Deploying IPv6 for African ISP

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Agenda I

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- Why IPv6 ? In Africa.
- IPv6 Fundamentals
  - IPv6 Addresses, IPv6 in Layer-2 Networks
  - ICMPv6, Stateless Autoconfiguration, Neighbor Discovery
  - DHCPv6
- IPv6 and DNS
- IPv6 & Unicast Routing Protocols
  - RIP, OSPF, IS-IS, EIGRP
- IPv6 Multicast
  - MLD, Multicast Routing: PIM-SM, Bidir, SSM
  - RP issues

Agenda II

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- **Advanced IPv6 Services**
  - **IPv6 QoS**
  - **IPv6 Security**
  - **Broadband Access Networks**
- **IPv6 Transition & Deployment**
- **IPv6 in MPLS Environments**
  - **6PE**
- **Wrap-up**
- **Q&A**

Why IPv6 ?

What is IPv6? Basic Perspectives

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The End-User Perspective

- The network capability to provide the desired services
- It's all about the applications, and their services

Don't care about IPv6!!!

The Network Manager Perspective

- Stability of a given technology, implementations and benefits
- Cost of deployment and operation

Care but…has to get confident

IPv6 – A Key Driver for the e-Economy

IPv4 Address Allocation History

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1981 - IPv4 protocol published

1985 ~ 1/16 of total space

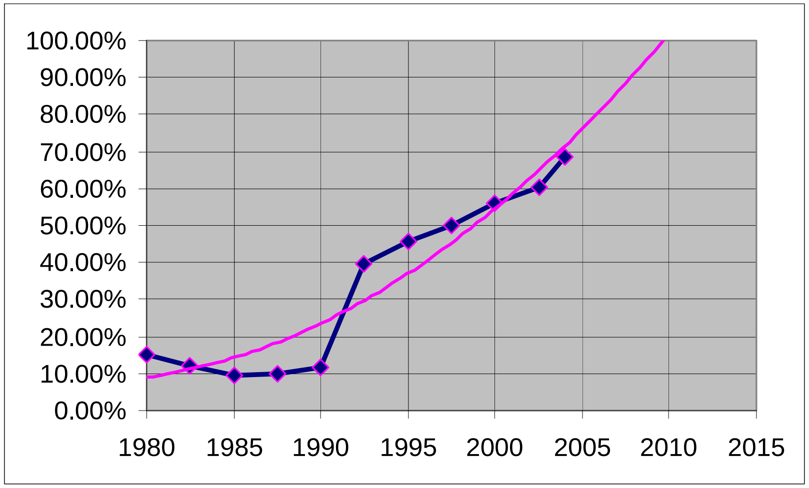
1990 ~ 1/8 of total space

1995 ~ 1/3 of total space

2000 ~ 1/2 of total space

2004 ~ 2/3 of total space

2004 ~ 80 /8s left in IANA Pool



In any case **these projections assume no change** from the historical rate

This despite increasingly intense conservation efforts

PPP / DHCP address sharing NAT (network address translation)

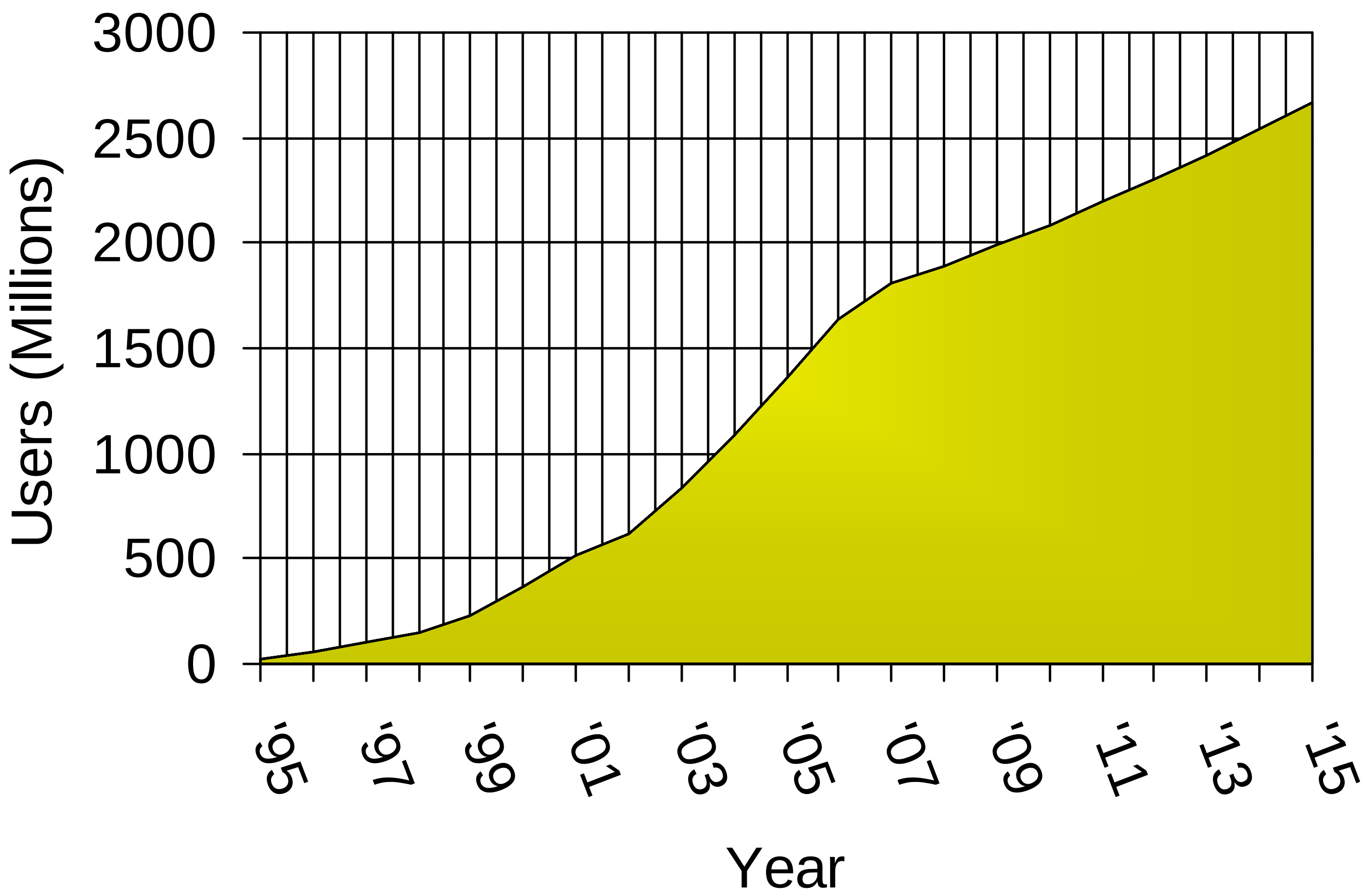
CIDR (classless inter-domain routing) plus some address reclamation

Theoretical limit of 32-bit space: ~4 billion devices

Practical limit of 32-bit space: ~250 million devices (RFC 3194)

U.S. DoC IPv6 RFC - http://www.ntia.doc.gov/ntiahome/ntiageneral/ipv6/commentsindex.html

Internet User Trends



Source: Nua Internet Surveys + vgc projections

Internet around the world

http://www.nav6tf.org/documents/e-Nations-data.pdf

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Nation (Internet code)	Population (2003)	Internet users (2002)	% Internet Penetration Rate	Global IPv4 address assigned per country	Current /8 equivalent	addresses needed to reach 20% H-ratio of 85%	Number of IPv4 /8 required for 20% H-ratio of 85%
209 countries							
Worldwide	6,321,688,311	613,040,319	9.70%	2,455,834,135	147	*6,229,490,197*	*372.3*
Specified use (IANA)				605,093,888	36.070		
China (.cn)	1,304,196,000	56,600,000	4.34%	44,007,936	2.630	1,761,501,891	105.00
India (.in)	1,065,462,000	7,000,000	0.66%	2,804,480	0.170	1,699,132,089	101.28
Indonesia (.id)	219,883,000	4,400,000	2.00%	1,141,504	0.070	261,377,868	15.58
Brazil (.br)	178,470,000	13,980,000	7.83%	1,199,160	0.080	202,594,158	12.08
Pakistan (.pk)	153,578,000	1,200,000	0.78%	254,464	0.020	175,020,149	10.44
Bangladesh (.bd)	146,736,000	150,000	0.10%	128,000	0.010	166,655,664	9.94
Nigeria (.ng)	124,009,000	100,000	0.08%	114,688	0.010	136,679,929	8.15
Russia (.ru)	143,246,000	18,000,000	12.57%	7,638,944	0.460	113,059,221	6.74
Vietnam (.vn)	81,377,000	400,000	0.49%	159,232	0.010	82,758,458	4.94
Philippines (.ph)	79,999,000	4,500,000	5.63%	765,696	0.050	77,455,760	4.62
Mexico (.mx)	103,457,000	3,500,000	3.38%	6,311,936	0.380	72,369,345	4.32
Ethiopa (.et)	70,678,000	20,000	0.03%	16,384	0.010	70,830,896	4.23
Egypt (.eg)	71,931,000	600,000	0.83%	853,504	0.060	67,382,138	4.02
Iran (.ir)	68,920,000	420,000	0.61%	581,888	0.040	65,449,815	3.91
Kenya (.tke)	31,987,000	500,000	1.56%	96,512	0.010	27,272,705	1.63

Do We Really Need a Larger Address Space?

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During the life cycle of a technology, a new product is often considered to have reached the early majority – or the mass market – after achieving 22 percent penetration.

- **Internet Population**
  - **~650M users in CY2003, ~945M by end CY 2004 – only 10-15%**
  - **How to address the future Worldwide population? (~9B in CY 2050)**
  - **Emerging Internet countries need address space, eg: China, India**
- **Mobile Internet introduces new generation of Internet devices**
  - **PDA (~20M in 2004), Mobile Phones (~1.5B in 2003), Tablet PC**
  - **Enable through several technologies, eg: 3G, 802.11,…**
- **Transportation – Mobile Networks**
  - **1B automobiles forecast for 2008 – Begin now on vertical markets**
  - **Internet access on buses (Paris), planes (Lufthansa), trains (Narita express)**
- **Consumer, Home and Industrial Appliances**

Explosion of New Internet Appliances

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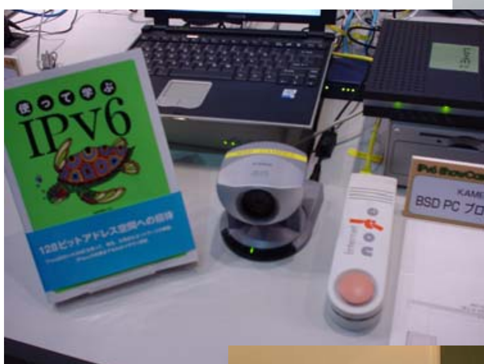

Source: N+I Tokyo

Explosion of New Internet Appliances

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Source: N+I Tokyo

IPv6 Drivers—Network's Architecture

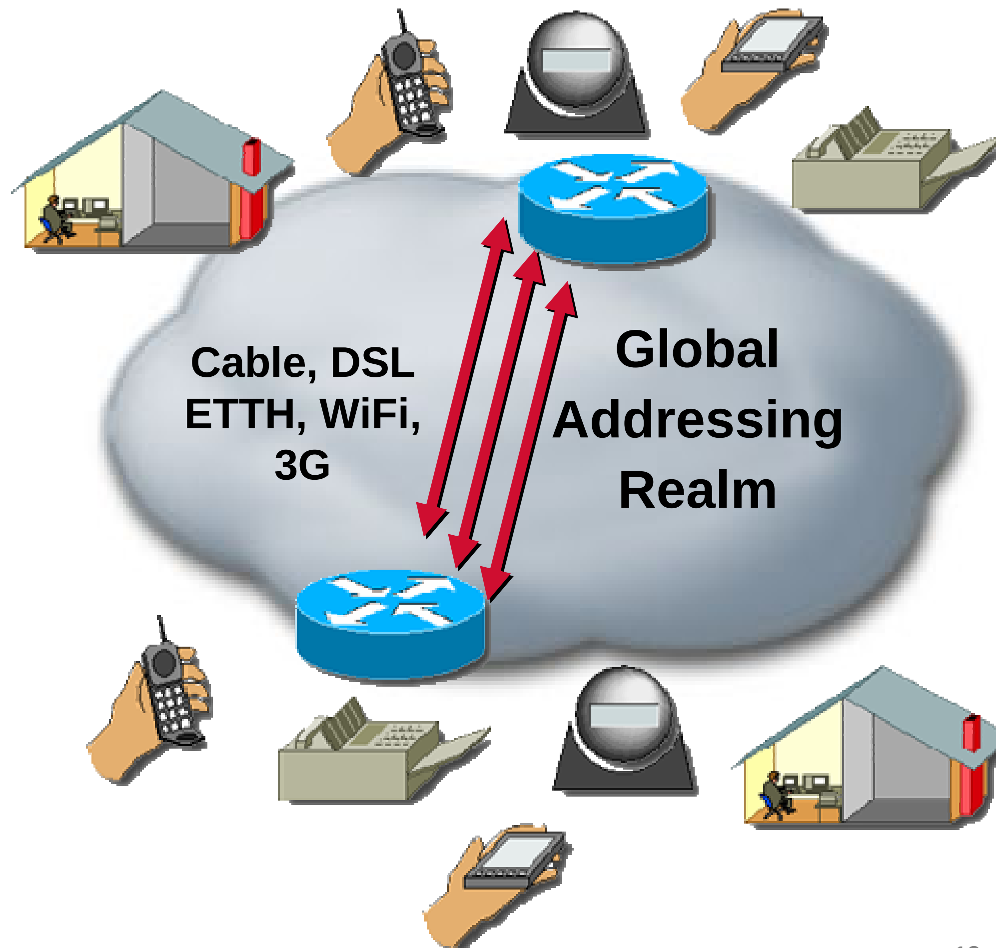
"Always-on" technologies enable new application environments

- **Today, Network Address Translation (NAT) and application-layer gateways connect disparate networks**

  Internet started with end-to-end connectivity for any application

- **Peer-to-peer or server-to-client applications mean global addresses**

  IP telephony, fax, video
  Mobility
  Distributed gaming
  Remote monitoring
  Instant messaging



Broadband Home – A necessity for IPv6 !

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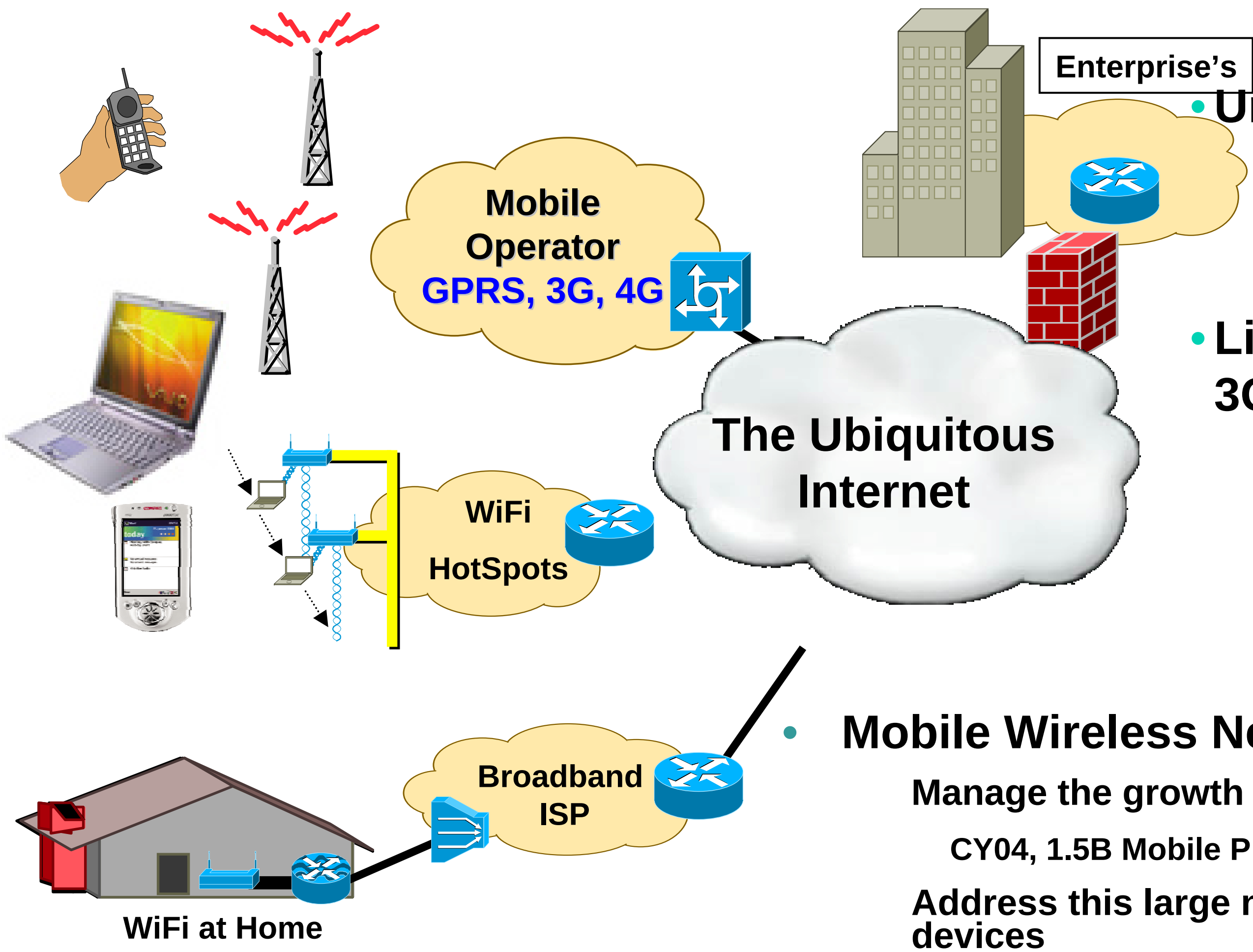
Mobile Wireless Networking – an IPv6 Must



- Unlicensed Band (WiFi,…)
  - Personal mobility
  - high data rate
  - incremental infrastructure
- Licensed Band (GPRS, 3G, DVB-T,…)
  - Full mobility
  - Modest data rate
  - New infrastructure

- Mobile Wireless Networking challenges
  - Manage the growth of subscribers
    - CY04, 1.5B Mobile Phone's users
  - Address this large number of "Always-reachable" devices
  - Support a Multimedia environment
    - *The IPv6 Benefits*

Traffic Evolution

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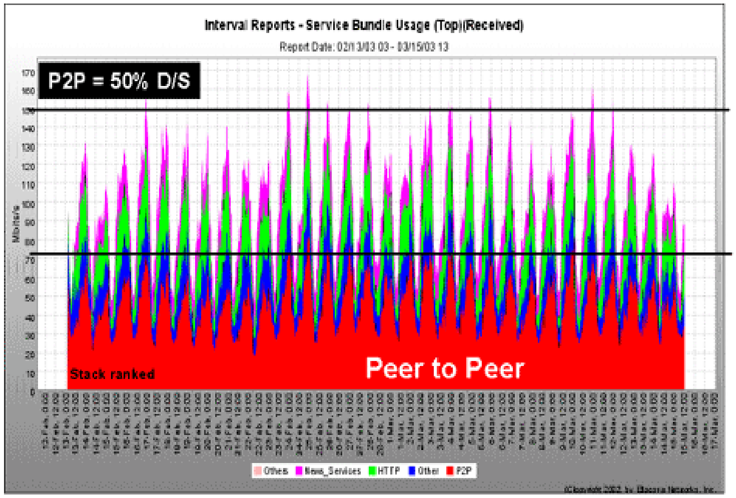
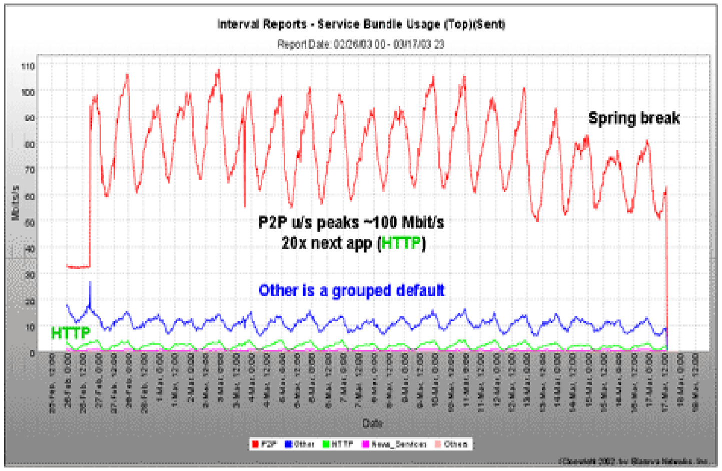
- **Applications – Server/Client, P2P, GRID – generate different traffic patterns than Client/Server**
  - **Symmetrical – as much upstream as downstream traffic (users become servers)**
  - **Very long sessions – Always-on devices may be left unattended. Streaming applications can run for a long period of time. Often 24/7.**
  - **Sustained high bandwidth – many devices can now use all bandwidth available. Multiple video sessions require high bandwidth capacity**
  - **Non-local – Traffic travels globally, and between ISP networks, hence putting load on the peering points (est. 60% of traffic) and expensive long haul links.**

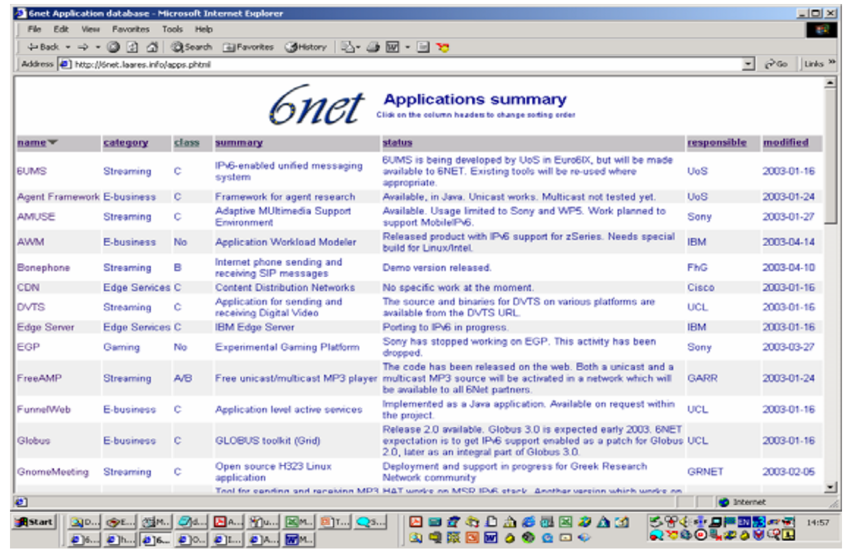




IPv6 Integration – Per Application Model

Today, all O.S. are Dual-Stack

- **As soon as the infrastructure is IPv6 capable…IPv6 integration can follow a non-disruptive "per application" model**



6net Applications summary

Click on the column headers to change sorting order

name	category	class	summary	status	responsible	modified
6UMS	Streaming	C	IPv6-enabled unified messaging system	6UMS is being developed by UoS in Euro6IX, but will be made available to 6NET. Existing tools will be re-used where appropriate.	UoS	2003-01-16
Agent Framework	E-business	C	Framework for agent research	Available, in Java. Unicast works. Multicast not tested yet.	UoS	2003-01-24
AMUSE	Streaming	C	Adaptive MUltimedia Support Environment	Available. Usage limited to Sony and WP5. Work planned to support MobileIPv6.	Sony	2003-01-27
AWM	E-business	No	Application Workload Modeler	Released product with IPv6 support for zSeries. Needs special build for Linux/Intel.	IBM	2003-04-14
Bonephone	Streaming	B	Internet phone sending and receiving SIP messages	Demo version released.	FhG	2003-04-10
CDN	Edge Services	C	Content Distribution Networks	No specific work at the moment.	Cisco	2003-01-16
DVTS	Streaming	C	Application for sending and receiving Digital Video	The source and binaries for DVTS on various platforms are available from the DVTS URL.	UCL	2003-01-16
Edge Server	Edge Services	C	IBM Edge Server	Porting to IPv6 in progress.	IBM	2003-01-16
EGP	Gaming	No	Experimental Gaming Platform	Sony has stopped working on EGP. This activity has been dropped.	Sony	2003-03-27
FreeAMP	Streaming	A/B	Free unicast/multicast MP3 player	The code has been released on the web. Both a unicast and a multicast MP3 source will be activated in a network which will be available to all 6Net partners.	GARR	2003-01-24
FunnelWeb	E-business	C	Application level active services	Implemented as a Java application. Available on request within the project.	UCL	2003-01-16
Globus	E-business	C	GLOBUS toolkit (Grid)	Release 2.0 available. Globus 3.0 is expected early 2003. 6NET expectation is to get IPv6 support enabled as a patch for Globus 2.0, later as an integral part of Globus 3.0.	UCL	2003-01-16
GnomeMeeting	Streaming	C	Open source H323 Linux application	Deployment and support in progress for Greek Research Network community	GRNET	2003-02-06

Call for Applications – protocol agnostic

New Generation of Internet Appliances

6NET Project Overview

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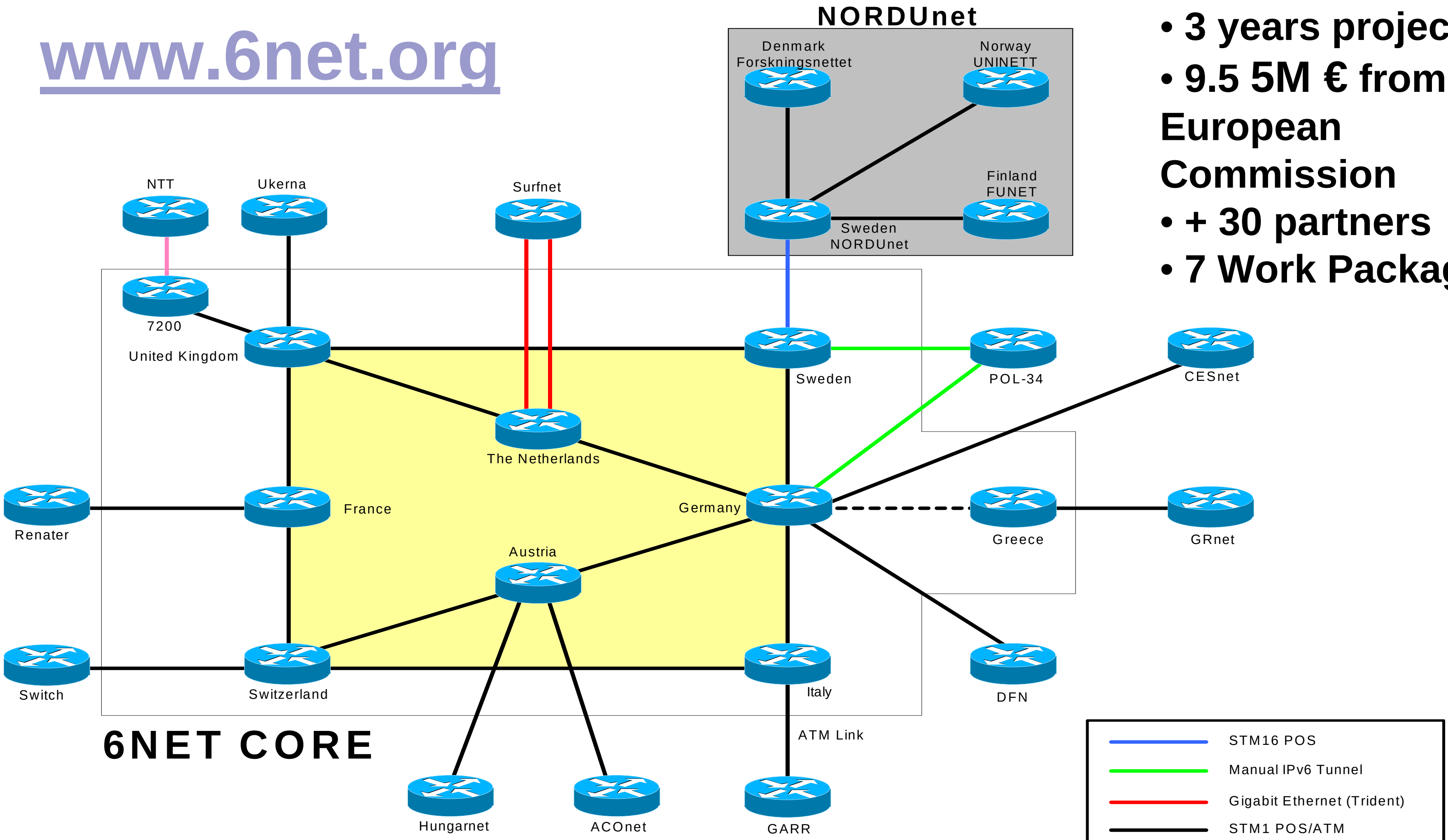
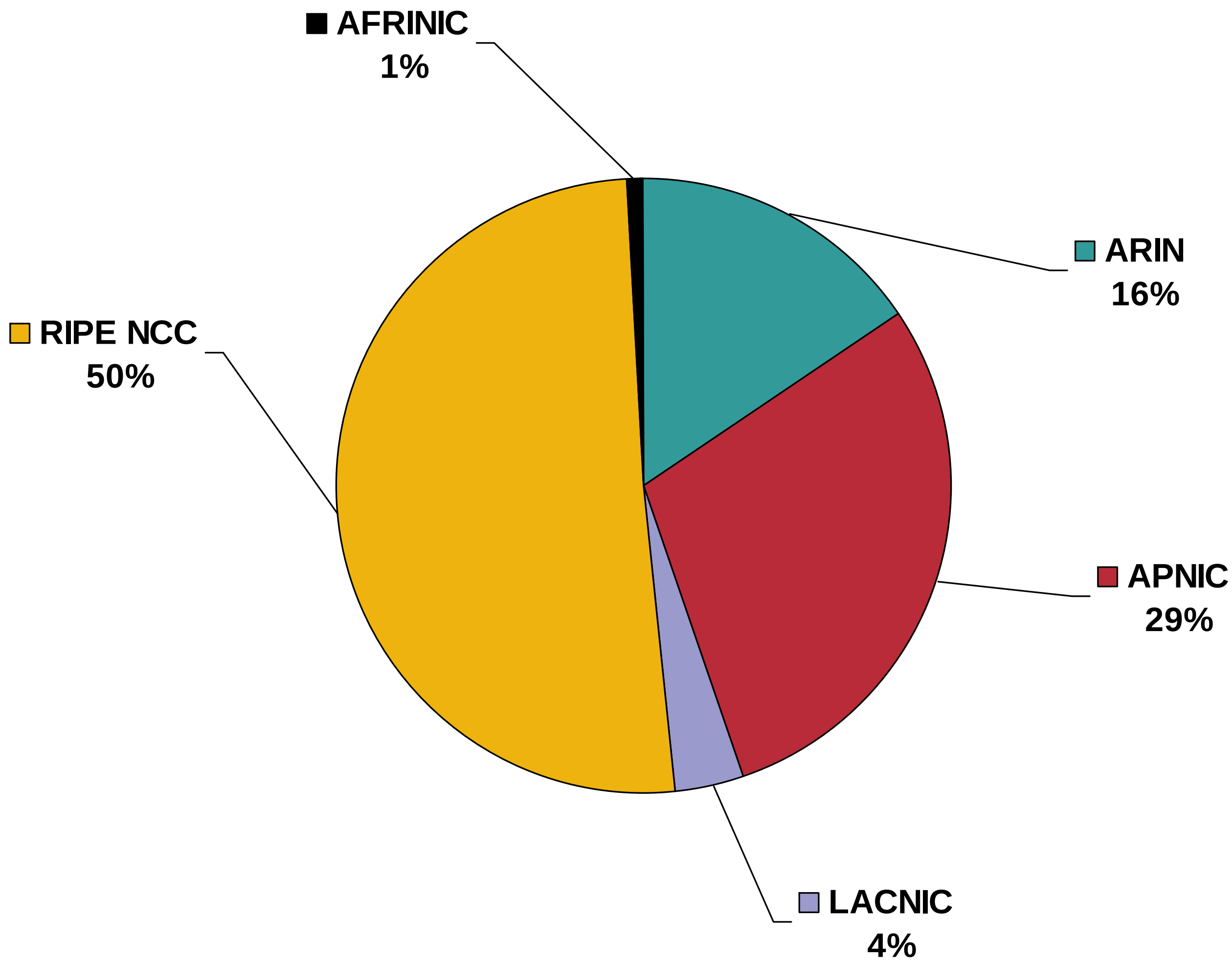
www.6net.org

- 3 years project
- 9.5 5M € from European Commission
- + 30 partners
- 7 Work Packages



Cisco 12400 and 7200 series

IPv6 Prefix Allocations (Apr 06)



http://www.ripe.net/ripencc/mem-services/registration/ipv6/ipv6allocs.html

African exchange points

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- **An increasing number of internet exchanges is essential to the growth of the internet in Africa and to prepare the continent for the upcoming IP convergence**
- **Too much African content is hosted outside the continent.**
- **IX’s would be ideal locations for initial deployment and support of both IPv4 andIPv6**

Source Afrispa 2006

Africa goes mobile

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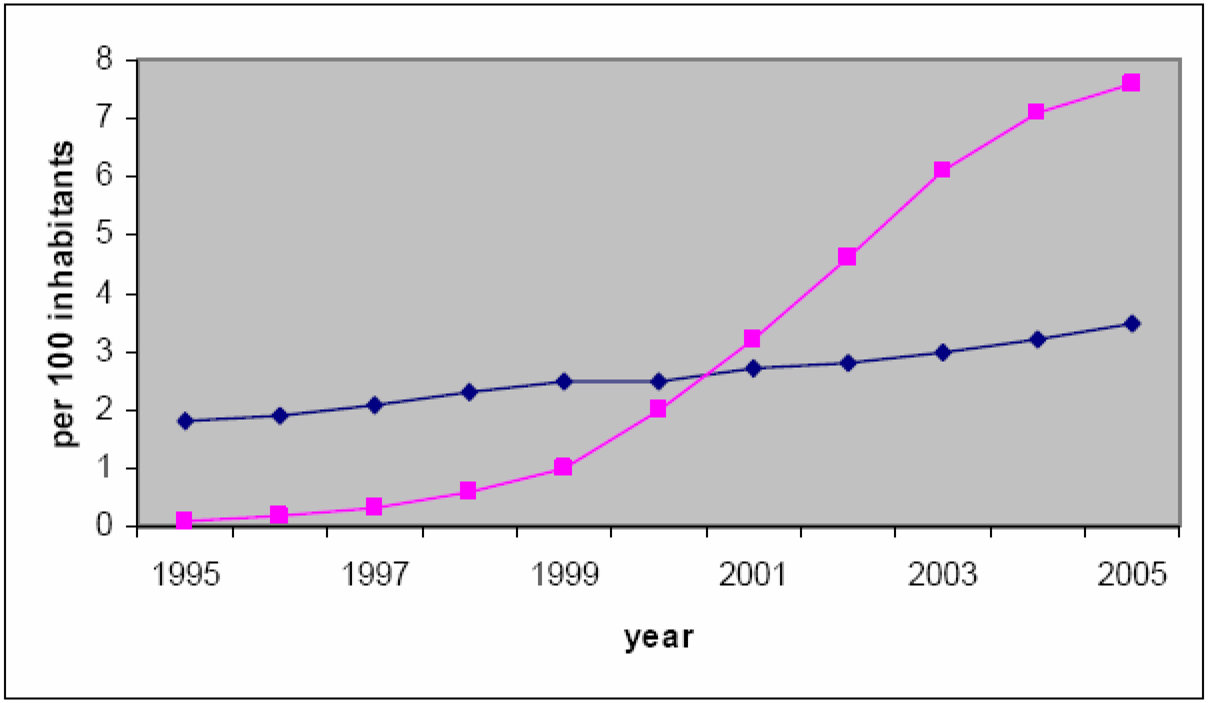

67 million mobile phones

31 million fixed line phones

Mobile and fixed subscribers per 100 inhabitants
source: ITU

Africa started on the path to 3G

Market	Q3 2003	Q4 2003	Q1 2004	Q2 2004	Q3 2004	Q4 2004	Q1 2005	Q2 2005	Q3 2005
World	1,621,103	2,754,129	4,356,108	7,477,462	11,446,130	16,517,916	23,622,605	29,357,065	40,072,811
Africa	---	---	---	---	---	---	10,853	26,341	50,359
Asia Pacific	1,138,597	2,079,622	3,383,308	5,114,795	7,222,355	9,470,851	13,066,071	15,791,601	21,451,689
Europe: Western	482,506	674,507	968,916	2,353,885	4,094,914	6,744,243	10,139,417	13,016,978	17,868,570
Middle East	---	---	3,884	8,782	19,326	44,997	75,667	112,440	157,390
USA/Canada	---	---	---	---	109,535	245,545	302,214	361,172	470,527

Source: GSMA number of WCDMA connections

Note that ITU estimates 67 million mobile phone users for Africa by end 2005 up from 61.2 million year before

Africa’s routes to WLAN’s

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- **Wi-fi?**
  - **–Knysna, S.A. : Africa's first Municipal Wi-FiBroadband Network offers VoIPand Internet Access (allAfrica.com nov7th)**
  - **–Wifinder (see http://www.wifinder.com/) lists African wi-fi hotspots for Egypt, Ghana, Morocco, Nigeria, South Africa, Tanzania, Tunisia**
- **WiMax?**
  - **–Alvarionto install Wi-max in Kinshasa**
  - **–Telkom SA trial Wi-Max**

What does IPv6 bring to the table?

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- Solves address shortage
- Restores p2p
- Mobility
  - –Better spectrum utilization
  - –Better batterylife!
- Security
  - –Ipsec mandatory
- Multicast
- Neighbour discovery
  - –Ad-Hoc networking
  - –Home networks
  - –Plug and play–Auto configuration
- Permanent addresses
  - –Identity (CLID)
  - –Traceability (RFID)
  - –Sensors and monitoring

Should Africa move now ?

