



# Introduction to IPv6

Philip Smith <pfs@cisco.com>

NANOG 42

17-20 February, San Jose

# Presentation Slides

- Will be available on  
[ftp://ftp-eng.cisco.com  
/pfs/seminars/NANOG42-IPv6-Introduction.pdf](ftp://ftp-eng.cisco.com/pfs/seminars/NANOG42-IPv6-Introduction.pdf)  
And on the NANOG42 website
- Feel free to ask questions any time

# Agenda

- **Background**
- Protocols & Standards
- Addressing
- Routing Protocols
- Integration & Transition
- Servers & Services

# Early Internet History

- Late 1980s
  - Exponential growth of the Internet
- Late 1990: CLNS proposed as IP replacement
- 1991-1992
  - Running out of “class-B” network numbers
  - Explosive growth of the “default-free” routing table
  - Eventual exhaustion of 32-bit address space
- Two efforts – short-term vs. long-term
  - More at “The Long and Windy ROAD”  
<http://rms46.vlsm.org/1/42.html>

# Early Internet History

- CIDR and Supernetting proposed in 1992-3  
Deployment started in 1994
- IETF “ipng” solicitation – RFC1550, Dec 1993
- Direction and technical criteria for ipng choice – RFC1719 and RFC1726, Dec 1994
- Proliferation of proposals:
  - TUBA – RFC1347, June 1992
  - PIP – RFC1621, RFC1622, May 1994
  - CATNIP – RFC1707, October 1994
  - SIP – RFC1710, October 1994
  - NIMROD – RFC1753, December 1994
  - ENCAPS – RFC1955, June 1996

# Early Internet History

## → 1996

- Other activities included:
  - Development of NAT, PPP, DHCP,...
  - Some IPv4 address reclamation
  - The RIR system was introduced
- → Brakes were put on IPv4 address consumption
- IPv4 32 bit address = 4 billion hosts
  - HD Ratio (RFC3194) realistically limits IPv4 to 250 million hosts

# Recent Internet History

## The “boom” years → 2001

- IPv6 Development in full swing
  - Rapid IPv4 consumption
  - IPv6 specifications sorted out
  - (Many) Transition mechanisms developed
- 6bone
  - Experimental IPv6 backbone sitting on top of Internet
  - Participants from over 100 countries
- Early adopters
  - Japan, Germany, France, UK,...

# Recent Internet History

## The “bust” years: 2001 → 2004

- The DotCom “crash”
  - i.e. Internet became mainstream
- IPv4:
  - Consumption slowed
  - Address space pressure “reduced”
- Indifference
  - Early adopters surging onwards
  - Sceptics more sceptical
  - Yet more transition mechanisms developed



## 2004 → Today

- Resurgence in demand for IPv4 address space
  - 19.5% address space still unallocated (01/2008)
  - Exhaustion predictions range from wild to conservative
  - ...but late 2010 seems realistic at current rates
  - ...but what about the market for address space?
- Market for IPv4 addresses:
  - Creates barrier to entry
  - Condemns the less affluent to use of NATs
- IPv6 offers vast address space
  - The only compelling reason for IPv6**

# Current Situation

- General perception is that “IPv6 has not yet taken hold”
  - IPv4 Address run-out is not “headline news” yet
  - More discussions and run-out plans proposed
  - Private sector requires a business case to “migrate”
  - No easy Return on Investment (RoI) computation
- But reality is very different from perception!
  - Something needs to be done to sustain the Internet growth
  - IPv6 or NAT or both or something else?

# Do we really need a larger address space?

- Internet population
  - ~630 million users end of 2002 – 10% of world pop.
  - ~1320 million users end of 2007 – 20% of world pop.
  - Future? (World pop. ~9B in 2050)
- US uses 81 /8s – this is 3.9 IPv4 addresses per person
  - Repeat this the world over...
  - 6 billion population could require 23.4 billion IPv4 addresses (6 times larger than the IPv4 address pool)
- Emerging Internet economies need address space:
  - China uses more than 94 million IPv4 addresses today (5.5 /8s)

# Do we really need a larger address space?

- RFC 1918 is not sufficient for large environments
  - Cable Operators (e.g. Comcast – NANOG37 presentation)
  - Mobile providers (fixed/mobile convergence)
  - Large enterprises
- The Policy Development process of the RIRs turned down a request to increase private address space
  - RIR membership guideline is to use global addresses instead
  - This leads to an accelerated depletion of the global address space
- 240/4 being proposed as new private address space

# IPv6 OS and Application Support

- All software vendors officially support IPv6 in their latest Operating System releases

Apple Mac OS X; HP (HP-UX, Tru64 & OpenVMS); IBM zSeries & AIX; Microsoft Windows XP, Vista, .NET, CE; Sun Solaris,...

\*BSD, Linux,...

- Application Support

Applications must be IPv4 and IPv6 agnostic

User should not have to “pick a protocol”

Successful deployment is driven by Applications

- Latest info:

[www.ipv6-to-standard.org](http://www.ipv6-to-standard.org)

# ISP Deployment Activities

- Several Market segments
  - IX, Carriers, Regional ISP, Wireless
- ISP have to get an IPv6 prefix from their Regional Registry
  - [www.ripe.net/ripenncc/mem-services/registration/ipv6/ipv6allocs.html](http://www.ripe.net/ripenncc/mem-services/registration/ipv6/ipv6allocs.html)
- Large carriers planning driven by customer demand:
  - Some running trial networks (e.g. Sprint)
  - Others running commercial services (e.g. NTT, FT,...)
- Regional ISP focus on their specific markets
- Much discussion by operators about transition
  - [www.civil-tongue.net/clusterf/](http://www.civil-tongue.net/clusterf/)
  - <http://www.nanog.org/mtg-0710/presentations/Bush-v6-op-reality.pdf>

# Why not use Network Address Translation?

- Private address space and Network address translation (NAT) could be used instead of IPv6
- But NAT has many serious issues:
  - Breaks the end-to-end model of IP
  - Layered NAT devices
  - Mandates that the network keeps the state of the connections
  - How to scale NAT performance for large networks?
  - Makes fast rerouting difficult
  - Service provision inhibited

# NAT has many implications

- Inhibits end-to-end network security
- When a new application is not NAT-friendly, NAT device requires an upgrade
- Some applications cannot work through NATs
- Application-level gateways (ALG) are not as fast as IP routing
- Complicates mergers
  - Double NATing is needed for devices to communicate with each other
- Breaks security
- Makes multihoming hard
- Simply does not scale
- RFC2993 – architectural implications of NAT



# Conclusion

- There is a need for a larger address space
  - IPv6 offers this – will eventually replace NAT
  - But NAT will be around for a while too
  - Market for IPv4 addresses looming also
- Many challenges ahead

# Agenda

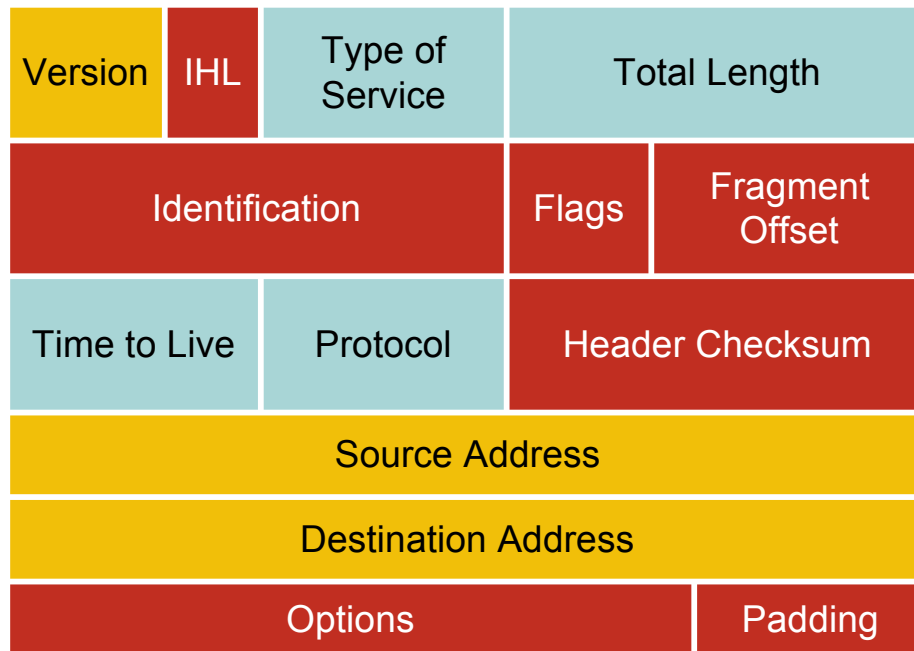
- Background
- **Protocols & Standards**
- Addressing
- Routing Protocols
- Integration & Transition

# So what has really changed?

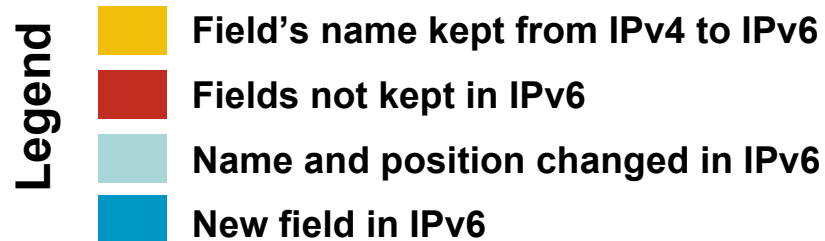
- Expanded address space
  - Address length quadrupled to 16 bytes
- Header Format Simplification
  - Fixed length, optional headers are daisy-chained
  - IPv6 header is twice as long (40 bytes) as IPv4 header without options (20 bytes)
- No checksum at the IP network layer
- No hop-by-hop segmentation
  - Path MTU discovery
- 64 bits aligned
- Authentication and Privacy Capabilities
  - IPsec is mandated
- No more broadcast

# IPv4 and IPv6 Header Comparison

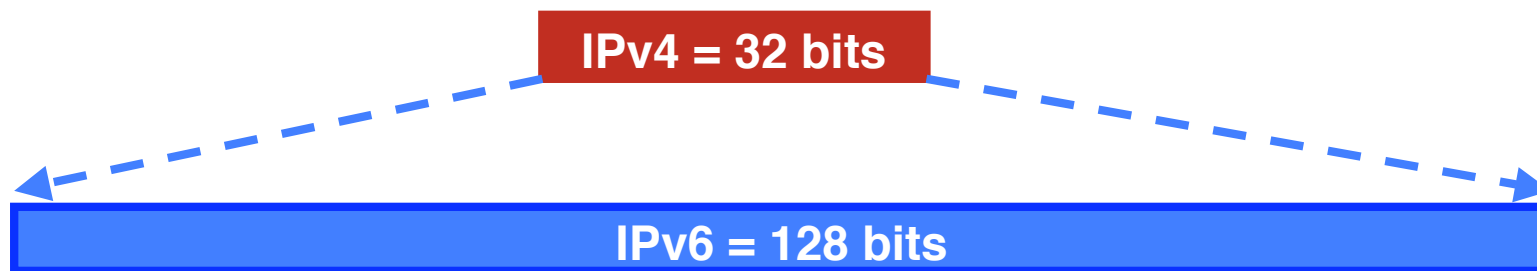
## IPv4 Header



## IPv6 Header



# Larger Address Space



## IPv4

32 bits

= 4,294,967,296 possible addressable devices

## IPv6

128 bits: 4 times the size in bits

=  $3.4 \times 10^{38}$  possible addressable devices

= 340,282,366,920,938,463,463,374,607,431,768,211,456

~  $5 \times 10^{28}$  addresses per person on the planet


# How was the IPv6 Address Size Chosen?

- Some wanted fixed-length, 64-bit addresses
  - Easily good for  $10^{12}$  sites,  $10^{15}$  nodes, at .0001 allocation efficiency (3 orders of magnitude more than IPv6 requirement)
  - Minimizes growth of per-packet header overhead
  - Efficient for software processing
- Some wanted variable-length, up to 160 bits
  - Compatible with OSI NSAP addressing plans
  - Big enough for auto-configuration using IEEE 802 addresses
  - Could start with addresses shorter than 64 bits & grow later
- Settled on fixed-length, 128-bit addresses

