IPv6 applications

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Agenda

Africa Network Operators Group

- IPv6 Business Case
- IPv6 Protocols & Standards
- IPv6 Routing
- Integration and Transition
- IPv6 Deployment scenarios

A need for IPv6?

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- **IETF IPv6 WG began in early 90s, to solve addressing growth issues, but**

  CIDR, NAT,… were developed

- **IPv4 32 bit address = 4 billion hosts**

  ~40% of the IPv4 address space is still unused

  BUT

- **IP is everywhere**

  Data, Voice, Audio and Video integration is a Reality

  Regional Registries apply a strict allocation control

- **So, Only compelling reason: *more IP addresses!***

IP Address Allocation History

1981 - IPv4 protocol published

1985 ~ 1/16 of total space

1990 ~ 1/8 of total space

1995 ~ 1/4 of total space

2000 ~ 1/2 of total space

- This despite increasingly intense conservation efforts
  - PPP / DHCP address sharing
  - CIDR (classless inter-domain routing)
  - NAT (network address translation)
  - plus some address reclamation
- Theoretical limit of 32-bit space: ~4 billion devices
  Practical limit of 32-bit space: ~250 million devices

  (see RFC 3194)

Do We Really Need a Larger Address Space?

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- **Overall Internet population is still growing**
  - ~420 million users in Q1 CY2001, ~620 million by 2005, less than 10% worldwide population
- **Emerging population/geopolitical and Address space**
  - Africa, China, India, Japan, Korea need/want global IP addresses
  - How to move to e-Economy without Global Internet access?
- **405 million mobile phones sold in 2000, over 1 billion by 2005**
  - UMTS Release 5 is Internet Mobility, eg. 1/3 of 1B should get connected
- **~1 Billion cars in 2010, 15% should get GPS and Yellow Page services**

Explosion of New Internet Appliances

Coming Back to an End-to-End Architecture

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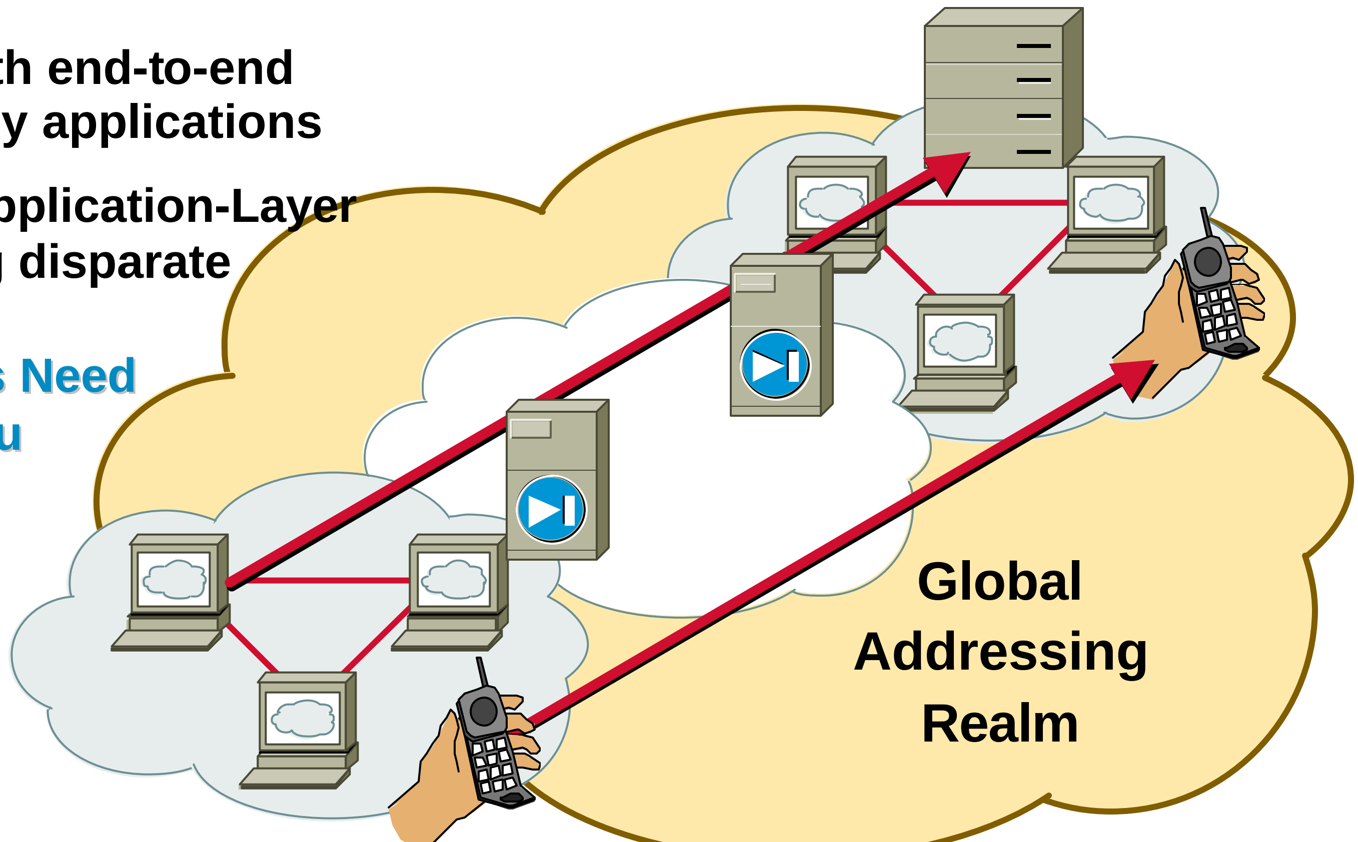
New Technologies/Applications for Home Users

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

- **Internet started with end-to-end connectivity for any applications**
- **Today, NAT and Application-Layer Gateways connecting disparate networks**
- **Always-on Devices Need an Address When You Call Them**



- **Mobile Phones**
- **Gaming**
- **Residential Voice over IP gateway**
- **IP Fax**

IPv6 Markets

- **Academic NRN**
  - Internet-II (Abilene, vBNS+), Canarie*3, Renater-II, Surfnet, DFN, CERNET, Nordunet,… 6REN/6TAP
- **Geographies & Politics**
  - IPv6 promotion council in Japan, Korea IPv6 Forum
  - EEC e-Europe & IPv6 Task Force -> 6NET and Euro6IX projects
- **Wireless (PDA, 3G Mobile Phone networks, Car,...)**
  - Multiple phases before deployment
  - RFP -> Integration -> trial -> commercial
  - Requires ‘client devices’, eg. IPv6 handset ?

IPv6 Markets

- Home Networking
  - Set-top box/Cable/xDSL/Ethernet-to-the-home
  - E.g. Japan Home Information Services initiative
- Gaming
  - Sony, (Sega), Nintendo, Microsoft
- Consumer Devices
- Enterprise
  - Requires IPv6 support by O.S. & Applications
  - SUN Solaris 8, BSD 4.x, Linux, Microsoft Windows XP Pro, etc.
- Service Providers
  - Regional ISP, Carriers, Mobile ISP, IPv6 IX, and Greenfield ISP’s

How to get an IPv6 Address?

- **How to get address space?**

  Real IPv6 address space now allocated by APNIC, ARIN and RIPE NCC to ISP

APNIC	**2001:0200::/23**
ARIN	**2001:0400::/23**
RIPE NCC	**2001:0600::/23**

- **6Bone 3FFE::/16**
- **6to4 tunnels 2002::/16**
- **Enterprises will get their IPv6 address space from their ISP.**

IPv6 Prefix Allocations: APNIC
(whois.apnic.net) – January 2002

CONNECT-AU-19990916 2001:210::/35
WIDE-JP-19990813 2001:200::/35
NUS-SG-19990827 2001:208::/35
KIX-KR-19991006 2001:220::/35
ETRI-KRNIC-KR-19991124 2001:230::/35
NTT-JP-19990922 2001:218::/35
HINET-TW-20000208 2001:238::/35
IIJ-JPNIC-JP-20000308 2001:240::/35
CERNET-CN-20000426 2001:250::/35
INFOWEB-JPNIC-JP-2000502 2001:258::/35
JENS-JP-19991027 2001:228::/35
BIGLOBE-JPNIC-JP-20000719 2001:260::/35
6DION-JPNIC-JP-20000829 2001:268::/35
DACOM-BORANET-20000908 2001:270::/35
ODN-JPNIC-JP-20000915 2001:278::/35
KOLNET-KRNIC-KR-20000927 2001:280::/35
HANANET-KRNIC-KR-20001030 2001:290::/35
TANET-TWNIC-TW-20001006 2001:288::/35
SONYTELECOM-JPNIC-JP-20001207 2001:298::/35
TTNET-JPNIC-JP-20001208 2001:2A0::/35
CCCN-JPNIC-JP-20001228 2001:02A8::/35
IMNET-JPNIC-JP-20000314 2001:0248::/35
KORNET-KRNIC-KR-20010102 2001:02B0::/35

NGINET-KRNIC-KR-20010115 2001:02B8::/35
OMP-JPNIC-JP-20010208 2001:02C8::/35
INFOSPHERE-JPNIC-JP-20010207 2001:02C0::/35
ZAMA-AP-20010320 2001:02D0::/35
SKTELECOMNET-KRNIC-KR-20010406 2001:02D8::/35
HKNET-HK-20010420 2001:02E0::/35
CONNECT-AU-19990916 2001:0210::/35
KT-KR-19991006 2001:0220::/35
DTI-JPNIC-JP-20010702 2001:02E8::/35
MEX-JPNIC-JP-20010801 2001:02F0::/35
SINET-JPNIC-JP-20010809 2001:02F8::/35
PANANET-JPNIC-JP-20010810 2001:0300::/35
HTCN-JPNIC-JP-20010814 2001:0308::/35
CWIDC-JPNIC-JP-20010815 2001:0310::/35
STCN-JPNIC-JP-20010817 2001:0318::/35
KREONET2-KRNIC-KR-20010823 2001:0320::/35
MANIS-MY-20010824 2001:0328::/35
UNITEL-KRNIC-KR-20010920 2001:0330::/35
KREONET2-KRNIC-KR-20010823 2001:0320::/35
U-NETSURF-JPNIC-JP-20011005 2001:0338::/35
FINE-JPNIC-JP-20011030 2001:0340::/35
QCN-JPNIC-JP-20011031 2001:0348::/35
MCNET-JPNIC-JP-20011108 2001:0350::/35
MIND-JPNIC-JP-20011115 2001:0358::/35
V6TELSTRAINTERNET-AU-20011211 2001:0360::/35
MEDIAS-JPNIC-JP-20011212 2001:0368::/35
GCTRJP-NET-20011212 2001:0370::/35
THRUNET-KRNIC-KR-20011218 2001:0378::/35

IPv6 Prefix Allocations: ARIN
(whois.arin.net) – January 2002

ESNET-V6 2001:0400::/35
ARIN-001 2001:0400::/23
VBNS-IPV6 2001:0408::/35
CANET3-IPV6 2001:0410::/35
VRIO-IPV6-0 2001:0418::/35
CISCO-IPV6-1 2001:0420::/35
QWEST-IPV6-1 2001:0428::/35
DEFENSENET 2001:0430::/35
ABOVENET-IPV6 2001:0438::/35
SPRINT-V6 2001:0440::/35
UNAM-IPV6 2001:0448::/35
GBLX-V6 2001:0450::/35
STEALTH-IPV6-1 2001:0458::/35
NET-CW-10BLK 2001:0460::/35
ABILENE-IPV6 2001:0468::/35
HURRICANE 2001:0470::/35
EP-NET 2001:0478::/35
DREN-V6 2001:0480::/35

AVANTEL-IPV6-1 2001:0488::/35
NOKIA-1 2001:0490::/35
ITESM-IPV6 2001:0498::/35

IPv6 Prefix Allocations: RIPE-NCC
(whois.ripe.net) – January 2002

UK-BT-19990903 2001:0618::/35
CH-SWITCH-19990903 2001:0620::/35
AT-ACONET-19990920 2001:0628::/35
UK-JANET-19991019 2001:0630::/35
DE-DFN-19991102 2001:0638::/35
NL-SURFNET-19990819 2001:0610::/35
RU-FREENET-19991115 2001:0640::/35
GR-GRNET-19991208 2001:0648::/35
EU-UUNET-19990810 2001:0600::/35
DE-TRMD-20000317 2001:0658::/35
FR-RENATER-20000321 2001:0660::/35
EU-EUNET-20000403 2001:0670::/35
DE-IPF-20000426 2001:0678::/35
DE-NACAMAR-20000403 2001:0668::/35
DE-XLINK-20000510 2001:0680::/35
DE-ECRC-19991223 2001:0650::/35
FR-TELECOM-20000623 2001:0688::/35
PT-RCCN-20000623 2001:0690::/35
SE-SWIPNET-20000828 2001:0698::/35
PL-ICM-20000905 2001:06A0::/35

DE-SPACE-19990812 2001:0608::/35
BE-BELNET-20001101 2001:06A8::/35
SE-SUNET-20001218 2001:06B0::/35
IT-CSELT-20001221 2001:06B8::/35
SE-TELIANET-20010102 2001:06C0::/35
DE-JIPPII-20000426 2001:0678::/35
DK-TELEDANMARK-20010131 2001:06C8::/35
RU-ROSNIIROS-20010219 2001:06D0::/35
PL-CYFRONET-20010221 2001:06D8::/35
SE-SUNET-20001218 2001:06B0::/35
NL-INTOUCH-20010307 2001:06E0::/35
FI-TELIVO-20010321 2001:06E8::/35
SE-DIGITAL-20010321 2001:06F0::/35
UK-EASYNET-20010322 2001:06F8::/35
UNINETT 2001:0700::/35
FI-FUNET-20010503 2001:0708::/35
UK-INS-20010518 2001:0710::/35
CZ-TEN-34-20010521 2001:0718::/35
ES-REDIRIS-20010521 2001:0720::/35

UK-VERIO-20010717 2001:0728::/35
AT-TELEKABEL-20010717 2001:0730::/35
HU-HUNGARNET-20010717 2001:0738::/35
DE-VIAG-20010717 2001:0740::/35
DE-ROKA-20010817 2001:0748::/35
IT-EDISONTEL-20010906 2001:0750::/35
UK-NETKONECT-20010918 2001:0758::/35
IT-GARR-20011004 2001:0760::/35
DE-CYBERNET-20011008 2001:0768::/35
IE-HEANET-20011008 2001:0770::/35
LT-LITNET-20011115 2001:0778::/35
DE-NORIS-20011203 2001:0780::/35
FI-SONERA-20011231 2001:0788::/35
EU-CARRIER1-20020102 2001:0790::/35
EU-ZZ-2001-07F8 2001:07F8::/29

Agenda

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- IPv6 Business Case
- IPv6 Protocols & Standards
- IPv6 routing
- Integration and Transition
- IPv6 Deployment scenarios

IPv6 - So what's really changed ?!

