IPv6 Address Management Tutorial

PACNOG 17

Apia, Samoa

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Presenter

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Areas of interests:

IPv6, DNS/DNSSEC, Network Security, IRM

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Overview

- Introduction to IPv6
- IPv6 Protocol Architecture
- IPv6 Addressing and Subnetting
- IPv6 Deployment and Address Planning Best Practices

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Internet Challenges 1992

- Address space depletion
  - IPv4 address space is finite
  - Historically, many wasteful allocations
- Routing chaos
  - Legacy routing structure, router overload
  - CIDR & aggregation are now vital
- Inequitable management
  - Unstructured and wasteful address space distribution

Classless & Classful addressing

Best Current Practice

Classful

Obsolete
- *inefficient*
- *depletion of B space*
- *too many routes from C space*

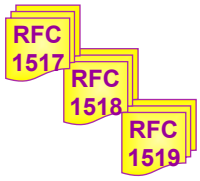
Classless

Addresses	Prefix	Classful	Net Mask
...	...	...	...
8	/29		255.255.255.248
16	/28		255.255.255.240
32	/27		255.255.255.224
64	/26		255.255.255.192
128	/25		255.255.255.128
256	/24	1 C	255.255.255.0
...	...	...	...
4096	/20	16 C's	255.255.240.0
8192	/19	32 C's	255.255.224
16384	/18	64 C's	255.255.192
32768	/17	128 C's	255.255.128
65536	/16	1 B	255.255.0.0
...	...	...	...*

- Network boundaries may occur at *any* bit

Evolution of Internet Resource Management

- 1993: Development of "CIDR"
  - addressed both technical problems



Address depletion
→ Through more accurate assignment
- variable-length network address

Routing table overload
→ Through address space aggregation
- " supernetting"

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Evolution of Internet Resource Management

- Administrative problems remained
  - Increasing complexity of CIDR-based allocations
  - Increasing awareness of conservation and aggregation
  - Need for fairness and consistency

- RFC 1366 (1992)
  - Described the "growth of the Internet and its increasing globalization"
  - Additional complexity of address management
  - Set out the basis for a regionally distributed Internet registry system

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Long-Term Solution

- IPv6 was seen as a long-term solution to IP address depletion
- Read more at “The Long and Windy ROAD”
  - http://rms46.vlsm.org/1/42.html

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What is IPv6?

- **IP** stands for Internet Protocol which is one of the main pillars that supports the Internet today
- Current version of IP protocol is IPv4
- The new version of IP protocol is IPv6
- There is a version of IPv5 but it was assigned for experimental use [RFC1190]
- IPv6 was also called IPng in the early days of IPv6 protocol development stage

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Background of IPv6 Protocol

- August 1990
  - First wake-up call by Solensky in IETF on IPv4 address exhaustion
- December 1994
  - IPng area were formed within IETF to manage IPng effort [RFC1719]
  - List of technical criteria was defined to choose IPng [RFC1726]
- January 1995
  - IPng director recommendation to use 128 bit address [RFC1752]
- December 1995
  - First version of IPv6 address specification [RFC1883]
- December 1998
  - Updated version changing header format from 1st version [RFC2460]

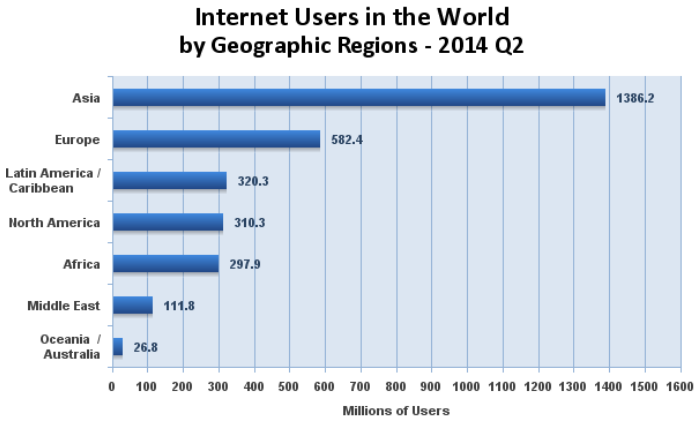
Motivation Behind IPv6 Protocol

- Plenty of address space (Mobile Phones, Tablet Computers, Car Parts, etc. ☺)
- Solution of very complex hierarchical addressing need, which IPv4 is unable to provide
- End to end communication without the need of NAT for some real time application (i.e online transaction)
- Ensure security, reliability of data and faster processing of protocol overhead
- Stable service for mobile network (i.e Internet in airline, trains)

Internet Penetration

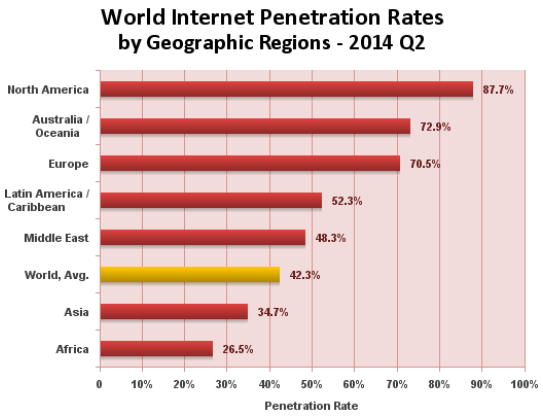
http://wearesocial.sg/blog/2015/01/digital-social-mobile-2015/

World Internet Users Today



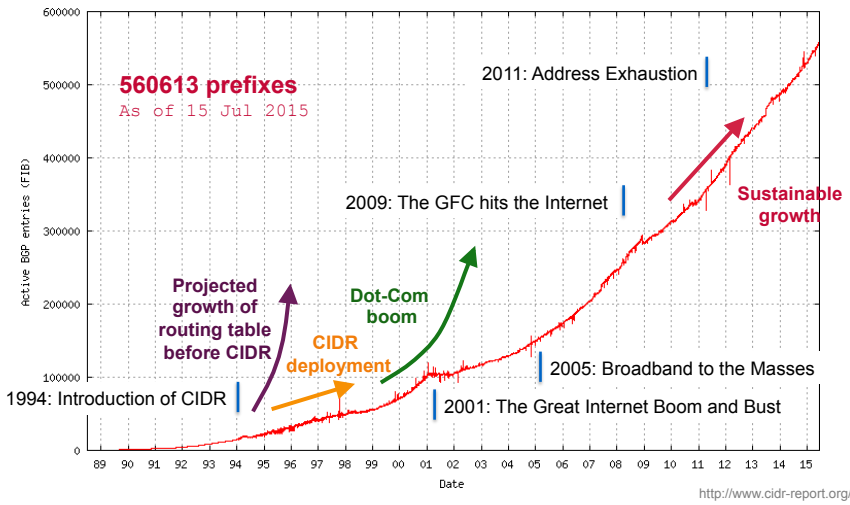
Source: Internet World Stats - www.internetworldstats.com/stats.htm
3,035,749,340 Internet users estimated for June 30, 2014
Copyright © 2014, Miniwatts Marketing Group

World Internet Penetration Today



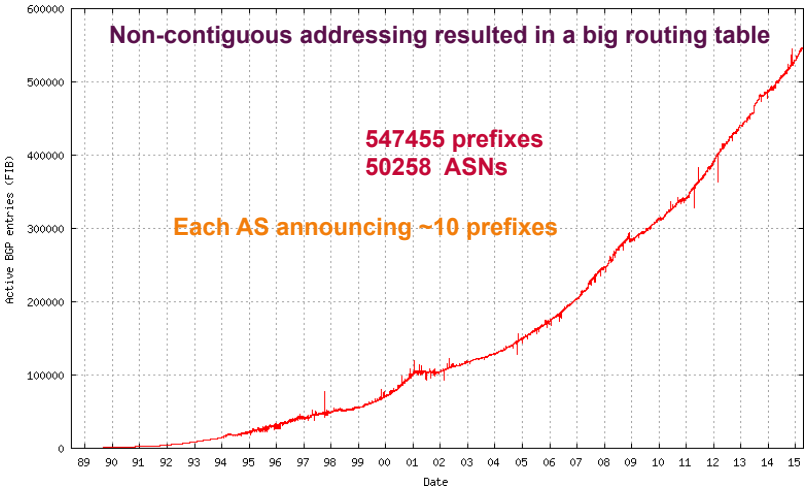
Source: Internet World Stats - www.internetworldststs.com/stats.htm
Penetration Rates are based on a world population of 7,182,406,565
and 3,035,749,340 estimated Internet users on June 30, 2014.

