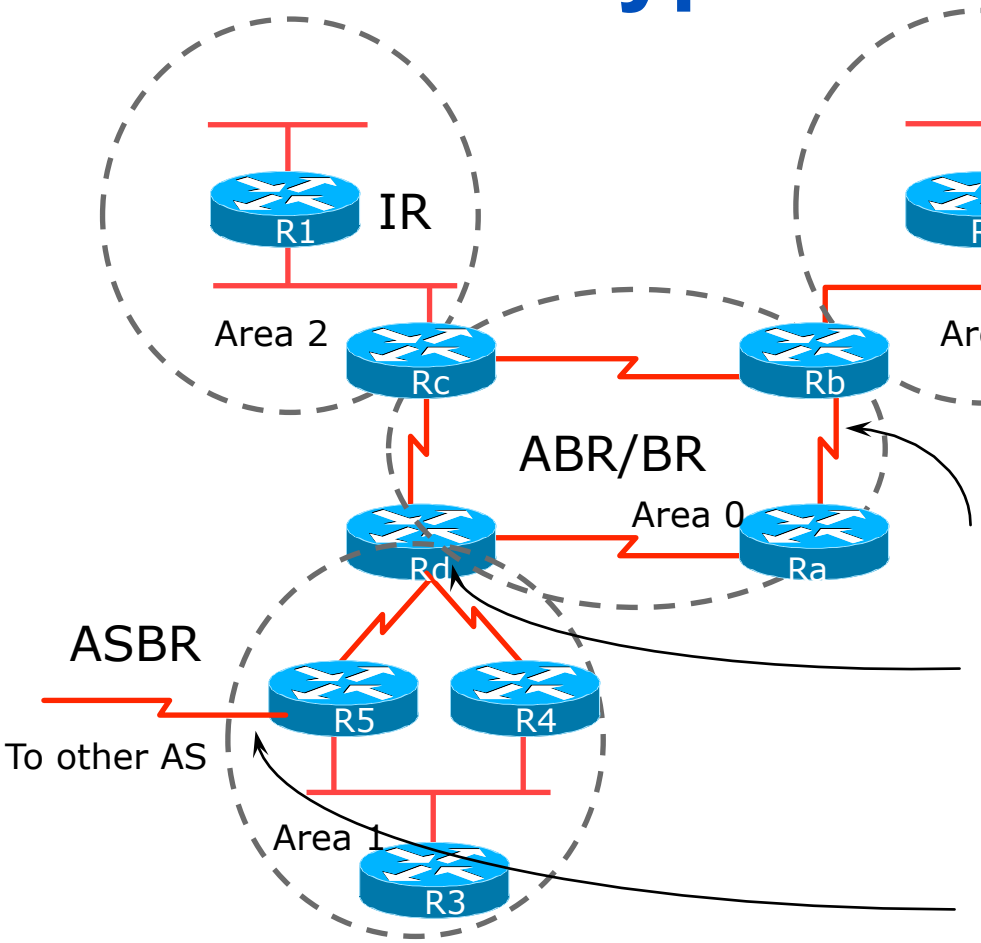


Classification of Routers



- Internal Router (IR)
- Area Border Router (ABR)
- Backbone Router (BR)
- Autonomous System Border Router (ASBR)

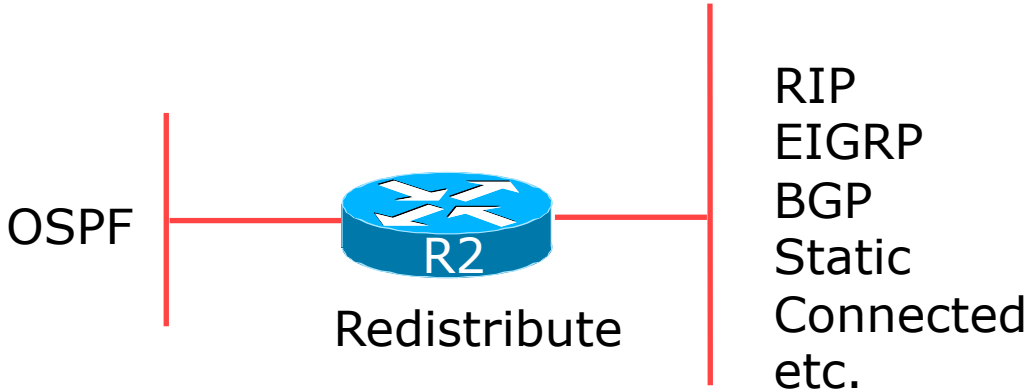
OSPF Route Types



- Intra-area Route
  - all routes inside an area
- Inter-area Route
  - routes advertised from one area to another by an Area Border Router
- External Route
  - routes imported into OSPF from other protocol or static routes

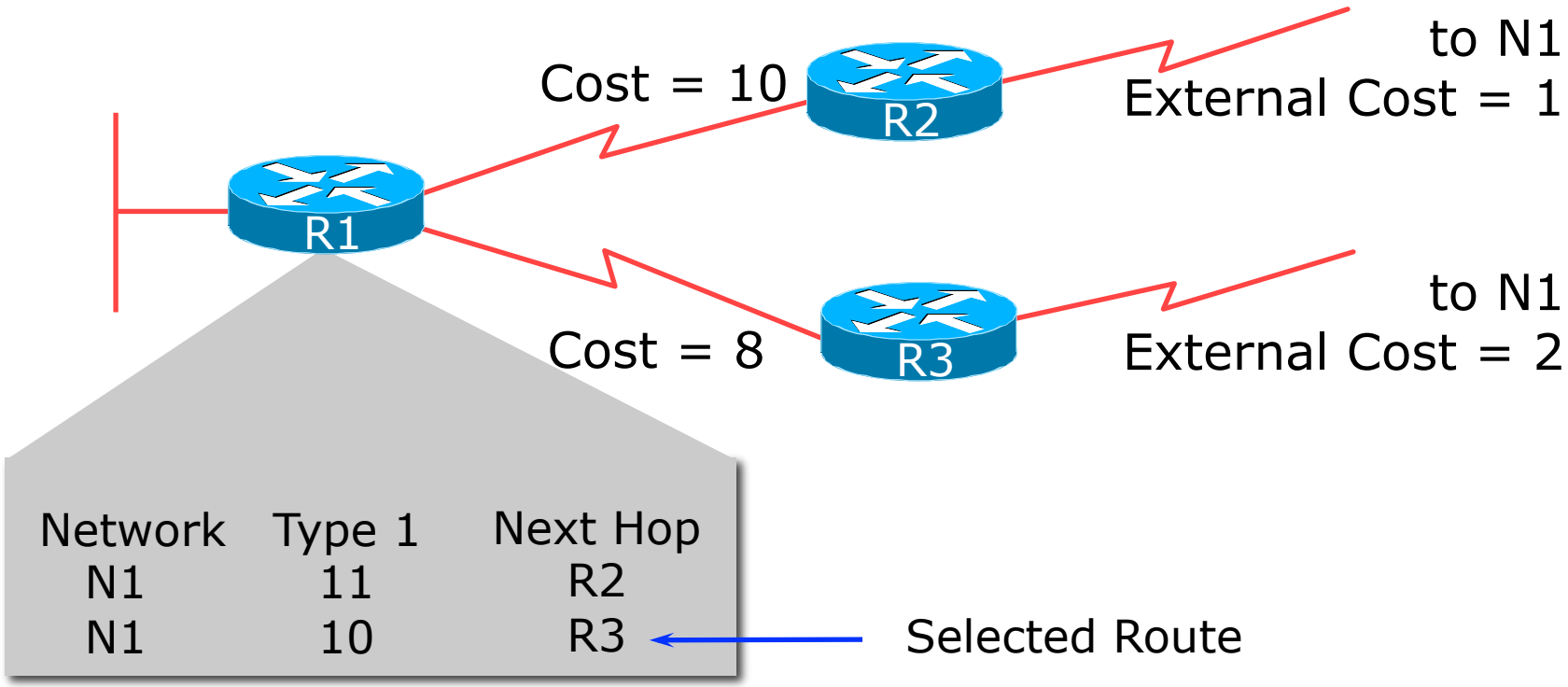
External Routes

- Prefixes which are redistributed into OSPF from other protocols
- Flooded unaltered throughout the AS
  - Recommendation: Avoid redistribution!!
- OSPF supports two types of external metrics
  - Type 1 external metrics
  - Type 2 external metrics (Cisco IOS default)



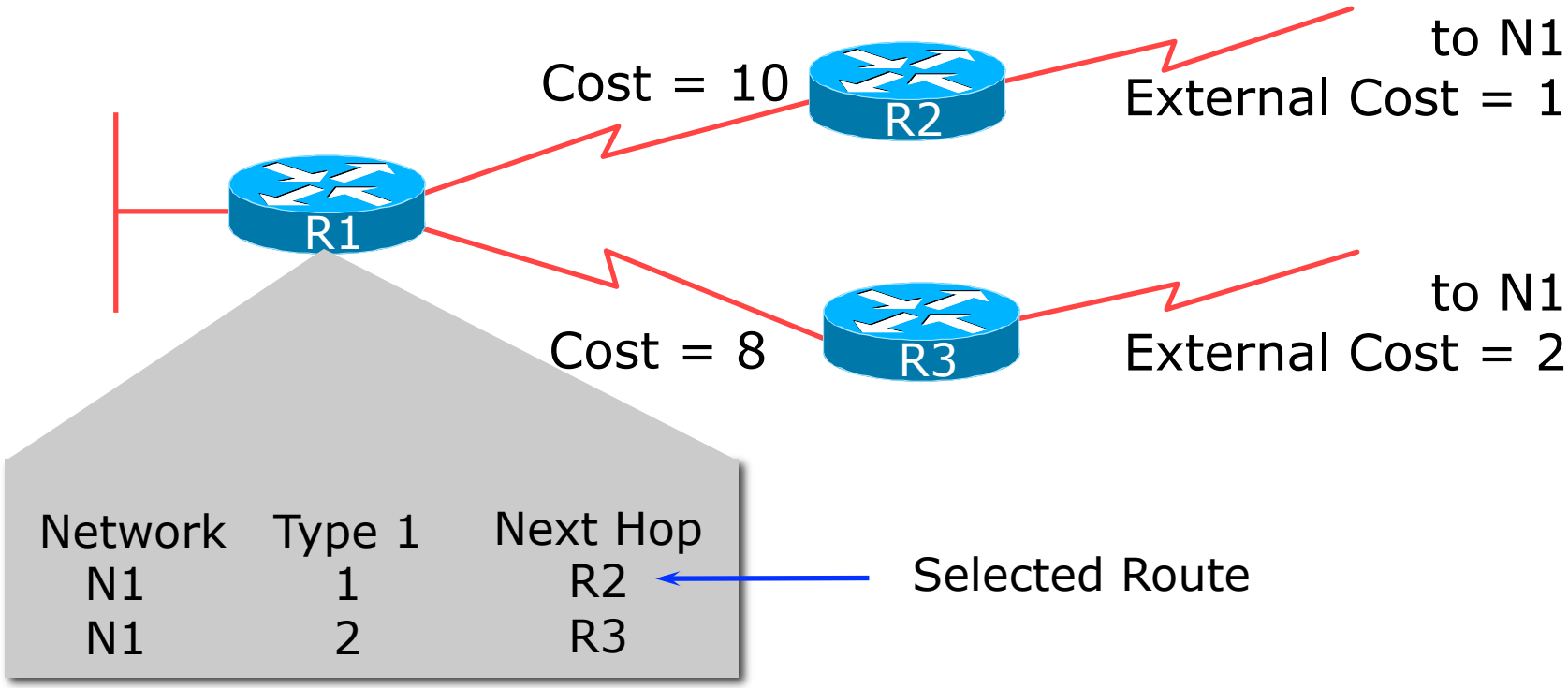
External Routes

- Type 1 external metric: metrics are added to the summarised internal link cost



External Routes

- Type 2 external metric: metrics are compared without adding to the internal link cost



Topology/Link State Database

- A router has a separate LS database for each area to which it belongs
- All routers belonging to the same area have identical database
- SPF calculation is performed separately for each area
- LSA flooding is bounded by area
- Recommendation:
  - Limit the number of areas a router participates in!!
  - 1 to 3 is fine (typical ISP design)
  - >3 can overload the CPU depending on the area topology complexity

Different Types of LSAs

- Six distinct type of LSAs
  - Type 1 : Router LSA
  - Type 2 : Network LSA
  - Type 3 & 4: Summary LSA
  - Type 5 & 7: External LSA (Type 7 is for NSSA)
  - Type 6: Group membership LSA
  - Type 9, 10 & 11: Opaque LSA (9: Link-Local, 10: Area)

Router LSA (Type 1)

- Describes the state and cost of the router's links to the area
- All of the router's links in an area must be described in a single LSA
- Flooded throughout the particular area and no more
- Router indicates whether it is an ASBR, ABR, or end point of virtual link

Network LSA (Type 2)

- Generated for every transit broadcast and NBMA network
- Describes all the routers attached to the network
- Only the designated router originates this LSA
- Flooded throughout the area and no more

Summary LSA (Type 3 and 4)

- Describes the destination outside the area but still in the AS
- Flooded throughout a single area
- Originated by an ABR
- Only inter-area routes are advertised into the backbone
- Type 4 is the information about the ASBR

External LSA (Type 5 and 7)

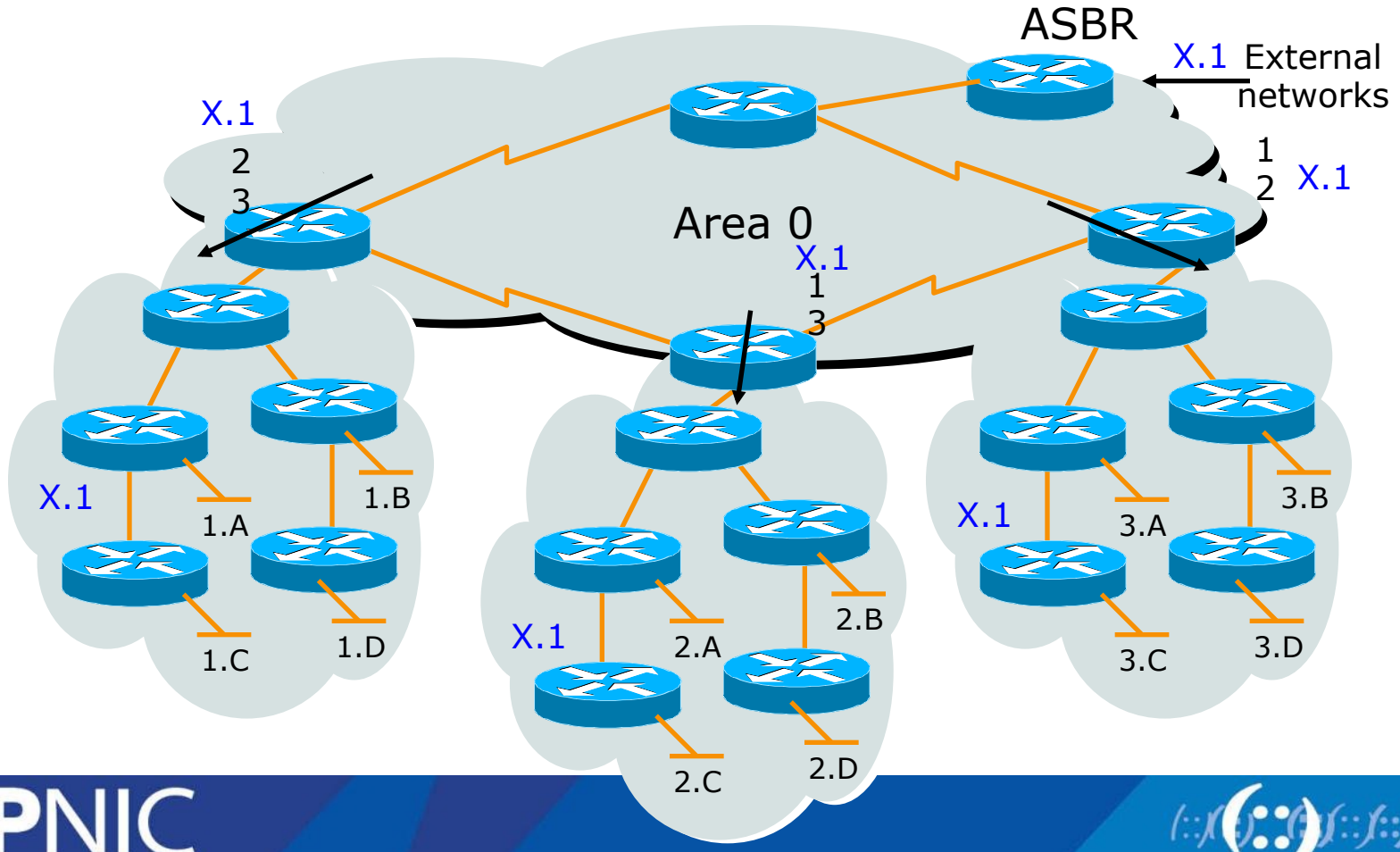
- Defines routes to destination external to the AS
- Default route is also sent as external
- Two types of external LSA:
  - E1: Consider the total cost up to the external destination
  - E2: Considers only the cost of the outgoing interface to the external destination
- (Type 7 LSAs used to describe external LSA for one specific OSPF area type)