# IPv6 Address Representation

- 16 bit fields in case insensitive colon hexadecimal representation  
2031:0000:130F:0000:0000:09C0:876A:130B
- Leading zeros in a field are optional:  
2031:0:130F:0:0:9C0:876A:130B
- Successive fields of 0 represented as ::, but only once in an address:

2031:0:130F::9C0:876A:130B                      is ok  
2031::130F::9C0:876A:130B                      is **NOT** ok



0:0:0:0:0:0:0:1 → ::1

(loopback address)

0:0:0:0:0:0:0:0 → ::

(unspecified address)

# IPv6 Address Representation

- IPv4-compatible (not used any more)

0:0:0:0:0:0:192.168.30.1

= ::192.168.30.1

= ::C0A8:1E01

- In a URL, it is enclosed in brackets (RFC3986)

[http://\[2001:db8:4f3a::206:ae14\]:8080/index.html](http://[2001:db8:4f3a::206:ae14]:8080/index.html)

Cumbersome for users

Mostly for diagnostic purposes

Use fully qualified domain names (FQDN)

- ⇒ The DNS has to work!!



# IPv6 Address Representation

- Prefix Representation

Representation of prefix is same as for IPv4 CIDR

Address and then prefix length

IPv4 address:

198.10.0.0/16

IPv6 address:

2001:db8:12::/40

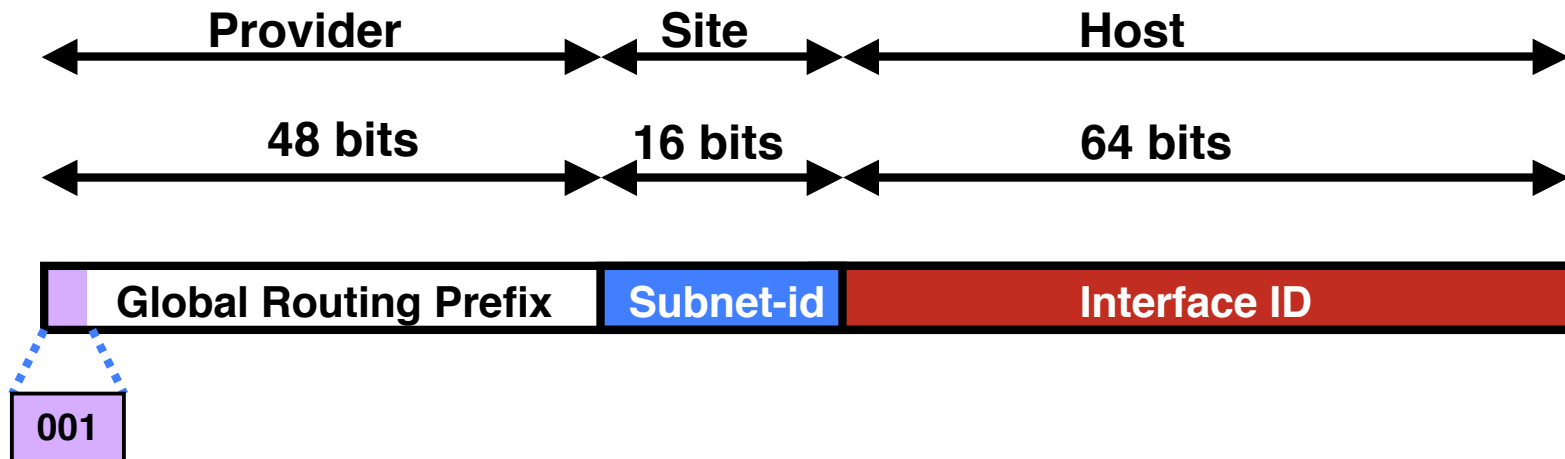
# IPv6 Addressing

- IPv6 Addressing rules are covered by multiples RFCs  
Architecture defined by RFC 4291
- Address Types are :
  - Unicast : One to One (Global, Unique Local, Link local)
  - 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

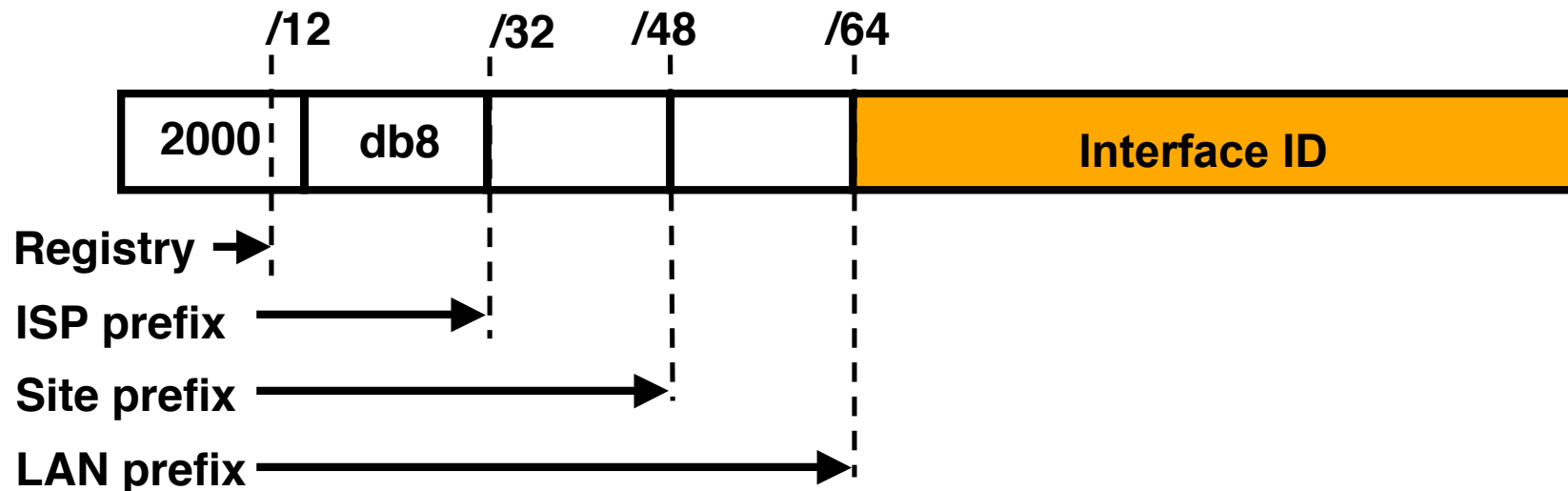
Type	Binary	Hex
Unspecified	000...0	::/128
Loopback	000...1	::1/128
Global Unicast Address	0010	2000::/3
Link Local Unicast Address	1111 1110 10	FE80::/10
Unique Local Unicast Address	1111 1100 1111 1101	FC00::/7
Multicast Address	1111 1111	FF00::/8

# IPv6 Global Unicast Addresses



- IPv6 Global Unicast addresses are:
  - Addresses for generic use of IPv6
  - Hierarchical structure intended to simplify aggregation

# IPv6 Address Allocation



- The allocation process is:

The IANA is allocating out of 2000::/3 for initial IPv6 unicast use

Each registry gets a /12 prefix from the IANA

Registry allocates a /32 prefix (or larger) to an IPv6 ISP

Policy is that an ISP allocates a /48 prefix to each end customer

# IPv6 Addressing Scope

- 64 bits reserved for the interface ID
  - Possibility of  $2^{64}$  hosts on one network LAN
  - Arrangement to accommodate MAC addresses within the IPv6 address
- 16 bits reserved for the end site
  - Possibility of  $2^{16}$  networks at each end-site
  - 65536 subnets equivalent to a /12 in IPv4 (assuming 16 hosts per IPv4 subnet)

# IPv6 Addressing Scope

- 16 bits reserved for the service provider

Possibility of  $2^{16}$  end-sites per service provider

65536 possible customers: equivalent to each service provider receiving a /8 in IPv4 (assuming a /24 address block per customer)

- 32 bits reserved for service providers

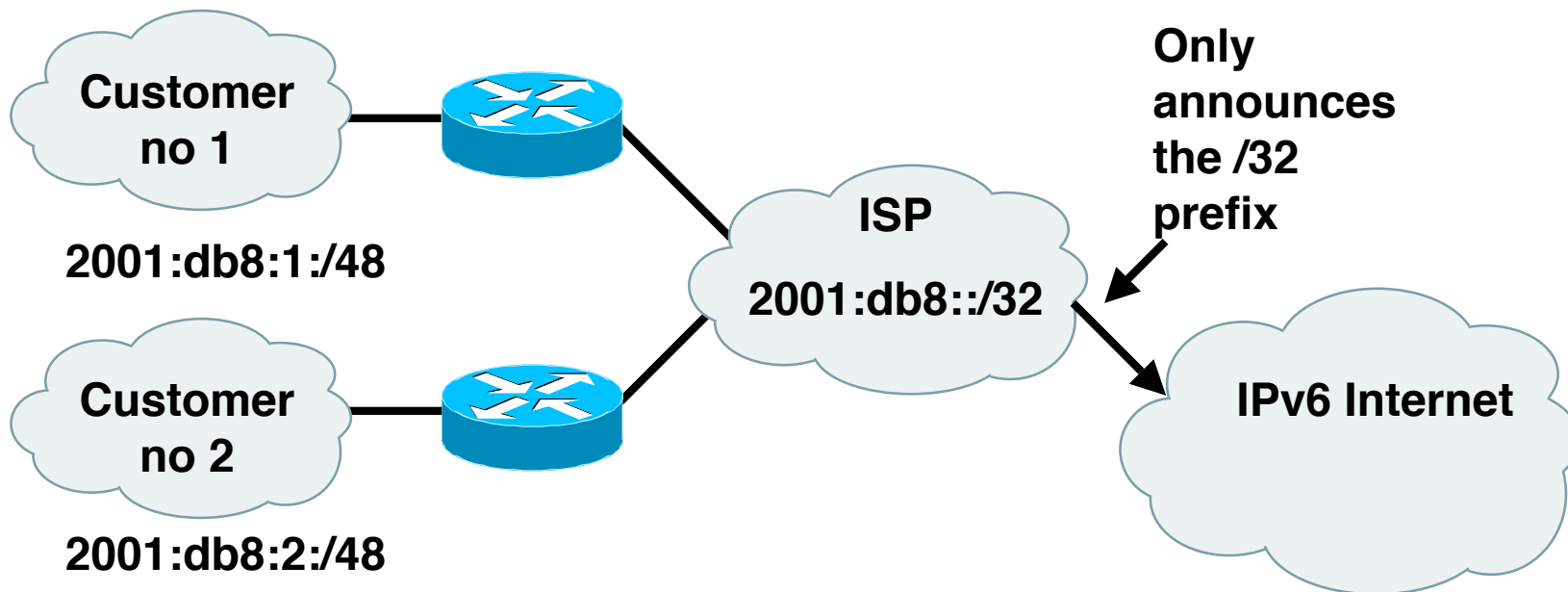
Possibility of  $2^{32}$  service providers

i.e. 4 billion discrete service provider networks

Although some service providers already are justifying more than a /32

Equivalent to the size of the entire IPv4 address space

# Aggregation hopes



- Larger address space enables aggregation of prefixes announced in the global routing table
- Idea was to allow efficient and scalable routing
- **But current Internet multihoming solution breaks this model**