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- **Yes**
  - IP convergence will impacts many aspects of human activities and practically all industries
  - Periods of rapid change give a chance to leapfrog to new technologies and close development and economic gaps.
  - Transition to IPv6 is one of the essential ingredients to reap the economic benefits of this new converged world.
- **The continent started the migration already**
  - The Research and Education Community and some progressive carriers show the way

IPv6 Fundamentals

IPv6 Header

IPv6 Packet Structure

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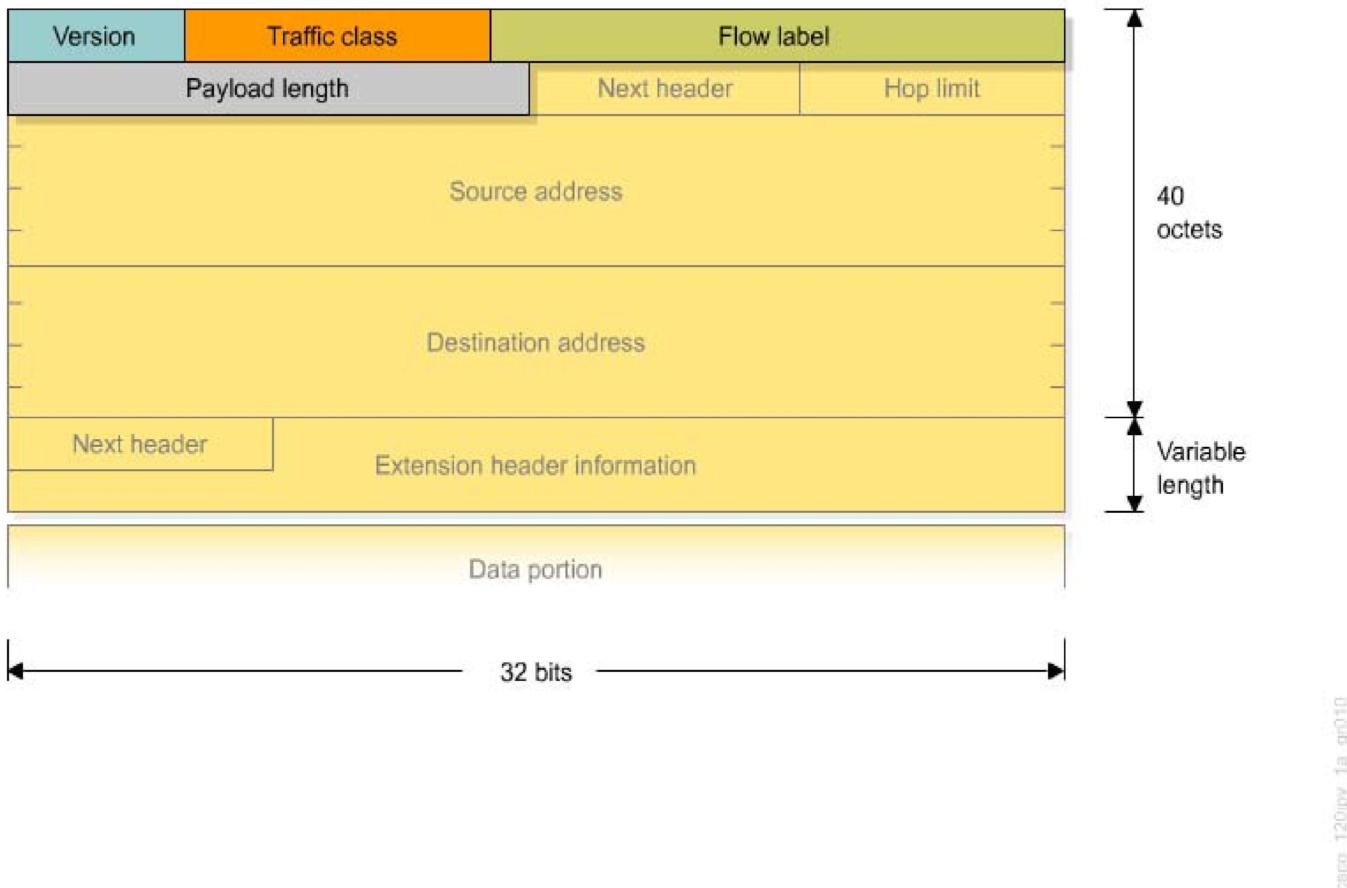
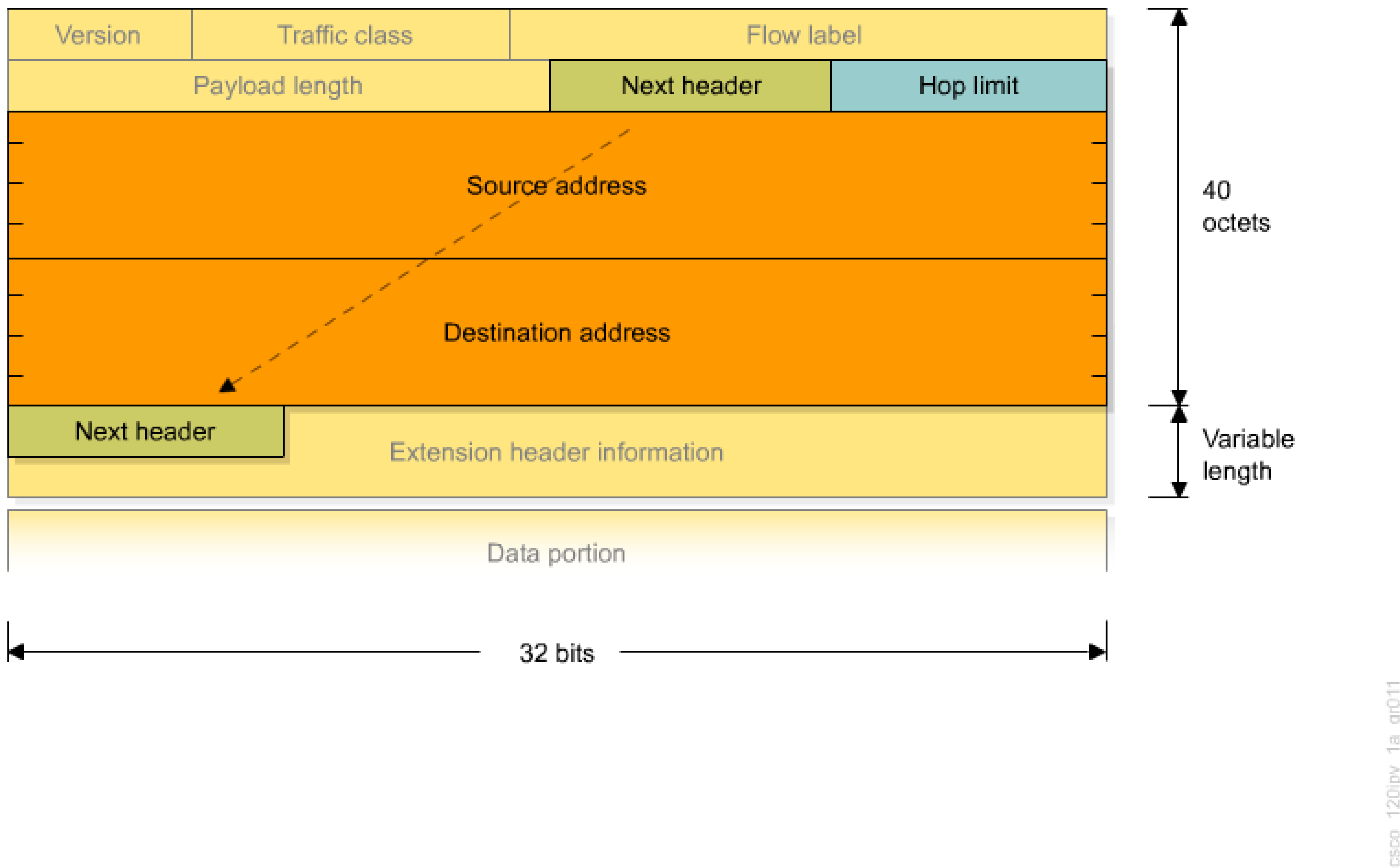
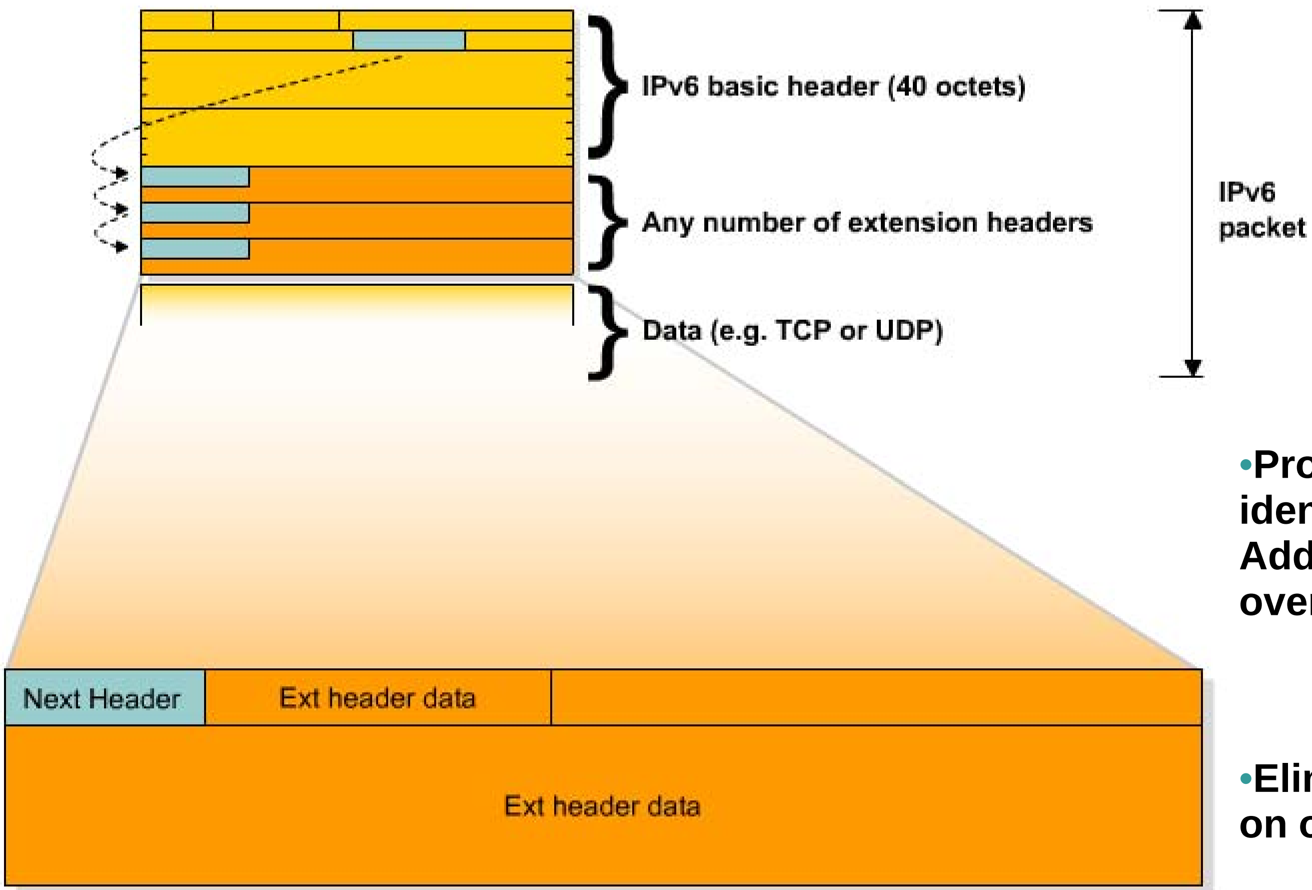


Packet Structure (Cont.)



Extension Headers (RFC2460)



- Processed only by node identified in IPv6 Destination Address field => much lower overhead than IPv4 options
  - exception: Hop-by-Hop Options header
- Eliminated IPv4's 40-octet limit on options
  - In IPv6, limit is total packet size, or Path MTU in some cases

IPv6 Extension Header Types

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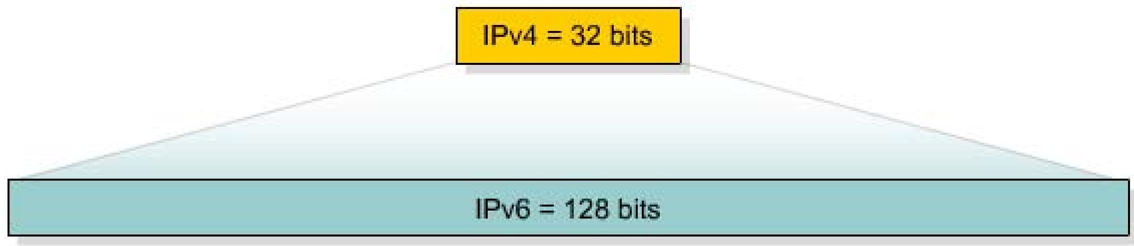
Header Type	Next Header Value	Description
Hop-by-hop options header	0	Processed by all hops in the path of a packet, when present follows immediately after the basic IPv6 packet header
Destination option header	60	When the destination options header follows hop-by-hop options header, it is processed at the final destination and also at each visited address specified by the routing header. If it follows the Encapsulating Security Payload(ESP) header, it is processed only at the final destination.
Routing Header	43	Used for Source Routing
Fragment Header	44	Used by source when packet is fragmented , fragment header is used in each fragmented packet
Authentication Header (RFC 1826) and ESP Header (RFC 1827)	51	These are used within IP Security Protocol(IPSEC) to provide authentication,integrity and confidentiality of a packet. These headers are identical for IPv4 and IPv6
Upper-layer Header	6 (TCP) 17 (UDP)	These are the typical headers used inside a packet to transport data.

IPv6 Addressing

IPv6 Addressing



- **128 bit long addresses**
  - **Allow hierarchy**
  - **Flexibility for network evolutions**
- **Represented as:**
  - **Use CIDR principles: Prefix / Prefix Length**
  - **x:x:x:x:x:x:x:x where x is a 16-bit hexadecimal field**
  - **2001:0DB8:010F:0001:0000:0000:0000:0ED1**
  - **2001:DB8:10F:1:0:0:0:ED1**
  - **2001:DB8:10F:1::ED1**

Address Representation

- **Format:**

  x:x:x:x:x:x:x:x where x is 16 bits hexadecimal field

  2031:0000:130F:0000:0000:09C0:876A:130B

  Case insensitive

  Leading zeros in a field are optional:

  2031:0:130F:0:0:9C0:876A:130B

  Successive fields of 0 are represented as ::, but only once in an address:

  2031:0:130F::9C0:876A:130B

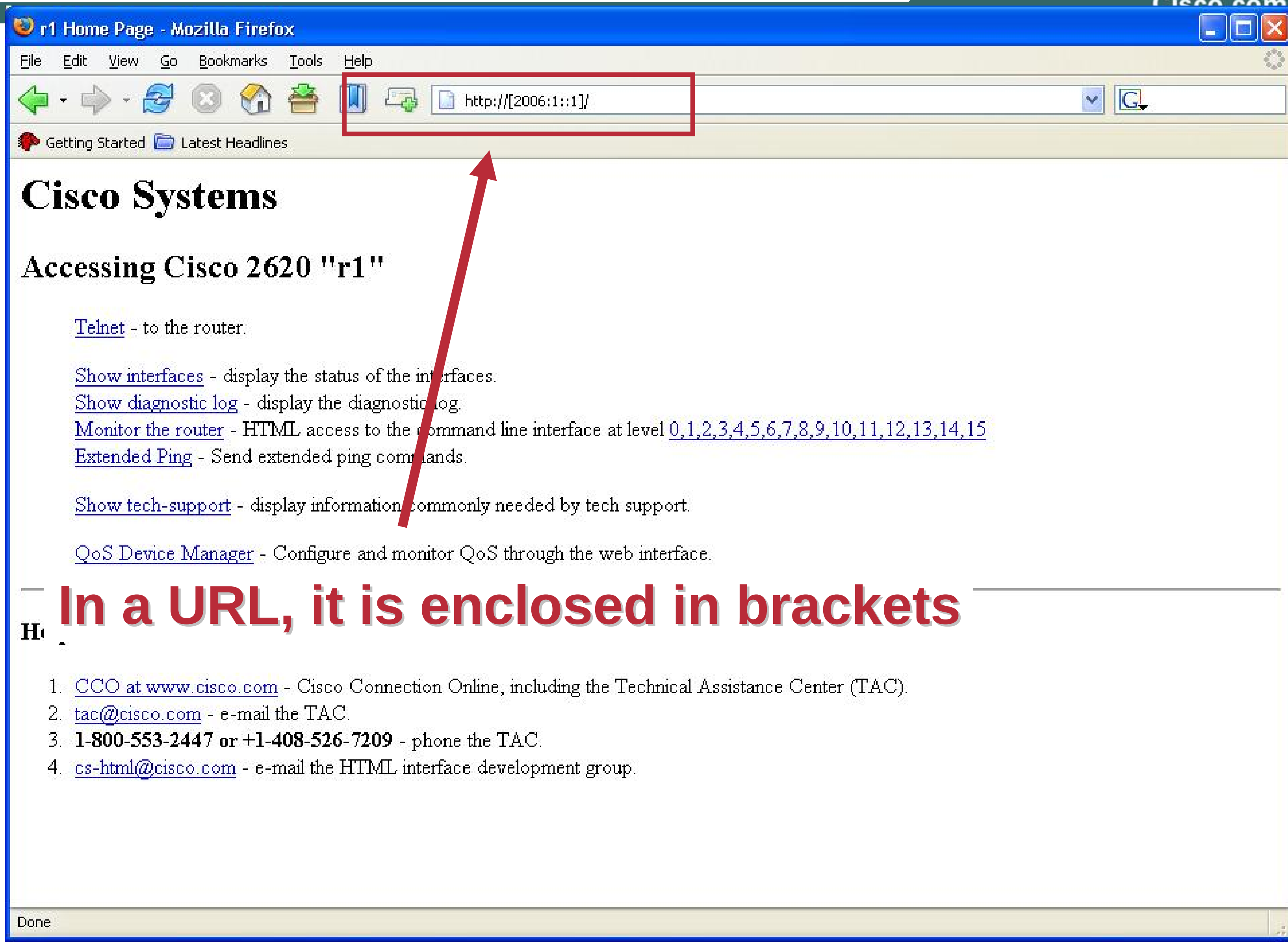
  ~~2031::130F::9C0:876A:130B~~

  FF01:0:0:0:0:0:0:1 => FF01::1

  0:0:0:0:0:0:0:1 => ::1

  0:0:0:0:0:0:0:0 => ::

Address Representation



In a URL, it is enclosed in brackets

IPv6 Addressing

- IPv6 Addressing rules are covered by multiples RFC's

  Architecture initially defined by RFC 2373

  Now RFC 3513 (obsoletes 2373)

- Address Types are :

  Unicast : One to One (Global, Link local, Site local, Compatible)

  Anycast : One to Nearest (Allocated from Unicast)

  Multicast : One to Many

- A single interface may be assigned multiple IPv6 addresses of any type (unicast, anycast, multicast)

  No Broadcast Address -> Use Multicast

IPv6 - Addressing Model

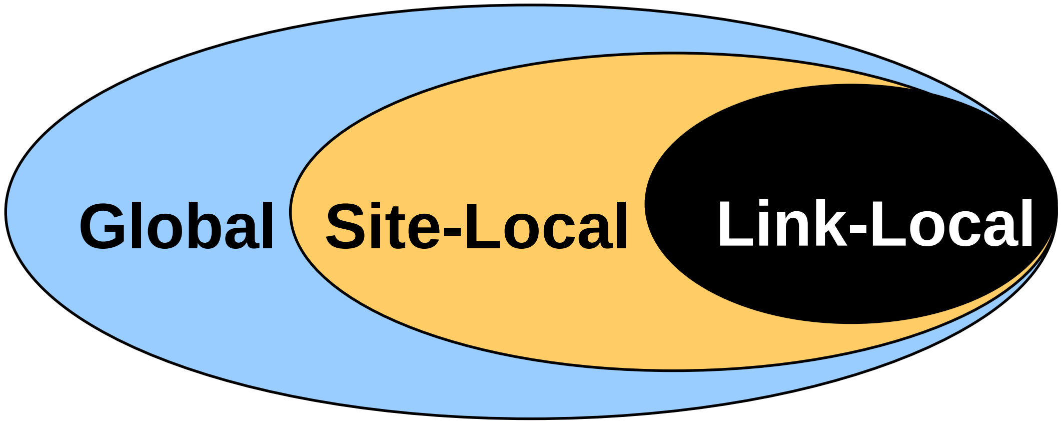
Addresses are assigned to interfaces

- change from IPv4 model :

Interface 'expected' to have multiple addresses

Addresses have scope

- Link Local
- Site Local
- Global



Addresses have lifetime

- Valid and Preferred lifetime

Address Type Identification (RFC 3513)

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- The type of an IPv6 address is identified by the high-order bits of the address, as follows

Address type	Binary prefix	IPv6 notation	Section
Unspecified	00...0 (128 bits)	::/128	2.5.2
Loopback	00...1 (128 bits)	::1/128	2.5.3
Multicast	11111111	FF00::/8	2.7
Link-local unicast	1111111010	FE80::/10	2.5.6
Site-local unicast	1111111011	FEC0::/10	2.5.6
Global unicast	(everything else)		

- Primary Goal is Simplification of Addressing Scheme

Obsoletes RFC2373

Unspecified and Loopback Addresses

- **Unspecified address:**

  0:0:0:0:0:0:0:0

  Used as a placeholder when no address available (initial DHCP request, DAD)

- **Loopback address:**

  0:0:0:0:0:0:0:1

  Same as 127.0.0.1 in IPv4

  Identifies self

Link-local Addresses

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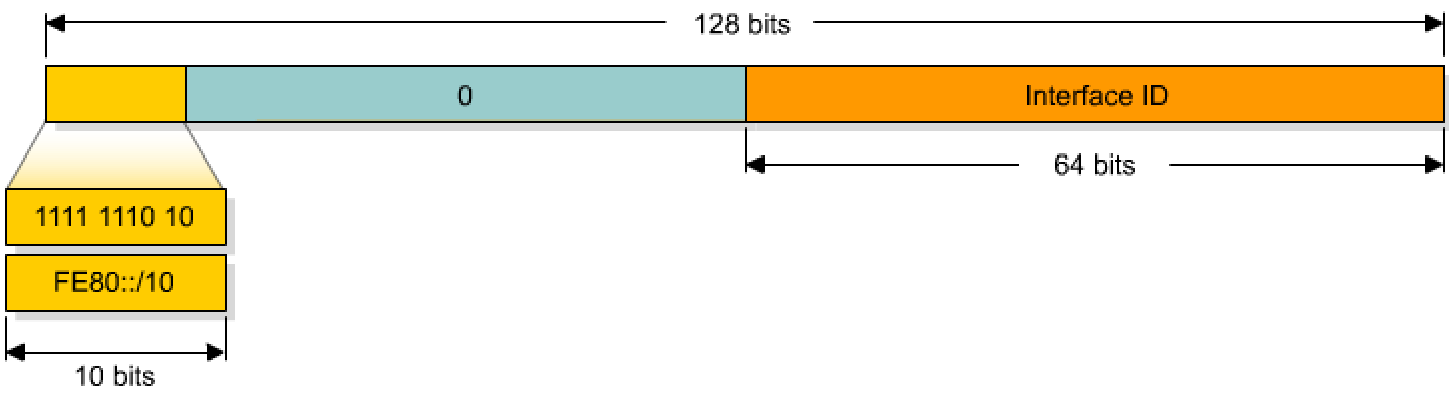

- **Have a scope limited to the link**
- **Are automatically configured with the interface ID**
- **For use during auto-configuration and when no routers are present**
- **Can connect to devices without using global addresses (Must specify an outgoing interface)**

Unique Local IPv6 Unicast Addresses

- Replaces Site-Local (FEC0::/10)
  - draft-ietf-ipv6-deprecate-site-local-04
- draft-ietf-ipv6-unique-local-addr-07.txt
- Defines an unicast address format that is globally unique and is intended for local communications, usually inside of a site. They are not expected to be routable on the global Internet given current routing technology
  - They are routable inside of a more limited area such as a site.
  - They may also be routed between a limited set of sites.

Unique Local IPv6 Unicast Addresses

- **Local IPv6 unicast addresses have the following characteristics:**

  Globally unique prefix.

  Well known prefix to allow for easy filtering at site boundaries.

  Allows sites to be combined or privately interconnected without creating any address conflicts or require renumbering of interfaces using these prefixes.

  Internet Service Provider independent and can be used for communications inside of a site without having any permanent or intermittent Internet connectivity.

  If accidentally leaked outside of a site via routing or DNS, there is no conflict with any other addresses.

  In practice, applications may treat these addresses like global scoped addresses.

Local IPv6 Unicast Addresses


```
| 7 bits |   41 bits    |  16 bits  |          64 bits          |
+--------+--------------+-----------+----------------------------+
| prefix | global ID    | subnet ID |        interface ID        |
+--------+--------------+-----------+----------------------------+
```

- **Prefix: FC00::/7 prefix to identify Local IPv6 unicast addresses.**
- **global ID: 41-bit global identifier used to create a globally unique prefix.**

  The allocation of global IDs should be pseudo-random

  FC00::/8 Centrally assigned

  FD00::/8 Locally assigned

- **Subnet ID: 16-bit subnet ID is an identifier of a subnet within the site.**
- **Interface ID: 64-bit IID** **see draft-ietf-ipv6-unique-local-addr-07.txt**

Global Unicast Addresses
RFC 3513 and RFC3587

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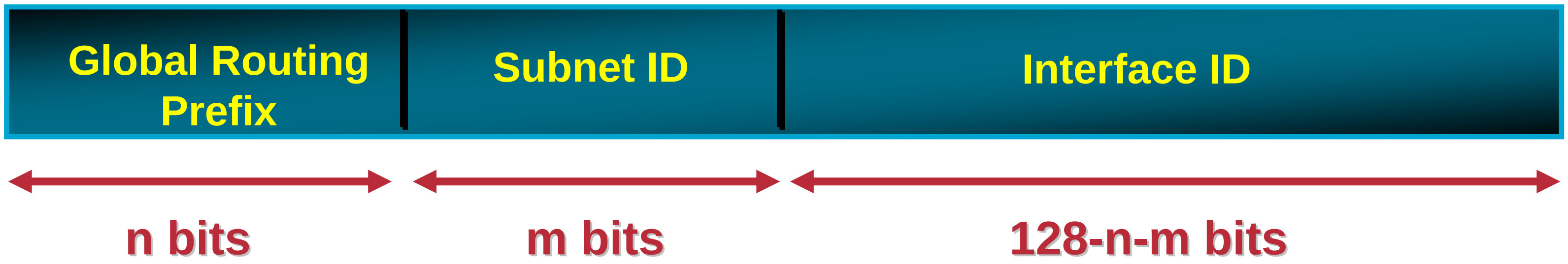

- **All global unicast addresses other than those that start with binary 000 have a 64-bit interface ID field (i.e., n + m = 64)**
- **Unicast addresses are hierarchical, just like IPv4**
- **The global routing prefix is itself hierarchically structured**
- **Usually the global routing prefix is a value assigned to a site**
- **A “subnet” is usually the same as a link, but:**

  may have more than one subnet ID for the same link

  (proposed) a subnet ID may span multiple links

Obsoletes RFC2373 and RFC2374

Global IPv6 allocations made by the Regional Internet Registries

- **Real IPv6 address space now allocated by Registries**
- **Registries are based on geographical location**

RIPE NCC (376 Prefixes)

2001:0600::/23
2001:0800::/23
2001:0A00::/23 …

APNIC (166 Prefixes)

2001:0200::/23
2001:0C00::/23
2001:0E00::/23 …

ARIN (94 Prefixes)

2001:0400::/23
2001:1800::/23

Allocated 16/11/2004
http://www.ripe.net/ipv6/ipv6allocs.html

- **Documentation : 2001:0DB8::/32**
- **6Bone 3FFE::/16**
- **6to4 tunnels 2002::/16**
- **Enterprises get their IPv6 address space from their ISP.**

http://www.iana.org/assignments/ipv6-tla-assignments

IPv6 Address Allocation Process

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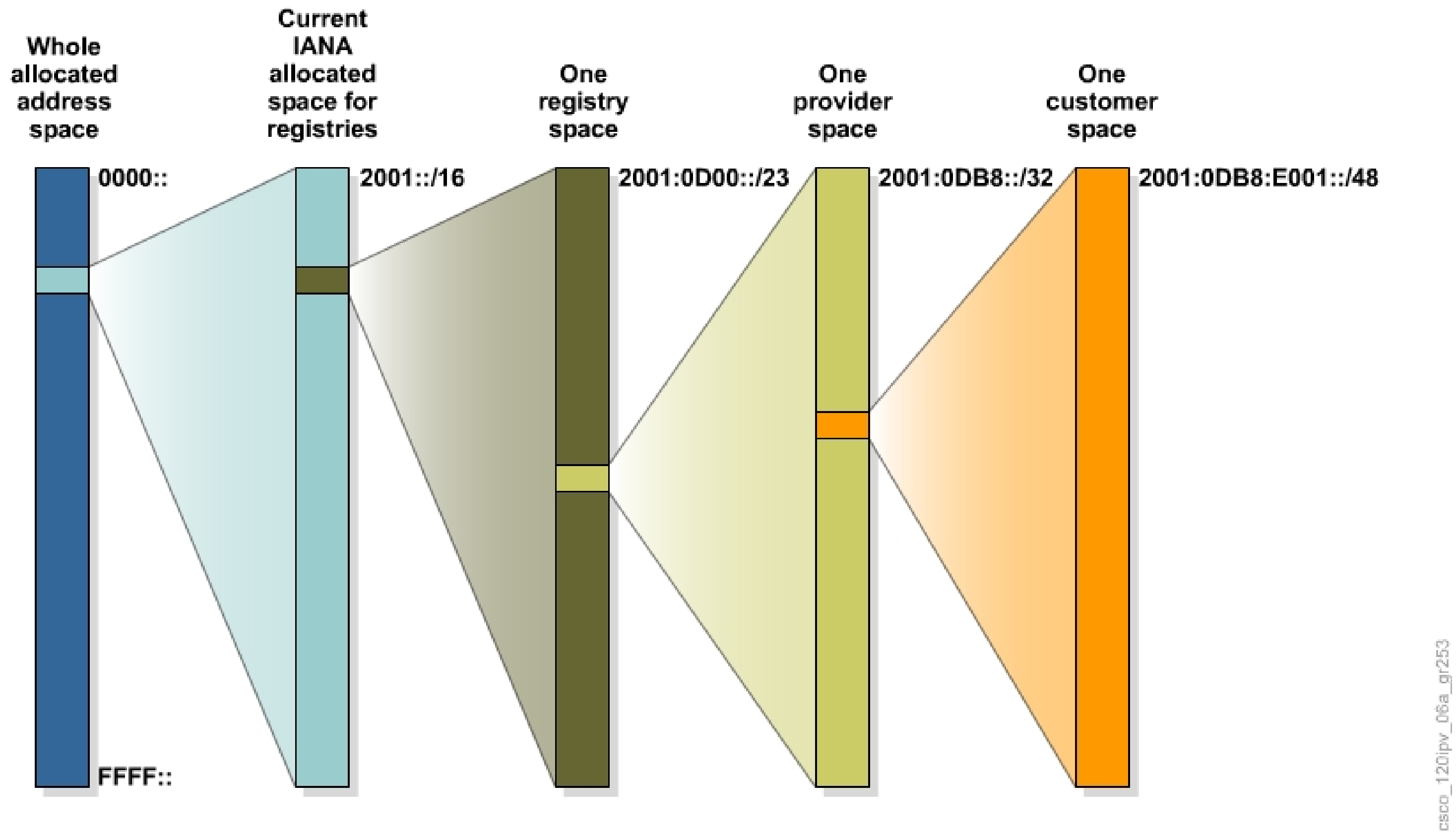
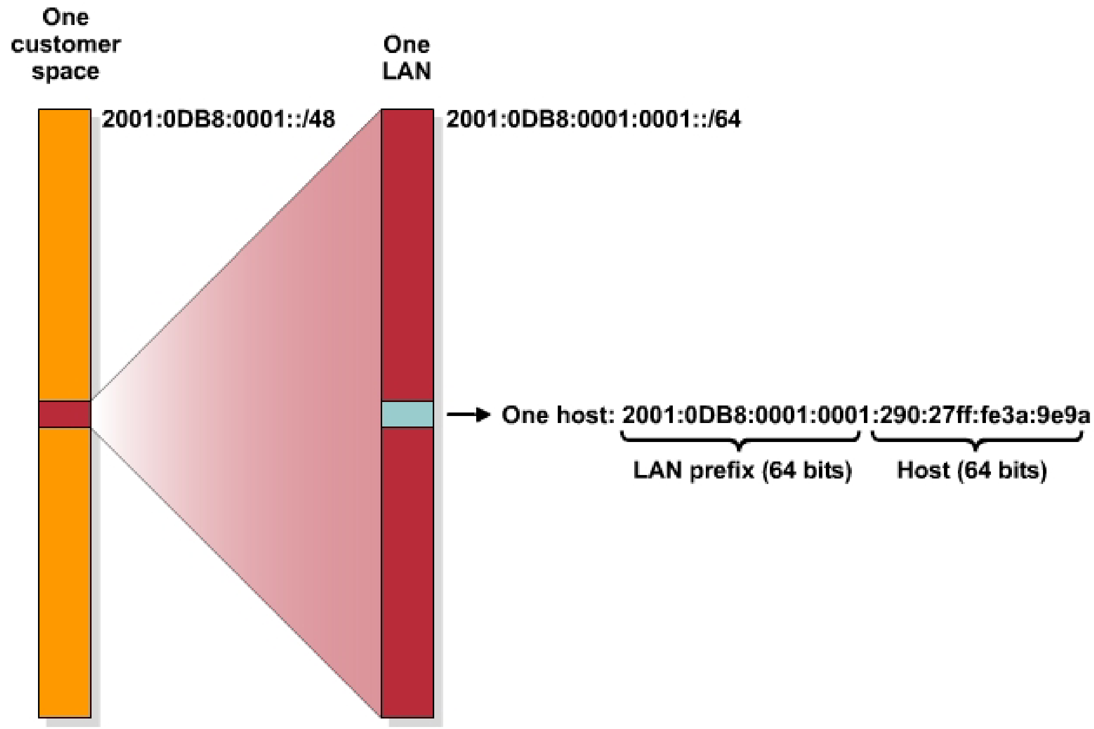
Partition of Allocated IPv6 Address Space



IPv6 Address Allocation Process

Partition of Allocated IPv6 Address Space (Cont.)



Multicast Addresses (RFC 2373, now 3513)

11111111	Flags	Scope	0	Group ID
8	4	4	80 Bits	32

- **Low-order flag indicates permanent/transient group; three other flags reserved**
- **Scope field:**

  1—node local

  2—link-local

  5—site-local

  8—organization-local

  B—community-local

  E—global

  (All other values reserved)

Permanent Multicast Addresses

Examples

	Meaning	Scope
FF02::1	All nodes	Link-local
FF02::2	All routers	Link-local
FF02::9	All RIP routers	Link-local
FF02::5 FF02::6	All OSPF routers	Link-local
FF02::1:FFXX:XXXX	Solicited-node	Link-local
FF05::101	All NTP servers	Site-local

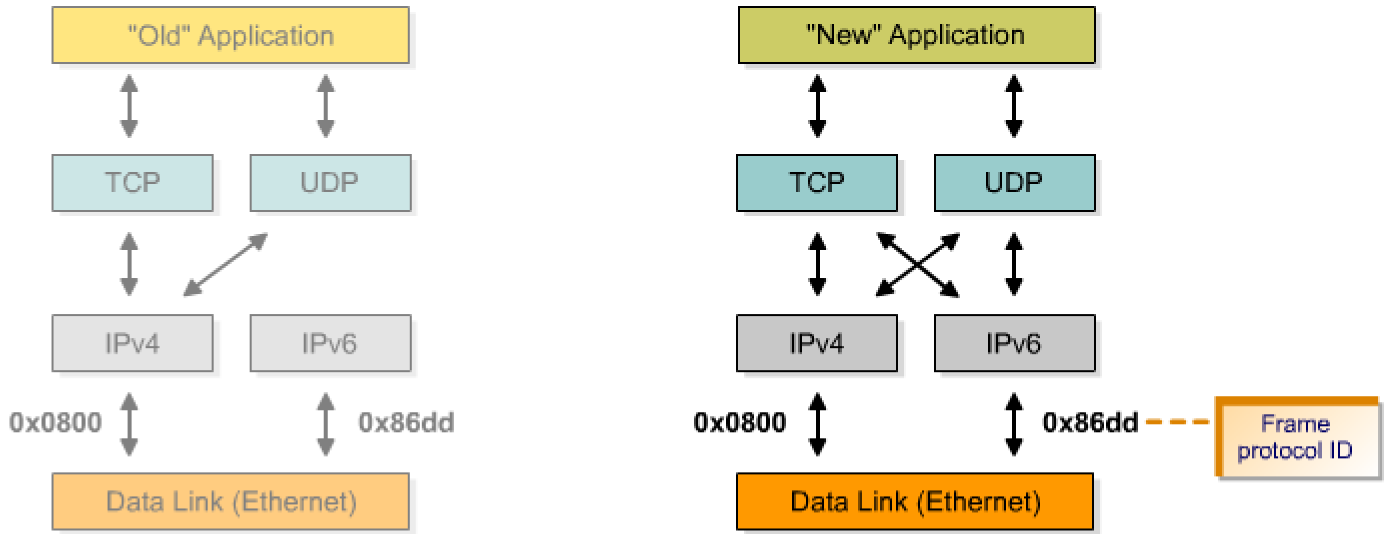
FF0X:: is reserved (X=0..F)

Ethernet and IP Protocol Numbers

Layer 2 Protocol ID Number for IPv6

Layer 2 Type	Ethernet	PPP	Frame Relay	FDDI	HDLC	Token Ring	IEEE 1394	ATM
Protocol ID# for IPv6	0x86DD	0x8057	0x8057	0x86DD	0x86DD	0x86DD	0x86DD	0x86DD
Protocol ID# for IPv4	0x0800	0x002D	0x002D	0x86DD	0x86DD	0x86DD	0x86DD	0x86DD
Protocol ID Type	Ethertype	PPP Protocol Field	Network Layer Protocol Identifier	Ethertype	Ethertype	Ethertype	Ethertype	Ethertype

Dual Stack

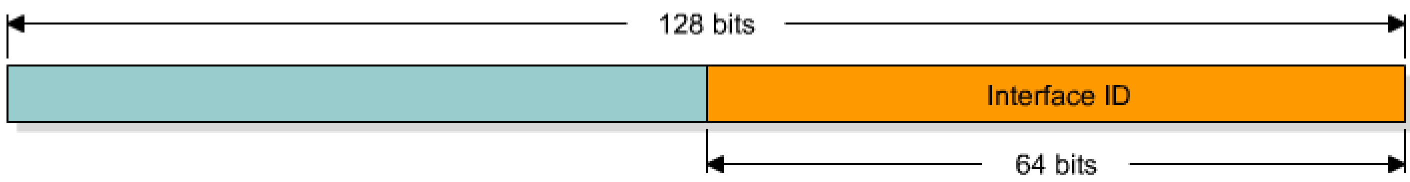


Both IPv4 and IPv6 stacks are enabled.