Types of Areas

- Regular
- Stub
- Totally Stubby
- Not-So-Stubby
- Only “regular” areas are useful for ISPs
  - Other area types handle redistribution of other routing protocols into OSPF – ISPs don’t redistribute anything into OSPF
- The next slides describing the different area types are provided for information only

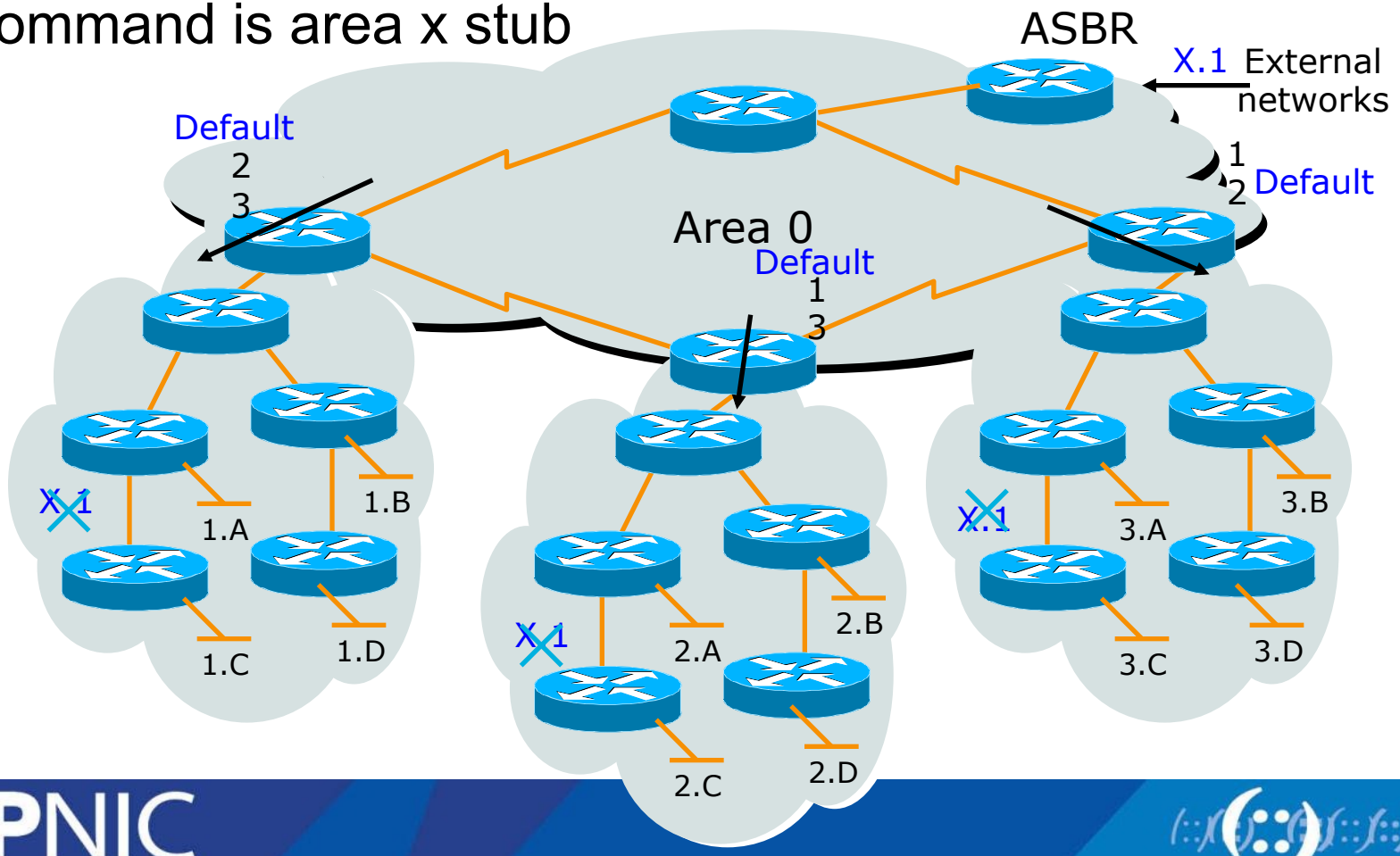
Regular Area (Not a Stub)

- From Area 1's point of view, summary networks from other areas are injected, as are external networks such as X.1



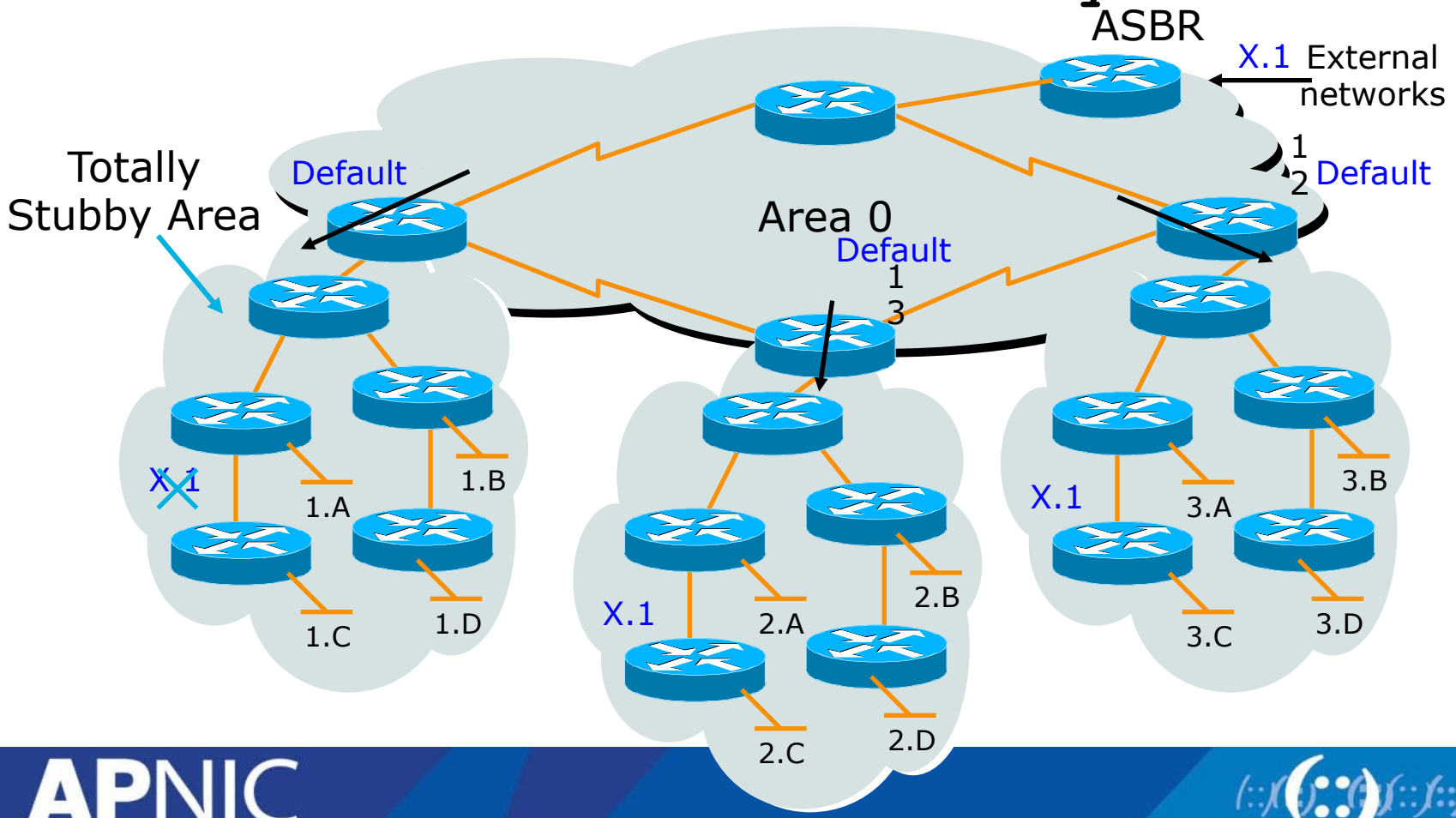
Normal Stub Area

- Summary networks, default route injected
- Command is area x stub



Totally Stubby Area

- Only a default route injected
  - Default path to closest area border router
- Command is **`area x stub no-summary`**



ISP Use of Areas

- ISP networks use:
  - Backbone area
  - Regular area
- Regular area
  - Summarisation of point to point link addresses used within areas
  - Loopback addresses allowed out of regular areas without summarisation

Questions?

APNIC

Overview

Routing Workshop (3 Days)

- Introduction to IP Routing
- Routing Protocol Basic
- IPv6 Address Structure
- Routing Lab Topology Overview
- Operation of OSPF Routing Protocol
- **Lab Exercise on Basic Router and OSPF Dynamic Routing Configuration**
- Basic BGP Operation
- BGP Attributes and Path Selection Process
- BGP Scaling Techniques
- Lab Exercise on iBGP, eBGP, RR, Peer group etc
- Internet Exchange [IX] Policy Overview and Configuration requirement

Configuration of OSPF as IGP

Scenario:

- Training ISP need to configure OSPF as IGP for both IPv4 and IPv6
- Dual stack mechanism will be used to ensure both IPv4 and IPv6 operation
- OSPFv3 supports IPv6 routed protocol
- IGP is used to carry next hop only for BGP

Configuration of OSPF as IGP

Minimum Router OS require for OSPF3:

- Cisco IOS
  - 12.2(15)T or later (For OSPFv3)
  - 12.2(2)T or later (For IPv6 support)
- Jun OS
  - JUNOS 8.4 or later

Configuration of OSPF as IGP

- Before enabling OSPF3 on an Interface following steps must be done on a Router:
  - Enable IPv6 unicast routing
  - Enable IPv6 CEF (Optional)

```
config t
ipv6 unicast-routing
ipv6 cef (distributed cef)
```

Configuration of OSPF as IGP

Configure interface for both IPv4 and IPv6:

```
interface e1/0
description WAN R1-R2
no ip redirects
no ip directed-broadcast
no ip unreachables
ip address 172.16.10.2 255.255.255.252
no shutdown

interface e1/0
ipv6 address 2406:6400:000F:0000::2/64
ipv6 enable
```

Configuration of OSPF as IGP

Verify Interface configuration:

```
sh ip interface e0/0
ping 172.16.10.1

sh ipv6 interface e0/0
ping 2406:6400:000F:0000::2
```

Configuration of OSPF as IGP

IPv4 Interface configuration for Router1:

```
interface loopback 0
description Router1 Loopback
no ip redirects
no ip directed-broadcast
no ip unreachables
ip address 172.16.15.1 255.255.255.255
no shutdown
interface e1/0
description WAN R1-R2
no ip redirects
no ip directed-broadcast
no ip unreachables
ip address 172.16.10.2 255.255.255.252
no shutdown
```

Configuration of OSPF as IGP

IPv4 Interface configuration for Router1:

```
interface e1/1
description WAN R1-R3
no ip redirects
no ip directed-broadcast
no ip unreachables
ip address 172.16.10.9 255.255.255.252
no shutdown
interface fa0/0
description Router1 customer network
no ip redirects
no ip directed-broadcast
no ip unreachables
no cdp enable
ip address 172.16.16.1 255.255.255.0
no shutdown
```

Configuration of OSPF as IGP

IPv6 Interface configuration for Router1:

```
interface loopback 0
ipv6 address 2406:6400:0000:0000::1/128
ipv6 enable
interface e1/0
ipv6 address 2406:6400:000F:0000::2/64
ipv6 enable
interface e1/1
ipv6 address 2406:6400:000F:0002::1/64
ipv6 enable
interface fa0/0
ipv6 address 2406:6400:0100:0000::1/48
ipv6 enable
```

Configuration of OSPF as IGP

- OSPF Configuration for IPv4:
  - OSPF for IPv4 can be configured from global configuration mode
  - Interface mode configuration will also activate OSPF process on your running config

Configuration of OSPF as IGP

- OSPF Configuration for IPv6:
  - OSPF for IPv6 need to configure from Interface configuration mode
  - Interface mode configuration will automatically activate OSPF process on your running config

Configuration of OSPF as IGP

OSPF for IPv6 Configuration Command:

```
router ospf 17821
log-adjacency-changes
passive-interface default
network 172.16.15.1 0.0.0.0 area 1
no passive-interface e1/0
network 172.16.10.0 0.0.0.3 area 1
no passive-interface e1/1
network 172.16.10.8 0.0.0.3 area 1
```

Configuration of OSPF as IGP

OSPF for IPv6 Configuration Command:

```
interface loopback 0
ipv6 ospf 17821 area 1
interface e1/0
ipv6 ospf 17821 area 1
interface e1/1
ipv6 ospf 17821 area 1
```

Configuration of OSPF as IGP

Verify OSPF configuration:

```
sh run
!
interface Ethernet1/0
 description WAN R1-R2
 ip address 172.16.10.2 255.255.255.252
 no ip redirects
 no ip unreachables
 half-duplex
 ipv6 address 2406:6400:F::2/64
 ipv6 enable
 ipv6 ospf 17821 area 1
```

Configuration of OSPF as IGP

Example OSPF configuration for Router1:

```
router ospf 17821
log-adjacency-changes
passive-interface default
network 172.16.15.1 0.0.0.0 area 1
no passive-interface e1/0
network 172.16.10.0 0.0.0.3 area 1
no passive-interface e1/1
network 172.16.10.8 0.0.0.3 area 1
```

Configuration of OSPF as IGP

Example OSPF configuration for Router1:

```
interface loopback 0
ipv6 ospf 17821 area 1
interface e1/0
ipv6 ospf 17821 area 1
interface e1/1
ipv6 ospf 17821 area 1
```

OSPF Packet Type

Five OSPF Packet Type:

t: Specifies the OSPF packet type:

1: hello	[every 10 sec]
2: DBD	[Database Descriptor Packet]
3: LSR	[Link State Request Packet]
4: LSU	[Link State Update Packet]
5: LSAck	[Link State Ack Packet]

debug ip ospf packet

debug ipv6 ospf packet

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APNIC

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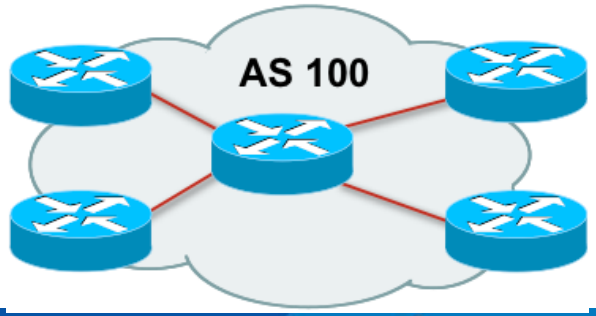
What is Border Gateway Protocol?