Growth of the Global Routing Table



http://www.cidr-report.org/as2.0/

IPv4 BGP Table



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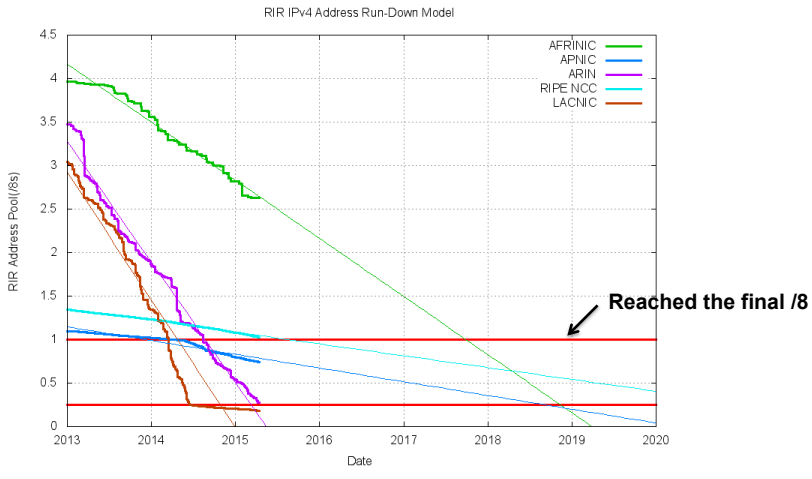
IPv4 Exhaustion



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IPv4 Projected RIR Pool Exhaustion

RIR	Projected Exhaustion Date	Remaining Addresses
APNIC	19 April 2011 (actual)	0.6749
RIPE NCC	14 Sep 2012 (actual)	1.0018
LACNIC	10 Jun 2014 (actual)	0.1621
ARIN	16 Jul 2015	0.0064
AFRINIC	26 April 2019	2.5821

Source: http://www.potaroo.net/tools/ipv4/index.html

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New Functional Improvement

- Address Space
  - Increase from 32-bit to 128-bit address space
- Management
  - Stateless autoconfiguration means no more need to configure IP addresses for end systems, even via DHCP
- Performance
  - Fixed header size (40 bytes) and 64-bit header alignment mean better performance from routers and bridges/switches
- No hop-by-hop segmentation
  - Path MTU discovery

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New Functional Improvement

- Multicast/Multimedia
  - Built-in features for multicast groups, management, and new "anycast" groups
- Mobile IP
  - Eliminate triangular routing and simplify deployment of mobile IP-based systems
- Virtual Private Networks
  - Built-in support for ESP/AH encrypted/ authenticated virtual private network protocols
- Built-in support for QoS tagging
- No more broadcast

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- IPv6 Addressing and Subnetting
- IPv6 Deployment and Address Planning Best Practices

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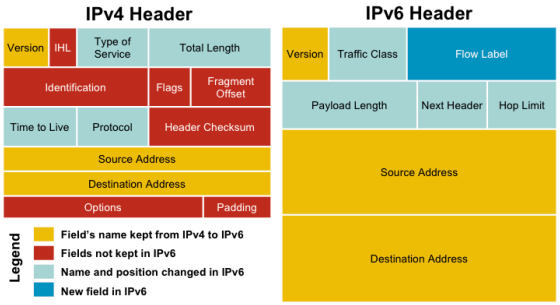
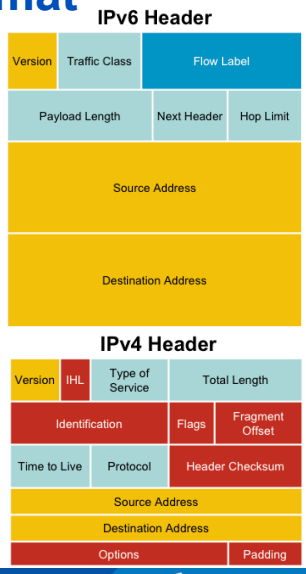
Protocol Header Comparison



- IPv4 contains 10 basic header field
- IPv6 contains 6 basic header field
- IPv6 header has 40 octets in contrast to the 20 octets in IPv4
- So a smaller number of header fields and the header is 64-bit aligned to enable fast processing by current processors

Diagram Source: www.cisco.com

IPv6 Protocol Header Format

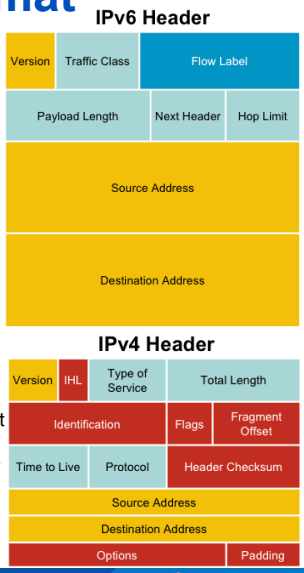


The IPv6 header fields:

- **Version**
  - 4-bit field (same as in IPv4)
  - contains the number 6 instead of the number 4 for IPv4
- **Traffic class**
  - 8-bit field similar to the type of service (ToS) field in IPv4.
  - tags packet with a traffic class that it uses in differentiated services (DiffServ)
- **Flow label**
  - completely new 20-bit field
  - tags a flow for the IP packets
  - can be used for multilayer switching techniques and faster packet-switching performance

IPv6 Protocol Header Format

- **Payload length**
  - 16-bit field is similar to the IPv4 Total Length Field
  - the length of the data carried after the header
  - IPv4 the Total Length Field included the header
  - 2^{16} = 65536 Octets
- **Next header**
  - 8-bit value of this field
  - determines the type of information that follows the basic IPv6 header.
    - can be a transport-layer packet, such as TCP or UDP, or it can be an extension header
  - similar to the protocol field of IPv4
- **Hop limit**
  - 8-bit field
  - maximum hops that a packet can remain in the network before it is destroyed
  - With the IPv4 TLV field, this was expressed in seconds and was typically a theoretical value and not very easy to estimate



IPv6 Extension Header

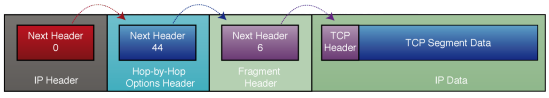
- Adding an optional Extension Header in IPv6 makes it simple to add new features in IP protocol in the future without major re-engineering of IP routers everywhere.
- The number of extension headers are not fixed, so the total length of the extension header chain is variable.
- The extension header will be placed in between main header and payload in an IPv6 packet.

IPv6 Extension Header

- If the Next Header field value (code) is 6, it determines that there is no extension header and the next header field is pointing to TCP header which is the payload of this IPv6 packet
- Code values of Next Header field:
  - 0 Hop-by-hop option
  - 2 ICMP
  - 6 TCP
  - 17 UDP
  - 43 Source routing
  - 44 Fragmentation
  - 50 Encrypted security payload
  - 51 Authentication
  - 59 Null (No next header)
  - 60 Destination option

Link listed Extension Header

IPv6 Datagram With No Extension Headers Carrying TCP Segment



IPv6 Datagram With Two Extension Headers Carrying TCP Segment

- Link listed extension header can be used by simply using next header code value
- Above example use multiple extension header creating link list by using next header code value i.e 0 44 6
- The link list will end when the next header point to transport header i.e next header code 6

Order Of Extension Header

- Source node follow the order:
  - 1. Hop-by-hop
  - 2. Routing
  - 3. Fragment
  - 4. Authentication
  - 5. Encapsulating security payload
  - 6. Destination option
  - 7. Upper-layer
- Order is important because:
  - Only hop-by-hop has to be processed by every intermediate nodes
  - Routing header need to be processed by intermediate routers
  - At the destination fragmentation has to be processed before others
  - This is how it is easy to implement using hardware and make faster processing engine

Fragmentation Handling In IPv6

- Routers handle fragmentation in IPv4 which cause variety of processing performance issues
- IPv6 routers no longer perform fragmentation. IPv6 host use a discovery process [Path MTU Discovery] to determine most optimum MTU size before creating end to end session
- In this discovery process, the source IPv6 device attempts to send a packet at the size specified by the upper IP layers [i.e TCP/Application].
- If the device receives an ICMP packet too big message, it informs the upper layer to discard the packet and to use the new MTU.
- The ICMP packet too big message contains the proper MTU size for the pathway.
- Each source device needs to track the MTU size for each session.