Applications can talk to both.

Choice of the IP version is based on name lookup and application preference.

Interface Identifiers



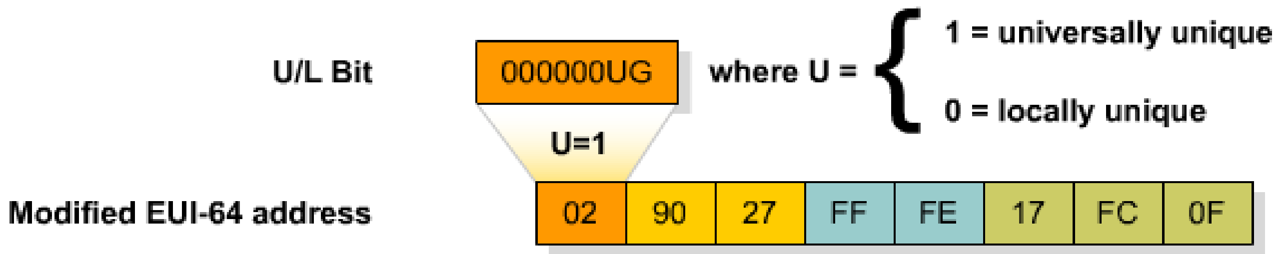
- **Used to identify interfaces on a link:**

  Must be unique on that link

  Can be globally unique

- **64 bits to be compatible with IEEE 1394 (Firewire)**
- **Ease autoconfiguration**
- **IEEE defines the mechanism to create an EUI-64 from IEEE 802 MAC addresses (Ethernet, FDDI)**

EUI-64 to IPv6 Interface Identifier



- **A modified EUI-64 address is formed by inserting “FFFE” and “complimenting” a bit identifying the uniqueness of the MAC address.**

Interface Identifier Privacy Issues

- **IEEE 24 bits OUI can be used to identify hardware**
  - **http://standards.ieee.org/regauth/oui/oui.txt**
- **Interface Identifier can be used to trace a user**
  - **The prefix changes, but the Interface ID remains the same**
  - **Psychological Issue**
- **Possibility to change the Interface ID (RFC3041)**
  - **If local storage, use MD5 Algorithm**
  - **Otherwise draw a random number**
- **Windows XP supports randomly generated interface identifiers**

IPv6 host addresses

- **A host is required to recognize the following addresses as identifying itself:**

  Its required Link-Local Address for each interface.

  Any additional Unicast and Anycast Addresses that have been configured for the node's interfaces (manually or automatically).

  The loopback address.

  The All-Nodes Multicast Addresses

  The Solicited-Node Multicast Address for each of its unicast and anycast addresses.

  Multicast Addresses of all other groups to which the node belongs.

IPv6 Host

Vendor	IPv6 Support	Versions	More Info
Microsoft	Yes	W2K – Preview XP (SP1) and .NET CE .NET (Pocket PC 4.1)	http://www.microsoft.com/ipv6
Sun	YES	Solaris 8 and 9	http://wwws.sun.com/software/solaris/ipv6/
IBM	YES	z/OS Rel. 1.4 AIX 4.3 - > OS/390 V2R6 eNCS	http://www-1.ibm.com/servers/eserver/zseries/zos/unix/release/bpxa1zr4.html http://www-3.ibm.com/software/network/commserver/library/publications/ipv6.html
BSD	YES	FreeBSD 4.0 - > OpenBSD 2.7 - > NetBSD 1.5 - > BSD/OS 4.2 - >	http://www.kame.net/
Linux	YES	RH 6.2 - > Mandrake 8.0 - > SuSE 7.1 - > Debian 2.2 - >	http://www.bieringer.de/linux/IPv6/status/IPv6+Linux-status-distributions.html
HP/Compaq	YES	HP-UX 11i Tru64 UNIX V5.1 OpenVMS V5.1	http://www.compaq.com/ipv6/next_gen.html
Novell	YES	Netware 6.1	http://playground.sun.com/ipng/ipng-implementations.html#Novell
Apple	YES	MAC OS X 10.2 - >	http://developer.apple.com/macosx/

IPv6 Router addresses

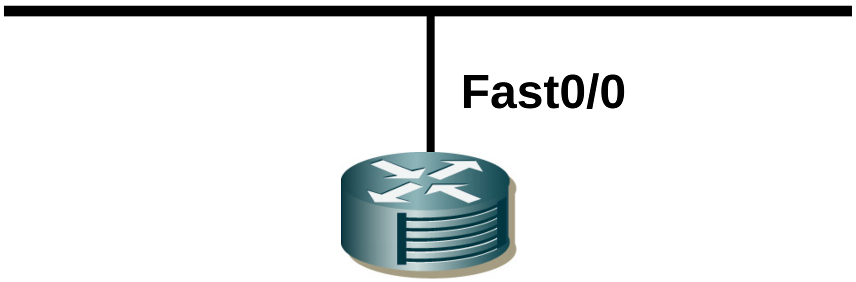
- **A router is required to recognize all addresses that a host is required to recognize, plus the following addresses as identifying itself:**

  The Subnet-Router Anycast Addresses for all interfaces for which it is configured to act as a router.

  All other Anycast Addresses with which the router has been configured.

  The All-Routers Multicast Addresses

IOS IPv6 Addressing Examples (1)
Manual Interface Identifier




```
!
interface FastEthernet0/0
 ip address 10.151.1.1 255.255.255.0
 ip pim sparse-mode
 duplex auto
 speed auto
 ipv6 address 2006:1::1/64
 ipv6 enable
 ipv6 nd ra-interval 30
 ipv6 nd prefix 2006:1::/64 300 300
!
```

IOS IPv6 Addressing Examples (1)

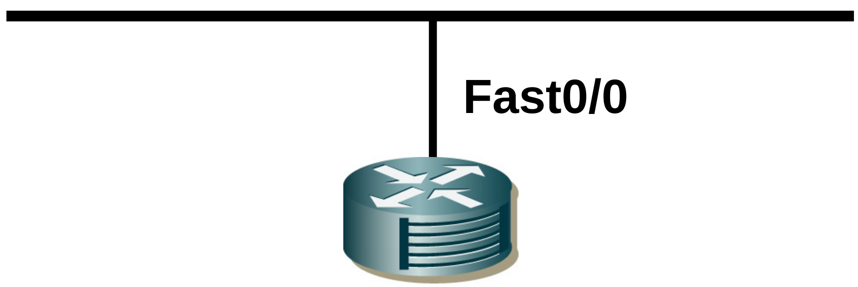
Manual Interface Identifier


```
r1#sh ipv6 int fast0/0
FastEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::207:50FF:FE5E:9460
  Global unicast address(es):
    2006:1::1, subnet is 2006:1::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::1:FF00:1
    FF02::1:FF5E:9460
  MTU is 1500 bytes
  ICMP error messages limited to one every 100 milliseconds
  ICMP redirects are enabled
  ND
  ND
  ND
  ND advertised retransmit interval is 0 milliseconds
  ND router advertisements are sent every 30 seconds
  ND router advertisements live for 1800 seconds
  Hosts use stateless autoconfig for addresses.
r1#
```

MAC Address : 0007.505e.9460

```
r1#sh int fast0/0
FastEthernet0/0 is up, line protocol is up
  Hardware is AmdFE, address is 0007.505e.9460 (bia 0007.505e.9460)
```

IOS IPv6 Addressing Examples (2)
EUI-64 Interface Identifier




```
!
interface FastEthernet0/0
 ip address 10.151.1.1 255.255.255.0
 ip pim sparse-mode
 duplex auto
 speed auto
 ipv6 address 2006:1::/64 eui-64
 ipv6 enable
 ipv6 nd ra-interval 30
 ipv6 nd prefix 2006:1::/64 300 300
!
```

IOS IPv6 Addressing Examples (2)

EUI-64 Interface Identifier

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```
r1#sh ipv6 int fast0/0
FastEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::207:50FF:FE5E:9460
  Global unicast address(es):
    2006:1::207:50FF:FE5E:9460, subnet is 2006:1::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::1:FF5E:9460
  MTU is 1500 bytes
  ICMP error messages limited to one every 100 milliseconds
  ICM
  ND
  ND
  ND advertised reachable time is 0 milliseconds
  ND advertised retransmit interval is 0 milliseconds
  ND router advertisements are sent every 30 seconds
  ND router advertisements live for 1800 seconds
  Hosts use stateless autoconfig for addresses.
r1#
```

MAC Address : 0007.505e.9460

```
r1#sh int fast0/0
FastEthernet0/0 is up, line protocol is up
  Hardware is AmdFE, address is 0007.505e.9460 (bia 0007.505e.9460)
```

Host IPv6 Addressing Example
Linux Display


```
[root@server2 cisco]# ip link
1: lo: <LOOPBACK,UP> mtu 16436 qdisc noqueue
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
2: sit0@NONE: <NOARP> mtu 1480 qdisc noop
    link/sit 0.0.0.0 brd 0.0.0.0
3: eth0: <BROADCAST,MULTICAST,UP> mtu 1500 qdisc pfifo_fast qlen 100
    link/ether 00:50:8b:ec:7a:23 brd ff:ff:ff:ff:ff:ff
[root@server2 cisco]#
```

```
[root@server2 cisco]# ip -6 addr
1: lo: <LOOPBACK,UP> mtu 16436 qdisc noqueue
    inet6 ::1/128 scope host
3: eth0: <BROADCAST,MULTICAST,UP> mtu 1500 qdisc pfifo_fast qlen 100
    inet6 2006:1::102/64 scope global
    inet6 2006:1::250:8bff:feec:7a23/64 scope global dynamic
       valid_lft 284sec preferred_lft 284sec
    inet6 fe80::250:8bff:feec:7a23/10 scope link
[root@server2 cisco]#
```

Host IPv6 Addressing Example

WinXP Display

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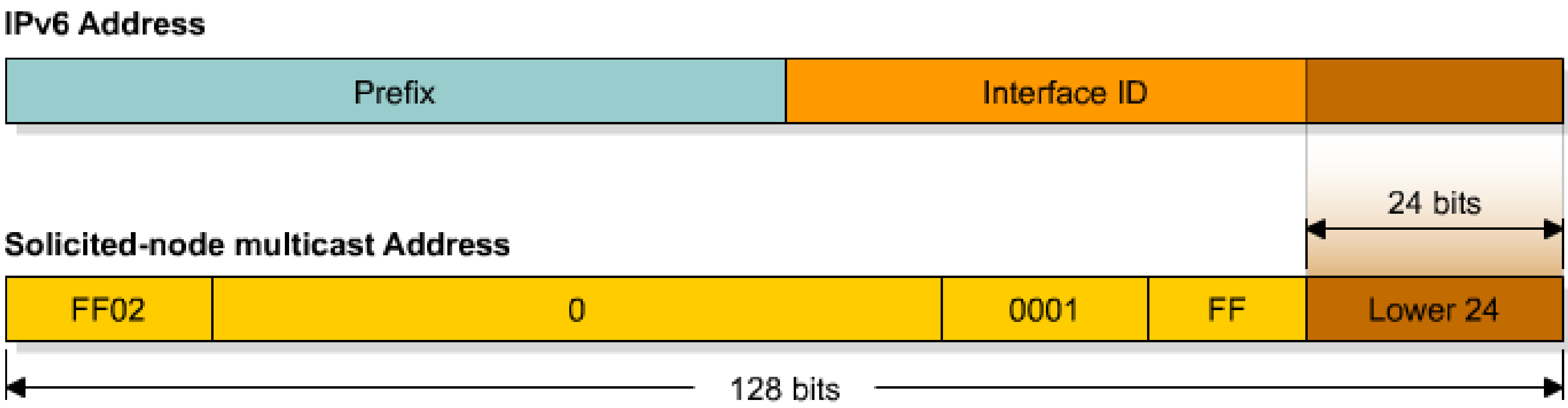
```
D:\>ipv6 if 4
Interface 4 (site 1): Local Area Connection
  uses Neighbor Discovery
  link-level address: 00-10-a4-91-43-b9
    preferred address 2006:1::210:a4ff:fe91:43b9, 9963s/5963s (addrconf)
    preferred address fe80::210:a4ff:fe91:43b9, infinite/infinite
    multicast address ff02::1, 1 refs, not reportable
    multicast address ff02::1:ff91:43b9, 2 refs, last reporter
  link MTU 1372 (true link MTU 1372)
  current hop limit 64
  reachable time 35500ms (base 30000ms)
  retransmission interval 1000ms
  DAD transmits 1

D:\>
```

Neighbor Discovery

Neighbor Discovery (RFC 2461)

- **IPv6 nodes which share the same physical medium (link) use Neighbor Discovery (ND) to:**
  - **discover their mutual presence**
  - **determine link-layer adresses of their neighbors**
  - **find routers**
  - **maintain neighbors' reachability information (NUD)**
- **Defines 5 ICMPv6 packet types**
  - **Router Solicitation / Router Advertisements**
  - **Neighbor Solicitation / Neighbor Advertisements**
  - **Redirect**

Solicited-Node Multicast Address



- Used in neighbor solicitation messages
- Multicast address with a link-local scope
- Solicited-node multicast consists of prefix + lower 24 bits from unicast, FF02::1:FF:

Router Interface

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```
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

Neighbor Solicitation


```
Neighbor Solicitation
ICMP type = 135

Src = A
Dst = Solicited-node multicast of B
Data = link-layer address of A
Query = what is your link address?
```

```
Neighbor Advertisement
ICMP type = 136
Src = B
Dst = A
Data = link-layer address of B
```

A and B can now exchange packets on this link

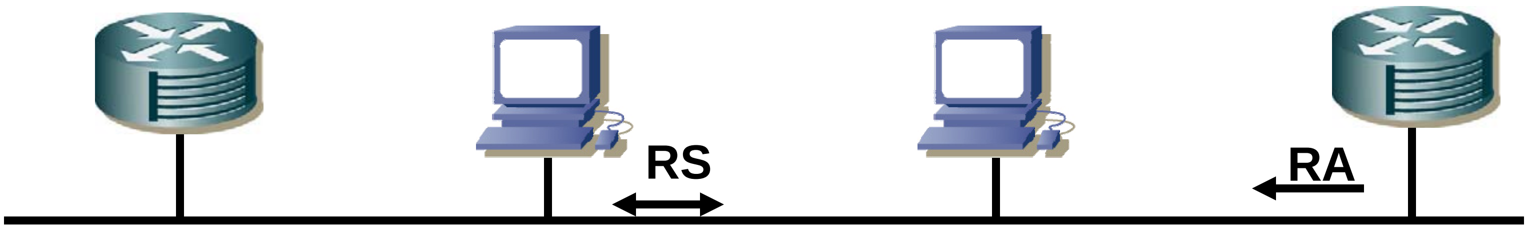
Router Advertisements (RA)


```
RA packet definitions:
ICMP Type = 134

Src = Router Link-local Address
Dst = All-nodes multicast address
Data= options, prefix, lifetime,
autoconfig flag
```

- **Routers send periodic Router Advertisements (RA) to the all-nodes multicast address.**

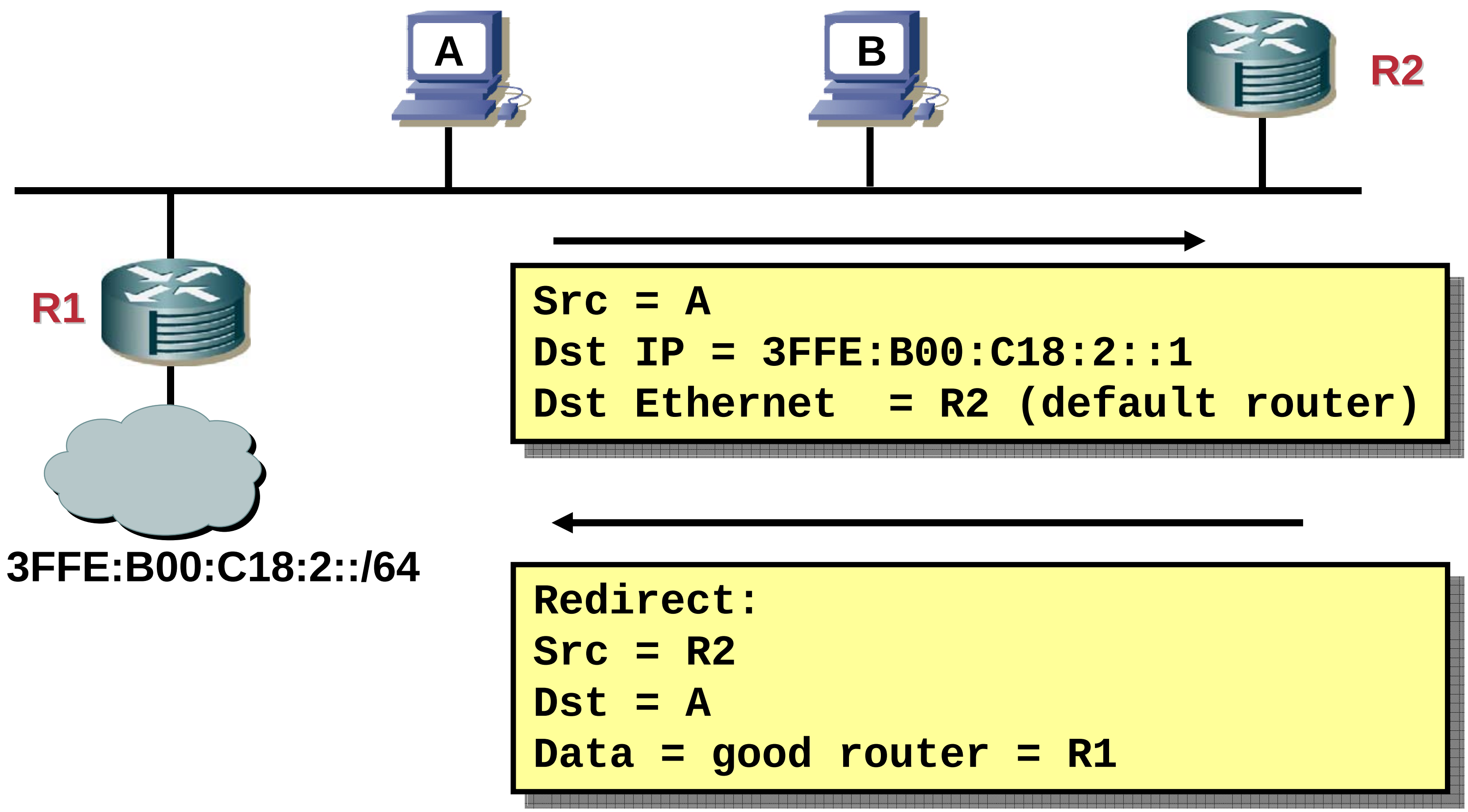
Router Solicitations




```
RS packet definitions:
ICMP Type = 133
Src = Unspecified Address
Dst = All-routers multicast address
```

- **At boot time, nodes sends Router Solicitations to receive promptly Router Advertisements.**

Redirect



- **Redirect is used by a router to signal the reroute of a packet to a better router**

Duplicate Address Detection

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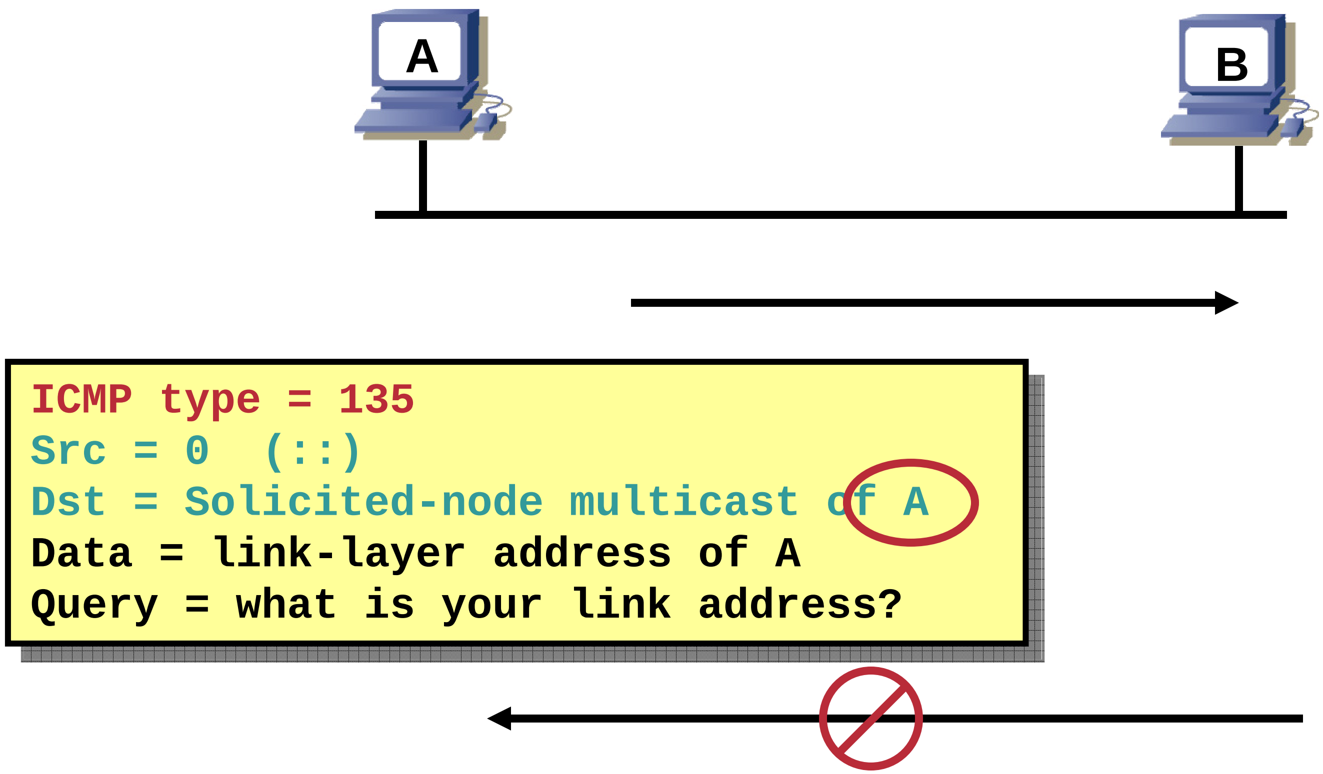

- **Duplicate Address Detection (DAD) uses neighbor solicitation to verify the existence of an address to be configured.**

IPv6 Auto-Configuration

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- **Stateless (RFC2462)**

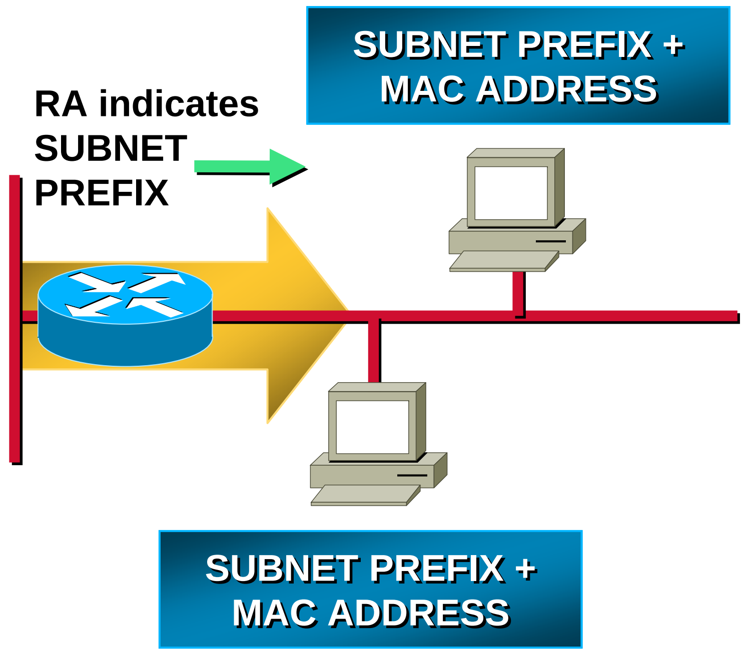
  Host autonomously configures its own Link-Local address

  Router solicitation are sent by booting nodes to request RAs for configuring the interfaces.

- **Stateful**

  DHCPv6 (under definition at IETF)

- **And Stateless DHCP ….**



At boot time, an IPv6 host build a Link-Local address, then its global IPv6 address(es) from RA

Stateless Autoconfiguration

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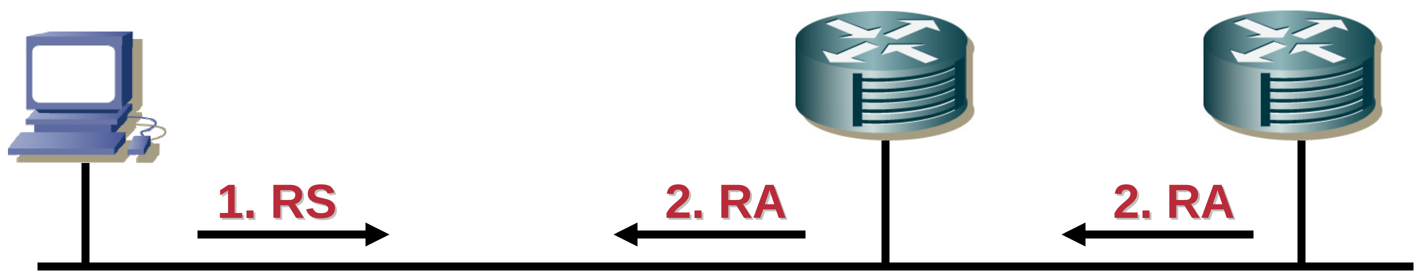


1. RS:
ICMP Type = 133

Src = ::
Dst = All-Routers multicast Address
query= please send RA

2. RA:
ICMP Type = 134

Src = Router Link-local Address
Dst = All-nodes multicast address
Data= options, prefix, lifetime, autoconfig flag

- **Router solicitations are sent by booting nodes to request RAs for configuring the interfaces.**

DHCPv6

- Updated version of DHCP for IPv4.
- Supports new addressing.
- Enables more control than stateless auto-configuration.
- Can be used for renumbering.
- Can be used for automatic domain name registration of hosts using dynamic DNS.
- Multicast addresses used:

  FF02::1:2 = All DHCP Agents (servers or relays, Link-local scope)

  FF05::1:3 = All DHCP Servers (Site-local scope)

DHCPv6 - Process

- Same as in IPv4, but:
- Client first detect the presence of routers on the link.
- If found, then examines router advertisements to determine if DHCP can be used.
- If no router found or if DHCP can be used, then

    DHCP Solicit message is sent to the All-DHCP-Agents multicast address

    Using the link-local address as the source address

IPv6 and DNS

IPv6 and DNS (RFC 3596)

	IPv4	IPv6
Hostname to IP Address	A record: www.abc.test. A 192.168.30.1	AAAA record: www.abc.test AAAA 3FFE:B00:C18:1::2 ~~A6 record (experimental, RFC3363)~~ ~~www.abc.test A6 0 3FFE:B00:C18:1::2~~
IP Address to Hostname	PTR record: 1.30.168.192.in-addr.arpa. PTR www.abc.test.	PTR record: 2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.0.0.0.8.1.c.0.0.0.b.0.e.f.f.3.ip6.arpa. PTR www.abc.test. (experimental, see RFC 3363) ~~\[x3ffe0c000c18000100000000000000002 /128].ip6.arpa. PTR www.abc.test.~~

Some Issues

- **Root name-servers support IPv6 since Jul 20, 2004, see** http://www.icann.org/announcements/announcement-20jul04.htm

    .JP, .KR and shortly thereafter .FR were first fully IPv6 enabled

- **DNS designed as a single, globally unique namespace [RFC 2826]**

    AAAA can be queried over IPv4, A can be queried over IPv6

    Avoid fragmentation, keep at least one authoritative NS IPv4-enabled

    See RFC 3901

What about special addresses ?

- **Link local [RFC 3513]**
  - **Should never be published in DNS**
- **Site local - deprecated [RFC 3879]**
  - **Would have required split-face DNS**
- **Temporary Addresses [RFC 3041]**
  - **Having AAAA records that are updated with address change would defeat purpose of mechanism...**

References

- draft-ietf-dnsop-ipv6-dns-issues-10.txt
- RFC 3596, 3363, 3364
- RFC 3363 or 3152 for background info
- RFC 3901

IPv6 & Unicast Routing Protocols

Agenda

- Introduction
- Static routing
- RIPng
- IS-IS for IPv6
- OSPFv3
- EIGRPv6
- MP-BGP

MTU Path Discovery

- IPv6 MTU must be at least 1280 bytes
  - Recommended MTU: 1500 bytes
- Fragmenting in IPv6 happens between two communicating peers, and not by an intermediate IPv6 router
- Nodes should implement MTU Path Discovery
  - Otherwise they must not exceed 1280 bytes
  - MTU path discovery uses ICMP "packet too big" error messages

Agenda

- Introduction
- Static routing
- RIPng
- IS-IS for IPv6
- OSPFv3
- EIGRPv6
- MP-BGP

Static Routes

- **Static route configuration syntax is the same as in IPv4**
- **Except Prefix and next-hop are IPv6**

IPv4 static route:

ip route *[ipv4_prefix][ipv4_address_mask][ipv4_if_address]*

IPv6 static route:

ipv6 route *[ipv6_prefix/prefix_length][ipv6_if_address]*

ipv6 route ::/0 FastEthernet1/40 FE80::206:2AFF:FE58:7820

Static Routes

- **It is not recommended to use a global unicast address as a next-hop addresss**
- **ICMPv6 redirect messages will not work if used**

RFC 2461:

A router must be able to determine the link-local address of each of its neighboring routers in order to ensure that the target address of a Redirect message identifies the neighbor router by its link-local address.

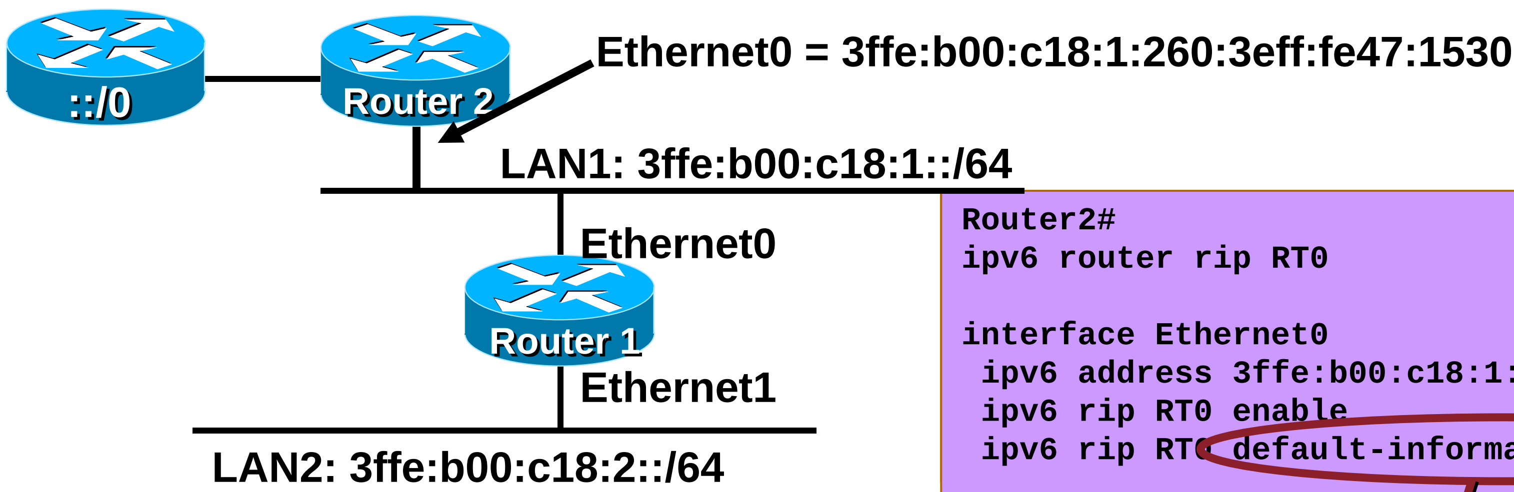
Agenda

- Introduction
- Static routing
- RIPng
- IS-IS for IPv6
- OSPFv3
- EIGRPv6
- MP-BGP

RIPng

- RFC 2080 describes RIPng
- Same as IPv4
  - Distance-vector, 15 hop Radius, split-horizon, poison reverse, etc..
  - Based on RIPv2
- Updated Features for IPv6
  - Uses IPv6 for transport
  - IPv6 prefix, next-hop IPv6 address
  - Uses the multicast group FF02::9 for RIP updates
  - Updates are sent on UDP port 521

Enhanced Routing Protocol Support RIPng Configuration and Display




```
Router2#
ipv6 router rip RT0

interface Ethernet0
 ipv6 address 3ffe:b00:c18:1::/64 eui-64
 ipv6 rip RT0 enable
 ipv6 rip RT0 default-information originate
```

```
Router1#
ipv6 router rip RT0

interface Ethernet0
 ipv6 address 3ffe:b00:c18:1::/64 eui-64
 ipv6 rip RT0 enable
Interface Ethernet1
 ipv6 address 3ffe:b00:c18:2::/64 eui-64
 ipv6 rip RT0 enable
```

```
Router2# debug ipv6 rip
RIPng: Sending multicast update on Ethernet0 for RT0
       src=FE80::260:3eff:fe47:1530
       dst=FF02::9 (Ethernet0)
       sport=521, dport=521, length=32
       command=2, version=1, mbz=0, #rte=1
       tag=0, metric=1, prefix=::/0
```

Multicast all Rip-Routers

Link-local src address

Agenda

- Introduction
- Static routing
- RIPng
- IS-IS for IPv6
- OSPFv3
- EIGRPv6
- MP-BGP

ISISv6

- Originally designed as an intra-domain routing protocol for Connectionless Network Service (CLNS) traffic; an OSI routing protocol
- Major operation remain unchanged:
  - Level 2(backbone) device route between Level 1(areas)
  - Each IS device still sends out LSP packets
  - Neighborship process is unchanged
- IPv6 support gets added based on 'draft-ietf-isis-ipv6-12.txt, Routing IPv6 with IS-IS'

ISISv6 (Cont.)

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- Two new Tag/Length/Values (TLV's) for IPv6:
  - IPv6 Reachability TLV (0xEC/236)
    - Describes network reach-ability, contains V6 routing prefix & Metric
  - IPv6 Interface Address TLV (0xE8/232)
    - Contains IPv6 interface address (128 bit vs. 32)
    - For Hello PDUs, must contain the Link-Local address
    - For LSP, must only contain the non-Link Local address
- •New Network Layer Protocol Indentifier
  - IPv6 NLPID (0x8E/142) is advertised by IPv6 enabled routers
  - IPv4 is 0xCC
- Runs on data link. If tunneled, must be mode GRE not IPV6IP

Cisco IOS IS-IS dual IP configuration

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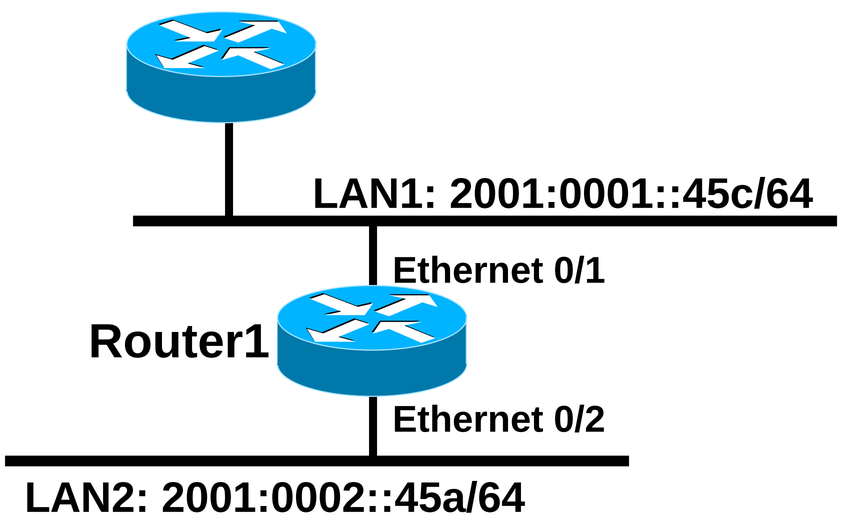


```
Router1#
 interface ethernet0/1
     ip address 10.1.1.1 255.255.255.0
     ipv6 address 2001:0001::45c/64
     ip router isis
     ipv6 router isis

  interface ethernet0/2
     ip address 10.2.1.1 255.255.255.0
     ipv6 address 2001:0002::45a/64
     ip router isis
     ipv6 router isis

  router isis
      address-family ipv6
      redistribute static
      exit-address-family
      net 42.0001.0000.0000.072c.00
      redistribute static
```

Dual IPv4/IPv6 configuration. Redistributing both IPv6 static routes and IPv4 static routes.

Single SPF rules

- **If IS-IS is used for both IPv4 and IPv6 in an area, both protocols must support the same topology within this area.**
  - **Could set "no adjacency-check" between L2 routers**
- **All interfaces configured with IS-ISv6 must support IPv6**
  - **Can't be configured on MPLS/TE since IS-ISv6 extensions for TE are not yet defined**
- **All interfaces configured with IS-IS for both protocols must support both of them**
  - **IPv6 configured tunnel won't work, GRE should be used in this configuration**
- **Otherwise, consider Multi-Topology IS-IS (separate SPF)**

The problem

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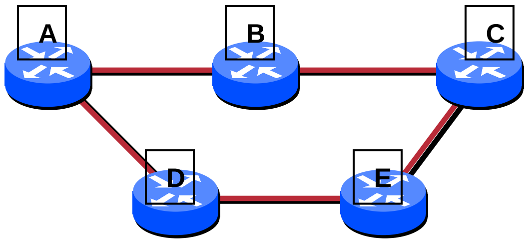
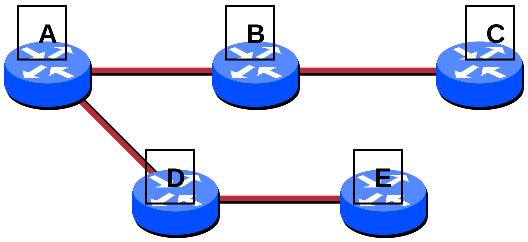


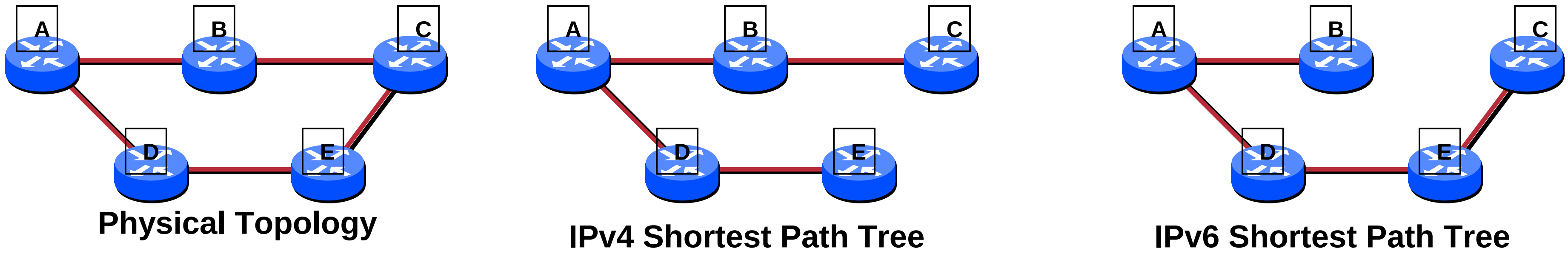
Physical Topology



Shortest Path Tree

- **From A perspective, C is only reachable through B**
  - **There is no path from E to C**
- **All protocols carried by IS-IS have to agree on the same SPT**
  - **No way to distribute traffic across the domain**
  - **All links need to understand all protocols**

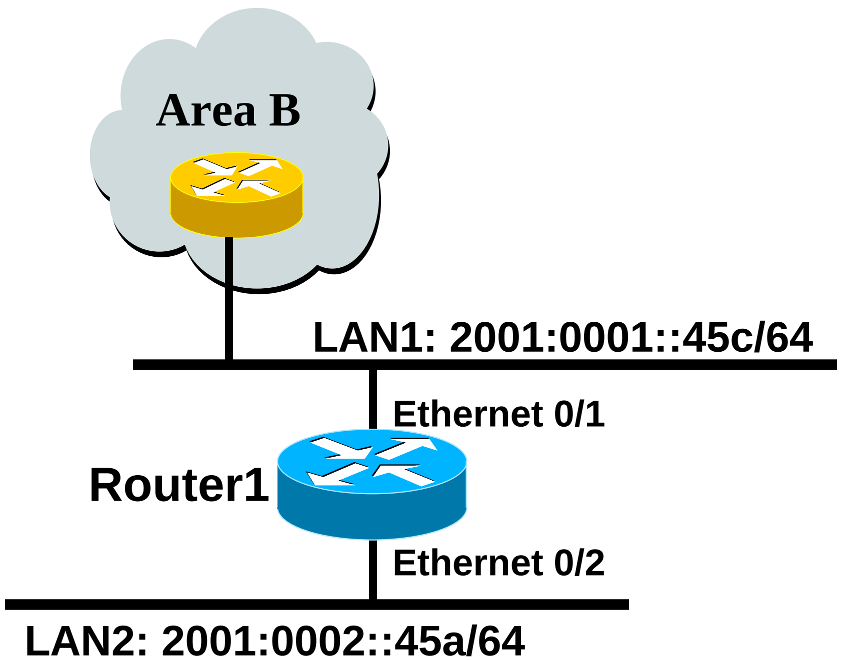
The need



- **Ability to distribute traffic across all links**

  Separate traffic per address families

Cisco IOS Multi-Topology IS-IS configuration example



- The optional keyword ***transition*** may be used for transitioning existing IS-IS IPv6 single SPF mode to MT IS-IS.
- Wide metric is mandated for Multi-Topology to work.