- BGP:
  - A path vector routing protocol to exchange routing information between different Autonomous System (AS)
  - ASes are the building block of BGP operational unites
  - AS is a collection of routers with a common routing policy
  - Specification is defined in RFC4271

What is an Autonomous System (AS)

- An AS is a collection of networks with same routing policy
- Usually under a single administrative control unit
- A public AS is identified by a unique number called AS number
- Around 32000 ASes are visible on the Internet now



BGP features

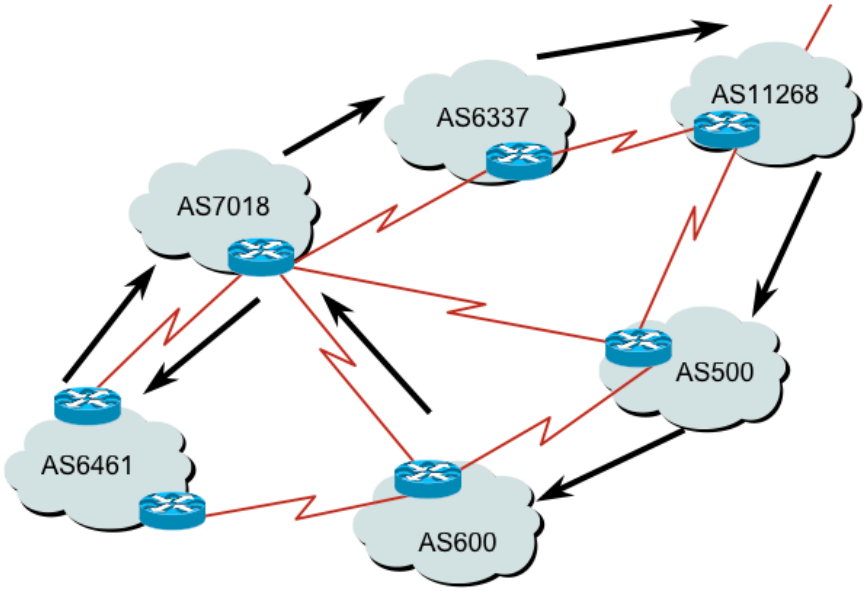
- Path Vector Routing Protocol
- Send incremental updates to peers
- Runs over TCP –Port 179
- Select path based on routing policy/ organization's business requirement
- Support Classless Inter Domain Routing (CIDR) concept
- Widely used in today's Internet Backbone
- Current BGP version is MP-BGP

What is Path Vector Routing Protocol

- A path vector routing protocol is used to span different autonomous systems
- It defines a route as a collection of a number of AS that it passes through from source AS to destination AS
- This list of ASes are called AS path and used to avoid routing loop
- AS path is also used to select path to destination

What is AS path?

- An AS path example:




```
12.6.126.0/24 207.126.96.43  1021  0 6461 7018 6337 11268 i
```

AS Path

BGP Traffic Arrangement Definition

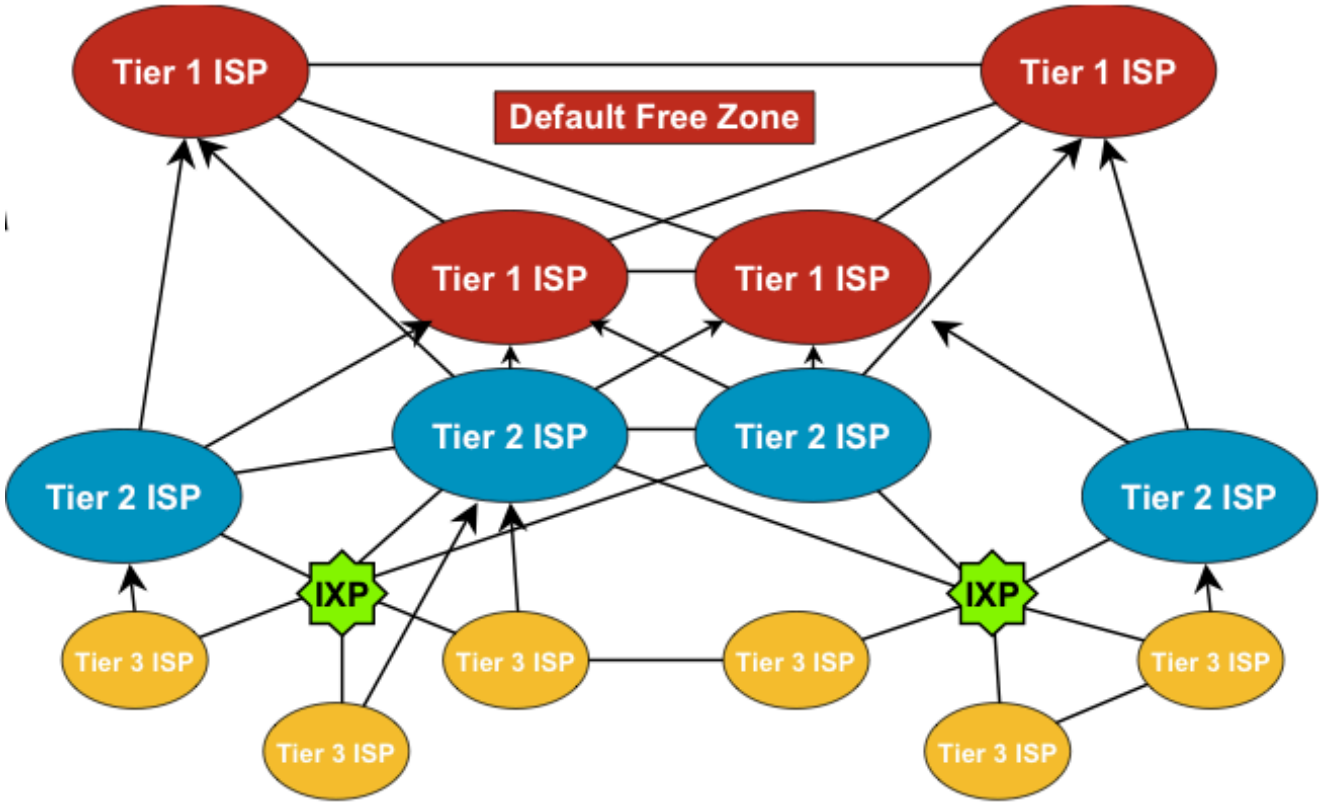
- Transit
  - Forwarding traffic through the network usually for a fee
  - I.e Internet service from upstream ISP
- Peering
  - Exchanging traffic without any fee
  - I.e Connection in an IXP
- Default
  - Where to send traffic if there no explicit route match in the routing table

What is Default Free Zone?

- Default free zone is made up of Tire One ISP routers which have explicit routing information about every part of the Global Internet
- So there is no need of default route
- If there is no destination network match, then that prefix is still not announced/ used by any ISP yet

ISP Hireracial Connection

- Connectivity Diagram:



BGP General Operation

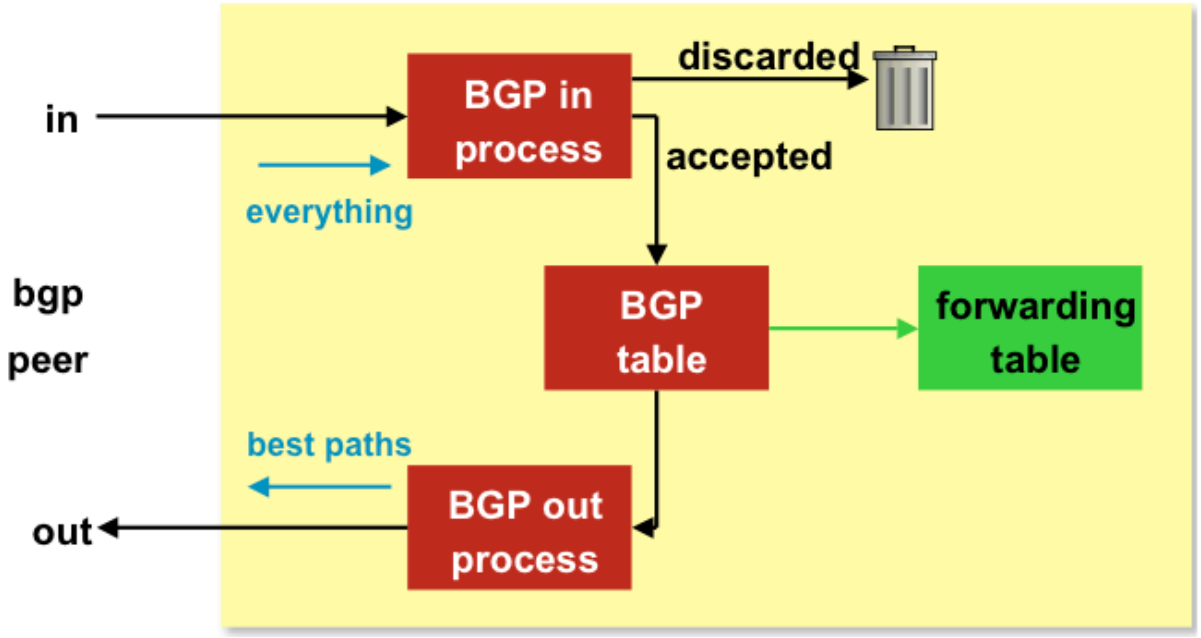
- BGP maintain 3 database i.e Neighbor Table, BGP Table and Forwarding Table
- Learns multiple paths via internal and external BGP speakers
- Picks the best path and installs them on the forwarding tables
- Best path is sent to external BGP neighbors
- Policies are applied by influencing the best path selection

Constructing the Forwarding Table

- BGP “In” process
  - Receives path information from peers
  - Results of BGP path selection placed in the BGP table “best path” flagged
- BGP “Out” process
  - Announce “best path” information to peers
- Best path installed in forwarding table if:
  - Prefix and prefix length are equal
  - Lowest protocol distance

Constructing the Forwarding Table

- Flowchart:
-



BGP Terminology

- Neighbor
  - Any two routers that have formed a TCP connection to exchange BGP routing information are called peers or neighbors
- iBGP
  - iBGP refers to the BGP neighbor relationship within the same AS.
  - The neighbors do not have to be directly connected.
- eBGP
  - When BGP neighbor relationship are formed between two peers belongs to different AS are called eBGP.
  - EBGP neighbors by default need to be directly connected.

Building Neighbor Relationship

- After adding BGP neighbor:
  - Both router establish a TCP connection and send open message
  - If open message is accepted then both send keepalive message to each other to confirm open message
  - After both confirm open message by sending keepalive message they establish BGP neighbor relationship and exchange routing information

BGP message type

- Open Message
  - To establish BGP neighbor relationship
- Keepalive message
  - Only contain message header to maintain neighbor relationship. Sent every periodic interval
- Update message
  - Contain path information. One update message contain one path information. Multiple path need multiple update message to be sent
- Notification message
  - Sent when an error condition occur and BGP connection closed immediately

BGP Open message

- Open message contain:
  - BGP Version number
  - AS number of the local router
  - BGP holdtime in second to elapse between the successive keepalive message
  - BGP router ID which is a 32 bit number. Usually an IPv4 address is used as router ID
  - Optional parameters i.e types, length and value encoded. An example optional parameter is session authentication info

BGP Keepalive Message

- Send between BGP peers after every periodic interval (60 Sec)
- It refresh hold timer from expiration (180sec)
- A keepalive message contain only the message header

BGP Update Message

- An update message contain:
  - Withdrawn routes: a list contain address prefix that are withdrawn from service
  - Path attributes: includes AS path, origin code, local pref etc
  - Network-layer reachablity information: includes a list of address prefix reachable by this path

BGP Notification message

- Only sent when an error condition occur and detected in a network and BGP connection is closed immediately
- Notification message contain an error code, an error subcode, and data that are related to that error

BGP Neighbor Relationship States

- BGP neighbor goes through following steps:
  - Idle: Router is searching its routing table to reach the neighbor
  - Connect: Router found route and completed TCP three-way handshake
  - Open Sent: Open message sent with the parameter for BGP session
  - Open Confirm: Router receive agreement on the parameter to establish BGP session
  - Established: Peering is established and routing information exchange began