MTU Size Guideline

- MTU for IPv4 and IPv6
  - MTU is the largest size datagram that a given link layer technology can support [i.e HDLC]
  - Minimum MTU 68 Octet [IPv4] 1280 Octet [IPV6]
  - Most efficient MTU 576 [IPv4] 1500 [IPv6]
- Important things to remember:
  - Minimum MTU for IPv6 is 1280
  - Most efficient MTU is 1500
  - Maximum datagram size 64k
  - With IPv6 in IPv4 tunnel 1560 [Tunnel Source Only]

IPv6 Header Compression

- IPv6 header size is double than IPv4
- Some time it becomes an issue on limited bandwidth link i.e Radio
- **Robust Header Compression [RoHC]** standard can be used to minimize IPv6 overhead transmission in limited bandwidth link
- RoHC is IETF standard for IPv6 header compression

IPv6 Security Features

- IPsec is mandatory in IPv6
- Since IPsec became part of the IPv6 protocol, all node can secure their IP traffic if they have required keying infrastructure
- In build IPsec does not replace standard network security requirement but introduce added layer of security with existing IP network

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IPv6 Addressing

- An IPv6 address is 128 bits long
- So the number of addresses are **2^128** or
  - 340282366920938463463374607431768211455
  - 3.40 x 10^{38}
  - 340 trillion trillion trillion addresses
- In hex, 4 bits (also called a 'nibble') is represented by a hex digit

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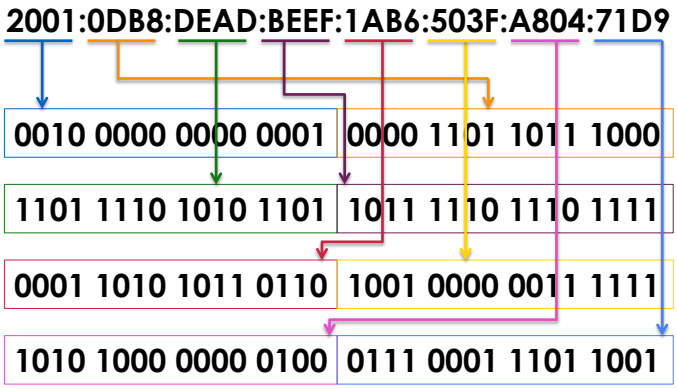
IPv6 Addressing



128 bits is reduced down to 32 hex digits

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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
  - Case insensitive
- Example:
  - FE38:DCE3:124C:C1A2:BA03:6735:EF1C:683D
  - Abbreviated form of address

    FE80:0023:**0000:0000:0000**:036E:1250:2B00 Leading zeroes / Groups of zeroes

    →FE80:23:**0:0:0**:36E:1250:2B00 Double colons

    →FE80:23**::**36E:1250:2B00

    (Null value can be used only once)

IPv6 Address Representation (2)

- Double colons (::) representation
  - RFC5952 recommends that the rightmost set of :0: be replaced with :: for consistency
    - 2001:db8:0:2f::5 rather than 2001:db8::2f:0:0:0:5
- In a URL, it is enclosed in brackets (RFC3986)
  - http://[2001:db8:4f3a::206:ae14]:8080/index.html
  - Cumbersome for users, mostly for diagnostic purposes
  - Use fully qualified domain names (FQDN)
- Prefix Representation
  - Representation of prefix is just like IPv4 CIDR
  - In this representation, you attach the prefix length
  - IPv6 address is represented as:
    - 2001:db8:12::/40

Exercise 1

1. 2001:0db8:0000:0000:0000:0000:0000:0000
2. 2001:0db8:0000:0000:d170:0000:0100:0ba8
3. 2001:0db8:0000:0000:00a0:0000:0000:10bc
4. 2001:0db8:0fc5:007b:ab70:0210:0000:00bb

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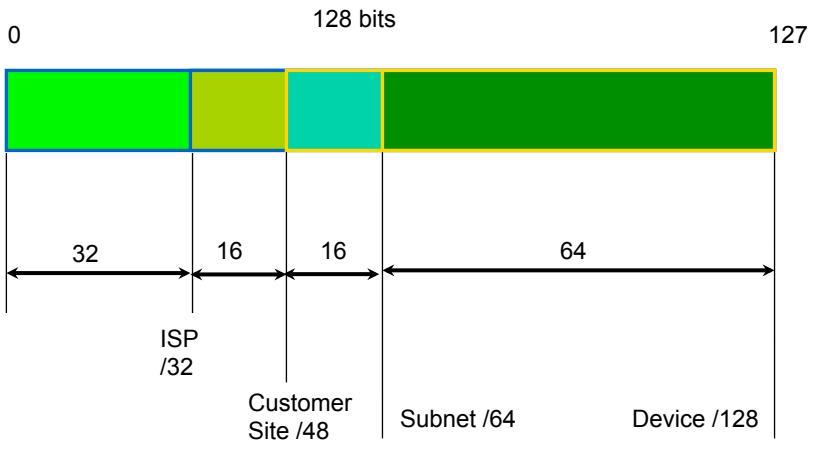
IPv6 Addressing Structure



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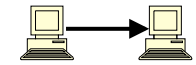
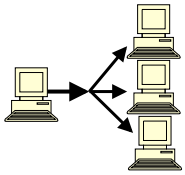
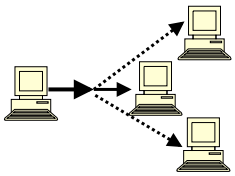
IPv6 Addressing Model

RFC 4291

- Unicast
  - An identifier for a single interface
- Multicast
  - An identifier for a group of nodes
- Anycast
  - An identifier for a set of interfaces







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IPv6 Unicast Address

- Address given to interface for communication between host and router
  - Global unicast address currently delegated by IANA

  - Local use unicast address
    - Link-local address (starting with FE80::)

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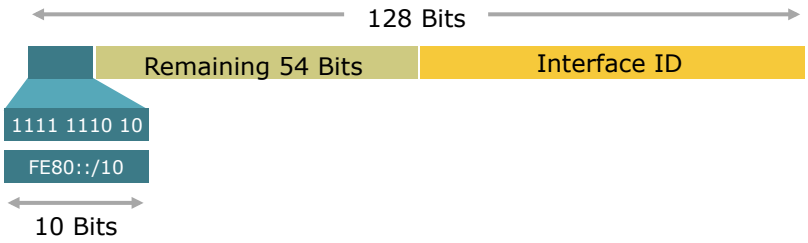
Local Addresses With Network Prefix

- **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)
  - The address in the packet destination would never pass through a router (local scope)
  - Mandatory address - automatically assigned as soon as IPv6 is enabled
  - **FE80::/10**

Local Addresses With Network Prefix



- Remaining 54 bits could be Zero or any manual configured value

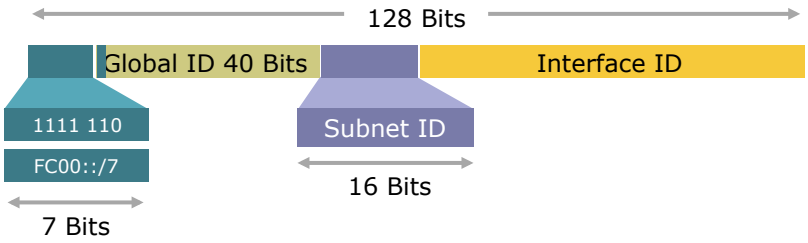
Local Addresses With Network Prefix

- **Site Local Address**
  - Addresses similar to the RFC 1918 / private address like in IPv4
  - **FEC0::/10**
- This address type is now *deprecated* by RFC 3879 because of lack of uniqueness
  - Ambiguity of addresses
  - Fuzzy definition of “sites”
- Still used in test lab