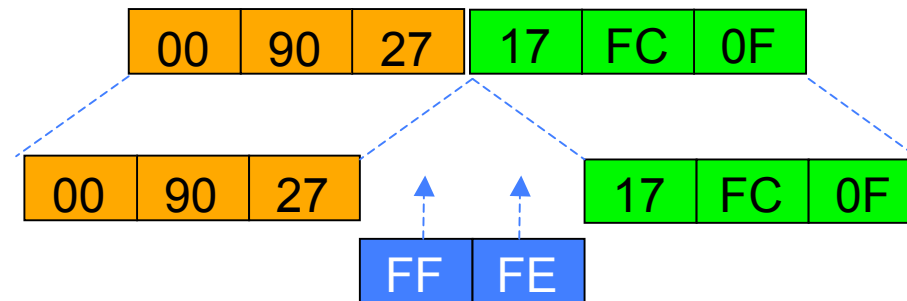


# Interface IDs

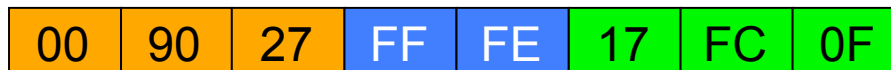
- Lowest order 64-bit field of unicast address may be assigned in several different ways:
  - Auto-configured from a 64-bit EUI-64, or expanded from a 48-bit MAC address (e.g., Ethernet address)
  - Auto-generated pseudo-random number (to address privacy concerns)
  - Assigned via DHCP
  - Manually configured

# EUI-64

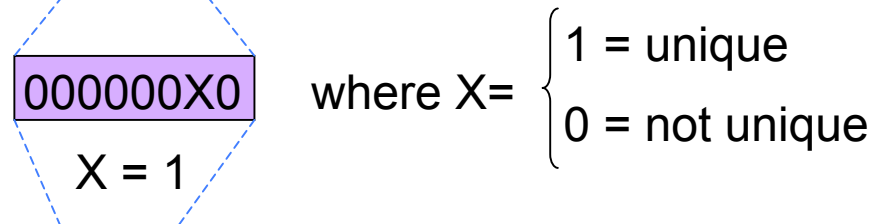
**Ethernet MAC address  
(48 bits)**



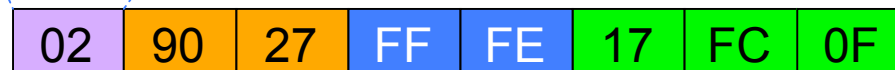
**64 bits version**



**Uniqueness of the MAC**

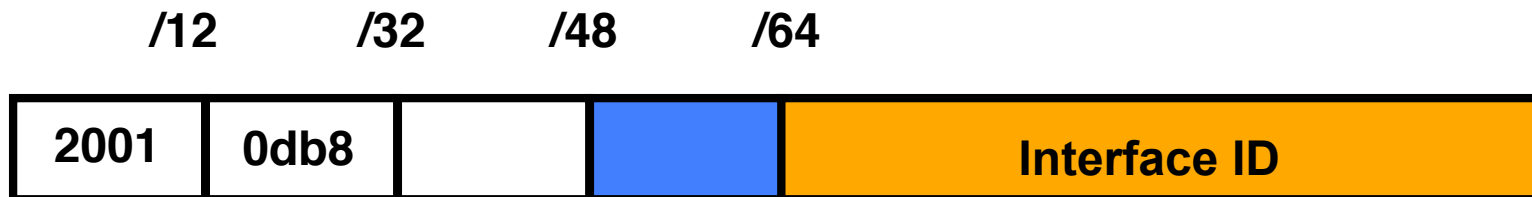


**Eui-64 address**



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

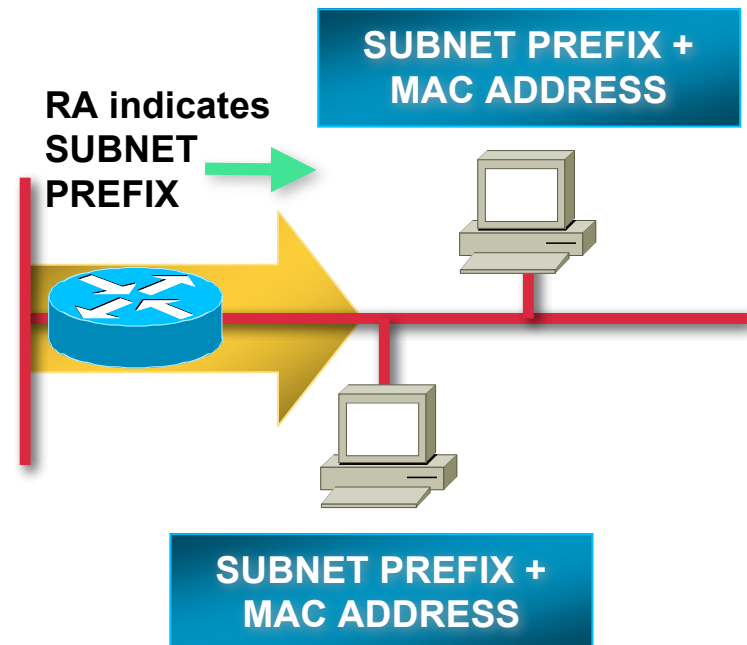
# IPv6 Address Privacy (RFC 3041)



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

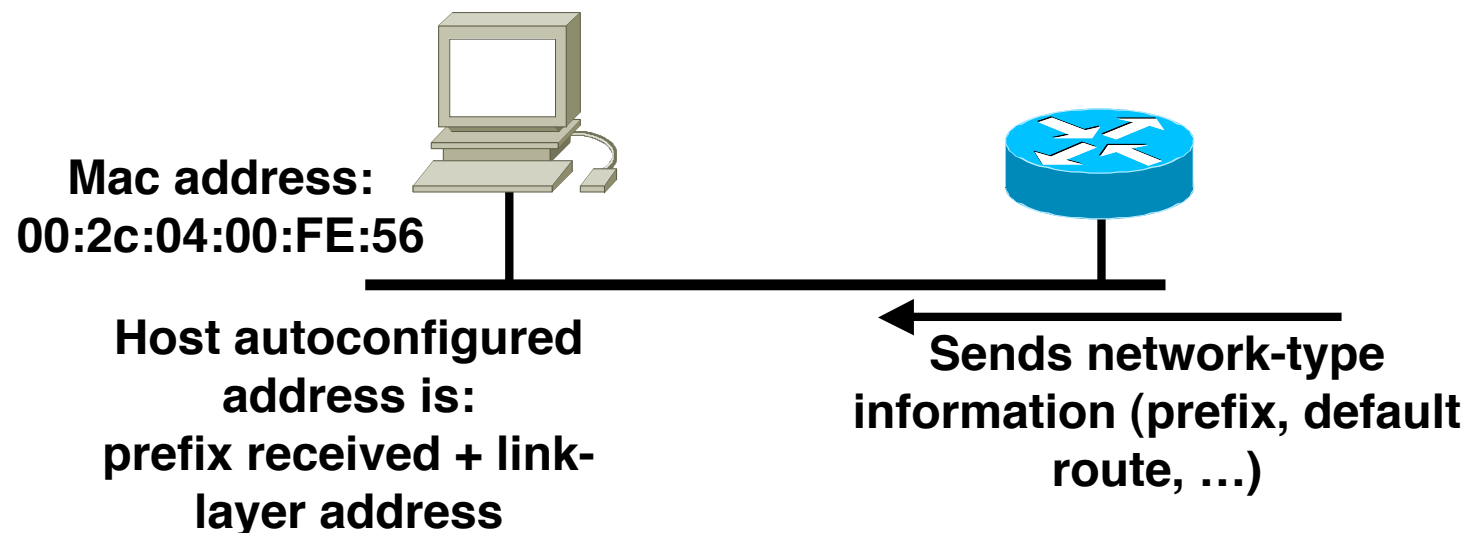
# IPv6 Auto-Configuration

- 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 – required by most enterprises
- Renumbering
  - Hosts renumbering is done by modifying the RA to announce the old prefix with a short lifetime and the new prefix
  - Router renumbering protocol (RFC 2894), to allow domain-interior routers to learn of prefix introduction / withdrawal



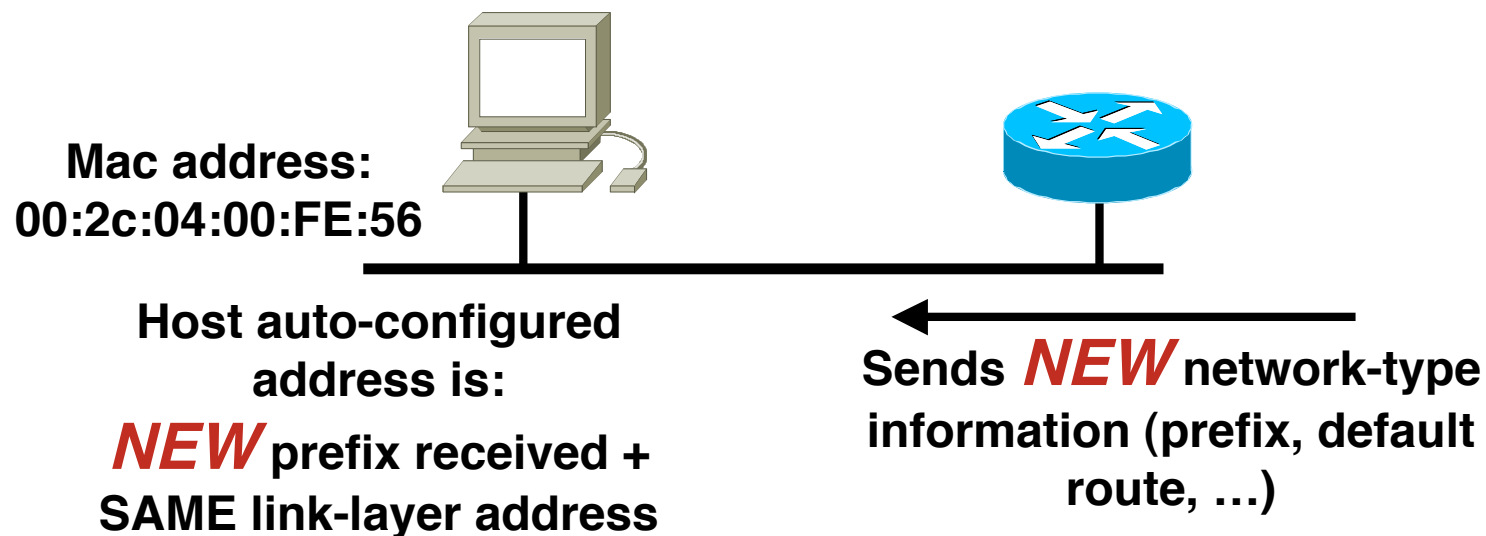
**At boot time, an IPv6 host build a Link-Local address, then its global IPv6 address(es) from RA**