```
Router1#
 interface ethernet 0/1
    ip address 10.1.1.1 255.255.255.0
    ipv6 address 2001:0001::45c/64
    ip router isis
    ipv6 router isis
    isis ipv6 metric 20

  interface ethernet 0/2
    ip address 10.2.1.1 255.255.255.0
    ipv6 address 2001:0002::45a/64
    ip router isis
    ipv6 router isis
    isis ipv6 metric 20

router isis
net 49.0000.0100.0000.0000.0500
metric-style wide
!
address-family ipv6
multi-topology
exit-address-family
```

Agenda

- Introduction
- Static routing
- RIPng
- IS-IS for IPv6
- OSPFv3
- EIGRPv6
- MP-BGP

OSPFv3 overview

- OSPF for IPv6 (RFC 2740)
- Based on OSPFv2, with enhancements
- Distributes IPv6 prefixes
- Runs directly over IPv6
- Ships-in-the-night with OSPFv2

IPv6 multicast address

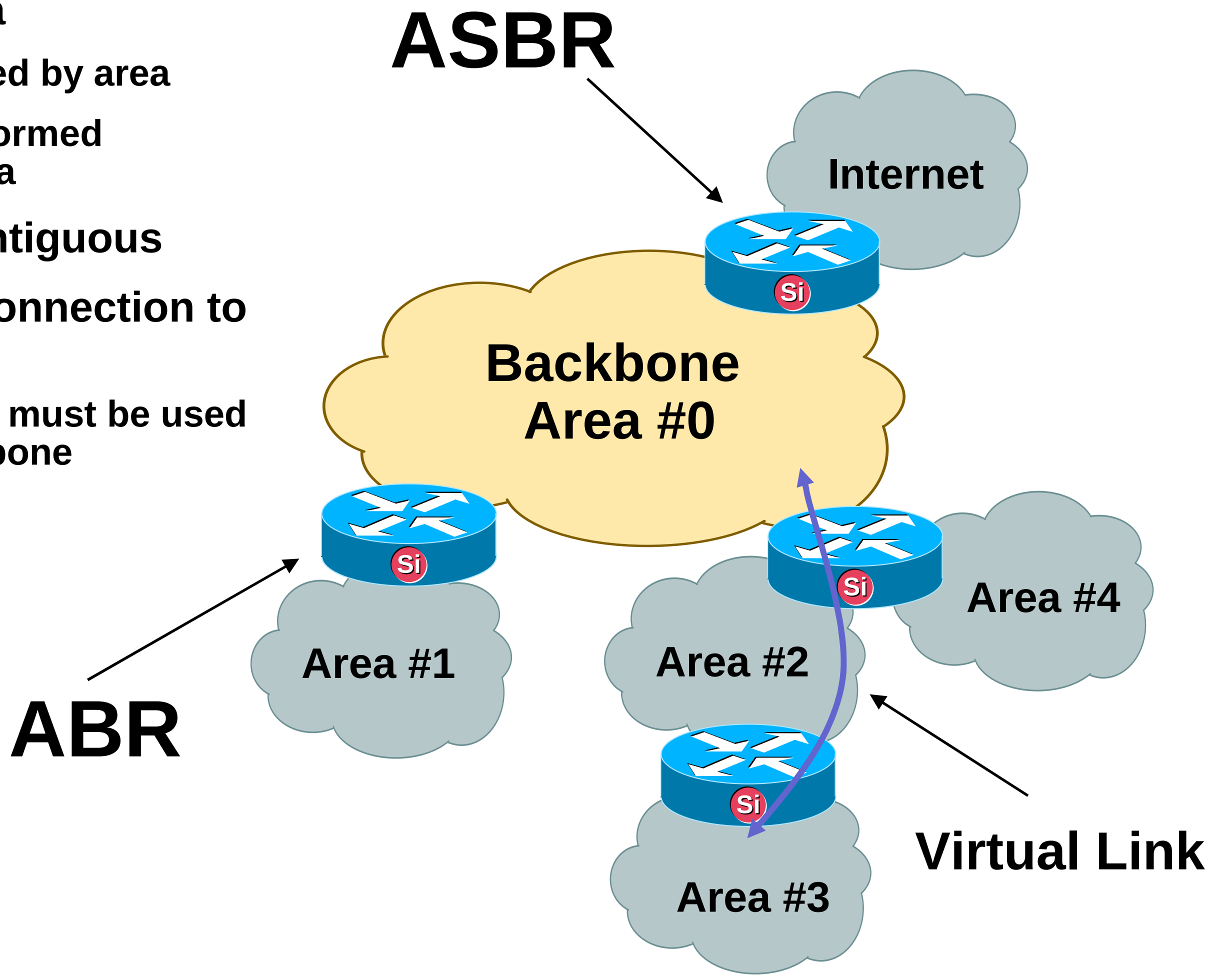
- **The multicast address AllSPFRouters is FF02::5 note that 02 means that this is a permanent address and has link scope.**
- **The multcast address ALLDRouters is FF02::6**

OSPFv3 / OSPFv2 Similarities

- **Basic packet types**
  - **Hello, DBD, LSR, LSU, LSA**
- **Mechanisms for neighbor discovery and adjacency formation**
- **Interface types**
  - **P2P, P2MP, Broadcast, NBMA, Virtual**
- **LSA flooding and aging**
- **Nearly identical LSA types**

OSPFv3 – Hierarchical Structure

- Topology of an area is invisible from outside of the area
    - LSA flooding is bounded by area
    - SPF calculation is performed separately for each area
- Backbones must be contiguous
- All areas must have a connection to the backbone
    - Otherwise a virtual link must be used to connect to the backbone



What IPv6 Attributes Affect OSPF?

- 128 bit addresses
- Link-Local address
- Multiple addresses per interface
- Authentication

OSPFv3 / OSPFv2 Differences

- OSPFv3 runs over a link, rather than a subnet
- Multiple instances per link
- OSPFv3 topology not IPv6-specific
  - Router ID
  - Link ID
- Standard authentication mechanisms
- Uses link-local addresses
- Generalized flooding scope

New LSA Types

- **Link LSA**
  - **Informs neighbors of link local address**
  - **Informs neighbors of IPv6 prefixes on link**
- **Intra-Area Prefix LSA**
  - **Associates IPv6 prefixes with a network or router**

LSA Overview

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	LSA Function Code	LSA type
Router-LSA	1	0x2001
Network-LSA	2	0x2002
Inter-Area-Prefix-LSA	3	0x2003
Inter-Area-Router-LSA	4	0x2004
AS-External-LSA	5	0x4005
Group-membership-LSA	6	0x2006
Type-7-LSA	7	0x2007
Link-LSA	8	0x0008
Intra-Area-Prefix-LSA	9	0x2009

Removal of Address Semantic

- **IPv6 address is not present in OSPFv3 packets**
  - **Exception: LSA payload**
- **Router-LSA and Network-LSA expressing topology**
- **Router ID, area ID, LSA link state ID remain a 32 bit number**
- **Neighbors are always identified by Router ID**

Show ipv6 ospf database

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Router Link States (Area 1)

ADV Router	Age	Seq#	Fragment ID	Link count	Bits
26.50.0.1	1812	0x80000048	0	1	None
26.50.0.2	1901	0x80000006	0	1	B

Net Link States (Area 1)

ADV Router	Age	Seq#	Link ID	Rtr count
26.50.0.1	57	0x8000003B	3	4

Inter Area Prefix Link States (Area 1)

ADV Router	Age	Seq#	Prefix
26.50.0.2	139	0x80000003	3FFE:FFFF:26::/64
26.50.0.2	719	0x80000001	3FFE:FFF:26::/64

Inter Area Router Link States (Area 1)

ADV Router	Age	Seq#	Link ID	Dest RtrID
26.50.0.2	772	0x80000001	1207959556	72.0.0.4
26.50.0.4	5	0x80000003	1258292993	75.0.7.1

Show ipv6 ospf database

Link (Type-8) Link States (Area 1)

ADV Router	Age	Seq#	Link ID	Interface
26.50.0.1	1412	0x80000031	3	Fa0/0
26.50.0.2	238	0x80000003	3	Fa0/0

Intra Area Prefix Link States (Area 1)

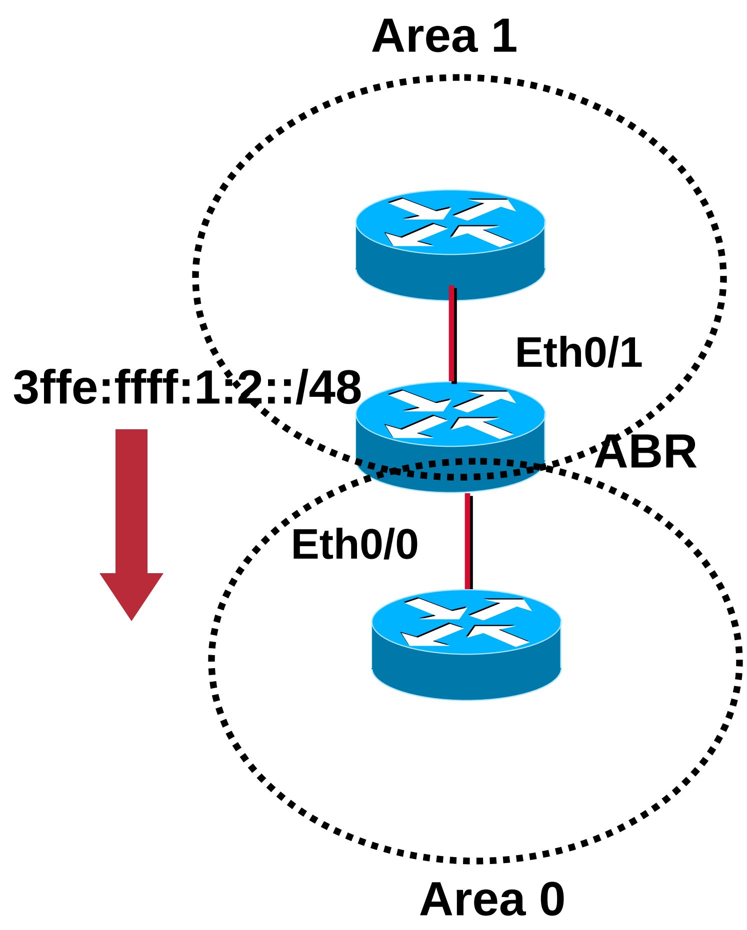
ADV Router	Age	Seq#	Link ID	Ref-lstype	Ref-LSID
26.50.0.1	1691	0x8000002E	0	0x2001	0
26.50.0.1	702	0x80000031	1003	0x2002	3
26.50.0.2	1797	0x80000002	0	0x2001	0

Type-5 AS External Link States

ADV Router	Age	Seq#	Prefix
72.0.0.4	287	0x80000028	3FFE:FFFF:A::/64
72.0.0.4	38	0x80000027	3FFE:FFFF:78::/64
75.0.7.1	162	0x80000007	3FFE:FFFF:8::/64

ABR Configuration


```
ipv6 unicast-routing
!
interface Ethernet0/0
ipv6 address 3ffe:ffff:1:1::1/64
ipv6 ospf 1 area 0
!
interface Ethernet0/1
ipv6 address 3ffe:ffff:1:2::2/64
ipv6 ospf 1 area 1
!
ipv6 router ospf 1
router-id 2.2.2.2
area 1 range 3ffe:ffff:1:2::/48
```



ASBR Configuration

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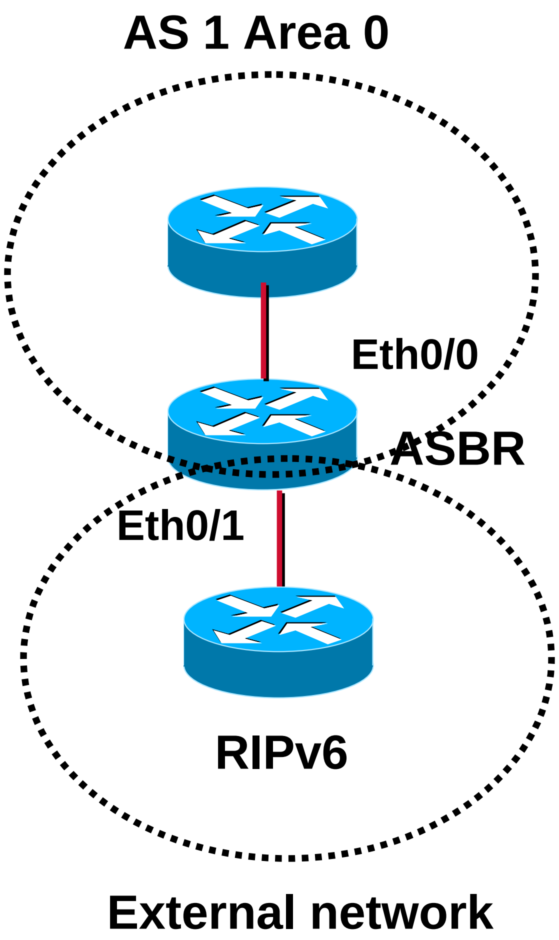
```
ipv6 unicast-routing
!
interface Ethernet0/0
ipv6 address 3ffe:ffff:1:1::1/64
ipv6 ospf 1 area 0
!
interface Ethernet0/1
ipv6 address 3ffe:ffff:1:2::2/64
ipv6 rip trial1 enable
!
ipv6 router ospf 1
router-id 2.2.2.2
redistribute rip trial1 metric 20
!
ipv6 router rip trial1
```



Agenda

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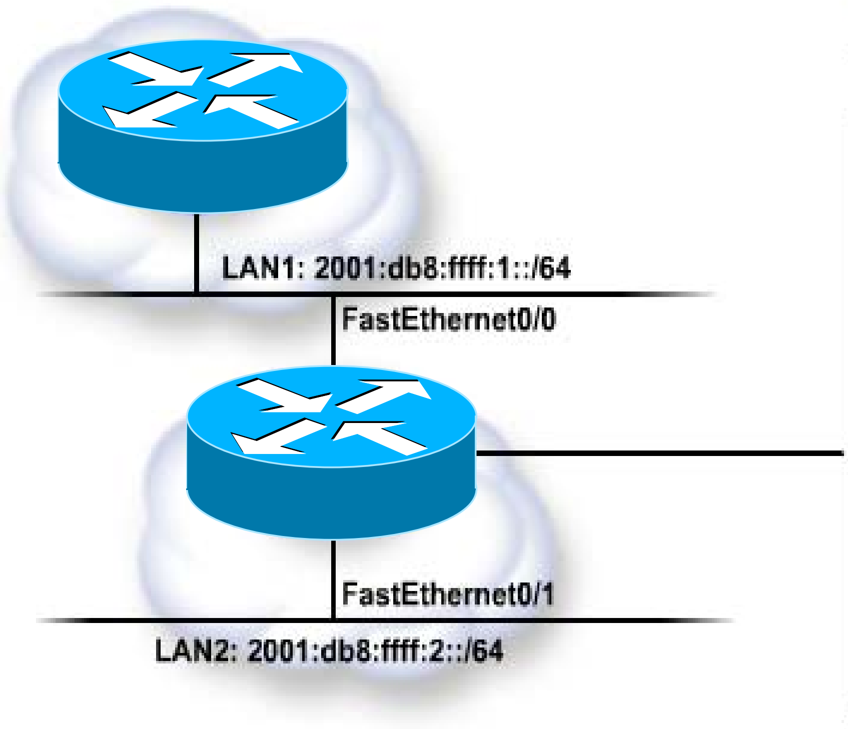
EIGRPv6

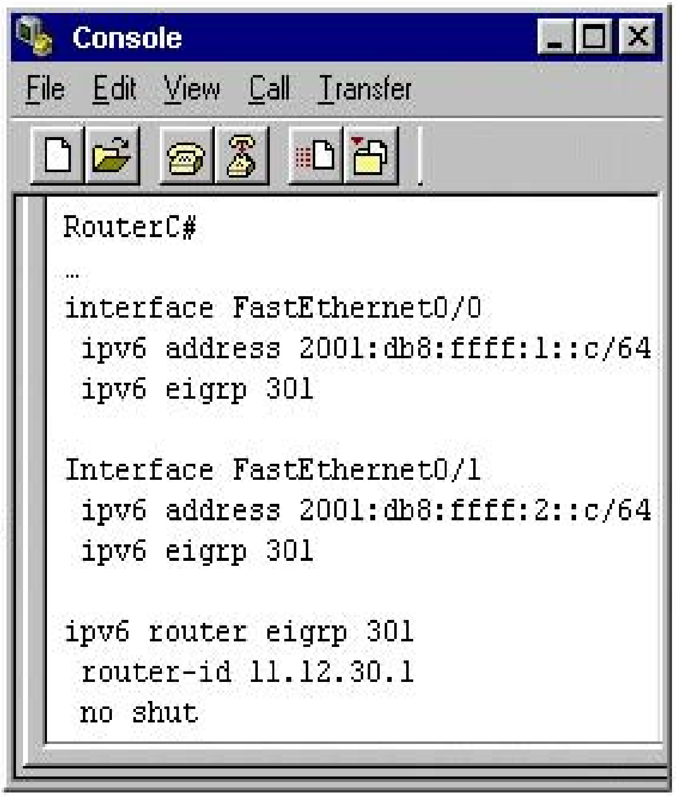
- **Best of Distance Vector and Link State (Advanced Distance Vector)**
- **Multi-protocol**

  EIGRP has a protocol dependent module for IPV4, IPX, Appletalk, and now IPv6

- **Easy to configure**
- **Fast convergence**

Example


LAN1: 2001:db8:ffff:1::/64
FastEthernet0/0
FastEthernet0/1
LAN2: 2001:db8:ffff:2::/64


Console
File Edit View Call Transfer
RouterC#
…
interface FastEthernet0/0
 ipv6 address 2001:db8:ffff:1::c/64
 ipv6 eigrp 301

Interface FastEthernet0/1
 ipv6 address 2001:db8:ffff:2::c/64
 ipv6 eigrp 301

ipv6 router eigrp 301
 router-id 11.12.30.1
 no shut

Agenda

- Introduction
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- MP-BGP

MP-BGP Basics

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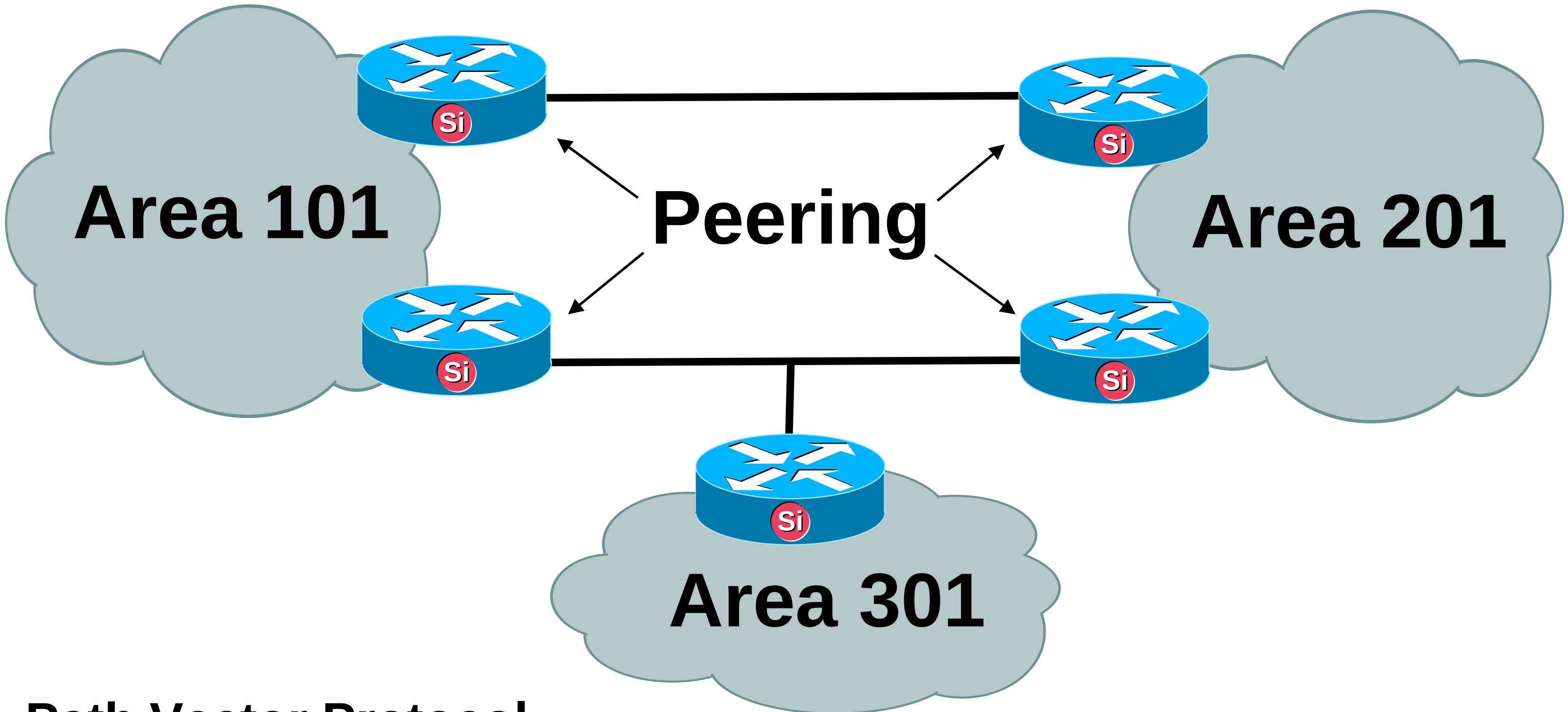

- **Path Vector Protocol**
  - **Carries sequence of AS numbers indicating path**
- **Ties Autonomous Systems together via Peering**
- **Multiple address families: ipv4, ipv6, unicast, multicast**

BGP-4 Extensions for IPv6 (RFC 2545)

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- **BGP-4 carries only 3 pieces of information which is truly IPv4 specific:**
  - **NLRI in the UPDATE message contains an IPv4 prefix**
  - **NEXT_HOP path attribute in the UPDATE message contains a IPv4 address**
  - **BGP Identifier is in the OPEN message & AGGREGATOR attribute**
- **To make BGP-4 available for other network layer protocols, RFC 2858 (obsoletes RFC 2283) defines multi-protocol extensions for BGP-4**
  - **Enables BGP-4 to carry information of other protocols e.g MPLS,IPv6**
  - **New BGP-4 optional and non-transitive attributes:**
    - **MP_REACH_NLRI**
    - **MP_UNREACH_NLRI**
  - **Protocol independent NEXT_HOP attribute**
  - **Protocol independent NLRI attribute**

BGP-4 Extensions for IPv6

- **New optional and non-transitive BGP attributes:**
  - **MP_REACH_NLRI (Attribute code: 14)**
    - **"Carry the set of reachable destinations together with the next-hop information to be used for forwarding to these destinations" (RFC2858)**
  - **MP_UNREACH_NLRI (Attribute code: 15)**
    - **Carry the set of unreachable destinations**
- **Attribute 14 and 15 contains one or more Triples:**
  - **Address Family Information (AFI)**
  - **Next-Hop Information (must be of the same address family)**
  - **NLRI**

BGP-4 Extensions for IPv6

- **Address Family Information (AFI) for IPv6**
  - AFI = 2 (RFC 1700)
  - Sub-AFI = 1 Unicast
  - Sub-AFI = 2 (Multicast for RPF check)
  - Sub-AFI = 3 for both Unicast and Multicast
  - Sub-AFI = 4 Label
  - Sub-AFI= 128 VPN

BGP-4 Extensions for IPv6

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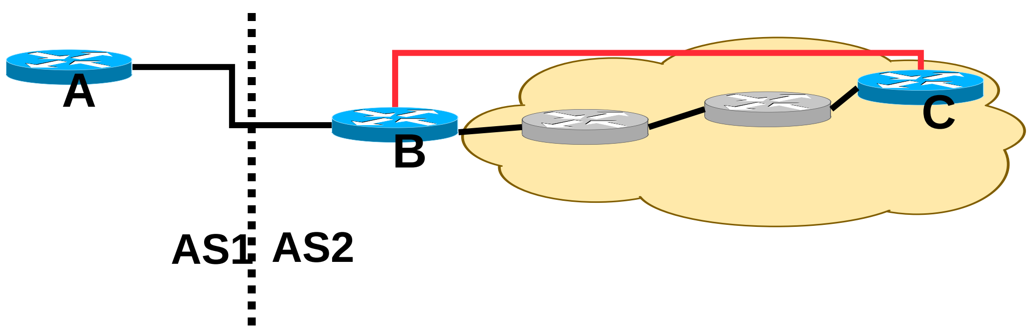
- **Next-hop contains a global IPv6 address or potentially a link local (for iBGP update this has to be changed to global IPv6 address with route-map)**
- **The value of the length of the next hop field on MP_REACH_NLRI attribute is set to 16 when only global is present and is set to 32 if link local is present as well**
- **Link local address as a next-hop is only set if the BGP peer shares the subnet with both routers (advertising and advertised)**



BGP-4 Extensions for IPv6

- **TCP Interaction**

  BGP-4 runs on top of TCP

  This connection could be setup either over IPv4 or IPv6

- **Router ID**

  When no IPv4 is configured, an explicit bgp router-id needs to be configured

  This is needed as a BGP Identifier, this is used as a tie breaker, and is send within the OPEN message

BGP-4 Configurations for IPv6 Non Link Local Peering

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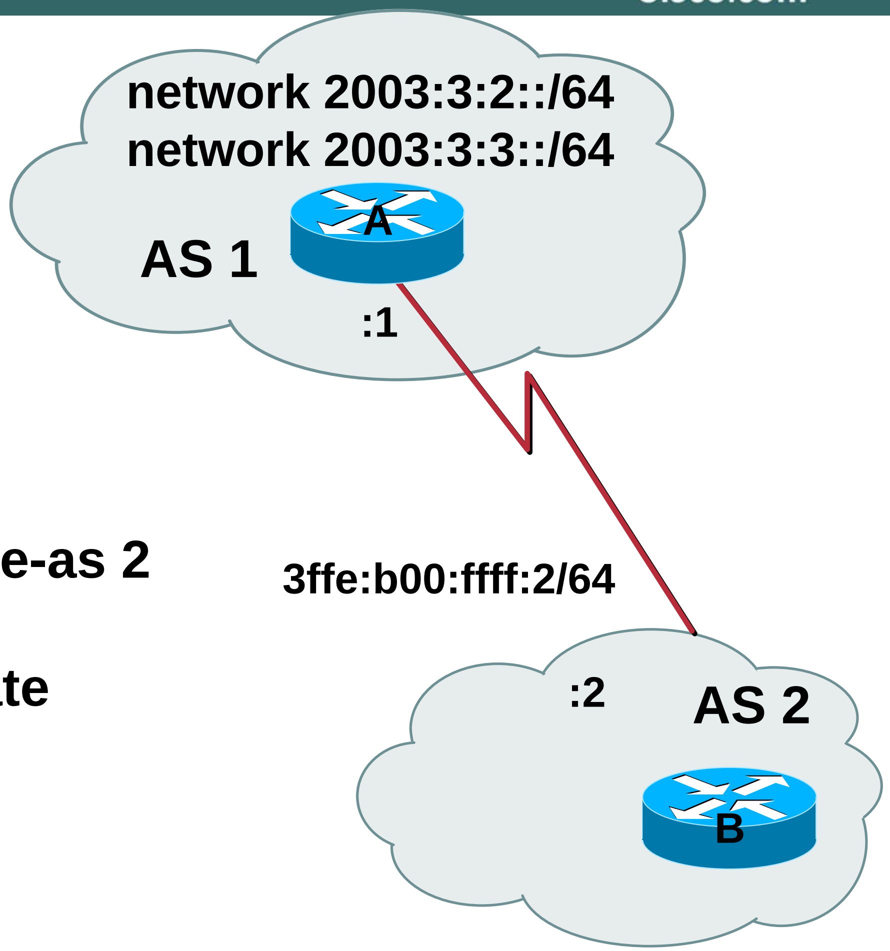
Router A

router bgp 1
no bgp default ipv4 unicast
bgp router-id 1.1.1.1
neighbor 3ffe:b00:ffff:2::2 remote-as 2
address-family ipv6
neighbor 3ffe:b00:ffff:2::2 activate
network 2003:3:2::/64
network 2003:3:3::/64



IPv6 Multicast

Agenda

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- IPv6 Multicast Technology
- MLD
- IPv6 Multicast Routing
- Deployment Issues
- Conclusion

IPv6 Multicast Technology

I had a dream…

“With IPv6, IP Multicast will be deployed as a ubiquitous day-1 service.”

Axel Clauberg
University of Cologne, Computing Centre
Early 1996

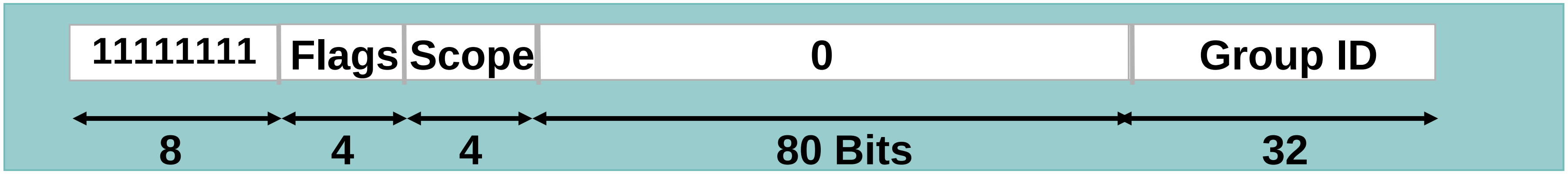
Why considering IPv6 Multicast?

- Customers impacted by IPv4 address scarcity
- Get new applications to support and utilize IP Multicast
- Facilitates deployment of mc apps to users behind v4 NATs
- Simplify and clean-up the v4 multicast model
    - Unicast prefix addresses, embedded RP addresses
    - No fragmentation below 1280 bytes
    - Powerful address based scoping – no TTL scoping
    - No DVMRP, hopefully no DM-PIM, what about MSDP ??
    - Proven Routing Technology - PIM

IPv4 versus IPv6 Multicast

IP Service	IPv4 Solution	IPv6 Solution
Address Range	32-bit, class D	128-bit
Routing	Protocol Independent All IGPs,and BGP4+	Protocol Independent All IGPs,and BGP4+ with v6 mcast SAFI
Forwarding	PIM-DM, PIM-SM, PIM-SSM, PIM-bidir	PIM-SM, PIM-SSM, PIM-bidir
Group Management	IGMPv1, v2, v3	MLDv1, v2
Domain Control	Boundary/Border	Scope Identifier
Interdomain Solutions	MSDP across Independent PIM Domains	Single RP within Globally Shared Domains

Multicast Addresses
(RFC 2373, now 3513)



- **Low-order flag indicates permanent/transient group; three other flags reserved**
- **Scope field:**

  1—node local
  2—link-local
  5—site-local
  8—organization-local
  B—community-local
  E—global
  (All other values reserved)

Permanently-Assigned Address Example

- **The "meaning" of a permanently-assigned multicast address is independent of the scope value. For example, if the "NTP servers group" is assigned a permanent multicast address with a group ID of 101 (hex), then:**
  - **FF01:0:0:0:0:0:0:101 means all NTP servers on the *same node* as the sender.**
  - **FF02:0:0:0:0:0:0:101 means all NTP servers on the *same link* as the sender.**
  - **FF05:0:0:0:0:0:0:101 means all NTP servers at the *same site* as the sender.**
  - **FF0E:0:0:0:0:0:0:101 means all NTP servers in the *internet***

Multicast Addresses / RFC3306

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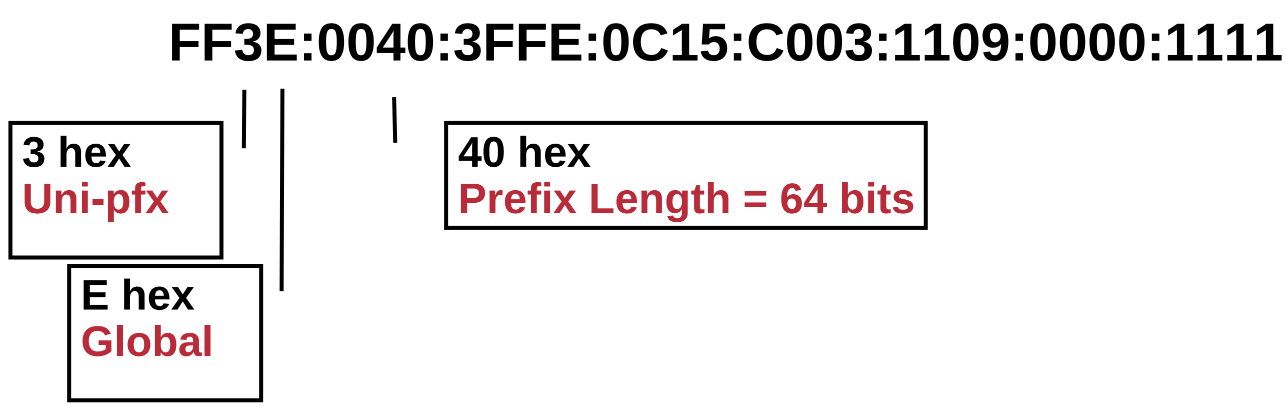
11111111	00PT	Scope	Res.	Plen	Prefix	Group ID
8	4	4	8	8	64	32

- New flag P:
  - 0—address not assigned on prefix, 1—prefix based assignment
- P == 1:
  - Plen—length of network prefix
  - Prefix—network prefix, at most 64 bits
  - SSM: plen = 0, prefix = 0 : FF3X::/32, current allocation is from FF3X::/96
- See also RFC 3307



MLD

Multicast Listener Discover – MLD

- MLD is equivalent to IGMP in IPv4
- MLD messages are transported over ICMPv6
- MLD uses link local source addresses
- MLD packets use “Router Alert” option in IPv6 header (RFC2711)
- Version number confusion:
  - MLDv1 (RFC2710) like IGMPv2 (RFC2236)
  - MLDv2 (draft-vida-mld-v2-07) like IGMPv3 (RFC3376) → SSM support
- MLD snooping
  - draft-ietf-magma-snoop-xx.txt

MLD - Joining a Group (REPORT)

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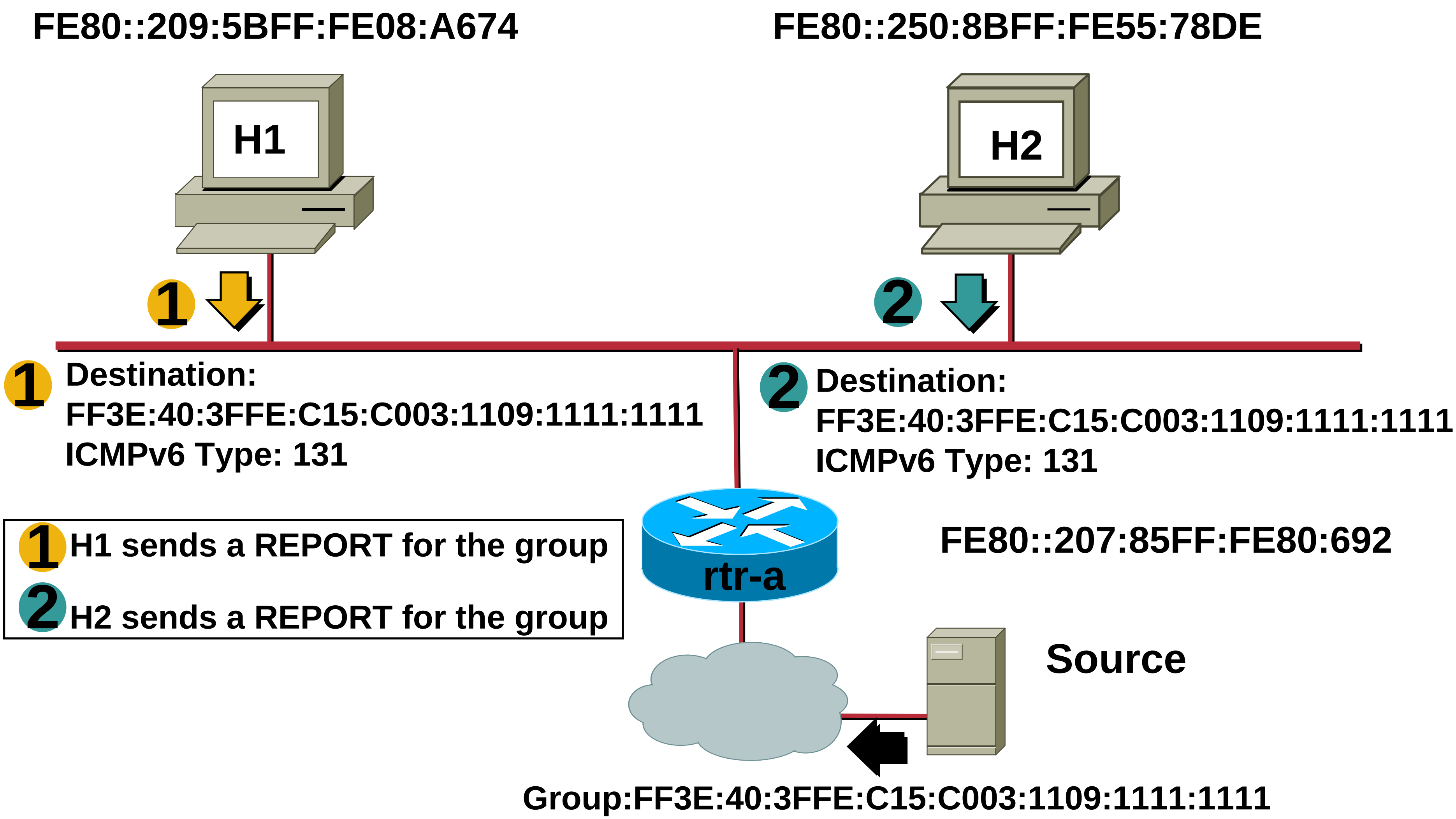

MLD - Host Management
(Group-Specific Query)

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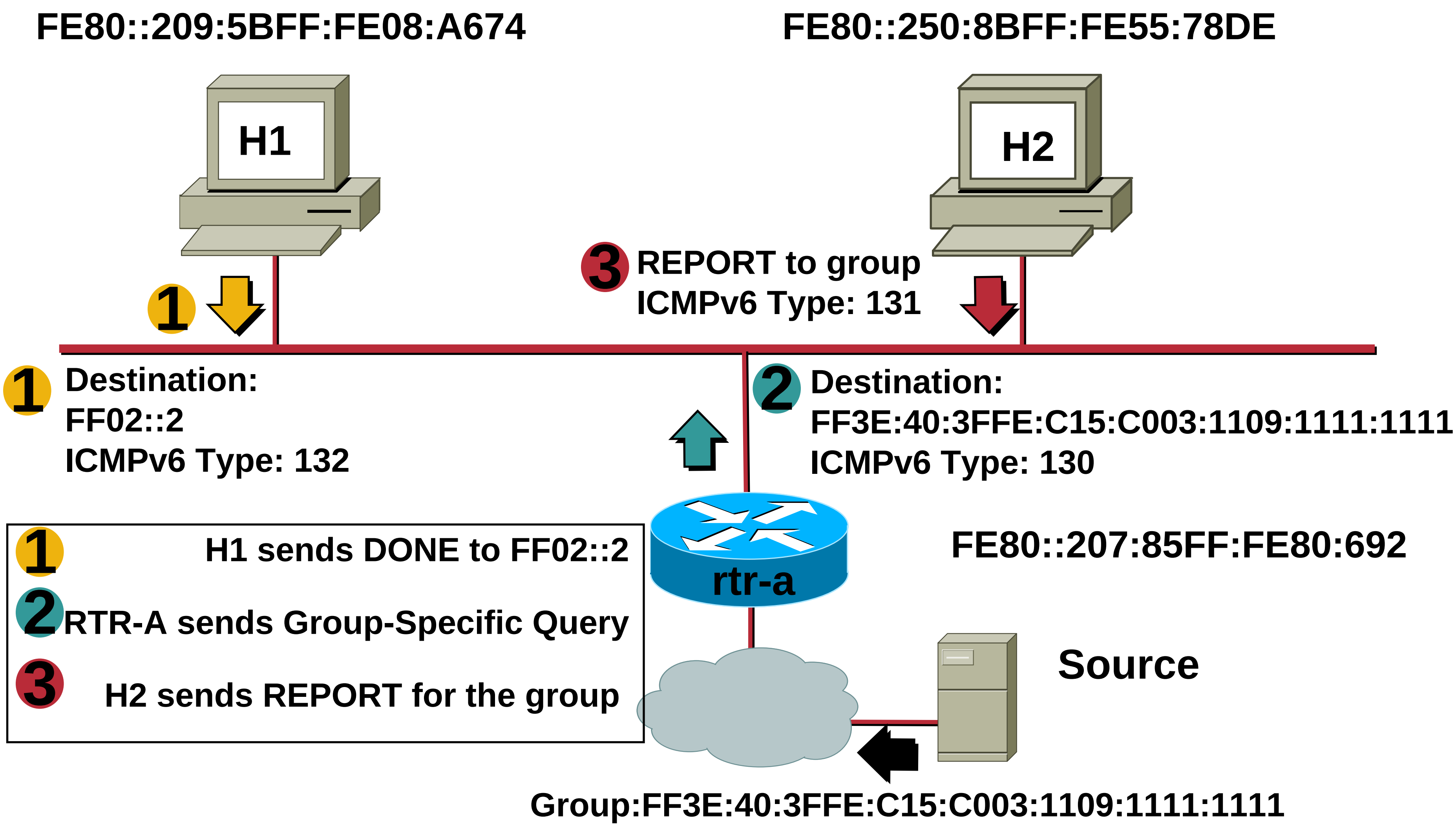

Other MLD Operations

- **Leave/DONE**
  - Last host leaves - Sends DONE (Type 132)
  - Router will respond with Group-Specific Query (Type 130)
  - Router will use the Last member query response interval (Default=1 sec) for each query
  - Query is sent twice and if no reports occur then entry is removed (2 seconds)
- **General Query (Type 130)**
  - Sent to learn of listeners on the attached link
  - Sets the Multicast Address Field to zero
  - Sent every 125 seconds (configurable)

Deployment Issues

Deployment Issues

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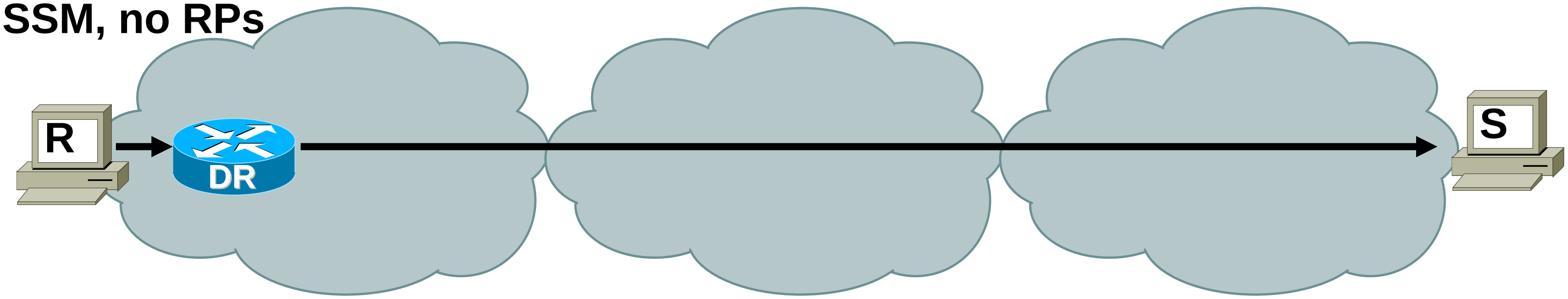
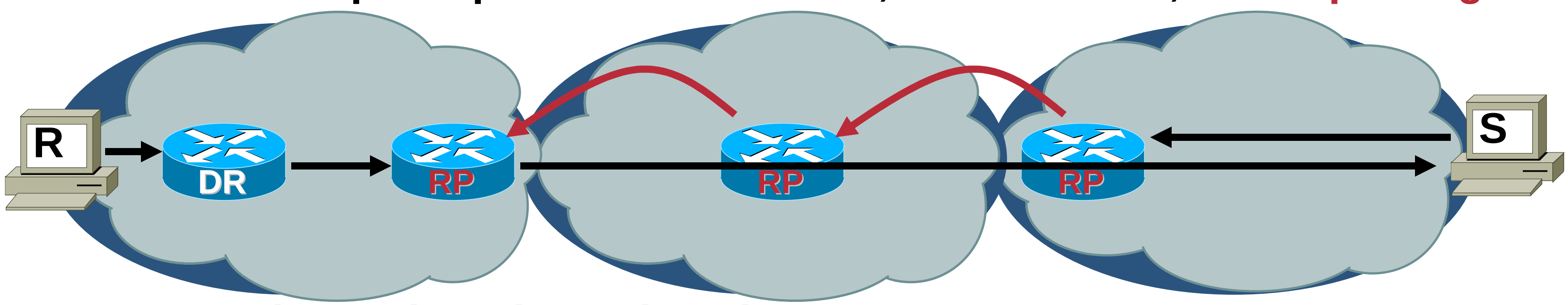
- Interdomain IPv6 Multicast
- RP distribution methods
- RP redundancy
- Scoping

IPv6 Interdomain Options

SSM, no RPs



ASM across multiple separate PIM domains, each with RP, MSDP peering



ASM across single shared PIM domain, one RP

RP Distribution Methods

- **Static RP assignment**
  - **Works the same as before**
- **Source Specific Multicast (SSM)**
  - **No RP or shared tree procedures (SPT only)**
  - **MLDv2 (IPv6) required**
  - **FF3x::/96**
- **Embedded-RP**
  - **Special case of unicast prefix-based addresses**
  - **R, P and T=1 (must) See later slides**
  - **Rpad is RP address for unicast prefix-based multicast address**
  - **plen is # of significant bits in network prefix**
  - **FF70::/12**
- **Bidirectional PIM (Bidir)**
- **Boot-Strap Router (BSR)**

IPv6 Multicast Static RP

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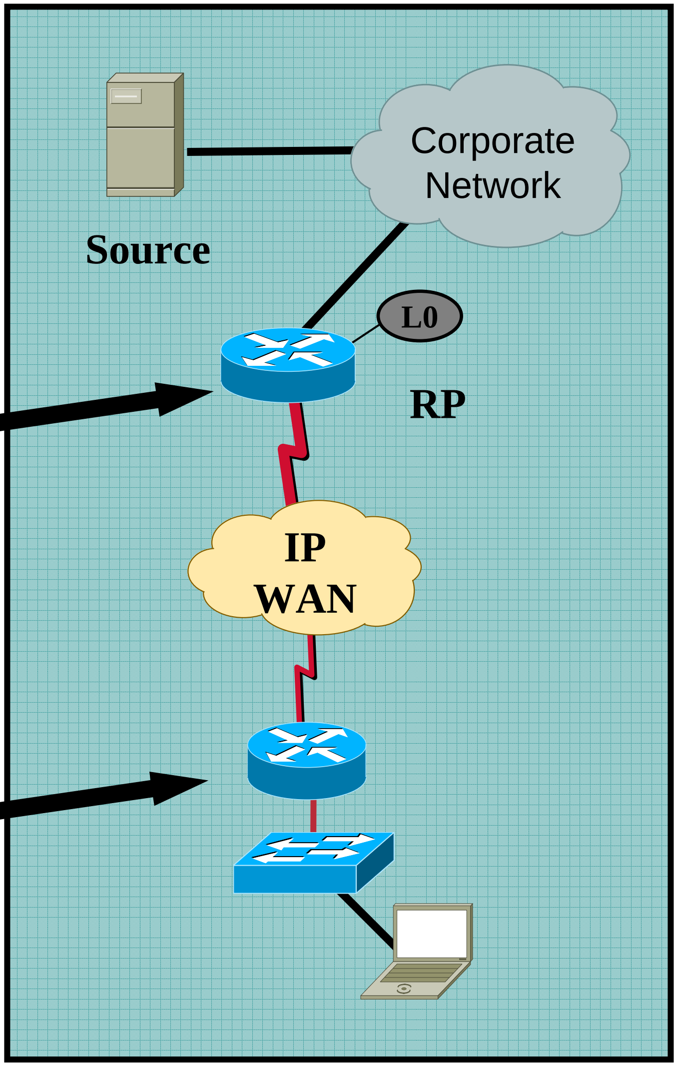
- **Easier than before as PIM is auto-enabled on every interface**