Local Addresses With Network Prefix

- **Unique Local IPv6 Unicast Address**
  - Addresses similar to the RFC 1918 (private address) in IPv4
  - Ensures 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/

Local Addresses With Network Prefix



- Unique-Local Addresses Used For:
  - Local communications & inter-site VPNs
  - Local devices such as printers, telephones, etc
  - Site Network Management systems connectivity
- Not routable on the Internet

Global Addresses With Network Prefix

- **IPv6 Global Unicast Address**
  - Global Unicast Range: 0010 2000::/3
    0011 3FFF:FFF:…:FFFF/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

Global Addresses With Network Prefix

- **6to4 Addresses**
  - **2002::/16**
  - Designed for a special tunneling mechanism [RFC 3056] to connect IPv6 Domains via IPv4 Clouds
  - Automatic tunnel transition Mechanisms for IPv6 Hosts and Routers
  - Need 6to4 relay routers in ISP network

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

Special addresses

- The unspecified address
  - A value of 0:0:0:0:0:0:0:0 (::)
  - It is comparable to 0.0.0.0 in IPv4
- The loopback address
  - It is represented as 0:0:0:0:0:0:0:1 (::1)
  - Similar to 127.0.0.1 in IPv4

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Addresses Without a Network Prefix

- Loopback ::1/128
- Unspecified Address ::/128
- IPv4-mapped IPv6 address ::FFFF:0:0/96 [a.b.c.d]
- IPv4-compatible IPv6 address ::/96 [a.b.c.d]
  (deprecated)

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IPv6 Multicast Address

- IP multicast address has a prefix **FF00::/8**
- The second octet defines the lifetime and scope of the multicast address.

8-bit	4-bit	4-bit	112-bit
1111 1111	Lifetime	Scope	Group-ID

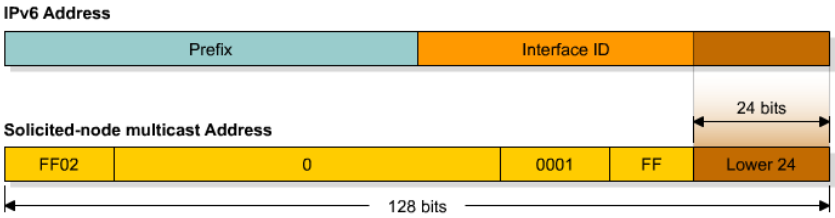
Lifetime	
0	If Permanent
1	If Temporary

Scope	
1	Node
2	Link
5	Site
8	Organisation
E	Global

IPv6 Multicast Address Examples

- RIPng
  - The multicast address AllRIPRouters is **FF02::9**
    - Note that 02 means that this is a permanent address and has link scope
- OSPFv3
  - The multicast address AllSPFRouters is **FF02::5**
  - The multicast address AllDRouters is **FF02::6**
- EIGRP
  - The multicast address AllEIGRPRouters is **FF02::A**

Solicited-Node Multicast Address



- Solicited-node multicast address consists of **FF02::1:FF00:0::/104** prefix joined with the lower 24 bits from the unicast or anycast IPv6 address

Solicited-Node Multicast Address

```
R1#sh ipv6 int e0
Ethernet0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::200:CFF:FE3A:8B18
  No global unicast address is configured
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::1:FF3A:8B18
  MTU is 1500 bytes
  ICMP error messages limited to one every 100 milliseconds
  ICMP redirects are enabled
  ND DAD is enabled, number of DAD attempts: 1
  ND reachable time is 30000 milliseconds
  ND advertised reachable time is 0 milliseconds
  ND advertised retransmit interval is 0 milliseconds
  ND router advertisements are sent every 200 seconds
  ND router advertisements live for 1800 seconds
  Hosts use stateless autoconfig for addresses.
R1#
```

Solicited-Node Multicast Address

IPv6 Anycast

- An IPv6 anycast address is an identifier for a set of interfaces (typically belonging to different nodes)
  - A packet sent to an anycast address is delivered to one of the interfaces identified by that address (the "nearest" one, according to the routing protocol's measure of distance).
- Anycast addresses are allocated from the unicast address space
  - Can't distinguish from unicast address
- In reality there is no known implementation of IPv6 Anycast as per the RFC
  - Most operators have chosen to use IPv4 style anycast instead

IPv6 Address Space

IPv6 Prefix	Allocation	RFC
0000::/8	Reserved by IETF	RFC 4291
2000::/3	Global Unicast	RFC 4291
FC00::/7	Unique Local Address	RFC 4193
FE80::/10	Link Local Unicast	RFC 4291
FEC0::/10	Reserved by IETF	RFC 3879
FF00::/8	Multicast	RFC 4291
2002::/16	6to4	RFC3056

http://www.iana.org/assignments/ipv6-address-space/ipv6-address-space.xml

Subnetting

- Network engineers must have a solid understanding of subnetting
  - Important for address planning
- IPv6 subnetting is similar (if not exactly the same) as IPv4 subnetting
- Note that you are working on hexadecimal digits rather than binary
  - 0 in hex = 0000 in binary
  - 1 in hex = 0001 in binary

APNIC

Subnetting (Example)

- Provider A has been allocated an IPv6 block

  2001:DB8::/32
- Provider A will delegate /48 blocks to its customers
- Find the blocks provided to the first 4 customers

APNIC

Subnetting (Example)

Original block: **2001:0DB8::/32**

Rewrite as a /48 block: **2001:0DB8:0000:/48**

This is your network prefix!

How many /48 blocks are there in a /32?

$$\frac{/32}{/48} = \frac{2^{128-32}}{2^{128-48}} = \frac{2^{96}}{2^{80}} = 2^{16}$$

Find only the first 4 /48 blocks…

Subnetting (Example)

Start by manipulating the LSB of your network prefix – write in BITS

2001:0DB8:0000::/48

In bits

2001:0DB8:	0000 0000 0000 0000	**::/48**	➡	**2001:0DB8:0000::/48**
2001:0DB8:	0000 0000 0000 0001	**::/48**	➡	**2001:0DB8:0001::/48**
2001:0DB8:	0000 0000 0000 0010	**::/48**	➡	**2001:0DB8:0002::/48**
2001:0DB8:	0000 0000 0000 0011	**::/48**	➡	**2001:0DB8:0003::/48**

Then write back into hex digits

Exercise 2.1: IPv6 subnetting

- Identify the first four /64 address blocks out of 2001:DB8:0::/48
  1. _____
  2. _____
  3. _____
  4. _____

APNIC

Exercise 2.2: IPv6 subnetting

- Identify the first four /36 address blocks out of 2406:6400::/32
  1. _____
  2. _____
  3. _____
  4. _____

APNIC

Exercise 2.3: IPv6 subnetting

- Identify the first six /35 address blocks out of 2406:6400::/32

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____

IPv6 Autoconfiguration

- Stateless mechanism
  - For a site not concerned with the exact addresses
  - No manual configuration required
  - Minimal configuration of routers
  - No additional servers
- Stateful mechanism
  - For a site that requires tighter control over exact address assignments
  - Can be assigned using a DHCPv6 server or manually

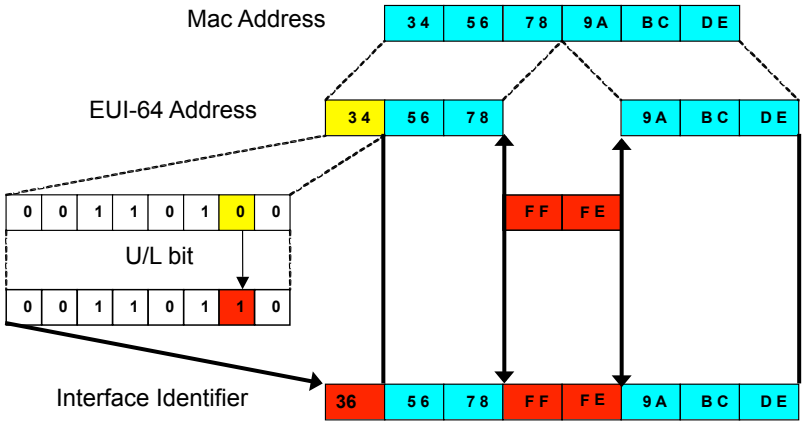
IPv6 Autoconfiguration

- IPv6 **S**tate**l**ess **A**ddress **A**utoconfiguration (SLACC)
- Allow a host to obtain or create unique addresses for its interface/s
  - Manual configuration should not be required
  - Even if no servers/routers exist to assign an IP address to a device, the device can still auto-generate an IP address
- Small sites should not require DHCPv6 server to communicate
  - Plug and play
  - Allows interfaces on the same link to communicate with each other
- Facilitate the renumbering of a site's machines

