IPv6 Tutorial

SANOG V

Dhaka, Bangladesh

11 February 2005

Presentation Slides

- **Available on**

  ftp://ftp-eng.cisco.com

  /pfs/seminars/SANOG5-IPv6-Tutorial.pdf

  And on the SANOG5 website

- **Feel free to ask questions any time**

Agenda

- Introduction to IPv6
- IPv6 Routing
- OSPFv3
- BGP for IPv6
- IPv6 Filtering
- Integration & Transition
- Deployment

Introduction to IPv6

Agenda

- The Case for IPv6
- **IPv6 Protocols & Standards**

A need for IPv6?

- IETF IPv6 WG began in early 1990s, to solve addressing growth issues, but
  - CIDR, NAT, PPP, DHCP were developed
  - Some address reclamation
  - The RIR system was introduced
  - → Brakes were put on IPv4 address consumption
- IPv4 32 bit address = 4 billion hosts
  - 38.1% address space still unallocated (09/2004)

A need for IPv6?

- **General perception is that "*IPv6 has not yet taken hold strongly*"**
  - **IPv4 Address shortage is not upon us yet**
  - **Private sector requires a business case**
  - **Data on Wireless infrastructure emerges recently**
- **But reality looks far better for the coming years! IPv6 needed to sustain the *Internet growth***
- **Only compelling reason for IPv6:**
  - **LARGER ADDRESS SPACE**
  - **HD Ratio (RFC3194) limits IPv4 to 250 million hosts**

Do we really need a larger address space?

- **Internet population**

  ~600 million users in Q4 CY2002

  ~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, e.g.:**

  China uses more than a /7 today

  China would need more than a /4 of IPv4 address space if every student (320M) is to get an IPv4 address

Do we really need a larger address space?

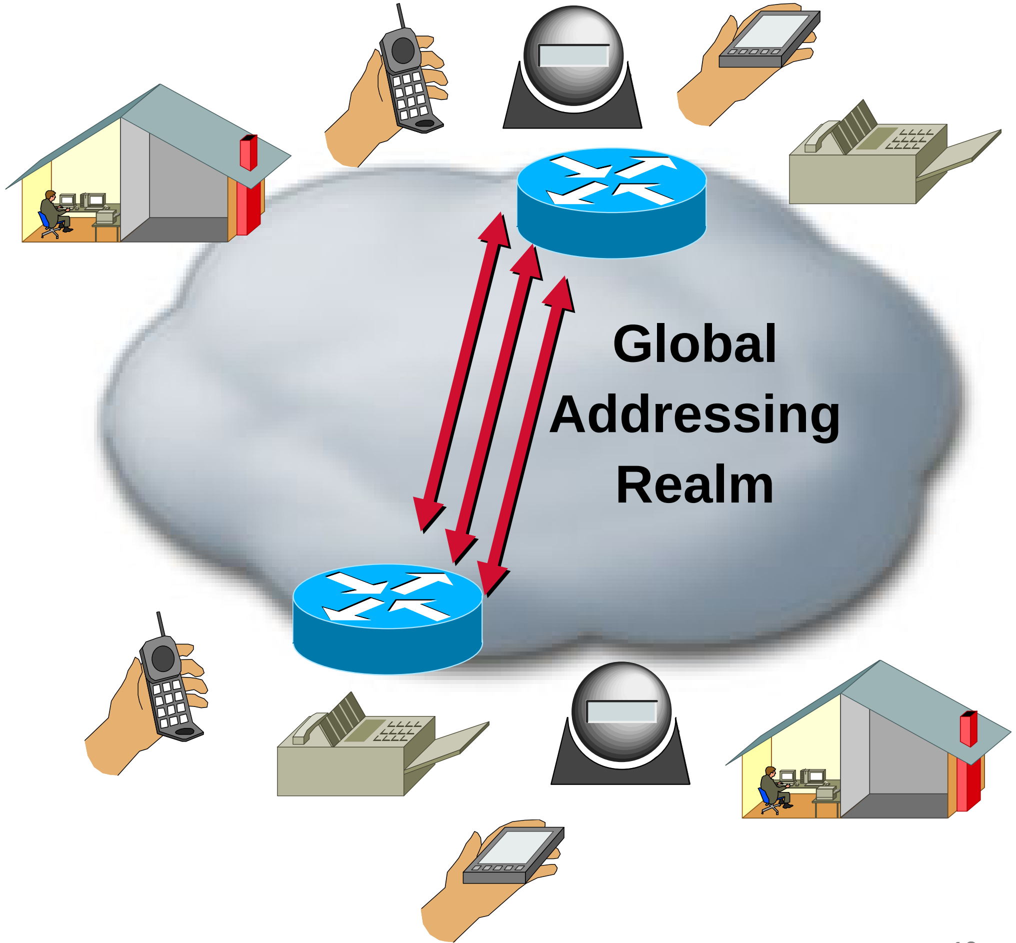
- **Mobile Internet introduces new generation of Internet devices**
  - **PDA (~20M in 2004), Mobile Phones (~1.5B in 2003), Tablet PC**
  - **Enable through several technologies, eg: 3G, 802.11,…**
- **Transportation – Mobile Networks**
  - **1B automobiles forecast for 2008 – Begin now on vertical markets**
  - **Internet access on planes, e.g. Connexion/Boeing**
  - **Internet access on trains, e.g. Narita express**
- **Consumer, Home and Industrial Appliances**

Restoring an End-to-End Architecture

New Technologies/Applications for Home Users

'Always-on'—Cable, DSL, Ethernet-to-the-Home, Wireless,…

- Internet started with end-to-end connectivity for any applications
  - Replacing ALG such as Decnet/SNA gateway
- Today, NAT and Application-Layer Gateways connect disparate networks
- Peer-to-Peer or Server-to-Client applications mean global adresses when you connect to
  - IP Telephony, Fax, Video Conf
    - Mobile, Residential,…
  - Distributed Gaming
  - Remote Monitoring
  - Instant Messaging



IPv6 Markets

- National Research & Education Networks (NREN) & Academia
- Geographies & Politics
- Wireless (PDA, 3G Mobile Phone networks, Car,...)
- Home Networking
    - Set-top box/Cable/xDSL/Ethernet-to-the-home
    - e.g. Japan Home Information Services initiative
    - Distributed Gaming
    - Consumer Devices
- Enterprise
    - Requires full IPv6 support on O.S. & Applications
- Service Providers

IPv6 O.S. & Applications support

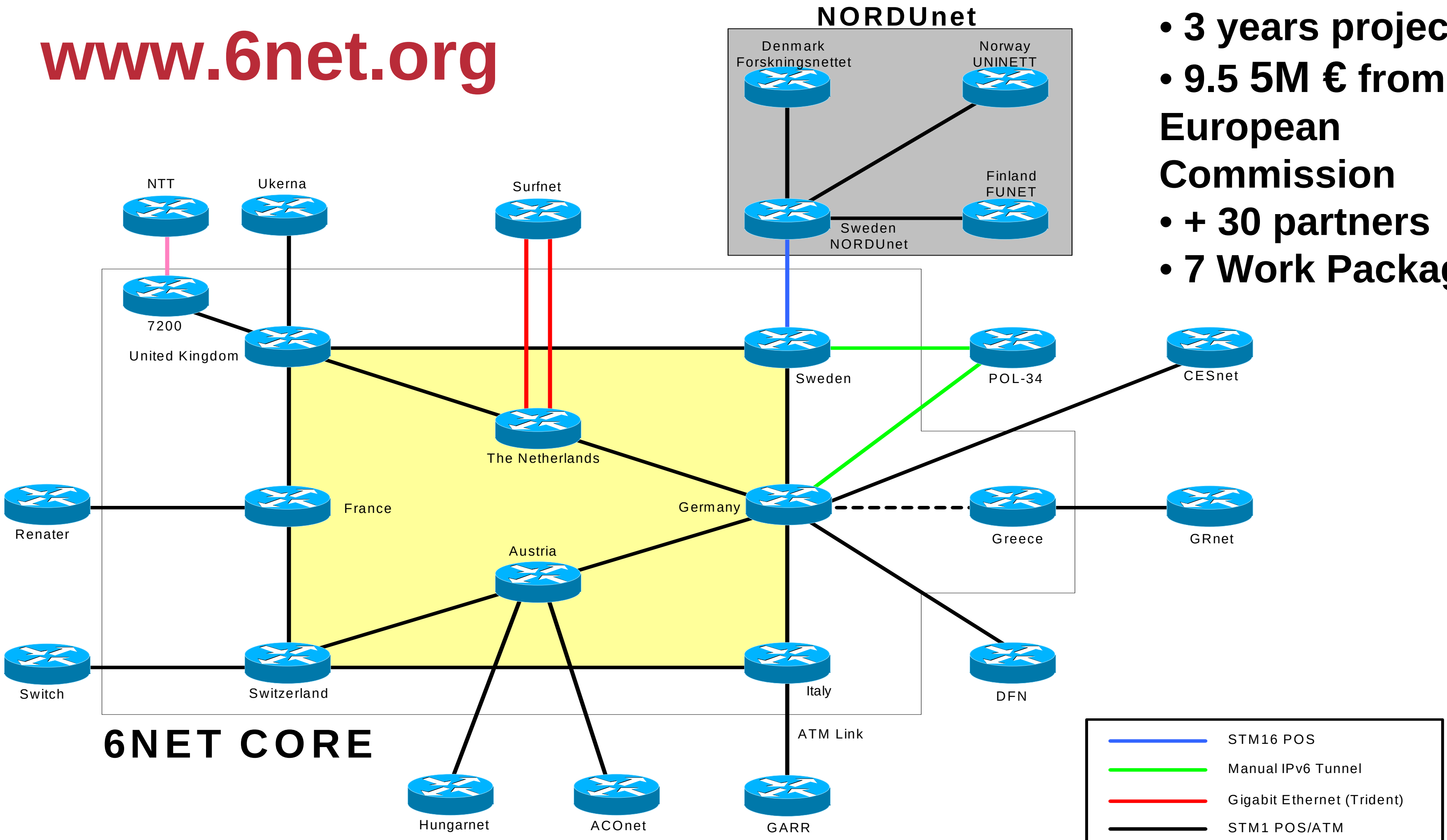
- **All software vendors officially support IPv6 in their latest O.S. releases**
    - **Apple MAC OS X, HP (HP-UX, Tru64 & OpenVMS), IBM zSeries & AIX, Microsoft Windows XP, .NET, CE; Sun Solaris,…**
    - ***BSD, Linux,…**
- **2004 and beyond: *Call for Applications***
    - **Applications must be agnostic regarding IPv4 or IPv6.**
    - **Successful deployment is driven by Applications**
- **Latest info:**
    - **playground.sun.com/ipv6/ipng-implementations.html**
    - **www.hs247.com**

IPv6 Geo-Politics

- **Regional and Countries IPv6 Task Force**
  - **Europe – http://www.ipv6-taskforce.org/**
    - **Belgium, France, Spain, Switzerland, UK,…**
  - **North- America – http://www.nav6tf.org/**
  - **Japan IPv6 Promotion Council – http://www.v6pc.jp/en/index.html**
  - **China, Korea, India,…**
- **Relationship**
  - **Economic partnership between governments**
    - **China-Japan, Europe-China,…**
- **Recommendations and project's funding**
  - **IPv6 2005 roadmap recommendations – Jan. 2002**
  - **European Commission IPv6 project funding: 6NET & EuroIX**
- **Tax Incentives**
  - **Japan only – 2002-2003 program**

6NET Project Overview

www.6net.org



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

Cisco 12400 and 7200 series

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/ripencc/mem-services/registration/ipv6/ipv6allocs.html**
- **Large carriers are running trial networks but**
  - **Plans are largely driven by customer's demand**
- **Regional ISP focus on their specific markets**
  - **Japan is leading the worldwide deployment**
  - **Target is Home Networking services (dial, DSL, Cable, Ethernet-to-the-Home,…)**
- **No easy Return on Investment (RoI) computation**

IPv6 & Wireless

- **Market segments**
  - Mobile phone industry goes to IP: 3GPP/3GPP2/MWIF
  - Wireless service providers have had IPv4 address requests rejected for long term business plan
  - Vertical markets need the infrastructure: Police, Army, Fire Department, Transports
  - Some 802.11 Hot Spots already offer an IPv6 connectivity
- **Commercial services need a phased approach**
  - R&D (03), Trial (04-05), Deployment (06 & beyond)
- **Key driver is the client's device & application**
  - Symbian 7.0, Microsoft Pocket PC 4.1, Netfront 3.x,…

Why not Use Network Address Translation?

- **Private address space and Network address translation (NAT) can be used instead of a new protocol**
- **But NAT has many implications:**

  Breaks the end-to-end model of IP

  Mandates that the network keeps the state of the connections

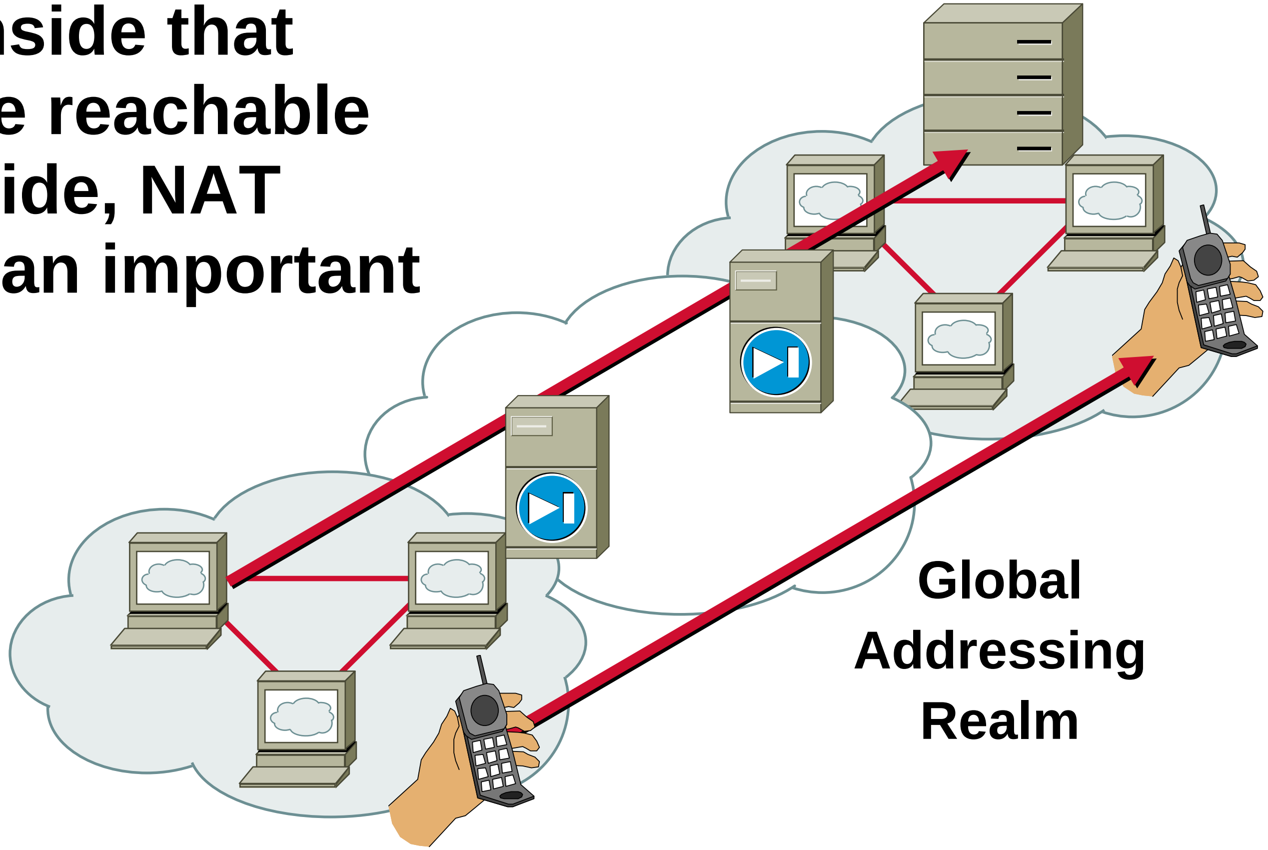
  Makes fast rerouting difficult

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
- Merging of private-addressed networks is difficult
- Simply does not scale
- RFC2993 – architectural implications of NAT

NAT Inhibits Access To Internal Servers

- **When there are many servers inside that need to be reachable from outside, NAT becomes an important issue.**



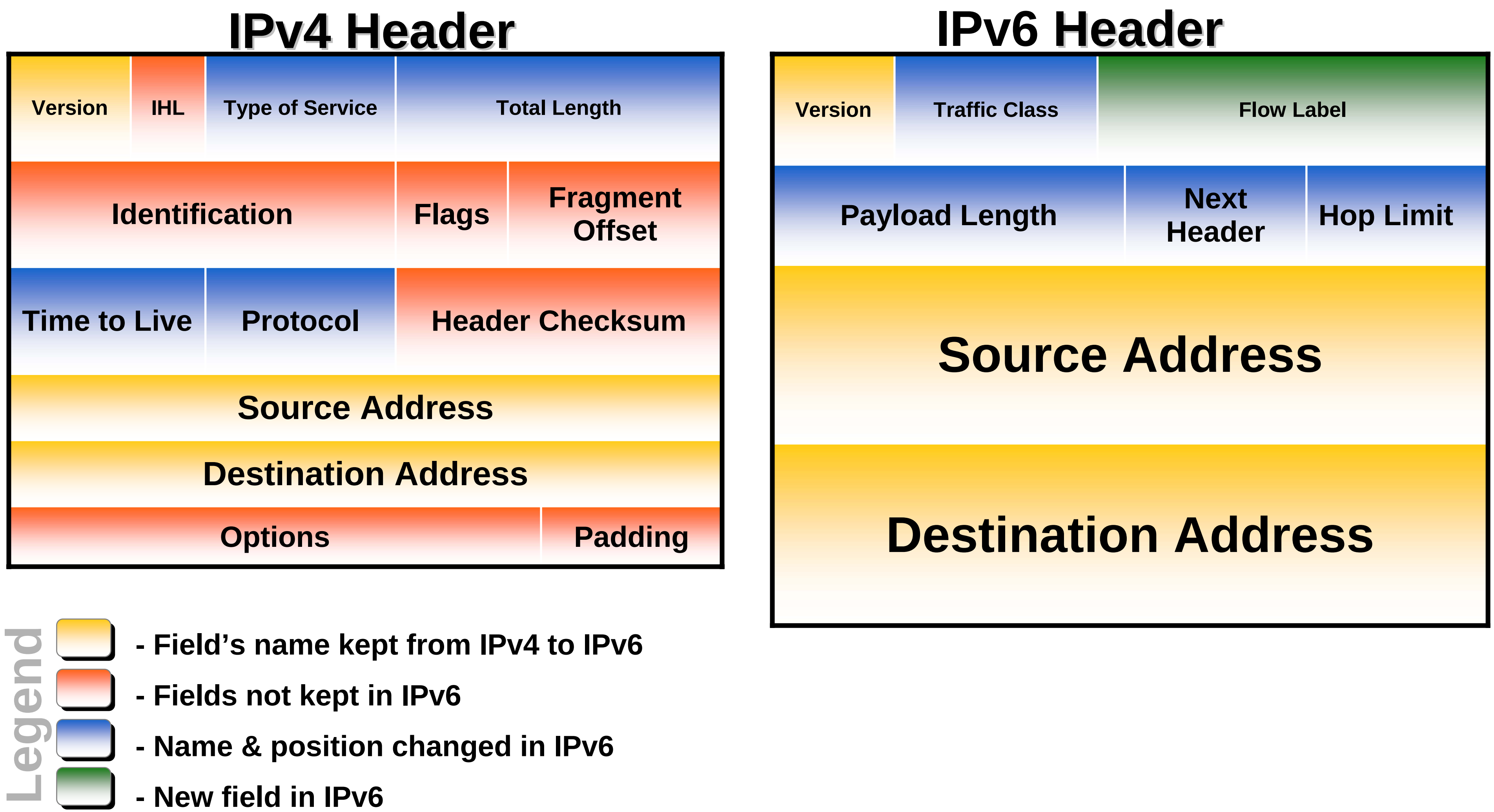
Agenda

- **The Case for IPv6**
- **IPv6 Protocols & Standards**

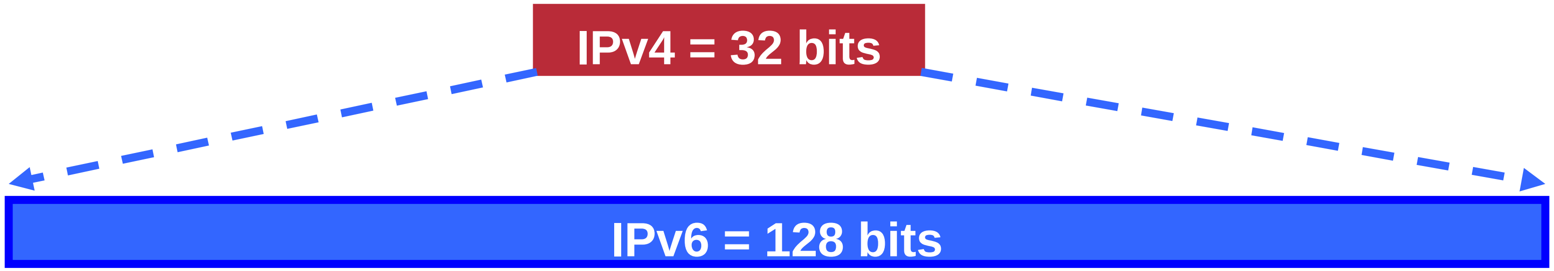
So what's really changed?