```
ipv6 multicast-routing
!
interface Loopback0
 description IPV6 IPmc RP
 no ip address
 ipv6 address 3FFE:C15:C003:110A::1/64
!
ipv6 pim rp-address 3FFE:C15:C003:110A::1/64
```

```
ipv6 multicast-routing
!
ipv6 pim rp-address 3FFE:C15:C003:110A::1/64
```



Source Specific Multicast (SSM)

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- **No configuration required other than enabling `ipv6 multicast-routing`**
- **SSM group ranges are automatically defined**

  FF3x::/96

- **Very few applications and operating systems support MLDv2…yet**

```
7507-agg-left#show ipv6 pim range-list
config SSM Exp: never Learnt from : ::
  FF33::/32 Up: 1d00h
  FF34::/32 Up: 1d00h
  FF35::/32 Up: 1d00h
  FF36::/32 Up: 1d00h
  FF37::/32 Up: 1d00h
  FF38::/32 Up: 1d00h
  FF39::/32 Up: 1d00h
  FF3A::/32 Up: 1d00h
  FF3B::/32 Up: 1d00h
  FF3C::/32 Up: 1d00h
  FF3D::/32 Up: 1d00h
  FF3E::/32 Up: 1d00h
  FF3F::/32 Up: 1d00h
```

SSM mroute

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```
1760-branch#show ipv6 mroute
Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group,
       C - Connected, L - Local, I - Received Source Specific Host Report,
       P - Pruned, R - RP-bit set, F - Register flag, T - SPT-bit set,
       J - Join SPT
Timers: Uptime/Expires
Interface state: Interface, State

(3FFE:C15:C003:1109::2, FF3E::DEAD), 00:03:28/never, flags: sTI
  Incoming interface: Serial1.1
  RPF nbr: FE80::210:7FF:FEDD:40
  Outgoing interface list:
    FastEthernet0, Forward, 00:03:28/never
```

Bidirectional PIM (Bidir)

- The same Many-to-Many model as before
- Configure Bidir RP and range via the usual `ip pim rp-address` syntax with the optional `bidir` keyword

```
ipv6 pim rp-address 3FFE:C15:C003:110A::1 bidir

2691-extra#show ipv6 pim range | include BD

Static BD RP: 3FFE:C15:C003:110A::1 Exp: never Learnt from : ::
```

Embedded-RP Addressing

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- **Draft-ietf-mboned-embeddedrp-07.txt**
- **Relies on a subset of RFC3306 IPv6 unicast-prefix multicast group addresses with special encoding rules:**

  Group address carries the RP address for the group!

  For each Unicast prefix you own, you now also own:

  16 RPs for each of the 16 Multicast Scopes (256 total)

  with 2^32 multicast groups assigned to each RP (2^40 total)

8	4	4	4	4	8	64	32
FF	Flags	Scope	Rsvd	RPaddr	Plen	Network prefix	Group id

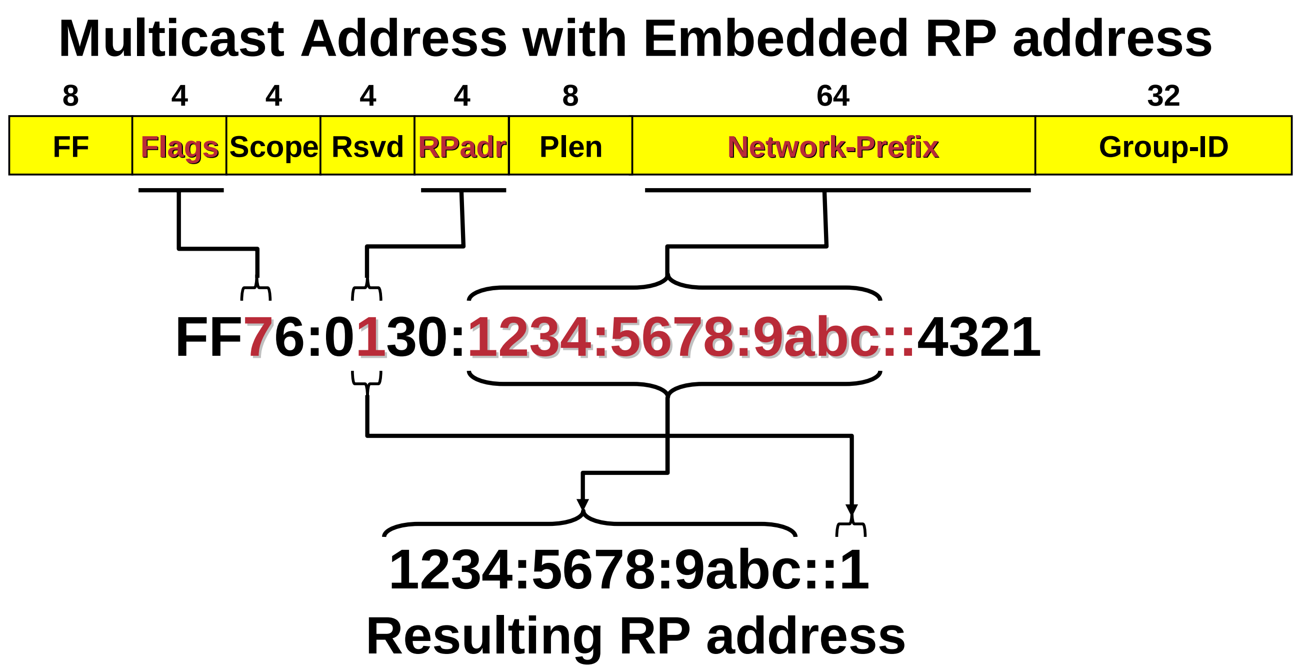
New Address format defined :

Flags = 0RPT, R = 1, P = 1, T = 1=> RP address embedded

Example Group: FF76:0130:1234:5678:9ab0::01020304

Embedded RP: 1234:5678:9ab0::1

Embedded-RP Addresses



- RP address = network prefix = Rpad
- 16 RP addresses per network prefix

Embedded-RP Addressing

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- **PIM-SM protocol operations with embedded-RP:**
  - No change in actual PIM-SM protocol operations
  - Embedded-RP can simply be considered as an automatic replacement to static RP configuration.
  - Can as well replace BSR for RP learning
  - Works so simple because of the large address space of IPv6.
    - No equivalent possible in IPv4
  - Intradomain transition into embedded-RP is easy:
    - Non-supporting routers simply need to be configured statically or via BSR for the embedded-RPs!

Embedded-RP Addressing:
General Limitations

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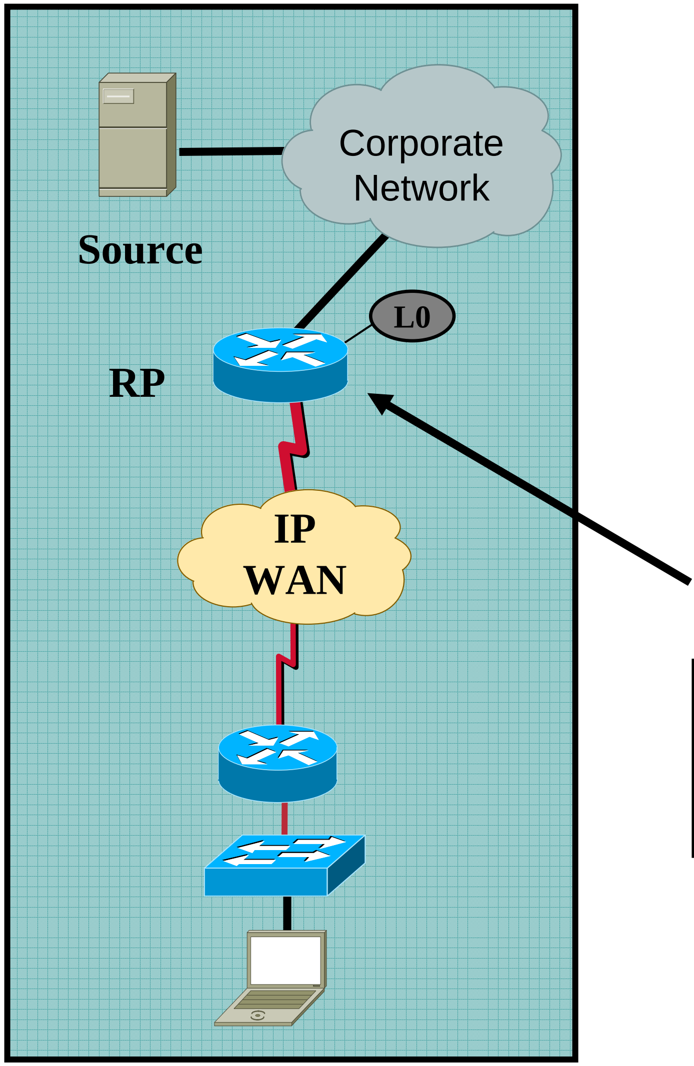
- Embedded-RP is just a method to learn ONE RP address for a multicast group:
  - It can not replace RP-redundancy as possible with BSR or MSDP/anycast-RP
    - Any RP redundancy solution that ought to work for an embedded RP must be some kind of anycast-RP solution because the embedded RP address is fixed through the mechanism – eg: If MSDP was available for IPv6, MSDP/anycast-RP could be used together with embedded RP.
    - See later slides!
- Embedded-RP does not support Bidir-PIM
  - Simply extending the mapping function to define Bidir-PIM RPs is not sufficient:
    - In Bidir-PIM routers carry per-RP state (DF per interface) prior to any data packet arriving. This would need to be changed in Bidir-PIM if Embedded-RP was to be supported.

Embedded-RP Configuration



- RP to be used as an Embedded-RP needs to be configured with address/ group range
- All other non-RP routers require no special configuration

```
ipv6 pim rp-address 3FFE:C15:C003:111D::1 ERP
!
ipv6 access-list ERP
permit ipv6 any FF7E:140:3FFE:C15:C003:111D::/96
```

Does it work?

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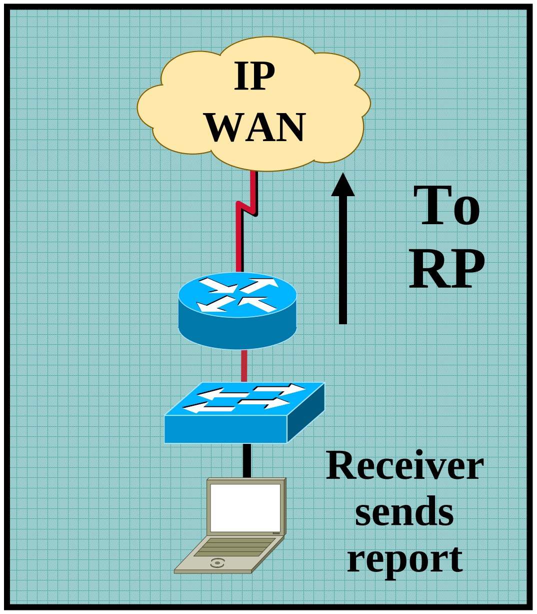
```
branch#show ipv6 pim group

FF7E:140:3FFE:C15:C003:111D::/96*
    RP       : 3FFE:C15:C003:111D::1
    Protocol: SM
    Client  : Embedded
    Groups  : 1
    Info    : RPF: Se0/0.1,FE80::210:7FF:FEDD:40
```

```
branch#show ipv6 mroute active

Active IPv6 Multicast Sources - sending >= 4 kbps
Group: FF75:140:3FFE:C15:C003:111D:0:1112
  Source: 3FFE:C15:C003:1109::2
    Rate: 21 pps/122 kbps(1sec), 124 kbps(last 100 sec)
```




```
branch#show ipv6 pim range | include Embedded

Embedded SM RP: 3FFE:C15:C003:111D::1 Exp: never Learnt from : ::

  FF7E:140:3FFE:C15:C003:111D::/96 Up: 00:00:24
```

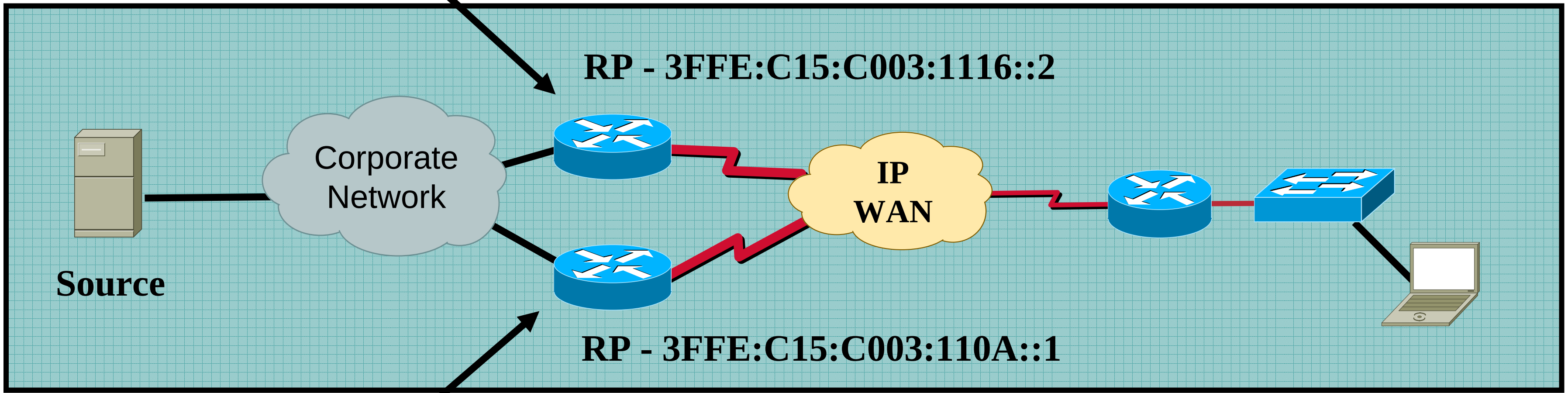
Administrative Control Issue

- Embedded-RP allows for the control of the multicast groups AND RPs to be handled by the applications group
- One reason why Cisco requires you to configure the router that will act as the RP beforehand
- Consider the issue when the WRONG RP is defined within the group address and a lonely 800 series router on a 128k line becomes to RP for hundreds of high-rate video streams (worse yet, you are using `ipv6 pim spt-threshold infinity`)
- Use the no `ipv6 pim rp embedded` command to disable Embedded-RP learning

IPv6 Multicast PIM BSR - Configuration


```
7206-agg-right#sh run | incl ipv6 pim bsr

ipv6 pim bsr candidate-bsr 3FFE:C15:C003:1116::2
ipv6 pim bsr candidate-rp 3FFE:C15:C003:1116::2
```




```
7507-agg-left#sh run | incl ipv6 pim bsr

ipv6 pim bsr candidate-bsr 3FFE:C15:C003:110A::1
ipv6 pim bsr candidate-rp 3FFE:C15:C003:110A::1
```

RP Redundancy
Overview

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- **ASM always requires an RP, whether it is PIM-SM or Bidir-PIM** (PIM-DM would be the exception to this rule for ASM)
- **RP is single point of failure and redundancy is a basic operational requirement**
  - **BSR is today the only available RP redundancy solution for IPv6:**
    - Static-RP configuration can by itself not provide for redundancy.
    - MSDP (for anycast RP redundancy) is not defined for IPv6 (***Cisco would consider it given demand by customers***)
    - BSR / AutoRP are in IPv4 considered to be inferior solutions to anycast:
      - Worse convergence times
      - Active protocol operations required in all routers
      - BSR has a set of limitation but further protocol work does not seem to happen in the IETF.

An anycast-RP solution for IPv6 could solve the issues at hand if combined together with embedded-RP

IPv6 RP Redundancy
Potential Anycast RP alternatives

- **MSDPv6**
  - Perfectly well suited to do support anycast-RP (one mesh-group)
  - Complex protocol – only a small subset of functions of MSDP are really required for anycast RP function.
  - MSDP was determined to be a temporary solution due to it's intrinsic (not anycast-RP related) restrictions. Reviving it for IPv6 is considered counter productive by many
- **Draft-ietf-farinacci-pim-anycast-rp-00.txt**
  - Most simple protocol doing exactly what MSDP needs to do in one mesh-group: PIM-SM register messages are unicast forwarded between the redundant RPs
  - (Almost) no operational differences to MSDP for anycast-RP.
- **Prefixlength/Anycast-RP (cisco internal idea right now)**
  - **Solution without any new protocol (in that way similar to embedded-RP) – aka: most simple solution ?**
  - **Could support PIM-SM and Bidir-PIM, IPv4 and IPv6**

IPv6 RP Redundancy
Prefixlength/Anycast-RP

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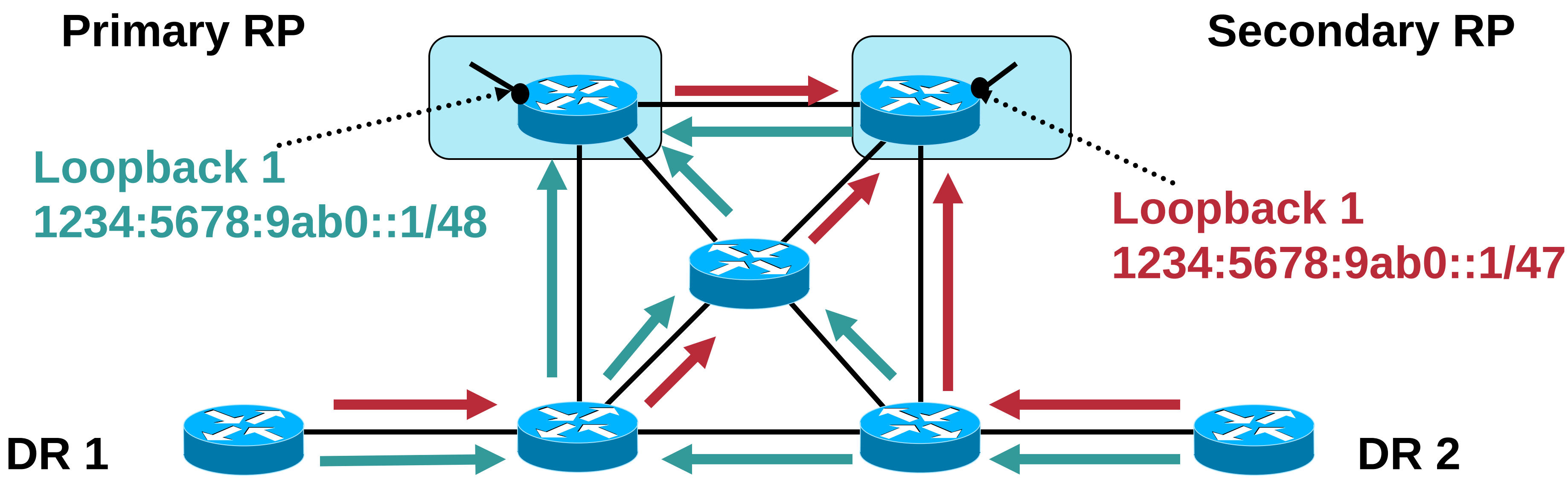

- NEW: Designate a primary and a secondary (tertiary, etc.. are possible too) RP for the anycast group.
- NEW: Configure Primary RP with longest subnet mask on the loopback, secondary has longer mask, etc...
- OLD: Distribute loopback interfaces routes into IGP

IPv6 RP Redundancy
Anycast-RP with prefixlength arbitration

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- **Result:**
  - **All routers will converge on the primary RP if it is available – because the longer mask route always wins!**
  - **If the primary RP fails, failover is as fast as with the known MSDP/anycast-RP it only depends on the convergence speed of the IGP**
  - **Because only one RP of the anycast group is active at any time, MSDP (or equivalent) is not needed !!!**
- **Major difference: No load-sharing between RPs**
  ..but we never saw load-sharing to be necessary in IPv4
  ..it just came for free with the MSDP/anycast-RP redundancy
- **Scalability behavior is also different than MSDP**
- **No new protocol, but: requires a few IOS code fixes on RP / DR before it can be used correctly**

IPv6 Scoping support

- Scopes: draft-ietf-ipngwg-addr-arch-v3-11.txt

  Example scopes:

  - link-local (2)
  - site-local (5)
  - global (E or 14)
- Zone is a connected region of a given scope
- Initial implementation similar to v4 boundaries:

  Can configure interface with zone and scope

  `ipv6 zone <zoneid> scope <2-15>`   CAUTION: This is still being worked.

  PIM messages and data traffic within that scope are ignored on that interface

  Initially a zone can only contain one interface

IPv6 ASM solutions summary

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- The solution elements (BSR, static-RP, embedded-RP, prefixlength/Anycast-RP or MSDP/replacement) are not independent of each other but form a potential framework:
- We consider BSR primarily important for intradomain interoperability reasons today.
- We consider ASM single-RP with embedded RP and future prefixlength/Anycast-RP to be the best approach to reduce complexity of interdomain PIM-SM
- We consider reduced complexity to be an important factor to reduce TCO and improve serviceability of IPv6 multicast.
- If customers point towards MSDP / other solutions, then we will do them!