Interface ID

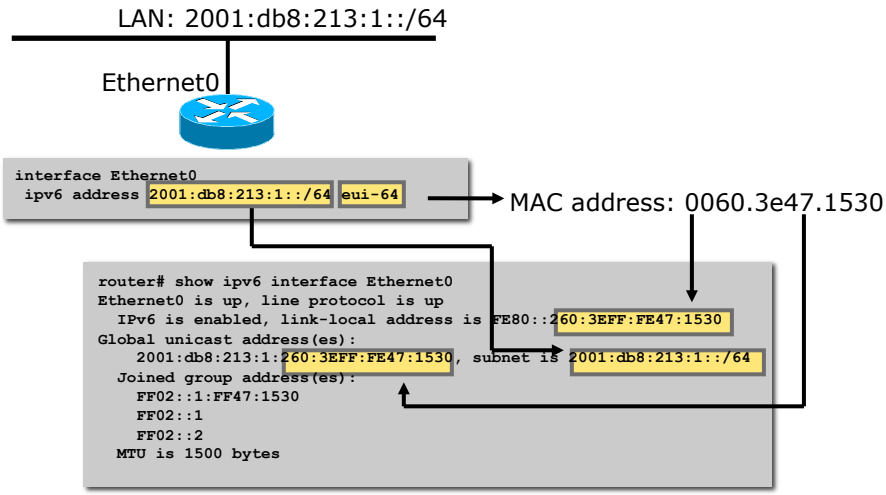
- The lowest-order 64-bit field addresses
- May be assigned in several different ways:
  - auto-configured from a 48-bit MAC address expanded into a 64-bit EUI-64
  - assigned via DHCP
  - manually configured
  - auto-generated pseudo-random number
  - possibly other methods in the future

Modified EUI-64

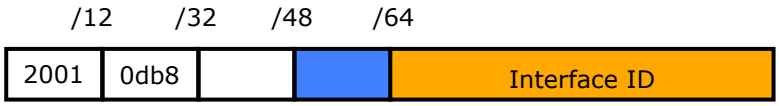


EUI-64 address is formed by inserting FFFE and OR'ing a bit identifying the uniqueness of the MAC address

IPv6 Addressing Examples



IPv6 Address Privacy



- Temporary address for IPv6 host client application
  - e.g. Web browser
- Intended to inhibit device/user tracking but is also a potential issue
  - More difficult to scan all IP addresses on a subnet
  - But port scan is identical when an address is known
- Random 64 bit interface ID, run DAD before using it
- Rate of change based on local policy
- Implemented on Microsoft Windows XP/Vista/7
  - Can be activated on FreeBSD/Linux/MacOS with a system call

Zone IDs for Local-Use Addresses

- In Windows XP for example:
- Host A:
  - fe80::2abc:d0ff:fee9:4121%4
- Host B:
  - fe80::3123:e0ff:fe12:3001%3
- Ping from Host A to Host B
  - ping fe80::3123:e0ff:fe12:3001%4 (not %3)
    - identifies the interface zone ID on the host which is connected to that segment.

IPv6 Neighbor Discovery (ND)

- IPv6 uses multicast (L2) instead of broadcast to find out target host MAC address
- It increases network efficiency by eliminating broadcast from L2 network
- IPv6 ND uses ICMPv6 as transport
  - Compared to IPv4 ARP, there is no need to write different ARP for different L2 protocol i.e. Ethernet etc.

IPv6 Neighbor Discovery (ND)

- Solicited-Node Multicast is used for Duplicate Address Detection
  - Part of the Neighbour Discovery process
  - Replaces ARP
  - Duplicate IPv6 Addresses are rare, but still have to be tested for
- For each unicast and anycast address configured, there is a corresponding solicited-node multicast address
  - This address is only significant for the local link

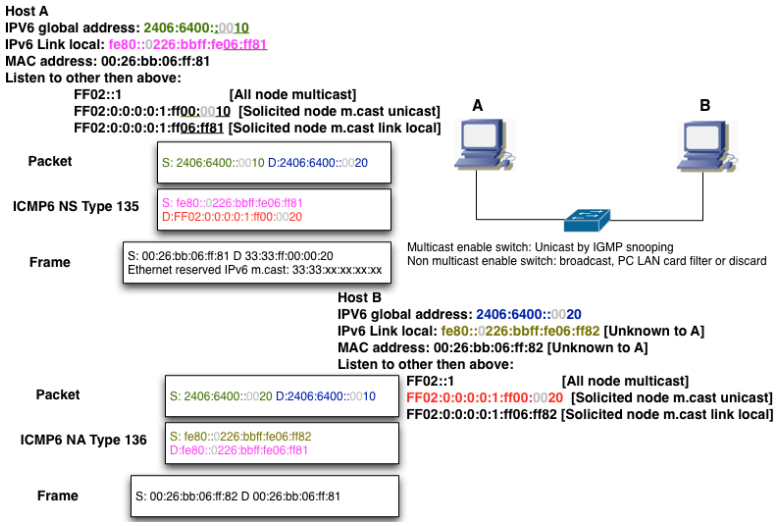
IPv6 Neighbor Discovery (ND)

- Solicited Node Multicast Address
  - Starts with FF02::1:FF00:0/104
  - Last 24 bit from the interface IPV6 address
- Example Solicited Node Multicast Address
  - IPV6 Address **2406:6400:0:0:0:0:0000:0010**
  - Solicited Node Multicast Address is FF02:0:0:0:0:1:FF**00:0010**
- All hosts listen to its solicited node multicast address corresponding to its unicast and anycast address (if defined)

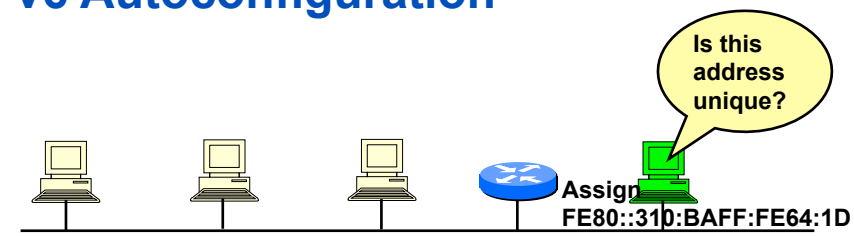
IPv6 Neighbor Discovery (ND)

- Host A would like to communicate with Host B
  - Host A IPv6 global address **2406:6400::10**
  - Host A IPv6 link local address **fe80::226:bbff:fe06:ff81**
  - Host A MAC address **00:26:bb:06:ff:81**
- Host B IPv6 global address **2406:6400::20**
  - Host B Link local **UNKNOWN** [Gateway if outside the link]
  - Host B MAC address **UNKNOWN**
- How will Host A create L2 frame for Host B?