- 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 & IPv6 Header Comparison



Larger Address Space



IPv4

- 32 bits
- = 4,294,967,296 possible addressable devices

IPv6

- 128 bits: 4 times the size in bits
- = 3.4 x 10^{38} possible addressable devices
- = 340,282,366,920,938,463,463,374,607,431,768,211,456
- ~ 5 x 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 (RFC2732)**

  http://[2001:1:4F3A::206:AE14]:8080/index.html

  Cumbersome for users

  Mostly for diagnostic purposes

  Use fully qualified domain names (FQDN)

- **⇒ The DNS has to work!!**

IPv6 Addressing

- **IPv6 Addressing rules are covered by multiples RFC's**

    Architecture defined by RFC 3513

- **Address Types are :**

    Unicast : One to One (Global, 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

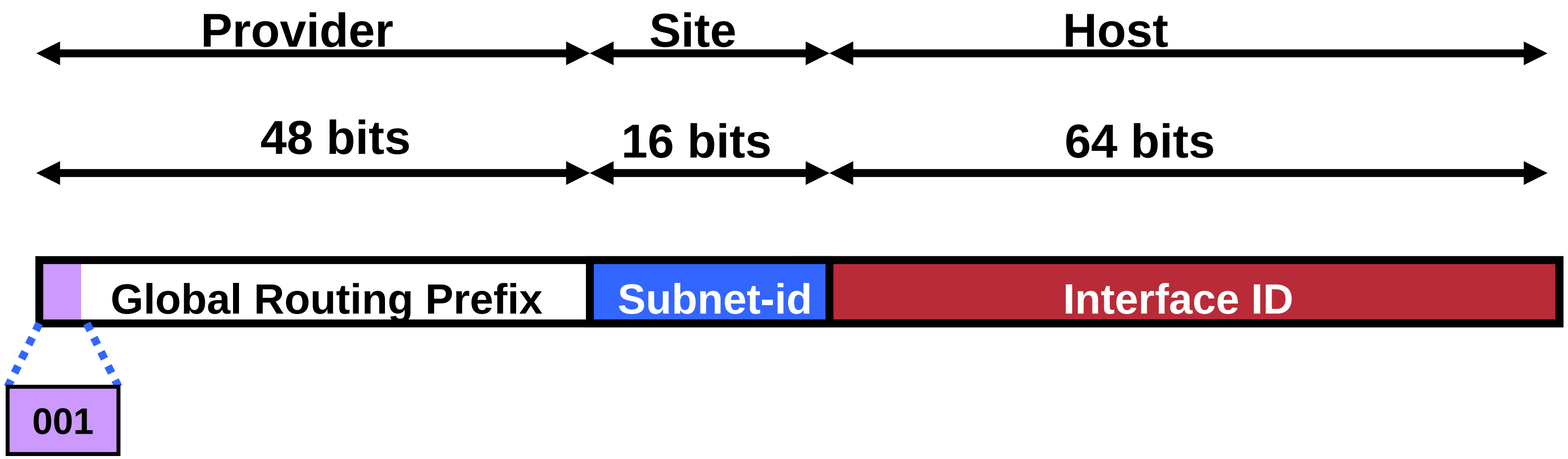
Address type identification

- **Address type identification**

Unspecified	00..0 (128 bits)	::/128
Loopback	00..1 (128 bits)	::1/128
Link Local	1111 1110 10	FE80::/10
Multicast	1111 1111	FF00::/8
Global Unicast	everything else	

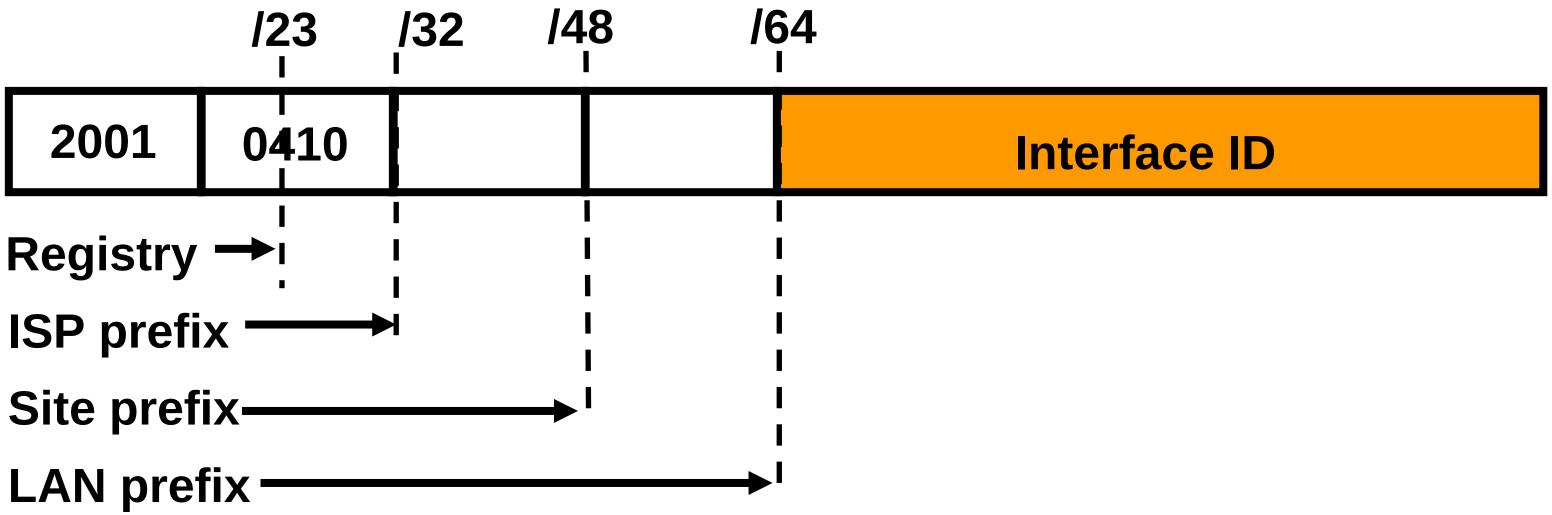
- **All address types have to support EUI-64 bits Interface ID setting**
  - Except for multicast

IPv6 Global Unicast Addresses



- **IPv6 Global Unicast addresses are:**
  - **Addresses for generic use of IPv6**
  - **Structured as a hierarchy to keep the aggregation**
- **First 3 bits 001 (2000::/3) is first allocation to IANA for use for IPv6 Unicast**

IPv6 Address Allocation



- **The allocation process is:**
  - **The IANA has allocated 2001::/16 for initial IPv6 unicast use**
  - **Each registry gets /23 prefixes from the IANA**
  - **Registry allocates a /32 prefix to an IPv6 ISP**
  - **Policy is that an ISP allocates a /48 prefix to each end customer**

How to get an IPv6 Address?

- IPv6 address space is allocated by the 4 RIRs:

  APNIC, ARIN, LACNIC, RIPE NCC

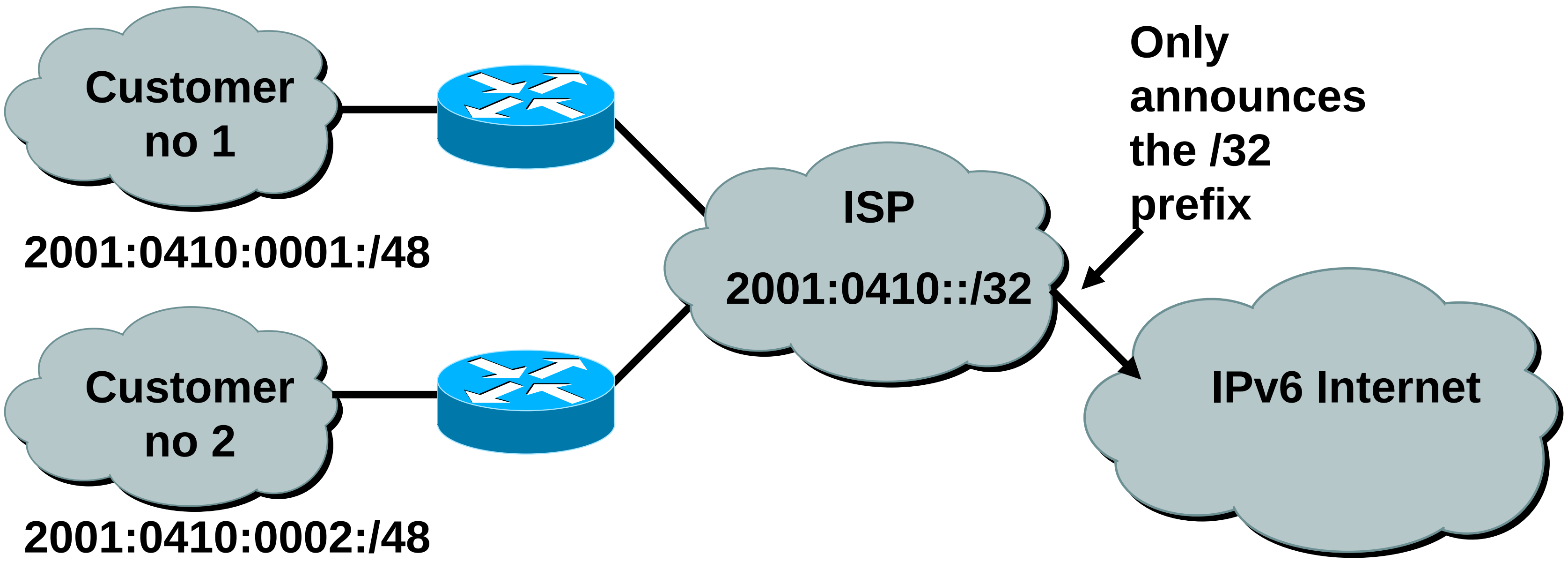
  ISPs get address space from the RIRs

  Enterprises get their IPv6 address space from their ISP

- 6to4 tunnels 2002::/16
- 6Bone

  IPv6 experimental network, now being actively retired, with end of service on 6th June 2006 (RFC3701)

Aggregation benefits



- Larger address space enables:

  Aggregation of prefixes announced in the global routing table

  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

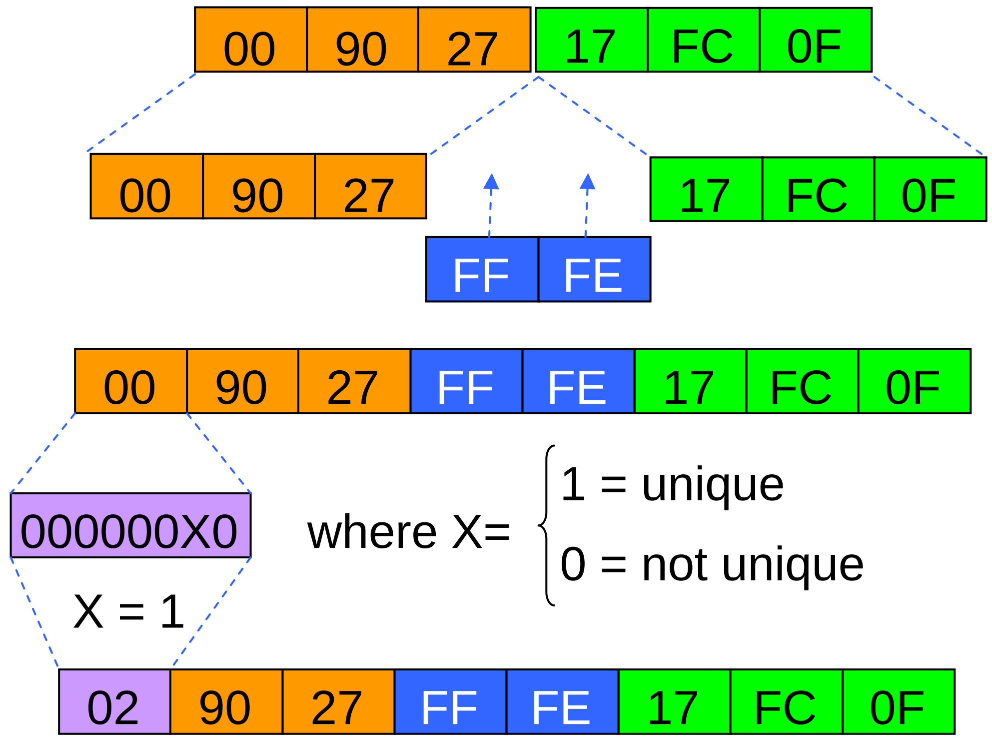
EUI-64

Ethernet MAC address (48 bits)

64 bits version

Uniqueness of the MAC

Eui-64 address

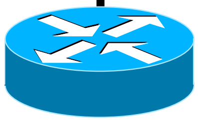


- **EUI-64 address is formed by inserting FFFE and OR'ing a bit identifying the uniqueness of the MAC address**

IPv6 Addressing Examples

LAN: 2001:410:213:1::/64

Ethernet0

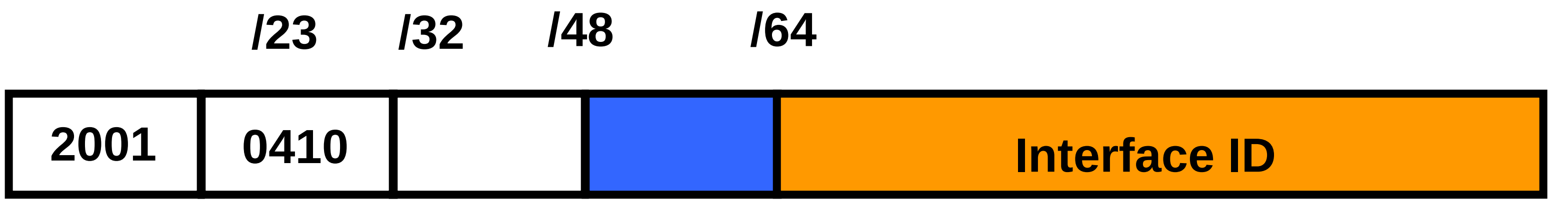


```
interface Ethernet0
 ipv6 address 2001:410:213:1::/64 eui-64
```

MAC address: 0060.3e47.1530

```
router# show ipv6 interface Ethernet0
Ethernet0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::260:3EFF:FE47:1530
Global unicast address(es):
    2001:410:213:1:260:3EFF:FE47:1530, subnet is 2001:410:213:1::/64
  Joined group address(es):
    FF02::1:FF47:1530
    FF02::1
    FF02::2
  MTU is 1500 bytes
```

IPv6 Address Privacy (RFC 3041)



- **Temporary addresses for IPv6 host client application, e.g. Web browser**
  - **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**
  - **From RFC 3041: "…interface identifier …facilitates the tracking of individual devices (and thus potentially users)…"**

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.

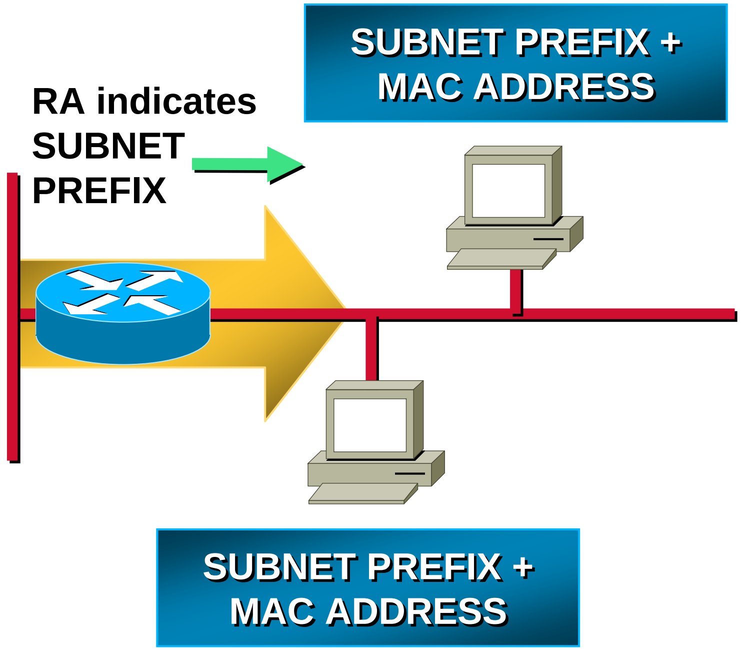
- **Stateful**

  DHCPv6 – required by most enterprises

- **Renumbering**

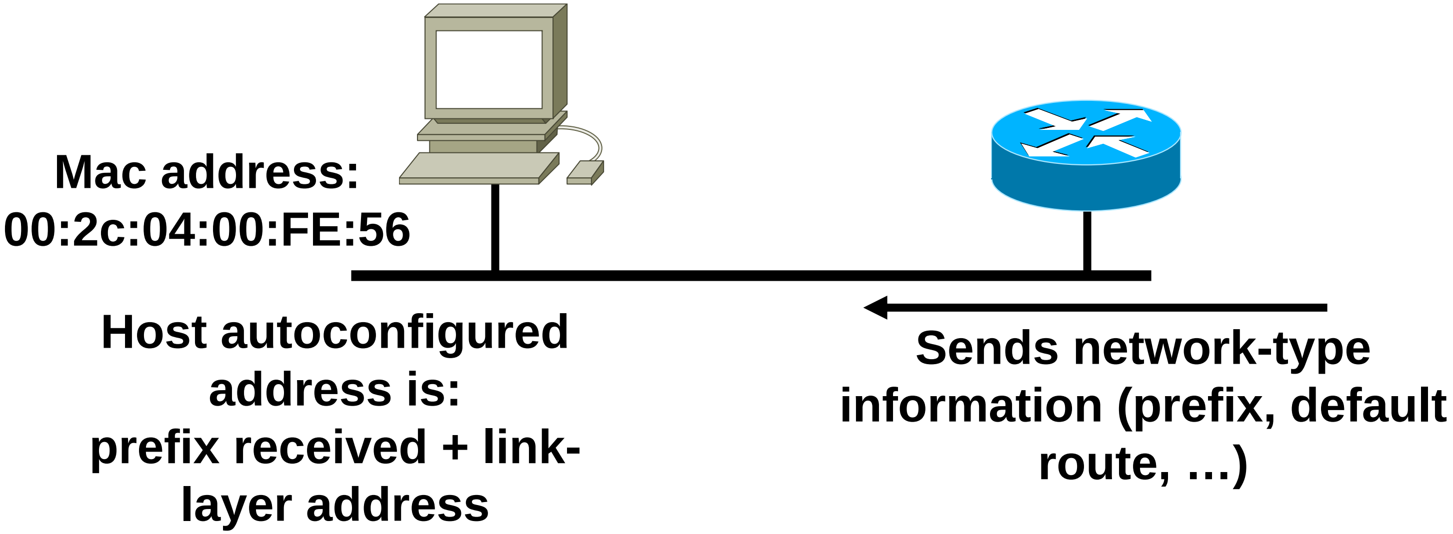
  Hosts renumbering is done by modifying the RA to announce the old prefix with a short lifetime and the new prefix

  Router renumbering protocol (RFC 2894), to allow domain-interior routers to learn of prefix introduction / withdrawal



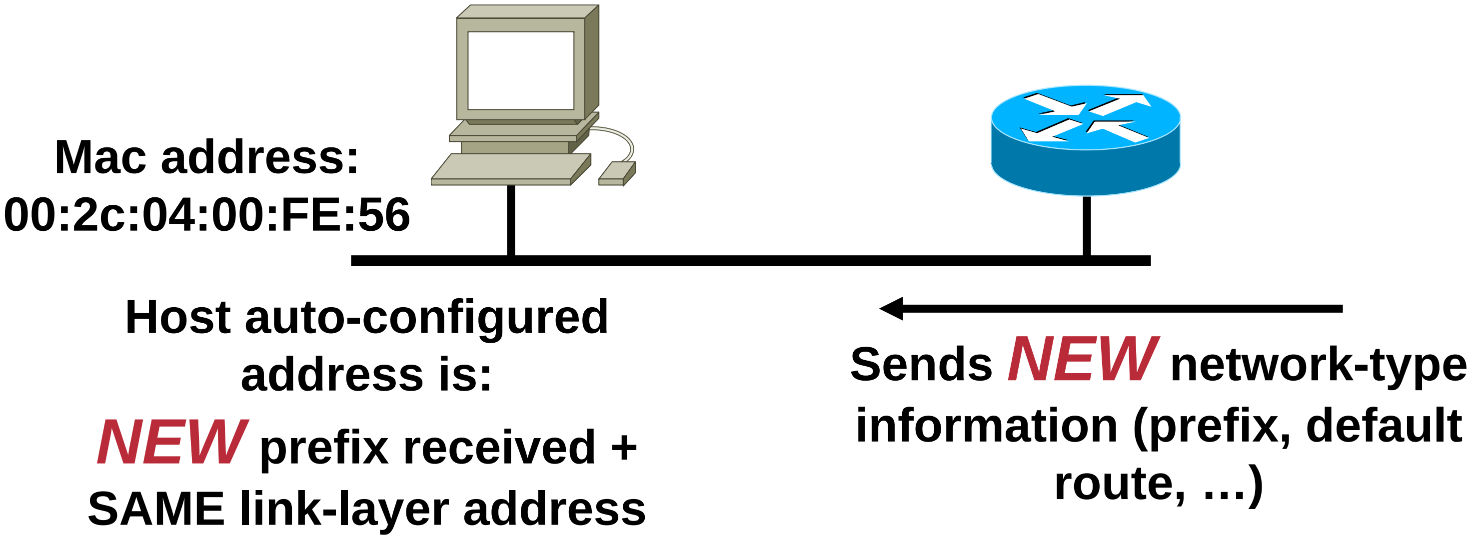
At boot time, an IPv6 host build a Link-Local address, then its global IPv6 address(es) from RA

Auto-configuration



- **Larger address space enables:**
  - The use of link-layer addresses inside the address space
  - Auto-configuration with "no collisions“
  - Offers "Plug and play"

Renumbering



- **Larger address space enables:**

  Renumbering, using auto-configuration and multiple addresses

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

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 (RFC 2461)

- **Protocol built on top of ICMPv6 (RFC 2463)**

  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 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.

IPv6 Technology Scope

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

What does IPv6 do for:

- **Security**

  Nothing IPv4 doesn't do – IPSec runs in both

  but IPv6 mandates IPSec

- **QoS**

  Nothing IPv4 doesn't do –

    Differentiated and Integrated Services run in both

    So far, Flow label has no real use

IPv6 Security

- IPsec standards apply to both IPv4 and IPv6
- All implementations required to support authentication and encryption headers (“IPsec”)
- Authentication separate from encryption for use in situations where encryption is prohibited or prohibitively expensive
- Key distribution protocols are not yet defined (independent of IP v4/v6)
- Support for manual key configuration required

IP Quality of Service Reminder

Two basic approaches developed by IETF:

- **"Integrated Service" (int-serv)**

  fine-grain (per-flow), quantitative promises (e.g., x bits per second), uses RSVP signaling

- **"Differentiated Service" (diff-serv)**

  coarse-grain (per-class), qualitative promises (e.g., higher priority), no explicit signaling

- **Signaled diff-serv (RFC 2998)**

  uses RSVP for signaling with course-grained qualitative aggregate markings

  allows for policy control without requiring per-router state overhead

IPv6 Support for Int-Serv

- **20-bit Flow Label field to identify specific flows needing special QoS**

  each source chooses its own Flow Label values; routers use Source Addr + Flow Label to identify distinct flows

  Flow Label value of 0 used when no special QoS requested (the common case today)

- **This part of IPv6 is standardised as RFC 3697**

IPv6 Support for Diff-Serv

- **8-bit Traffic Class field to identify specific classes of packets needing special QoS**

  same as new definition of IPv4 Type-of-Service byte

  may be initialized by source or by router enroute; may be rewritten by routers enroute

  traffic Class value of 0 used when no special QoS requested (the common case today)

IPv6 Standards

- Core IPv6 specifications are IETF Draft Standards → well-tested & stable

  IPv6 base spec, ICMPv6, Neighbor Discovery, PMTU Discovery,...

- Other important specs are further behind on the standards track, but in good shape

  mobile IPv6, header compression,...

  for up-to-date status: playground.sun.com/ipv6

- 3GPP UMTS Rel. 5 cellular wireless standards mandate IPv6; also being considered by 3GPP2

IPv6 Status – Standardisation

- **Several key components on standards track…**

Specification (RFC2460)	Neighbour Discovery (RFC2461)
ICMPv6 (RFC2463)	IPv6 Addresses (RFC3513/3587)
RIP (RFC2080)	BGP (RFC2545)
IGMPv6 (RFC2710)	OSPF (RFC2740)
Router Alert (RFC2711)	Jumbograms (RFC2675)
Autoconfiguration (RFC2462)	Radius (RFC3162)
DHCPv6 (RFC3315)	Flow Label (RFC3697)
IPv6 Mobility (RFC3775)	GRE Tunnelling (RFC2473)

- **IPv6 available over:**

PPP (RFC2023)	Ethernet (RFC2464)
FDDI (RFC2467)	Token Ring (RFC2470)
NBMA (RFC2491)	ATM (RFC2492)
Frame Relay (RFC2590)	ARCnet (RFC2497)
IEEE1394 (RFC3146)	FibreChannel (RFC3831)

Recent IPv6 "Hot Topics" in the IETF

- Multi-homing
- Address selection
- Address allocation
- DNS discovery
- 3GPP usage of IPv6
- Anycast addressing
- Scoped address architecture
- Flow-label semantics
- API issues

  (flow label, traffic class, PMTU discovery, scoping,…)

- Enhanced router-to-host info
- Site renumbering procedures
- Inter-domain multicast routing
- Address propagation and AAA issues of different access scenarios
- End-to-end security vs. firewalls
- And, of course, transition / co-existence / interoperability with IPv4 (a bewildering array of transition tools and techniques)

Note: this indicates vitality, not incompleteness, of IPv6!