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- **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 checksumming at the IP network layer**

- **No hop-by-hop segmentation**

  Path MTU discovery

- **64 bit aligned**

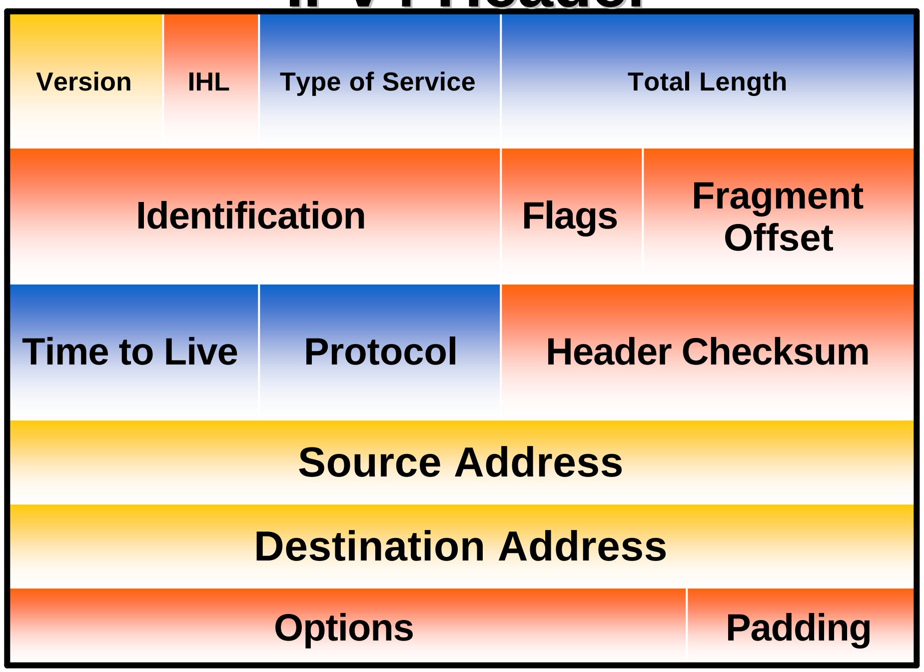
- **Authentication and Privacy Capabilities**

  IPsec is mandated

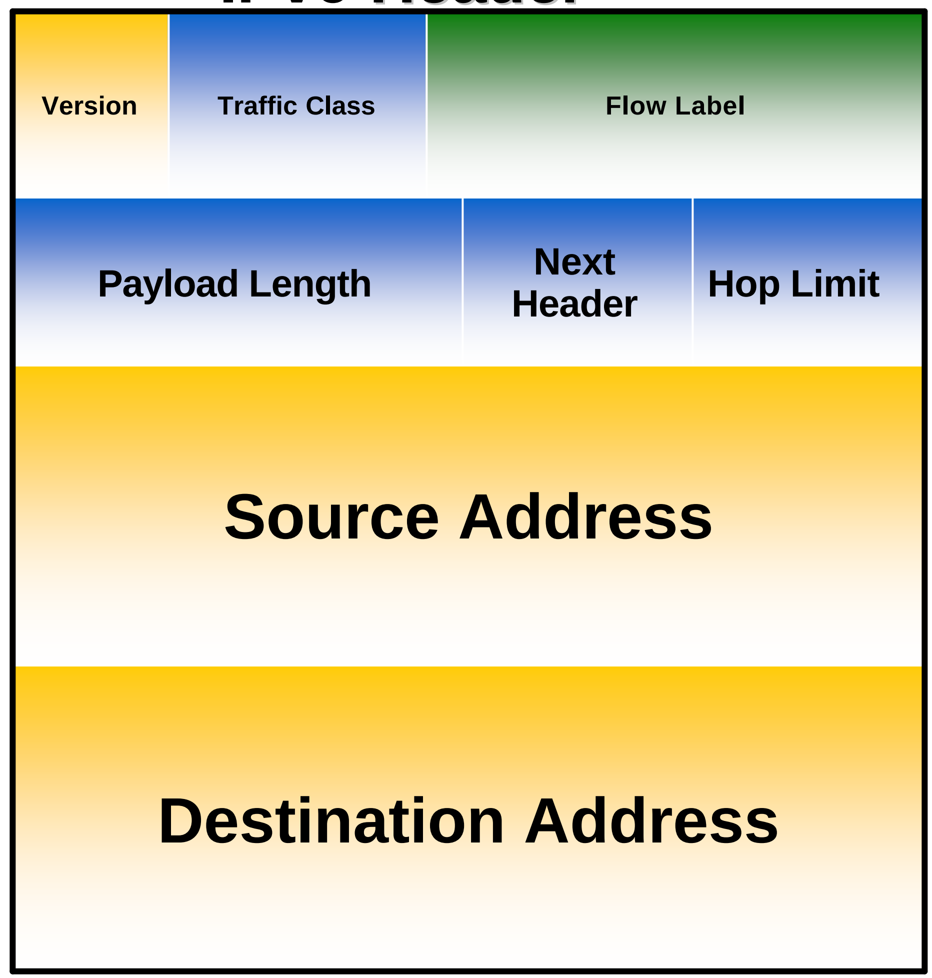
- **No more broadcast**

IPv4 & IPv6 Header Comparison

IPv4 Header



IPv6 Header



Legend

- field's name kept from IPv4 to IPv6
- fields not kept in IPv6
- Name & position changed in IPv6
- New field in IPv6

How Was 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**

  (340,282,366,920,938,463,463,374,607,431,768,211,456 in all!)

IPv6 Addressing

- **IPv6 Addressing rules are covered by multiples RFC's**
  - **Architecture defined by RFC 2373**
- **Address Types are :**
  - **Unicast : One to One (Global, Link local, Site local, Compatible)**
  - **Anycast : One to Nearest (Allocated from Unicast)**
  - **Multicast : One to Many**
  - **Reserved**
- **A single interface may be assigned multiple IPv6 addresses of any type (unicast, anycast, multicast)**
  - **No Broadcast Address -> Use Multicast**

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**
  - **2031::130F::9C0:876A:130B**
  - **0:0:0:0:0:0:0:1 => ::1**
  - **0:0:0:0:0:0:0:0 => ::**

- **IPv4-compatible address representation**
  - **0:0:0:0:0:0:192.168.30.1 = ::192.168.30.1 = ::C0A8:1E01**

IPv6 Addressing

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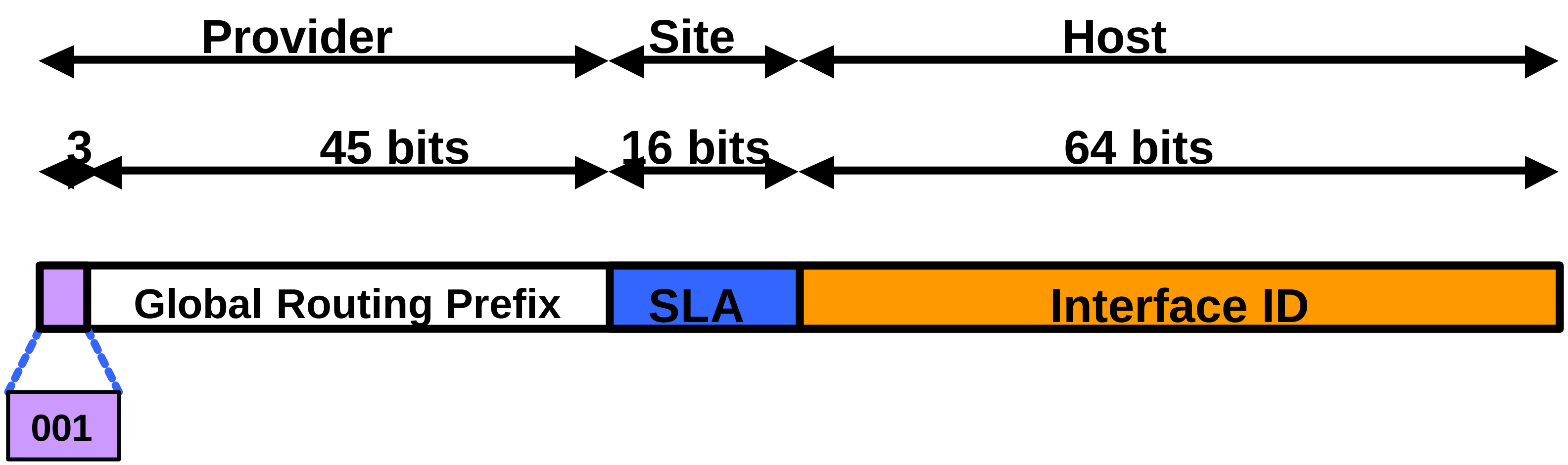
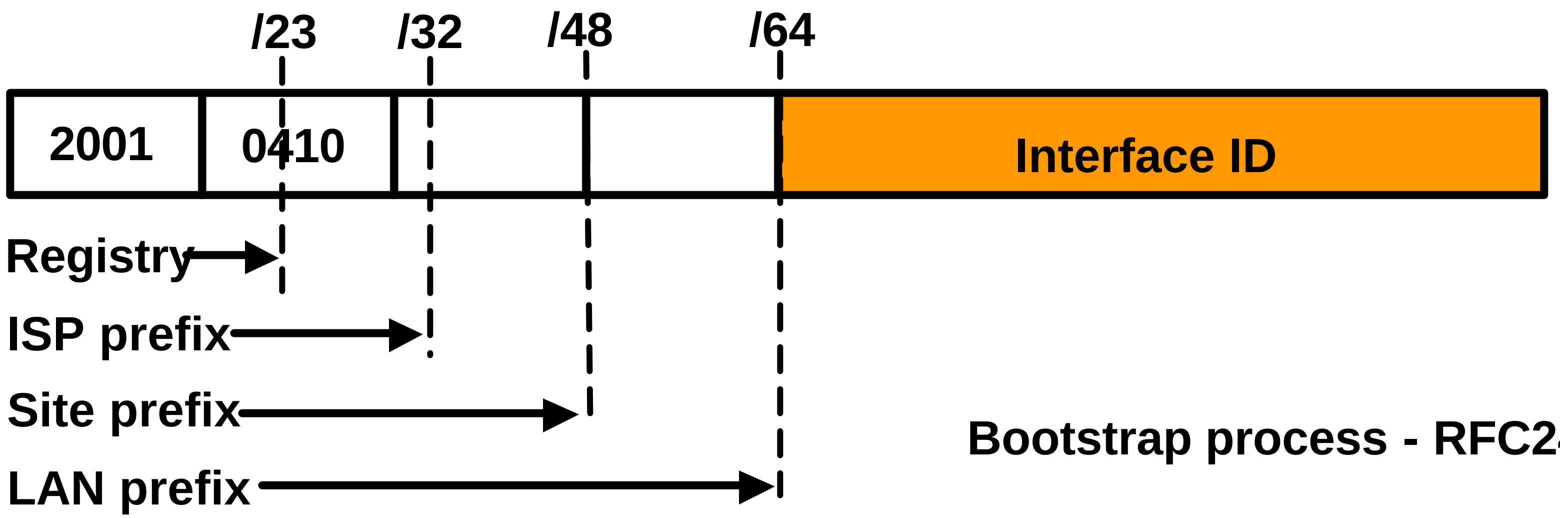
- **Prefix Format (PF) Allocation**
  - PF = 0000 0000 : Reserved
  - PF = 001 : Aggregatable Global Unicast Address
  - PF = 1111 1110 10 : Link Local Use Addresses
  - PF = 1111 1110 11 : Site Local Use Addresses
  - PF = 1111 1111 : Multicast Addresses
  - Other values are currently Unassigned (approx. 7/8th of total)
- **All Prefix Formats have to have EUI-64 bits Interface ID**
  - But Multicast

Aggregatable Global Unicast Addresses



- Aggregatable Global Unicast addresses are:
  - Addresses for generic use of IPv6
  - Structured as a hierarchy to keep the aggregation
- See draft-ietf-ipngwg-addr-arch-v3-07

Address Allocation



Bootstrap process - RFC2450

- **The allocation process is:**

  IANA allocates 2001::/16 to registries

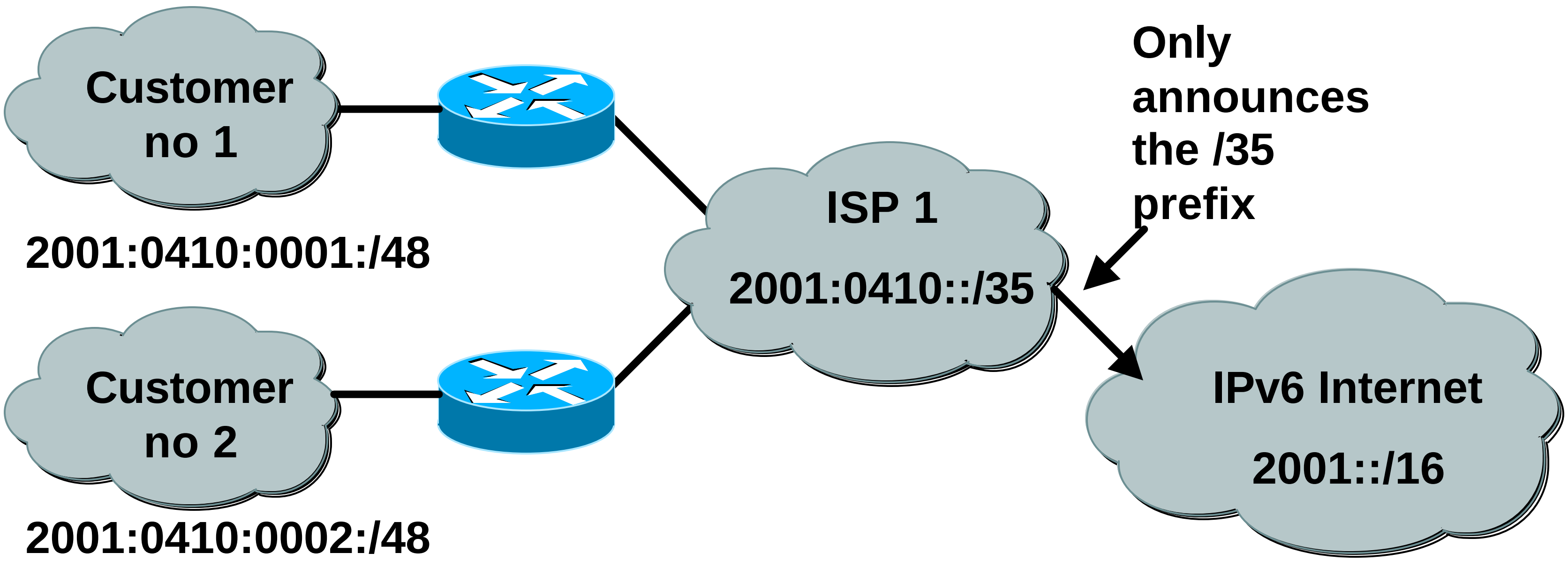
  Each registry gets a /23 prefix from IANA

  Registry allocates a /32 prefix to an IPv6 ISP

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

  ftp://ftp.cs.duke.edu/pub/narten/ietf/global-ipv6-assign-2002-04-25.txt

Hierarchical Addressing & Aggregation



- Larger address space enables:
  - Aggregation of prefixes announced in the global routing table.
  - Efficient and scalable routing.
- But current Multi-Homing schemes break the model

Link-Local & Site-Local Unicast Addresses

- **Link-local addresses for use during auto-configuration and when no routers are present:**

1111111010	0	interface ID

- **Site-local addresses for independence from changes of TLA / NLA*:**

1111111011	0	SLA*	interface ID

Multicast Addresses (RFC 2375)

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11111111	flags	scope	group ID
8	4	4	112 bits

- **low-order flag indicates permanent / transient group; three other flags reserved**
- **scope field:**
  1 - node local
  2 - link-local
  5 - site-local
  8 - organization-local
  B - community-local
  E - global