IPv6 Neighbor Discovery (ND)



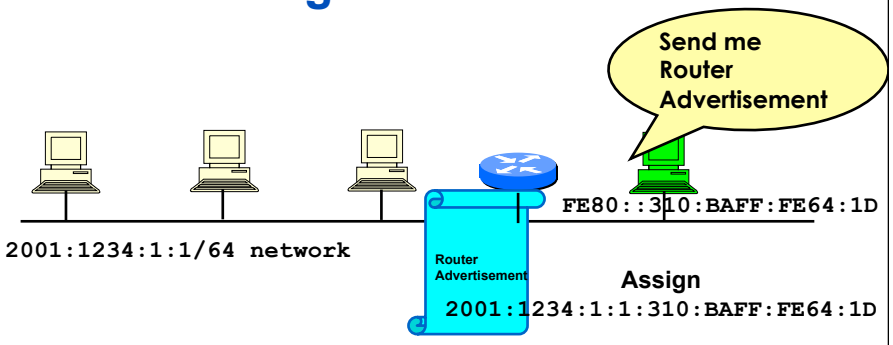
IPv6 Autoconfiguration



Tentative address (link-local address)
Well-known link local prefix +Interface ID (EUI-64)
Ex: FE80::310:BAFF:FE64:1D

1. A new host is turned on.
2. Tentative address will be assigned to the new host.
3. Duplicate Address Detection (DAD) is performed. First the host transmit
   - a Neighbor Solicitation (NS) message to all-nodes multicast address (FF02::1)
5. If no Neighbor Advertisement (NA) message comes back then the address is unique.
6. FE80::310:BAFF:FE64:1D will be assigned to the new host.

IPv6 Autoconfiguration



1. The new host will send Router Solicitation (RS) request to the all-routers multicast group (FF02::2).
2. The router will reply Routing Advertisement (RA).
3. The new host will learn the network prefix. E.g, 2001:1234:1:1/64
4. The new host will assigned a new address Network prefix+Interface ID E.g, 2001:1234:1:1:310:BAFF:FE64:1D

APNIC

ICMPv6 Messages for Autoconfiguration

- 133 Router Solicitation
  - Prompts a router to send a Router Advertisement.
- 134 Router Advertisement
  - Sent by routers to tell hosts on the local network the router exists and describe its capabilities.
- 135 Neighbor Solicitation
  - Sent by a device to request the layer two address of another device while providing its own as well.
- 136 Neighbor Advertisement
  - Provides information about a host to other devices on the network

APNIC

Configuration of IPv6 Nodes

- There are 3 ways to configure IPv6 address on an IPv6 node:
  - Static address configuration
  - DHCPv6 assigned node address
  - Stateless autoconfiguration

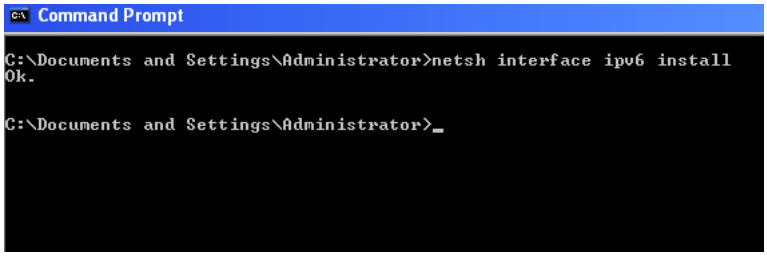
Configuration of IPv6 Node Address

Quantity	Address	Requirement	Context
One	Loopback [::1]	Must define	Each node
One	Link-local	Must define	Each Interface
Zero to many	Unicast	Optional	Each interface
Zero to many	Unique-local	Optional	Each interface
One	All-nodes multicast [ff02::1]	Must listen	Each interface
One	Solicited-node multicast ff02:0:0:0:0:1:ff/104	Must listen	Each unicast and anycast define
Any	Multicast Group	Optional listen	Each interface

ULA are unicast address globally unique but used locally within sites. Any sites can have /48 for private use. Each /48 is globally unique so no Collision of identical address in future when they connect together

IPv6 Host Configuration (Windows)

- Windows XP SP2
  - `netsh interface ipv6 install`
- Windows XP
  - `ipv6 install`



IPv6 Host Configuration (Windows)

- Configuring an interface

```
netsh interface ipv6 add address "Local
Area Connection" 2406:6400::1
```

- Note: Prefix length is not specified with address which will force a /64 on the interface
- Verify your Configuration

```
ipconfig
```

- Verify your neighbour table
  - `netsh interface ipv6 show neighbors`

IPv6 Host Configuration (Windows)

- Disable privacy state variable

```
netsh interface ipv6 set privacy state=disable
```

OR

```
netsh interface ipv6 set global
randomizeidentifiers=disabled
```


IPv6 Host Configuration (Windows)

- Testing your configuration

```
ping fe80::260:97ff:fe02:6ea5%4
```

Zone ID

- Note: the Zone ID is your interface index

IPv6 Host Configuration (Mac OS X)

- Disable privacy address

```
sysctl -w net.inet6.ip6.use_tempaddr=0
```

- Configuring an interface from the Terminal

```
ifconfig en0 inet6 2406:6400::2/48
route add -inet6 -prefixlen 0 default \
      2406:6400::1
```

- Verify your neighbor table

```
ndp -a
```


IPv6 Host Configuration (Linux)

- Enabling IPv6 on Linux
  - Set the NETWORKING_IPV6 variable to yes in /etc/sysconfig/network

```
vi /etc/sysconfig/network
   NETWORKING_IPV6=yes
service network restart
```

- Adding IPv6 address on an interface

```
ifconfig eth0 add inet6 2406:6400::1/64 (OR)
ifconfig eth0 add 2406:6400::1/64
```

IPv6 Host Configuration (Linux)

- Configuring Router Advertisement (RA) on Linux
  - Set IPv6 address forwarding on

```
echo "1" /proc/sys/net/ipv6/conf/all/forward
```

  - Need radvd-0.7.1-3.i386.rpm installed
  - On the demon conf file /etc/radvd.conf

```
vi /etc/radvd.conf
interface eth1 {
advSendAdvert on;
prefix 2406:6400::/64 {
AdvOnLink on; }; };
```


IPv6 Host Configuration (FreeBSD)

- Enabling IPv6 on FreeBSD
  - Set the ipv6_enable variable to yes in the /etc/rc.conf

```
vi /etc/rc.conf
  ipv6_enable=yes
```

- Adding IPv6 address on an interface

```
ifconfig fxp0 inet6 2406:6400::1/64
```

IPv6 Host Configuration (FreeBSD)

- Configuring RA on FreeBSD
  - Set IPv6 address forwarding on

```
sysctl -w net.inet6.ip6.forwarding=1
```

  - Assign IPv6 address on an interface

```
ifconfig en1 inet6 2001:07F9:0400:010E::1 \
       prefixlen 64
```

  - RA on an interface

```
rtadvd en1
```


Exercise 1: IPv6 Host Configuration

- Configure RA on Cisco

```
config t
interface e0/1
ipv6 nd prefix-advertisement 2406:6400::/64
```

Overview

- Introduction to IPv6
- IPv6 Protocol Architecture
- IPv6 Addressing and Subnetting
- **IPv6 Deployment and Address Planning Best Practices**

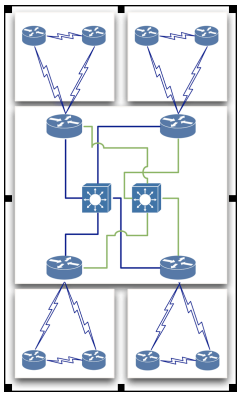
APNIC

Training ISP Network Topology

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

APNIC

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

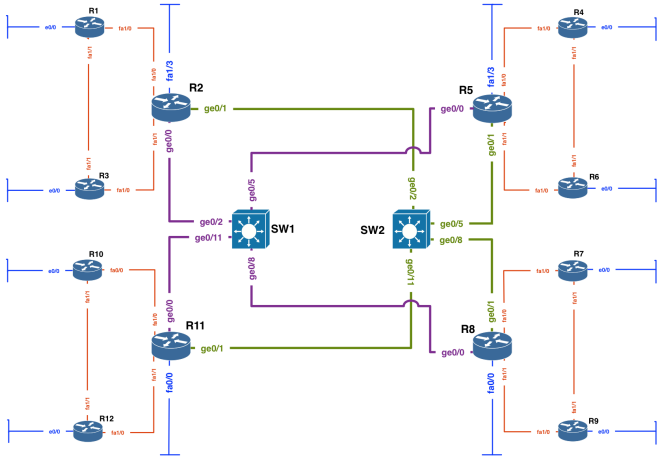
Training ISP Network Topology

- 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 prefixes

Training ISP Network Topology

- Transport Link:
  - Inter-connection between regional core router
  - Higher data transmission capacity than access link
  - Training ISP has 2 transport links for link redundancy
  - 2 Transport links i.e Purple link & Green link are connected to two carrier-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 (RFC6177):
  - 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