Status of other IPv6 related WGs in the IETF

- **V6ops**
  - Replaces ngtrans working group
  - Focus moved to IPv6 operations from developing transition tools and techniques
- **Multi6**
  - Focus on multihoming for IPv6
  - Little progress apart from defining the problem

Conclusion

- **There is a need for IPv6**
  - **Larger address space and replacement of NATs**
- **Protocol is "ready to go" with much of the core components seeing several years field experience already**

IPv6 Routing Protocols

Routing in IPv6

- 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-ipv6-05)
- EGP : MP-BGP4 (RFC 2858 and RFC 2545)

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

EIGRP for IPv6

- Cisco EIGRP has had IPv6 protocol support added
- Uses similar CLI to existing IPv4 protocol support
- Easy deployment path for existing IPv4 EIGRP users
- In EFT images, coming soon to 12.3T

OSPFv3 overview

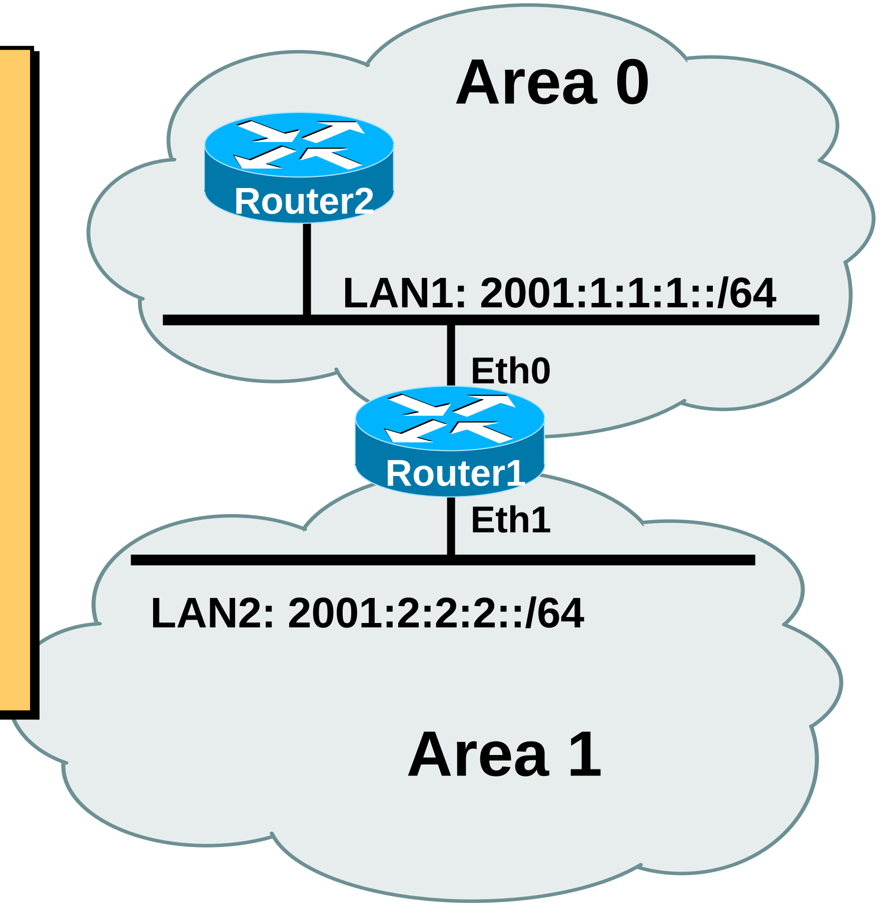
- OSPFv3 is OSPF for IPv6 (RFC 2740)
- Based on OSPFv2, with enhancements
- Distributes IPv6 prefixes
- Runs directly over IPv6
- Ships-in-the-night with OSPFv2

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

OSPFv3 configuration example

```
Router1#
 interface Ethernet0
  ipv6 address 2001:1:1:1::1/64
  ipv6 ospf 1 area 0

 interface Ethernet1
  ipv6 address 2001:2:2:2::2/64
  ipv6 ospf 1 area 1

 ipv6 router ospf 1
  router-id 1.1.1.1
  area 1 range 2001:2:2::/48
```



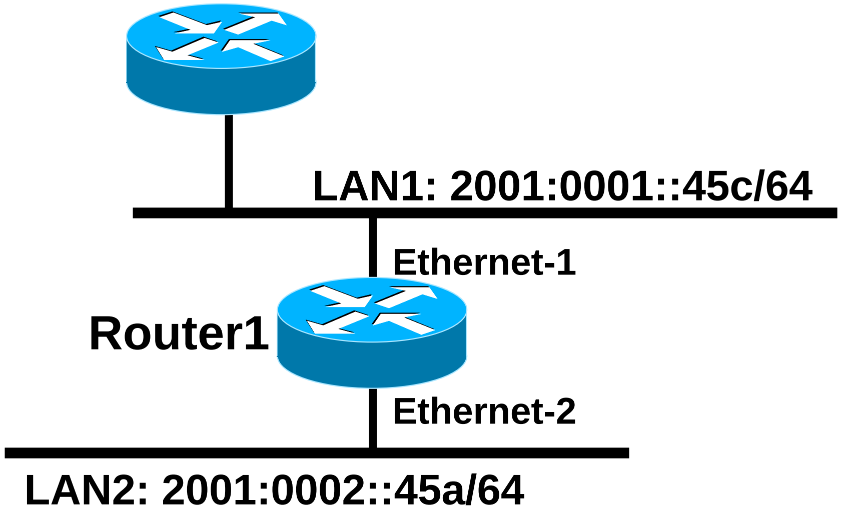
ISIS Standards History

- **IETF ISIS for Internets Working Group**
- **ISO 10589 specifies OSI IS-IS routing protocol for CLNS traffic**
  - **Tag/Length/Value (TLV) options to enhance the protocol**
  - **A Link State protocol with a 2 level hierarchical architecture.**
- **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**
- **Internet Draft defines how to add IPv6 address family support to IS-IS**
  - **www.ietf.org/internet-drafts/draft-ietf-isis-ipv6-06.txt**
- **Internet Draft introduces Multi-Topology concept for IS-IS**
  - **www.ietf.org/internet-drafts/draft-ietf-isis-wg-multi-topology-07.txt**

IS-IS for IPv6

- 2 Tag/Length/Values added to introduce IPv6 routing
- IPv6 Reachability TLV (0xEC)
  - External bit
  - Equivalent to IP Internal/External Reachability TLV's
- IPv6 Interface Address TLV (0xE8)
  - For Hello PDUs, must contain the Link-Local address
  - For LSP, must only contain the non-Link Local address
- IPv6 NLPID (0x8E) is advertised by IPv6 enabled routers

Cisco IOS IS-IS dual IP configuration




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

interface ethernet-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.

Multi-Topology IS-IS extensions

- **New TLVs attributes for Multi-Topology extensions.**

  ***Multi-topology TLV*: contains one or more multi-topology ID in which the router participates. It is theoretically possible to advertise an infinite number of topologies. This TLV is included in IIH and the first fragment of a LSP.**

  ***MT Intermediate Systems TLV*: this TLV appears as many times as the number of topologies a node supports. A MT ID is added to the extended IS reachability TLV type 22.**

  ***Multi-Topology Reachable IPv4 Prefixes TLV*: this TLV appears as many times as the number of IPv4 announced by an IS for a give n MT ID. Its structure is aligned with the extended IS Reachability TLV Type 236 and add a MT ID.**

  ***Multi-Topology Reachable IPv6 Prefixes TLV*: this TLV appears as many times as the number of IPv6 announced by an IS for a given MT ID. Its structure is aligned with the extended IS Reachability TLV Type 236 and add a MT ID.**

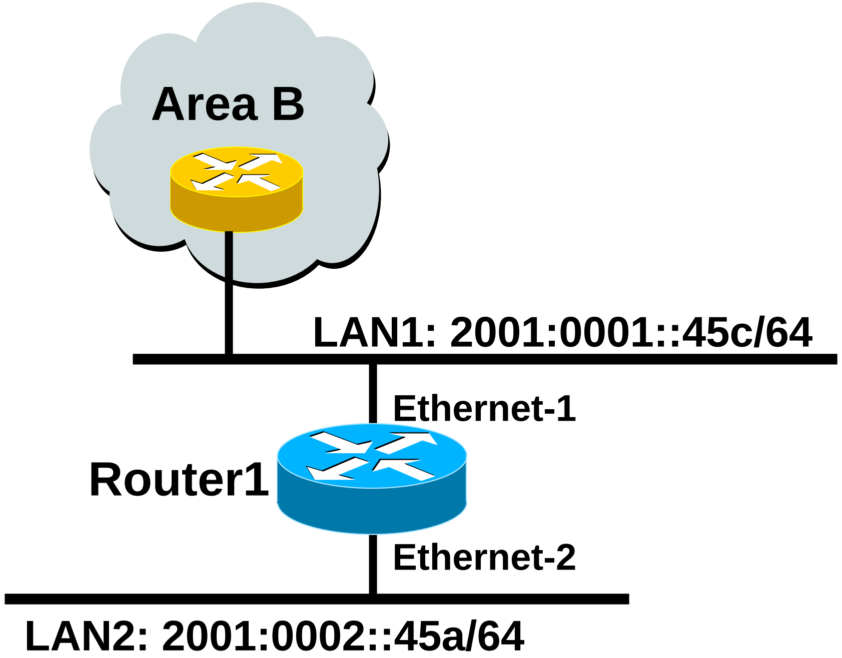
- **Multi-Topology ID Values**

  Multi-Topology ID (MT ID) standardized and in use in Cisco IOS:

  MT ID #0 – “standard” topology for IPv4/CLNS

  MT ID #2 – IPv6 Routing Topology.

Cisco IOS Multi-Topology ISIS 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-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-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
```

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)

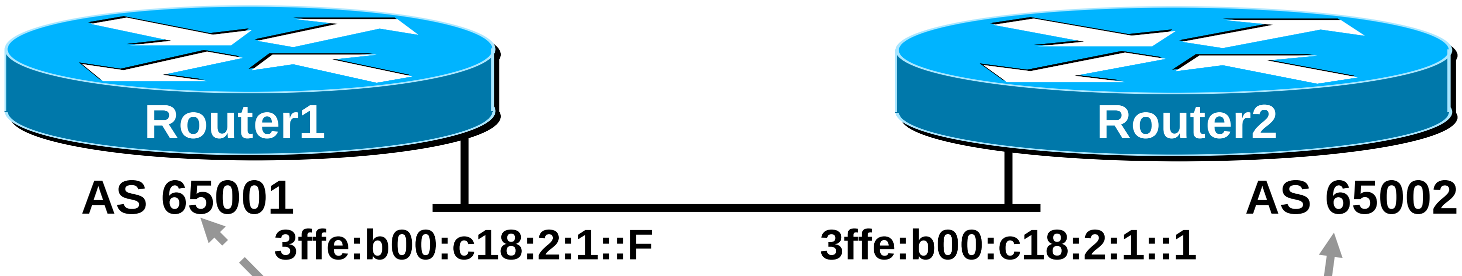
    Sub-AFI = 1 (NLRI is used for unicast)

    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)

A Simple MP-BGP Session




```
Router1#
interface Ethernet0
 ipv6 address 3FFE:B00:C18:2:1::F/64
!
router bgp 65001
 bgp router-id 10.10.10.1
 no bgp default ipv4-unicast
 neighbor 3FFE:B00:C18:2:1::1 remote-as 65002
 address-family ipv6
  neighbor 3FFE:B00:C18:2:1::1 activate
  neighbor 3FFE:B00:C18:2:1::1 prefix-list bgp65002in in
  neighbor 3FFE:B00:C18:2:1::1 prefix-list bgp65002out out
  exit-address-family
```

Routing Protocols for IPv6 Summary

- **Support for IPv6 in the major routing protocols**
- **More details for OSPF and BGP in following slides**

OSPF for IPv6

OSPFv2

- April 1998 was the most recent revision (RFC 2328)
- OSPF uses a 2-level hierarchical model
- SPF calculation is performed independently for each area
- Typically faster convergence than DVRPs
- Relatively low, steady state bandwidth requirements

OSPFv3 overview

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

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 / OSPFv2 Differences

- OSPFv3 runs over a link, rather than a subnet
- Multiple instances per link
- OSPFv2 topology not IPv6-specific
  - Router ID
  - Link ID
- Standard authentication mechanisms
- Uses link-local addresses
- Generalized flooding scope
- Two new LSA types

LSA Type Review

	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

Link LSA

- A link LSA per link
- Link local scope flooding on the link with which they are associated
- Provide router link local address
- List all IPv6 prefixes attached to the link
- Assert a collection of option bit for the Router-LSA

Inter-Area Prefix LSA

- **Describes the destination outside the area but still in the AS**
- **Summary is created for one area, which is flooded out in all other areas**
- **Originated by an ABR**
- **Only intra-area routes are advertised into the backbone**
- **Link State ID simply serves to distinguish inter-area-prefix-LSAs originated by the same router**
- **Link-local addresses must never be advertised in inter-area- prefix-LSAs**

Configuring OSPFv3 in Cisco IOS® Software

- **Similar to OSPFv2**
  - **Prefixing existing Interface and Exec mode commands with “ipv6”**
- **Interfaces configured directly**
  - **Replaces `network` command**
- **“Native” IPv6 router mode**
  - **Not a sub-mode of `router ospf`**

Configuration Modes in OSPFv3

- **Entering router mode**

  [no] ipv6 router ospf <process ID>

- **Entering interface mode**

  [no] ipv6 ospf <process ID> area <area ID>

- **Exec mode**

  [no] show ipv6 ospf [<process ID>]

  clear ipv6 ospf [<process ID>]

Cisco IOS OSPFv3 Specific Attributes

- **Configuring area range**

  [no] area <area ID> range <prefix>/<prefix length>

- **Showing new LSA**

  show ipv6 ospf [<process ID>] database link

  show ipv6 ospf [<process ID>] database prefix

OSPFv3 Debug Commands

- **Adjacency is not appearing**

  [no] debug ipv6 ospf adj

  [no] debug ipv6 ospf hello

- **SPF is running constantly**

  [no] debug ipv6 ospf spf

  [no] debug ipv6 ospf flooding

  [no] debug ipv6 ospf events

  [no] debug ipv6 ospf lsa-generation

  [no] debug ipv6 ospf database-timer

- **General purpose**

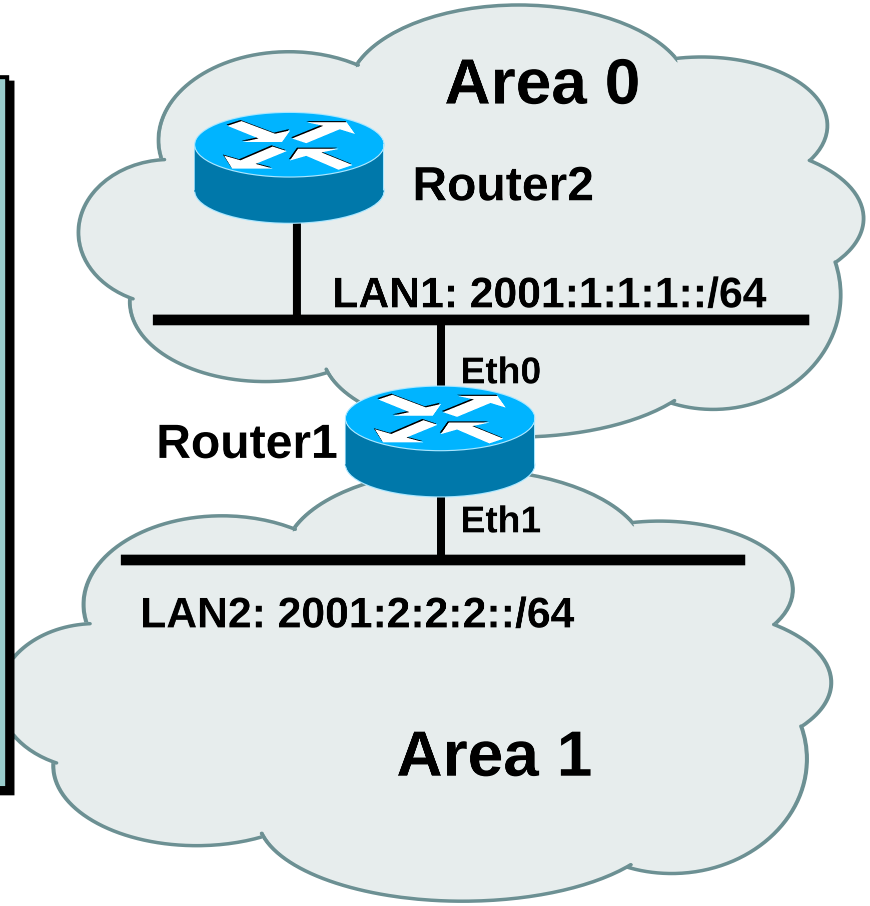
  [no] debug ipv6 ospf packets

  [no] debug ipv6 ospf retransmission

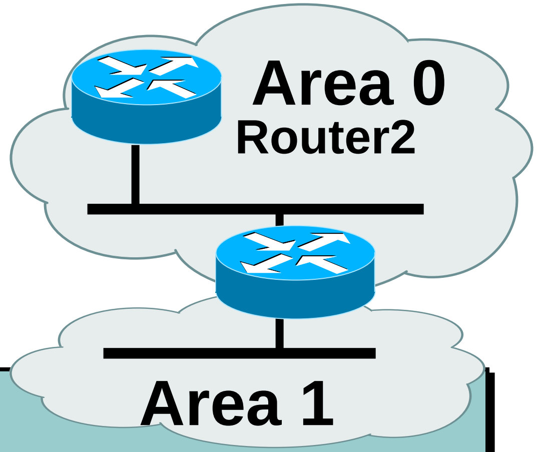
  [no] debug ipv6 ospf tree

OSPFv3 configuration example

```
Router1#
 interface Ethernet0
  ipv6 address 2001:1:1:1::1/64
  ipv6 ospf 1 area 0

 interface Ethernet1
  ipv6 address 2001:2:2:2::2/64
  ipv6 ospf 1 area 1

 ipv6 router ospf 1
  router-id 1.1.1.1
  area 1 range 2001:2:2::/48
```



Cisco IOS OSPFv3 Display




```
Router 2# show ipv6 route ospf
IPv6 Routing Table - 9 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
O   2001:1:1:2::1/128 [110/1]
     via FE80::205:5FFF:FEAF:2C38, Ethernet0
OI  2001:2:2::/48 [110/2]
     via FE80::205:5FFF:FEAF:2C38, Ethernet0
```

Cisco IOS OSPFv3 Database Display

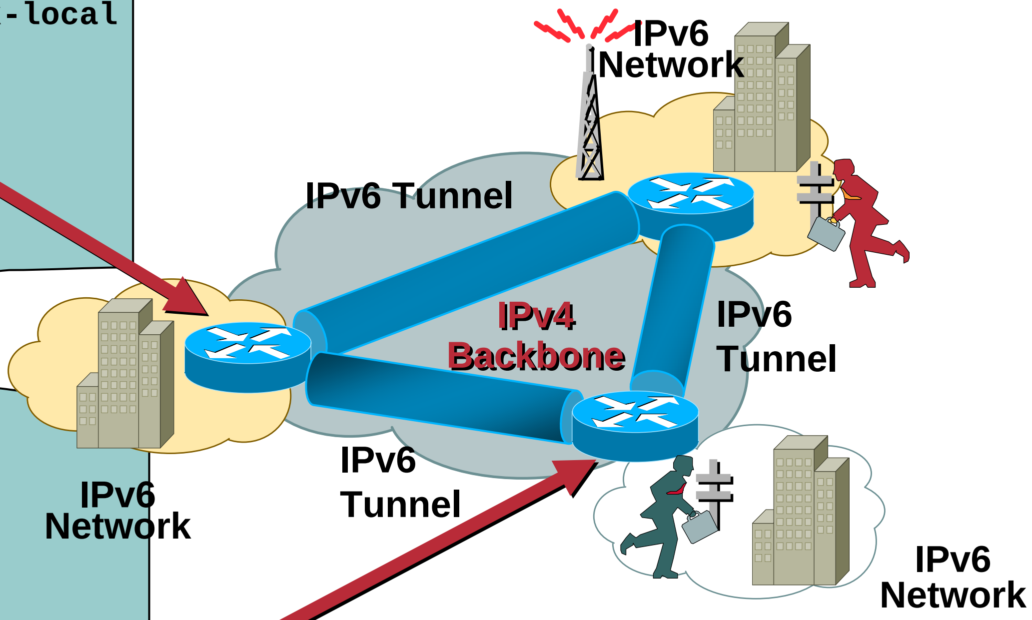
```
Router2# show ipv6 ospf database

OSPF Router with ID (3.3.3.3) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
0               1.1.1.1         2009        0x8000000A 0x2DB1   1
0               3.3.3.3         501         0x80000007 0xF3E6   1

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
7               1.1.1.1         480         0x80000006 0x3BAD

                Inter Area Prefix Link States (Area 0)

ADV Router      Age         Seq#        Prefix
1.1.1.1         1761        0x80000005  2001:2:2:2::/64
1.1.1.1         982         0x80000005  2001:2:2:4::2/128

                Link (Type-8) Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Interface
11              3.3.3.3         245         0x80000006 0xF3DC   Lo0
7               1.1.1.1         236         0x80000008 0x68F    Fa2/0
7               3.3.3.3         501         0x80000008 0xE7BC   Fa2/0

                Intra Area Prefix Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Ref lstype
0               1.1.1.1         480         0x80000008 0xD670   0x2001
107             1.1.1.1         236         0x80000008 0xC05F   0x2002
0               3.3.3.3         245         0x80000006 0x3FF7   0x2001
```

Cisco IOS OSPFv3 Detailed LSA Display

```
show ipv6 ospf 1 database inter-area prefix

  LS age: 1714
  LS Type: Inter Area Prefix Links
  Link State ID: 0
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000006
  Checksum: 0x25A0
  Length: 36
  Metric: 1
  Prefix Address: 2001:2:2:2::
  Prefix Length: 64, Options: None

 show ipv6 ospf 1 database link

  LS age: 283
  Options: (IPv6 Router, Transit Router, E-Bit, No Type 7-to-5, DC)
  LS Type: Link-LSA (Interface: Loopback0)
  Link State ID: 11 (Interface ID)
  Advertising Router: 3.3.3.3
  LS Seq Number: 80000007
  Checksum: 0xF1DD
  Length: 60
  Router Priority: 1
  Link Local Address: FE80::205:5FFF:FEAC:1808
  Number of Prefixes: 2
  Prefix Address: 2001:1:1:3::
  Prefix Length: 64, Options: None
  Prefix Address: 2001:1:1:3::
  Prefix Length: 64, Options: None
```

OSPFv3 on IPv6 Tunnels over IPv4

```
interface Tunnel0
 no ip address
 ipv6 address 2001:0001::45A/64
 ipv6 address FE80::10:7BC2:ACC9:10 link-local
 ipv6 router ospf 1 area 0
 tunnel source Ethernet1
 tunnel destination 10.42.2.1
 tunnel mode ipv6ip
!
ipv6 router ospf 1
```