# Auto-configuration



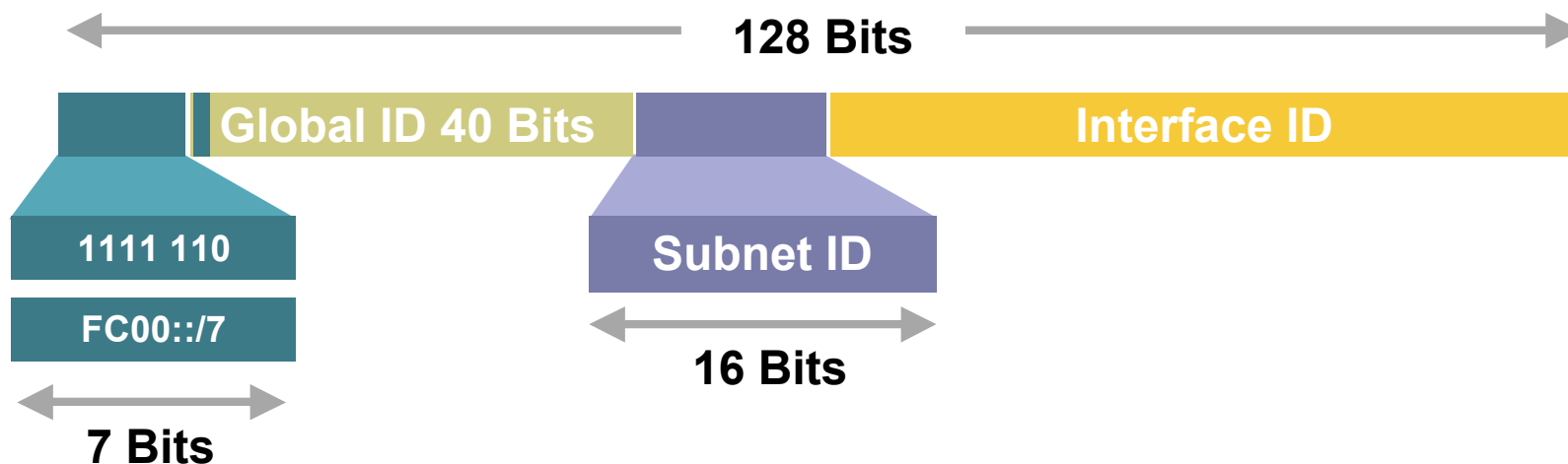
- Client sends router solicitation (RS) messages
- Router responds with router advertisement (RA)  
This includes prefix and default route
- Client configures its IPv6 address by concatenating prefix received with its EUI-64 address

# Renumbering



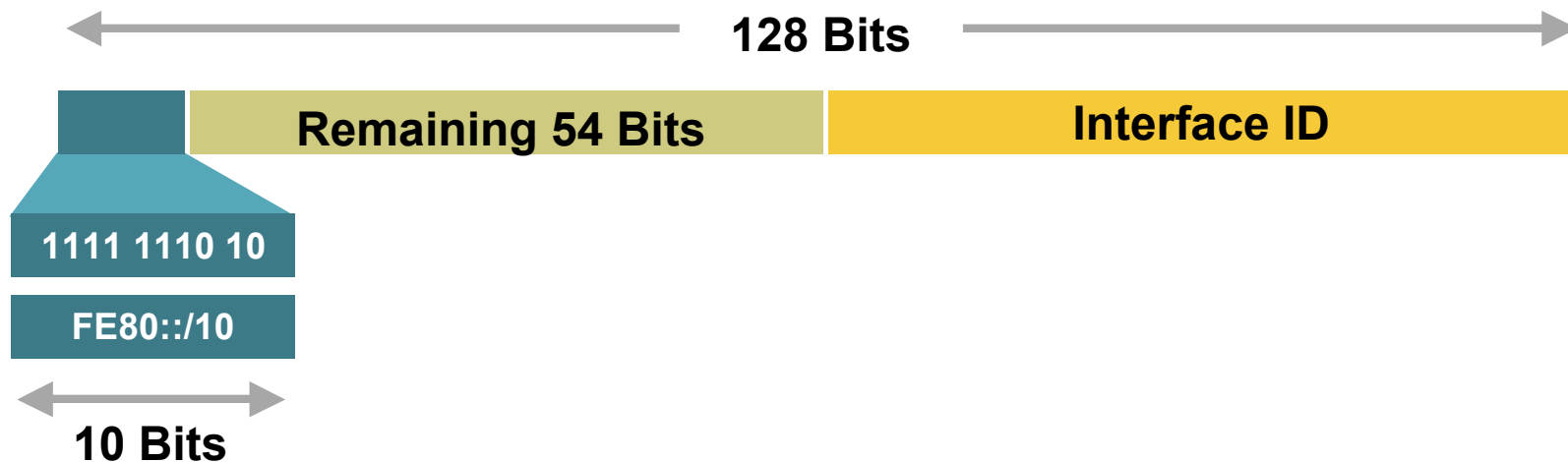
- Router sends router advertisement (RA)
  - This includes the new prefix and default route (and remaining lifetime of the old address)
- Client configures a new IPv6 address by concatenating prefix received with its EUI-64 address
  - Attaches lifetime to old address

# Unique-Local



- Unique-Local Addresses Used For:
  - Local communications
  - Inter-site VPNs
- **Not** routable on the Internet
- Reinvention of the deprecated site-local? It's future is unclear.

# Link-Local



- Link-Local Addresses Used For:
  - Communication between two IPv6 device (like ARP but at Layer 3)
  - Next-Hop calculation in Routing Protocols
- Automatically assigned by Router as soon as IPv6 is enabled
- Mandatory Address
- Only Link Specific scope
- Remaining 54 bits could be Zero or any manual configured value



# Multicast use

- Broadcasts in IPv4

  - Interrupts all devices on the LAN even if the intent of the request was for a subset

  - Can completely swamp the network (“broadcast storm”)

- Broadcasts in IPv6

  - Are not used and replaced by multicast

- Multicast

  - Enables the efficient use of the network

  - Multicast address range is much larger

# IPv6 Multicast Address

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

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

Lifetime	
0	If Permanent
1	If Temporary

Scope	
1	Node
2	Link
5	Site
8	Organization
E	Global

# IPv6 Multicast Address Examples

- RIPng

The multicast address **AllRIPRouters** is **FF02::9**

Note that 02 means that this is a permanent address and has link scope

- OSPFv3

The multicast address **AllSPFRouters** is **FF02::5**

The multicast address **AllDRouters** is **FF02::6**

- EIGRP

The multicast address **AllEIGRPRouters** is **FF02::A**

# IPv6 Anycast

- An IPv6 anycast address is an identifier for a set of interfaces (typically belonging to different nodes)
  - A packet sent to an anycast address is delivered to one of the interfaces identified by that address (the “nearest” one, according to the routing protocol’s measure of distance).
  - RFC4291 describes IPv6 Anycast in more detail
- In reality there is no known implementation of IPv6 Anycast as per the RFC
  - Most operators have chosen to use IPv4 style anycast instead**

# Anycast on the Internet

- A global unicast address is assigned to all nodes which need to respond to a service being offered
  - This address is routed as part of its parent address block
- The responding node is the one which is closest to the requesting node according to the routing protocol
  - Each anycast node looks identical to the other
- Applicable within an ASN, or globally across the Internet
- Typical (IPv4) examples today include:
  - Root DNS and ccTLD/gTLD nameservers
  - SMTP relays within ISP autonomous systems

# MTU Issues

- Minimum link MTU for IPv6 is 1280 octets (versus 68 octets for IPv4)
  - ⇒ on links with MTU < 1280, link-specific fragmentation and reassembly must be used
- Implementations are expected to perform path MTU discovery to send packets bigger than 1280
- Minimal implementation can omit PMTU discovery as long as all packets kept  $\geq$  1280 octets
- A Hop-by-Hop Option supports transmission of “jumbograms” with up to  $2^{32}$  octets of payload

# Neighbour Discovery (RFCs 2461 & 4311)

- Protocol built on top of ICMPv6 (RFC 4443)  
combination of IPv4 protocols (ARP, ICMP, IGMP,...)
- Fully dynamic, interactive between Hosts & Routers  
defines 5 ICMPv6 packet types:
  - Router Solicitation / Router Advertisements
  - Neighbour Solicitation / Neighbour Advertisements
  - Redirect

# IPv6 and DNS

	IPv4	IPv6
Hostname to IP address	A record: www.abc.test. A 192.168.30.1	AAAA record: www.abc.test AAAA 2001:db8:c18:1::2
IP address to hostname	PTR record: 1.30.168.192.in-addr.arpa. PTR www.abc.test.	PTR record: 2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.0.0.0.8.1.c.0. 8.b.d.0.1.0.0.2.ip6.arpa PTR www.abc.test.



# IPv6 Technology Scope

<i>IP Service</i>	<i>IPv4 Solution</i>	<i>IPv6 Solution</i>
Addressing Range	32-bit, Network Address Translation	<b>128-bit, Multiple Scopes</b>
Autoconfiguration	DHCP	<b>Serverless, Reconfiguration, DHCP</b>
Security	IPSec	IPSec Mandated, <b>works End-to-End</b>
Mobility	Mobile IP	Mobile IP <b>with Direct Routing</b>
Quality-of-Service	Differentiated Service, Integrated Service	Differentiated Service, Integrated Service
IP Multicast	IGMP/PIM/Multicast BGP	MLD/PIM/Multicast BGP, <b>Scope Identifier</b>

# What does IPv6 do for:

- Security

Nothing IPv4 doesn't do – IPSec runs in both  
But IPv6 architecture mandates IPSec

- QoS

Nothing IPv4 doesn't do –  
Differentiated and Integrated Services run in both  
So far, Flow label has no real use

# IPv6 Status – Standardisation

- Several key components on standards track...