Conclusion

Conclusion

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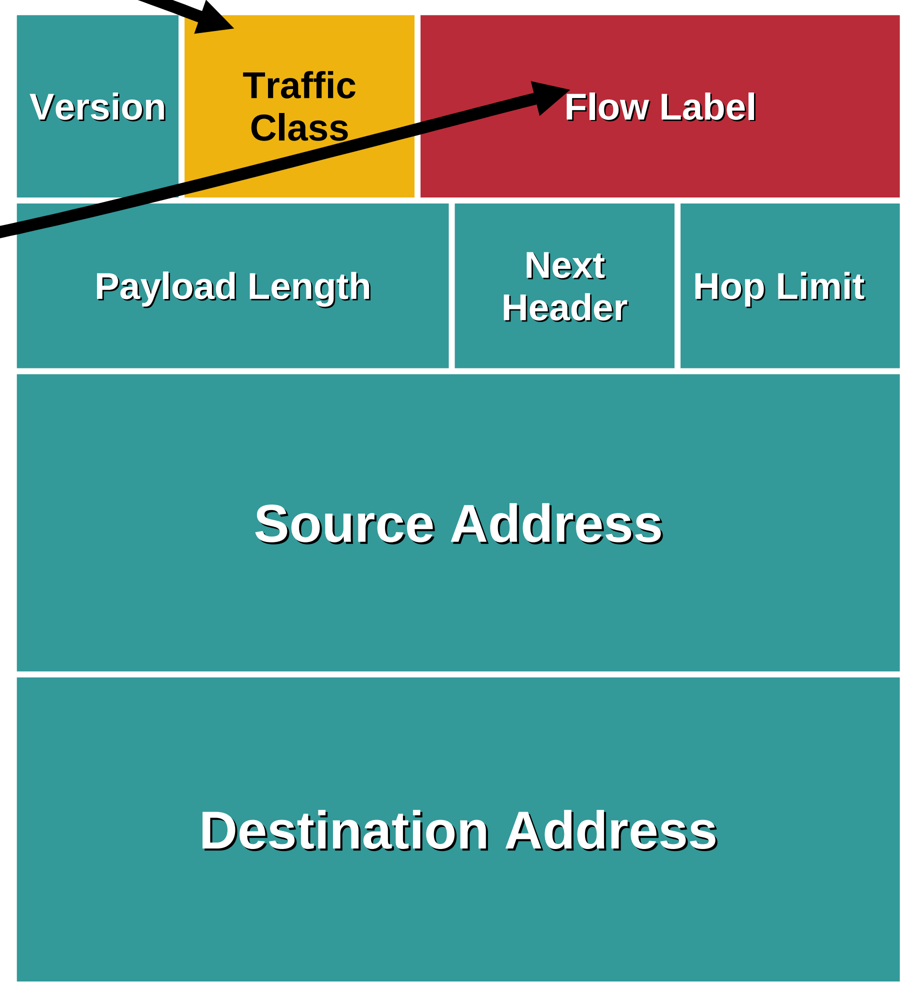
- **Cisco IOS IPv6 Multicast in initial deployment now**
- **Multicast Applications can be developed and tested over an infrastructure running Cisco IOS IPv6 Multicast**
- **IPv6 Multicast is an IPv6 service fully integrated with other Cisco IPv6 and IP Multicast solutions**

Advanced IPv6 Services

IPv6 QoS Mechanisms

IPv6 QoS: Header Fields

- **IPv6 traffic class**
  - Exactly the same as TOS field in IPv4
- **IPv6 flow label**
  - RFC3697
  - A new 20-bit field in the IPv6 basic header which:
    - Labels packets belonging to particular flows
    - Can be used for special sender requests



IPv6 Header Fields Used for QoS

IPv6 Flow Label

- Flow label enables per-flow processing for differentiation at the IP layer
- Router does not have to open the transport inner packet to identify the flow
- The flow label is a new 20-bit field in the IPv6 basic header:

    It labels packets belonging to particular flows.

    It can be used for special sender requests.

    Multiple flows per source-destination IPv6 pair are supported.

    RFC defines flow label field structure and base handling requirements.

    Flow label usage is still being defined.

IETF RFC available on Flow Label

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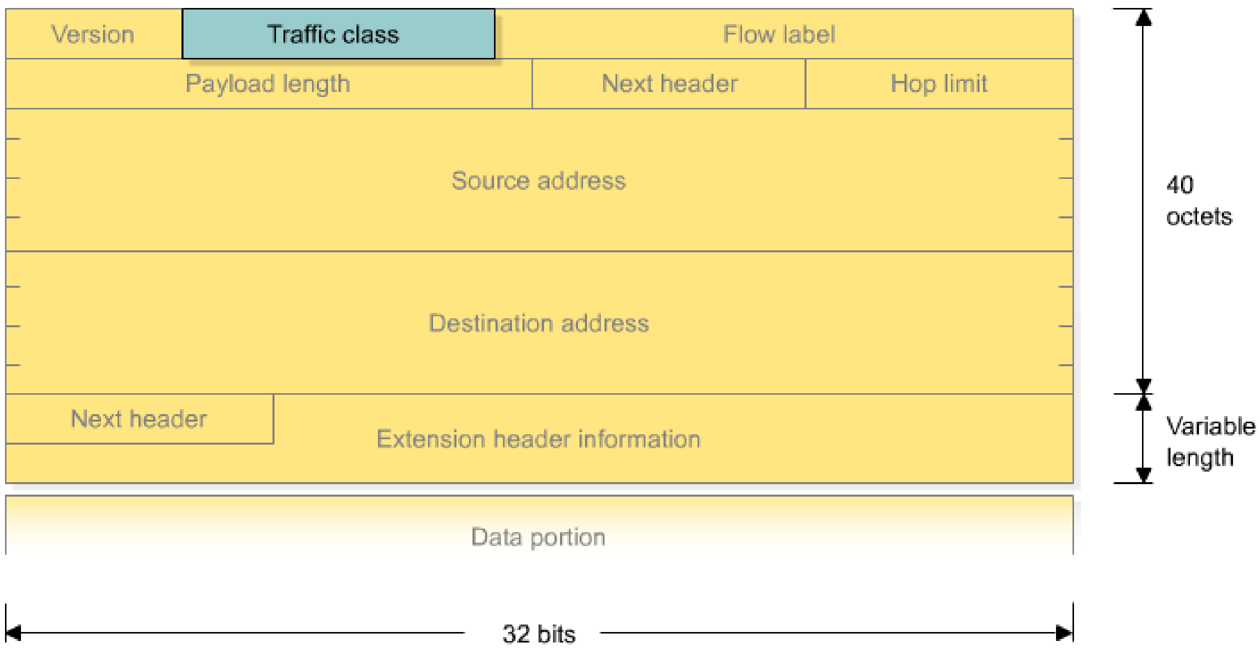
- **Now RFC3697**
  - **IPv6 Flow Label Specification**
- **More efficient; uses fewer header fields**
- **Source sets flow label**
- **Mechanisms in process track and reutilizes flow labels**
- **Man-in-middle attacks possible**

IPv6 Header Fields Used for QoS

Traffic Class



- **The traffic class field is an eight-bit field similar to the TOS field in IPv4.**

Qos Capabilities

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- Identification and marking for coordinating end-to-end QoS
- Policing
- Queuing, scheduling, and traffic-shaping
- QoS policy, management, and accounting

IPv6 Security

Introduction

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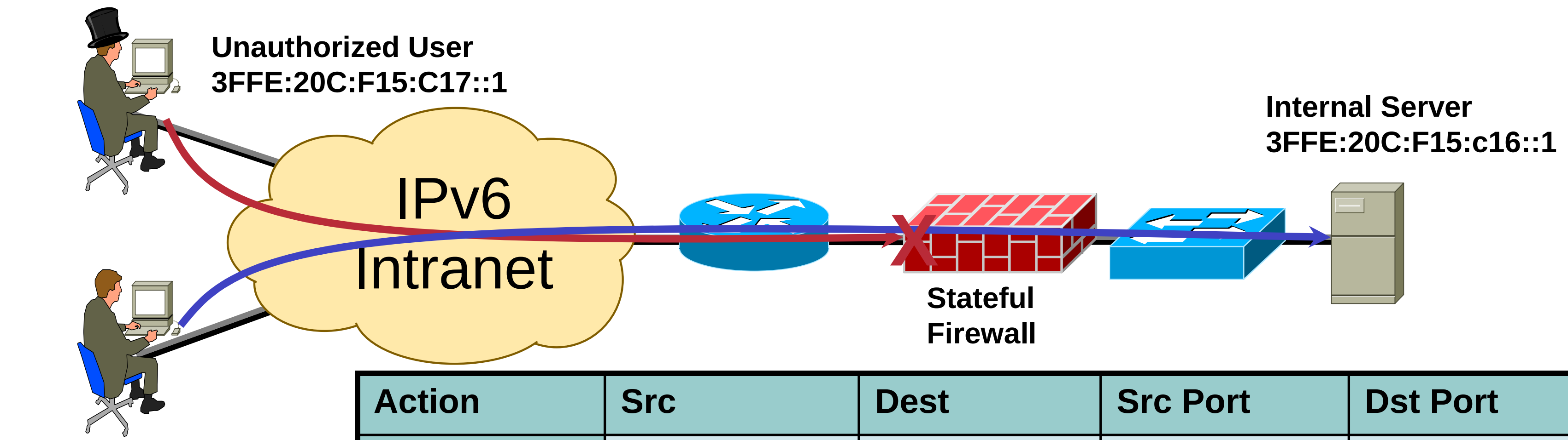
- **Discussions around IPv6 security have centered on IPsec**
  - **Though IPsec is mandatory in IPv6, the same issues with IPsec deployment remain from IPv4:**
    - **Configuration complexity**
    - **Key management**
  - **Many IPv6 stacks do not today support IPsec**
  - **Therefore, IPv6 will be deployed largely without cryptographic protections of any kind**
- **Security in IPv6 is a much broader topic than just IPsec**
  - **Even with IPsec, there are many threats which still remain issues in IP networking**
- **This presentation will cover things you need to know to begin to consider the security implications of v6 on your network ☺**

Filtering Unauthorized Access

Unauthorized Access in IPv6

- **Implementation of Policy in IPv6 still relies on access control being implemented using Layer 3 and Layer 4 information**
- **In addition IPv6 has some unique considerations that the network designer must be aware of in order to implement their policy correctly**



Action	Src	Dest	Src Port	Dst Port
Permit	3FFE:20C:F15:C18::1	3FFE:20C:F15:C16::1	Any	ssh
Deny	Any	Any		

Cisco IOS IPv6 ACL

- **IPv6 Access Control Lists**
  - **12.3M: Standard and Extended ACL**
  - **12.3T and 12.2S have the same feature set.**
  - **Hardware support available on 12.0(25)S C12000 engine 3, 12.0(26)S on 10720 and 12.2(17a)SX1 on C6500 sup.720**
  - **IPv6 and IPv4 ACL functionality**
  - **Implicit deny any any as final rule in each ACL.**
  - **A reference to an empty ACL will permit any any.**
  - **ACLs are NEVER applied to self-originated traffic.**

Filtering Extension Headers

- IPv6 headers and optional extensions need to be scanned to access the upper layer protocols (UPL)
- May require searching through several extensions headers
- Important: a router must be able to filter both option header and L4 at the same time

IPv6 Extended Access Control Lists

- Upper Layers : ICMP (next header 58), TCP (6), UDP (17), SCTP (132) – Could filter on any next header value (0-255)
- ICMPv6 code and type
- syn, ack, fin, psh, urg, rst and established (ack && rst)
- L4 port numbers
- Traffic class (only 6 bits/8) = DSCP
- Flow Label (0-0xFFFFF)
- IPv6 header options (Fragments, Routing, ...)

ICMPv4 vs. ICMPv6

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- **ICMPv6 has changed significantly from ICMPv4 and is more heavily relied upon within IPv6 that it was in IPv4.**

ICMP Message Type	ICMPv4	ICMPv6
Connectivity Checks	X	X
Informational/Error Messaging	X	X
Fragmentation Needed Notification	X	X
Address Assignment		X
Address Resolution		X
Multicast Group Management		X
Mobile IPv6 Support		X

- **With this in mind ICMP Policy on Firewalls needs to change to accommodate the changes in ICMPv6**

IPv6 ACL Implicit Rules

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- **Implicit permit for enable neighbor discovery**

  The following implicit rules exist at the end of each IPv6 ACL to allow ICMPv6 neighbour discovery:

  permit icmp any any nd-na
  permit icmp any any nd-ns
  deny ipv6 any any

  Be careful when adding « deny ipv6 any any log » at the end !

Conclusion

Conclusion

- A new protocol brings new security issues with it
- Likely to be more difficult to filter IPv6 packets
- More thorough deployment planning

By the Way … it is REAL ☹
IPv6 Hacking Tools

- **Sniffers/packet capture**
  - Snort
  - TCPdump
  - Sun Solaris snoop
  - COLD
  - Ethereal
  - Analyzer
  - Windump
  - WinPcap
  - NetPeek
  - Sniffer Pro
- **Worms**
  - Slapper
- **Scanners**
  - IPv6 Security Scanner
  - Halfscan6
  - Nmap
  - Strobe
  - Netcat
- **DoS Tools**
  - 6tunneldos
  - 4to6ddos
  - Imps6-tools
- **Packet forgers**
  - SendIP
  - Packit
  - Spak6

Cisco IPv6 Security Solutions

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Integration and Coexistence

Now

- Secure connectivity
  - IPSec
    - IPv4 dynamic IPSec to protect IPv6 over IPv4 tunnels with dynamic IPv4 end point
    - IPv4 IPSec over UDP to offer protection when crossing a firewall or NAT
    - IPv6 IPSec to authenticate OSPFv3
- Threat protection
  - Packet filtering
    - Standard, reflexive, extended access control list
    - Hardware filtering (Cisco 12000 Series IP Service Engine, Catalyst 6500 Series Supervisor Engine 720)

IPv6 Firewalls :

IOS FW and PIX Firewall 7.0

Stateful Packet Filtering

Protecting your network for IPv6 — 2005

Broadband Access Networks

Wholesale Architecture

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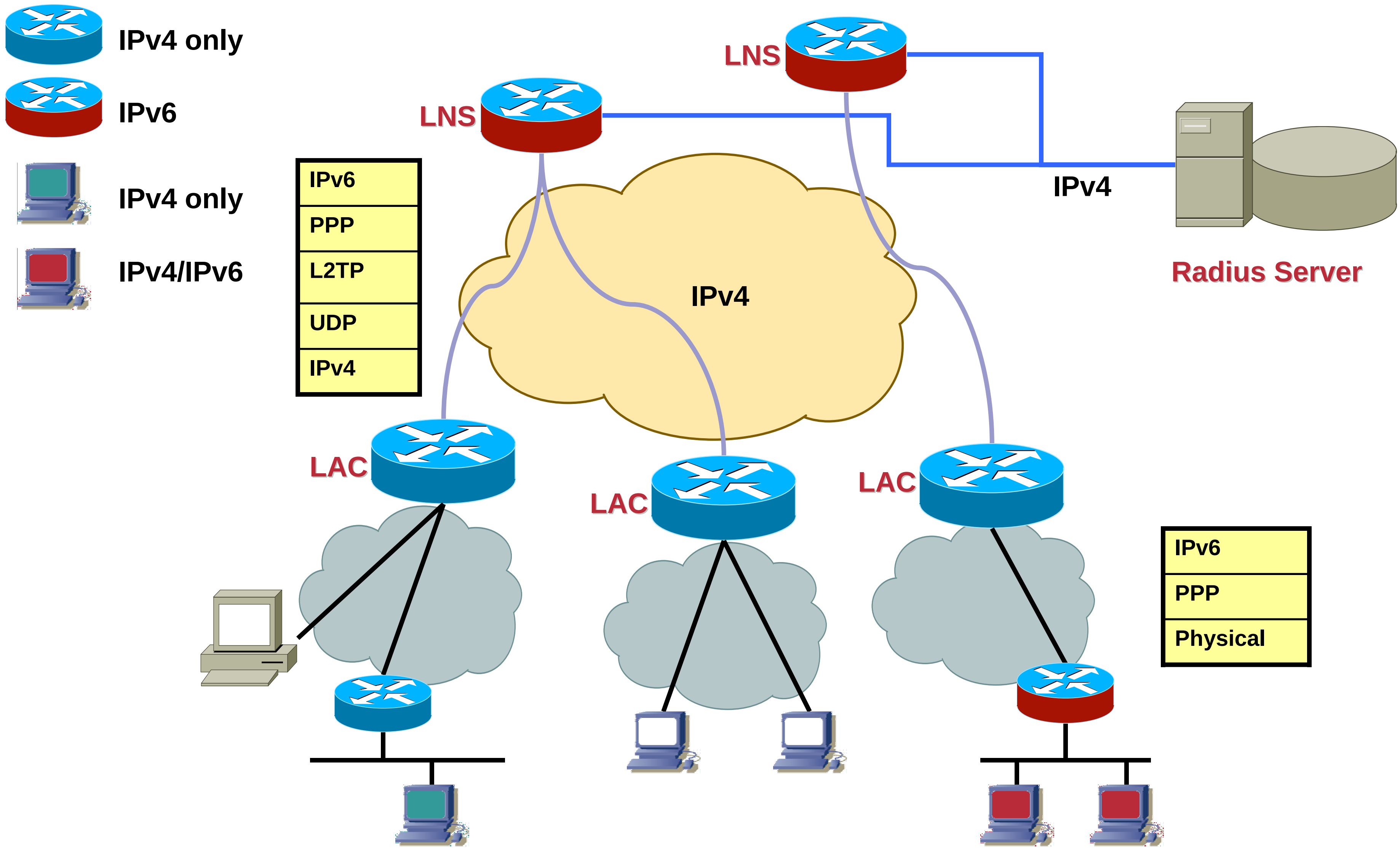

ISP Operated

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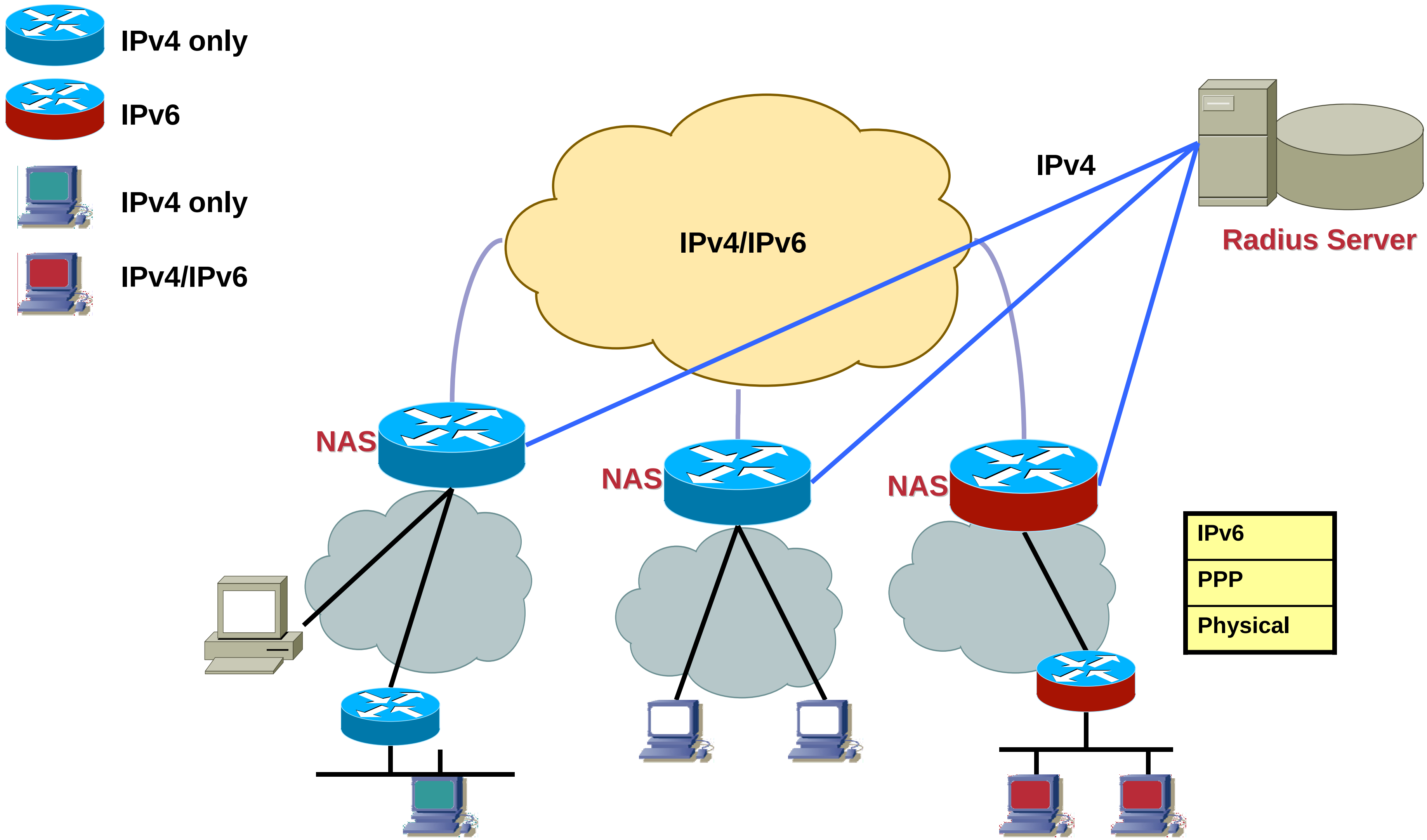
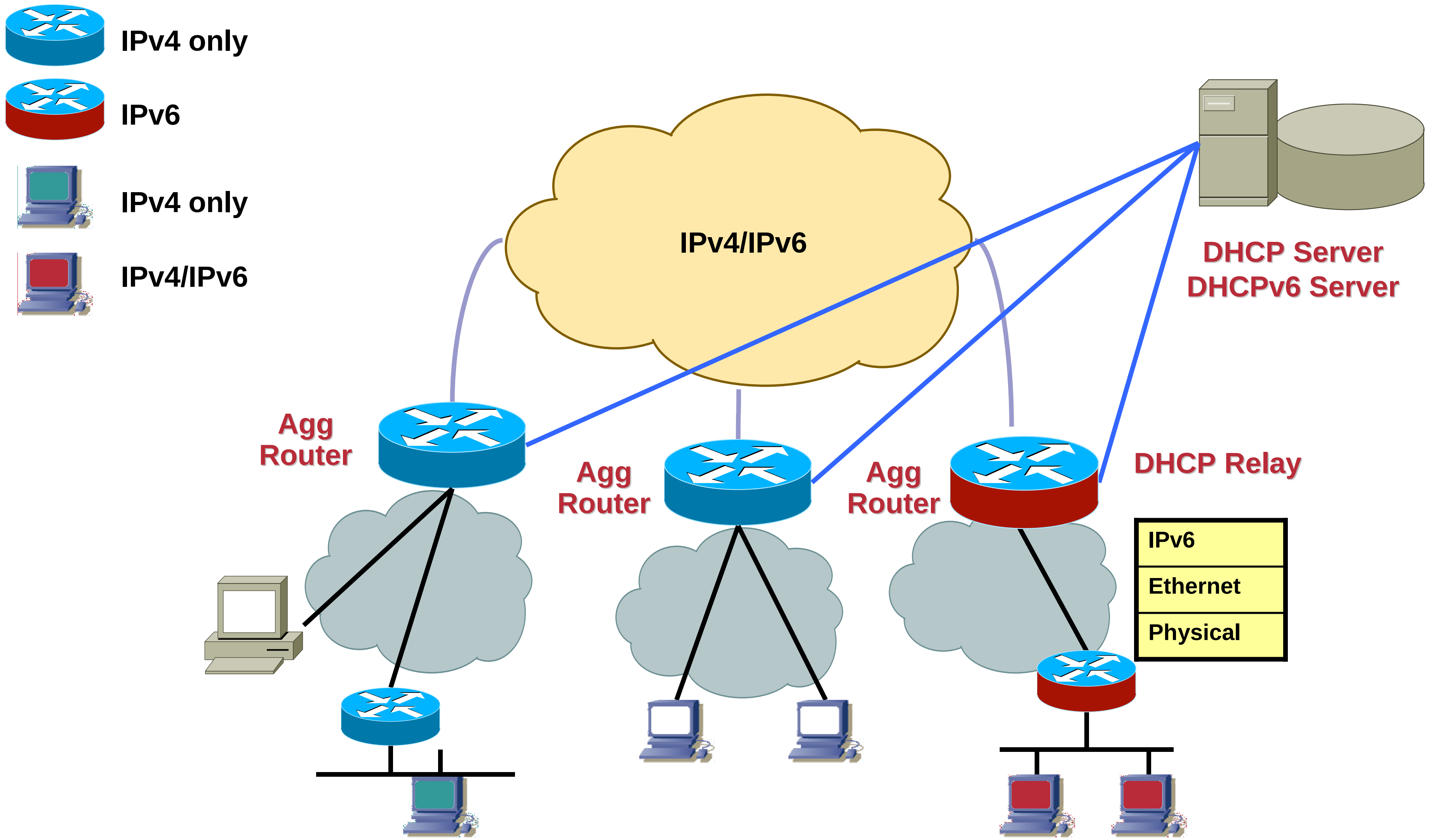
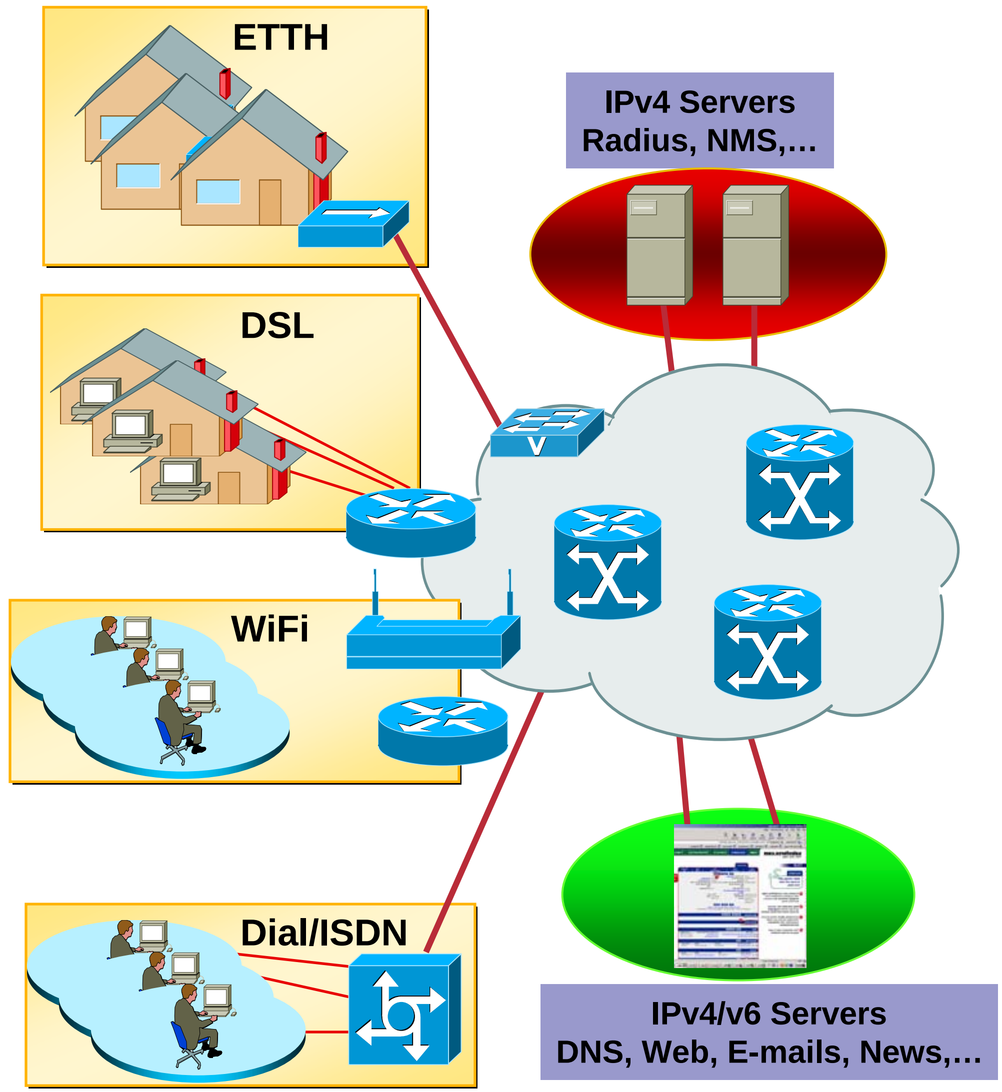


Now coming: without PPP – DHCPv6 Based

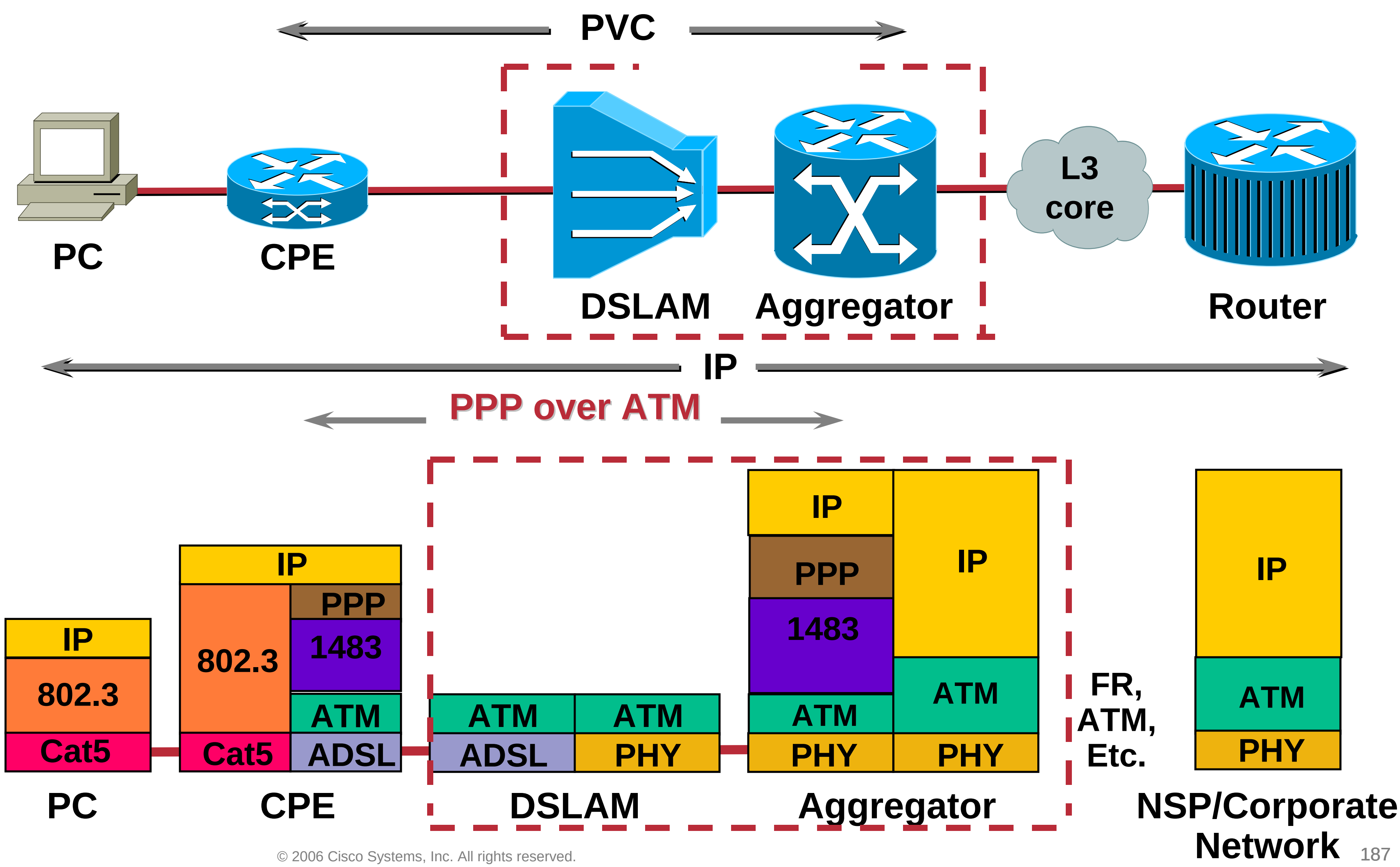


Data Link Layers

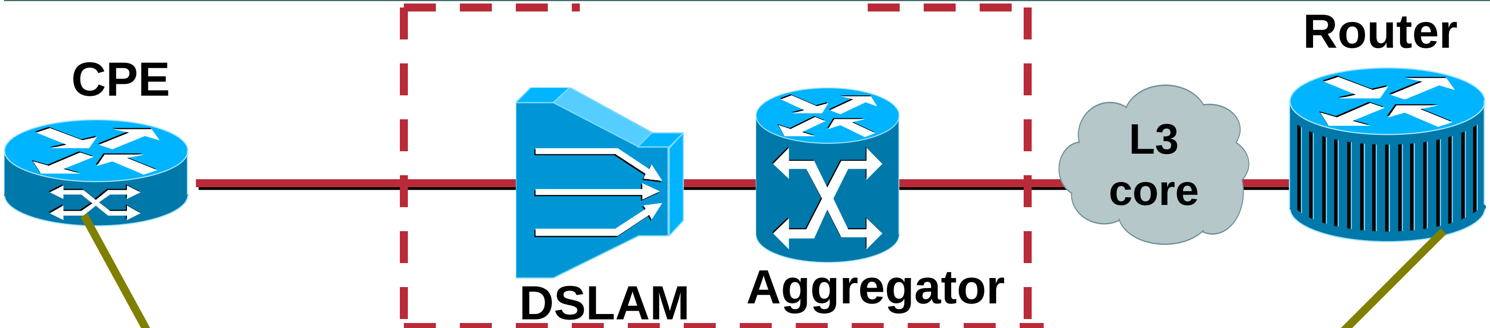
- Dial/ISDN
  - PPP
- Ethernet-To-The-Home
  - Ethernet
- 802.11 (WiFi) Hot Spots
  - Ethernet like
- ADSL
  - ATM RFC 1483 Routed
  - ATM RFC 1483 Bridged (RBE)
  - PPPoA
  - PPPoE
- Available from Cisco IOS routers running 12.3M and 12.3B releases



Protocol Stack - PPP over ATM



PPP over ATM configuration




```
interface FastEthernet0
 ipv6 address 2001:DB8:1111::1/64
!
interface Atm 0
pvc 1/23
 encapsulation aal5mux ppp dialer
 dialer pool-member 1
!
interface dialer1
 encapsulation ppp
 dialer pool 1
 ipv6 address autoconfig
 ppp authentication chap foo
 ppp chap hostname user@domain.net
 ppp chap password 7 1111111111
 ppp ipcp address accept
!
ipv6 route ::/0 Dialer1
!
```

```
!
vpdn enable
!
vpdn-group 1
accept dialin l2tp virtual-template 1
remote sp_lac
local name lns
!
interface Loopback0
ipv6  address 2001:DB8:2222::1/64
!
interface Virtual-Template1
 ipv6 enable
 ipv6 mtu 1480
 no ipv6 nd suppress-ra
 ppp authentication chap default
 !
radius-server host 172.22.66.16
!
```

AAA/RADIUS

- Cisco Vendor Specific Attributes
  - IPv6 Prefix, IPv6 Route, IPv6 ACL (Input & Output)
- RADIUS and IPv6 (RFC3162)
  - Framed-IPv6-Prefix
    Framed-IPv6-Route
    Framed-IPv6-Pool
    NAS-IPv6-Address
    Login-IPv6-Host
    Framed-Interface-Id
- On Cisco IOS, RADIUS transport is IPv4 as today most Radius server are used for both protocols
  - IPv6 should be added later
- IPv6 AAA available on Cisco IOS
  - Cisco VSA available now from Cisco IOS 12.3M and 12.3B
  - RFC 3162 available from Cisco IOS 12.3T

AAA per-user attributes

- **Route#**

  Installs a per-user static route in the RIB
  cisco-avpair="ipv6:route=2001:DB8:1::/48"

- **Prefix#**

  Adds the prefix to RA's sent out the interface, and adds a route in the RIB.
  cisco-avpair="ipv6:prefix=2001:DB8:2::/64"

- **ACL**

  cisco-avpair="ipv6:inacl=permit 2001:DB8:2::/64"

- **Framed-Interface-Id**

  Framed-Interface-Id=0:0:0:0:0:0:1
  Included in accounting records

IPv6 prefix-pools

- **Normal prefix pools:**
  ipv6 prefix-pool foo 2001:DB8:1::/48 64

  A Separate /64 is assigned each user/interface. The prefix is advertised in RA's and a route is installed in the RIB.

- **Shared prefix pools:**
  ipv6 prefix-pool foo 2001:DB8:2::/64 128 shared

  /64 prefix is shared between all users of the pool. The same /64 prefix is advertised in RA's out all interfaces. The user gets an /128 based on the prefix and his Interface-Identifier. A route in the RIB is installed only for the /128.

IPv6 Address Allocation Guidelines

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"…recommends the assignment of /48 in the general case, /64 when it is known that one and only one subnet is needed…"

RFC3177
IAB/IESG Recommendations on IPv6 Address Allocations to Sites

Deployment Scenarios

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- Most commonly, a /48 prefix will be delivered to every remote site with more than one subnet.
- A /64 prefix will be assigned to a customer with only one subnet or a host.
- As a last resort, a /128 prefix might be assigned to individual remote PCs.
- The customer address allocation will be either static or dynamic

  Static: when the customer network is always numbered with the same address prefix

  Dynamic: when the assigned address prefix changes with each connection

Connecting Home Users

Connecting Home Users

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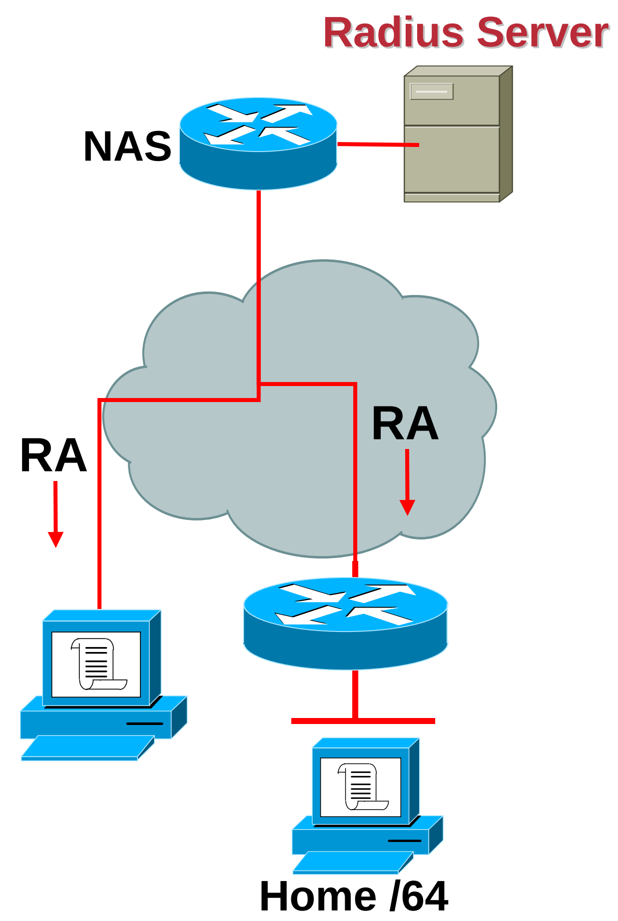
- **Permanent /64 prefix**
  - Assignment of a permanent /64 address prefix to a single PC
  - The PE will send an RA along PE-CPE link.
- **There are two options available for a single PC:**
  - Upon reception of the RA, the PC completes its own the 64 least significant bits of the IPv6 address on its own
  - Before receipt of the RA, at IPv6CP level, an Interface Identifier is given to the PC. The “Interface-Id” attribute in the user profile to provide a fixed interface identifier to the PC

Connecting Home Users Permanent /64

- **Use: for single PC or network with only one link**
- **AAA static prefix attribute. Interface-Id attribute to specify the complete address**
- **CPE: single PC or configured router**




```
Radius config:
Auth-Type = Local, Password = "foo"
User-Service-Type = Framed-User,
Framed-Protocol = PPP,
cisco-avpair = "ipv6:prefix=2001:db8:1::/64
Framed-Interface-Id = 0:0:0:1
```

Connecting Home Users

- **Short-lived /64 from a prefix-pool**

  A Separate /64 is assigned each user/interface.