```
interface Tunnel0
 no ip address
 ipv6 address 2001:0001::45C/64
 ipv6 address FE80::10:7BC2:B280:11 link-local
 ipv6 router ospf 1 area 0
 tunnel source Ethernet2
 tunnel destination 10.42.1.1
 tunnel mode ipv6ip
!
ipv6 router ospf 1
```

Conclusion

- **Based on existing OSPFv2 implementation**
- **Similar CLI and functionality**
- **Cisco IOS Software availability:**

  Release 12.2(15)T and 12.3

  Release 12.2(18)S for Cisco 7000 Series Routers and Cisco Catalyst 6000 Series Switches

  Release 12.0(24)S the Cisco 12000 Series Internet Routers

BGP Enhancements for IPv6

Adding IPv6 to BGP…

- **RFC2858**

  Defines *Multi-protocol Extensions for BGP4*

  Enables BGP to carry routing information of protocols other than IPv4

  - **e.g. MPLS, IPv6, Multicast etc**

  Exchange of multiprotocol NLRI must be negotiated at session startup

- **RFC2545**

  Use of BGP Multiprotocol Extensions for IPv6 Inter-Domain Routing

Adding IPv6 to BGP…

- **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 contains one or more Triples:**

  AFI Address Family Information

  Next-Hop Information (must be of the same address family)

  NLRI Network Layer Reachability Information

Adding IPv6 to BGP…

- **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 Considerations

- **Rules for constructing the NEXTHOP attribute:**

  When two peers share a common subnet the NEXTHOP information is formed by a global address and a link local address

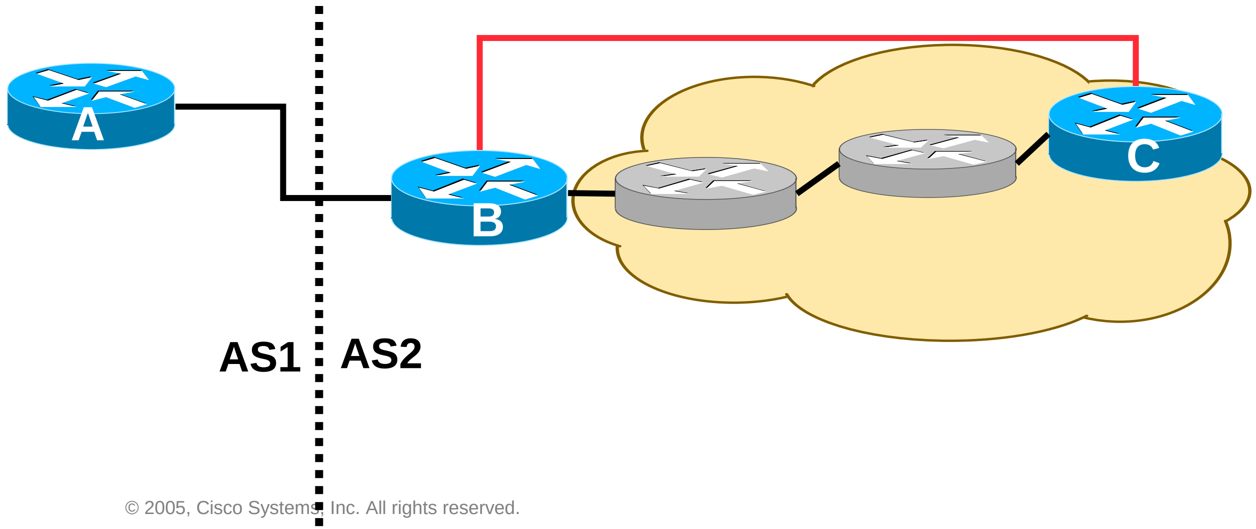
  Redirects in IPv6 are restricted to the usage of link local addresses

Routing Information

- **Independent operation**
  - **One RIB per protocol**
    - **e.g. IPv6 has its own BGP table**
  - **Distinct policies per protocol**
- **Peering sessions <u>can</u> be shared when the topology is congruent**

BGP next-hop attribute

- **Next-hop contains a global IPv6 address (or potentially a link local address)**
- **Link local address as a next-hop is only set if the BGP peer shares the subnet with both routers (advertising and advertised)**



More BGP considerations

- **TCP Interaction**

  BGP runs on top of TCP

  This connection could be set up either over IPv4 or IPv6

- **Router ID**

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

    BGP identifier is a 32 bit integer currently generated from the router identifier – which is generated from an IPv4 address on the router

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

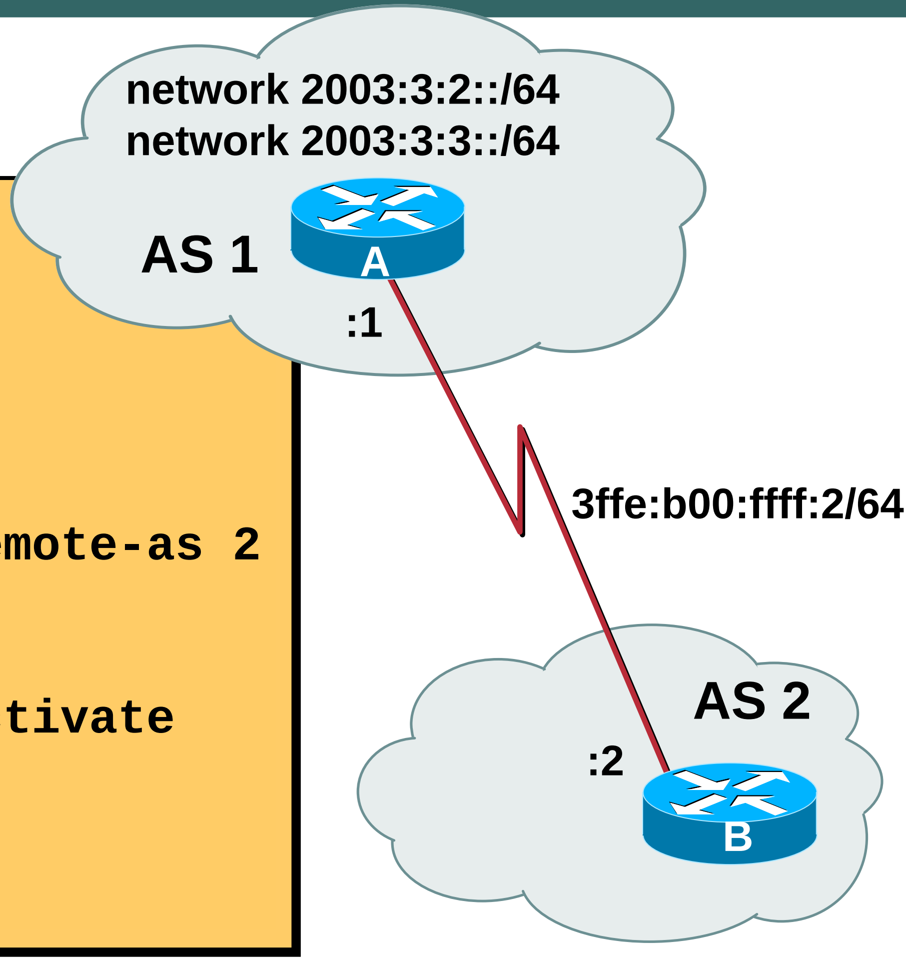
BGP Configuration

- **Two options for configuring iBGP peering**
- **Using link local addressing**
  - **ISP uses FE80:: addressing for iBGP neighbours**
  - **NOT RECOMMENDED**
    - **There are plenty of IPv6 addresses**
    - **Configuration complexity**
- **Using global unicast addresses**
  - **As with IPv4**
  - **RECOMMENDED**

BGP Configurations
Non Link Local Peering

Router A

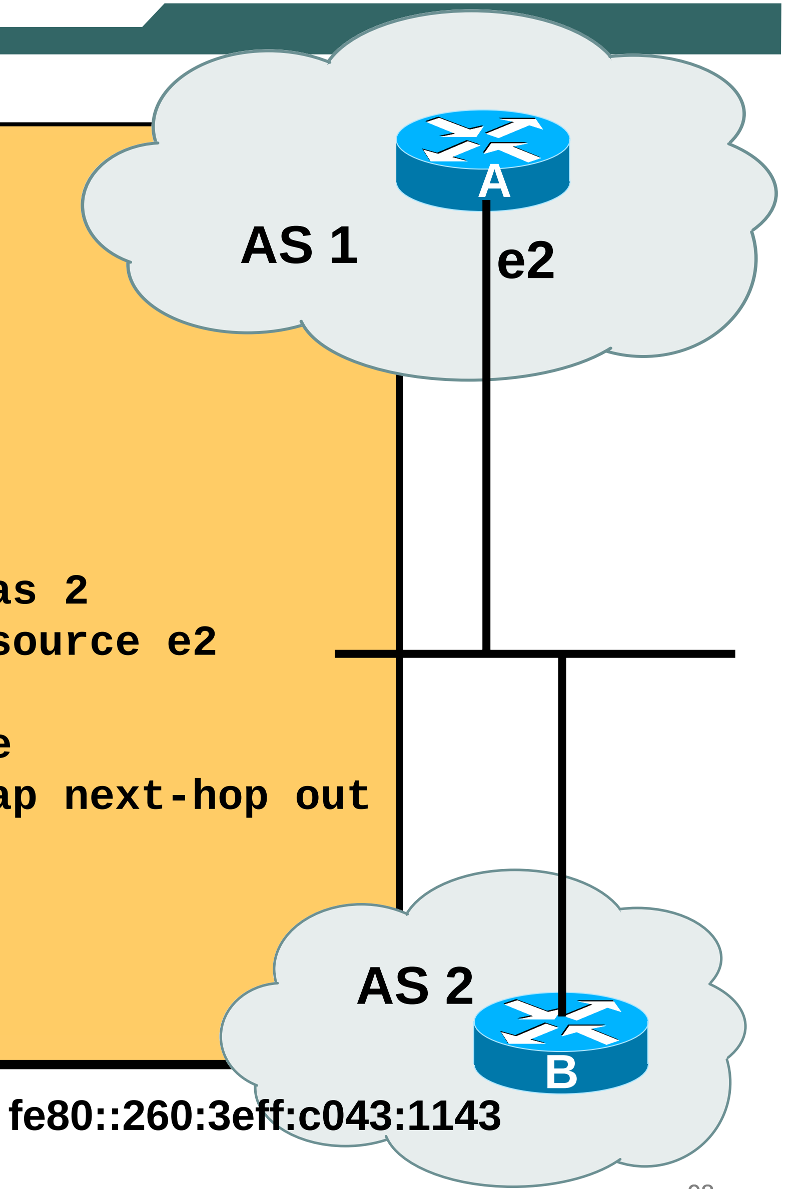
```
router bgp 1
 no bgp default ipv4 unicast
 bgp router-id 1.1.1.1
 neighbor 3ffe:b00:ffff:2::2 remote-as 2
!
 address-family ipv6
 neighbor 3ffe:b00:ffff:2::2 activate
 network 2003:3:2::/64
 network 2003:3:3::/64
!
```



BGP Configurations
Link Local Peering

Router A

```
interface e2
 ipv6 address 2001:412:ffco:1::1/64
!
router bgp 1
 no bgp default ipv4 unicast
 bgp router-id 1.1.1.1
 neighbor fe80::260:3eff:c043:1143 remote-as 2
 neighbor fe80::260:3eff:c043:1143 update source e2
address-family ipv6
 neighbor fe80::260:3eff:c043:1143 activate
 neighbor fe80::260:3eff:c043:1143 route-map next-hop out
!
route-map next-hop permit 5
 set ipv6 next-hop 2001:412:ffco:1::1
!
```



BGP Configuration
Filtering Prefixes

- **IOS Prefix-list is used for filtering prefixes in IPv4**
  - **And for IPv6 too!**
- **Example:**

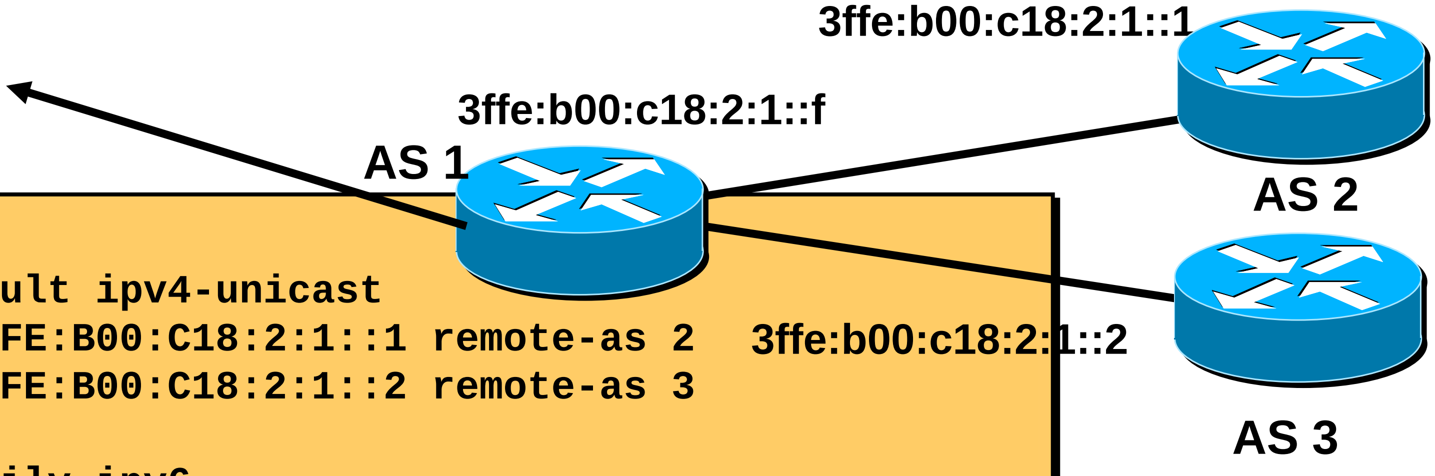
```
ipv6 prefix-list in-filter seq 5 permit 3ffe::/16 le 32
ipv6 prefix-list in-filter seq 6 permit 2001::/16 le 48
```

- **Apply to the BGP neighbor:**

```
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
 neighbor 3ffe:b00:ffff:2::2 prefix-list in-filter in
```

BGP Configuration
Manipulating Attributes

- **Prefer routes from AS 2 (local preference)**




```
router bgp 1
 no bgp default ipv4-unicast
 neighbor 3FFE:B00:C18:2:1::1 remote-as 2
 neighbor 3FFE:B00:C18:2:1::2 remote-as 3
!
 address-family ipv6
 neighbor 3FFE:B00:C18:2:1::1 activate
 neighbor 3FFE:B00:C18:2:1::1 prefix-list in-filter in
 neighbor 3FFE:B00:C18:2:1::1 route-map fromAS2 in
 neighbor 3FFE:B00:C18:2:1::2 activate
 neighbor 3FFE:B00:C18:2:1::2 prefix-list in-filter in
 network 3FFE:B00::/24
 exit-address-family
!
route-map fromAS2 permit 10
 set local-preference 120
```

BGP Configuration
Carrying IPv4 inside IPv6 peering

- **IPv4 prefixes can be carried inside an IPv6 peering**

  Note that we need to "fix" the next-hop

- **Example**

```
router bgp 1
 neighbor 3ffe:b00:ffff:2::2 remote-as 2
!
address-family ipv4
 neighbor 3ffe:b00:ffff:2::2 activate
 neighbor 3ffe:b00:ffff:2::2 route-map ipv4 in
!
route-map ipv4 permit 10
 set ip next-hop 131.108.1.1
```

BGP Status Commands

- **IPv6 BGP show commands take *ipv6* as argument**

  show bgp ipv6 unicast *parameter*

```
Router1#show bgp ipv6 unicast 2017::/96
BGP routing table entry for 2017::/96, version 11
Paths: (1 available, best #1)
Local
    3FFE:B00:C18:2:1::1 from 3FFE:B00:C18:2:1::1 (10.10.20.2)
      Origin incomplete, localpref 100, valid, internal, best
```

BGP Status Commands

Display summary information regarding the state of the BGP neighbours

show bgp ipv6 unicast summary

```
BGP router identifier 128.107.240.254, local AS number 109
BGP table version is 400386, main routing table version 400386
585 network entries using 78390 bytes of memory
9365 path entries using 674280 bytes of memory
16604 BGP path attribute entries using 930384 bytes of memory
8238 BGP AS-PATH entries using 228072 bytes of memory
42 BGP community entries using 1008 bytes of memory
9451 BGP route-map cache entries using 302432 bytes of memory
584 BGP filter-list cache entries using 7008 bytes of memory
BGP using 2221574 total bytes of memory
Dampening enabled. 3 history paths, 11 dampened paths
2 received paths for inbound soft reconfiguration
BGP activity 63094/62437 prefixes, 1887496/1878059 paths, scan interval 60 secs

Neighbor        V    AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
2001:1458:C000::64B:4:1
                4   513 1294728  460213   400386    0    0 3d11h         498
```

Neighbour Information **BGP Messages Activity**

Conclusion

- **BGP extended to support multiple protocols**
  - **IPv6 is but one more address family**
- **Operators experienced with IPv4 BGP should have no trouble adapting**
  - **Configuration concepts and CLI is familiar format**

IPv6 Filtering

IPv6 Standard Access Control Lists

- IPv6 access-lists (ACL) are used to filter traffic and restrict access to the router
- IPv6 prefix-lists are used to filter routing protocol updates.
- IPv6 Standard ACL (Permit/Deny)
  - IPv6 source/destination addresses
  - IPv6 prefix-lists
  - On Inbound and Outbound interfaces

IPv6 Extended ACL

- **Adds support for IPv6 option header and upper layer filtering**
- **Only named access-lists are supported for IPv6**
- **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.

IPv6 Extended ACL overview

- CLI mirrors IPv4 extended ACL CLI
- Implicit permit rules, enable neighbor discovery
- ULP, DSCP, flow-label,… matches
- Logging
- Time-based
- Reflexive
- CEFv6 and dCEFv6 ACL feature support

IPv6 ACL Implicit Rules

- **Implicit permit rules, enable neighbor discovery**

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

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

IPv6 Extended ACL Match

- TCP/UDP/SCTP and ports (eq, lt, gt, neq, range)
- ICMPv6 code and type
- Fragments
- Routing Header
- Undetermined transport

  The first unknown NH can be matched against (numerically rather than by name).

  Since an unknown NH cannot be traversed, the ULP cannot be determined.

IPv6 Extended ACL

- **Logging**

```
(conf-ipv6-acl)# permit tcp any any log-input
(conf-ipv6-acl)# permit ipv6 any any log
```

- **Time based**

```
(conf)# time-range bar
(conf-trange)# periodic daily 10:00 to 13:00
(conf-trange)# ipv6 access-list tin
(conf-ipv6-acl)# deny tcp any any eq www time-range bar
(conf-ipv6-acl)# permit ipv6 any any
```

IPv6 ACL Reflexive

- **Reflect**

  A reflexive ACL is created dynamically, when traffic matches a permit entry containing the reflect keyword.

  The reflexive ACL mirrors the permit entry and times out (by default after 3 mins), unless further traffic matches the entry (or a FIN is detected for TCP traffic).

  The timeout keyword allows setting a higher or lower timeout value.

  Reflexive ACLs can be applied to TCP, UDP, SCTP and ICMPv6.

- **Evaluate**

  Apply the packet against a reflexive ACL.

  Multiple evaluate statements are allowed per ACL.

  The implicit deny any any rule does not apply at the end of a reflexive ACL; matching continues after the evaluate in this case.

Cisco IOS IPv6 ACL CLI (1)

- **Entering address-family sub-mode**

  [no] ipv6 access-list <name>

  Add or delete an ACL.

- **IPv6 address-family sub-mode**

  [no] permit | deny ipv6 | <protocol> any | host <src> | src/len [sport] any | host <dest> | dest/len [dport] [reflect <name> [timeout <secs>]] [fragments] [routing] [dscp <val>] [flow-label <val>][time-range <name>] [log | log-input] [sequence <num>]

  Permit or deny rule defining the acl entry. Individual entries can be inserted or removed by specifying the sequence number.

  Protocol is one of TCP, UDP, SCTP, ICMPv6 or NH value.

Cisco IOS IPv6 ACL CLI (2)

[no] evaluate

Evaluate the dynamically created acl via the permit reflect keyword.

[no] remark

User description of an ACL.

- **Leaving the sub-mode**

  exit

- **Showing the IPv6 ACL configuration**

  # show ipv6 access-list [name]
  # show access-list [name]

- **Clearing the IPv6 ACL match count**

  # clear ipv6 access-list [name]
  # clear access-list [name]

Cisco IOS IPv6 ACL CLI (3)

- **Applying an ACL to an interface**

  (config-int)# ipv6 traffic-filter <acl_name> in | out

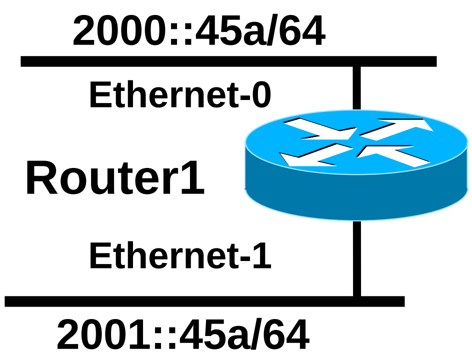
- **Restricting access to the router**

  (config-access-class)# ipv6 access-class <acl_name> in | out

- **Applying an ACL to filter debug traffic**

  (Router)# debug ipv6 packet [access-list <acl_name>] [detail]

Cisco IOS IPv6 Reflexive ACL



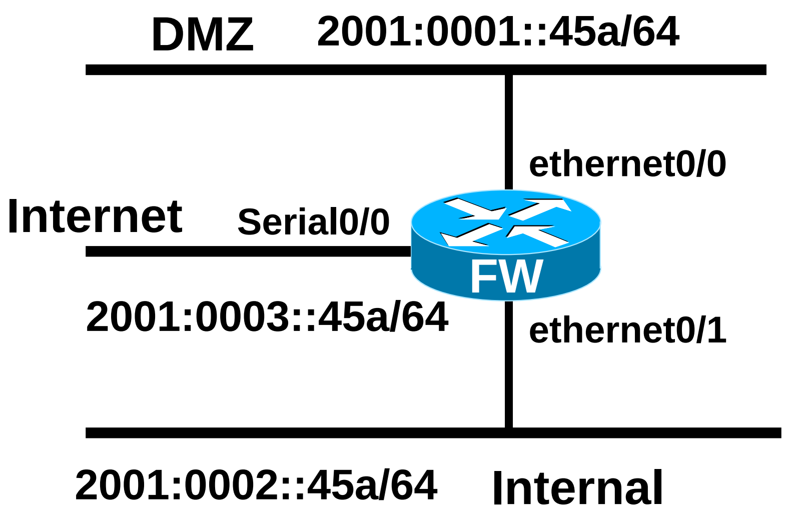
Allow www traffic via a Reflexive ACL, based on time of day

```
Router1#
interface ethernet-0
  ipv6 address 2000::45a/64
  ipv6 traffic-filter In in
  ipv6 traffic-filter Out out

interface ethernet-1
  ipv6 address 2001::45a/64
  ipv6 traffic-filter Ext-out out

ipv6 access-list In
  permit tcp host 2000::1 eq www host 2001::2 time-range
tim reflect myp
  permit icmp any any router-solicitation

ipv6 access-list Out
  evaluate myp
  evaluate another

time-range tim
  periodic daily 16:00 to 21:00
```

Cisco IOS IPv6 ACL Display

```
brum-45c#show ipv6 access-list
IPv6 access list In
   permit tcp host 2000::1 eq www host 2001::2 time-range tim (active)
reflect myp (1 match)

IPv6 access list Out
   evaluate myp
   evaluate another

IPv6 access list myp (Reflexive)
   permit tcp host 2001::2 2432 host 2000::1 eq www (timeout 180)
```

Cisco IOS IPv6 Firewall (1)



IPv6 Firewall

```
FW#
  interface ethernet0/0
   ipv6 address 2001:0001::45a/64
   ipv6 traffic-filter dmz-in6 in
  interface ethernet0/1
   ipv6 address 2001:0002::45a/64
   ipv6 traffic-filter internal-in6 in
   ipv6 traffic-filter internal-out6 out
  interface serial0/0
   ipv6 address 2001:0003::45a/64
   ipv6 traffic-filter exterior-in6 in
   ipv6 traffic-filter exterior-out6 out

  ipv6 access-list vty
   deny ipv6 any any log-input

  line vty 0 4
   ipv6 access-class vty in

  ipv6 access-list dmz-in6
   permit ipv6 host 2001:0001::100 any
```


Cisco IOS IPv6 Firewall (2)