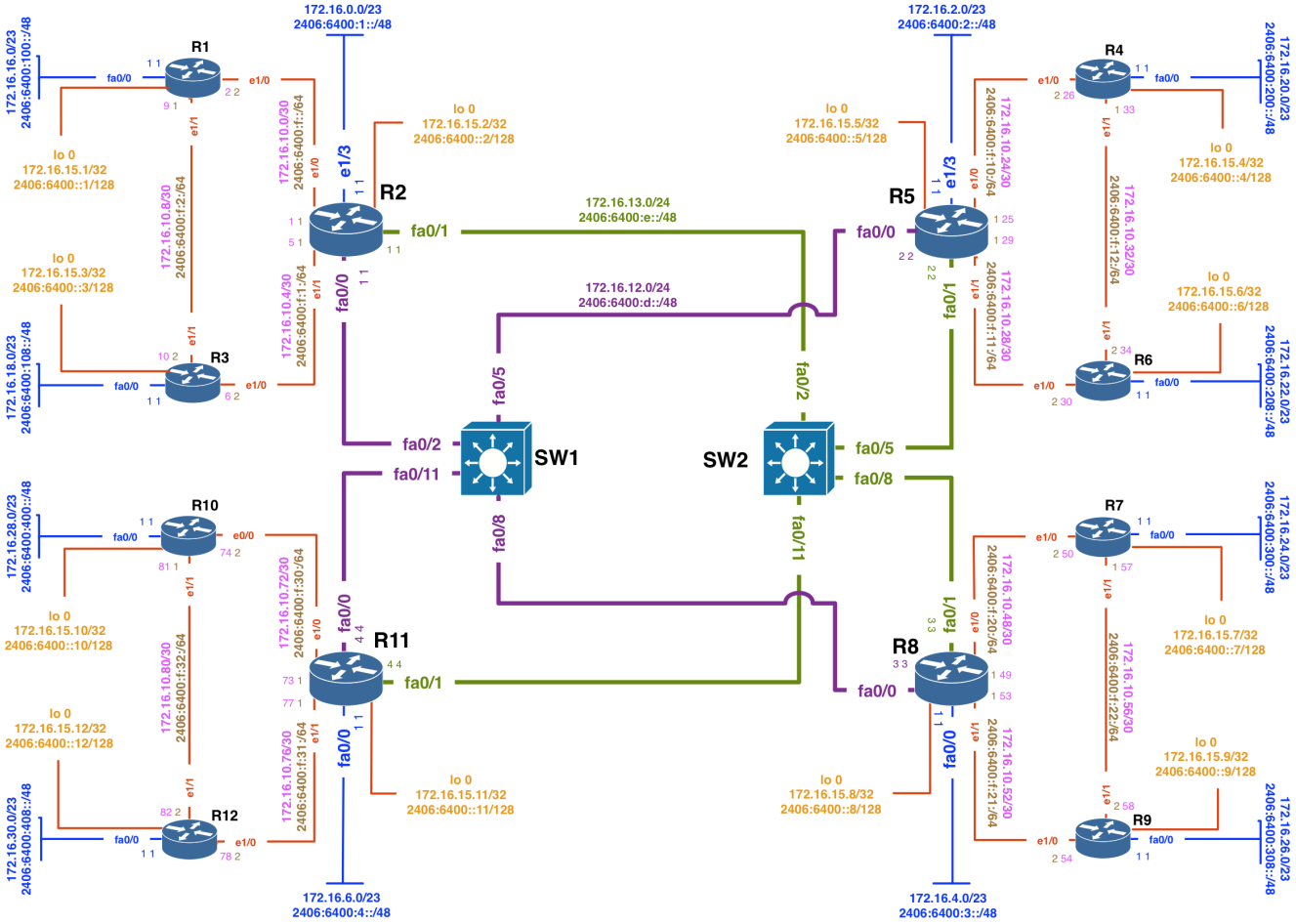
Troubleshoot BGP Neighbor Relation

- Idle:
  - The router can not find address of the neighbor in its routing table
- Active:
  - Router found address of the neighbor in its routing table sent open message and waiting for the response from the neighbor
- Cycle between Active/Idle
  - Neighbor might peer with wrong address
  - Does not have neighbor statement on the other side
  - BGP open message source IP address does not match with remote side neighbor statement or no route to source IP address

iBGP Peering

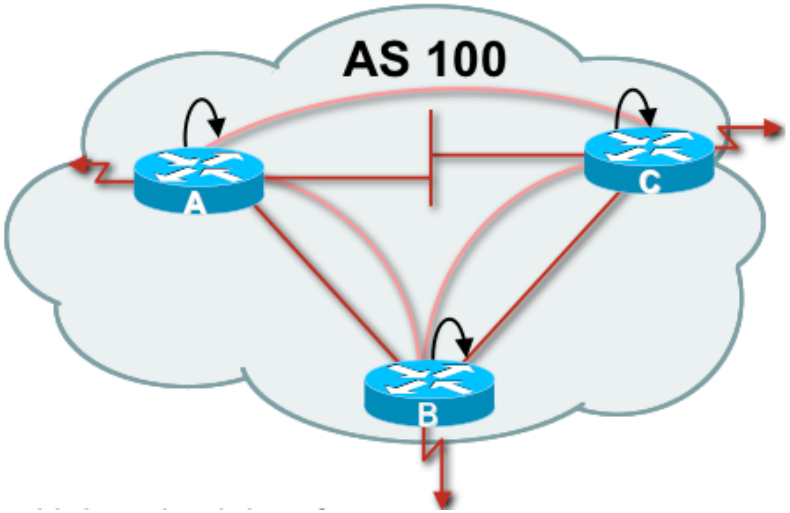
- BGP peer within the same AS
- Not required to be directly connected
- iBGP peering require full mesh peering
  - Within an AS all iBGP speaker must peer with other iBGP speaker
  - They originate connected network
  - Pass on prefixes learned from outside AS
  - They do not forward prefixes learned from other iBGP peer

Training ISP IPV6 Addressing Pan



Training ISP IPv6 Address Plan

iBGP Peering with Loopback Interface

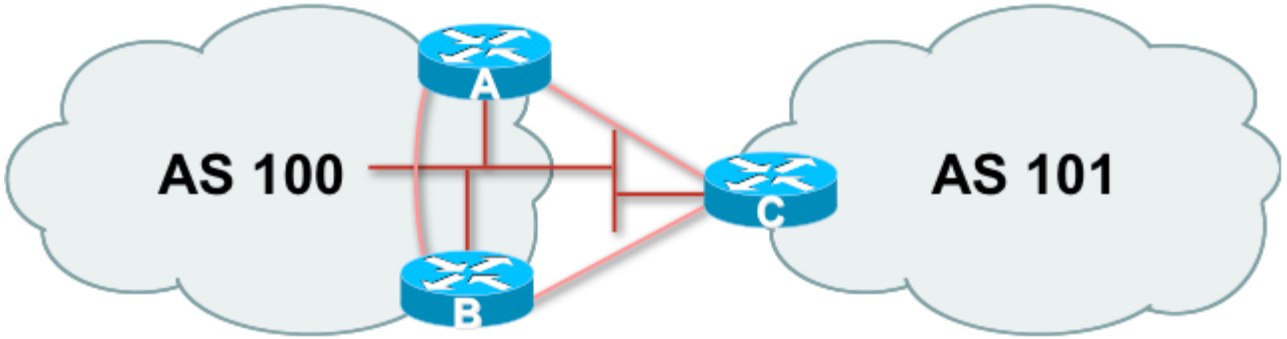


- If iBGP speakers has multiple connection then it is advisable to peer with loopback
- Connected network can go down which might loose iBGP peering
- Loopback interface will never go down

iBGP Neighbor Update Source

- This command allows the BGP process to use the IP address of a specified interface as the source IP address of all BGP updates to that neighbor
- A loopback interface is usually used as it will never goes down as long as the router is operational
- All BGP message will use the referenced interface as source of the messages

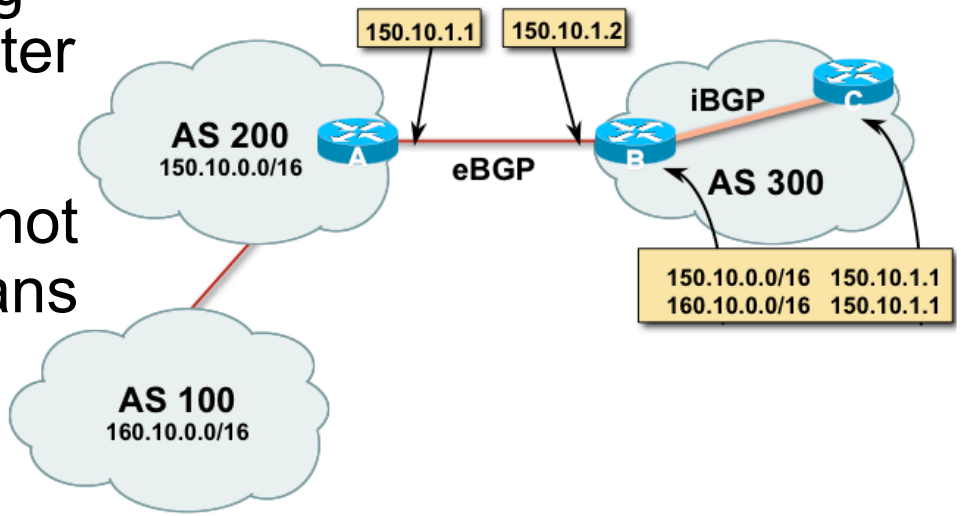
eBGP Peering



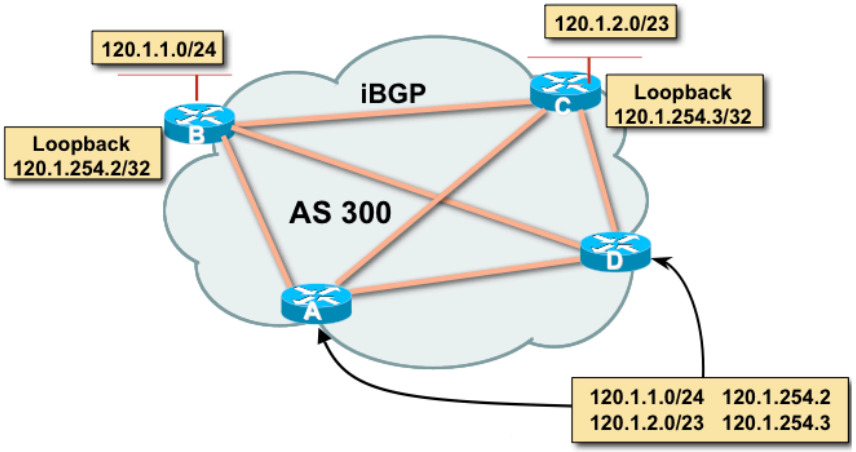
- Peering with BGP speaker in different AS
- Peers should be directly connected and share same WAN link
- eBGP neighbors are usually routed through connected network

BGP Next Hop Behavior

- BGP is an AS-by-AS routing protocol not a router-by router routing protocol.
- In BGP, the next hop does not mean the next router it means the IP address to reach the next AS
  - I.e Router A advertise 150.10.0.0/16 and 160.10.0.0/16 to router B in eBGP with next hop 150.10.1.1
  - Router B will update Router C in iBGP keeping the next hop unchanged



iBGP Next Hop



- Next hop is iBGP router loopback address
- Recursive route look-up
- Loopback address need to announce through IGP (OSPF)

BGP Synchronous Rule

- BGP do not use or advertise any route to an external neighbor learned by iBGP until a matching route has been learned from an IGP i.e OSPF or static
- It ensure consistency of information throughout the AS
- Avoid black hole route within an AS
- It is safe to turn off if all routers with in the AS run full-mesh iBGP
- Advisable to disable this feature (BCP)

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APNIC

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BGP Attributes

BGP metrics are called path attributes. Here is the classifications BGP attributes:

Well-known mandatory
- AS-Path
- Next-hop
- Origin

Well-known discretionary
- Local preference
- Atomic aggregate

Optional transitive
- Community
- Aggregator

Optional non-transitive
- Multi-exit-discriminator (MED)

Well-Known Attributes

- Must be recognized by all compliant BGP implementations
- Are propagated to other neighbors

Well-Known Mandatory Attributes

- Must be present in all update messages
- ***AS Path***
- ***Next-hop***
- ***Origin***

Well-Known Discretionary Attributes

- May be present in update messages
- ***Local preference***
- ***Atomic aggregate***

Optional Attributes

- Recognized by some implementations (could be private) expected not to be recognized by everyone
- Recognized optional attributes are propagated to other neighbors based on their meaning

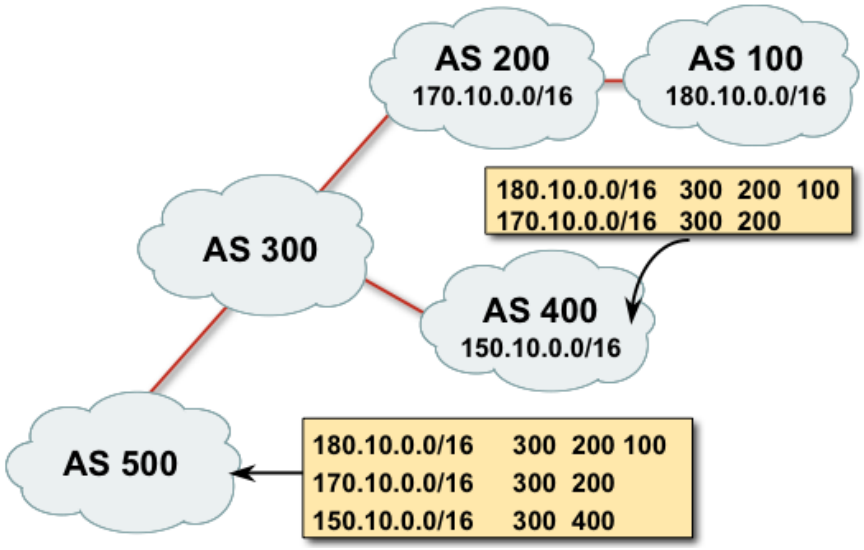
Optional Transitive Attributes

- If not recognized, are marked as partial and propagated to other neighbors
- ***Community***
- ***Aggregator***

Optional Non Transitive attributes

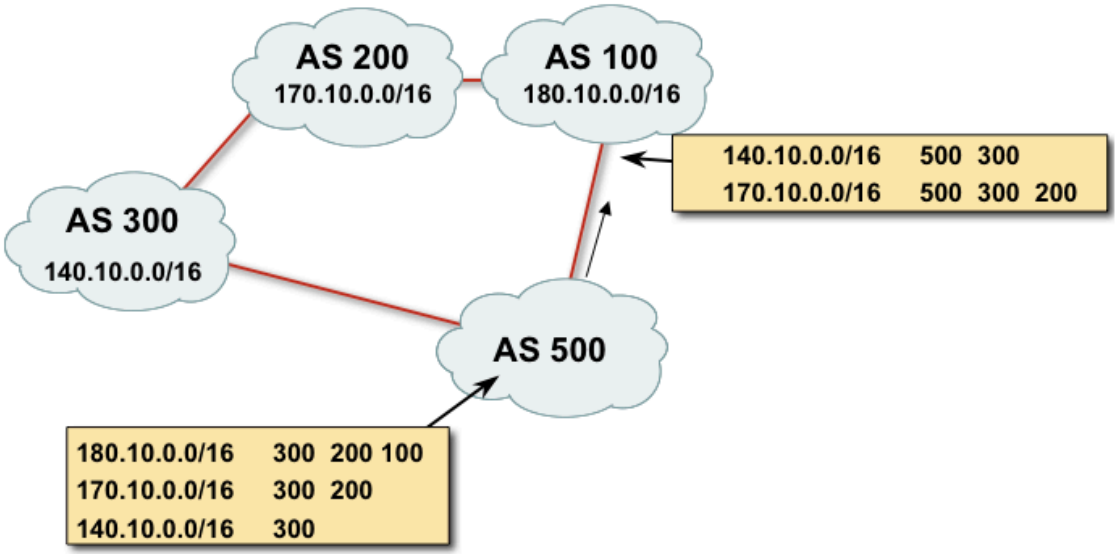
- Discarded if not recognized
- ***Multi Exit Discriminator (MED)***

AS Path Attribute



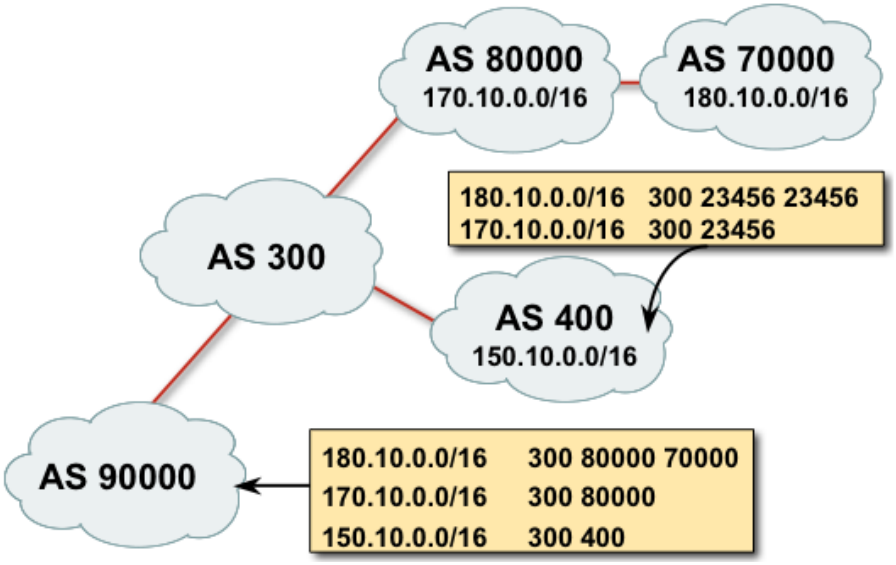
- Sequence of ASes a route has traversed
- Used for
  - Loop detection
  - Path metrics where the length of the AS Path is used as in path selection