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)

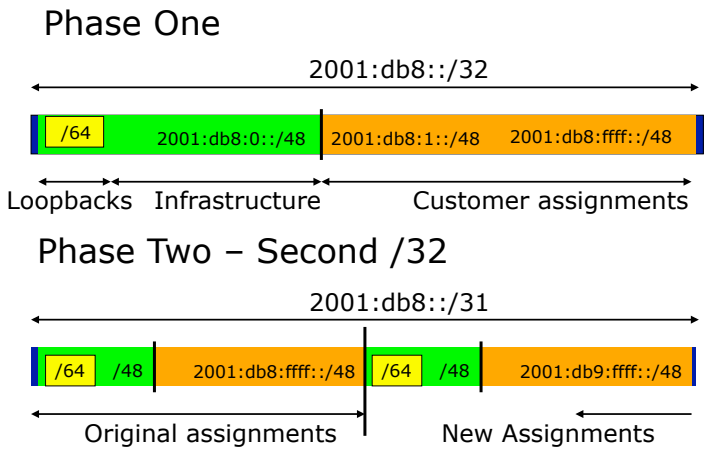
Addressing Plans – Advice

- 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

Addressing Plans – ISP Infrastructure

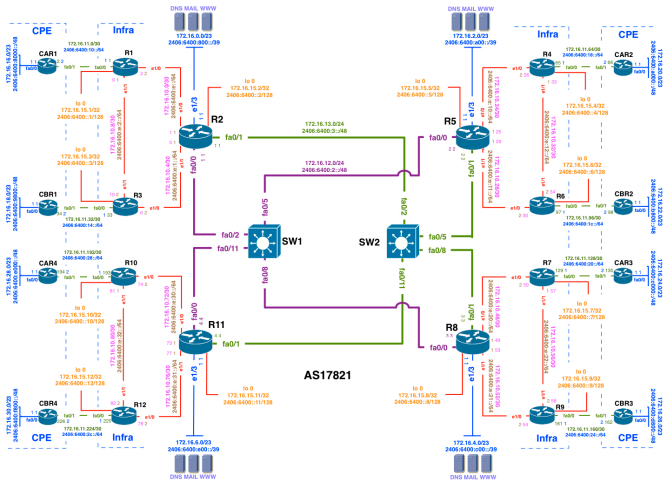


Example Address Plan

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

APNIC

Training ISP IPv6 Addressing Plan



APNIC

Training ISP IPV6 Addressing Plan

- IPv6 Address 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

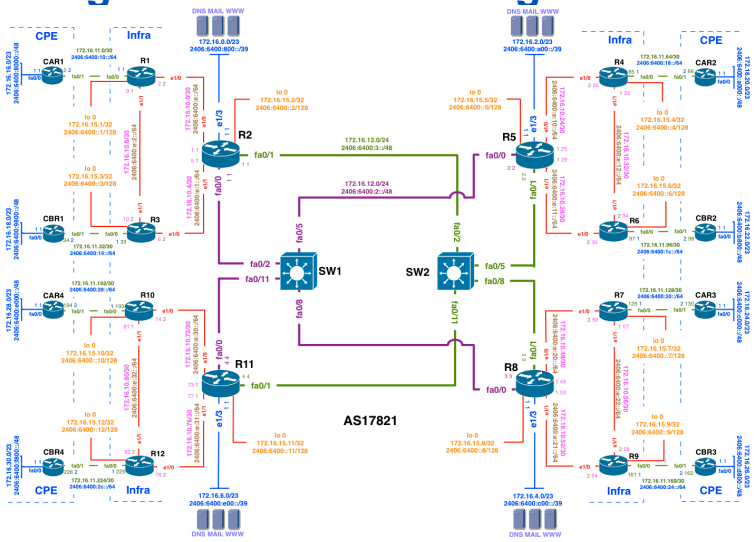
- IPv6 Address Plan:

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

APNIC

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

- IPv6 Address 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				

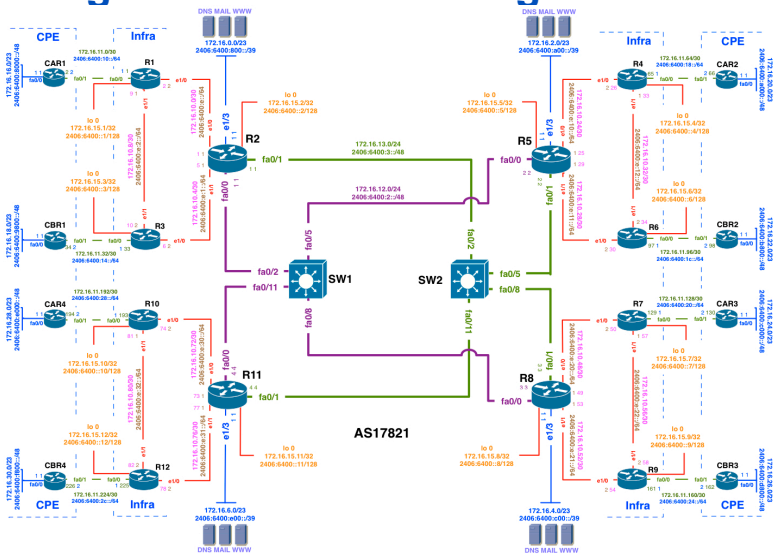
Training ISP IPV6 Addressing Plan

- IPv6 Address 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 3 DC Summary [R8]	

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

- IPv6 Address 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				

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- IPv6 Address 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				

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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]	

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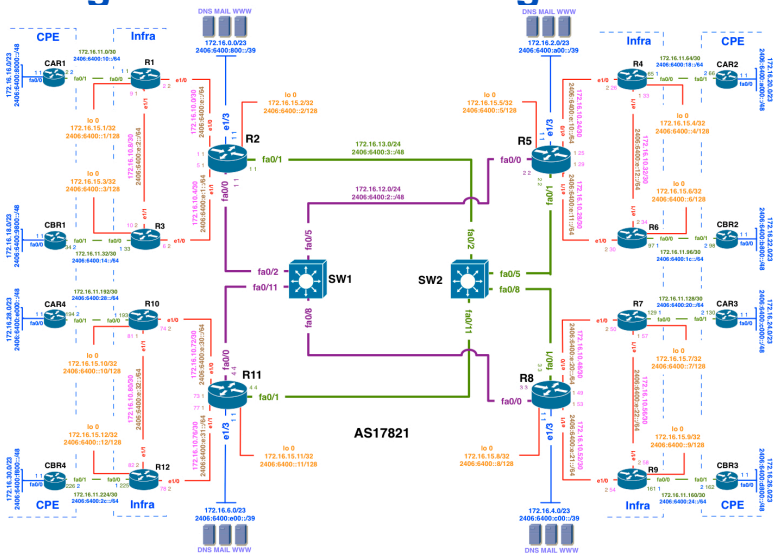

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Table 8: Further detail loopback

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

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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

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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				

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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

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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 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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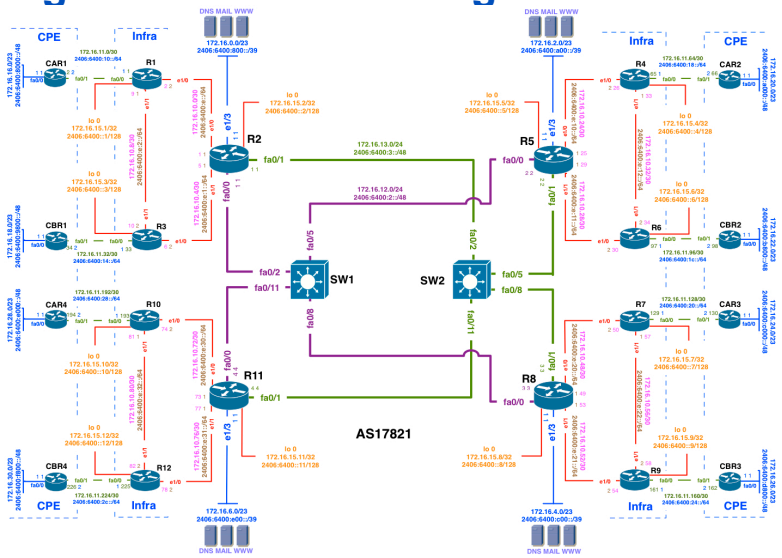