  A different /64 prefix RA is sent every time.

  A route is installed in the RIB.

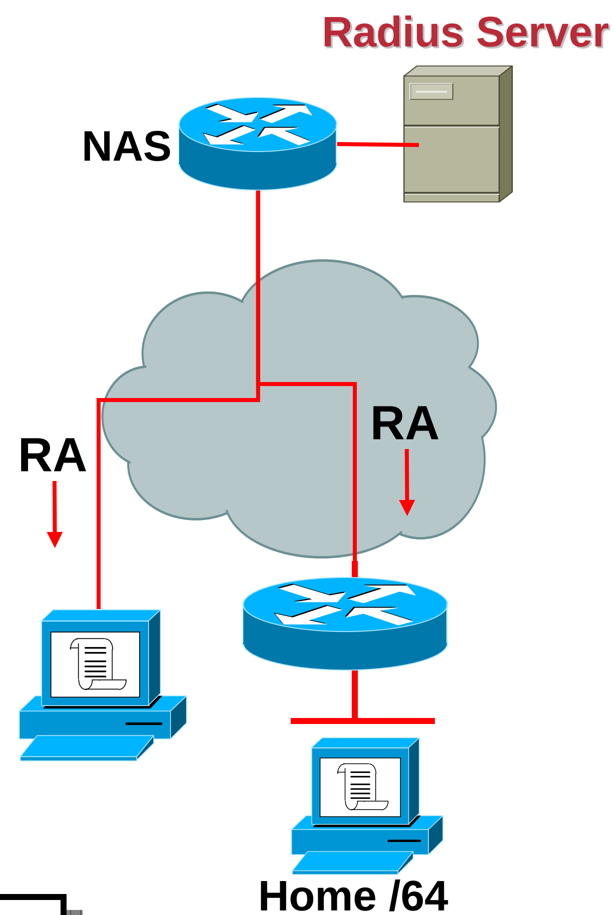
  This is limiting as it does not allow the PC to keep a long-lived address and provide content.

  If there is a requirement for a permanent Interface ID, then the Interface-Id Radius attribute can be stored in the Radius profile

Connecting Home Users

Short-lived /64

- For single PC or very simple network
- NAS: IPv6 prefix pool
- CPE: multi-link subnet/bridging Renumbering issues

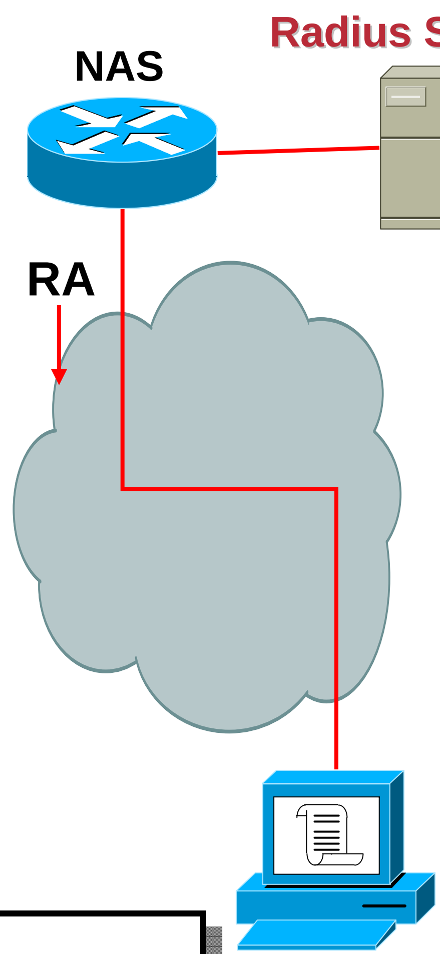



```
Radius config:
Auth-Type = Local, Password = "foo"
User-Service-Type = Framed-User,
Framed-Protocol = PPP,
cisco-avpair = "addr-pool="foo-shared"
```

```
PE config:
ipv6 prefix-pool foo-shared 2001:db8:e::/48 64
```

Connecting Home Users
Short-lived /128

- For single PC only. Allows one address
- Does not bring anything on top of a classical IPv4 remote access scheme
- /64 prefix shared between all users of the pool
- The user gets an /128 based on the prefix and his Interface-Identifier
- Not really used




```
AAA config:
Auth-Type = Local, Password = “foo”
User-Service-Type = Framed-User,
Framed-Protocol = PPP,
cisco-avpair = “addr-pool=“foo-shared”
```

```
PE config:
ipv6 prefix-pool foo-shared 2001:db8:e::/64 128 shared
```

SOHO Deployment

Typical SOHO Characteristics

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- **SOHO characteristics**
  - No fulltime IT expertise
  - The network should be simple, stable, reliable and in-expensive
  - Typical end-user environment
  - Often Connectivity is Internet Access oriented
- **Example 1:**
  - 'SmallCo' is an office-branch of 5 people. They are connected to the internet via an ASP or ISP 'BigISP'
- **Example 2:**
  - 'John Doe' works from home and has an aDSL connection with NAT and wireless connectivity. He has several computers and uses a VPN tunnel from his laptop to connect to his main office

SOHO Planning Considerations

- **Step 1: Is the HW IPv6 Capable?**
- **Step 2: Can ISP deliver IPv6 Connectivity?**
- **Step 3: IPv6 Addressing?**

Step 1: Is the HW IPv6 Capable?

Which HW to consider initially?

a) Access Router

b) End-systems (i.e. Computer)

c) LAN infrastructure

d) Wireless infrastructure

Step 1: Is the HW IPv6 Capable?

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A) Access Router Considerations

- Is the router doing IPv4 NAT?
  - Yes Then this limits the use of tunneling mechanisms by the end-systems
    - (i.e. IPv6 over Cisco VPN client)
  - NO This allows most flexible IPv6 integration
- Does Access Router allow Dual IPv4/IPv6 Stack?
  - Cisco CPEs allow IPv6 dual-stack and various tunneling mechanisms as well
- Does Access Router support DHCPv6 Prefix Delegation?
- Does Access Router support 6to4 tunneling?

Step 1: Is the HW IPv6 Capable?

B) End-systems (Computers)

- Does the OS support Native IPv6?
  - Useful when the CPE supports IPv6 or when Cisco VPN client is used
- Does the OS support IPv6/IPv4 Tunneling?
  - Useful when the IPv4 NAT is NOT used and the CPE is not configured or supporting IPv6
  - Investigate which tunnel mechanism fits best the use case (Manual tunnels? Cisco VPN? ISATAP? Etc..)
- Does the system have a Cisco VPN client?
  - Useful for NAT traversal
- Does the system have a DHCPv6 stack?
  - Currently this is unlikely, however IPv4 DHCP could be used in co-existence

Step 1: Is the HW IPv6 Capable?

C) LAN infrastructure

In SOHO environment this is mainly OSI Layer2 and hence IPv6 or IPv4 unaware

Note: Some L2 LAN switches have a management interface, and for SOHO this will often still be IPv4 only

D) Wireless infrastructure

In SOHO environment this is mainly OSI Layer2 and hence IPv6 or IPv4 unaware

Note: Some Wireless AP's have a management interface, and for SOHO environment this will mainly be IPv4 only

Step 2: Can ISP deliver IPv6 Connectivity?

Yes

- In this situation the SOHO should get official IPv6 address space allocated from the ISP
- In addition, the ISP could support also DHCPv6 Prefix Delegation to automate the IPv6 prefix assignment process and minimize configuration requirements at the SOHO Location

No

- Access Router Could use 6to4 Tunneling if it has been allocated a Global IPv4 address
- If Access Router IS NOT performing IPv4 NAT then end-systems could use IPv6 tunneling techniques
- If Access Router IS performing IPv4 NAT then tunneling techniques on the end-systems are severely restricted
  - (IPv6 over Cisco VPN client will still work, but i.e. manual and ISATAP IPv6 tunnels will not)

Step 3: IPv6 Addressing?

RFC3177
IAB/IESG Recommendations on IPv6 Address Allocations to Sites

"…recommends the assignment of /48 in the general case, /64 when it is known that one and only one subnet is needed…"

Note: /128 assignment can be used when it is absolutely known that one and only one device is connecting

Step 3: IPv6 Addressing?

- **Normally a site should get according RFC3177 a /48 prefix allocation**
  - **It would be operationally most interesting if the IPv6 prefix allocated by ISP for the SOHO is fixed when NOT using DHCPv6-PD**
  - **When Access Router is using 6to4 addressing then it makes sense to verify if the IPv4 address allocated for the Access Router is fixed for the particular SOHO site**
- **Which prefix length to use inside the SOHO network?**
  - **Normally on a LAN segment /64 prefixes are recommended due to SLAAC**

Deploying IPv6 in SOHO Networks

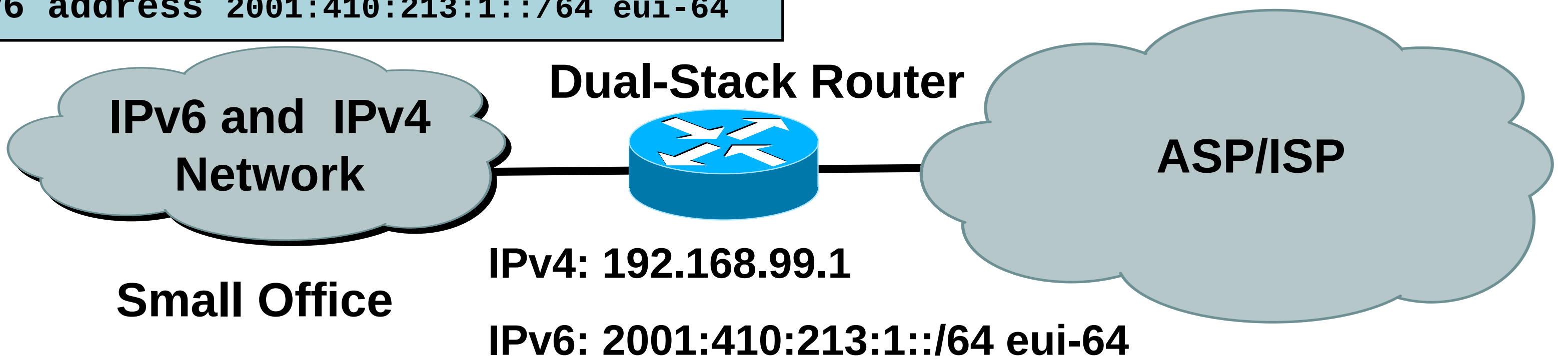
Cisco.com

- **Deploying IPv6 on the Access Router**
- **Deploying IPv6 on End-Systems**

Cisco IOS Dual Stack Configuration


```
router#
ipv6 unicast-routing

interface Ethernet0
 ip address 192.168.99.1 255.255.255.0
 ipv6 address 2001:410:213:1::/64 eui-64
```



Gateway is IPv6-enabled:

- The Access or Internet Service Provider offers native IPv6 forwarding. Similar design can be used if the ISP offers native IPv6 service and the subscriber connects to the ISP over PPP
- If IPv4 and IPv6 are configured on one interface, the router is dual-stacked
- Telnet, Ping, Traceroute, SSH, DNS client, TFTP,…

Prefix/Options Assignment

(1) CPE sends DHCP solicit with ORO = PD

(2) PE sends RADIUS request for the user

(3) RADIUS responds with user's prefix(es)

(4) PE sends DHCP REPLY with Prefix Delegation options

(5) CPE configures addresses from the prefix on its downstream interfaces, and sends an RA. O-bit is set to on

(6) Host configures addresses based on the prefixes received in the RA. As the O-bit is on, it sends a DHCP INFORMATION-REQUEST message, with an ORO = DNS

(7) CPE sends a DHCP REPLY containing request options

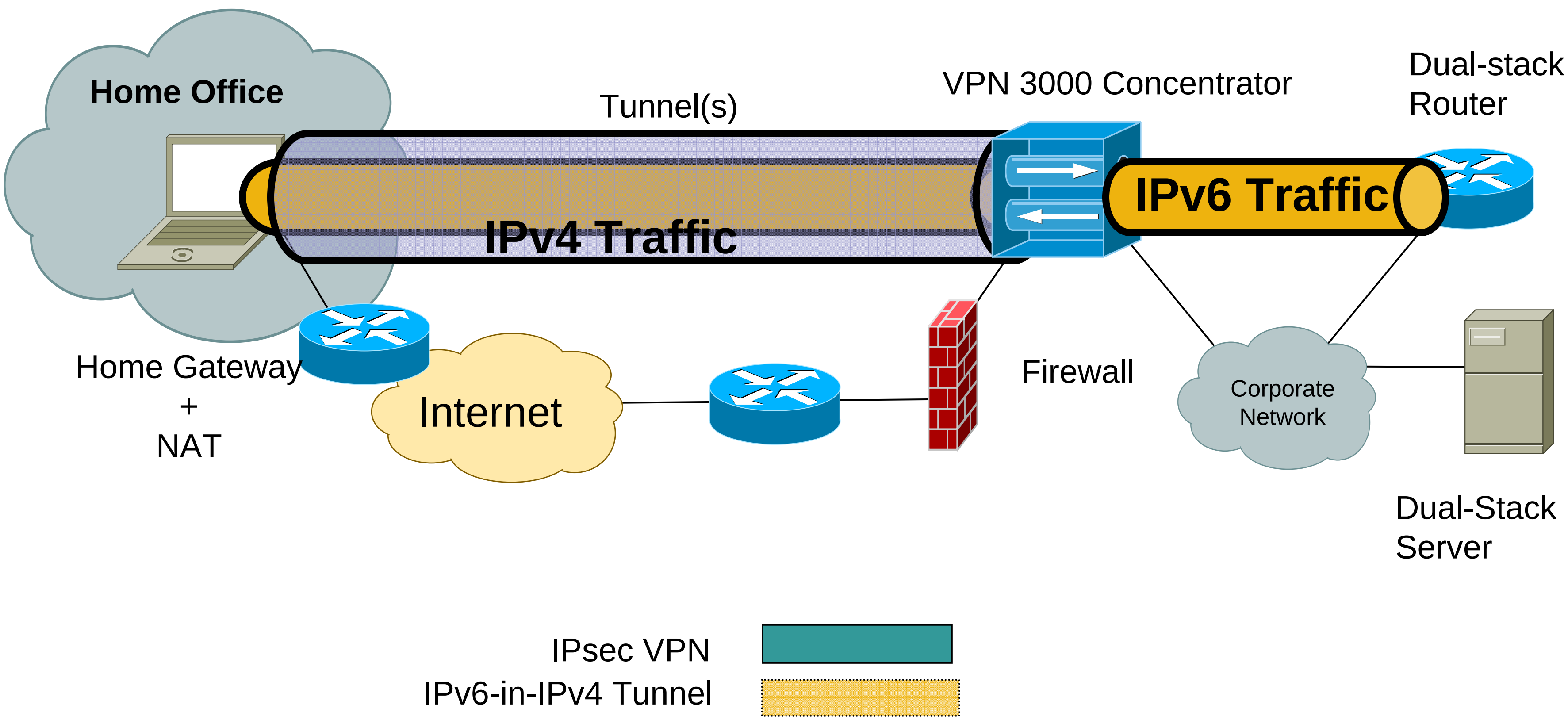
Deploying IPv6 in SOHO Networks

- **Deploying IPv6 on the Access Router**
- **Deploying IPv6 on End-Systems**

Deploying IPv6 on Clients

Vendor	IPv6 Support	Versions	More Info
Microsoft	YES	XP and .NET server 2003, CE .NET Pocket PC 2003	http://www.microsoft.com/ipv6
Sun	YES	Solaris 8, 9 and 10	http://wwws.sun.com/software/solaris/ipv6/
IBM	YES	z/OS Rel. 1.4, AIX 4.3 OS/390 V2R6 eNCS	http://www-3.ibm.com/software/os/zseries/ipv6/
BSD	YES	FreeBSD 4.0 OpenBSD 2.7, NetBSD 1.5 BSD/OS 4.2	http://www.kame.net/
Linux	YES	RH 6.2, Mandrake 8.0, SuSE 7.1, Debian 2.2	http://www.bieringer.de/linux/IPv6/status/IPv6+Linux-status-distributions.html
HP/Compaq	YES	HP-UX 11i Tru64 UNIX V5.1 OpenVMS V5.1	http://h18000.www1.hp.com/ipv6/next_gen.html
Novell	YES	Netware 6.1	http://www.novell.com/documentation/lg/nw65/index.html?page=/documentation/lg/nw65/readme/data/ajzlp6r.html
Apple	YES	MAC OS X 10.2	http://developer.apple.com/macosx/

Remote Access – Cisco VPN Client & IPv6



Note: The VPN concentrator could be replaced with a VPN-enabled IOS Router or PIX

Deploying IPv6 on Windows XP

Cisco.com

IPv6 installation on Windows XP:

- If no service packs are installed:
  - type ipv6 install from the command prompt
- If SP1 is installed:
  - install “Microsoft IPv6 Developer Edition” from the Connection Properties window
- If SP2 is installed:
  - install “Microsoft TCP/IP version 6” from the the Connection Properties window

Command for IPv6 configuration

- ipv6 (will be discontinued, not present in Windows Server 2003)
- netsh interface ipv6

Commands for autoconfiguration

- netsh interface ipv6 4
- interface 1 - loopback
- interface 2 - ISATAP
- interface 3 - 6to4 interface
- interface 4 - real network interfaces
- interface 5 - Teredo interface

Commands for setting manual address:

- netsh ipv6 interface {add|set} address [interface=] <interface> [address=] <address>
- <interface> - interface name or index
- <address> - address in IPv6 format

Commands for deleting manual address:

- netsh ipv6 interface delete address [interface=] <interface> [address=] <address>

Commands for setting/removing static IPv6 routes:

- netsh ipv6 interface {add|set|delete} route [prefix=] <prefix>/<length> [interface=] <interface> [[nexthop=] <address>]

Commands associated with applications:

- ipconfig, netstat, ping6, tracert6, pathping
- All Wininet.dll based applications (ftp, telnet, IExplorer,)

Commands on Windows 2003 server:

- netsh interface ipv6 (only!)
- file/print sharing-et (site-local) supported over IPv6
- IIS and media server

Neighbour cache:

- netsh interface ipv6 show neighbors (ipv6 nc)

IPv6 routing table:

- netsh interface ipv6 show routes (ipv6 rt)

Reconfiguration:

- netsh interface ipv6 renew (ipv6 renew)

Address selection policy

- netsh interface ipv6 show prefixpolicy
- netsh interface ipv6 set prefixpolicy [prefix=]<prefix>/<length> [precedence=]precedence [label=]label

Conclusions

Cisco.com

Multiple approaches possible:

- **Various IPv6 over IPv4 tunnel types**
- **Dual-stack if service is available from the access/internet service provider**
- **Leverage the security of deployed IPv4 VPN based connections**

IPv6 Transition and Deployment

IPv4-IPv6 Transition / Co-Existence

- **A wide range of techniques have been identified and implemented, basically falling into three categories:**

  (1) Dual-stack techniques, to allow IPv4 and IPv6 to co-exist in the same devices and networks

  (2) Tunneling techniques, to avoid order dependencies when upgrading hosts, routers, or regions

  (3) Translation techniques, to allow IPv6-only devices to communicate with IPv4-only devices

- **Expect all of these to be used, in combination**

IPv6 Deployment

IPv6 Deployment Scenario for Enterprises

	Environment	Scenario	Cisco IOS support
WAN	IPv6 services available from ISP	Dual Stack	Yes
	Dedicated Data Link layers, eg. LL, ATM & FR PVC, dWDM Lambda	Dual Stack	Yes
	No IPv6 services from ISP or experimentation – few sites	Configured Tunnels	Yes
	No IPv6 services from ISP or experimentation – many sites, any to any communication	6to4	Yes
Campus	L3 infrastructure – IPv6 capable	Dual Stack	Yes
	L3 infrastructure – not IPv6 capable, or sparse IPv6 hosts population	ISATAP	Yes

IPv6 Deployment Scenario for ISP

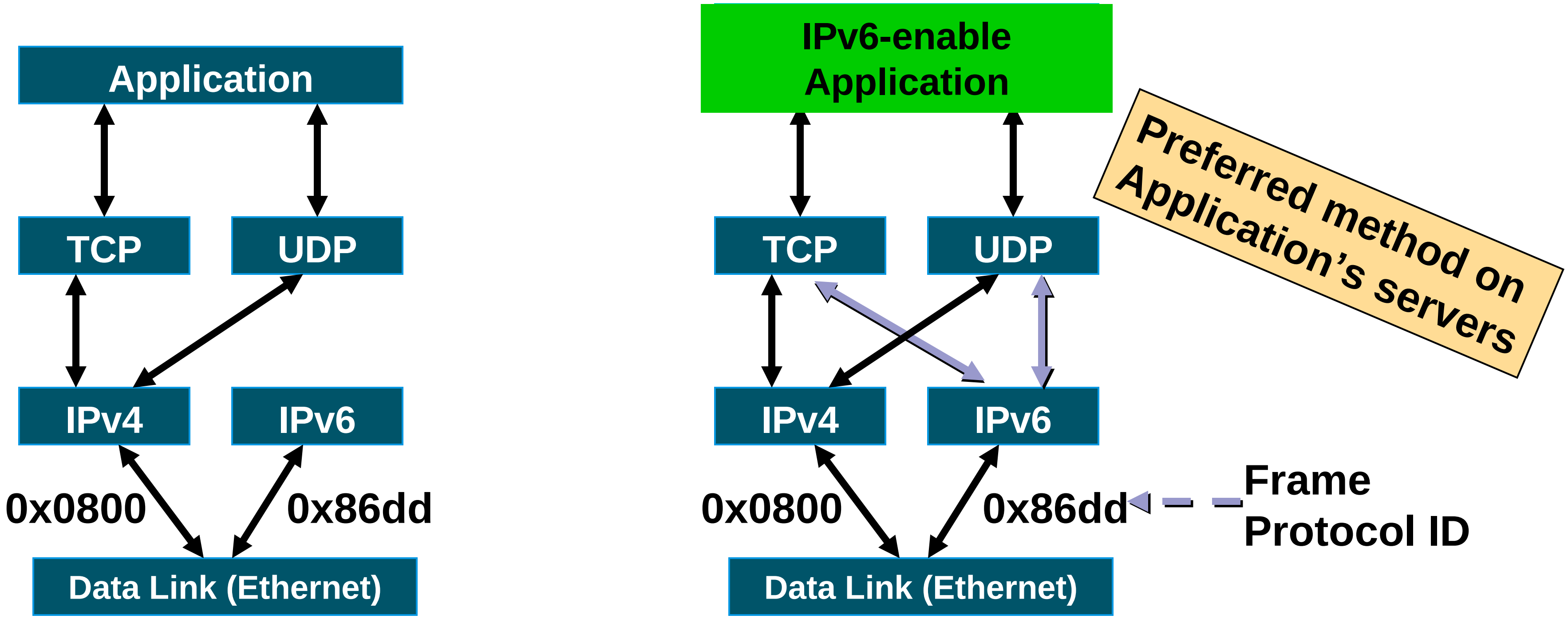
Cisco.com

	Environment	Scenario	Cisco IOS support
Access	Few customers, no native IPv6 service form the PoP or Data link is not (yet) native IPv6 capable, ie: Cable Docsis	Tunnels	Yes
	Native IPv4-IPv6 services between aggregation and end-users	Dual Stack	Yes
	Dedicated circuits – IPv4 – IPv6	Dual Stack	Yes
Core	Native IP – Core is IPv6 aware	Dual Stack	Yes
	MPLS – Core is IPv6 unaware	6PE/6VPE	Yes

Dual Stack

Dual Stack Approach

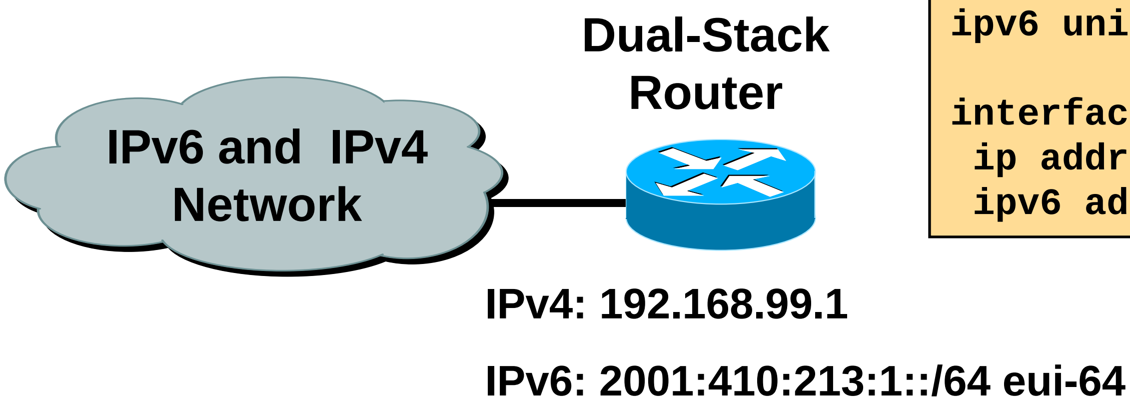
Cisco.com



- **Dual stack node means:**
  - **Both IPv4 and IPv6 stacks enabled**
  - **Applications can talk to both**
  - **Choice of the IP version is based on name lookup and application preference**

Cisco IOS Dual Stack Configuration

Cisco.com




```
router#
ipv6 unicast-routing

interface Ethernet0
 ip address 192.168.99.1 255.255.255.0
 ipv6 address 2001:410:213:1::/64 eui-64
```

- **Cisco IOS is IPv6-enable:**

  If IPv4 and IPv6 are configured on one interface, the router is dual-stacked

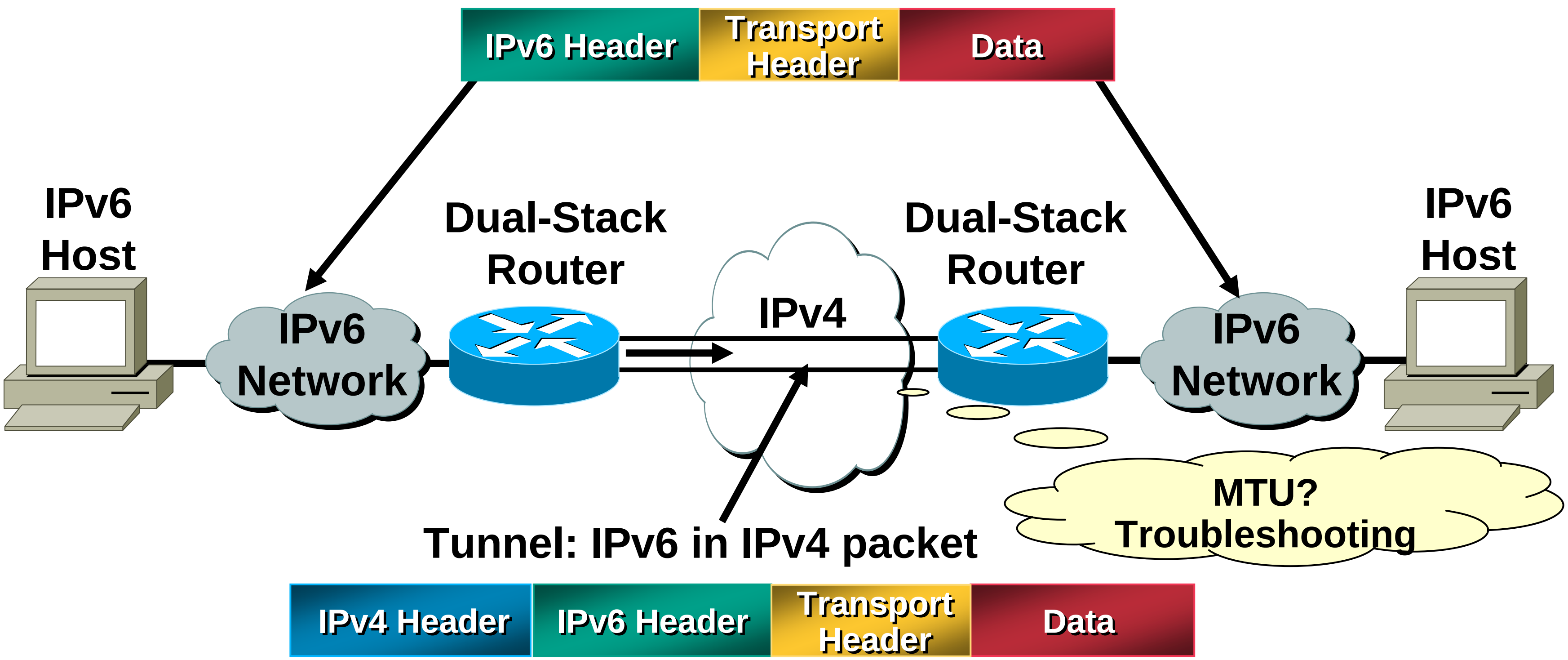
  Telnet, Ping, Traceroute, SSH, DNS client, TFTP,…

IPv6 Tunnels

Using Tunnels for IPv6 Deployment

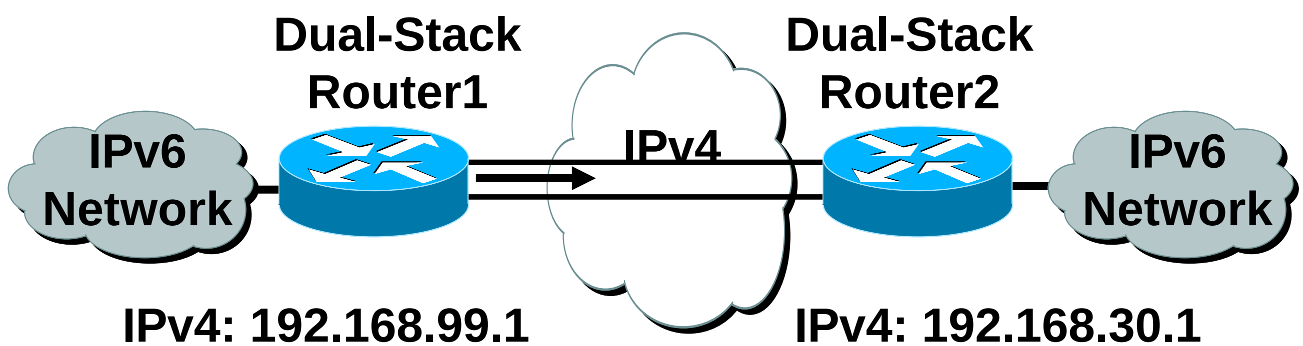
- Many techniques are available to establish a tunnel:
    - Manually configured
        - Manual Tunnel (RFC 2893)
        - GRE (RFC 2473)
    - Semi-automated
        - Tunnel broker
        - Cisco VPN
    - Automatic
        - 6to4 (RFC 3056)
        - ISATAP
        - 6PE/6VPE
- Other Mechanisms

IPv6 over IPv4 Tunnels



- Tunneling is encapsulating the IPv6 packet in the IPv4 packet
- Tunneling can be used by routers and hosts

Manually Configured Tunnel (RFC 2893)



IPv4: 192.168.99.1
IPv6: 3ffe:b00:c18:1::3

IPv4: 192.168.30.1
IPv6: 3ffe:b00:c18:1::2

```
router1#

interface Tunnel0
 ipv6 address 3ffe:b00:c18:1::3/64
 tunnel source 192.168.99.1
 tunnel destination 192.168.30.1
 tunnel mode ipv6ip
```

```
router2#

interface Tunnel0
 ipv6 address 3ffe:b00:c18:1::2/64
 tunnel source 192.168.30.1
 tunnel destination 192.168.99.1
 tunnel mode ipv6ip
```

- **Manually Configured tunnels require:**

  Dual stack end points

  Both IPv4 and IPv6 addresses configured at each end

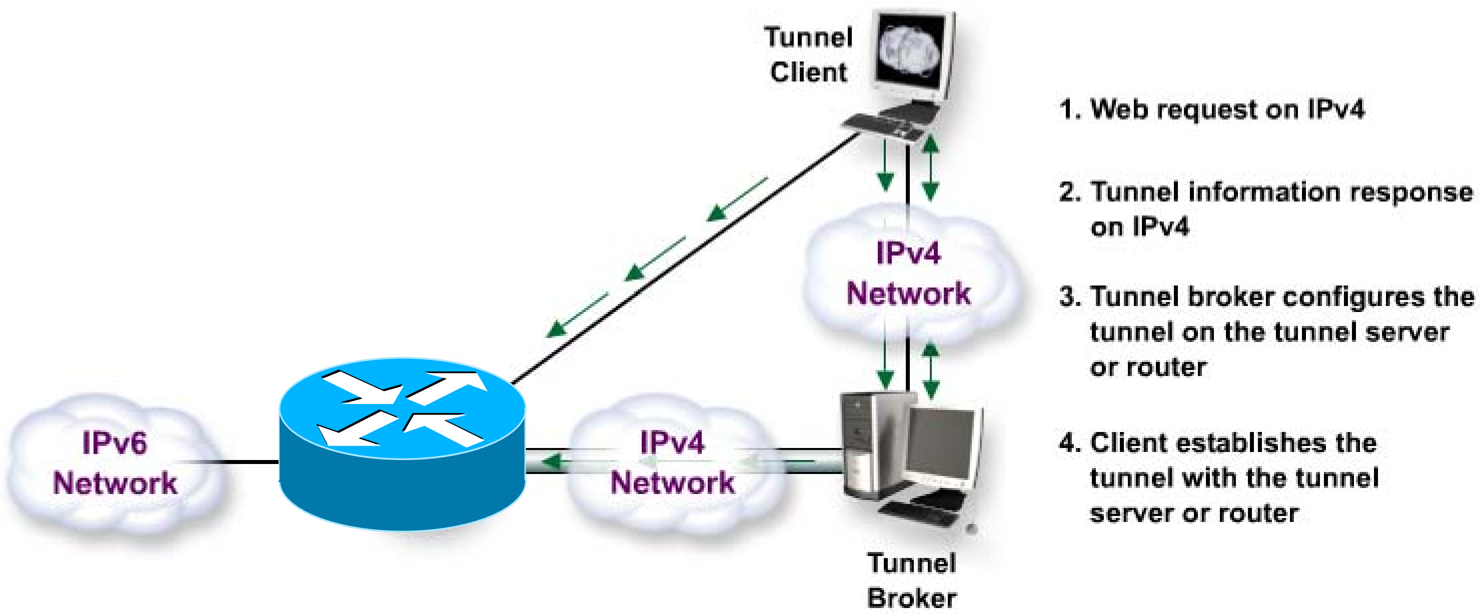
Using Tunnels for IPv6 Deployment

Cisco.com

- Many techniques are available to establish a tunnel:
  - Manually configured
    - Manual Tunnel (RFC 2893)
    - GRE (RFC 2473)
  - Semi-automated
    - Tunnel broker
    - Cisco VPN
  - Automatic
    - 6to4 (RFC 3056)
    - ISATAP
    - 6PE/6VPE
- Other Mechanisms

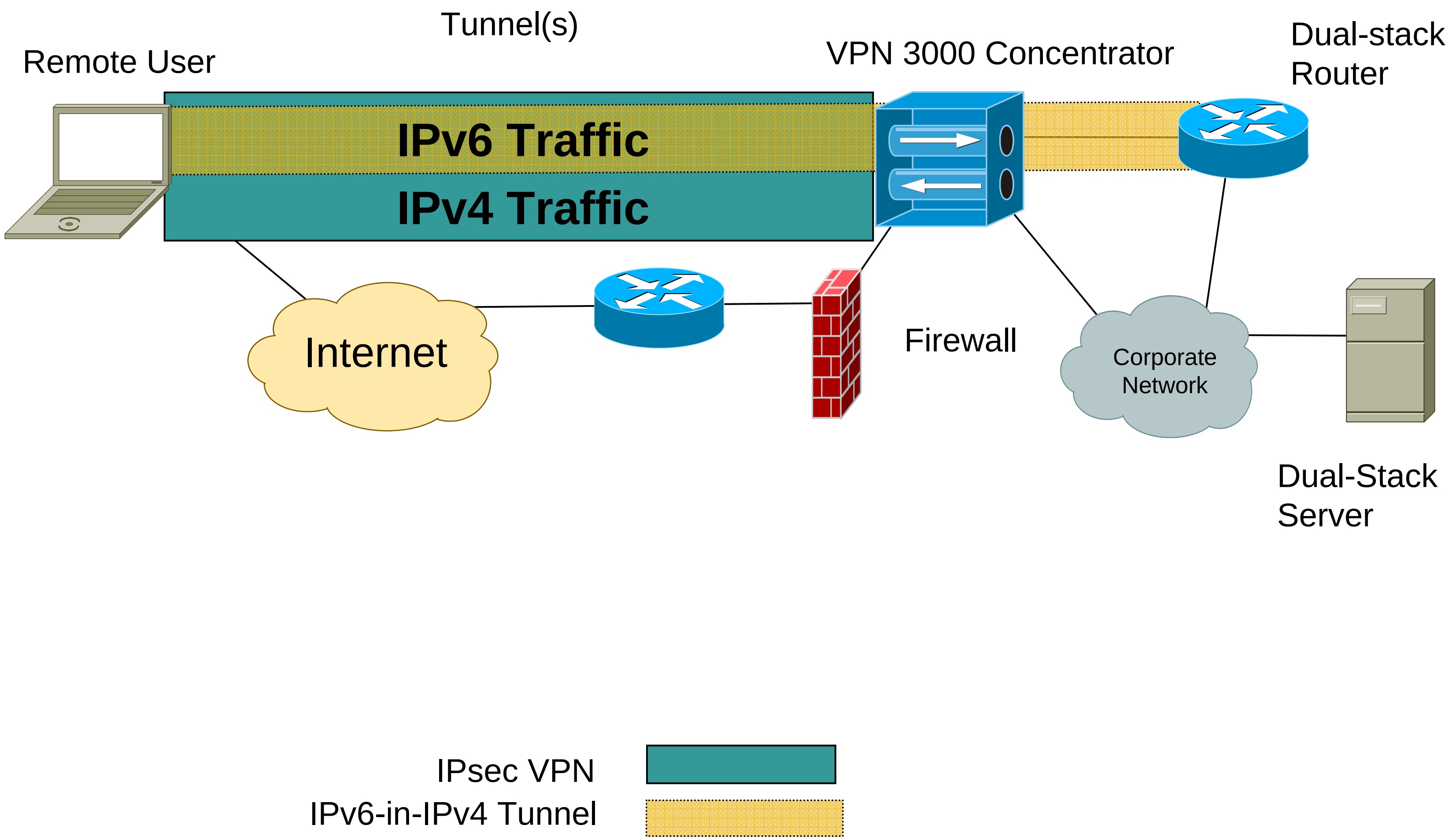
Tunneling (Cont.)