AS Path Loop Detection



- 180.10.0.0/16 is not accepted by AS100 as the prefix has AS100 in its AS-PATH
- This is loop detection in action

AS Path Attribute (2 byte and 4 byte)



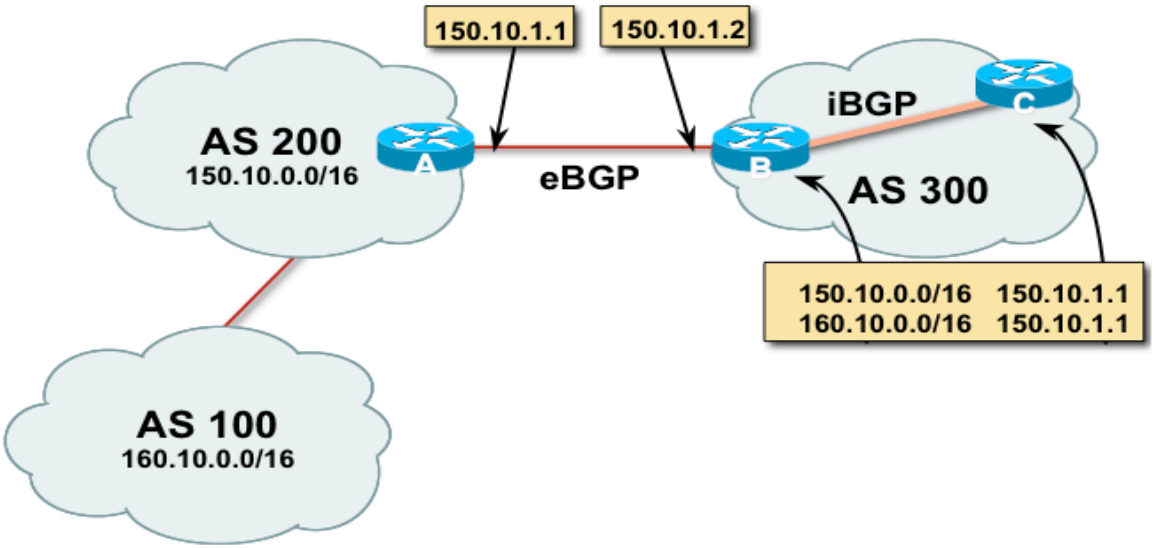
- Internet with 16-bit and 32-bit ASNs
  - 32-bit ASNs are 65536 and above
  - AS-PATH length maintained

AS Path and AS4 Path Example

Router5:

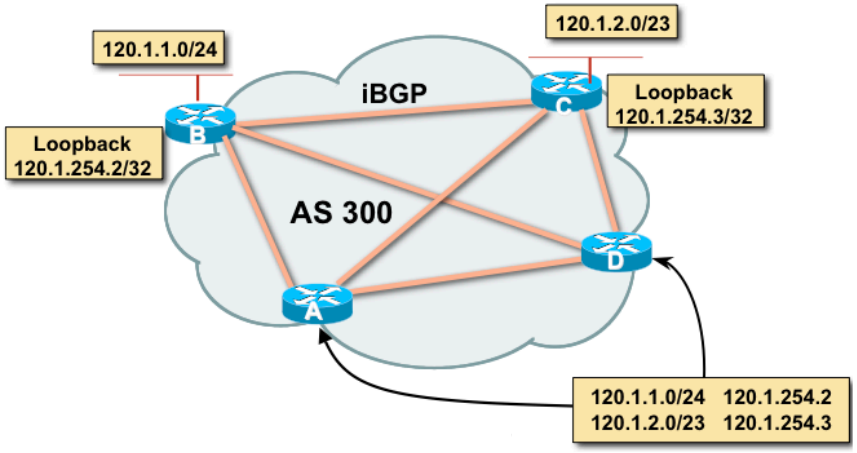
```
Network          Next Hop            Metric  LocPrf Weight          Path
*> 2001::/32     2406:6400:F:41::1
                                                    0 23456 38610 6939 I
* i              2406:6400:D::5 0        100    0 45192 4608 4826 6939 i

*> 2001:200::/32    2406:6400:F:41::1
                                                    0 23456 38610 6939 2500 i
* i              2406:6400:D::5 0 100 0 45192 4608 4826 6939 2500 i
```

eBGP Next Hop



- The IP address to reach the next AS
  - Router A advertise 150.10.0.0/16 and 160.10.0.0/16 to router
  - B in eBGP with next hop 150.10.1.1 (Change it to own IP)
  - Router B will update Router C in iBGP keeping the next hop unchanged
- Well known mandatory attribute

iBGP Next Hop



- Next hop is iBGP router loopback address
- Recursive route look-up
- Loopback address need to announce through IGP (OSPF)
- iBGP send update next-hop unchanged

Next Hop Best Practice

- IOS default is for external next-hop to be propagated unchanged to iBGP peers
  - This means that IGP has to carry external next-hops
  - Forgetting means external network is invisible
  - With many eBGP peers, it is unnecessary extra load on IGP
- ISP Best Practice is to change external next-hop to be that of the local router
  - neighbor x.x.x.x next-hop-self

Next Hop Self Configuration

- Next hop default behavior can be changed by using next-hop-self command
- Forces all updates for this neighbor to be advertised with this router as the next hop
- The IP address used for next-hop-self will be the same as the source IP address of the BGP packet

BGP Origin Attribute

- The origin attribute informs all autonomous systems how the prefix introduced into BGP
- Well known mandatory attribute
- Three values: IGP, EGP, incomplete
  - IGP generated by BGP network statement
  - EGP generated by EGP
  - Incomplete redistributed from another routing protocol

BGP Origin Attribute Example

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,

r RIB-failure, S Stale

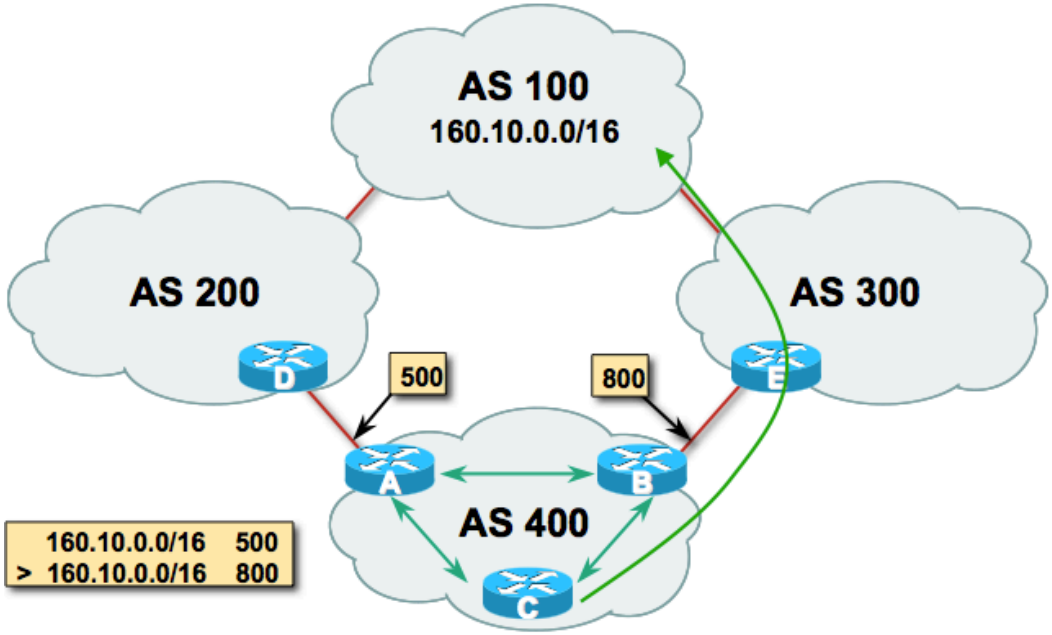
Origin codes: i - IGP, e - EGP, ? – incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 2001::/32	2406:6400:F:41::1	0		23456	38610 6939 i
* i	2406:6400:D::5	0	100	0	45192 4608 4826 6939 i

BGP Local Preference Attribute

- Local preference is used to advertise to IBGP neighbors only about how to leave their AS (Outbound Traffic).
- Paths with highest preference value are most desirable
- Local preference attribute is well-known and discretionary and is passed only within the AS
- Cisco Default Local Pref is 100

BGP Local Preference Attribute



- For destination 160.10.0.0/16 Router A advertise local pref 500 and Router B advertise local pref 800 in iBGP
- 800 will win best path (Router B)

BGP Local Pref Attribute Example

Network Next Hop Metric LocPrf Weight Path

*> 2001::/32 2406:6400:F:41::1

0 23456 38610 6939 i

* i 2406:6400:D::5 0 100 0 45192 4608 4826 6939 i

*> 2001:200::/32 2406:6400:F:41::1

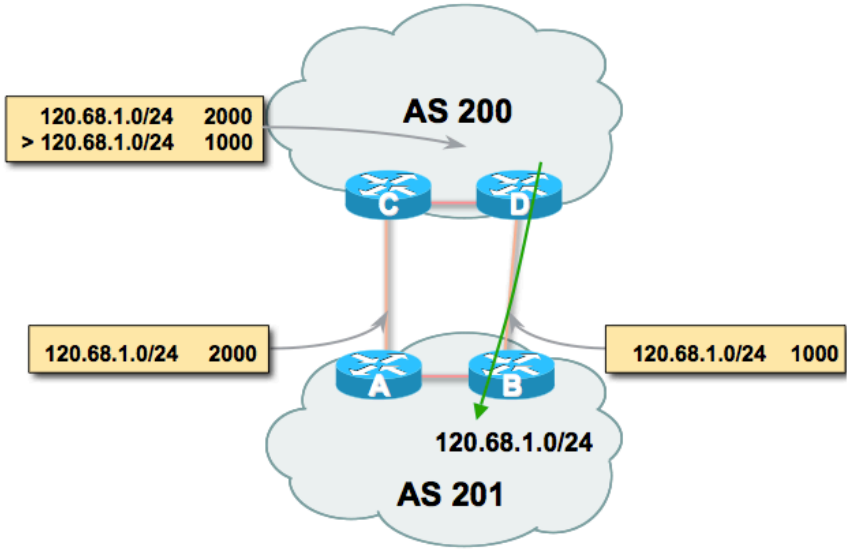
0 23456 38610 6939 2500 i

* i 2406:6400:D::5 0 100 0 45192 4608 4826 6939 2500 i

BGP MED Attribute

- MED is used to advertise to EBGP neighbors about how to exit their AS to reach networks owned by this AS (Incoming traffic).
- MED is sent to EBGP neighbors only.
- The paths with the lowest MED value are the most desirable
- The MED attribute is optional and non transitive

BGP MED Attribute



- For prefix 120.68.1.0/24 Router B send MED 1000 and router A send MED 2000 to eBGP neighbor
- Incoming traffic from AS200 will choose Router B since lowest MED will win

BGP MED Example

Network Next Hop Metric LocPrf Weight Path

*> 2001::/32 2406:6400:F:41::1

0 23456 38610 6939 i

* i 2406:6400:D::5 0 100 0 45192 4608 4826 6939 i

*> 2001:200::/32 2406:6400:F:41::1

0 23456 38610 6939 2500 i

* i 2406:6400:D::5 0 100 0 45192 4608 4826 6939 2500 i

BGP Community Attribute

- Community is a tagging technique to mark a set of routes
- Upstream service provider routers can then use these flags to apply specific routing polices (i.e local preference etc) within their network
- Represented as two 16 bit integers (RFC1998)
- Common format is <local-ASN>:xx
- I.e 0:0 to 0:65535 and 65535:0 to 65535:65535 are reserved
- Very useful in applying policies within and between ASes
- Optional & transitive attribute

BGP Route Selection Process

- Step 1: Prefer highest weight (local to router)
- Step 2: Prefer highest local preference (global within AS)
- Step 3: Prefer route originated by the local router
- Step 4: Prefer shortest AS path
- Step 5: Prefer lowest origin code (IGP < EGP < incomplete)
- Step 6: Prefer lowest MED (from other AS)
- Step 7: Prefer EBGP path over IBGP path
- Step 8: Prefer the path through the closest IGP neighbor
- Step 9: Prefer oldest route for EBGP paths
- Step 10: Prefer the path with the lowest neighbor BGP router ID

Questions?

APNIC

Overview

Routing Workshop (3 Days)

- Introduction to IP Routing
- Routing Protocol Basic
- IPv6 Address Structure
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- Operation of OSPF Routing Protocol
- Lab Exercise on Basic Router and OSPF Dynamic Routing Configuration
- Basic BGP Operation
- BGP Attributes and Path Selection Process
- **BGP Scaling Techniques**
- Lab Exercise on iBGP, eBGP, RR, Peer group etc
- Internet Exchange [IX] Policy Overview and Configuration requirement

BGP Peer Group

- Defines a template with parameters set for a group of neighbors instead of individually
- Useful when many neighbors have the same outbound policies
- Members can have a different inbound policy
- Updates generated once per peer group
- Simplifies configuration

BGP Peer Group

- Problem – how to scale iBGP
  - Large iBGP mesh slow to build
  - iBGP neighbors receive the same update
  - Router CPU wasted on repeat calculations
- Solution – peer-groups
  - Group peers with the same outbound policy
  - Updates are generated once per group

BGP Peer Group -Advantages

- Makes configuration easier
- Makes configuration less prone to error
- Makes configuration more readable
- Lower router CPU load
- iBGP mesh builds more quickly
- Members can have different inbound policy
- Can be used for eBGP neighbors too!