```
ipv6 access-list internal-in6
   permit tcp 2001:0002::/64 any reflect internal-tcp
   permit udp 2001:0002::/64 any reflect internal-udp
   permit icmp 2001:0002::/64 any
   permit icmp any any router-solicitation
ipv6 access-list internal-out6
   evaluate internal-tcp
   evaluate internal-udp
   permit icmp any 2001:0002::/64 echo-reply
ipv6 access-list exterior-in6
   evaluate exterior-tcp
   evaluate exterior-udp
   remark Allow access to ftp/http server on the DMZ
   permit tcp any host 2001:0001::100 eq ftp
   permit tcp any host 2001:0001::100 eq www
   permit tcp any host 2001:0001::100 range 49152 65535
   permit icmp any any echo-reply
   permit icmp any any unreachable
   deny ipv6 any any log-input
ipv6 access-list exterior-out6
   permit tcp 2001:0002::/64 any reflect exterior-tcp
   permit udp 2001:0002:;/64 any reflect exterior-udp
```

Cisco IOS IPv6 ACL Behaviour

- **Common ACL name space.**
  - **ACL names cannot begin with a numeric.**
- **IPv6 access-lists are used to filter traffic and restrict access to the router.**
  - **IPv6 prefix-lists are used to filter routing protocol updates.**
- **Non-consecutive bit match patterns are not allowed**

Cisco IOS IPv6 ACL Troubleshooting

- ***sh ipv6 access-list [<name>]***

  Hit count for matching entries.

  (In)active time-based entries.

- ***clear ipv6 access-list [<aclname>]* to reset the hit counts for an ACL.**

- **Configure logging for an ACL entry.**

- ***debug ipv6 packet detail* to determine which packets are being dropped by an ACL.**

IPv6 Integration & Transition

IETF v6ops Working Group

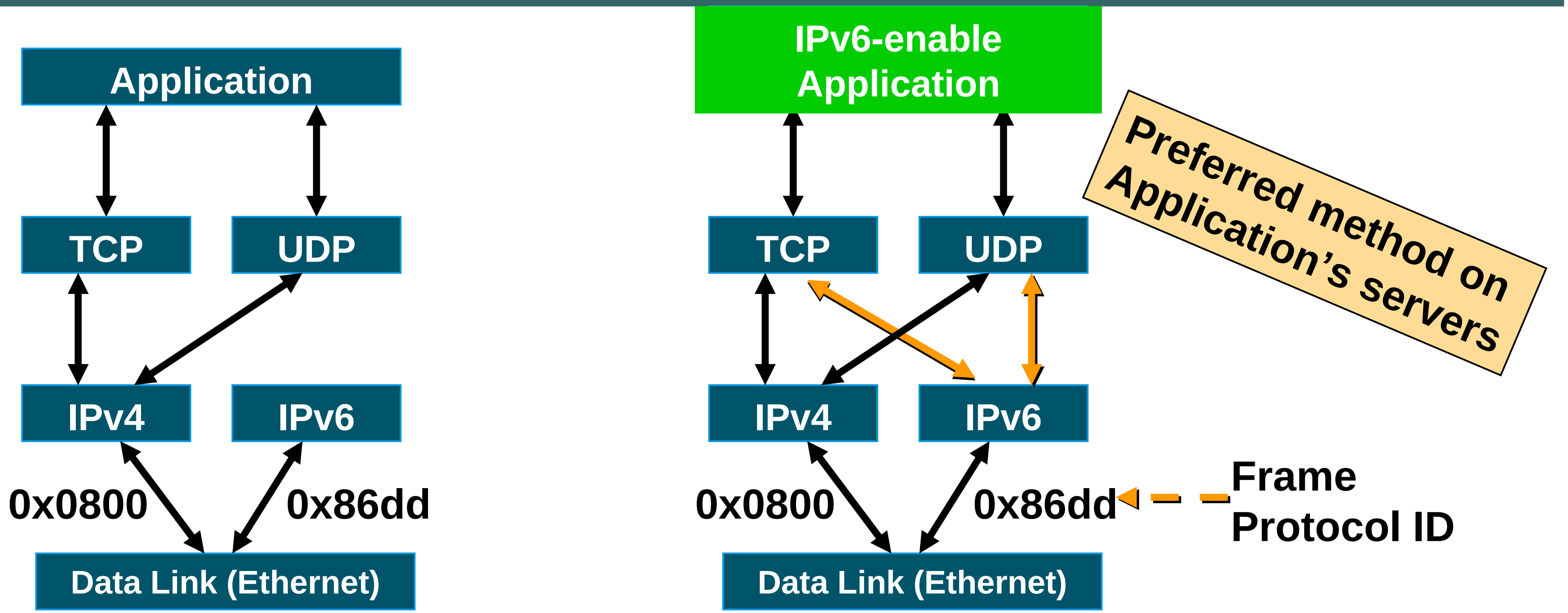
- **Define the processes by which networks can be transitioned from IPv4 to IPv6**
- **Define & specify the mandatory and optional mechanism that vendors are to implement in Hosts, Routers and other components of the Internet in order for the Transition**

www.ietf.org/html.charters/v6ops-charter.html

IPv4-IPv6 Co-existence/Transition

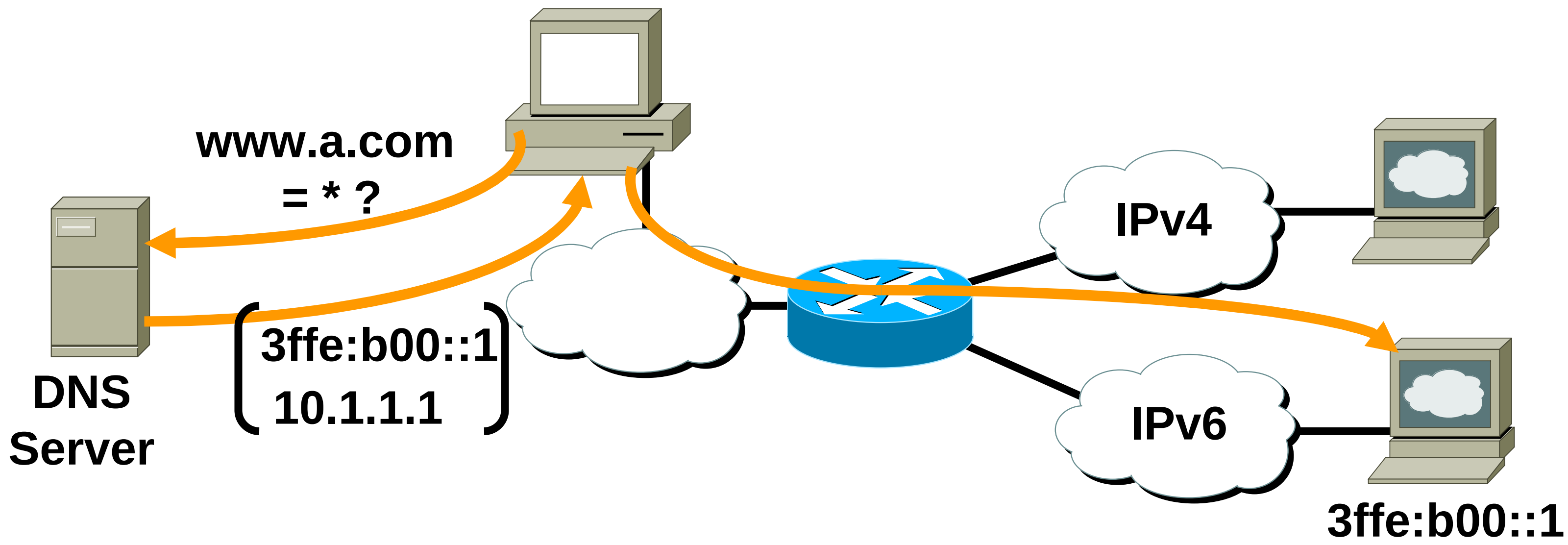
- **A wide range of techniques have been identified and implemented, basically falling into three categories:**
  - **(1) Dual-stack techniques, to allow IPv4 and IPv6 to co-exist in the same devices and networks**
  - **(2) Tunneling techniques, to avoid order dependencies when upgrading hosts, routers, 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**

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 Approach & DNS



- **In a dual stack case, an application that:**

  Is IPv4 and IPv6-enabled

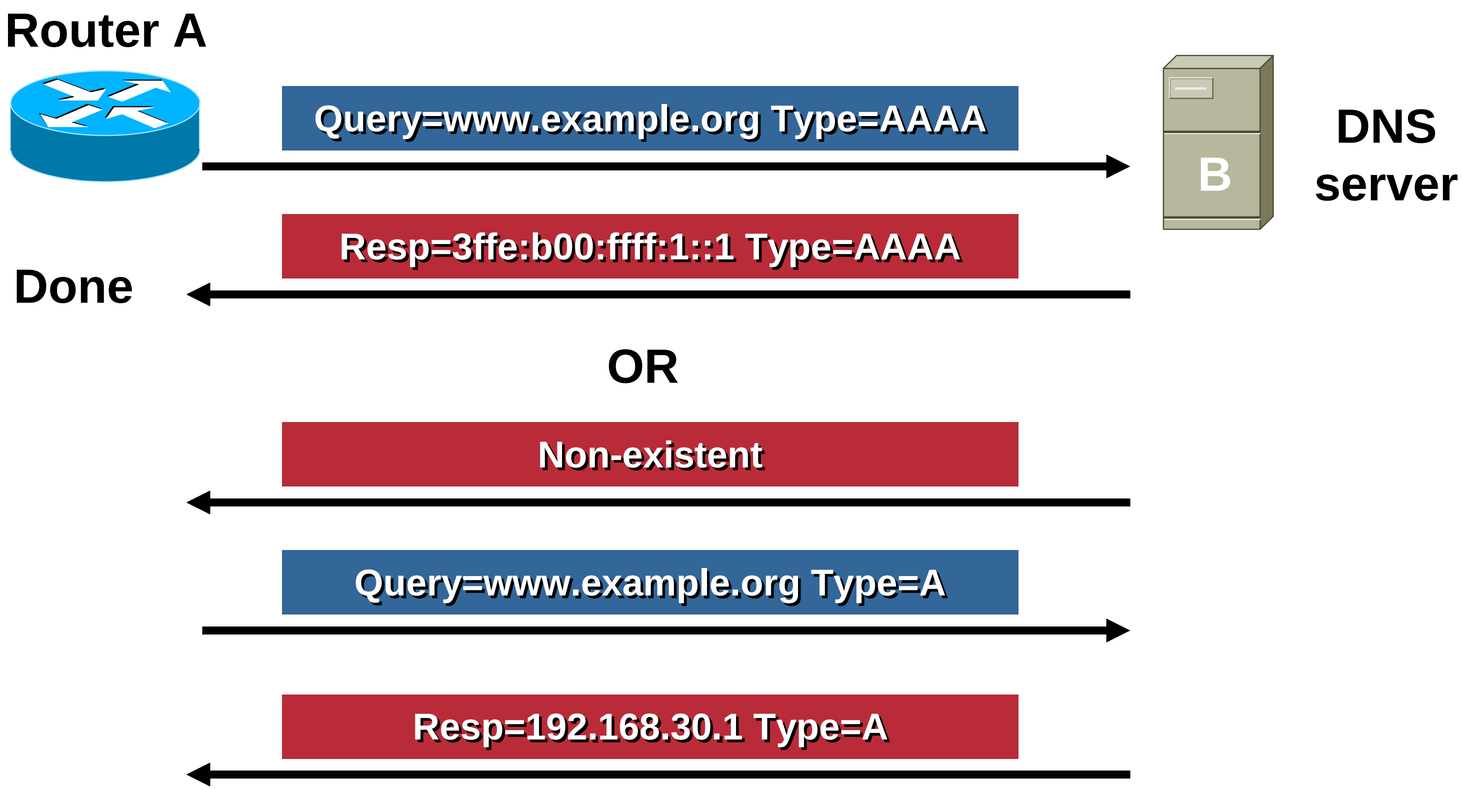
  Asks the DNS for all types of addresses

  Chooses one address and, for example, connects to the IPv6 address

IOS IPv6 DNS Client Support

- IOS supports IPv6 DNS client
- Queries DNS servers for IPv6/IPv4:
  - First tries queries for an IPv6 address (AAAA record)
  - If no IPv6 address exists, then query for an IPv4 address (A record)
  - When both IPv6 and IPv4 records exists, the IPv6 address is picked first
- Static hostname to IPv6 address can also be configured
- Note: IPv6 stacks on Windows XP, Linux, FreeBSD, etc also pick IPv6 address before IPv4 address if both exist
  - Check out www.kame.net for example

Example of DNS query



- **DNS resolver picks IPv6 AAAA record first**

IOS DNS configuration

- **DNS commands for IPv6**

  Define static name for IPv6 addresses

  ipv6 host <name> [<port>] <ipv6addr> [<ipv6addr> ...]

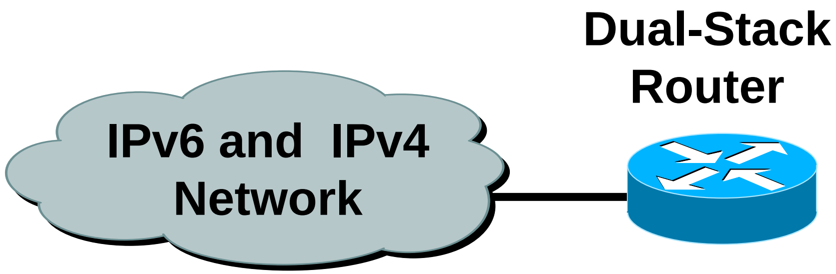
  Example: ipv6 host router1 3ffe:b00:ffff:b::1

  Configuring DNS servers to query

  ip name-server <address>

  Example: ip name-server 3ffe:b00:ffff:1::10

A 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::1/64
```

IPv4: 192.168.99.1

IPv6: 2001:410:213:1::1/64

- **IPv6-enable router**

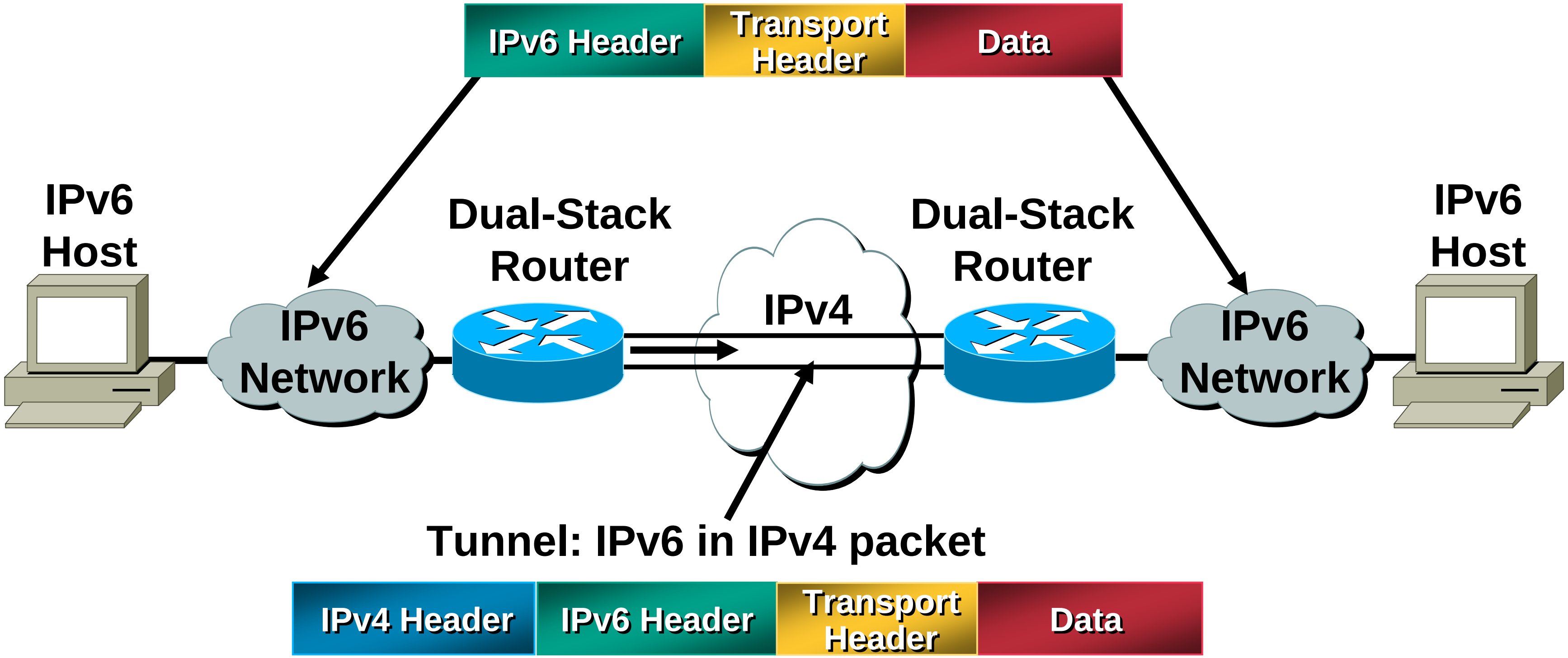
  If IPv4 and IPv6 are configured on one interface, the router is dual-stacked

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

Using Tunnels for IPv6 Deployment

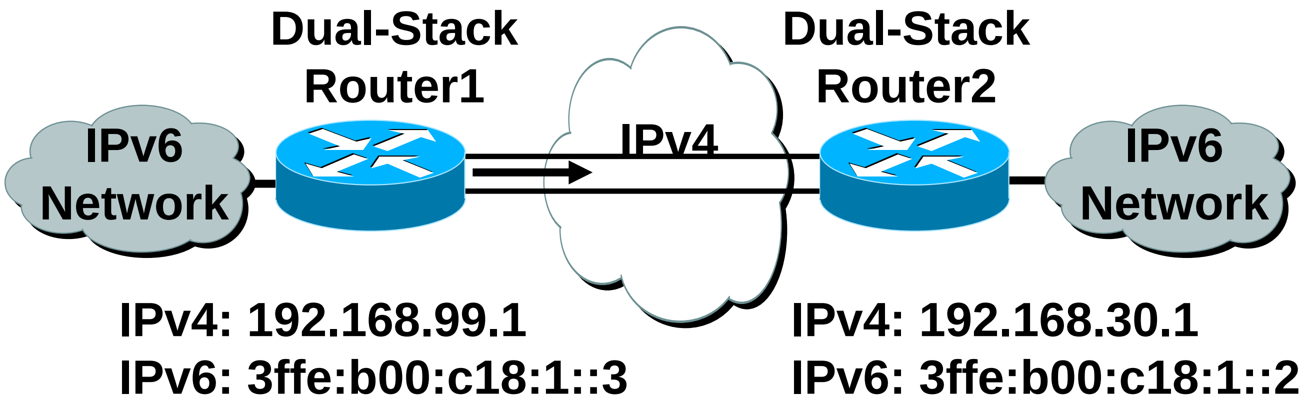
- **Many techniques are available to establish a tunnel:**
  - Manually configured
    - Manual Tunnel (RFC 2893)
    - GRE (RFC 2473)
  - Semi-automated
    - Tunnel broker
  - Automatic
    - Compatible IPv4 (RFC 2893) : Deprecated
    - 6to4 (RFC 3056)
    - 6over4: Deprecated
    - ISATAP

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 (RFC2893)

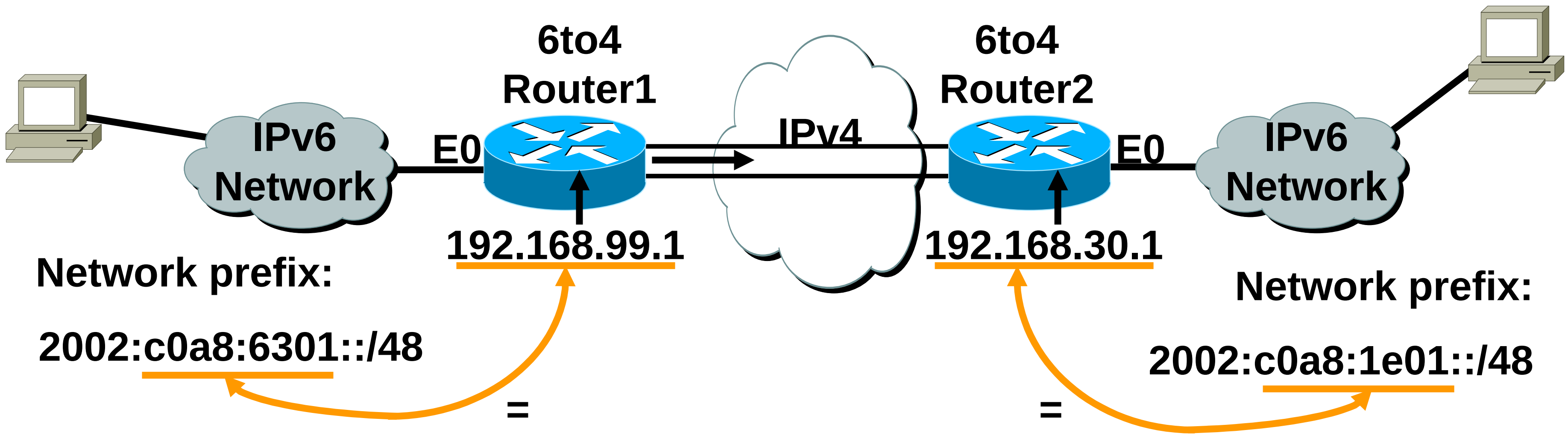



```
router1#

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**

6to4 Tunnel (RFC 3056)



- **6to4 Tunnel:**

  Is an automatic tunnel method

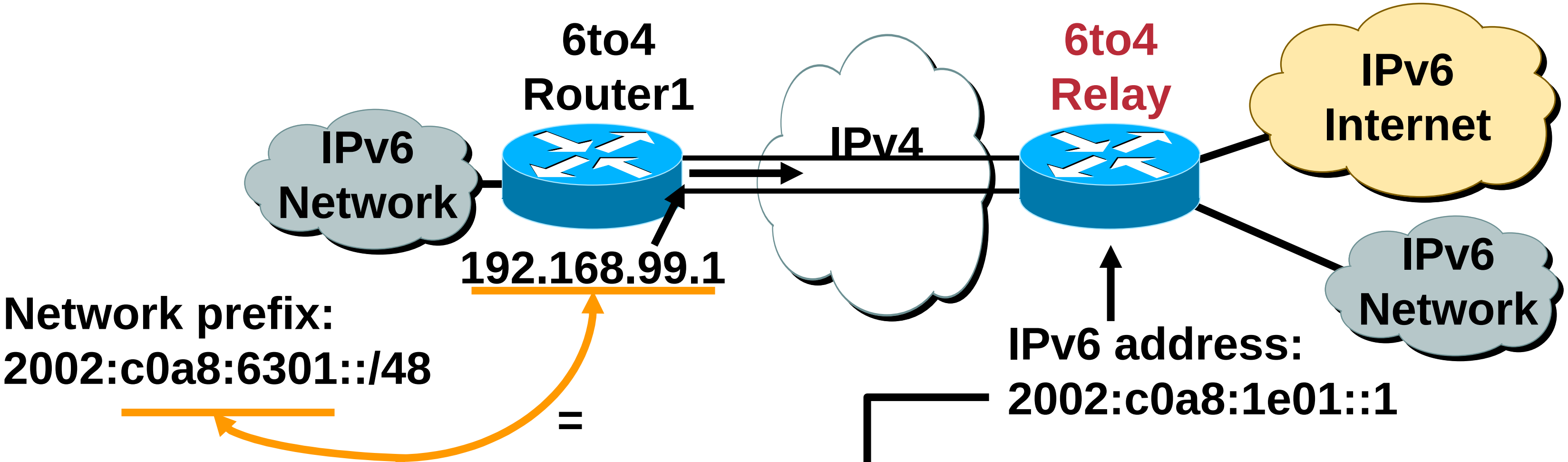
  Gives a prefix to the attached IPv6 network

  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 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
```