  (all other values reserved)

more on IPv6 Addressing

80 bits	16 bits	32 bits
0000…………………………….0000	0000	IPv4 Address

IPv6 Addresses with Embedded IPv4 Addresses

80 bits	16 bits	32 bits
0000…………………………….0000	FFFF	IPv4 Address

IPv4 mapped IPv6 address

IPv6 Addressing Examples

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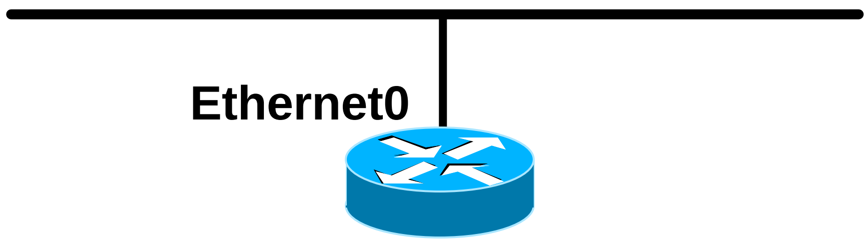


```
interface Ethernet0
 ipv6 address 2001:410:213:1::/64 eui-64
```

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
```

6BONE

- **The 6bone is an IPv6 testbed setup to assist in the evolution and deployment of IPv6 in the Internet.**

  The 6bone is a virtual network layered on top of portions of the physical IPv4-based Internet to support routing of IPv6 packets, as that function has not yet been integrated into many production routers. The network is composed of islands that can directly support IPv6 packets, linked by virtual point-to-point links called "tunnels". The tunnel endpoints are typically workstation-class machines having operating system support for IPv6.

- **Over 50 countries are currently involved**
- **Registry, maps and other information may be found on http://www.6bone.net/**

6Bone Addressing

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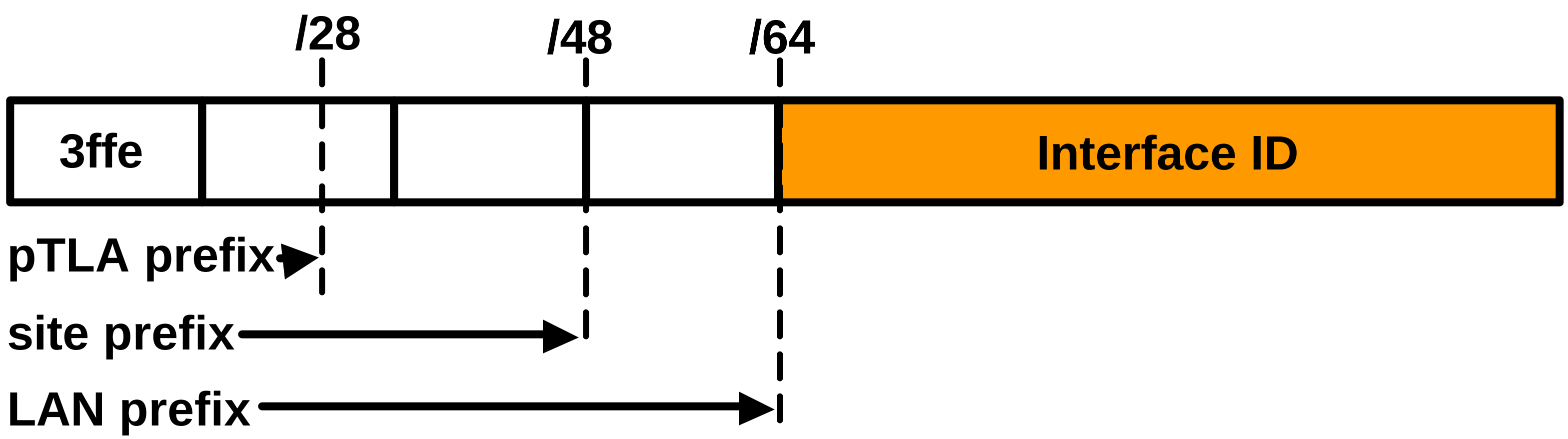

- **6Bone address space defined in RFC2471 uses 3FFE::/16**

  A pTLA receives a /28 prefix

  A site receives a /48 prefix

  A LAN receives a /64 prefix

- **Guidelines for routing on 6bone - RFC2772**

6Bone Topology

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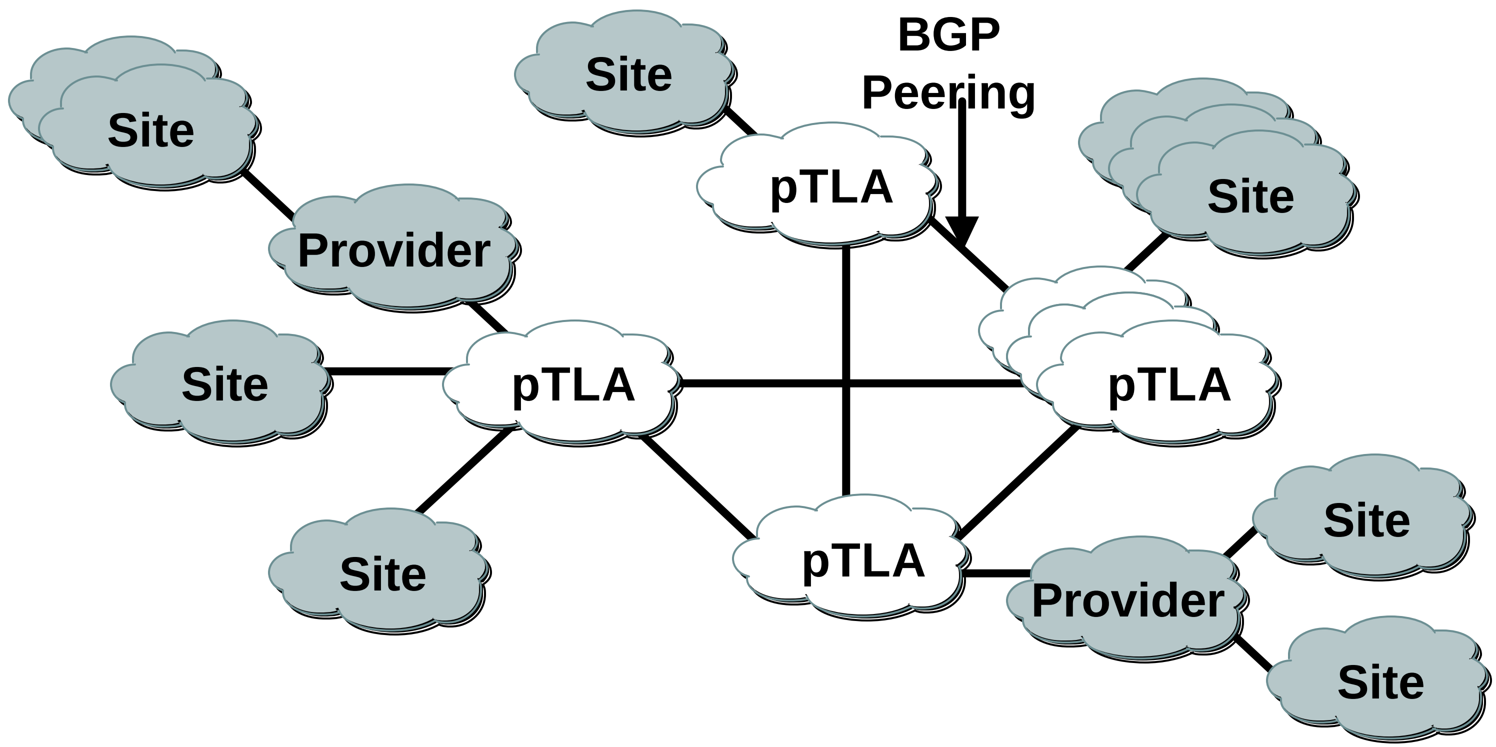

- 6Bone is a test bed network with hundreds of sites from 50 countries
- The 6Bone topology is a hierarchy of providers
- First-level nodes are backbone nodes called pseudo Top-Level Aggregator (pTLA)

IPv6 Header Options (RFC 2460)

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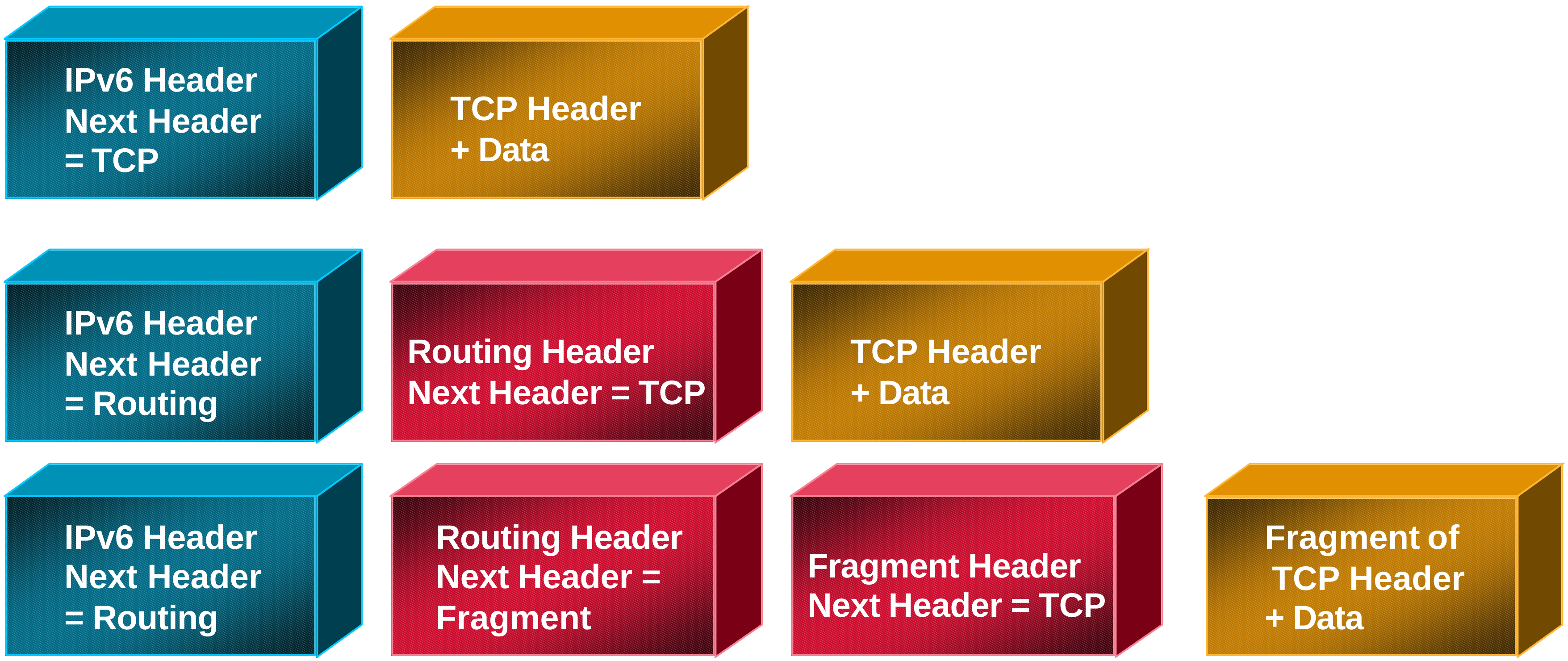

- Processed only by node identified in IPv6 Destination Address field lower overhead than IPv4 options
    - exception: Hop-by-Hop Options header
- Eliminated IPv4's 40-octet limit on options
    - in IPv6, limit is total packet size, or Path MTU in some cases

IPv6 Header Options (RFC2460)

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- Currently defined Headers should appear in the following order

  IPv6 header

  Hop-by-Hop Options header

  Destination Options header

  Routing header

  Fragment header

  Authentication header (RFC 1826)

  Encapsulating Security Payload header (RFC 1827)

  Destination Options header

  upper-layer header

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 = 1280 octets
- a Hop-by-Hop Option supports transmission of “jumbograms” with up to 2^{32} octets of payload

Neighbour Discovery (RFC 2461)

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- **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

    Neighbor Solicitation / Neighbor Advertisements

    Redirect

Neighbour Discovery (RFC 2461)

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- **defined mechanisms between nodes attached on the same link**
  - **Router discovery**
  - **Prefix discovery**
  - **Parameters discovery, i.e.: link MTU, hop limit,…**
  - **Address auto-configuration**
  - **Address Resolution (same function as ARP)**
  - **Next-hop determination**
  - **Neighbor Unreachability Detection (useful for default routers)**
  - **Duplicate Address Detection**
  - **Redirect**

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.

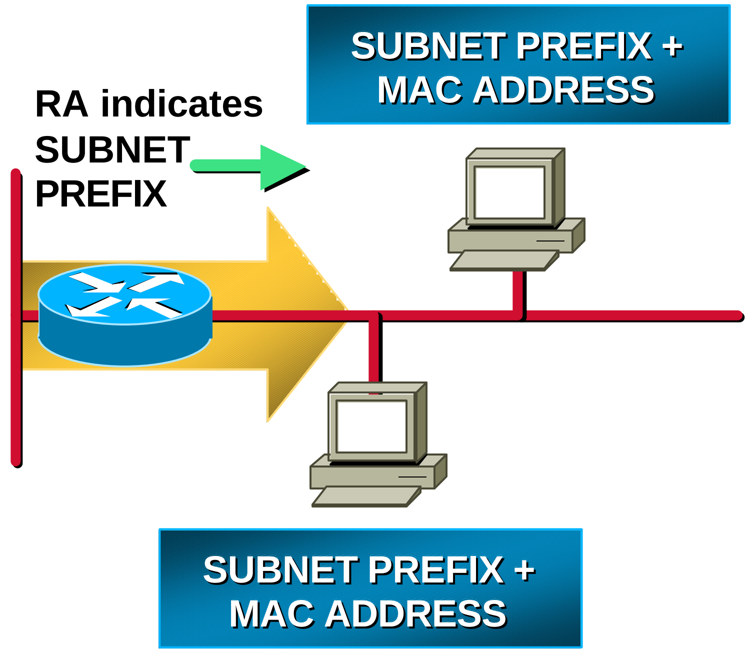
- **Stateful**

  DHCPv6 (under definition at IETF)

- **Renumbering**

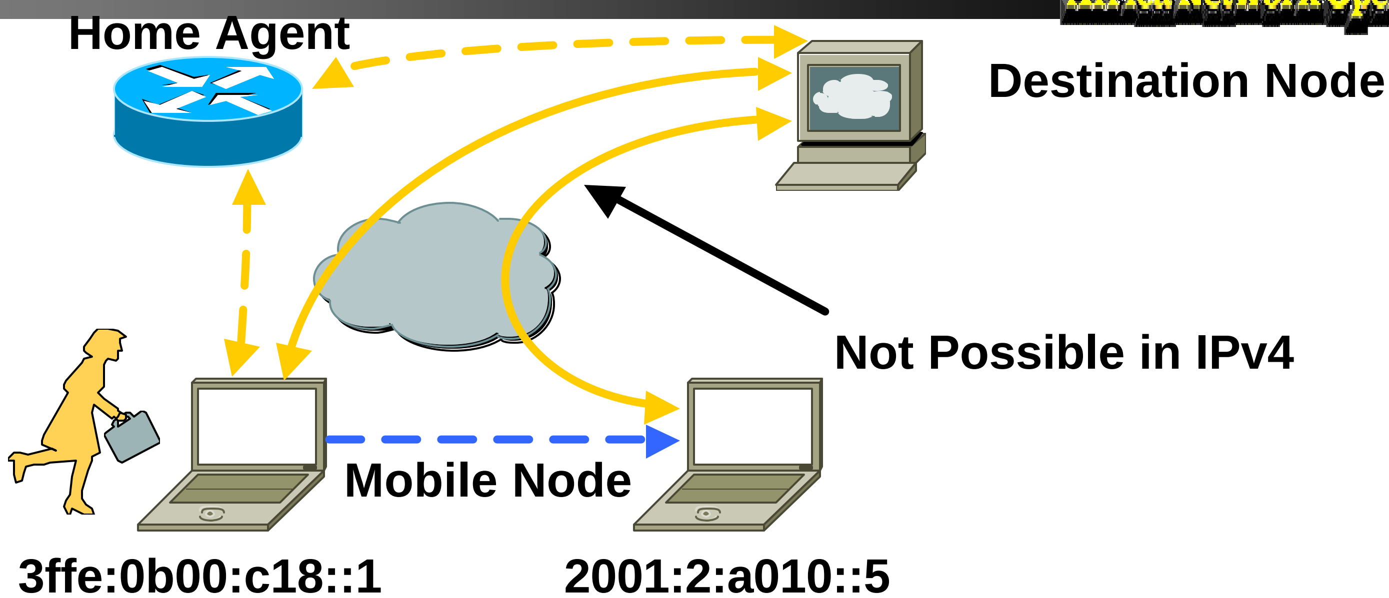
  Hosts renumbering is done by modifying the RA to announce the old prefix with a short lifetime and the new prefix.

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



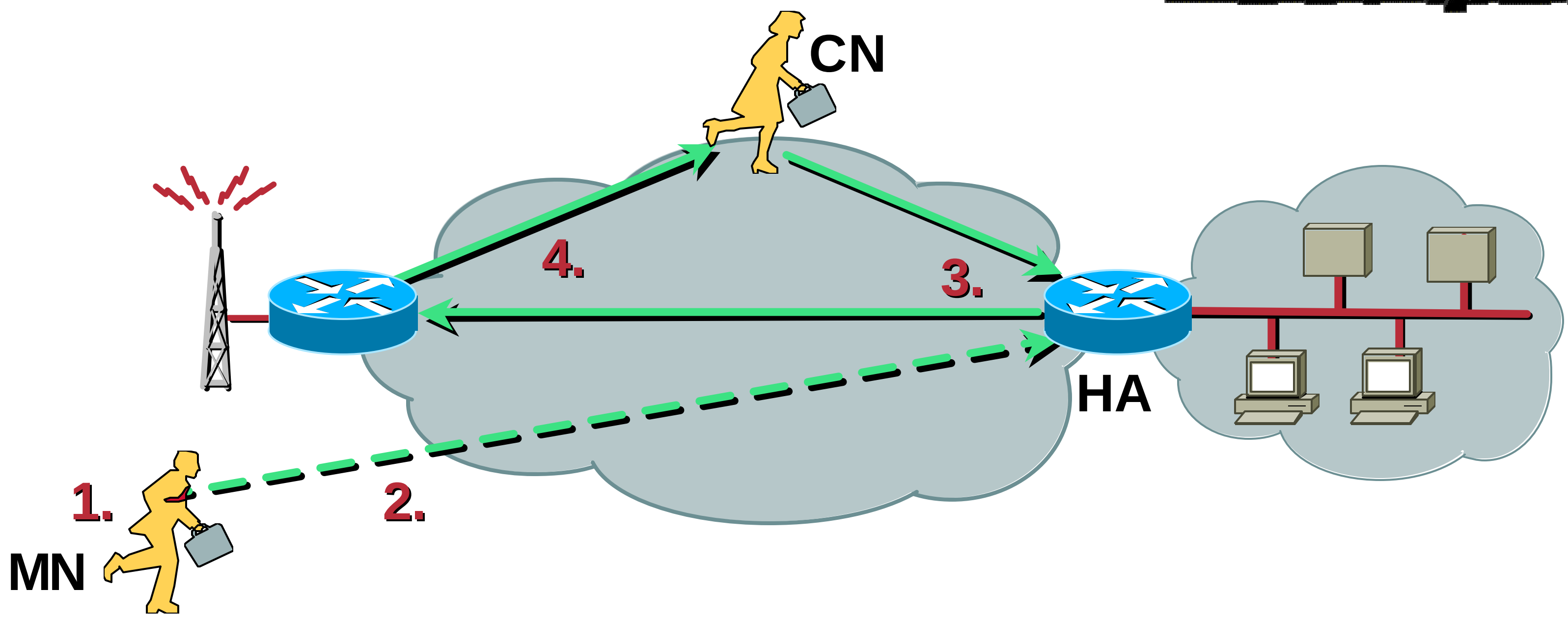
At boot time, an IPv6 host build a Link-Local address, then its global IPv6 address(es) from RA

IP Mobility



- **Mobility means:**
  - Mobile devices are fully supported while moving
  - Built-in on IPv6
    - Any node can use it
  - Efficient routing means performance for end-users

Overview of Mobile IPv6 Functionality



- 1. MN obtains IP address using stateless or stateful autoconfiguration
- 2. MN registers with HA
- 3. HA tunnels packets from CN to MN
- 4. MN sends packets from CN directly or via tunnel to HA

IPv6 Technology Scope

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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

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 Current Status - Standardisation

- **Several key components now on Standards Track:**

Specification (RFC2460)	**Neighbour Discovery (RFC2461)**
ICMPv6 (RFC2463)	**IPv6 Addresses (RFC2373/4/5)**
RIP (RFC2080)	**BGP (RFC2545)**
IGMPv6 (RFC2710)	**OSPF (RFC2740)**
Router Alert (RFC2711)	**Jumbograms (RFC2675)**
Autoconfiguration (RFC2462)	

IPv6 over:	**PPP (RFC2023)**	**Ethernet (RFC2464)**
	FDDI (RFC2467)	**Token Ring (RFC2470)**
	NBMA(RFC2491)	**ATM (RFC2492)**
	Frame Relay (RFC2590)	**ARCnet (RFC2549)**

Recent IPv6 "Hot Topics" in the IETF

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- 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!

Agenda

Africa Network Operators Group

- IPv6 Business Case
- IPv6 Protocols & Standards