BGP Peer Group -BCP

- Always configure peer-groups for iBGP
  - Even if there are only a few iBGP peers
  - Easier to scale network in the future
- Consider using peer-groups for eBGP
  - Especially useful for multiple BGP customers using same AS (RFC2270)
  - Also useful at Exchange Points where ISP policy is generally the same to each peer

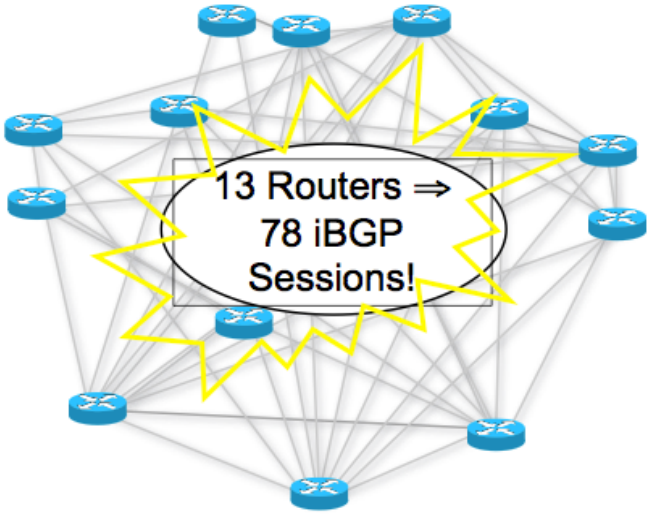
BGP Route Reflector

- In a transit AS all router in the core need to know the complete routing table coming from Internet
- Global routing table size is above 300k prefix
- Practically impossible to redistribute these route in IGP i.e OSPF
- Solution is to forward these large routing information by iBGP

BGP Route Reflector

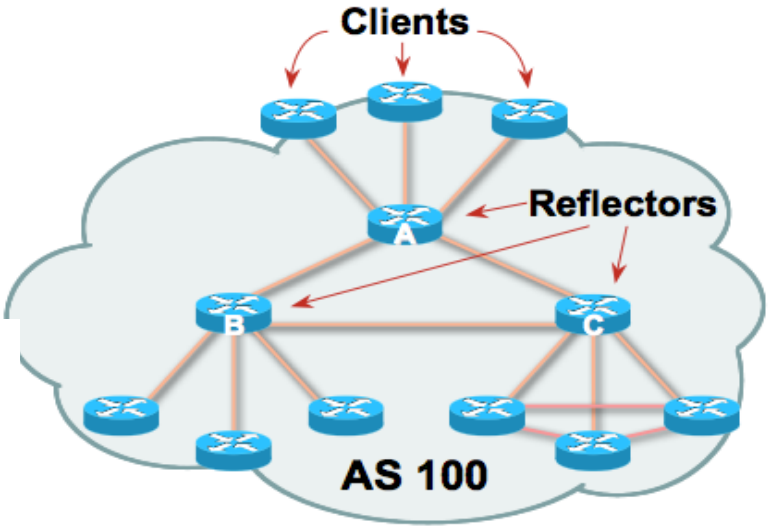
- iBGP use TCP to make reliable delivery of these large routing information across all core router in a transit ISP
- TCP can not broadcast so need to make individual delivery to all iBGP speaker
- To protect routing loop iBGP use split horizon rule so can not send routing information to neighbor learn via iBGP
- So iBGP need full mesh peering with other core router in a transit ISP

BGP Route Reflector



- Avoid ½n(n-1) iBGP mesh
- n=1000 ⇒ nearly half a million iBGP sessions!
- Solution -Route reflector

BGP Route Reflector



- There will be Reflector, Client and Non-Client
- Reflector receives path from clients and non-clients
- Select the best path then If best path is from client, reflect to other clients and non-clients
- If best path is from non-client, reflect to clients only
- Described in RFC4456

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APNIC

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Case study- Deployment IPv6 in EGP

- Scenario:
  - BGP4 is used in Training ISP network
  - iBGP is used between internal routers in Training ISP to carry external prefixes (i.e Customer & Global Internet Prefixes)
  - Route Reflector is used to resolve iBGP full mesh scalability issue.

Case study- Deployment IPv6 in EGP

- Scenario:
  - Transit service with upstream ASes is configured with eBGP
  - Customer network from downstream can also be configured with eBGP or static
  - Training ISP is having one native IPv6 transit and one tunnel IPv6 transit with AS45192 & AS131107 (2.35 as dot)

Case study- Deployment IPv6 in EGP

- Basic BGP Configuration:

```
router bgp 17821
address-family ipv6
no synchronization
```

Case study- Deployment IPv6 in EGP

Adding iBGP Neighbor:

```
router bgp 17821
address-family ipv6
!
neighbor 2406:6400:0000:0000::2 remote-as 17821
neighbor 2406:6400:0000:0000::2 update-source loopback 0
neighbor 2406:6400:0000:0000::2 activate
```

iBGP neighbor is always recommended with loopback interface

Case study- Deployment IPv6 in EGP

Announcing IPv6 Prefix:

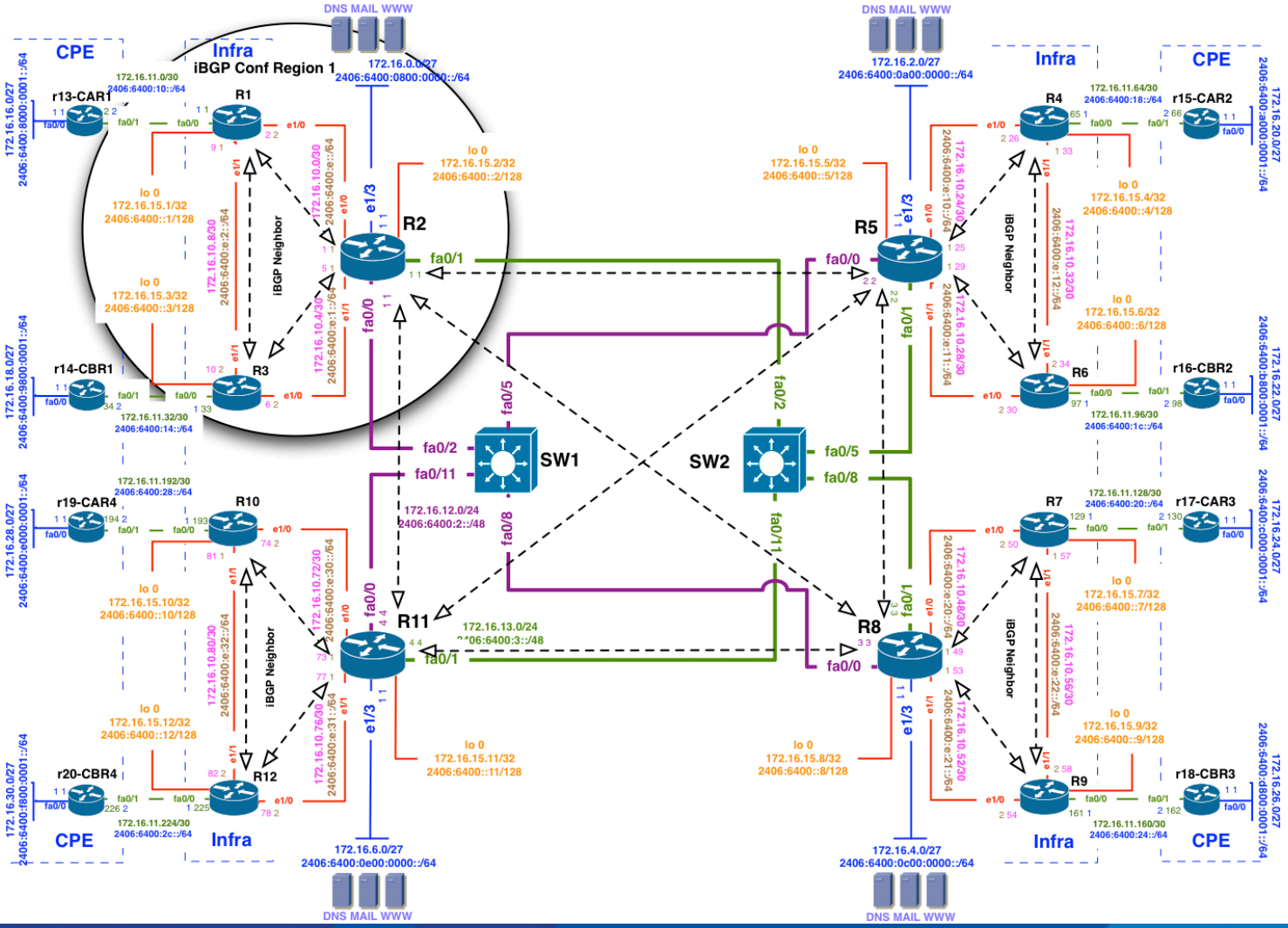
```
router bgp 17821
address-family ipv6
!
neighbor 2406:6400:0000:0000::2 remote-as 17821
neighbor 2406:6400:0000:0000::2 update-source loopback 0
neighbor 2406:6400:0000:0000::2 activate
!
network 2406:6400:0100:0000::/48
```

Case study- Deployment IPv6 in EGP

Add Pull-up route if needed:

```
router bgp 17821
address-family ipv6
!
neighbor 2406:6400:0000:0000::2 remote-as 17821
neighbor 2406:6400:0000:0000::2 update-source loopback 0
neighbor 2406:6400:0000:0000::2 activate
!
network 2406:6400:0100:0000::/48
exit
exit
ipv6 route 2406:6400:0100:0000::/48 null 0
```

iBGP Peering For Region 1



IPv4 iBGP Conf POP Router

Router1

```
config t
router bgp 17821
address-family ipv4
no auto-summary
no synchronization
neighbor 172.16.15.2 remote-as 17821
neighbor 172.16.15.2 update-source loopback 0
neighbor 172.16.15.2 activate
neighbor 172.16.15.3 remote-as 17821
neighbor 172.16.15.3 update-source loopback 0
neighbor 172.16.15.3 activate
network 172.16.16.0 mask 255.255.254.0
exit
exit
ip route 172.16.16.0 255.255.254.0 null 0 permanent
exit
wr
```

IPv4 iBGP Configuration Verification

POP Router

```
sh bgp ipv4 unicast summary

sh bgp ipv4 unicast

sh ip route bgp

sh bgp ipv4 unicast neighbors [router 1……router12
  loopback] advertised-routes

sh bgp ipv4 unicast neighbors [router 1……router12
  loopback] received-routes

sh ip route [R2, R5, R8, R11 datacenter prefix]
```

IPv6 iBGP Conf POP Router

Router1

```
config t
router bgp 17821
address-family ipv6
no synchronization
neighbor 2406:6400:0000:0000::2 remote-as 17821
neighbor 2406:6400:0000:0000::2 update-source loopback 0
neighbor 2406:6400:0000:0000::2 activate
neighbor 2406:6400:0000:0000::3 remote-as 17821
neighbor 2406:6400:0000:0000::3 update-source loopback 0
neighbor 2406:6400:0000:0000::3 activate
network 2406:6400:0100:0000::/45
exit
exit
ipv6 route 2406:6400:0100:0000::/45 null 0
exit
wr
```

IPv6 iBGP Configuration Verification

POP Router

sh bgp ipv6 unicast summary

sh bgp ipv6 unicast

sh ipv6 route bgp

sh bgp ipv6 unicast neighbors [router 1……router12 loopback] advertised-routes

sh bgp ipv6 unicast neighbors [router 1……router12 loopback] received-routes

sh ipv6 route [R2, R5, R8, R11 datacenter prefix]

IPv4 iBGP Conf Core Router

Router2 Configuration

```
config t
router bgp 17821
address-family ipv4
no auto-summary
no synchronization
neighbor 172.16.15.1 remote-as 17821
neighbor 172.16.15.1 update-source loopback 0
neighbor 172.16.15.1 activate
neighbor 172.16.15.3 remote-as 17821
neighbor 172.16.15.3 update-source loopback 0
neighbor 172.16.15.3 activate
neighbor 172.16.15.5 remote-as 17821
neighbor 172.16.15.5 update-source loopback 0
neighbor 172.16.15.5 activate
neighbor 172.16.15.8 remote-as 17821
neighbor 172.16.15.8 update-source loopback 0
neighbor 172.16.15.8 activate
neighbor 172.16.15.11 remote-as 17821
neighbor 172.16.15.11 update-source loopback 0
neighbor 172.16.15.11 activate
network 172.16.0.0 mask 255.255.254.0
exit
exit
ip route 172.16.0.0 255.255.254.0 null 0 permanent
exit
Wr
```

IPv4 iBGP Conf Core Router

Router2 Configuration

```
config t
router bgp 17821
address-family ipv4
no auto-summary
no synchronization
neighbor 172.16.15.1 remote-as 17821
neighbor 172.16.15.1 update-source loopback 0
neighbor 172.16.15.1 activate
neighbor 172.16.15.3 remote-as 17821
neighbor 172.16.15.3 update-source loopback 0
neighbor 172.16.15.3 activate
neighbor 172.16.15.5 remote-as 17821
neighbor 172.16.15.5 update-source loopback 0
neighbor 172.16.15.5 activate
neighbor 172.16.15.8 remote-as 17821
neighbor 172.16.15.8 update-source loopback 0
neighbor 172.16.15.8 activate
neighbor 172.16.15.11 remote-as 17821
neighbor 172.16.15.11 update-source loopback 0
neighbor 172.16.15.11 activate
network 172.16.0.0 mask 255.255.254.0
exit
exit
ip route 172.16.0.0 255.255.254.0 null 0 permanent
exit
Wr
```

IPv4 iBGP Configuration Verification

Core Router

```
sh bgp ipv4 unicast summary

sh bgp ipv4 unicast

sh ip route bgp

sh bgp ipv4 unicast neighbors [router 1……router12
  loopback] advertised-routes

sh bgp ipv4 unicast neighbors [router 1……router12
  loopback] received-routes

sh ip route [R2, R5, R8, R11 datacenter prefix]
```

IPv6 iBGP Conf Core Router

Router2 Configuration

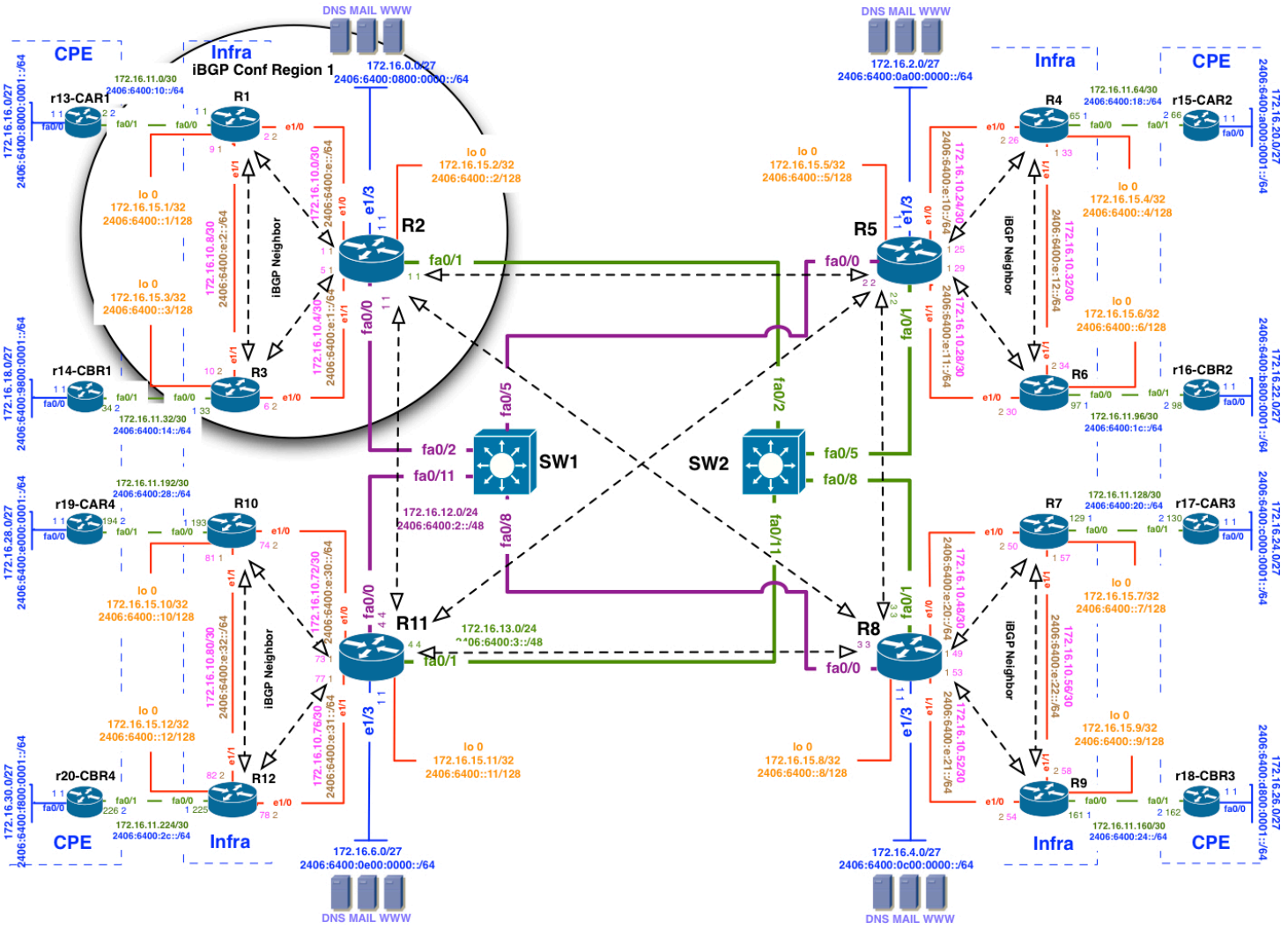
```
config t
router bgp 17821
address-family ipv6
no synchronization
neighbor 2406:6400:0000:0000::1 remote-as 17821
neighbor 2406:6400:0000:0000::1 update-source loopback 0
neighbor 2406:6400:0000:0000::1 activate
neighbor 2406:6400:0000:0000::3 remote-as 17821
neighbor 2406:6400:0000:0000::3 update-source loopback 0
neighbor 2406:6400:0000:0000::3 activate
neighbor 2406:6400:0000:0000::5 remote-as 17821
neighbor 2406:6400:0000:0000::5 update-source loopback 0
neighbor 2406:6400:0000:0000::5 activate
neighbor 2406:6400:0000:0000::8 remote-as 17821
neighbor 2406:6400:0000:0000::8 update-source loopback 0
neighbor 2406:6400:0000:0000::8 activate
neighbor 2406:6400:0000:0000::11 remote-as 17821
neighbor 2406:6400:0000:0000::11 update-source loopback 0
neighbor 2406:6400:0000:0000::11 activate
network 2406:6400:0001:0000::/48
exit
exit
ipv6 route 2406:6400:0001:0000::/48 null 0
exit
wr
```