Tunnel Broker Concept



Tunnel information is sent via http-ipv4.

Remote Access – Cisco VPN Client & IPv6



Note: The VPN concentrator could be replaced with a VPN-enabled IOS Router or PIX

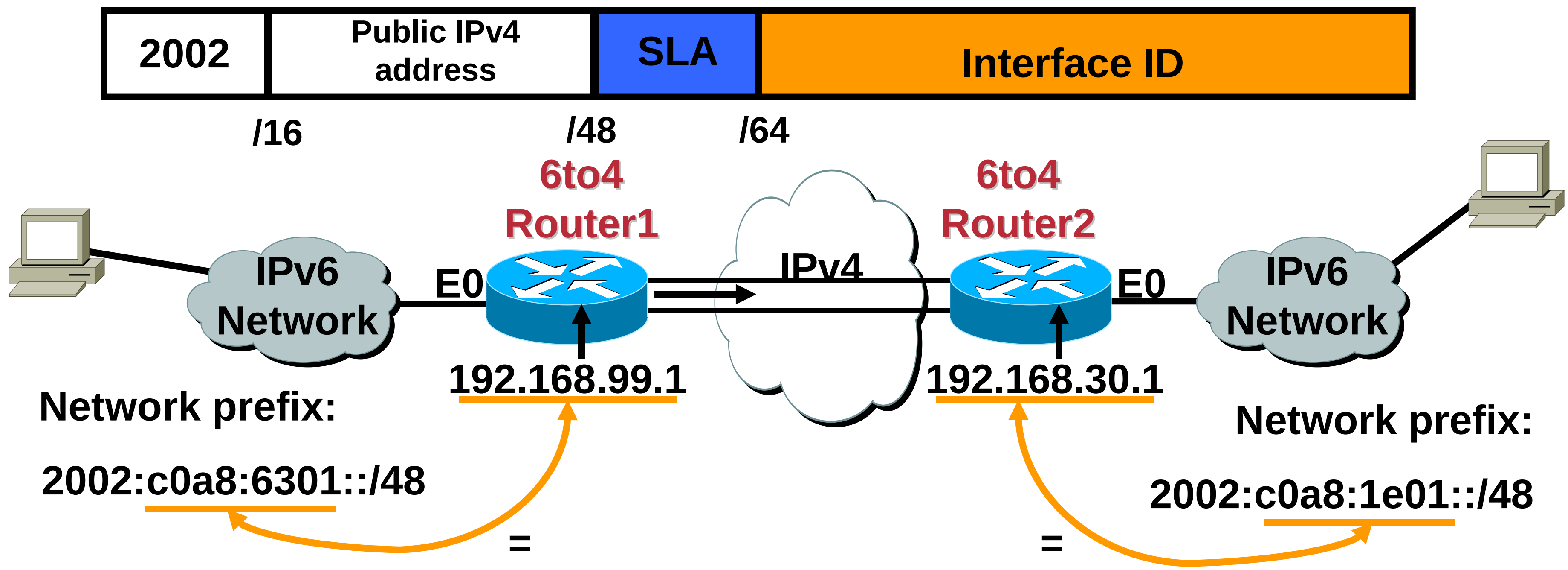
IPv6 For Remote Devices
Solutions

- **Enabling IPv6 traffic inside the Cisco VPN Client tunnel**
  - **NAT and Firewall traversal support**
- **Allow remote host to establish a v6-in-v4 tunnel either automatically or manually**
  - **ISATAP - Intra Site Automatic Tunnel Addressing Protocol**
  - **Configured - Static configuration for each side of tunnel**
    - **Fixed IPv6 address enables server's side of any application to be configured on an IPv6 host that could roam over the world.**
- **Encrypt/Decrypt works for native IPv4 packets as well as the tunneled IPv6-in-IPv4 packets**
- **Client-side - IPv6 tunneled traffic terminates using the IPv4 VPN Client address**
- **Router-side - IPv6 tunneled traffic terminates using IPv4 statically assigned address**

Using Tunnels for IPv6 Deployment

- Many techniques are available to establish a tunnel:
  - Manually configured
    - Manual Tunnel (RFC 2893)
    - GRE (RFC 2473)
  - Semi-automated
    - Tunnel broker
    - Cisco VPN
  - Automatic
    - 6to4 (RFC 3056)
    - ISATAP
    - 6PE/6VPE
- Other Mechanisms

6to4 Tunnel (RFC 3056)



- **6to4 Tunnel:**
  - Is an automatic tunnel method
  - Gives a prefix to the attached IPv6 network
  - 2002::/16 assigned to 6to4
  - Requires one global IPv4 address on each Ingress/Egress site

```
router2#
interface Loopback0
 ip address 192.168.30.1 255.255.255.0
 ipv6 address 2002:c0a8:1e01:1::/64 eui-64
interface Tunnel0
 no ip address
 ipv6 unnumbered Ethernet0
 tunnel source Loopback0
 tunnel mode ipv6ip 6to4

ipv6 route 2002::/16 Tunnel0
```

6to4: Addressing

6to4 Address:

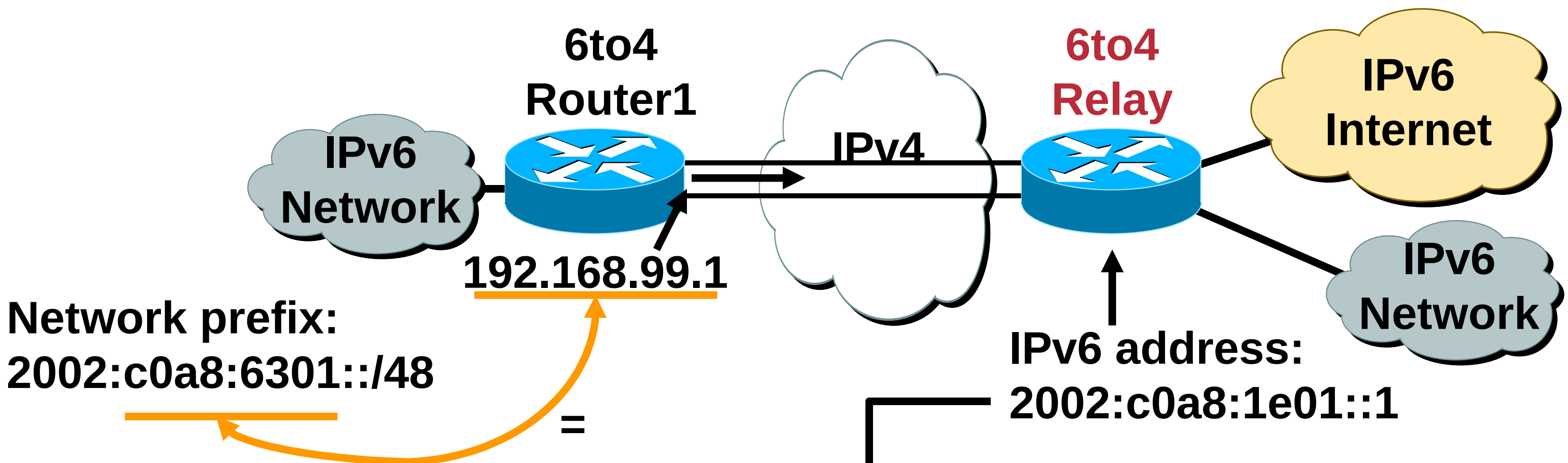
2002: & IPv4 Address

→

192.168.99.1 = C0A8:6301 → 2002:9001:6301::1/128

192.168.30.1 = C0A8:1E01 → 2002:9001:1E01::1/128

6to4 Relay




```
router1#
interface Loopback0
 ip address 192.168.99.1 255.255.255.0
 ipv6 address 2002:c0a8:6301:1::/64 eui-64
interface Tunnel0
 no ip address
 ipv6 unnumbered Ethernet0
 tunnel source Loopback0
 tunnel mode ipv6ip 6to4

ipv6 route 2002::/16 Tunnel0
ipv6 route ::/0 2002:c0a8:1e01::1
```

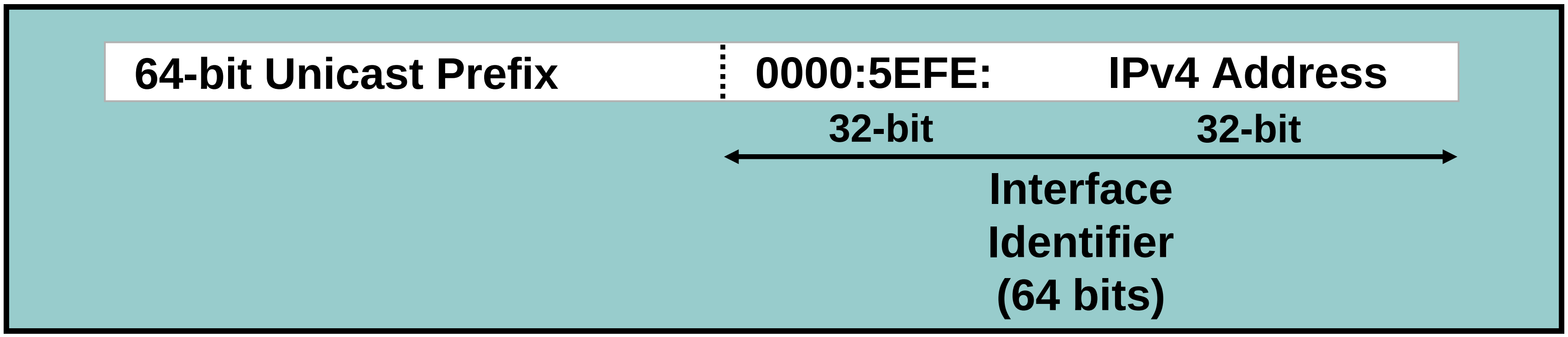
- **6to4 relay:**
  - Is a gateway to the rest of the IPv6 Internet
  - Default router
  - Anycast address (RFC 3068) for multiple 6to4 Relay

ISATAP

- Intra-Site Automatic Tunnel Adressing Protocol
- Connect IPv6 nodes to IPv6 routers within a predominantly IPv4 environment
    - Treats IPv4 network as an NBMA link layer
- Ideal for sparse distribution of IPv6 nodes
- E.g. Campus Networks with IPv4-only L3-Switches
- See draft-ietf-ngtrans-isatap-21.txt (Fred Templin, SRI, co-authored by Cisco)
- Nodes are assumed to be dual-stack

ISATAP Details

Use IANA‘s OUI 00-00-5E and encode IPv4 address as part of EUI-64

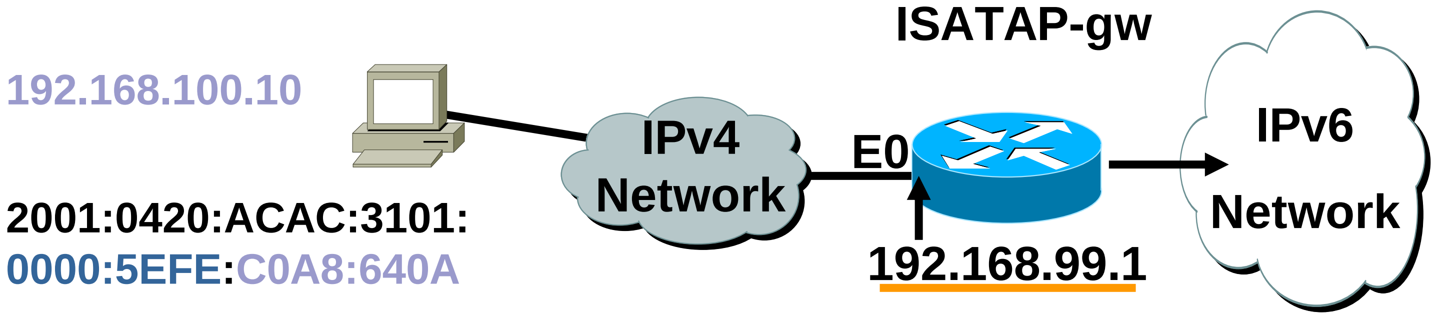


- **Automatic discovery of ISATAP routers**
  - **DNS "isatap.domainname" A record lookup**
  - **Need to create a DNS record for any ISATAP Routers**
  - **Automatic deprecation when end system receives native IPv6 router advertisements**

draft-ietf-ngtrans-isatap-21
draft-ietf-ngtrans-isatap-scenario-02

ISATAP Router

Cisco.com




```
ISATAP-gw#
!
interface Ethernet0
 ip address 192.168.99.1 255.255.255.0
!
interface Tunnel0
 ipv6 address 2001:0420:ACAC:3101::/64 eui-64
 no ipv6 nd suppress-ra
 tunnel source Ethernet0
 tunnel mode ipv6ip isatap
!
```

Cisco IOS 12.2(15)T, 12.3(1)M, 12.3(2)T 12.2(14)S. 12.2(17a)SX1

Supported in Windows XP Pro SP1

The tunnel source command must point to an interface with an IPv4 address configured.

Configure the ISATAP IPv6 address, and prefixes to be advertised just as you would with a native IPv6 interface.

The IPv6 address has to be configured as an EUI-64 address since the last 32 bits in the interface identifier is used as the IPv4 destination address.

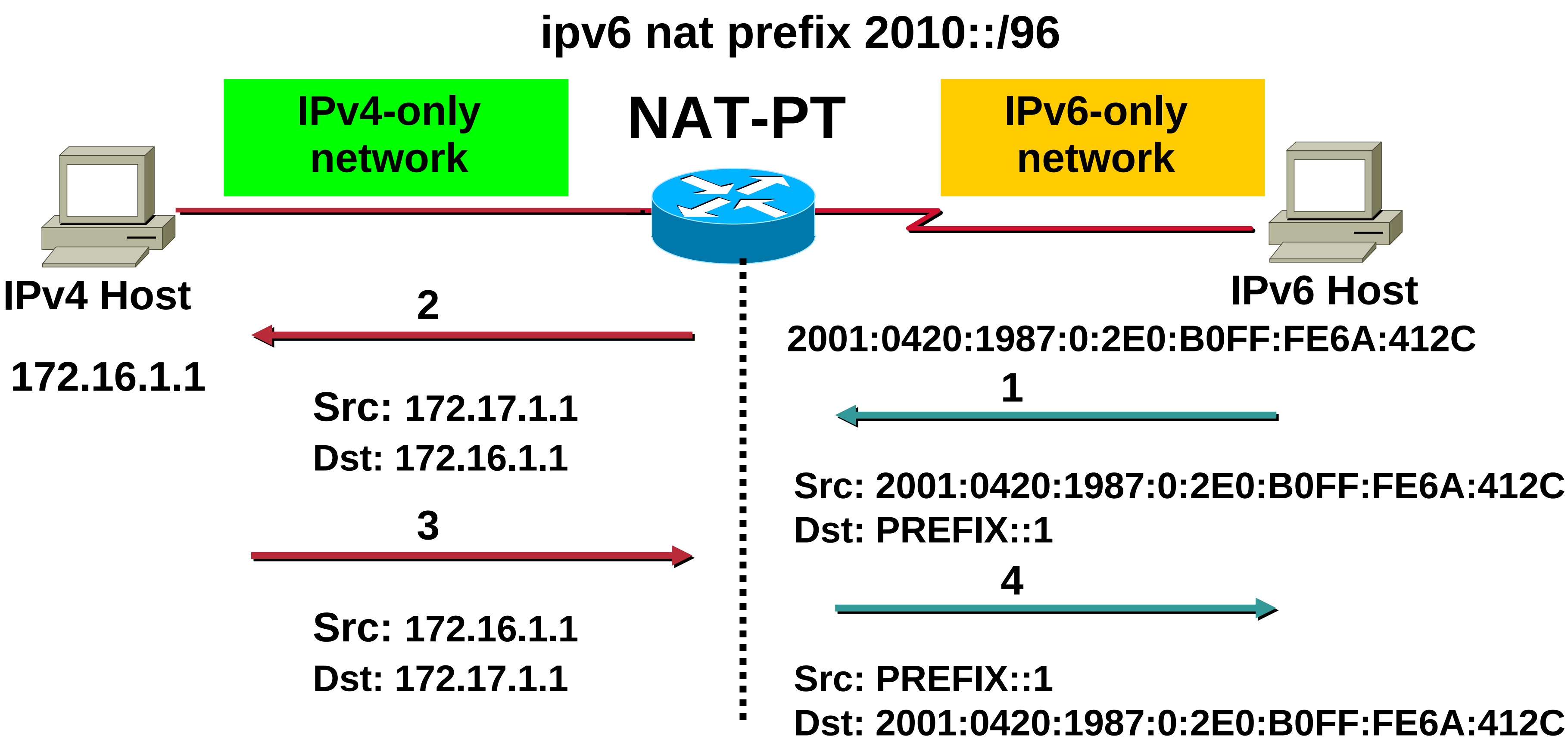
Using Tunnels for IPv6 Deployment

- **Many techniques are available to establish a tunnel:**
  - **Manually configured**
    - **Manual Tunnel (RFC 2893)**
    - **GRE (RFC 2473)**
  - **Semi-automated**
    - **Tunnel broker**
    - **Cisco VPN**
  - **Automatic**
    - **Compatible IPv4 (RFC 2893): Deprecated**
    - **6to4 (RFC 3056)**
    - **6over4: Deprecated**
    - **ISATAP**
    - **6PE/6VPE**
- **Other Mechanisms**

IPv6-IPv4 Communication Mechanisms

- Translation
  - NAT-PT (RFC 2766)
  - TCP-UDP Relay (RFC 3142)
- DSTM (Dual Stack Transition Mechanism)
- Teredo
- API
  - BIS (Bump-In-the-Stack) (RFC 2767)
  - BIA (Bump-In-the-API)
- ALG
  - SOCKS-based Gateway (RFC 3089)
  - NAT-PT (RFC 2766)

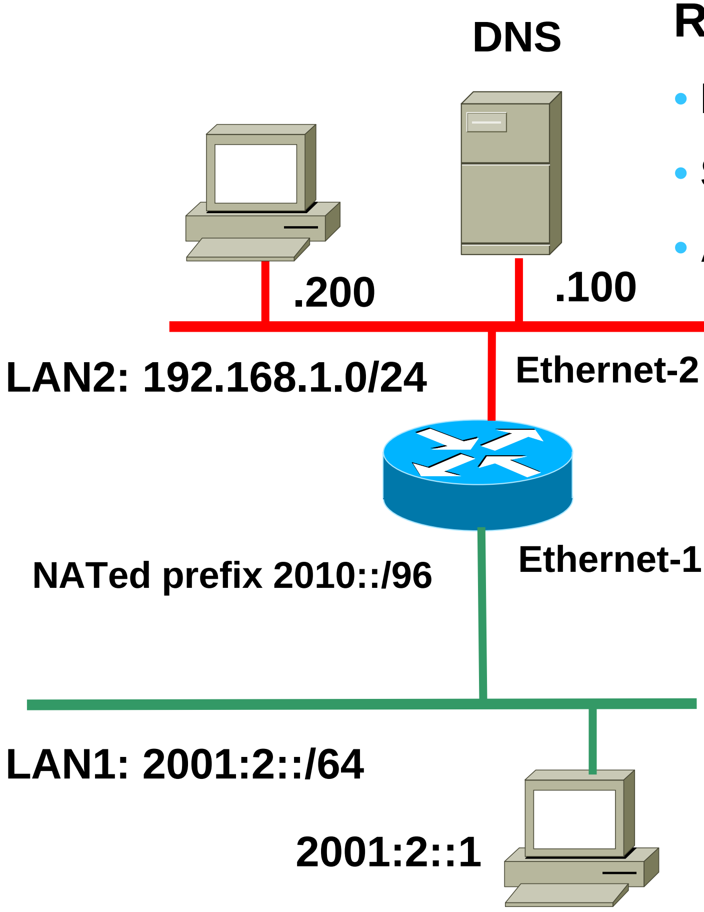
NAT-PT Overview



PREFIX is a 96-bit field that allows routing back to the NAT-PT device

Configuring Cisco IOS NAT-PT

Cisco.com



Network Address Translation-Protocol Translation RFC 2766

- IP Header and Address translation
- Support for ICMP and DNS embedded translation
- Auto-aliasing of NAT-PT IPv4 Pool Addresses

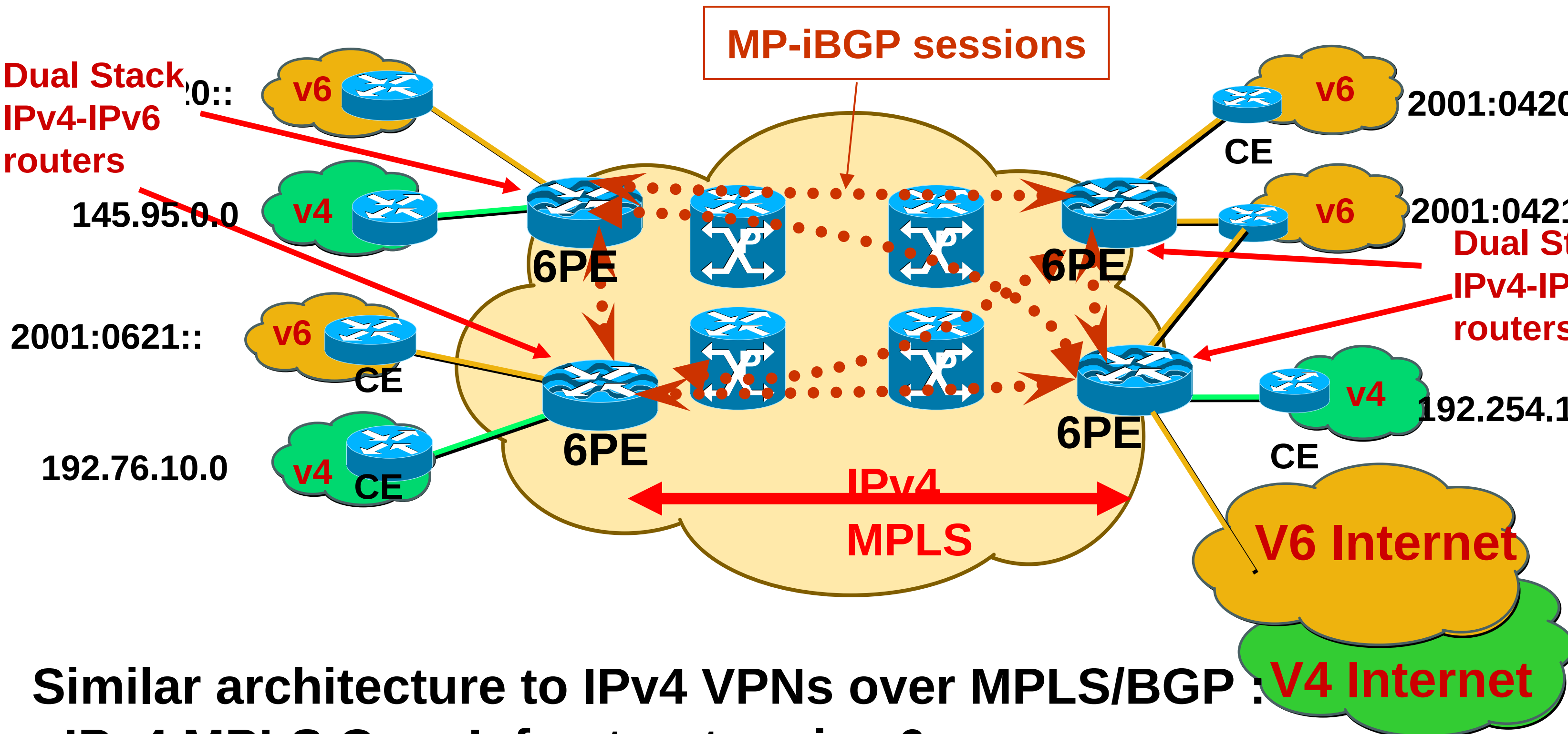
```
interface ethernet-1
   ipv6 address 2001:2::10/64
   ipv6 nat
!
interface ethernet-2
   ip address 192.168.1.1 255.255.255.0
   ipv6 nat prefix 2010::/96
   ipv6 nat
!
ipv6 nat v4v6 source 192.168.1.100 2010::1
!
ipv6 nat v6v4 source route-map map1 pool v4pool1
ipv6 nat v6v4 pool v4pool1 192.168.2.1 192.168.2.10
prefix-length 24
!
route-map map1 permit 10
 match interface Ethernet-2
```

IPv6 in MPLS Environments

IPv6 Over MPLS (6PE)

6PE Operation

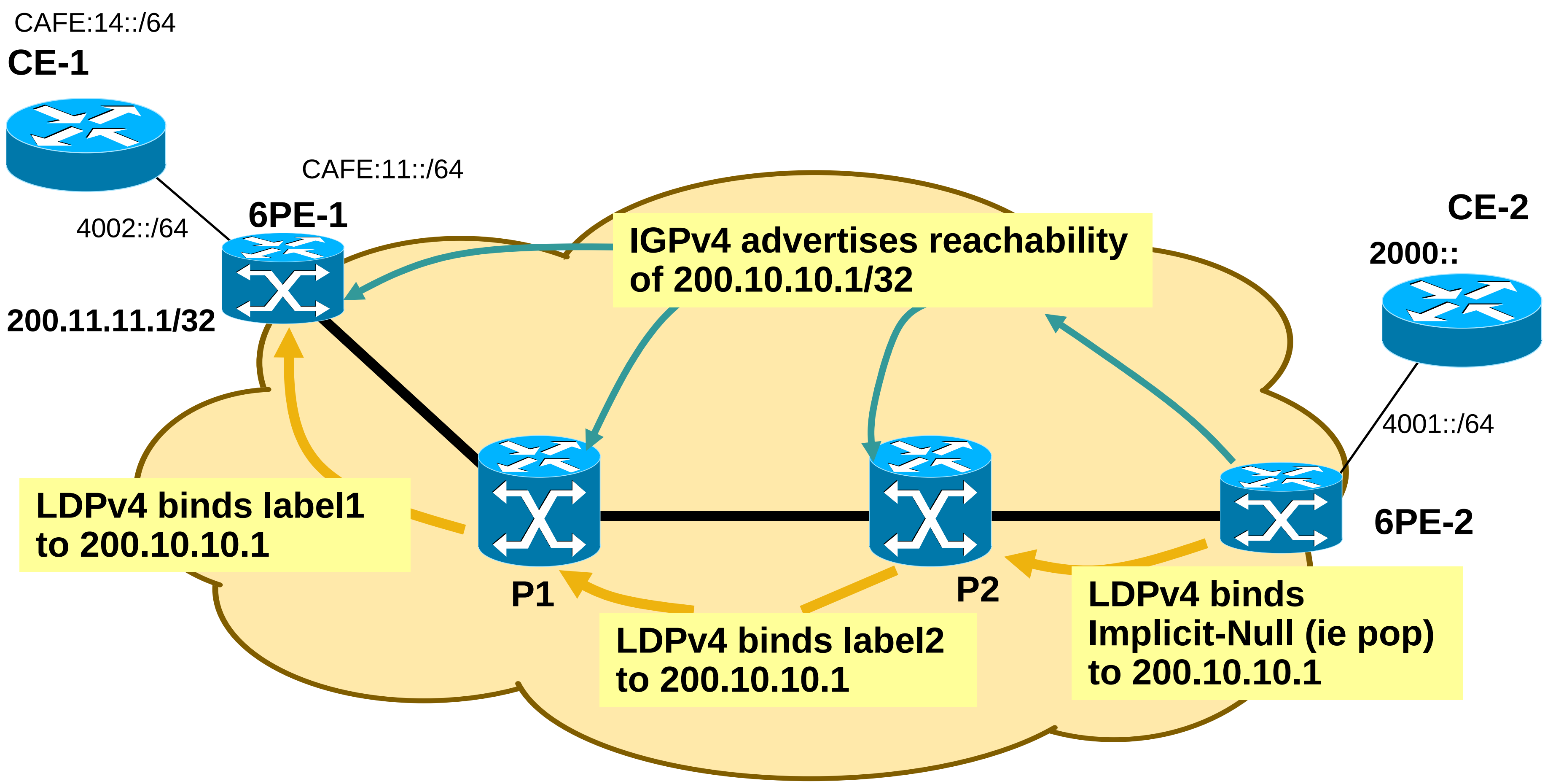
IPv6 over MPLS Provider Edge Router (6PE)



Similar architecture to IPv4 VPNs over MPLS/BGP :

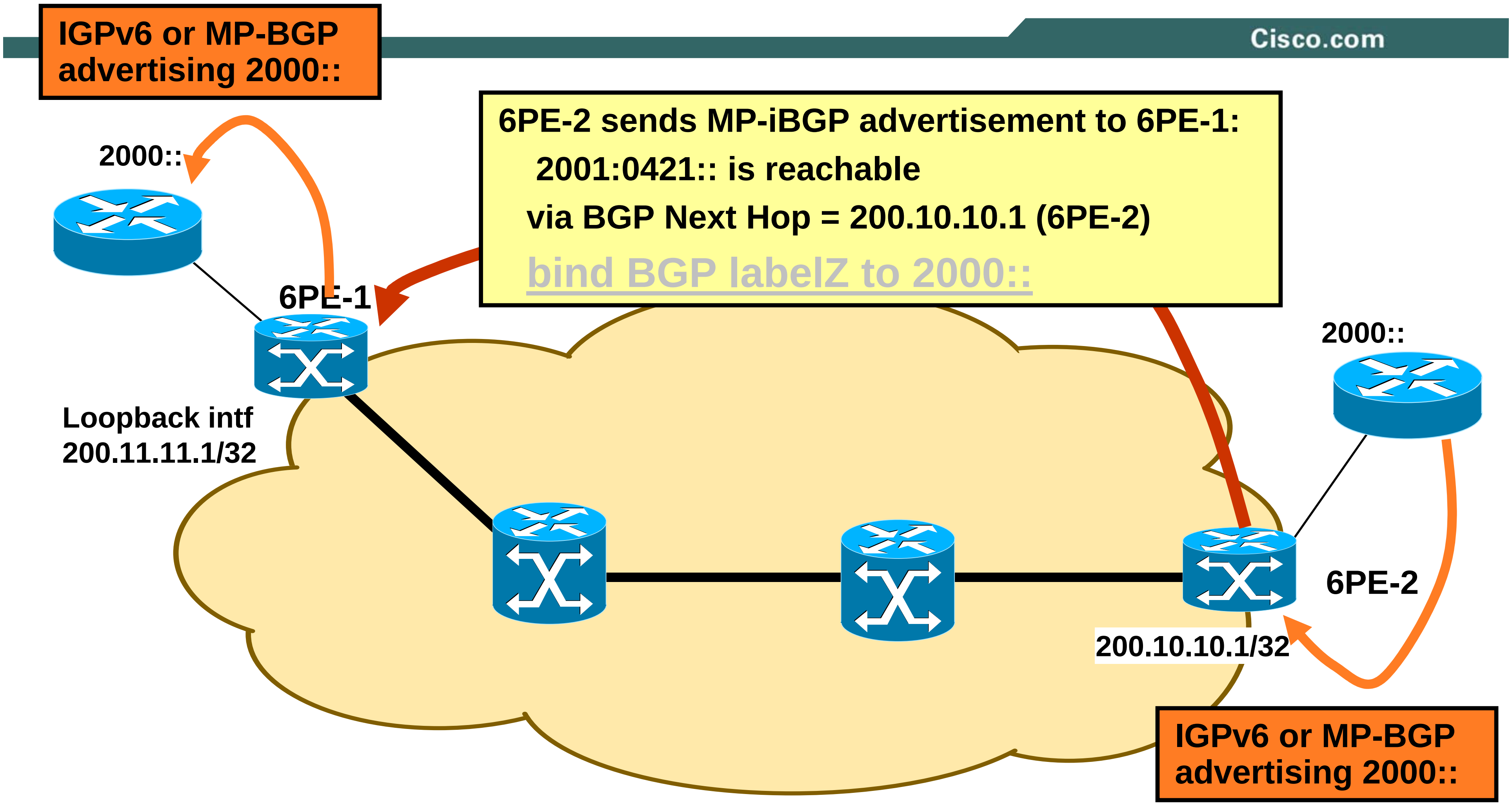
- **IPv4 MPLS Core Infrastructure is v6-unaware**
- **PEs support Dual Stack/6PE**
- **IPv6 reachability exchanged among PEs via i-MP-BGP**
- **IPv6 packets transported from PE to PE inside IPv4 MPLS LSPs**

6PE Routing/Label Distribution



Regular IPv4 routing and IPv4 Label Distribution

6PE Routing/Label Distribution



- Regular IPv6 routing on Edge,
- MP-BGP IPv6 routing PE-to-PE

6PE Configuration

6PE Configuration

Cisco.com

```
router bgp 100
 neighbor 6pe peer-group
 neighbor 6pe remote-as 100
 neighbor 6pe update-source Loopback0
 neighbor 4002::1 remote-as 65014
 neighbor 200.10.10.1 peer-group 6pe
 !
 address-family ipv6
 neighbor 6pe activate
 neighbor 6pe send-label
 neighbor 4002::1 activate
 neighbor 200.10.10.1 peer-group 6pe
 no synchronization
 maximum-paths 2
 exit-address-family
```

4002::1 is a local CE

200.10.10.1 is a remote 6PE

Wrap-Up

IPv6 Forum

- ~170 members (February 2004)
  - Created in 1999
  - Cisco is a founding member
- Mission is to promote IPv6 not to specify it (IETF)
  - www.ipv6forum.com
- IPv6 Forum OneWorld working group
  - Australian, India, Korea, Mexico, Russian, UK,…
- Held 'IPv6 summit' around the World

More Information

- CCO IPv6 - http://www.cisco.com/ipv6
- The ABC of IPv6

  http://www.cisco.com/en/US/products/sw/iosswrel/products_abc_ios_overview.html
- IPv6 e-Learning [requires CCO username/password]

  http://www.cisco.com/warp/customer/732/Tech/ipv6/elearning/
- IPv6 Access Services :

  http://www.cisco.com/warp/public/732/Tech/ipv6/docs/ipv6_access_wp_v2.pdf
- ICMPv6 Packet Types and Codes TechNote:

  http://www.cisco.com/warp/customer/105/icmpv6codes.html
- Cisco IOS IPv6 Product Manager – pgrosset@cisco.com

For More Information

- http://www.ipv6forum.com
- http://www.ipv6.org
- http://www.cisco.com/ipv6
- http://www.microsoft.com/ipv6
- http://www.6bone.net

For More Information

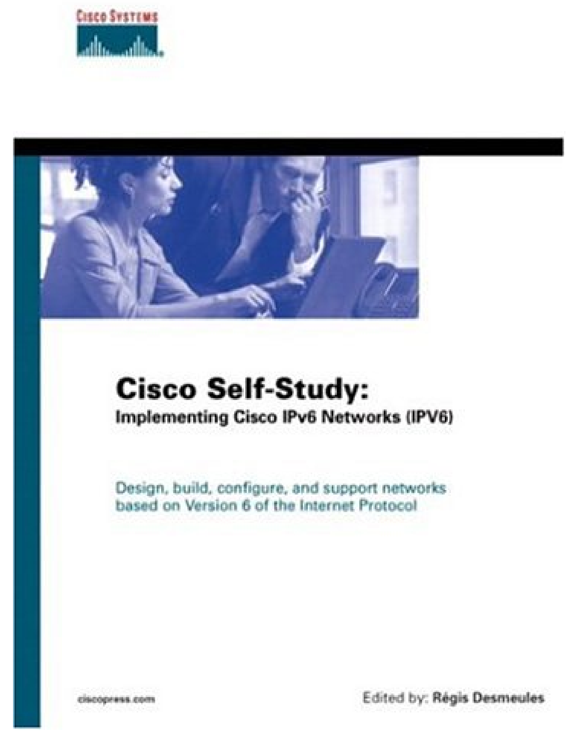
Cisco.com

- http://www.ietf.org/html.charters/ipngwg-charter.html
- http://www.ietf.org/html.charters/v6ops-charter.html
- http://playground.sun.com/ipv6/
- http://www.6bone.net/ngtrans/

Recommended Reading

Cisco Self-Study: Implementing Cisco IPv6 Networks (IPV6)
ISBN: 1587050862

Routing TCP/IP Vol II
ISBN: 1578700892



Q and A