- IPv6 Routing
- Integration and Transition
- IPv6 Deployment scenarios

Routing in IPv6

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- As in IPv4, IPv6 supports IGP and EGP routing protocols:
  - IGP for within an autonomous system are
    - RIPng (RFC 2080)
    - OSPFv3 (RFC 2740)
    - Integrated IS-ISv6 (draft-ietf-isis-ipv6-02.txt)
    - EIGRP for IPv6 (Cisco)
  - EGP for peering between autonomous systems
    - MP-BGP4 (RFC 2858 and RFC 2545)
- IPv6 still uses the longest-prefix match routing algorithm

IPv6 IGP LSP Option

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- **i/IS-ISv6**
  - Shared IGP for IPv4 & IPv6
  - Route from A to B same for IPv4 & IPv6
  - Separate SPFs may provide SIN routing
- **OSPFv3**
  - « Ships in the Night » routing
  - Need to run another IGP for IPv4
  - Route from A to B may differ for IPv4 & IPv6

Integrated IS-IS for IPv6

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- **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.**
- **IETF 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**
- **IETF Draft RFC defines how to support IPv6 on I/IS-IS**
  - **draft-ietf-isis-ipv6-02.txt**

New Tag/Length/Values for IPv6 routing

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- 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

Single SPF rules

- **If IS-IS is used for both IPv4 and IPv6 in an area, both protocols must support the same topology within this area.**

- **All interfaces configured with IS-ISv6 must support IPv6**

  Can't be configured on MPLS/TE since IS-ISv6 extensions for TE are not yet defined

- **All interfaces configured with IS-IS for both protocols must support both of them**

  IPv6 configured tunnel won't work, GRE should be used in this configuration

IS-IS Hierarchy & IPv6 example

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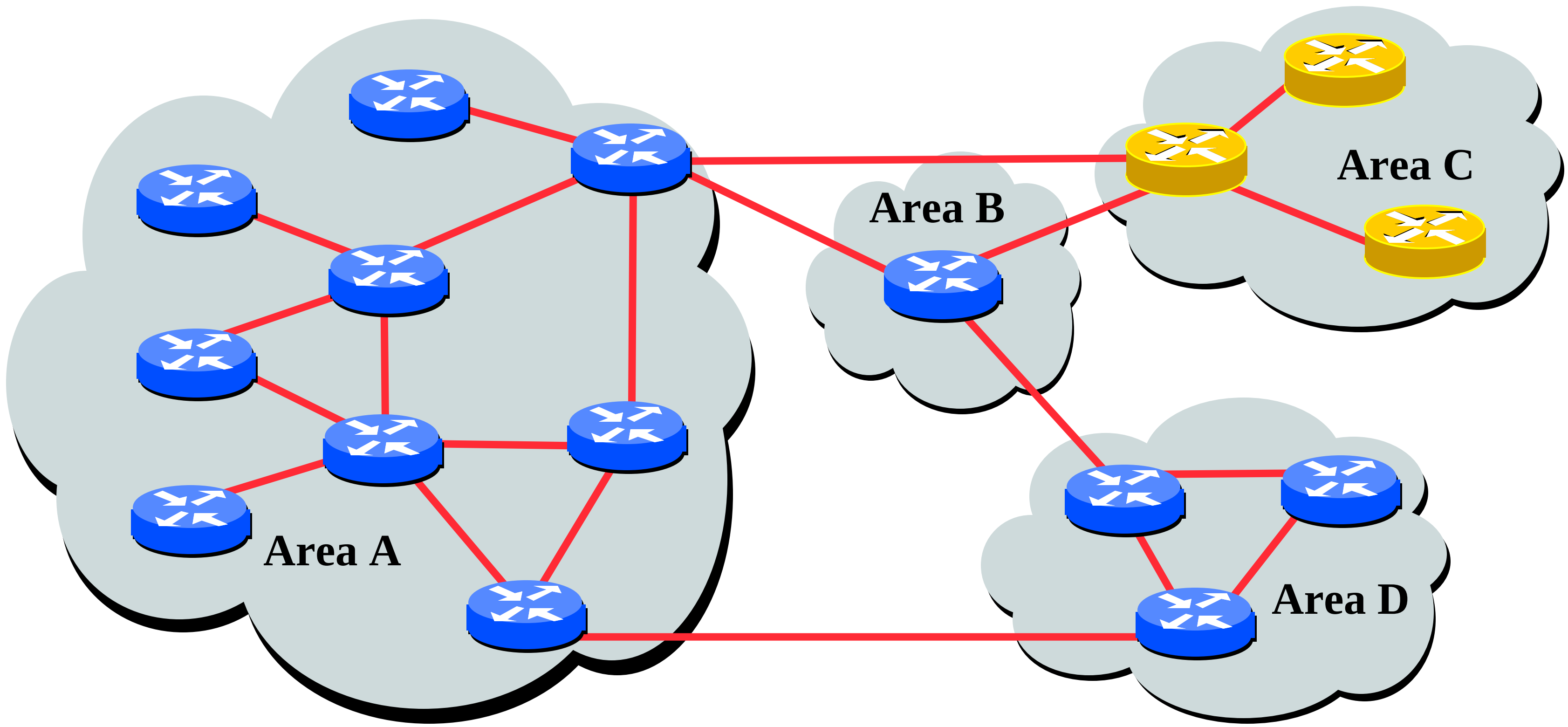

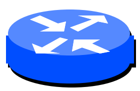

IPv4-IPv6 enable router

IPv4-only enable router

OSPFv3 overview

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

Similarities to OSPFv2

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- **Same basic packet types**
  - **Hello, DBD, LSR, LSU, LSA**
- **Same mechanisms for neighbor discovery and adjacency formation**
- **Same interface types**
  - **P2P, P2MP, Broadcast, NBMA, Virtual**
- **Same LSA flooding and ageing**
- **Almost same LSA type**

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

LSA Type Review

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

U	S2	S1	LSA function code

Link LSA

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- A link LSA per link
- link local scope flooding on the link they are associated with
- Provide router link local address
- List all IPv6 prefixes attached to the link

Intra-area prefix LSA

- **Multiple LSA with the different Link State ID**
- **Area flooding scope**
- **1- associate prefix with transit network referencing a Network-LSA**
- **2- associate prefix with a router or a stub referencing a Router-LSA**

Multi-Protocol BGP - RFC2283

- Extension to the BGP protocol in order to carry routing information about other protocols
    - Multicast
    - MPLS VPN
    - IPv6
    - IPv6+label
    - CLNS
- Exchange of Multi-Protocol NLRI must be negotiated at session set up

Two new attributes

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- New non-transitive and optional BGP attributes
  - MP_REACH_NLRI

    "Carry the set of reachable destinations together with the next-hop information to be used for forwarding to these destinations"

  - MP_UNREACH_NLRI

    Carry the set of unreachable destinations

MP_REACH_NRLI structure

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- Attribute contains one or more Triples
  - Address Family Information(AFI) and Sub-AFI
    - AFI =1 (IPv4)
    - AFI=2 (IPv6)
  - Next-hop information
  - NLRI (Network Layer Reachability Info)

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)

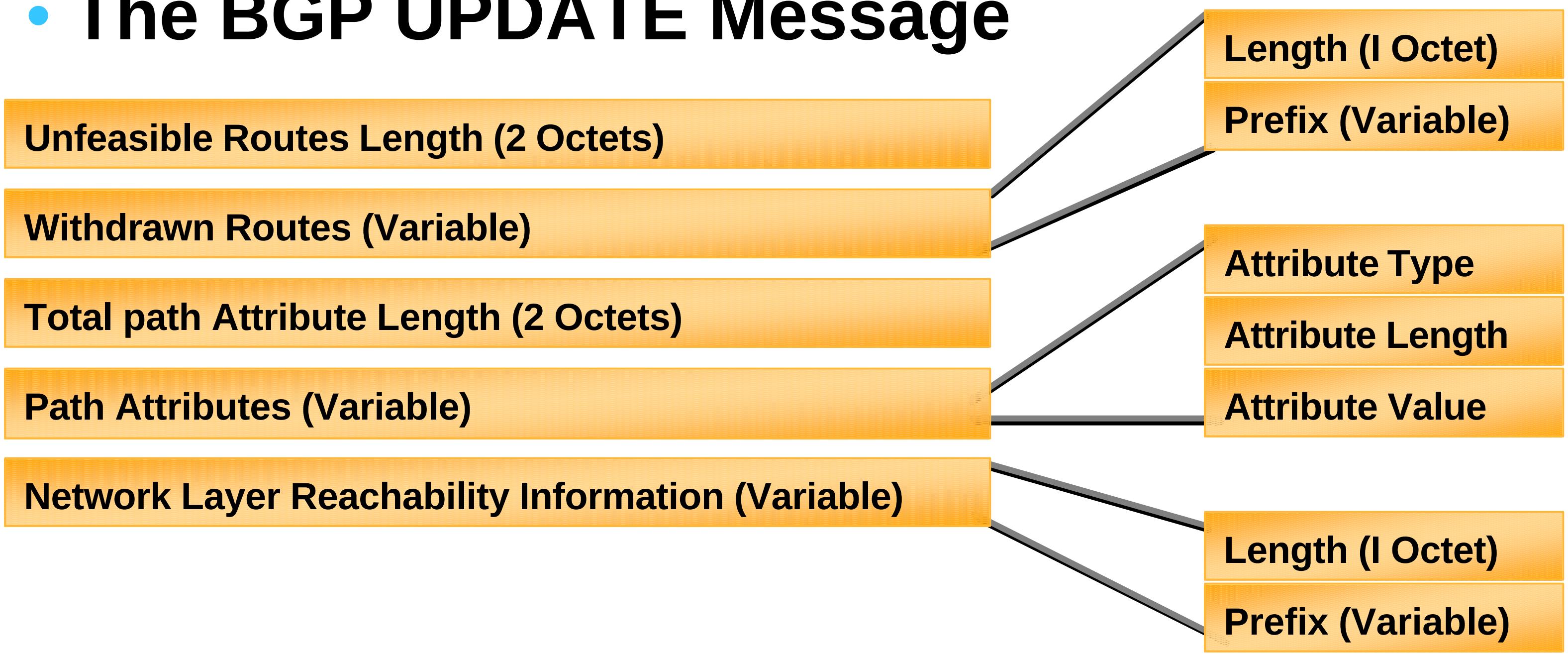
Sub-AFI = 1 (NLRI is used for unicast)

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

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

Multi-Protocol BGP – Packet format

- The BGP UPDATE Message



- Each update message contains attributes, like origin, AS-Path, Next-Hop, ……. MP_REACH_NLRI

MBGP – Packet format for IPv6

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- **MP_REACH_NLRI Attribute**

Address Family Identifier (2)
Subsequent Address Family Identifier (1)
Length of the Next-Hop Address (16 or 32)
Network Address of Next-Hop (global and/or Link local)
Network Layer Reachability Information (Variable)

Network Layer Reachability Information:

Length (Variable)
Prefix (Variable)

BGP Capabilities Negotiation

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- BGP routers establish BGP sessions through the OPEN message
- OPEN message contains optional parameters
- BGP session is terminated if OPEN parameters are not recognised
- A new optional parameter: CAPABILITIES

BGP Capabilities Negotiation

- **A BGP router sends an OPEN message with CAPABILITIES parameter containing its capabilities:**

  Multiprotocol extension (AFI/SAFI)

  Route Refresh

  Outbound Route Filtering

MBGP—Capability Negotiation

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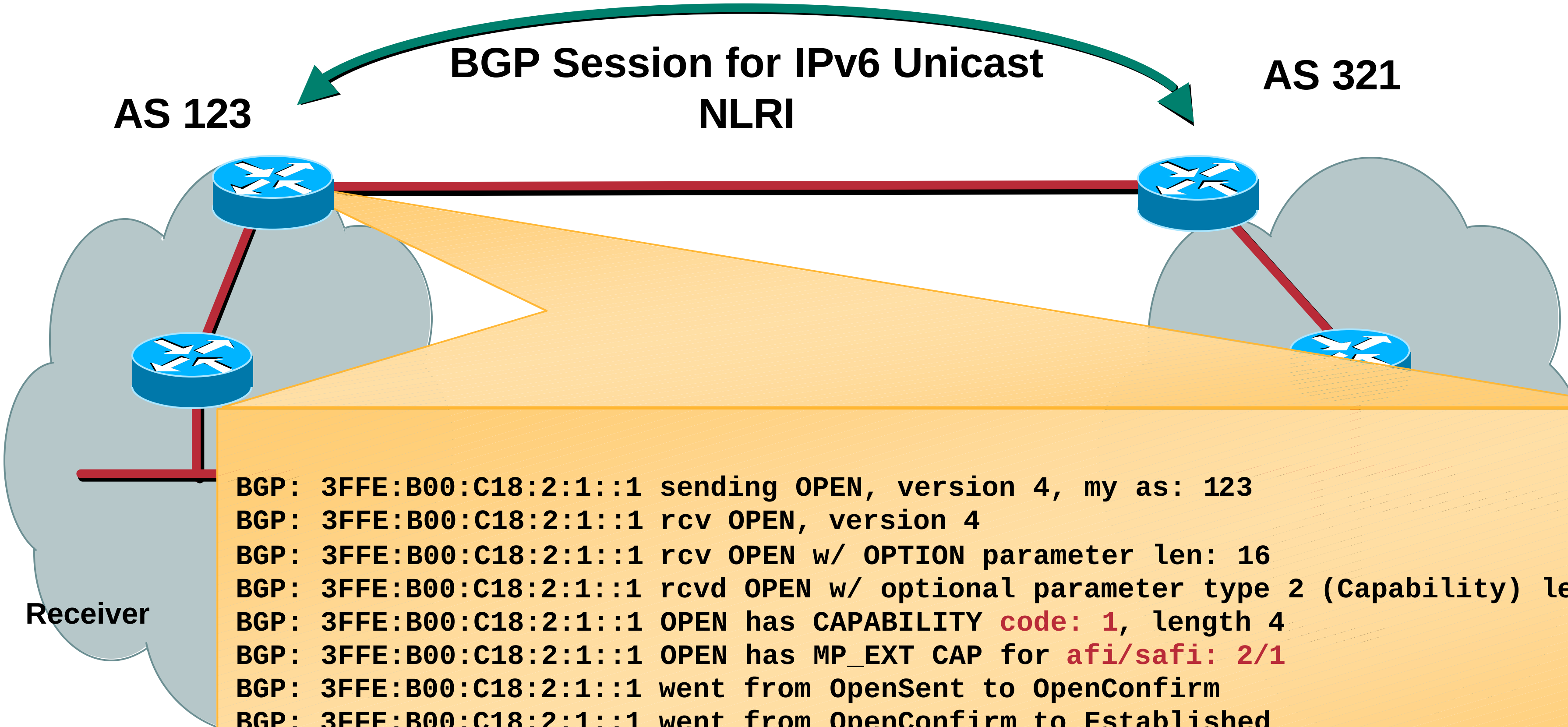