IPv6 iBGP Configuration Verification

- Core Router

```
sh bgp ipv6 unicast summary

sh bgp ipv6 unicast

sh ipv6 route bgp

sh bgp ipv6 unicast neighbors [router 1……router12
  loopback] advertised-routes

sh bgp ipv6 unicast neighbors [router 1……router12
  loopback] received-routes

sh ipv6 route [R2, R5, R8, R11 datacenter prefix]
```

iBGP Full Mesh Issue

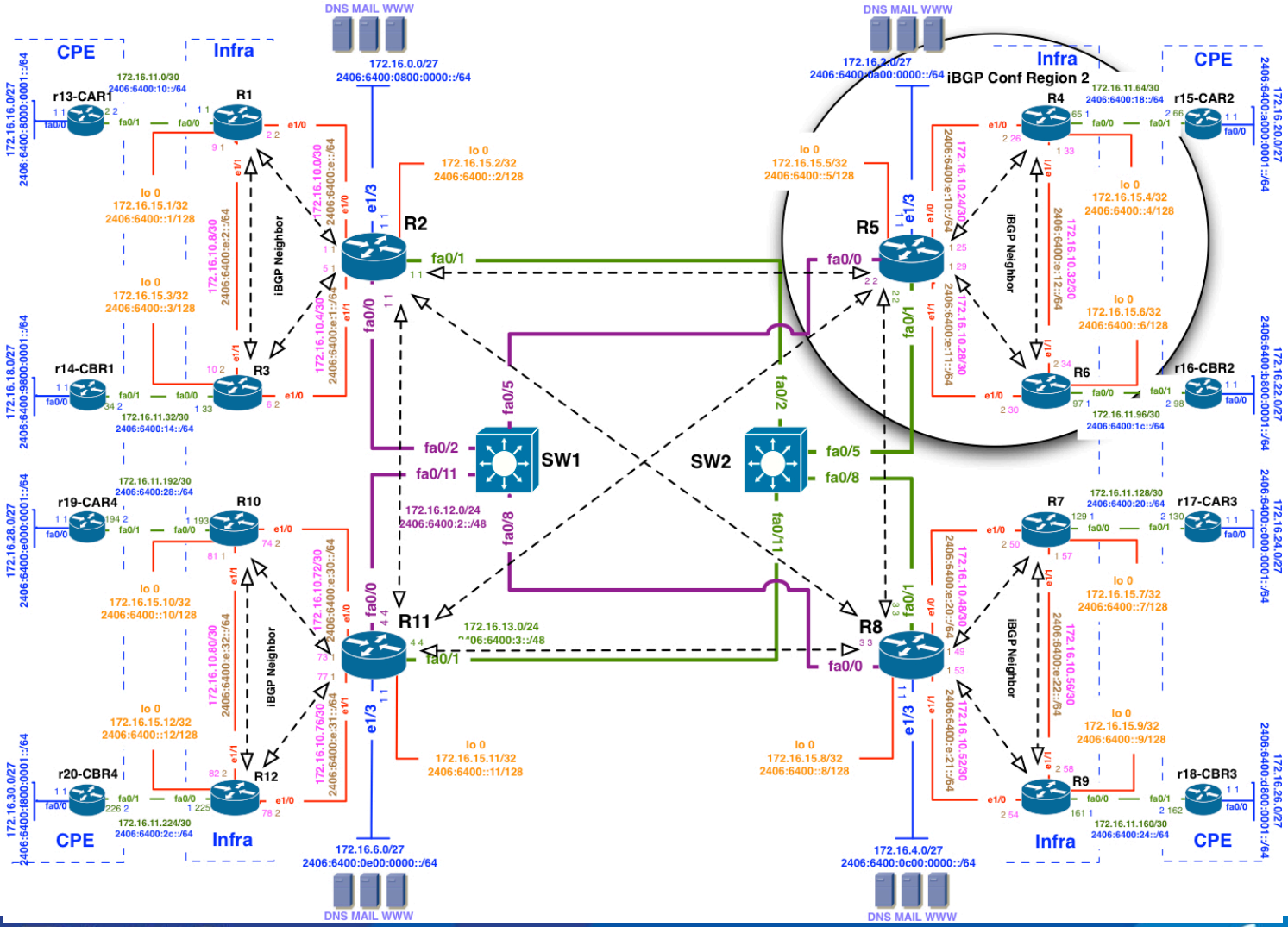


iBGP Full Mesh Issue

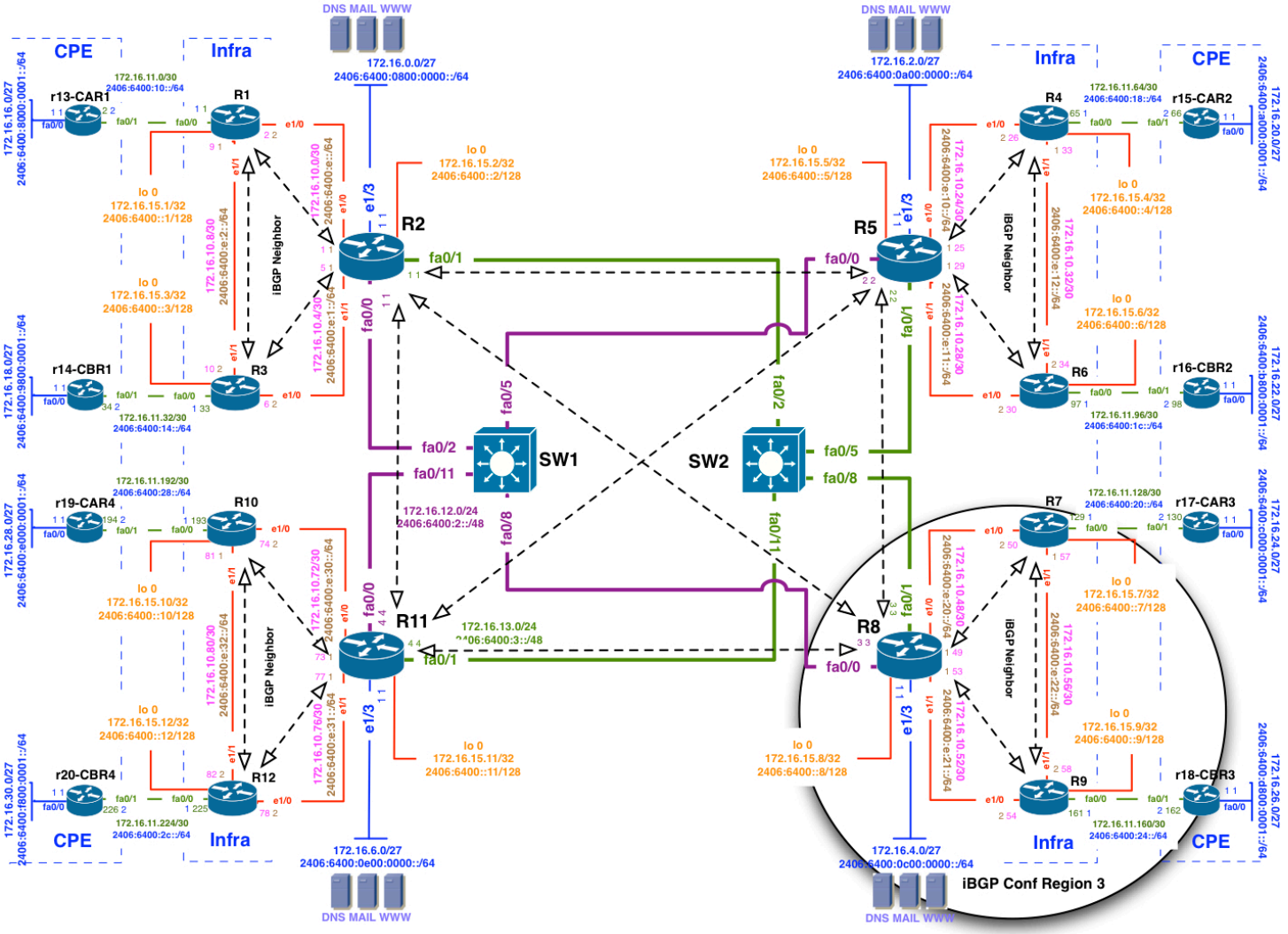
Route reflector configuration:

```
router bgp 17821
address-family ipv6
!
neighbor 2406:6400:0000:0000::1 remote-as 17821
neighbor 2406:6400:0000:0000::1 update-source loopback 0
neighbor 2406:6400:0000:0000::1 activate
!
neighbor 2406:6400:0000:0000::1 route-reflector-client
```