- Specification (RFC2460)

- ICMPv6 (RFC4443)

- RIP (RFC2080)

- IGMPv6 (RFC2710)

- Router Alert (RFC2711)

- Autoconfiguration (RFC4862)

- DHCPv6 (RFC3315 & 4361)

- IPv6 Mobility (RFC3775)

- GRE Tunnelling (RFC2473)

- DAD for IPv6 (RFC4429)

- Neighbour Discovery (RFC4861 & 4311)

- IPv6 Addresses (RFC4291 & 3587)

- BGP (RFC2545)

- OSPF (RFC2740)

- Jumbograms (RFC2675)

- Radius (RFC3162)

- Flow Label (RFC3697)

- Mobile IPv6 MIB (RFC4295)

- Unique Local IPv6 Addresses (RFC4193)

- Teredo (RFC4380)

- IPv6 available over:

- PPP (RFC5072)

- FDDI (RFC2467)

- NBMA (RFC2491)

- Frame Relay (RFC2590)

- IEEE1394 (RFC3146)

- Ethernet (RFC2464)

- Token Ring (RFC2470)

- ATM (RFC2492)

- ARCnet (RFC2497)

- FibreChannel (RFC4338)

# Agenda

- Background
- Protocols & Standards
- Addressing
- Routing Protocols
- Integration & Transition

# Getting IPv6 address space

- Become a member of your Regional Internet Registry and get your own allocation
  - Require a plan for a year ahead
  - General allocation policies and specific details for IPv6 are on the individual RIR website
- or
- Take part of upstream ISP's PA space
- or
- Use 6to4
- There is **plenty** of IPv6 address space
  - The RIRs require high quality documentation

# Getting IPv6 address space

- From the RIR

  - Receive a /32 (or larger if you have more than 65k /48 assignments)

- From your upstream ISP

  - Get one /48 from your upstream ISP

  - More than one /48 if you have more than 65k subnets

- Use 6to4

  - Take a single public IPv4 /32 address

  - 2002:<ipv4 /32 address>::/48 becomes your IPv6 address block, giving 65k subnets

  - Requires a 6to4 gateway

# Addressing Plans – ISP Infrastructure

- ISPs should receive /32 from their RIR
- Address block for router loop-back interfaces
  - Generally number all loopbacks out of **one** /64
- Address block for infrastructure
  - /48 allows 65k subnets
  - /48 per PoP or region (for large networks)
  - /48 for whole backbone (for small to medium networks)
  - Summarise between sites if it makes sense

# Addressing Plans – ISP Infrastructure

- What about LANs?

  - /64 per LAN

- What about Point-to-Point links?

  - Expectation is that /64 is used

  - People have used /126s

    - Mobile IPv6 Home Agent discovery won't work

  - People have used /112s

    - Leaves final 16 bits free for node IDs

  - See RFC3627 for more discussion



# Addressing Plans – Customer

- Customers get **one** /48

Unless they have more than 65k subnets in which case they get a second /48 (and so on)

(Still on going RIR policy discussion about giving “small” customers a /56 and single LAN end-sites a /64)

- Should not be reserved or assigned on a per PoP basis

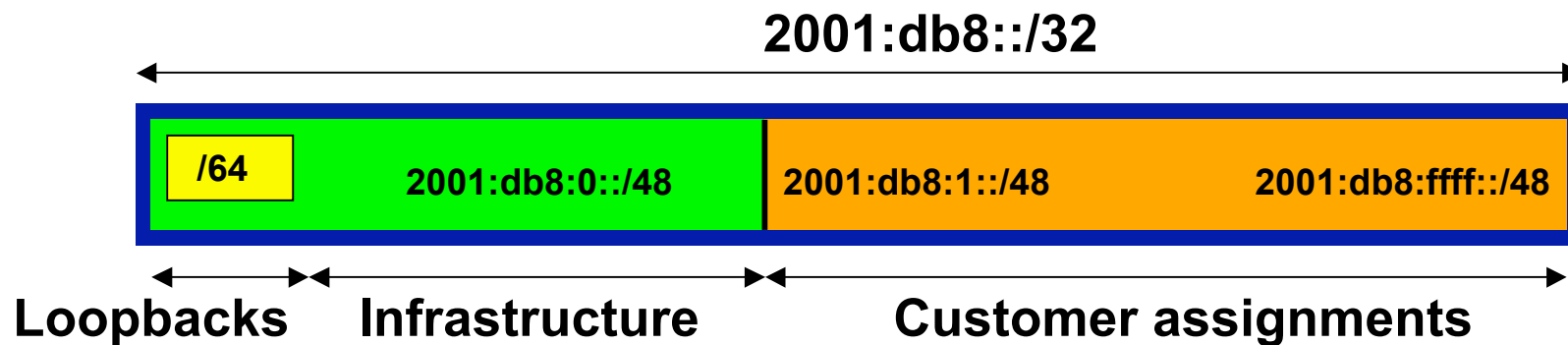
ISP iBGP carries customer nets

Aggregation within the iBGP not required and usually not desirable

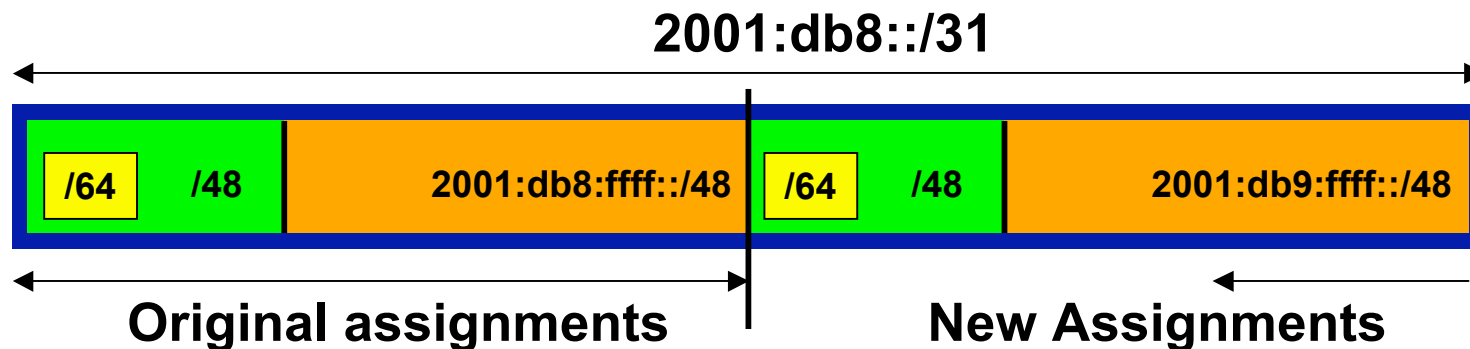
Aggregation in eBGP is very necessary

# Addressing Plans – ISP Infrastructure

- Phase One



- Phase Two – second /32



# Addressing Plans Planning

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

# Agenda

- Background
- Protocols & Standards
- Addressing
- Routing Protocols
- Integration & Transition

# Static Routing in IPv6

- Unchanged from IPv4

  - Default route is now `::/0`

  - On most platforms, the CLI is very similar

- Cisco IOS Static Routing Example:

```
ipv6 route 2001:db8::/64 2001:db8:0:CC::1 110
```

Routes packets for network `2001:db8::/64` to a networking device at `2001:db8:0:CC::1` with an administrative distance of 110

# Dynamic Routing Protocols in IPv6

- Dynamic Routing in IPv6 is unchanged from IPv4:
  - IPv6 has 2 types of routing protocols: IGP and EGP
  - IPv6 still uses the longest-prefix match routing algorithm
- IGP
  - RIPng (RFC 2080)
  - Cisco EIGRP for IPv6
  - OSPFv3 (RFC 2740)
  - Integrated IS-ISv6 (draft-ietf-isis-ipv6-06)
- EGP
  - MP-BGP4 (RFC 4760 and RFC 2545)

# Configuring Routing Protocols

- Dynamic routing protocols require router-id

Router-id is a 32 bit integer

Cisco IOS auto-generates these from loopback interface address if configured, else highest IPv4 address on the router

**Most ISPs will deploy IPv6 dual stack** – so router-id will be automatically created

- Early adopters choosing to deploy IPv6 in the total absence of any IPv4 addressing need to be aware:

Router-id needs to be manually configured:

```
ipv6 router ospf 100
  router-id 10.1.1.4
```

# RIPng

- For the ISP industry, simply don't go here
- ISPs do not use RIP in any form unless there is absolutely no alternative

And there usually is

- RIPng was used in the early days of the IPv6 test network

Sensible routing protocols such as OSPF and BGP rapidly replaced RIPng when they became available



# OSPFv3 overview

- OSPFv3 is OSPF for IPv6 (RFC 2740)
- Based on OSPFv2, with enhancements
- Distributes IPv6 prefixes
- Runs directly over IPv6
- Completely independent of OSPFv2

# Differences from OSPFv2

- Runs over a link, not a subnet
  - Multiple instances per link
- Topology not IPv6 specific
  - Router ID
  - Link ID
- Standard authentication mechanisms
- Uses link local addresses
- Generalized flooding scope
- Two new LSA types

# IS-IS Standards History

- ISO 10589 specifies OSI IS-IS routing protocol for CLNS traffic
  - Tag/Length/Value (TLV) options to enhance the protocol
- RFC 1195 added IP support, also known as Integrated IS-IS (I/IS-IS)
  - I/IS-IS runs on top of the Data Link Layer
  - Requires CLNP to be configured
- IPv6 address family support added to IS-IS
  - [www.ietf.org/internet-drafts/draft-ietf-isis-ipv6-06.txt](http://www.ietf.org/internet-drafts/draft-ietf-isis-ipv6-06.txt)
  - IPv4 and IPv6 topologies have to be identical
- Multi-Topology concept for IS-IS added:
  - [www.ietf.org/internet-drafts/draft-ietf-isis-wg-multi-topology-11.txt](http://www.ietf.org/internet-drafts/draft-ietf-isis-wg-multi-topology-11.txt)
  - Permits IPv4 and IPv6 topologies which are not identical

# IS-IS for IPv6

- 2 TLVs added to introduce IPv6 routing
  - IPv6 Reachability TLV (0xEC)
  - IPv6 Interface Address TLV (0xE8)
- 4 TLVs added to support multi-topology ISIS
  - Multi Topology
  - Multi Topology Intermediate Systems
  - Multi Topology Reachable IPv4 Prefixes
  - Multi Topology Reachable IPv6 Prefixes
- Multi Topology IDs
  - #0 – standard topology for IPv4/CLNS
  - #2 – topology for IPv6

# Multi-Protocol BGP for IPv6 – RFC2545

- IPv6 specific extensions

Scoped addresses: Next-hop contains a global IPv6 address and/or potentially a link-local address

NEXT\_HOP and NLRI are expressed as IPv6 addresses and prefix

Address Family Information (AFI) = 2 (IPv6)

Sub-AFI = 1 (NLRI is used for unicast)

Sub-AFI = 2 (NLRI is used for multicast RPF check)

Sub-AFI = 3 (NLRI is used for both unicast and multicast RPF check)

Sub-AFI = 4 (label)