```
BGP: 3FFE:B00:C18:2:1::1 sending OPEN, version 4, my as: 123
BGP: 3FFE:B00:C18:2:1::1 rcv OPEN, version 4
BGP: 3FFE:B00:C18:2:1::1 rcv OPEN w/ OPTION parameter len: 16
BGP: 3FFE:B00:C18:2:1::1 rcvd OPEN w/ optional parameter type 2 (Capability) len 6
BGP: 3FFE:B00:C18:2:1::1 OPEN has CAPABILITY code: 1, length 4
BGP: 3FFE:B00:C18:2:1::1 OPEN has MP_EXT CAP for afi/safi: 2/1
BGP: 3FFE:B00:C18:2:1::1 went from OpenSent to OpenConfirm
BGP: 3FFE:B00:C18:2:1::1 went from OpenConfirm to Established
%BGP-5-ADJCHANGE: neighbor 3FFE:B00:C18:2:1::1 Up
```

Agenda

Africa Network Operators Group

- IPv6 Business Case
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- IPv6 Routing
- Integration and Transition
- IPv6 Deployment scenarios

IETF NGTrans Working Group

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- 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.
- http://www.ietf.org/html.charters/ngtrans-charter.html

IPv4-IPv6 Transition / Co-Existence

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

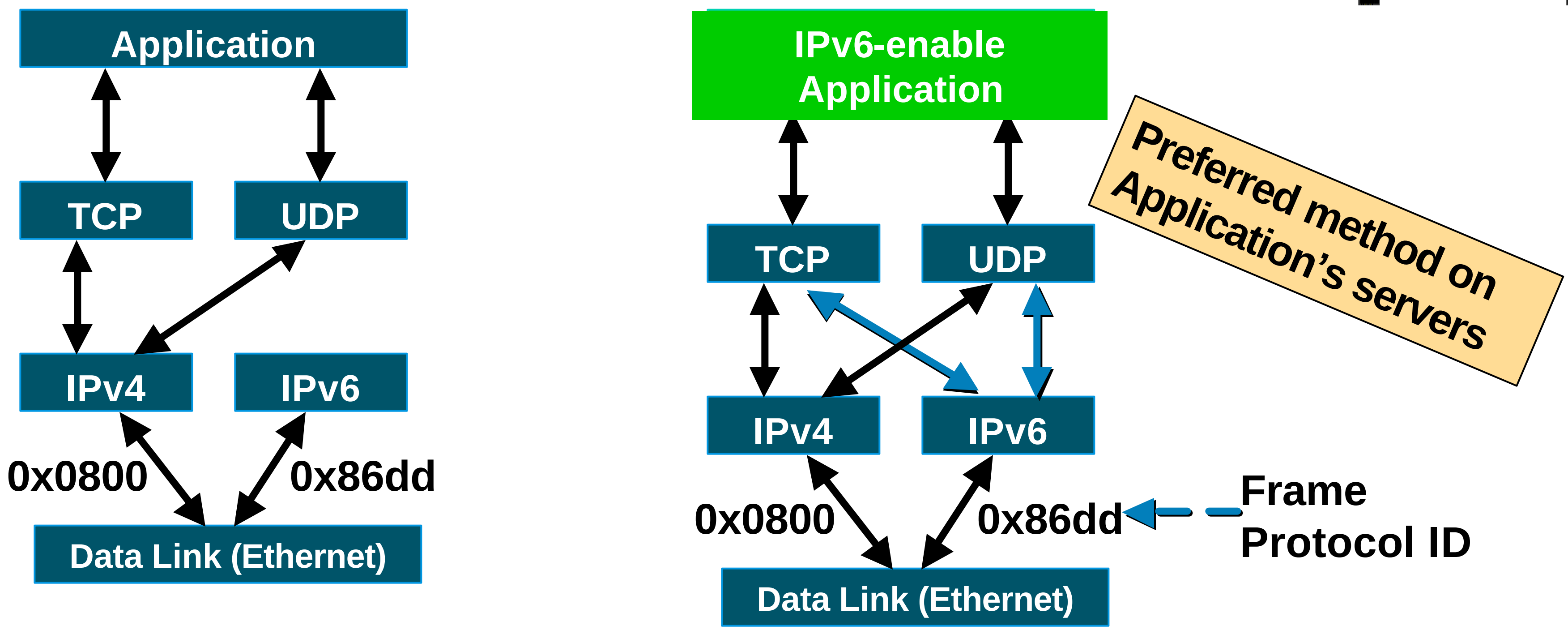
(1) Dual-stack techniques, to allow IPv4 and IPv6 to co-exist in the same devices and networks

(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

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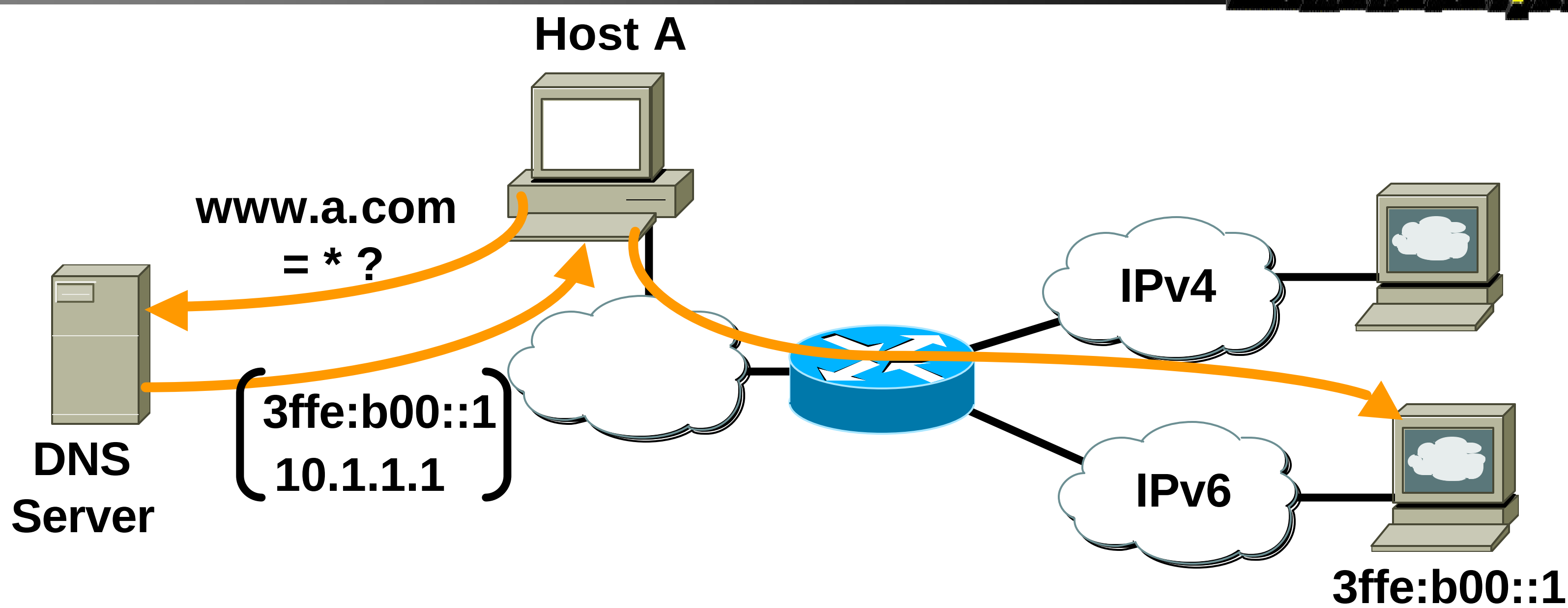

- In a dual stack case, an application that:

  Is IPv4 and IPv6-enabled

  Asks the DNS for all types of addresses

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

A Dual Stack Configuration

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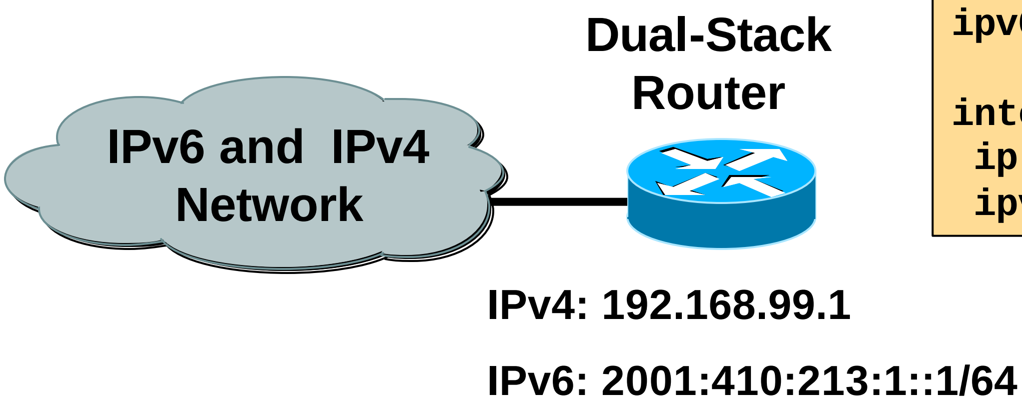



```
router#
ipv6 unicast-routing

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

- **IPv6-enable router**

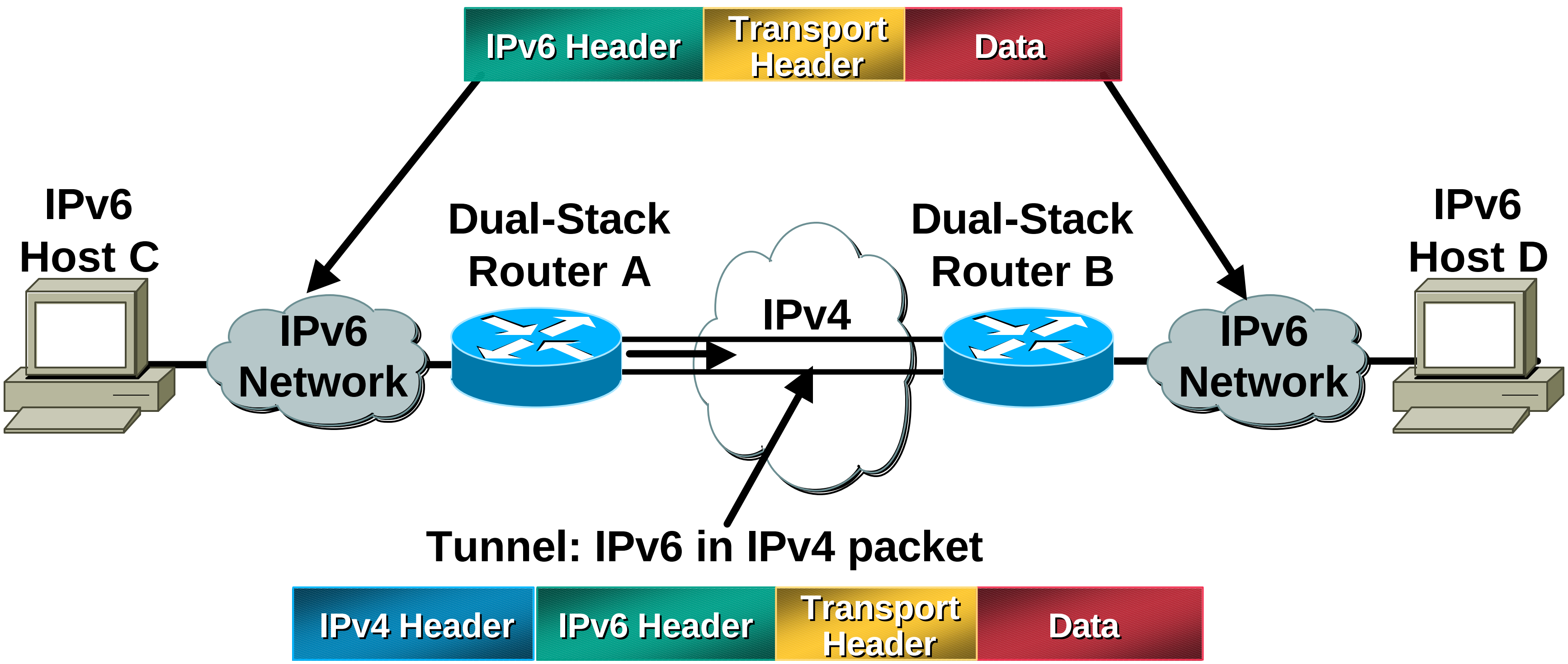
  If IPv4 and IPv6 are configured on one interface, the router is dual-stacked