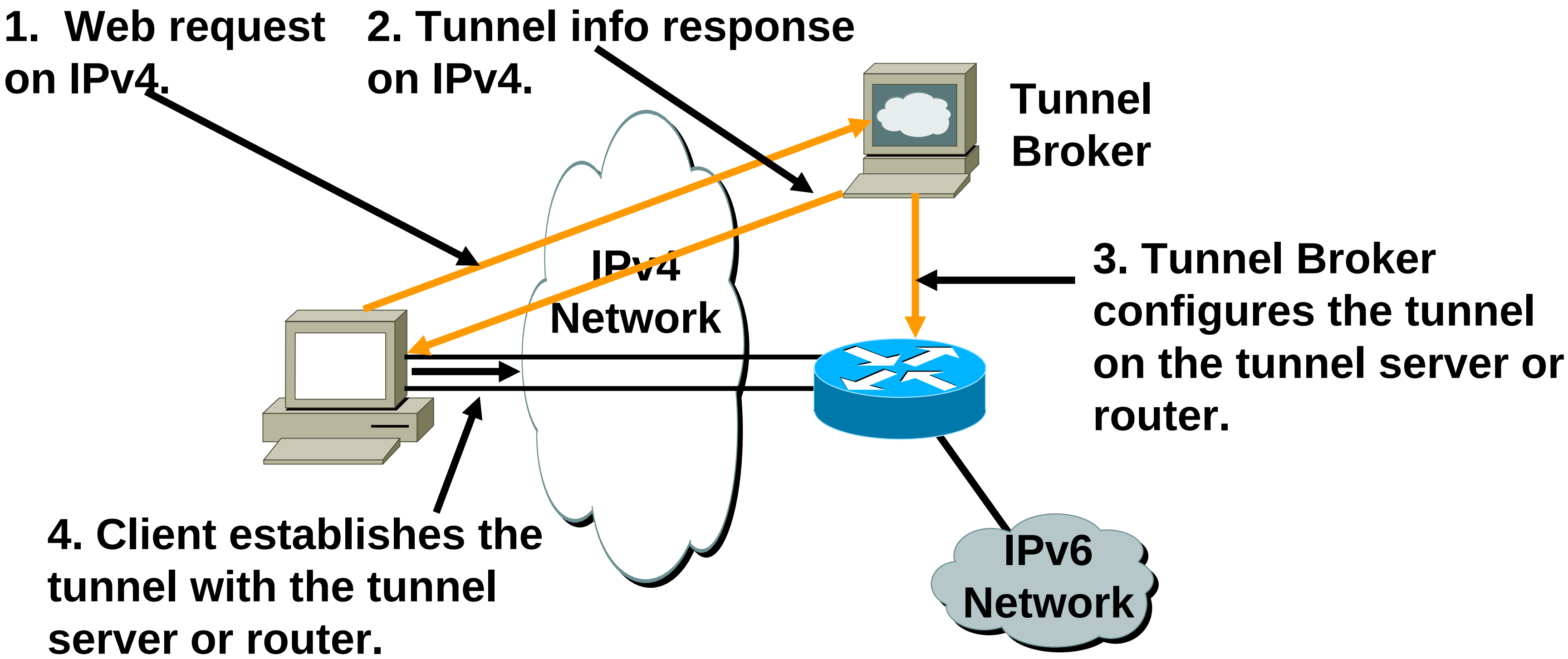
- **6to4 relay:**

  Is a gateway to the rest of the IPv6 Internet

  Default router

  Anycast address (RFC 3068) for multiple 6to4 Relay

Tunnel Broker



- **Tunnel broker:**

  Tunnel information is sent via http-ipv4

ISATAP – Intra Site Automatic Tunnel Addressing Protocol

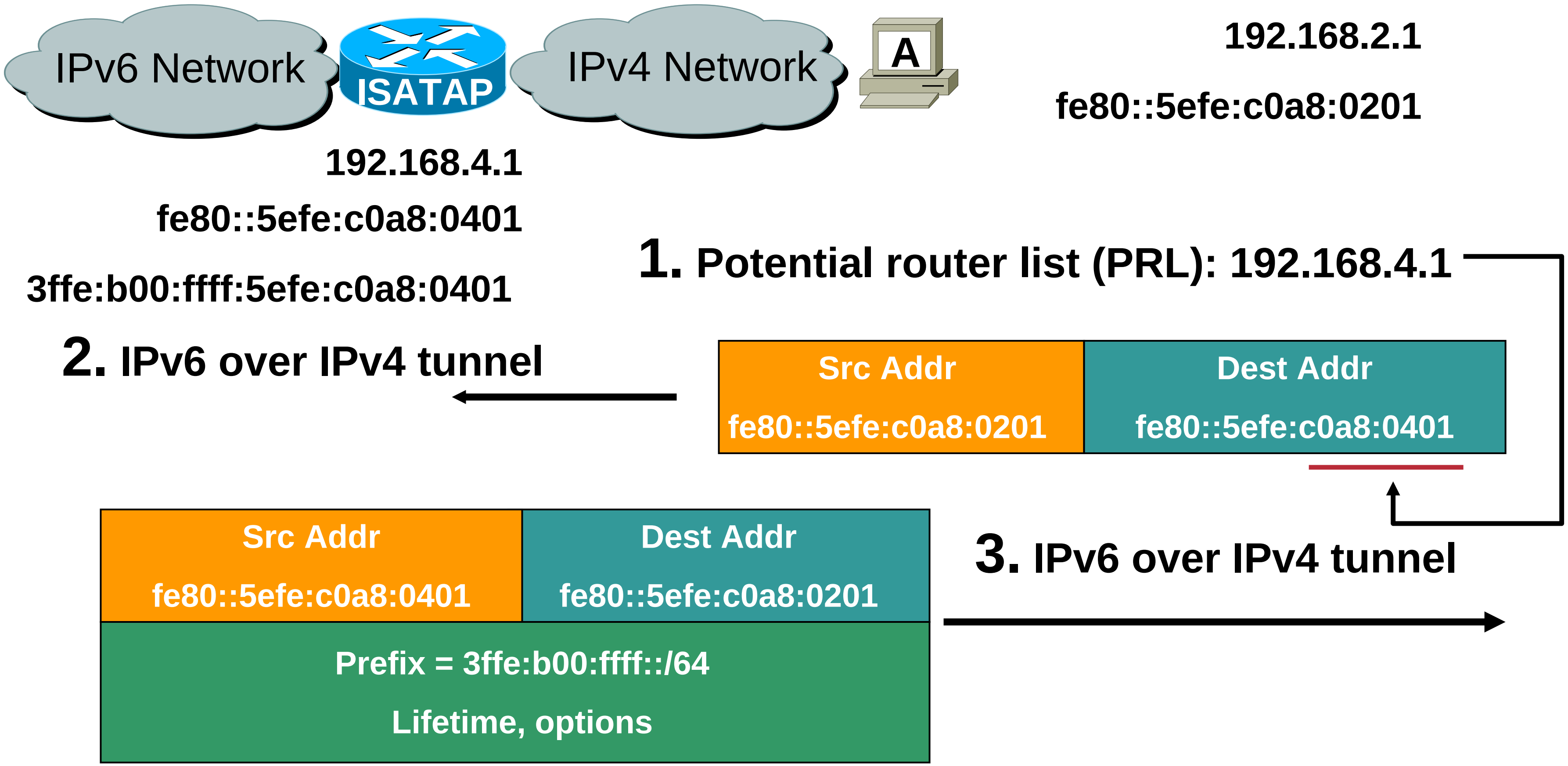
- Tunnelling of IPv6 in IPv4
- Single Administrative Domain
- Creates a virtual IPv6 link over the full IPv4 network
- Automatic tunnelling is done by a specially formatted ISATAP address which includes:
  - A special ISATAP identifier
  - The IPv4 address of the node
- ISATAP nodes are dual stack

ISATAP Addressing Format

- **An ISATAP address of a node is defined as:**
  - **A /64 prefix dedicated to the ISATAP overlay link**
  - **Interface identifier:**
    - **Leftmost 32 bits = 0000:5EFE:**
      - **Identify this as an ISATAP address**
    - **Rightmost 32 bits = <ipv4 address>**
      - **The IPv4 address of the node**

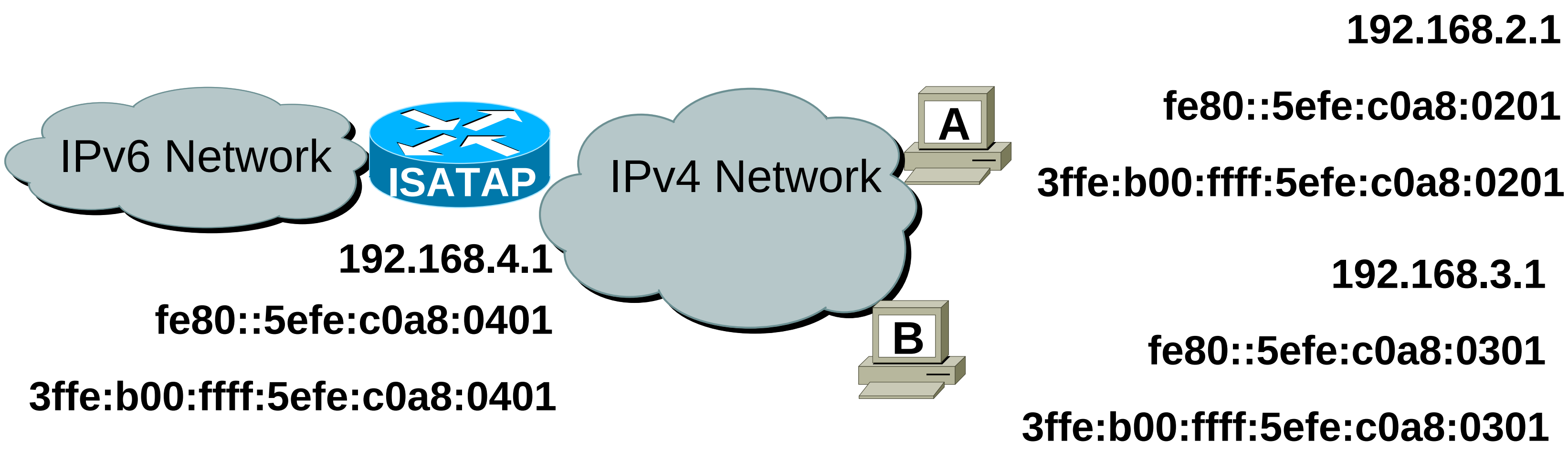
ISATAP dedicated prefix	**0000:5EFE**	**IPv4 address**

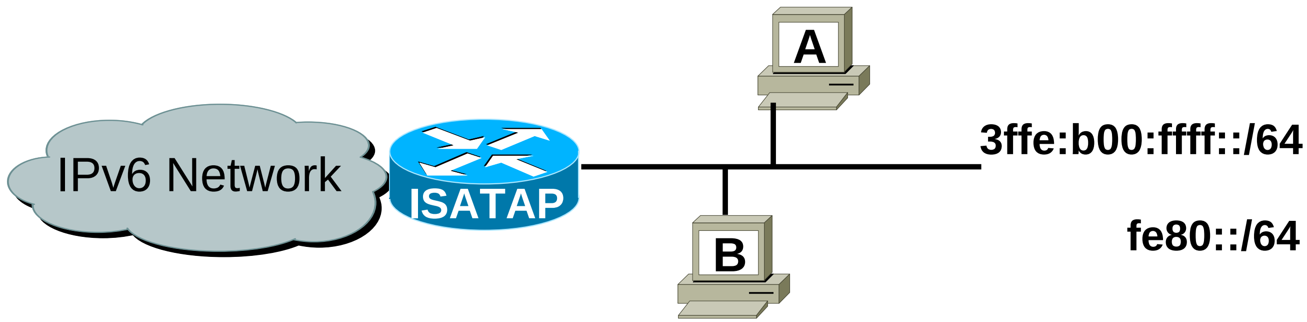
ISATAP prefix advertisement



4. Host A configures global IPv6 address using ISATAP prefix 3ffe:b00:ffff:/64

ISATAP configuration example





IPv6 to IPv4 Translation Mechanisms

- Translation
  - NAT-PT (RFC 2766 & RFC 3152)
  - TCP-UDP Relay (RFC 3142)
  - DSTM (Dual Stack Transition Mechanism)
- API
  - BIS (Bump-In-the-Stack) (RFC 2767)
  - BIA (Bump-In-the-API)
- ALG
  - SOCKS-based Gateway (RFC 3089)
  - NAT-PT (RFC 2766 & RFC 3152)

NAT-PT for IPv6

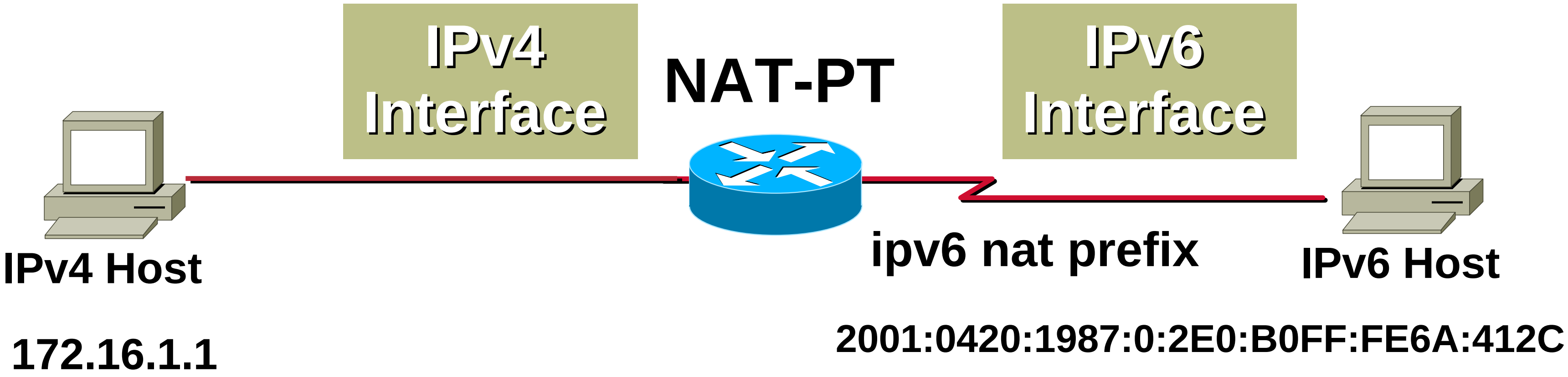
- **NAT-PT**

  (Network Address Translation – Protocol Translation)

  RFC 2766 & RFC 3152

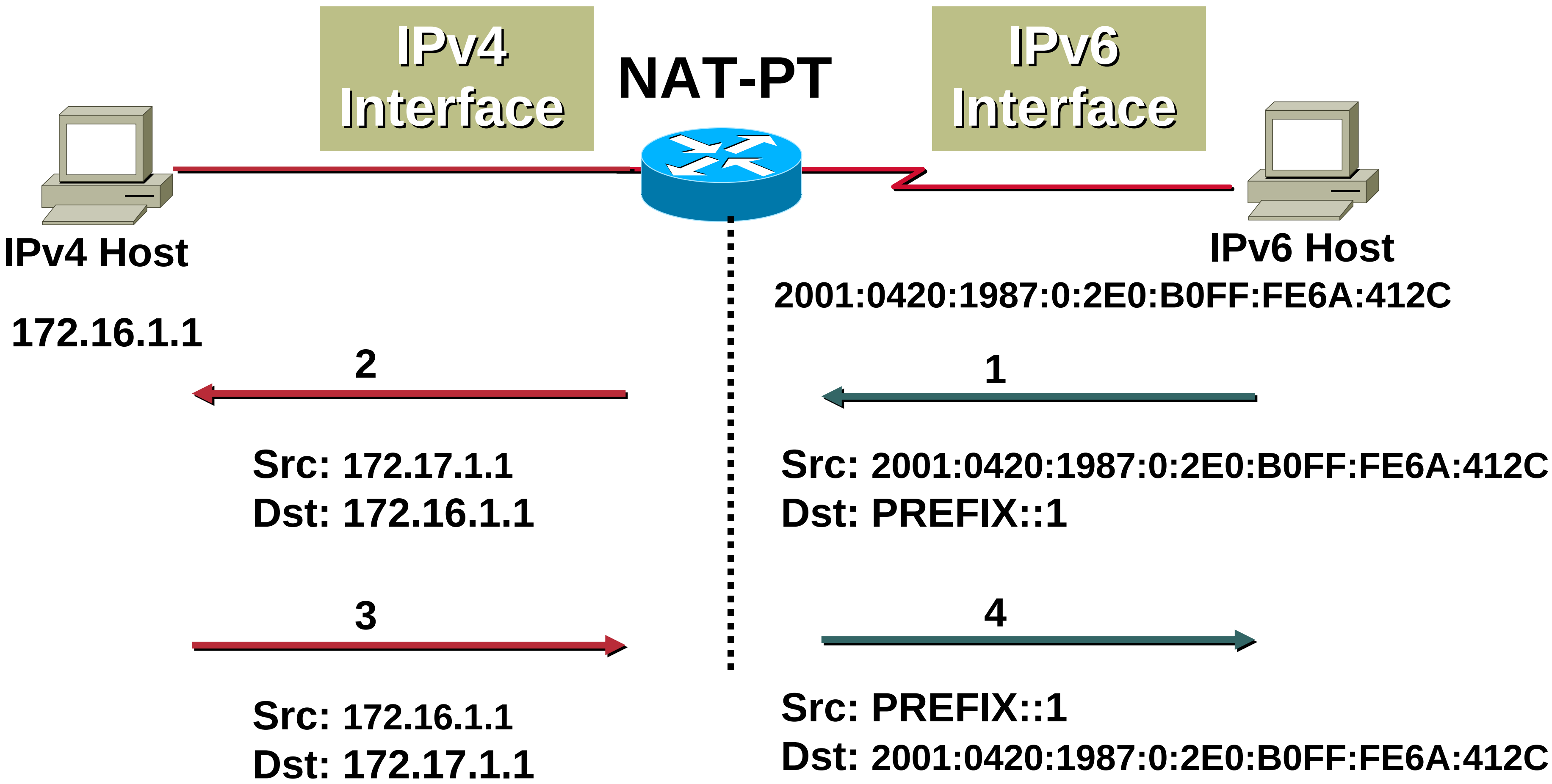
- **Allows native IPv6 hosts and applications to communicate with native IPv4 hosts and applications, and vice versa**
- **Easy-to-use transition and co-existence solution**

NAT-PT Concept



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

NAT-PT packet flow



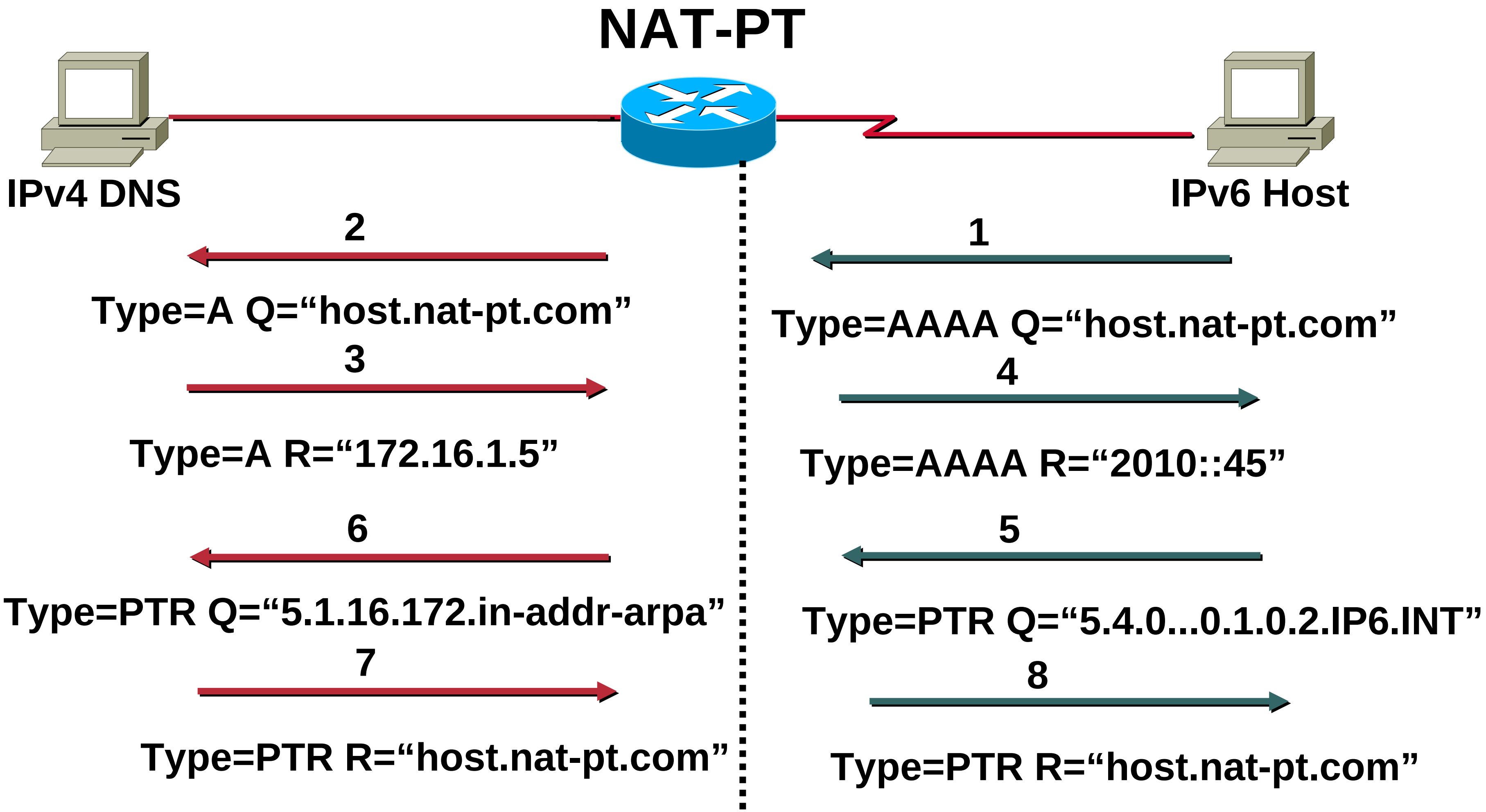
Cisco IOS NAT-PT features

- **IP Header and Address translation**
- **Support for ICMP and DNS embedded translation**
- **Auto-aliasing of NAT-PT IPv4 Pool Addresses**
- **Future developments will add FTP ALG, Address Overload and fragmentation support**

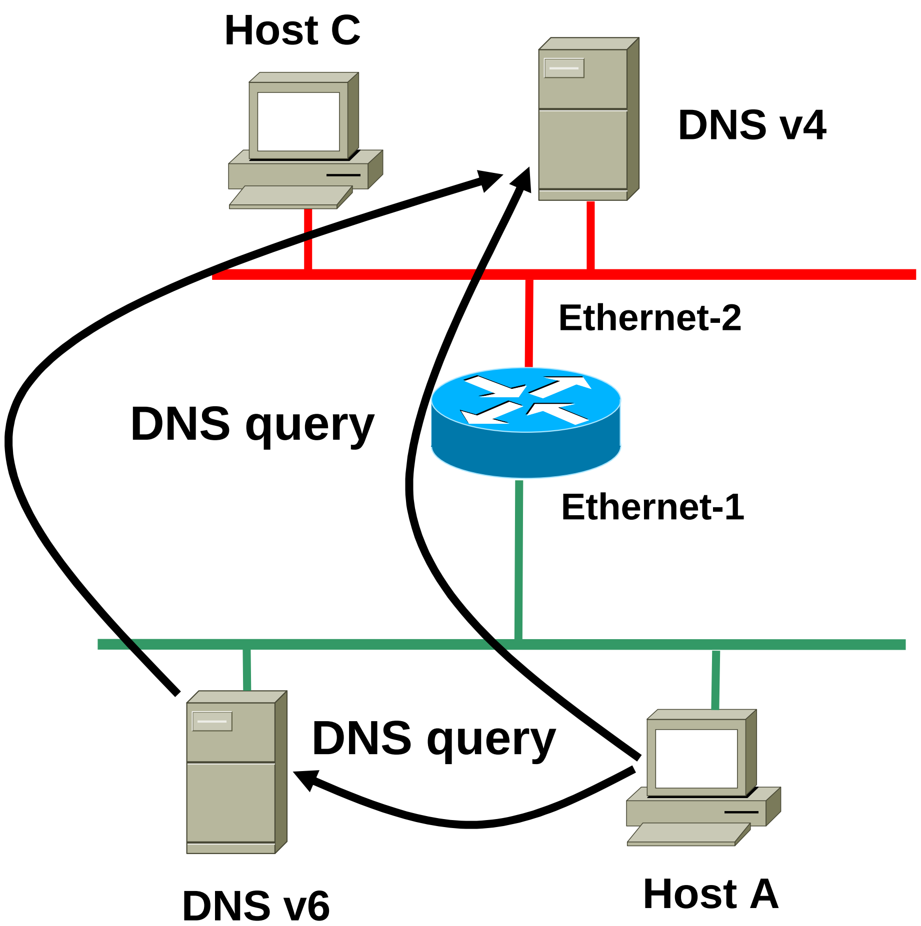
Stateless IP ICMP Translation

Ipv6 field	IPv4 field	Action
Version = 6	Version = 4	Overwrite
Traffic class	DSCP	Copy
Flow label	N/A	Set to 0
Payload length	Total length	Adjust
Next header	Protocol	Copy
Hop limit	TTL	Copy