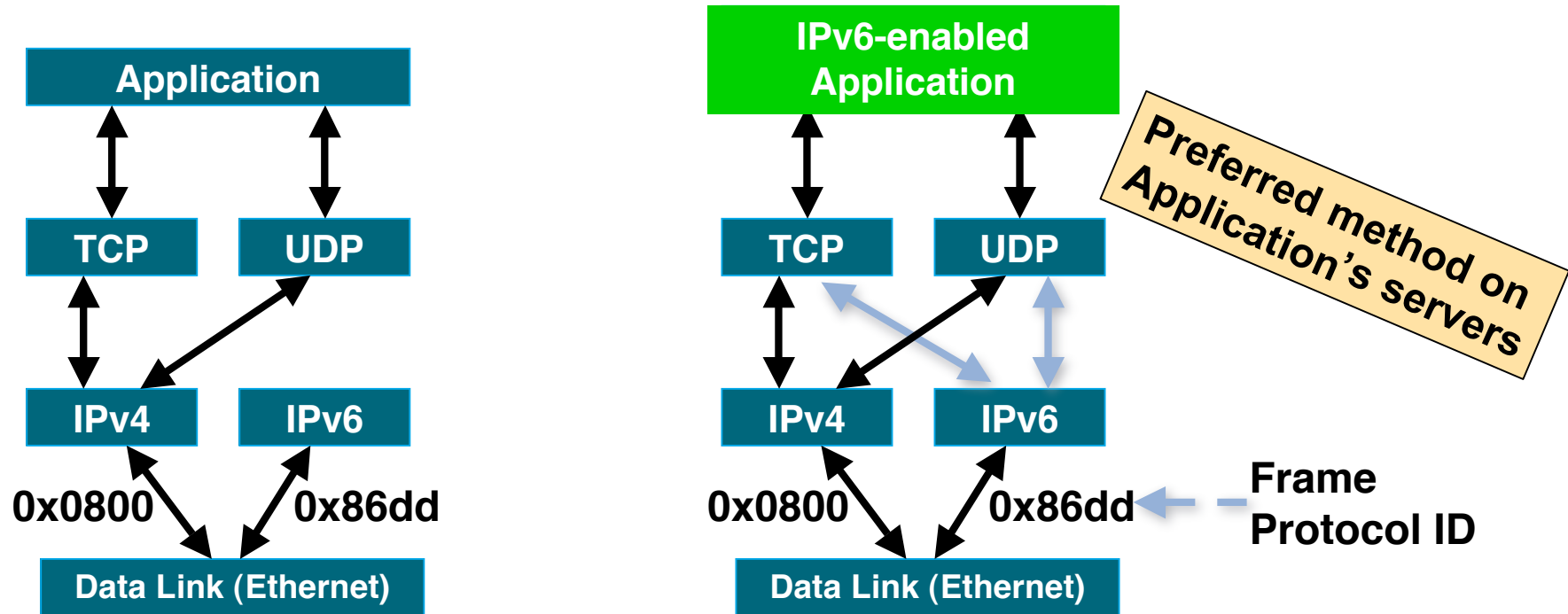
# Agenda

- Background
- Protocols & Standards
- Addressing
- Routing Protocols
- Integration & Transition

# IPv4-IPv6 Co-existence/Transition

- A wide range of techniques have been identified and implemented, basically falling into three categories:
  - Dual-stack techniques**, to allow IPv4 and IPv6 to co-exist in the same devices and networks
  - Tunneling techniques**, to avoid dependencies when upgrading hosts, routers, or regions
  - Translation techniques**, to allow IPv6-only devices to communicate with IPv4-only devices
- Expect all of these to be used, in combination

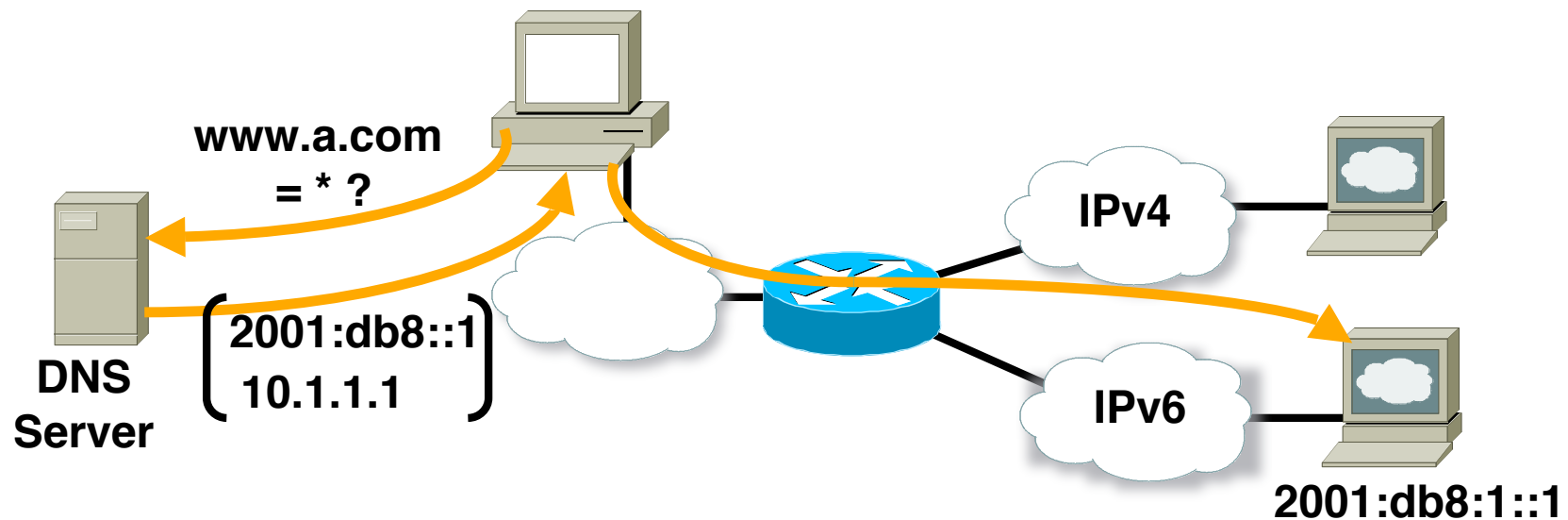
# Dual Stack Approach



- 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

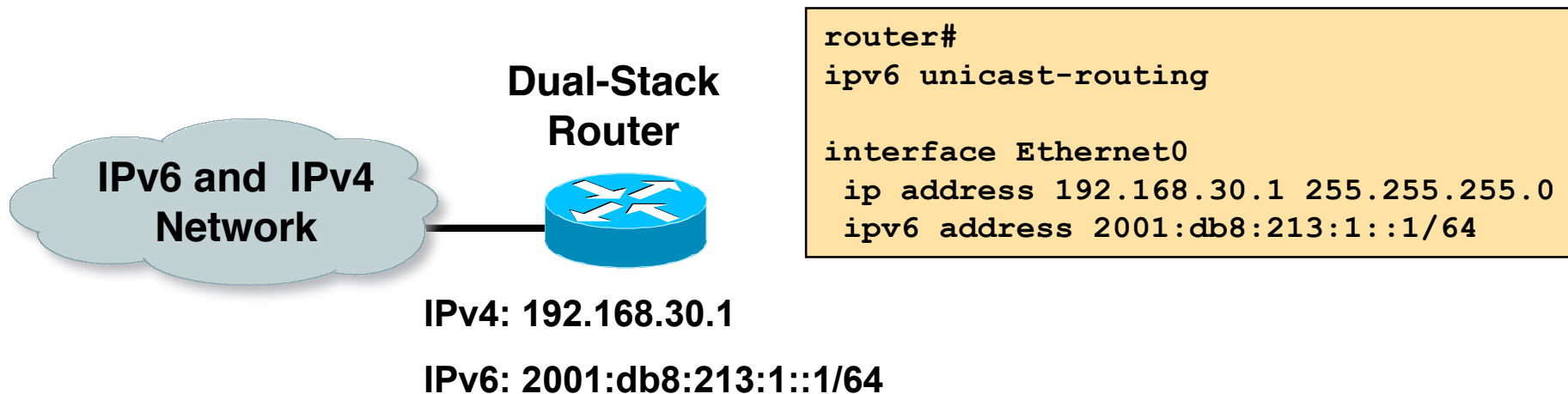


# Dual Stack & DNS



- On a system running dual stack, an application that is both IPv4 and IPv6 enabled will:
  - Ask the DNS for an IPv6 address (AAAA record)
  - If that exists, IPv6 transport will be used
  - If it does not exist, it will then ask the DNS for an IPv4 address (A record) and use IPv4 transport instead

# Sample Dual Stack Configuration



- IPv6-enabled router

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

Telnet, Ping, Traceroute, SSH, DNS client, TFTP etc will all use IPv6 if transport and destination are available

# Using Tunnels for IPv6 Deployment

- Many techniques are available to establish a tunnel:

- Manually configured

- Manual Tunnel (RFC 4213)

- GRE (RFC 2473)

- Semi-automated

- Tunnel broker

- Automatic

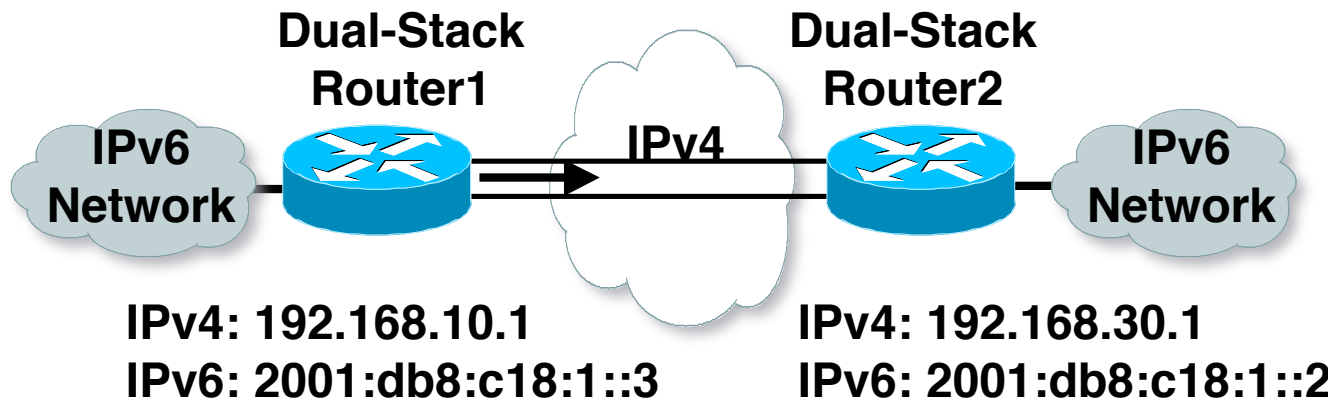
- 6to4 (RFC 3056)

- ISATAP (RFC 4214)

- TEREDO (RFC 4380)