  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)
    - 6to4 (RFC 3056)
    - 6over4 (RFC 2529)
    - 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 (RFC 2893)

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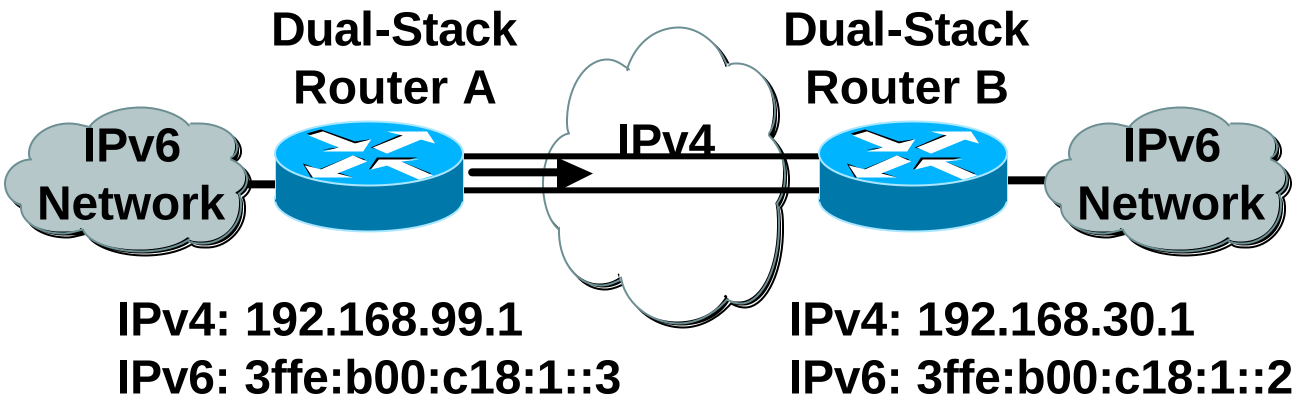


```
routerA#

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
```

```
routerB#

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

IPv4 Compatible Tunnel (RFC 2893)

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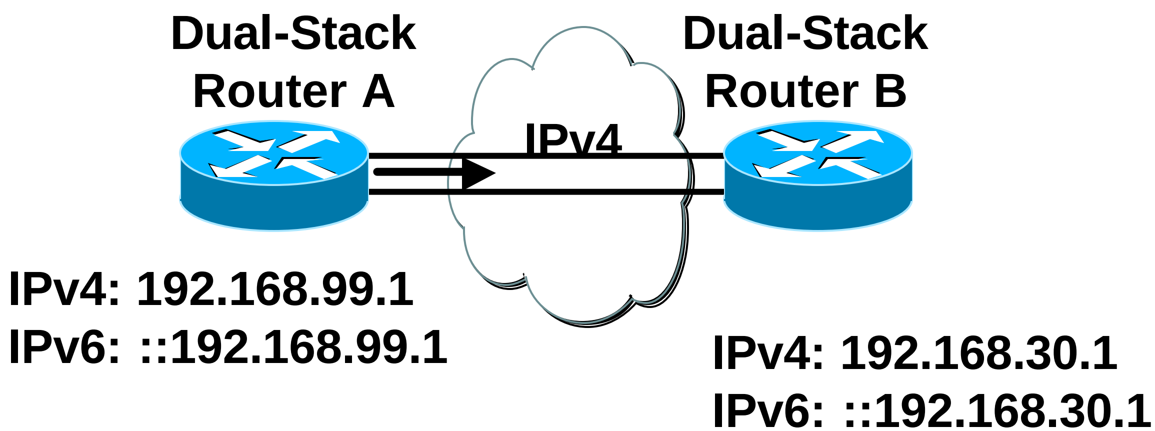

- **IPv4-compatible addresses are easy way to auto-tunnel**

6to4 Tunnel (RFC 3056)

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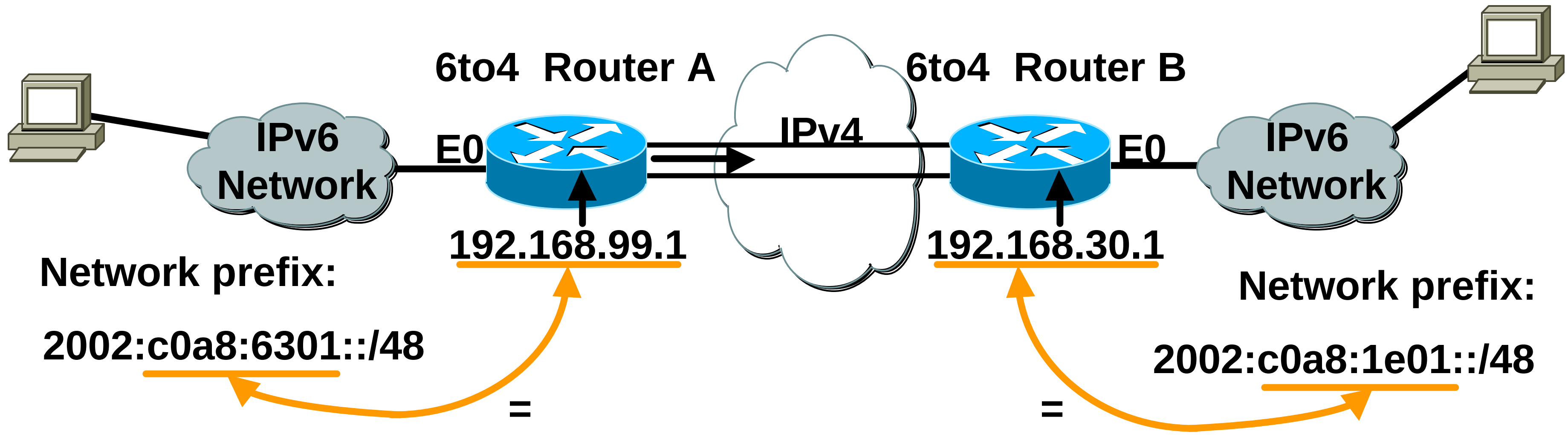
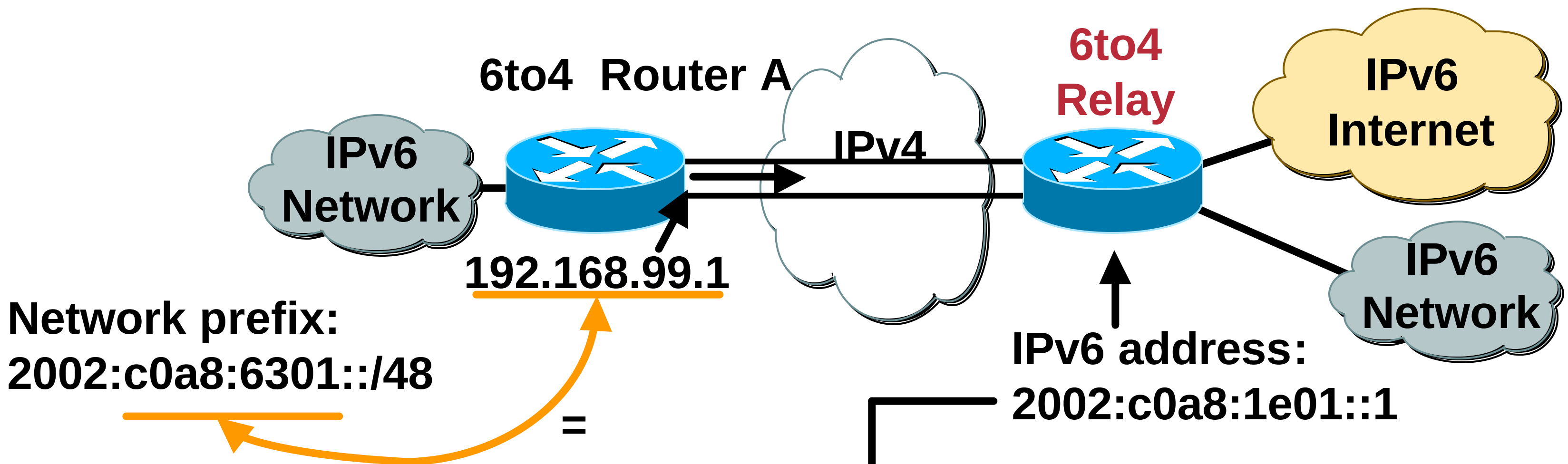


- **6to4 Tunnel:**
  - Is an automatic tunnel method
  - Gives a prefix to the attached IPv6 network
  - 2002::/16 assigned to 6to4
  - Requires one global IPv4 address on each Ingress/Egress site