DNS Application Layer Gateway



DNS ALG address assignment



- **TTL value in DNS Resource Record = 0**

Configuring NAT-PT (1)

- **Enabling NAT-PT**

  [no] ipv6 nat

- **Configure global/per interface NAT-PT prefix**

  [no] ipv6 nat prefix <prefix>::/96

- **Configuring static address mappings**

  [no] ipv6 nat v6v4 source <ipv6 address> <ipv4 address>

  [no] ipv6 nat v4v6 source <ipv4 address> <ipv6 address>

Configuring NAT-PT (2)

- **Configuring dynamic address mappings**

  [no] ipv6 nat v6v4 source <list,route-map> <ipv6 list, route-map> pool <v4pool>

  [no] ipv6 nat v6v4 pool <v4pool> <ipv4 addr> <ipv4addr> prefix-length <n>

- **Configure Translation Entry Limit**

  [no] ipv6 nat translation max-entries <n>

- **Debug commands**

  debug ipv6 nat

  debug ipv6 nat detailed

NAT-PT translation timeouts

- **Dynamic translations time out after 24 hours**

  [no] ipv6 nat translation timeout <seconds>

- **Non-DNS UDP translations time out after 5 minutes**

  [no] ipv6 nat translation udp-timeout <seconds>

- **DNS translations time out after 1 minute**

  [no] ipv6 nat translation dns-timeout <seconds>

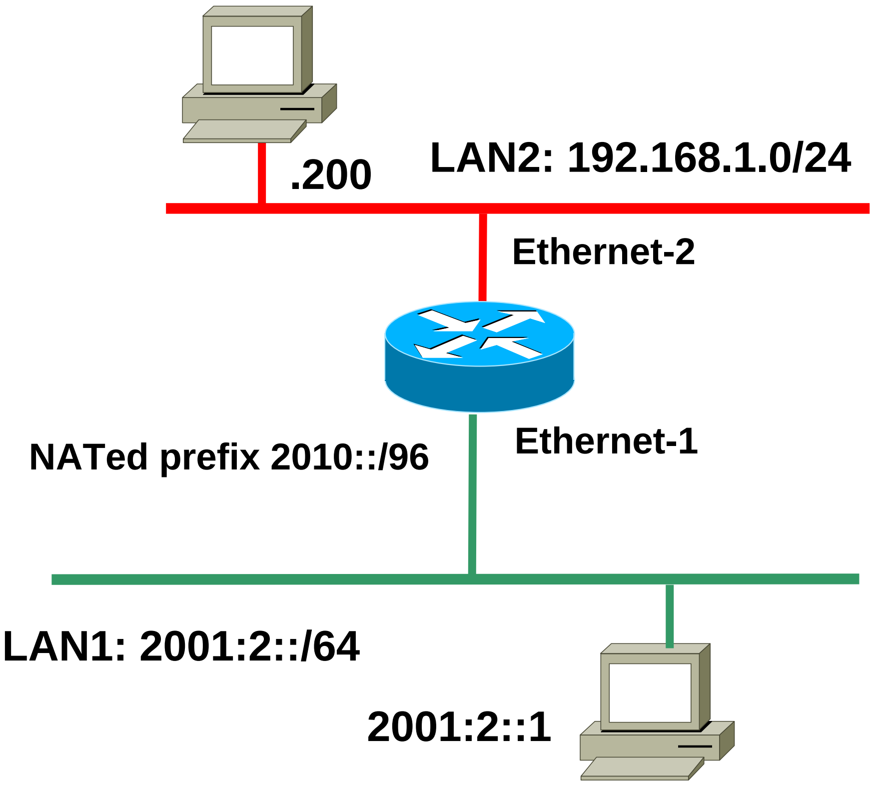
- **TCP translations time out after 24 hours, unless a RST or FIN is seen on the stream, in which case it times after 1 minute**

  [no] ipv6 nat translation tcp-timeout <seconds>

  [no] ipv6 nat translation finrst-timeout <seconds>

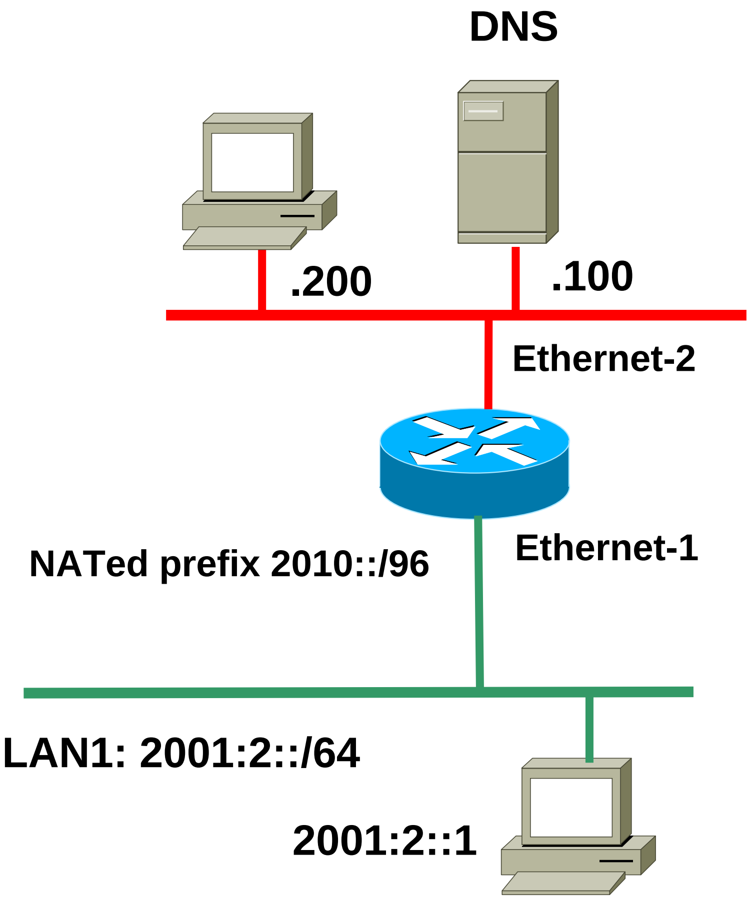
  [no] ipv6 nat translation icmp-timeout <seconds>

Cisco IOS NAT-PT configuration example




```
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 v6v4 source 2001:2::1 192.168.2.1
ipv6 nat v4v6 source 192.168.1.200 2010::60
!
```

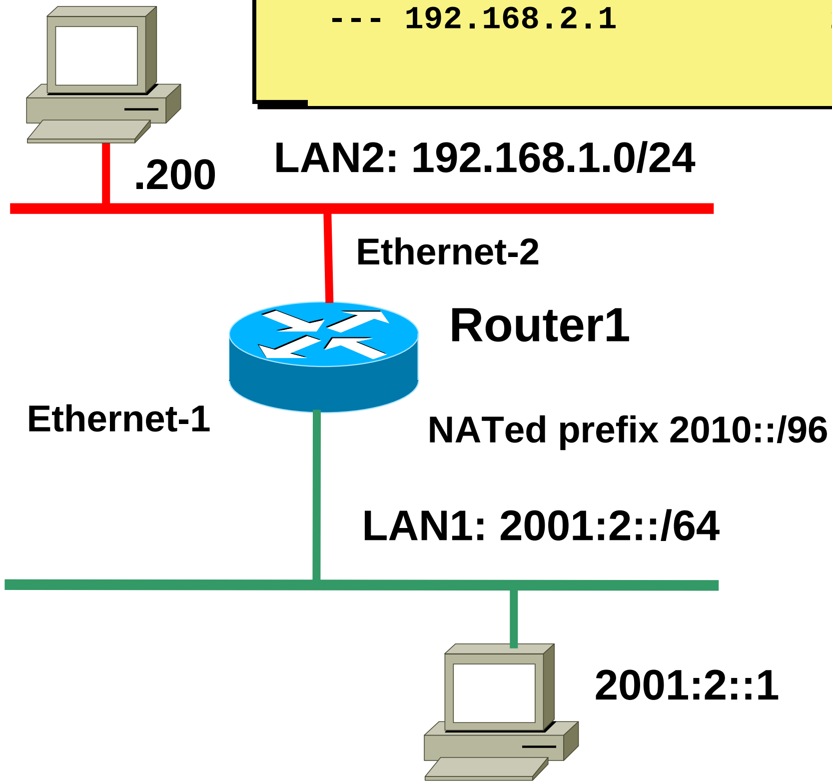
Cisco IOS NAT-PT w/ DNS ALG Configuration



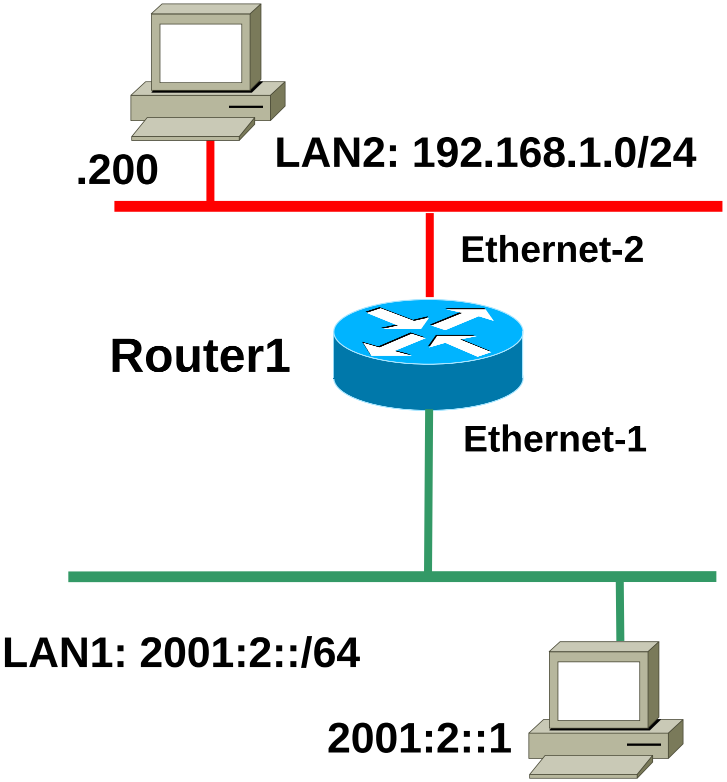

```
interface ethernet-1
   ipv6 address 2001:2::10/64
   ipv6 nat
!
interface ethernet-2
   ip address 192.168.1.1 255.255.255.0
   ipv6 nat
   ipv6 nat prefix 2010::/96

!
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
```

Cisco IOS NAT-PT display (1)

```
Router1 #show ipv6 nat translations

Pro IPv4 source        IPv6 source       IPv6 destn       IPv4 destn
--- ---                    ---           2010::60         192.168.1.200
--- 192.168.2.1           2001:2::1                        ---
```



Cisco IOS NAT-PT display (2)




```
Router1#show ipv6 nat statistics

Total active translations: 15 (2 static, 3 dynamic;
10 extended)
NAT-PT interfaces:
Ethernet-1, Ethernet-2
Hits: 10  Misses: 0
Expired translations: 0
```

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

IPv6 Servers and 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 [2001:410:10::1]:80

  So that the webserver will listen to requests coming on the interface configured with 2001:410:10::1/64