ISATAP & TEREDO are more useful for Enterprises than for Service Providers

# Manually Configured Tunnel (RFC4213)

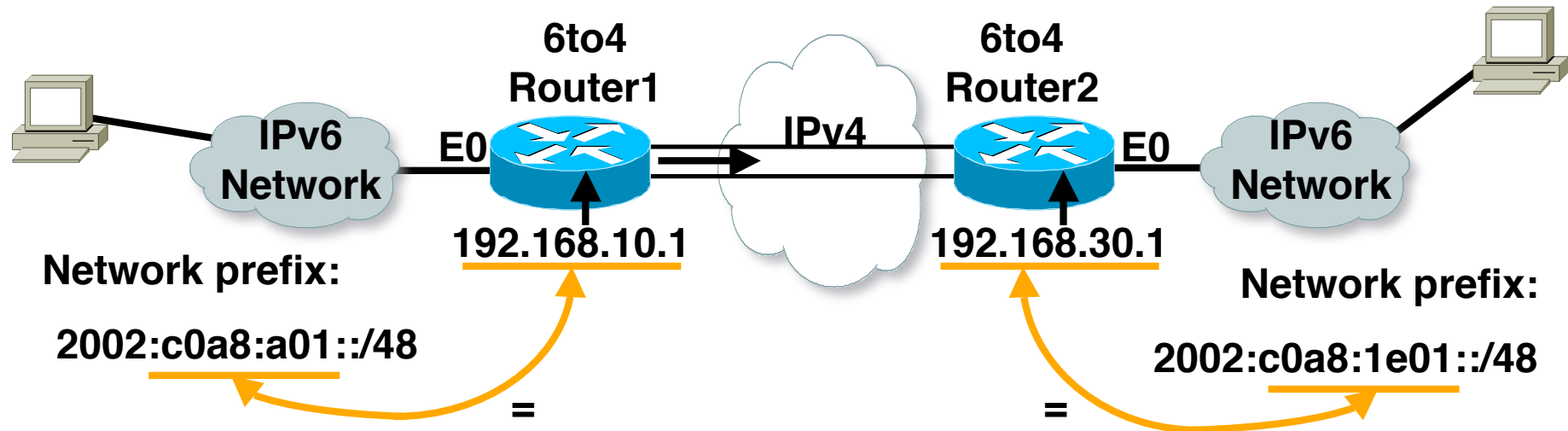


```
router1#  
  
interface Tunnel0  
  ipv6 address 2001:db8:c18:1::3/64  
  tunnel source 192.168.10.1  
  tunnel destination 192.168.30.1  
  tunnel mode ipv6ip
```

```
router2#  
  
interface Tunnel0  
  ipv6 address 2001:db8:c18:1::2/64  
  tunnel source 192.168.30.1  
  tunnel destination 192.168.10.1  
  tunnel mode ipv6ip
```

- Manually Configured tunnels require:
  - Dual stack end points
  - Both IPv4 and IPv6 addresses configured at each end

# 6to4 Tunnel (RFC 3056)



- 6to4 Tunnel:

Is an automatic tunnel method

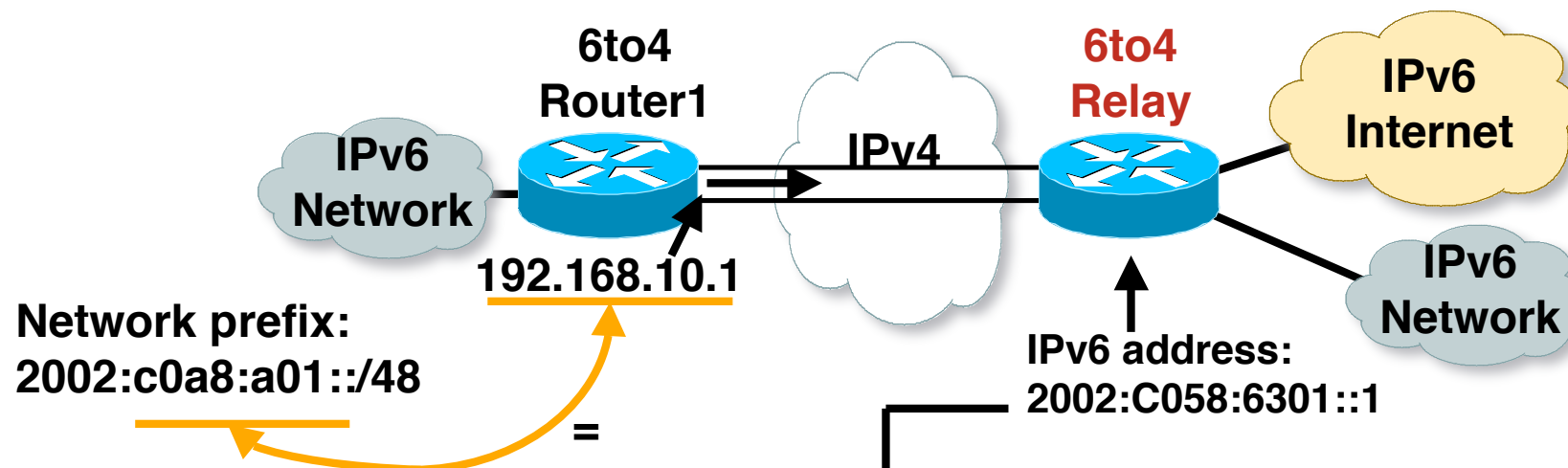
Gives a prefix to the attached IPv6 network

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::1/128  
  
interface Tunnel0  
 no ip address  
 ipv6 unnumbered Ethernet0  
 tunnel source Loopback0  
 tunnel mode ipv6ip 6to4  
  
ipv6 route 2002::/16 Tunnel0
```

# 6to4 Relay



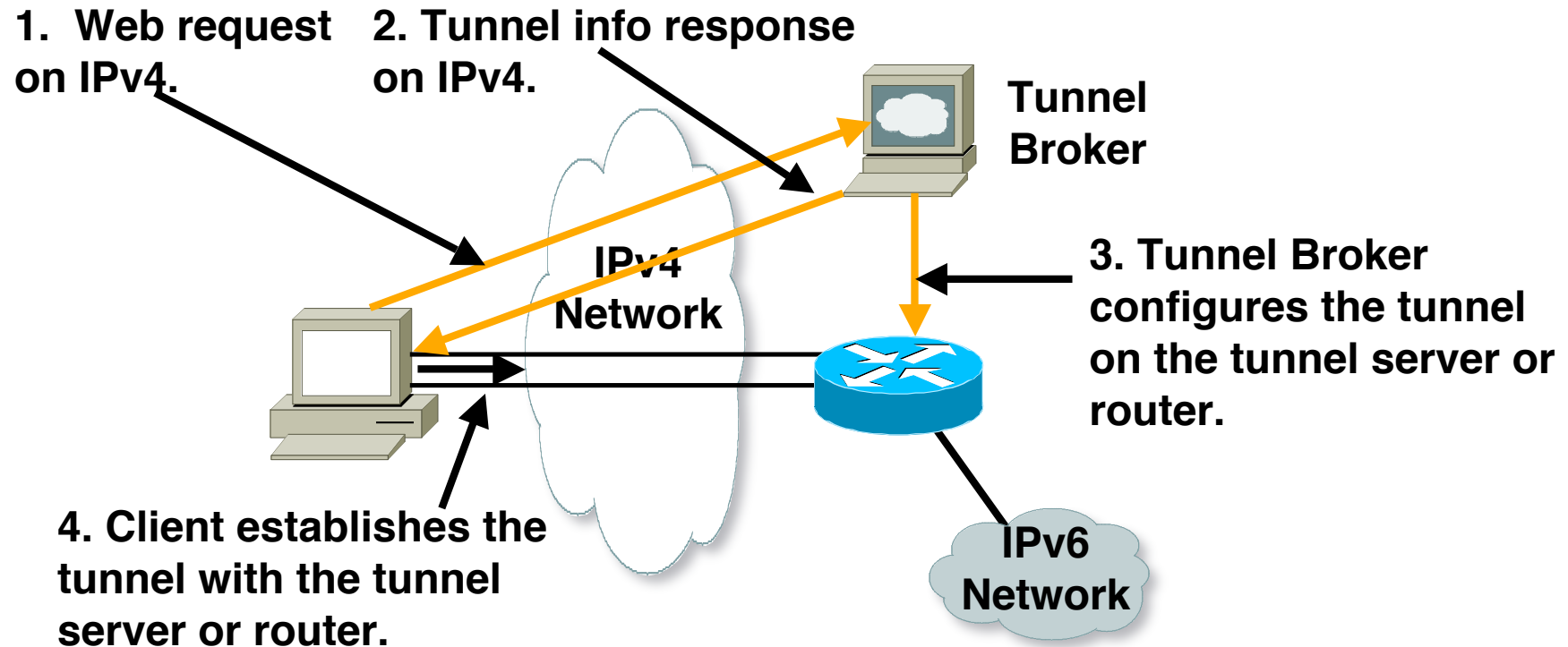
```
router1#  
  
interface Loopback0  
 ip address 192.168.10.1 255.255.255.0  
 ipv6 address 2002:c0a8:a01::1/128  
  
interface Tunnel0  
 no ip address  
 ipv6 unnumbered Ethernet0  
 tunnel source Loopback0  
 tunnel mode ipv6ip 6to4  
  