```
routerB#
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

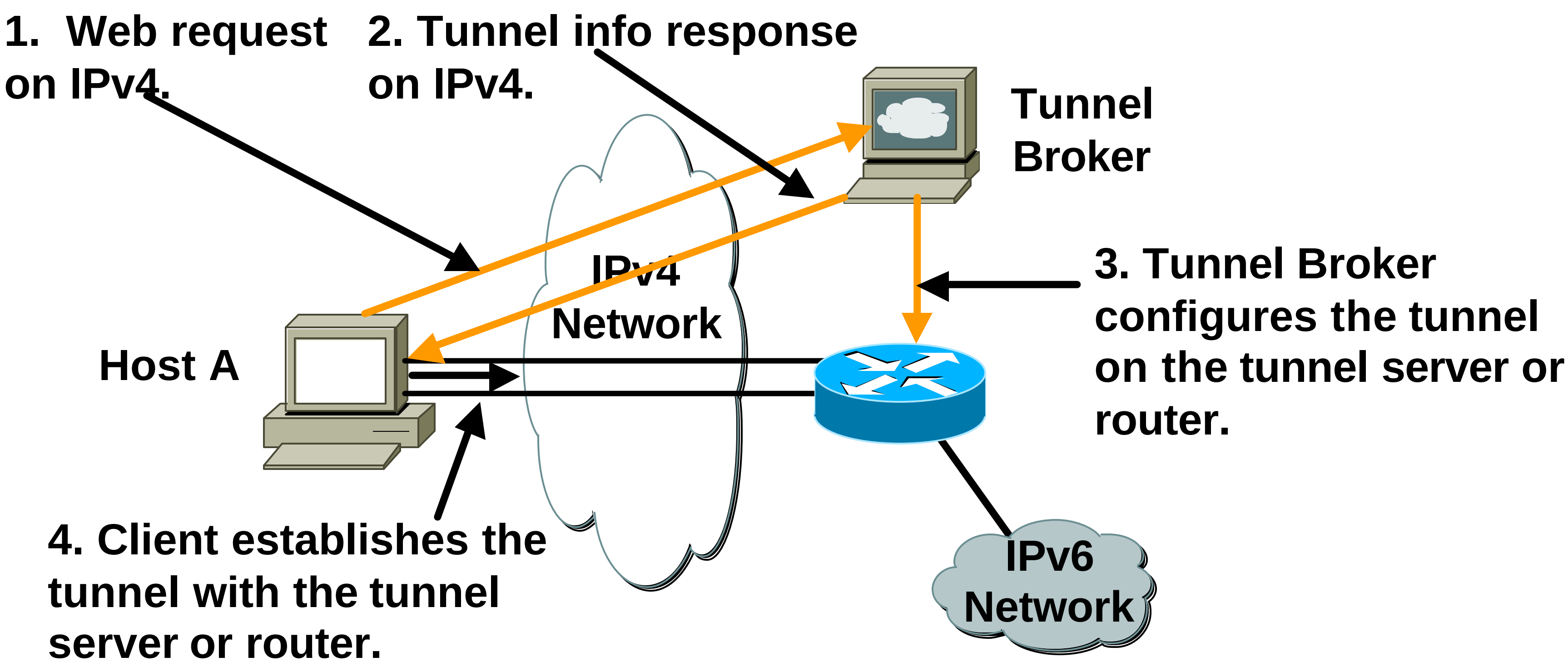



```
routerA#
interface Loopback0
 ip address 192.168.99.1 255.255.255.0
 ipv6 address 2002:c0a8:6301:1::/64 eui-64
interface Tunnel0
 no ip address
 ipv6 unnumbered Ethernet0
 tunnel source Loopback0
 tunnel mode ipv6ip 6to4

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

IPv6-IPv4 Communication Mechanisms

- **Translation**
  - **NAT-PT (RFC 2766)**
  - **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)**

ISATAP - Intra-Site Automatic Tunnel Addressing Protocol

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- Tunnelling of IPv6 in IPv4
- In a 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
  - An ISATAP special identifier
  - The IPv4 address of the node
- ISATAP nodes are dual-stack

ISATAP address 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 an ISATAP address
  - Rightmost 32 bits = <ipv4 address>
    - The IPv4 address of the node

ISATAP dedicated prefix	0000:5EFE	IPv4 address

ISATAP prefix advertisement

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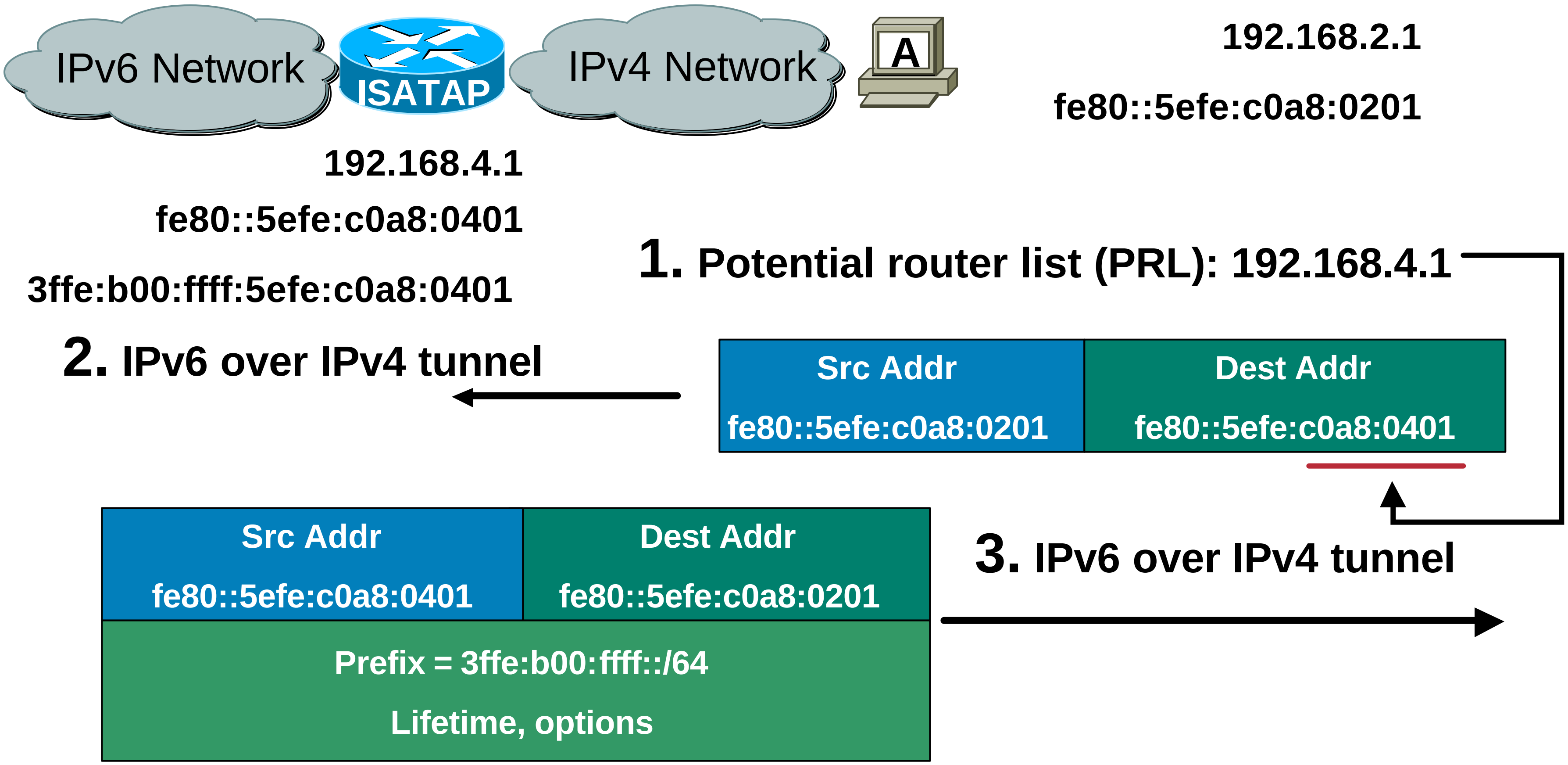
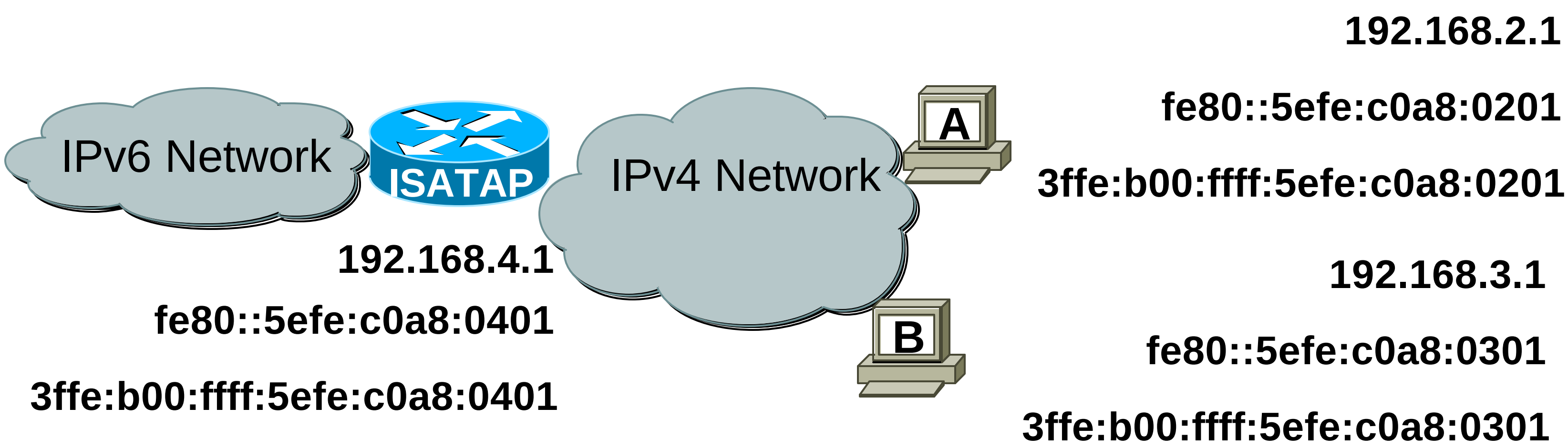
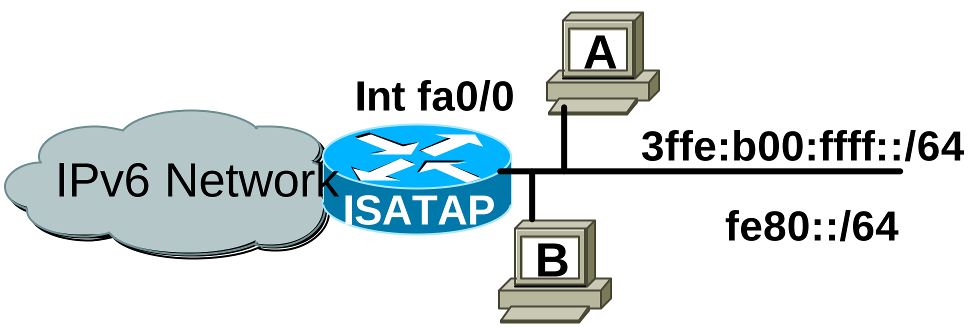


4. Host A configures global IPv6 address using ISATAP prefix 3ffe:b00:ffff:/64

ISATAP configuration example