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Table 18: Customer block Region 2

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				

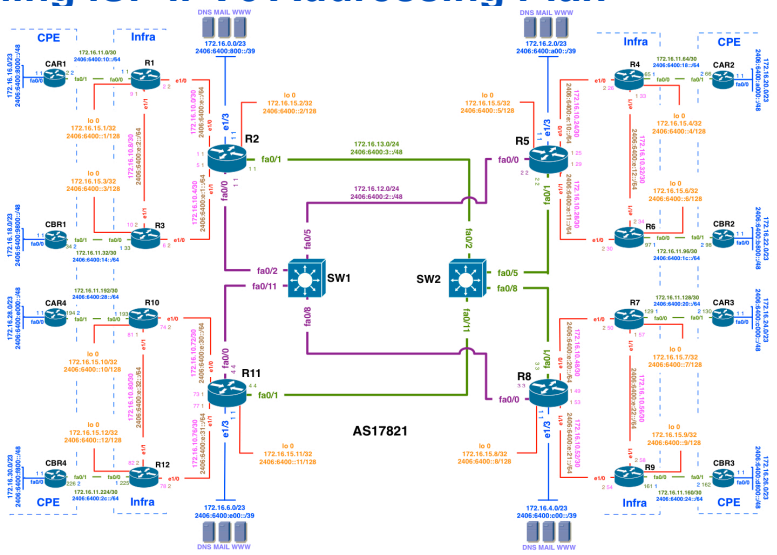
Training ISP IPV6 Addressing Plan

- IPv6 Address Plan:

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]	

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

- IPv6 Address Plan:

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				

Training ISP IPV6 Addressing Plan

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				

APNIC

Training ISP IPV6 Addressing Plan

- IPv6 Address 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]	

APNIC

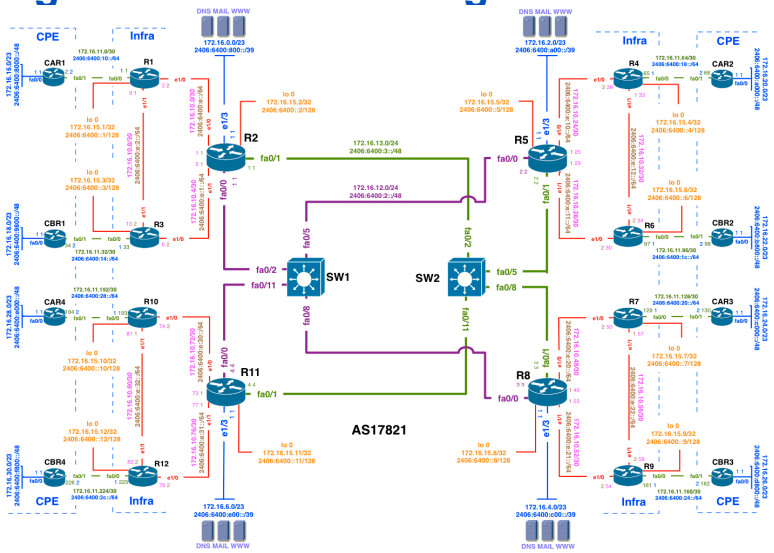
Training ISP IPV6 Addressing Plan

- IPv6 Address 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				

Training ISP IPV6 Addressing Plan



Training ISP IPV6 Addressing Plan

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				

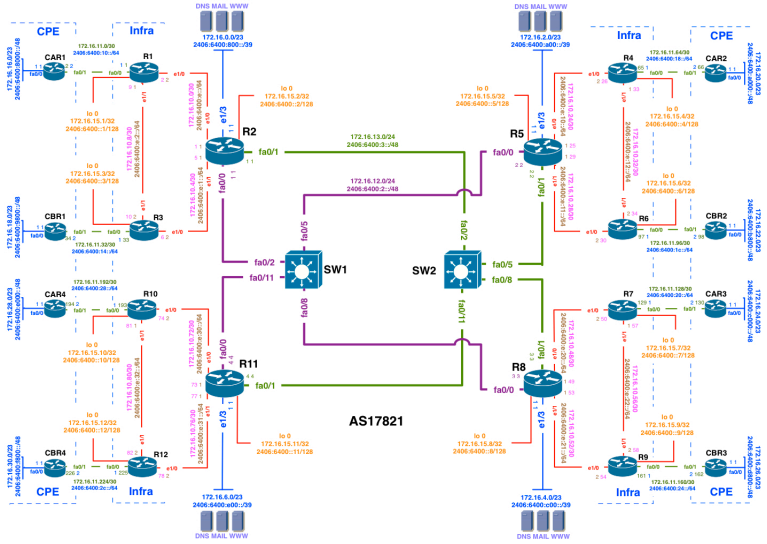
Training ISP IPV6 Addressing Plan

- IPv6 Address 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



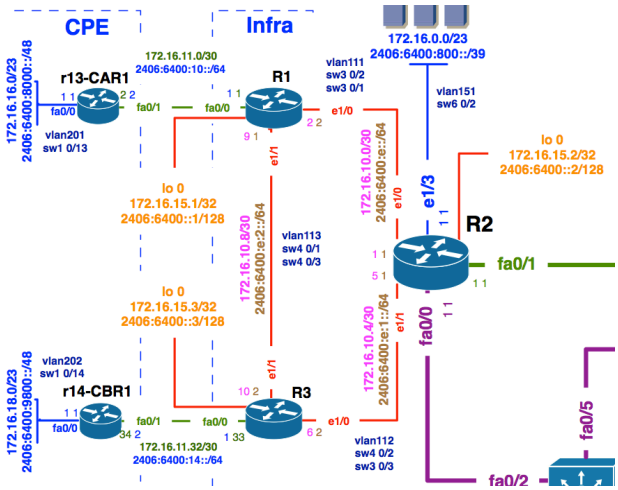
Training ISP IPV6 Addressing Plan

- IPv6 Address 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				

Training ISP IPv4 Addressing Plan



Training ISP IPv4 Addressing Plan

- Current 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

- Current 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

- Current 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

- Current IPv4 Addressing Plan:

Detail infrastructure block Transport & Loopback IPV4

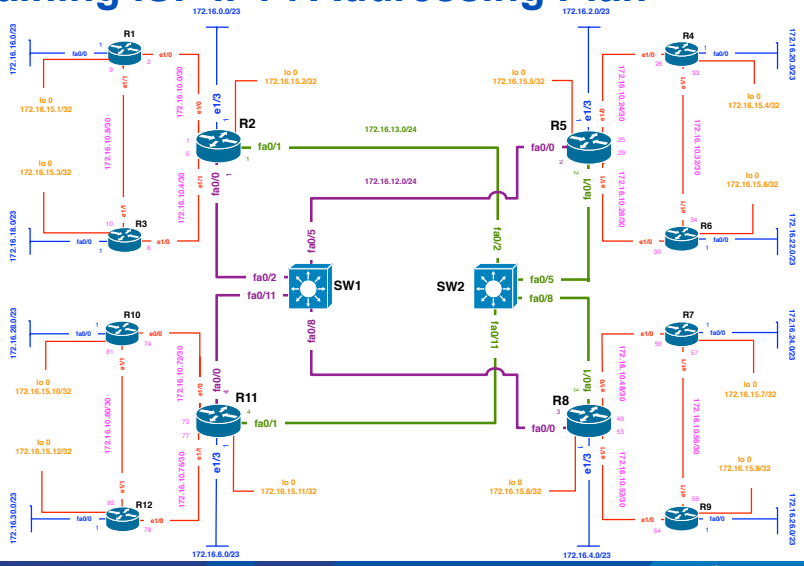
25	172.16.12.0	/24	Transport link PURPLE	No	
26	172.16.13.0	/24	Transport link GREEN	No	
27	172.16.15.0	/24	Loopback	No	

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



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