ipv6 route 2002::/16 Tunnel0  
 ipv6 route ::/0 2002:c058:6301::1
```

- 6to4 relay:
  - Is a gateway to the rest of the IPv6 Internet
  - Carries 2002:c058:6301::1 IPv6 address
  - Carries 192.88.99.1 IPv4 address
  - Anycast address (RFC 3068) for multiple 6to4 Relay

# 6to4 in the Internet

- 6to4 prefix is 2002::/16
- 192.88.99.0/24 is the IPv4 anycast network for 6to4 routers
- 6to4 relay service
  - An ISP who provides a facility to provide connectivity over the IPv4 Internet between IPv6 islands
    - Is connected to the IPv6 Internet and announces 2002::/16 by BGP to the IPv6 Internet
    - Is connected to the IPv4 Internet and announces 192.88.99.0/24 by BGP to the IPv4 Internet
  - Their router is configured with local address of 192.88.99.1

# Tunnel Broker



- Tunnel broker:

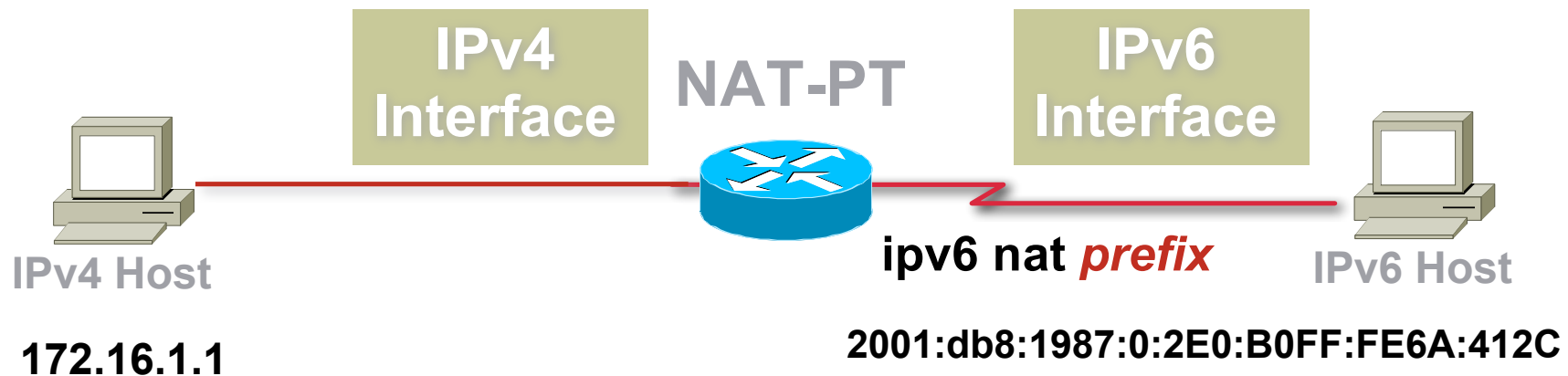
Tunnel information is sent via http-ipv4



# NAT-PT for IPv6

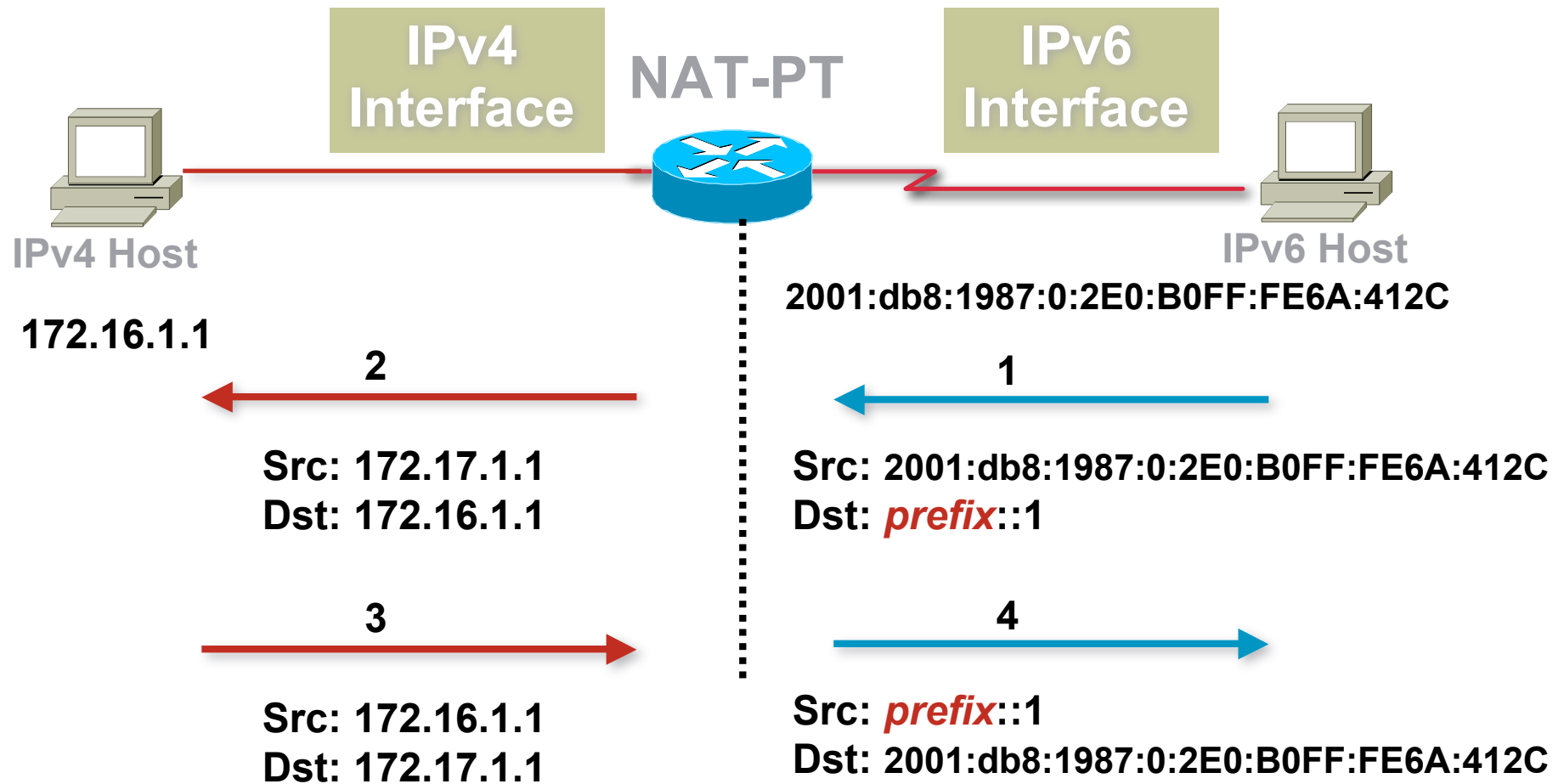
- NAT-PT  
(Network Address Translation – Protocol Translation)  
RFC 2766 & RFC 3596
- Allows native IPv6 hosts and applications to communicate with native IPv4 hosts and applications, and vice versa
- Easy-to-use transition and co-existence solution

# NAT-PT Concept

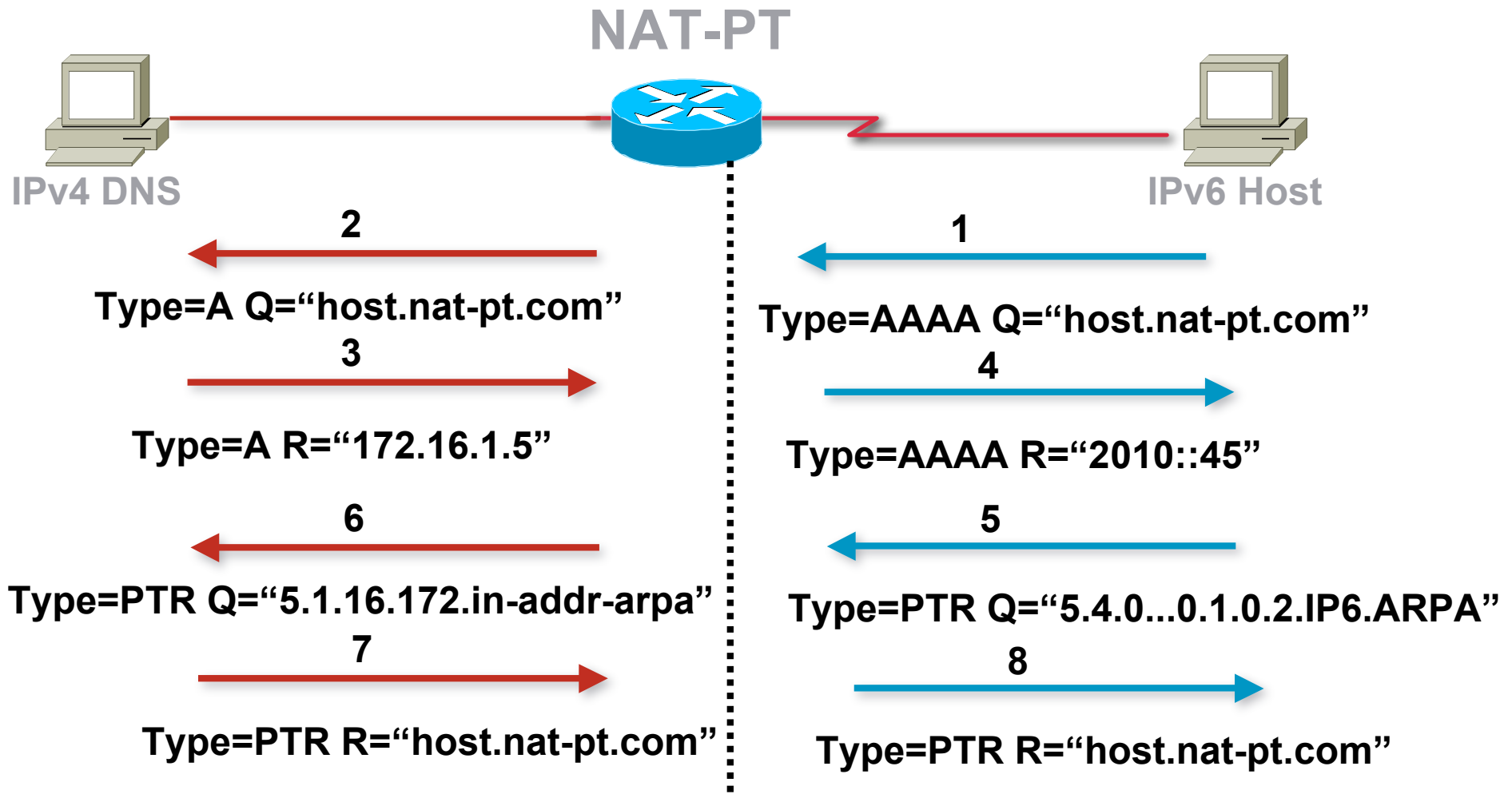


- *prefix* is a 96-bit field that allows routing back to the NAT-PT device

# NAT-PT packet flow



# DNS Application Layer Gateway



# NAT-PT Summary

- Points of note:

- ALG per application carrying IP address

- No End to End security

- No DNSsec

- No IPsec because different address realms

- Conclusion

- Easy IPv6 / IPv4 co-existence mechanism

- Enable applications to cross the protocol barrier

# Agenda

- Background
- Protocols & Standards
- Addressing
- Routing Protocols
- Integration & Transition
- Servers & Services

# Unix Webserver

- Apache 2.x supports IPv6 by default
- Simply edit the `httpd.conf` file

HTTPD listens on all IPv4 interfaces on port 80 by default

For IPv6 add:

```
Listen [2001:db8:10::1]:80
```

So that the webserver will listen to requests coming on the interface configured with 2001:db8:10::1/64

# Unix Nameserver

- BIND 9 supports IPv6 by default
- To enable IPv6 nameservice, edit /etc/named.conf:

```
options {  
    listen-on-v6 { any; };  
};  
zone "abc.net" {  
    type master;  
    file "abc.net.zone";  
};  
zone "8.b.d.0.1.0.0.2.ip6.arpa" {  
    type master;  
    file "abc.net.rev-zone";  
};
```

Tells bind to listen  
on IPv6 ports



Forward zone contains  
v4 and v6 information



Sets up reverse  
zone for IPv6 hosts





# Unix Sendmail

- Sendmail 8 as part of a distribution is usually built with IPv6 enabled

But the configuration file needs to be modified

- If compiling from scratch, make sure NETINET6 is defined

- Then edit `/etc/mail/sendmail.mc` thus:

Remove the line which is for IPv4 only and enable the IPv6 line thus (to support both IPv4 and IPv6):

```
DAEMON_OPTIONS(`Port=smtp, Addr::, Name=MTA-v6,  
Family=inet6')
```

Remake `sendmail.cf`, then restart sendmail

# Unix Applications

- OpenSSH

Uses IPv6 transport before IPv4 transport if IPv6 address available

- Mozilla/Firefox/Thunderbird

Supports IPv6, but still hampered by broken IPv6 nameservers and IPv6 connectivity

In `about:config` the value `network.dns.disableIPv6` is set to `true` by default

Change to `false` to enable IPv6

# MacOS X

- IPv6 installed
- IPv6 enabled by default
- Applications will use IPv6 transport if IPv6 address offered in name lookups

# RedHat/Fedora Linux

- IPv6 installed, but disabled by default
- To enable:
  - simply edit `/etc/sysconfig/network` to include the line  
`NETWORKING_IPV6=yes`
  - And then reboot (or `/sbin/service network restart`)
- System will then use IPv6 transport if IPv6 addresses are offered in name lookups
- Other Linux distributions will use similar techniques
  - Best see Peter Bieringer's LINUX HOWTO  
<http://www.bieringer.de/linux/IPv6/>

# Windows XP & Vista

- XP

- IPv6 installed, but disabled by default

- To enable, start command prompt and run “**ipv6 install**”

- Vista

- IPv6 installed, enabled by default

- Most apps (including IE) will use IPv6 transport if IPv6 address offered in name lookups



# Introduction to IPv6

Philip Smith <pfs@cisco.com>

NANOG 42

17-20 February, San Jose