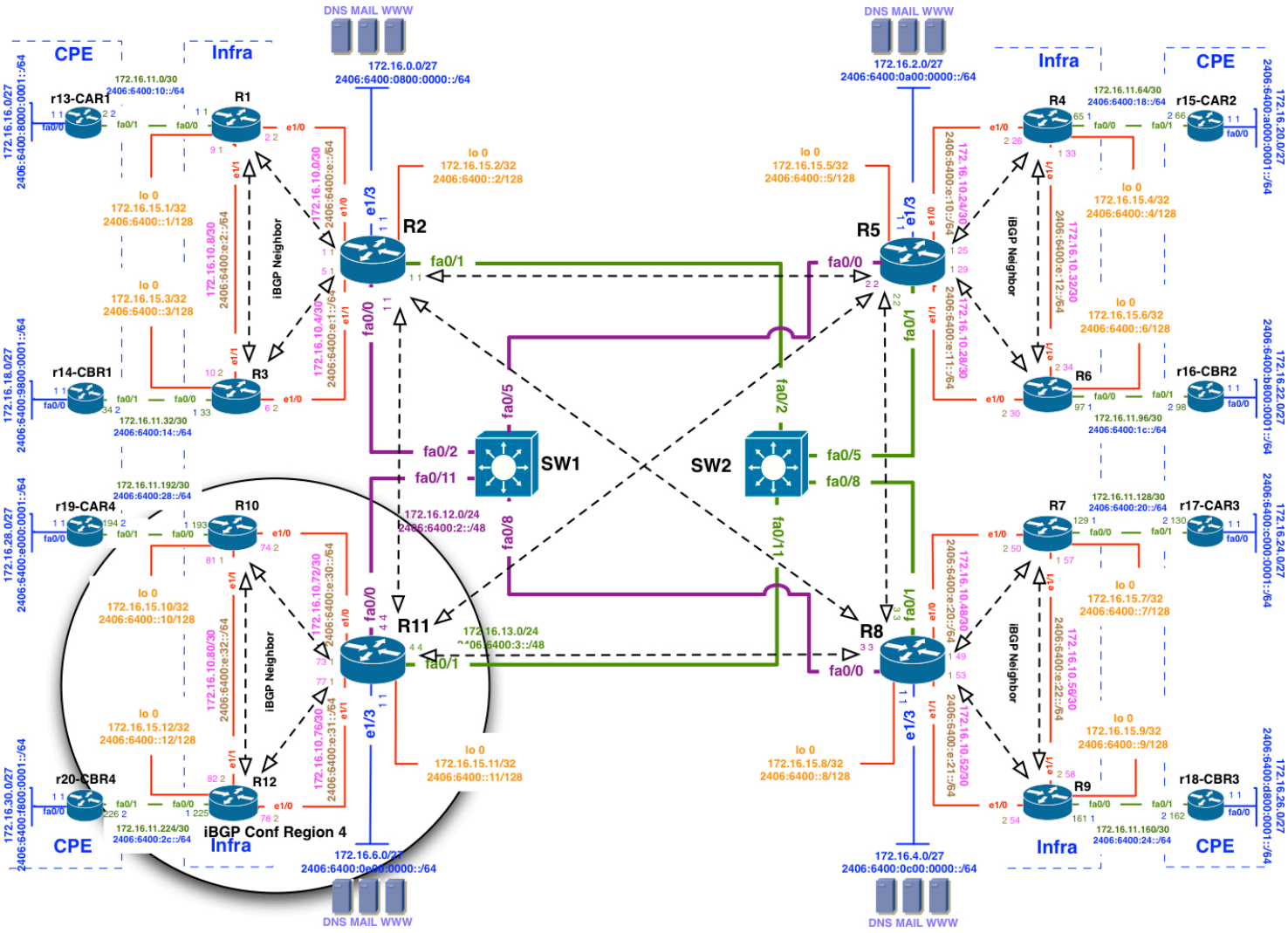
iBGP Peering For Region 2



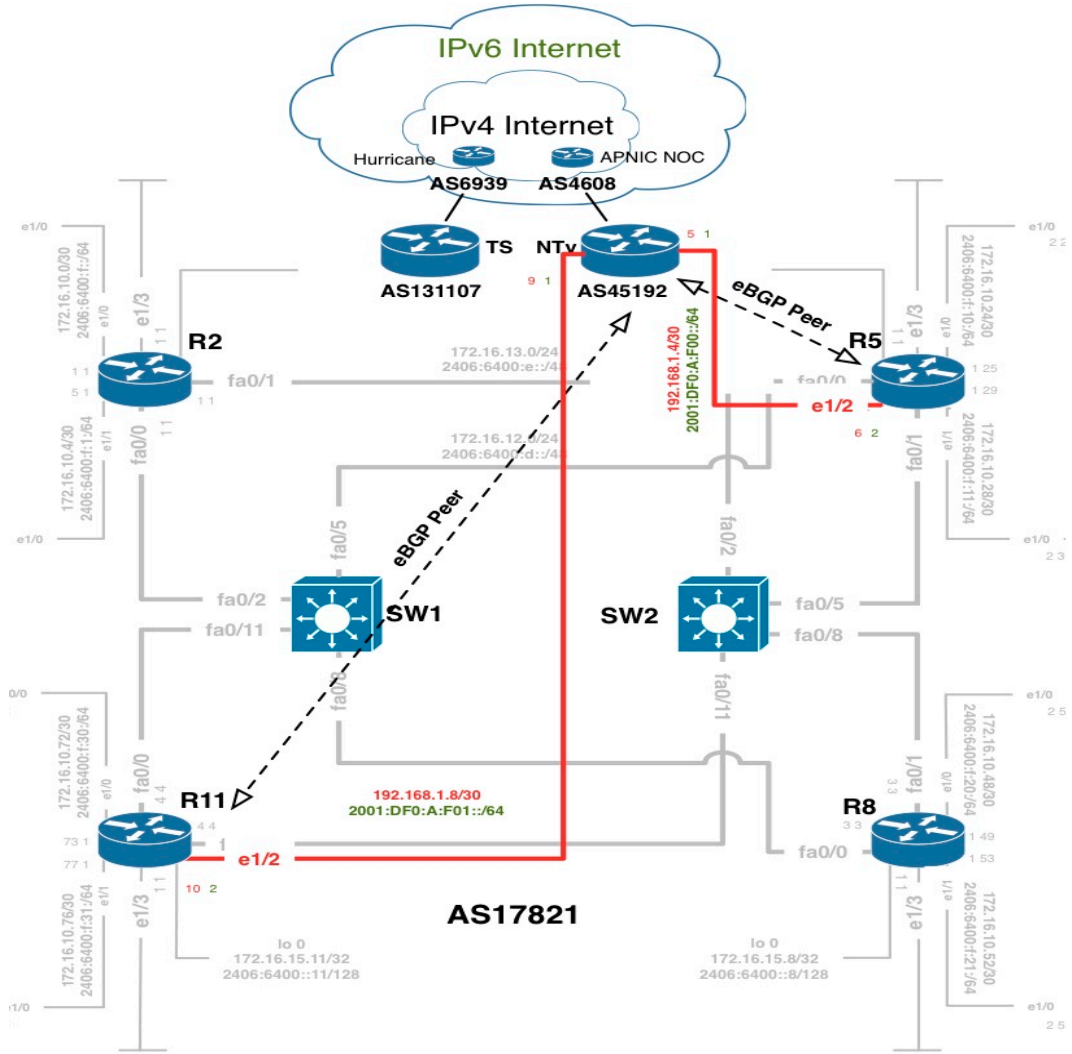
iBGP Peering For Region 3



iBGP Peering For Region 4



IPv6 Native Transit Conf Plan



IPv6 IOS Command For eBGP

Adding eBGP Neighbor:

```
router bgp 17821
address-family ipv6
!
neighbor 2406:6400:000D:0000::5 remote-as 45192
neighbor 2406:6400:000D:0000::5 activate
```

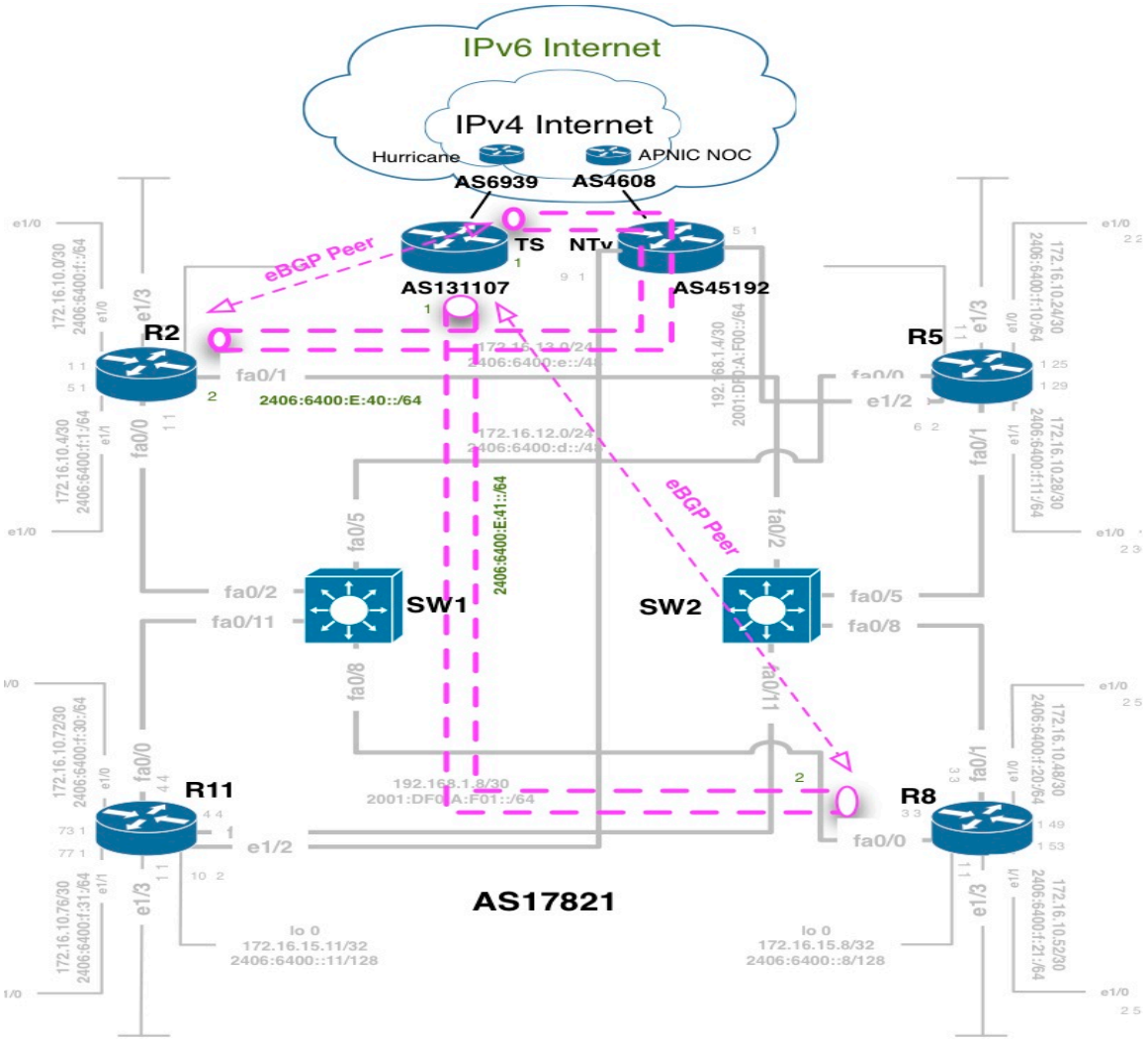
eBGP neighbor is always recommended with directly connected interface

IPv6 Native Transit Configuration

- Router5

```
config t
router bgp 17821
address-family ipv6
neighbor 2406:6400:000D:0000::5 remote-as 45192
neighbor 2406:6400:000D:0000::5 activate
neighbor 2406:6400:000E:0000::5 remote-as 45192
neighbor 2406:6400:000E:0000::5 activate
exit
exit
exit
Wr
```

IPv6 Tunnel Transit Configuration



6 to 4 Tunnel Configuration

IOS Command for Tunnel Interface:

Router2

```
config t
interface Tunnel0
tunnel source 172.16.15.2
tunnel destination 192.168.1.1
tunnel mode ipv6ip
ipv6 address 2406:6400:F:40::2/64
ipv6 enable
```

6 to 4 Tunnel Configuration

IOS Command for Tunnel Peering:

```
router bgp 17821
address-family ipv6
neighbor 2406:6400:F:40::1 remote-as 23456
neighbor 2406:6400:F:40::1 activate
```

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APNIC

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- Lab Exercise on iBGP, eBGP, RR, Peer group etc
- **Internet Exchange [IX] Policy Overview and Configuration requirement**

Case Study- IXP Configuration

- Two type of traffic exchange between ISPs
- Transit
  - Where ISP will pay to send/receive traffic
  - Downstream ISP will pay upstream ISP for transit service
- Peering
  - ISPs will not pay each other to interchange traffic
  - Works well if win win for both
  - Reduce cost on expensive transit link

IX Peering Model

- BLPA (Bi-Lateral Peering Agreement)
  - IX will only provide layer two connection/switch port to ISPs
  - Every ISPs will arrange necessary peering arrangement with others by their mutual business understanding.

- MLPA (Multi-Lateral Peering Agreement)
  - IX will provide layer two connection/switch port to ISPs
  - Each ISP will peer with a route server on the IX.
  - Route server will collect and distribute directly connected routes to every peers.

IXP Peering Policy

- BLPA is applicable where different categories of ISPs are connected in an IX
  - Large ISPs can choose to peer with large ISPs (base on their traffic volume)
  - Small ISPs will arrange peering with small ISPs
- Would be preferable for large ISPs
  - They will peer with selected large ISPs (Equal traffic interchange)
  - Will not loose business by peering with small ISP

IXP Peering Policy

- MLPA model works well to widen the IX scope of operation (i.e national IX).
- Easy to manage peering
  - Peer with the route server and get all available local routes.
  - Do not need to arrange peering with every ISPs connected to the IX.
- Unequal traffic condition can create not intersected situation to peer with route server

IXP Peering Policy

- Both peering model can be available in an IX.
- Member will select peering model i.e either BLPA or MLPA (Route Server Peering)
- IX will provide switch port
- Mandatory MLPA model some time not preferred by large ISP (Business Interest)
  - Can create not interested situation to connect to an IX

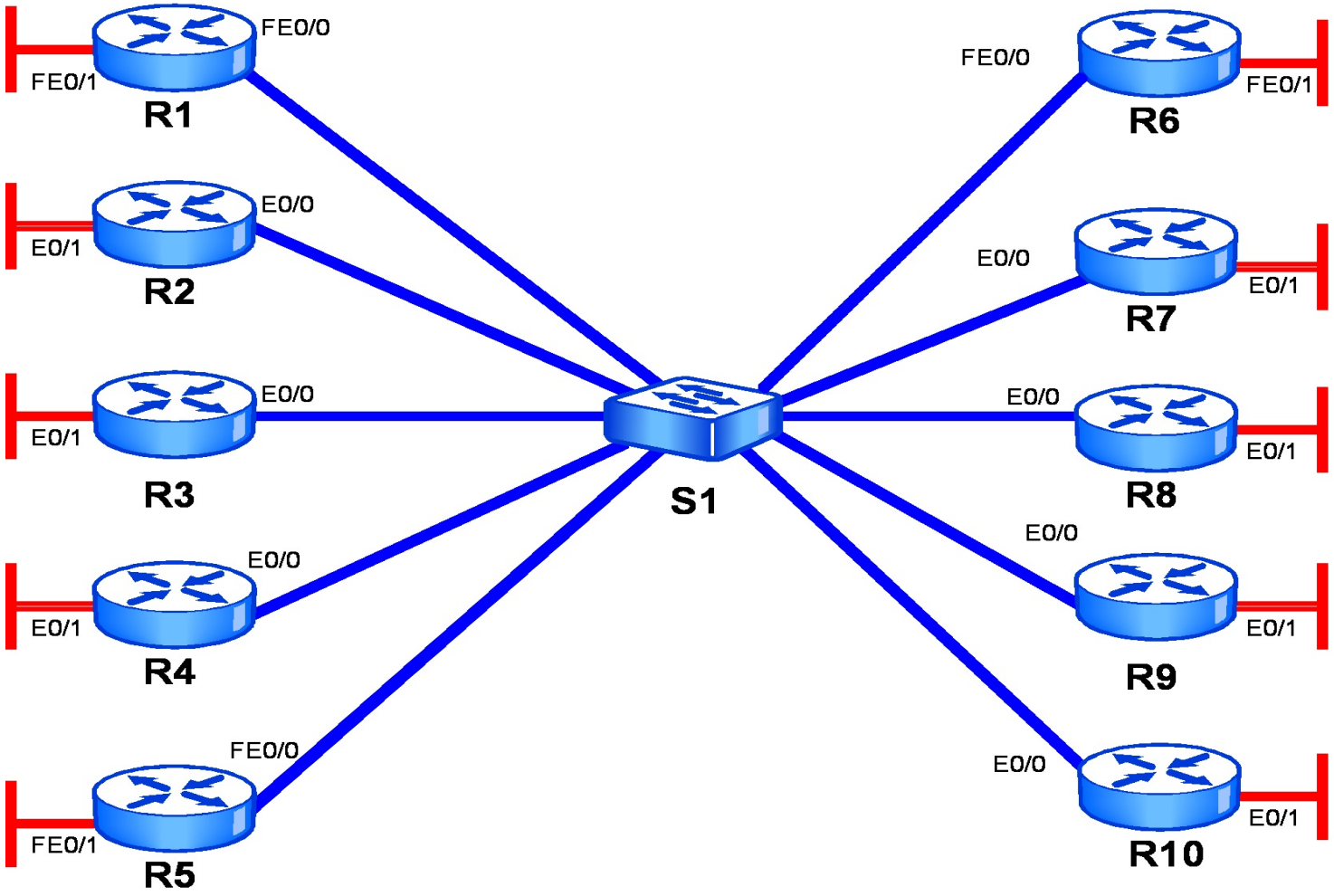
IXP Operating Cost

- Access link
- Link maintenance
- Utility
- Administration

IXP Cost Model

- Not for profit
- Cost sharing
- Membership based
- Commercial IX

IXP Network Diagram



Case Study- IXP Configuration

- Required **global & interface** commands to enable IPv6

```
Router(Config)#ipv6 unicast-routing
Router(Config)#ipv6 cef (optional)
```

- Configure IPv6 address on interface

```
Router(Config-if)#ipv6 address 2001:0df0:00aa::1/64
Router(Config-if)#ipv6 enable
```

- Verify IPv6 configuration

```
Router#sh ipv6 interface fa0/0
```

- Verify connectivity

```
Router#ping  2001:0df0:00aa::1
```

Case Study- IXP Configuration

- Required **BGP** commands to enable IPv6 routing

```
Router(config)# router bgp 1
  Router2(config-router)#bgp router-id 10.0.0.1
```
(if no 32 bit address on any interface)

```
Router(config-router)# address-family ipv6
  Router(config-router-af)# no synchronization
  Router(config-router-af)#neighbor 2001:0df0:00aa::1
  remote-as 2 (EBGP)
  Router(config-router-af)#neighbor 2001:0df0:00aa::1
  activate
  Router(config-router-af)#network 2001:0df0:00aa::/48
```

- Verify BGP IPv6 configuration

```
Router#sh bgp ipv6 unicast summary (summarized
  neighbor list)
  Router#sh bgp ipv6 unicast (BGP database)
  Router#sh ipv6 route bgp (BGP routing table)
```

Case Study- IXP Configuration

Required command to add IX prefix filter

- Create prefix filter in global mode

```
Router(config)#ipv6 prefix-list AS1 seq 2 permit 2001:0df0:aa::/48
```

- Apply prefix filter in BGP router configuration mode

```
Router(config-router)# address-family ipv6
Router(config-router-af)#neighbor 2001:0df0:aa::1
  prefix-list AS1 in
Router(config-router-af)#neighbor 2001:0df0:aa::1
  prefix-list AS1 out
```

Case Study- IXP Configuration

- Controlling routing update traffic (Not data traffic)

- Incoming routing update (Will control outgoing data traffic)
- Outgoing routing update (Will control incoming data traffic)

Questions?

APNIC

Thank you

APNIC