Unix Nameserver

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

```
options {
        listen-on-v6 { any; };
};
zone “workshop.net"  {
        type master;
        file “workshop.net.zone";
};
zone “0.1.4.0.1.0.0.2.ip6.arpa" {
        type master;
        file “workshop.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**

  Supports IPv6, but still hampered by broken IPv6 nameservers

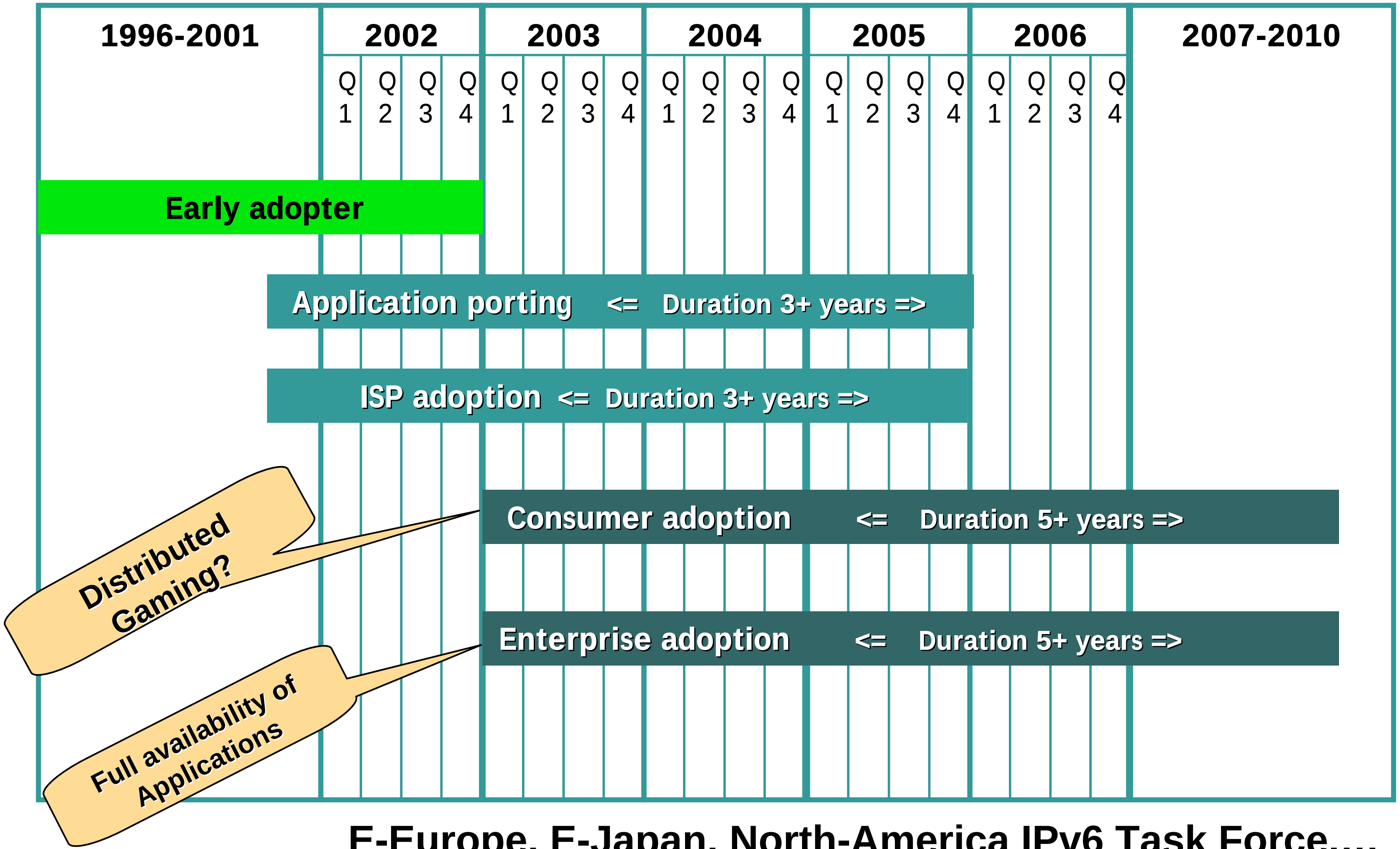
Windows XP

- IPv6 installed, but disabled by default
- To enable, start command prompt and run "ipv6 install"
- Most apps (including IE) will use IPv6 transport if IPv6 address offered in name lookups

IPv6 Deployment Scenarios

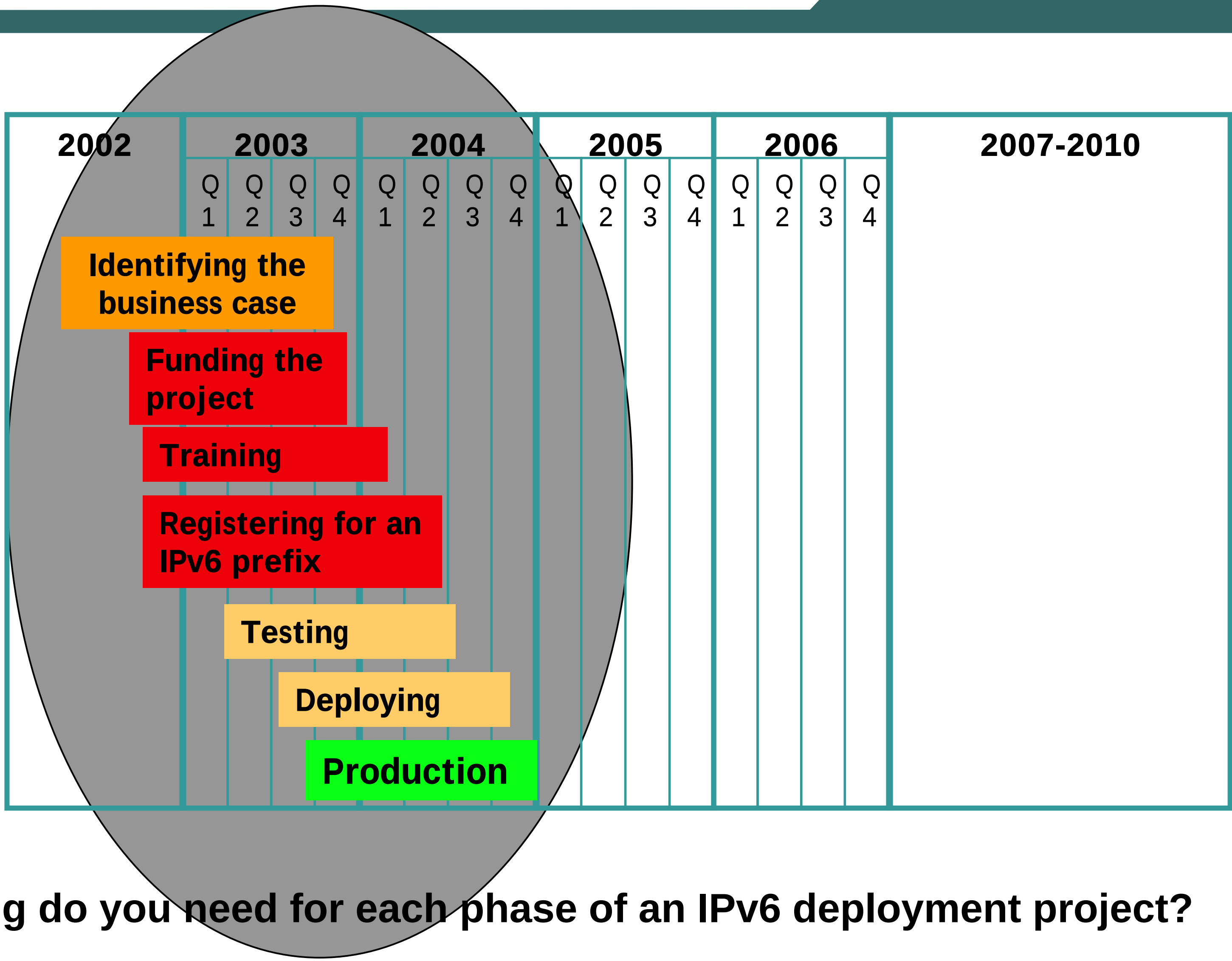
ISP/IXP Workshops

IPv6 – Looking at the Crystal Ball



E-Europe, E-Japan, North-America IPv6 Task Force,…

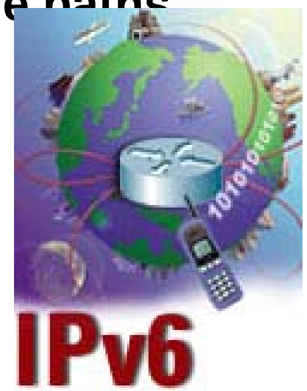
IPv6 – Working out the Timeline



How long do you need for each phase of an IPv6 deployment project?

IPv6 Deployment Scenarios

- **Many ways to deliver IPv6 services to End Users**
  - **End-to-end IPv6 traffic forwarding is the Key feature**
  - **Minimize operational upgrade costs**
- **Service Providers and Enterprises may have different deployment needs**
  - **Incremental Upgrade/Deployment**
  - **ISP's differentiate Core and Edge infrastructures upgrade**
  - **Enterprise Campus and WAN may have separate upgrade paths**
- **IPv6 over IPv4 tunnels**
- **Dedicated Data Link layers for native IPv6**
- **Dual stack Networks**
  - **IPv6 over MPLS or IPv4-IPv6 Dual Stack Routers**



IPv6 over IPv4 Tunnels

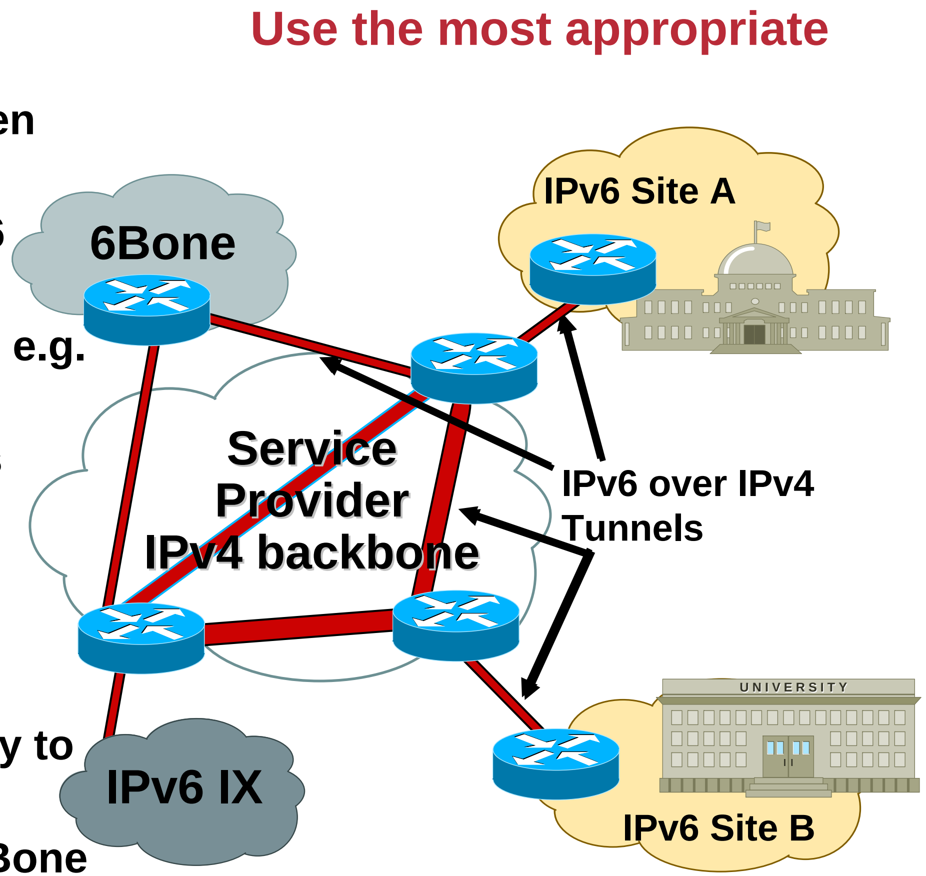
- Several Tunnelling mechanisms defined by IETF
  - Apply to ISP and Enterprise WAN networks
    - GRE, Configured Tunnels, Automatic Tunnels using IPv4 compatible IPv6 Address, 6to4
  - Apply to Campus
    - ISATAP
- Leverages 6Bone experience
- No impact on Core infrastructure
  - Either IPv4 or MPLS

Native IPv6 over Dedicated Data Links

- **Native IPv6 links over dedicated infrastructures**
  - **ATM PVC, dWDM Lambda, Frame Relay PVC, Serial, Sonet/SDH, Ethernet**
- **No impact on existing IPv4 infrastructures**
  - **Only upgrade the appropriate network paths**
  - **IPv4 traffic (and revenues) can be separated from IPv6**
- **Network Management done through IPv4**

IPv6 Tunnels & Native Case Study

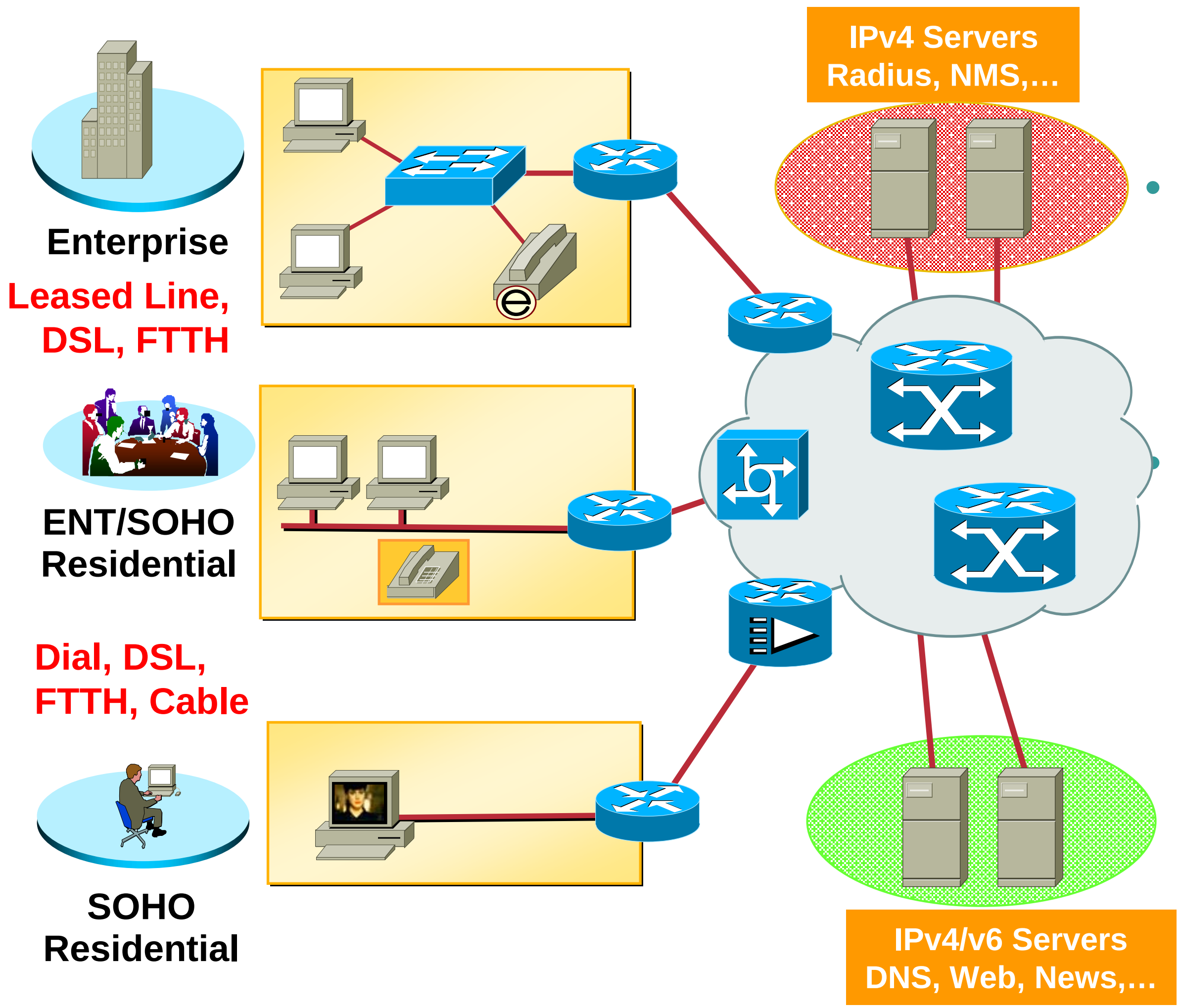
- ISP scenario
  - Configured Tunnels or Native IPv6 between IPv6 Core Routers
  - Configured Tunnels or Native IPv6 to IPv6 Enterprise's Customers
  - Tunnels for specific access technologies, e.g. Cable
  - MP-BGP4 Peering with other 6Bone users
  - Connection to an IPv6 IX
  - 6to4 relay service
- Enterprise/Home scenario
  - 6to4 tunnels between sites, use 6to4 Relay to connect to the IPv6 Internet
  - Configured tunnels between sites or to 6Bone users
  - ISATAP tunnels or Native IPv6 on a Campus



Dual Stack IPv4-IPv6 Infrastructure

- It is generally a long term goal when IPv6 traffic and users will be rapidly increasing
- May be easier on network's portion such as Campus or Access networks
- Theoretically possible but the network design phase has to be well planned
  - Memory size to handle the growth for both IPv4 & IPv6 routing tables
  - IGP options & its management: Integrated versus "Ships in the Night"
  - Full network upgrade impact
- IPv4 and IPv6 Control & Data planes should not impact each other
  - Feedback, requirements & experiments are welcome

Dual Stack IPv4-IPv6 Case Study



- Campus scenario

  Upgrade all layer 3 devices to allow IPv6 hosts deployment anywhere, similar to IPX/IP environment

- ISP

  Access technologies may have IPv4 dependencies, eg. for User's management

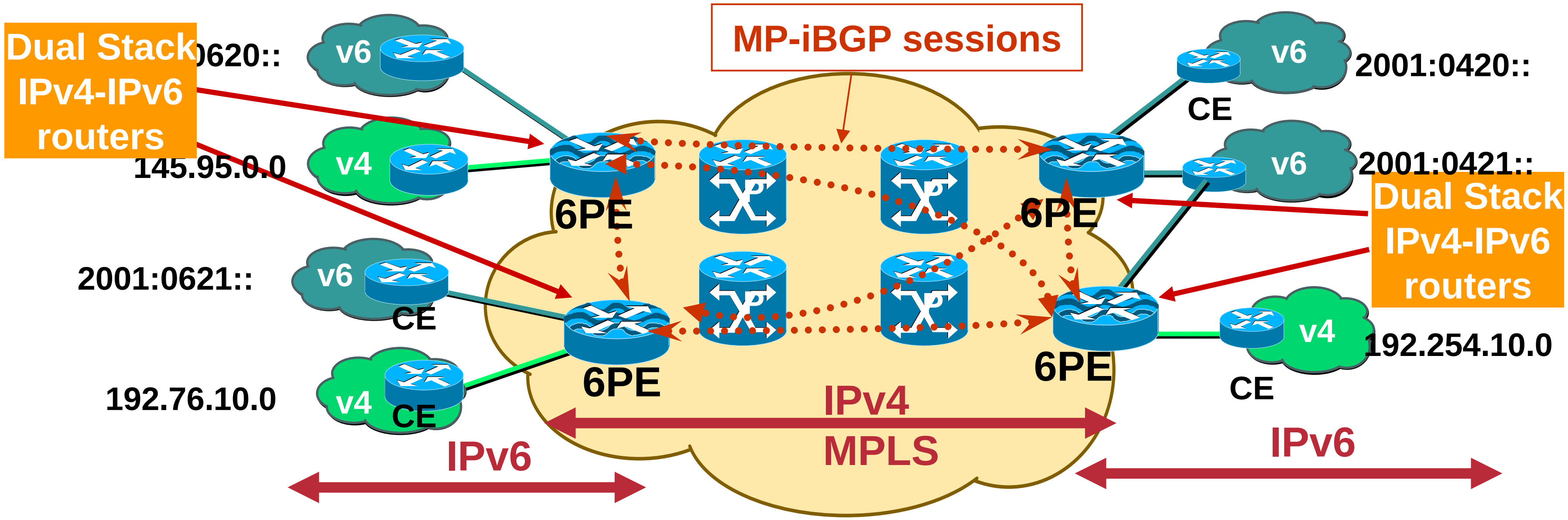
  Transparent IPv4-IPv6 access services

  Core may not go dual-stack before sometimes to avoid a full network upgrade

IPv6 over MPLS Infrastructure

- Service Providers have already deployed MPLS in their IPv4 backbone for various reasons
  - MPLS/VPN, MPLS/QoS, MPLS/TE, ATM + IP switching
- Several IPv6 over MPLS scenarios
  - IPv6 Tunnels configured on CE (no impact on MPLS)
  - IPv6 over Circuit_over_MPLS (no impact on IPv6)
  - IPv6 Provider Edge Router (6PE) over MPLS (no impact on MPLS core)
  - Native IPv6 MPLS (require full network upgrade)
- Upgrading software to IPv6 Provider Edge Router (6PE)
  - Low cost and risk as only the required Edge routers are upgraded or installed
  - Allows IPv6 Prefix delegation by ISP

IPv6 Provider Edge Router (6PE) over MPLS



- IPv4 or MPLS core infrastructure is IPv6-unaware
- PEs are updated to support Dual Stack/6PE
- IPv6 reachability exchanged among 6PEs via iBGP
- IPv6 packets transported from 6PE to 6PE inside MPLS

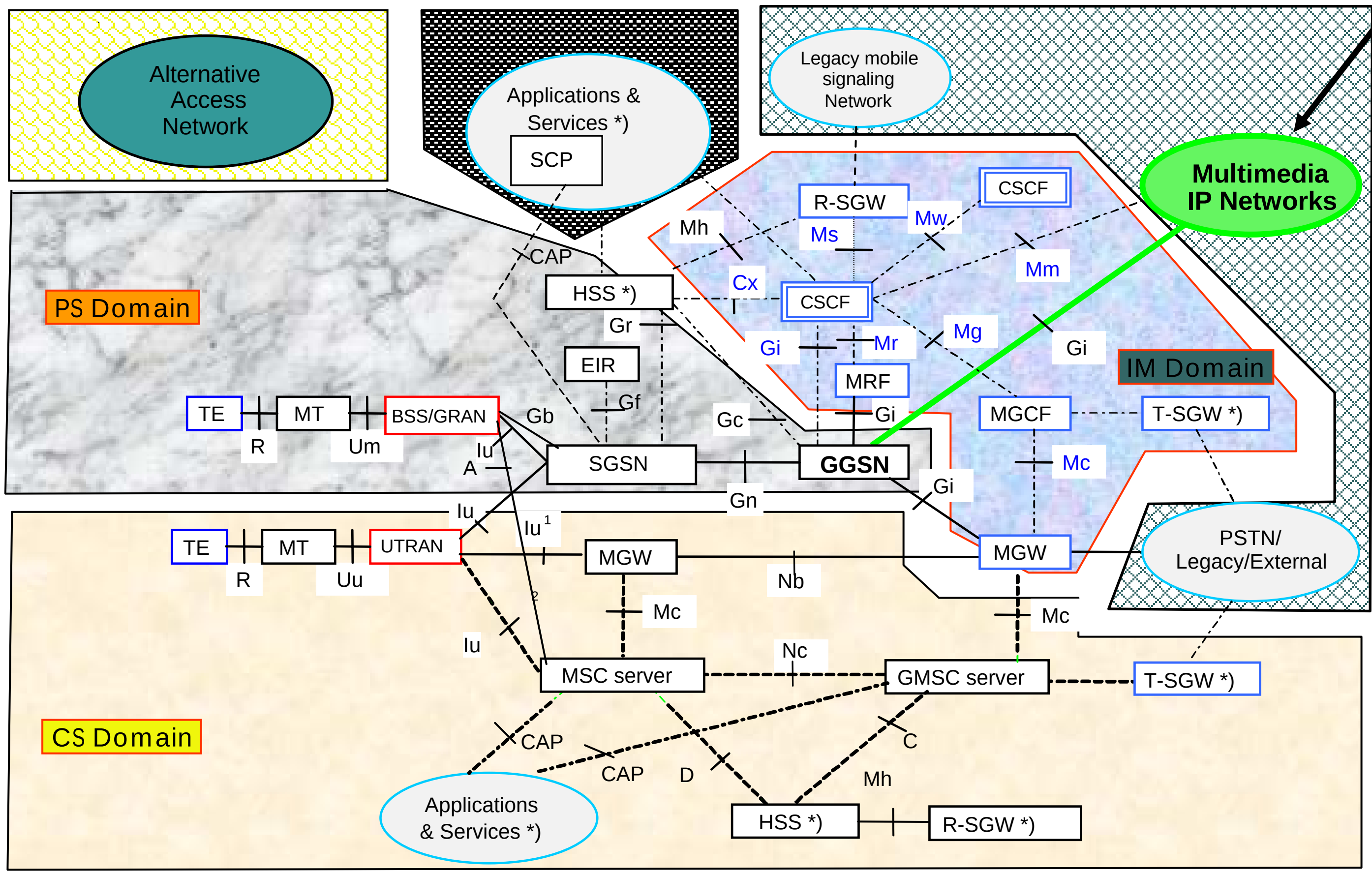
3GPP/UMTS Release 5: a 6PE Application

IPv6 Mandated

GPRS Access Network

MPLS offers ATM + IP + IPv6 switching

MS Circuit Switch Access Network



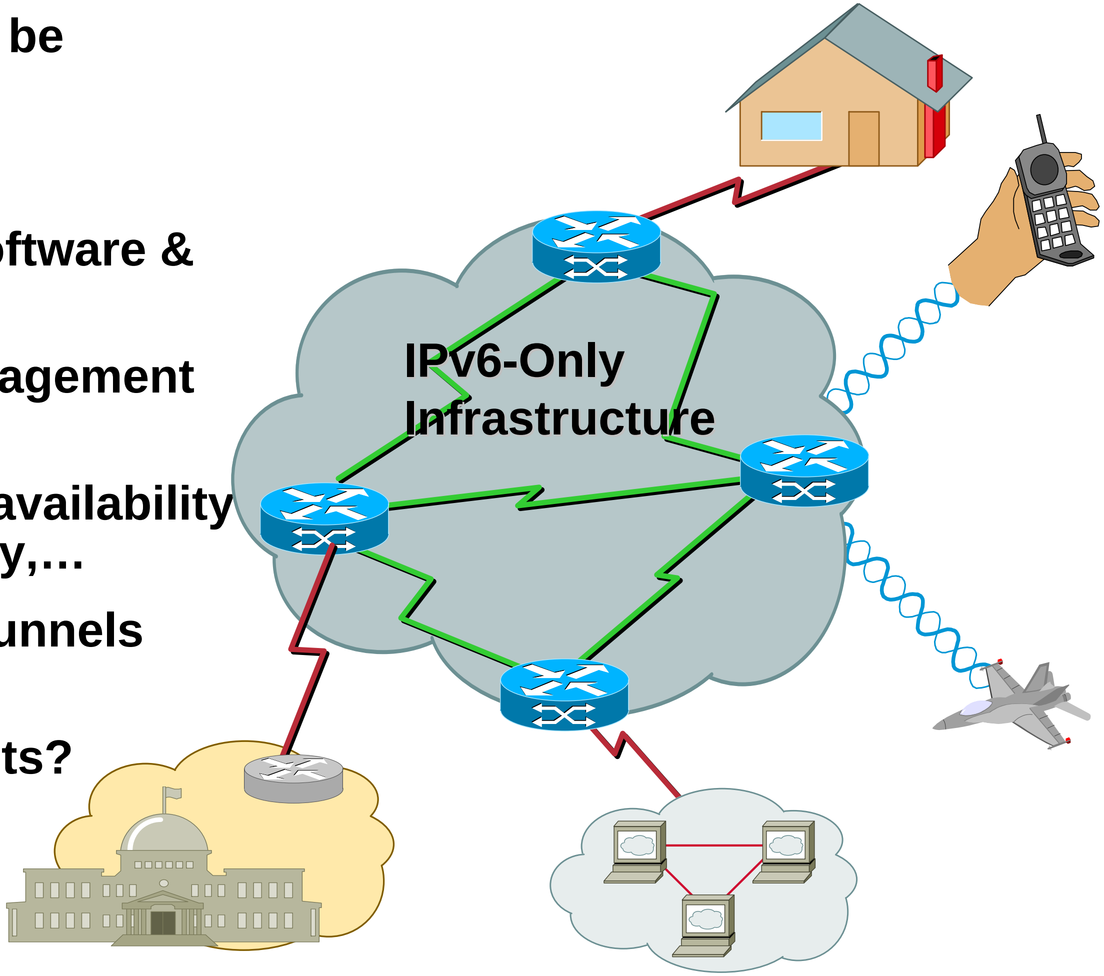
Signalling Interface
Signalling and Data Transfer Interface

*) those elements are duplicated for figure layout purpose only, they belong to the same logical element in the reference model

IM Domain is now a sub-set of the PS Domain

Native IPv6-only Infrastructure?

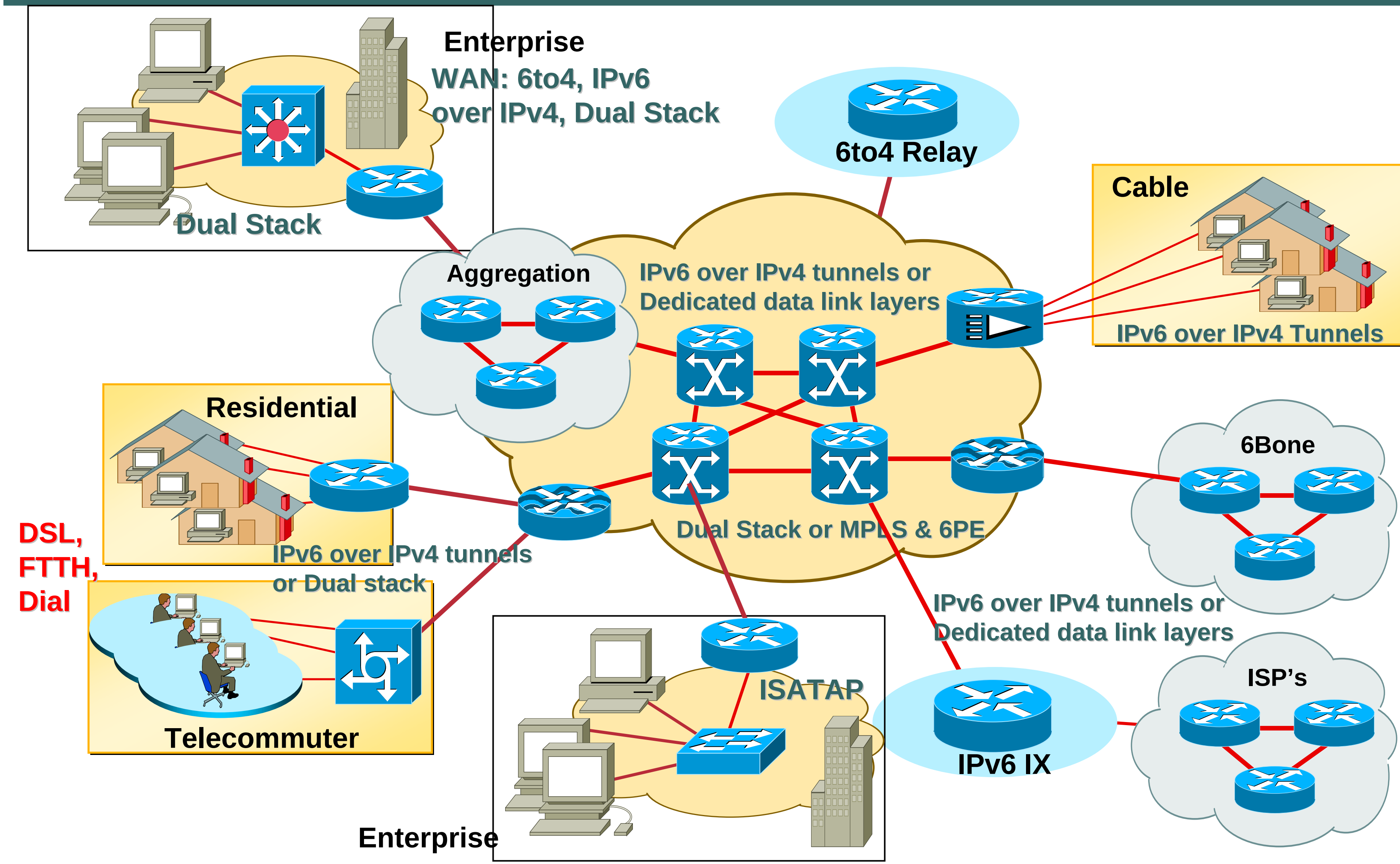
- **Application's focus**
  - **When will the IPv6 traffic be important enough?**
- **Requires**
  - **Full Network upgrade (software & potentially hardware)**
  - **Native IPv6 Network Management Solutions**
  - **Enhanced IPv6 services availability**
    - **Multicast, QoS, security,…**
  - **Transport IPv4 through tunnels over IPv6**
    - **IPv4 traffic requirements?**



IPv6 Deployment Phases

Phases	Benefits
IPv6 Tunnels over IPv4	Low cost, low risk to offer IPv6 services. No infrastructure change. Has to evolve when many IPv6 clients get connected
Dedicated Data Link layers for Native IPv6	Natural evolution when connecting many IPv6 customers. Require a physical infrastructure to share between IPv4 and IPv6 but allow separate operations
MPLS 6PE	Low cost, low risk , it requires MPLS and MP-BGP4. No need to upgrade the Core devices , keep all MPLS features (TE, IPv4-VPN)
Dual stack	Requires a major upgrade. Valid on Campus or Access networks as IPv6 hosts may be located anywhere
IPv6-Only	Requires upgrading all devices. Valid when IPv6 traffic will become predominant

Moving IPv6 to Production



Still a lot to do…

- **Though IPv6 has all the functional capability of IPv4 today:**

  Implementations are not as advanced (e.g., with respect to performance, multicast support, compactness, instrumentation, etc.)

  Deployment has only just begun

  Much work to be done moving application, middleware, and management software to IPv6

  Much training work to be done (application developers, network administrators, sales staff,…)

  Some of the advanced features of IPv6 still need specification, implementation, and deployment work

IPv6 Implementations

- Most Operating Systems now deliver an IPv6 stack
- Internetworking vendors are committed on IPv6 support
  - Interoperability events, e.g. TAHI, UNH, ETSI,…
- For an update status, please check on
  - playground.sun.com/ipv6/ipng-implementations.html
- Applications IPv6 awareness (see www.hs247.com)
  - Net Utilities (ping, finger,...etc), NFS, Routing Daemons
  - FTP, TELNET, WWW Server & Browser, Sendmail, SMTP

IPv6 Forum

- **+100 companies**

  Cisco is a founding member

- **www.ipv6forum.com**
- **Mission is to promote IPv6 not to specify it (IETF)**
- **Holds and supports the ‘IPv6 summit’ in many countries around the World**

IPv6 – Conclusion

IPv6 Ready for Production Deployment?

- **Evaluate IPv6 products and services, as available**
  - Major O.S., applications and infrastructure for the IT industry
  - New IP appliances, e.g…3G (NTT DoCoMo,…), gaming,…
  - IPv6 services from ISP
- **Plan for IPv6 integration and IPv4-IPv6 co-existence**
  - Training, applications inventory, and IPv6 deployment planning
- **Upgrade your router with IPv6 ready software**

Presentation Slides

- **Available on**

  ftp://ftp-eng.cisco.com

  /pfs/seminars/SANOG5-IPv6-Tutorial.pdf

  And on the SANOG5 website

- **Feel free to ask questions any time**

IPv6 Tutorial

SANOG V

Dhaka, Bangladesh

11 February 2005