```
interface FastEthernet0/0
 ipv6 address3FFE:ffff:123:1999::1/64
!
Int tu0
Tunnel mode isatap
!
Int fa0/0
```

NAT-PT for IPv6

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- NAT-PT (Network Address Translation - Protocol Translation) - RFC 2766
- NAT-PT 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

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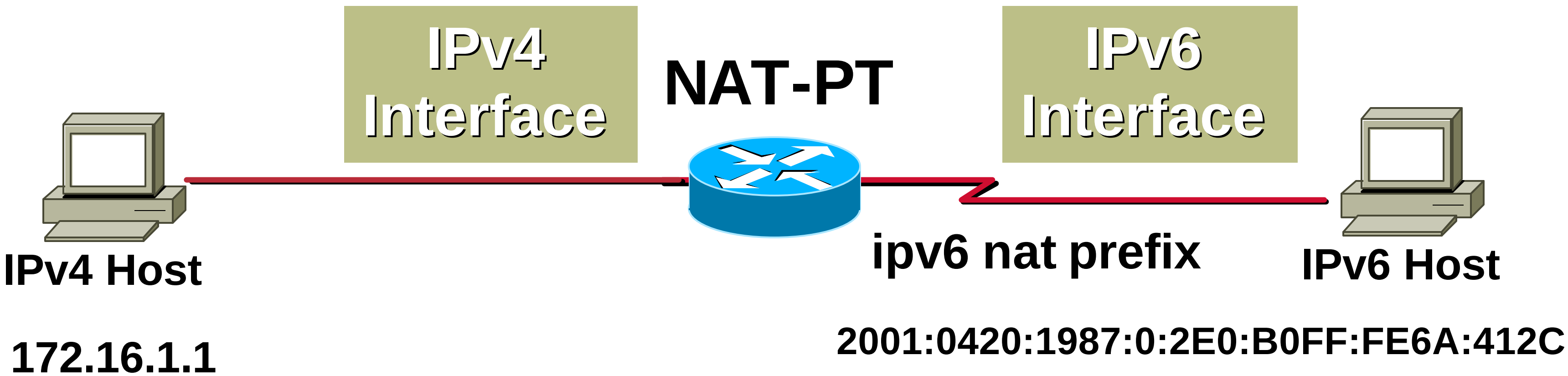

- **PREFIX is a 96-bit field that allows routing back to the NAT-PT device**

NAT-PT packet flow

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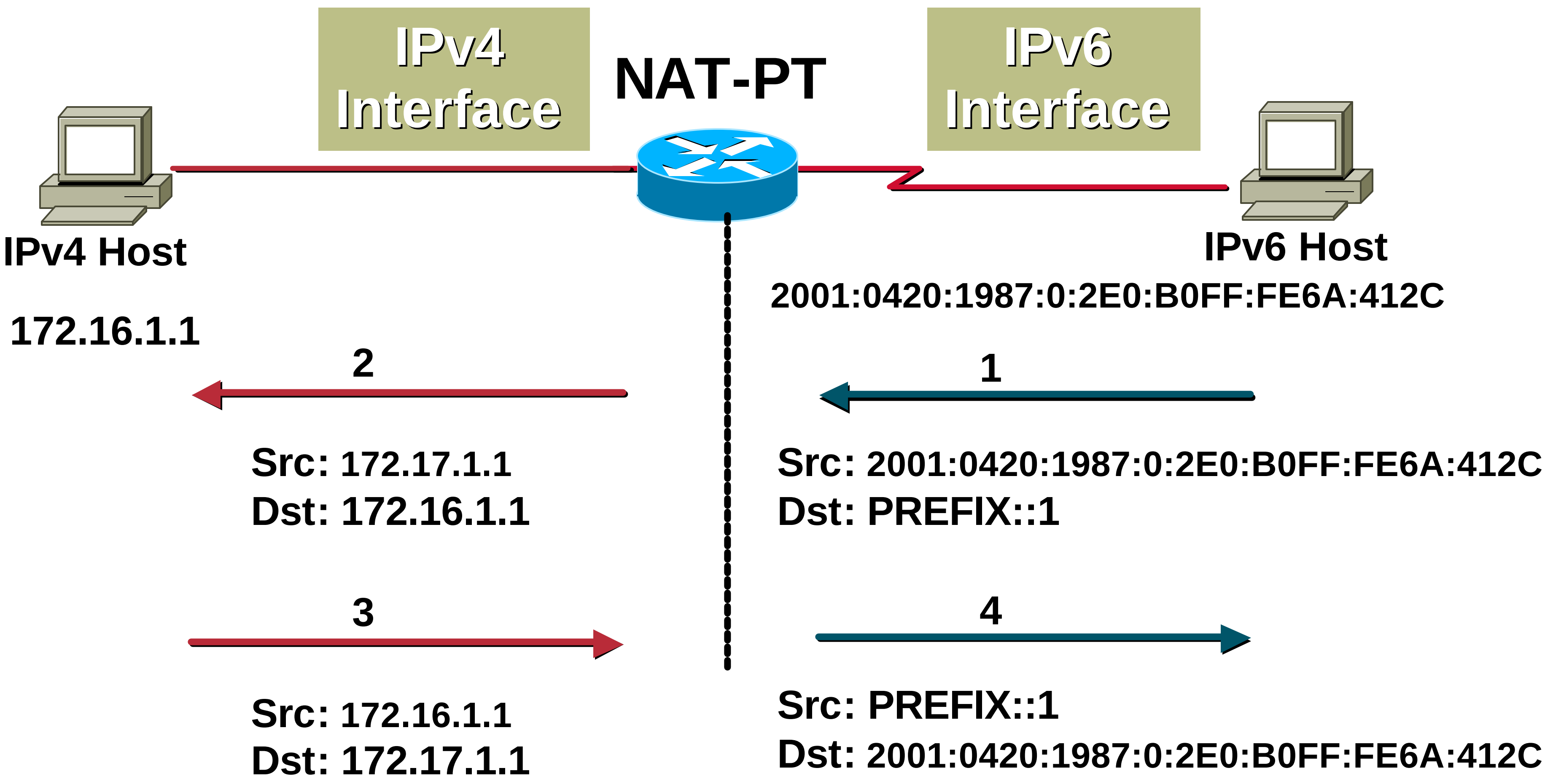

Stateless IP ICMP Translation

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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

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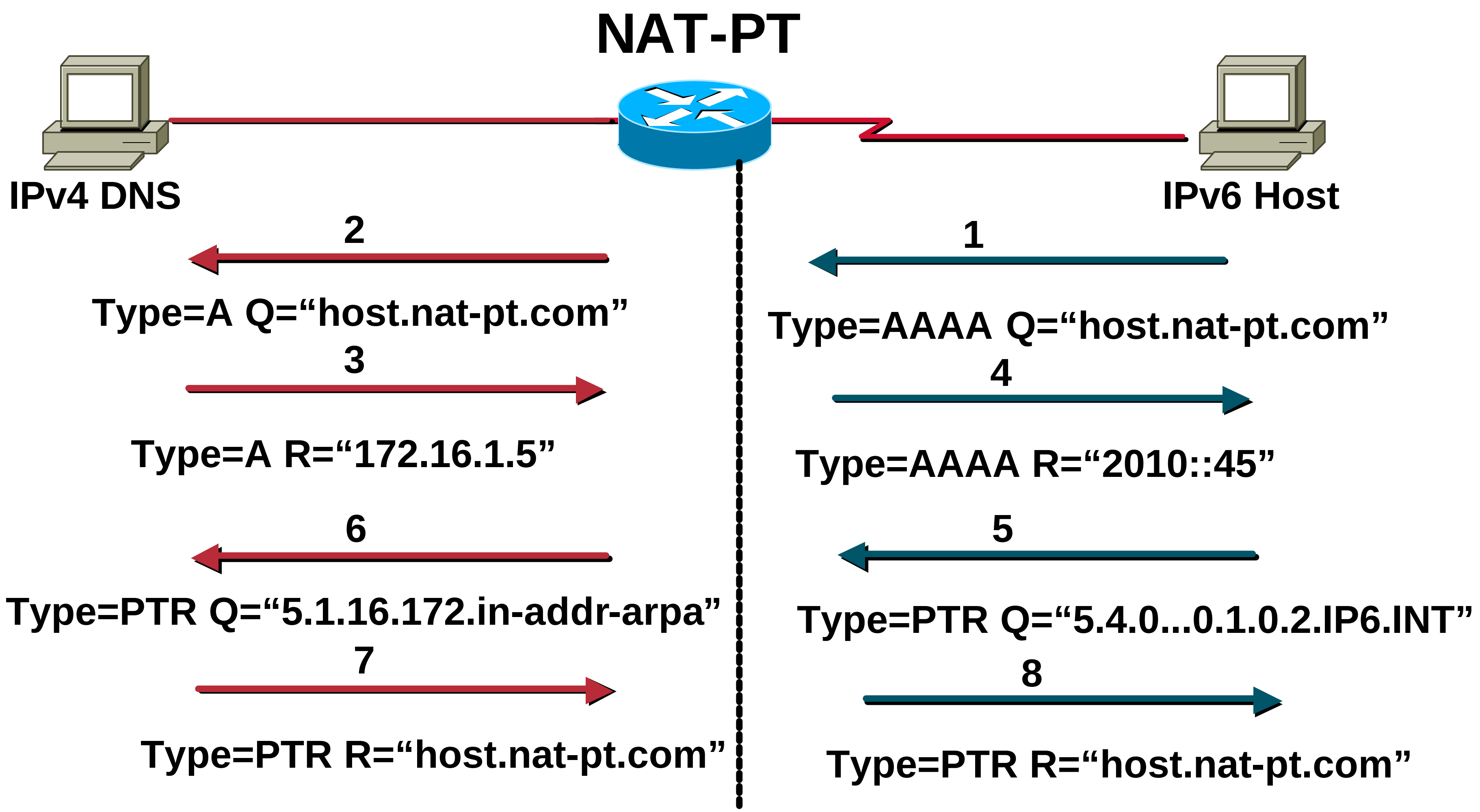

NAT-PT points of attention

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- ALG per application carrying IP address
- No End to End security
  - no DNSsec
  - no IPsec because different address realms

Agenda

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IPv6 Timeline

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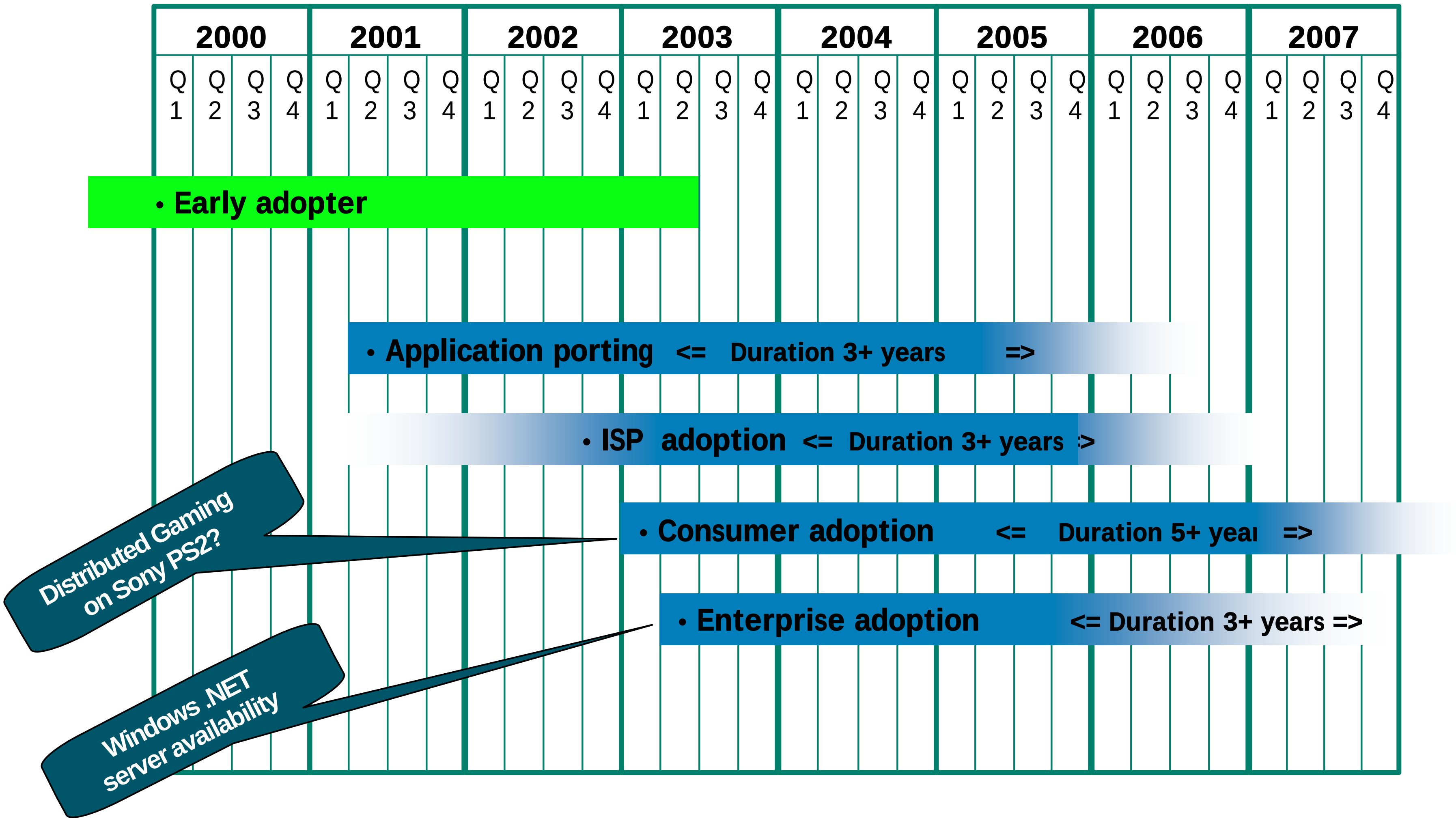

IPv6 – Working out the Timeline

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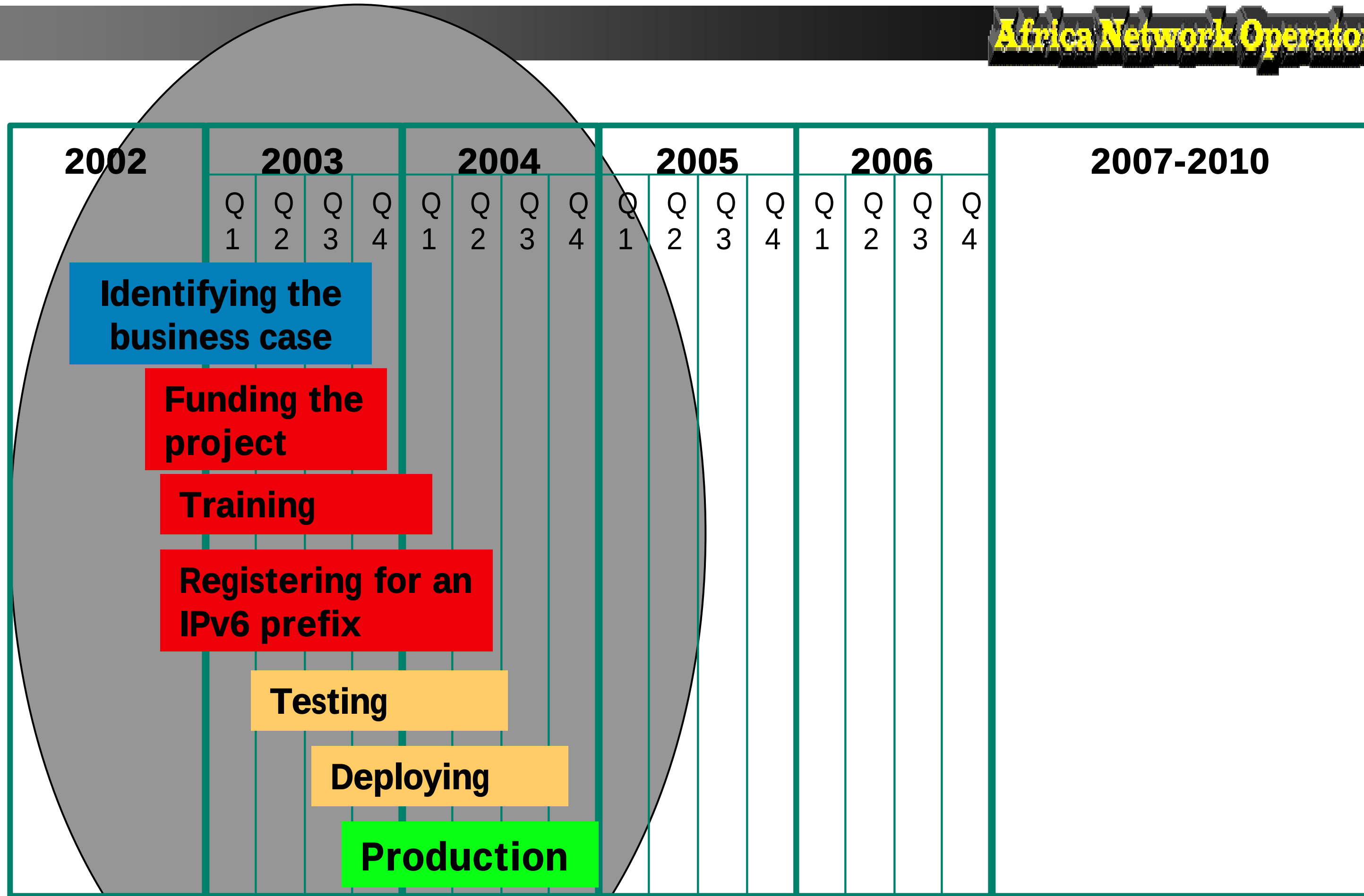
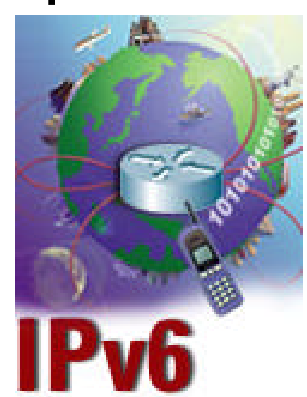


How long do you need for each phase of an IPv6 deployment project?

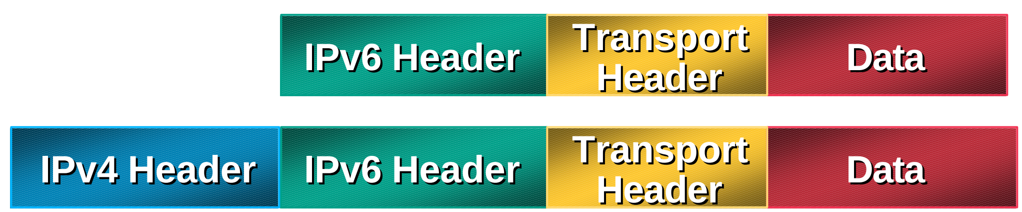
IPv6 Deployment Scenarios

- **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**
  - **ISPs 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

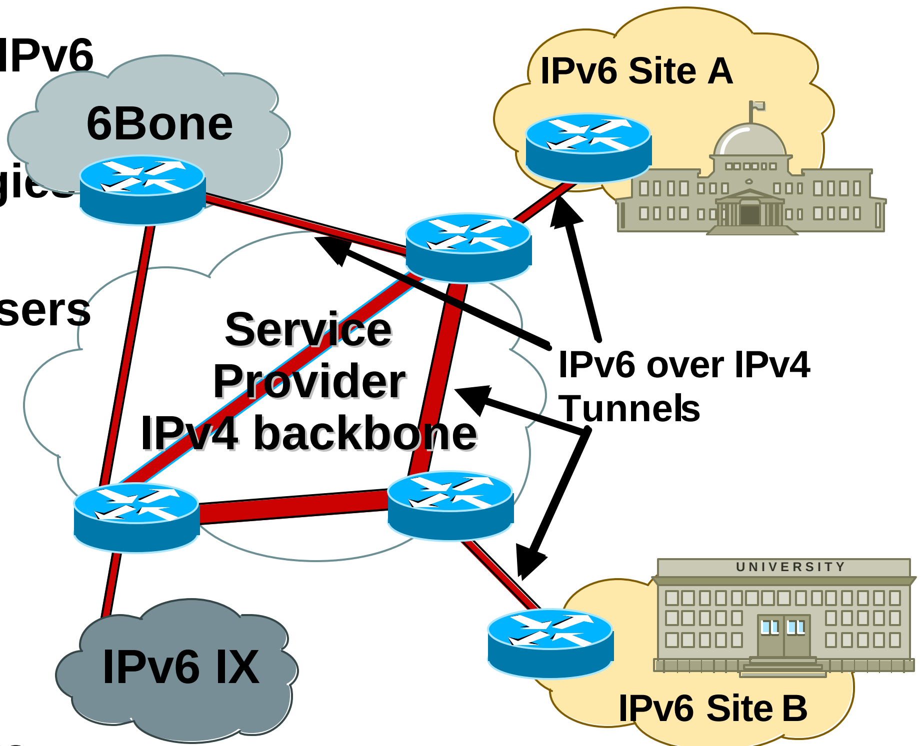
  IPv4 traffic (and revenues) can be separated from IPv6

- **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 eg. 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

Use the most appropriate



Dual Stack IPv4-IPv6 Infrastructure

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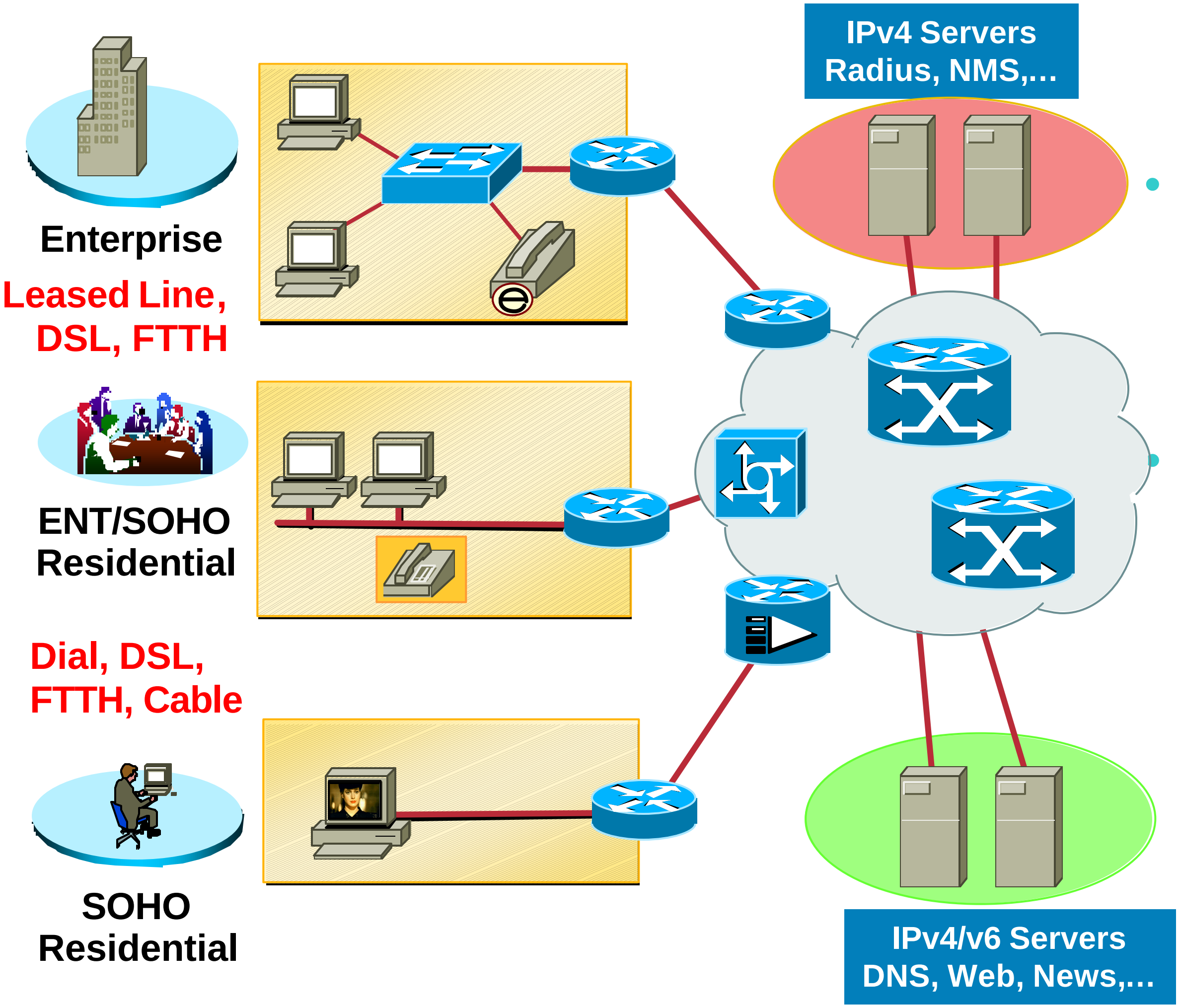
- It is generally a long term goal when IPv6 traffic and users will be rapidly increasing
- May be easier on network's portion such as Campus or Access networks
- Theoretically possible but the network design phase has to be well planned
  - Memory size to handle the growth for both IPv4 & IPv6 routing 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

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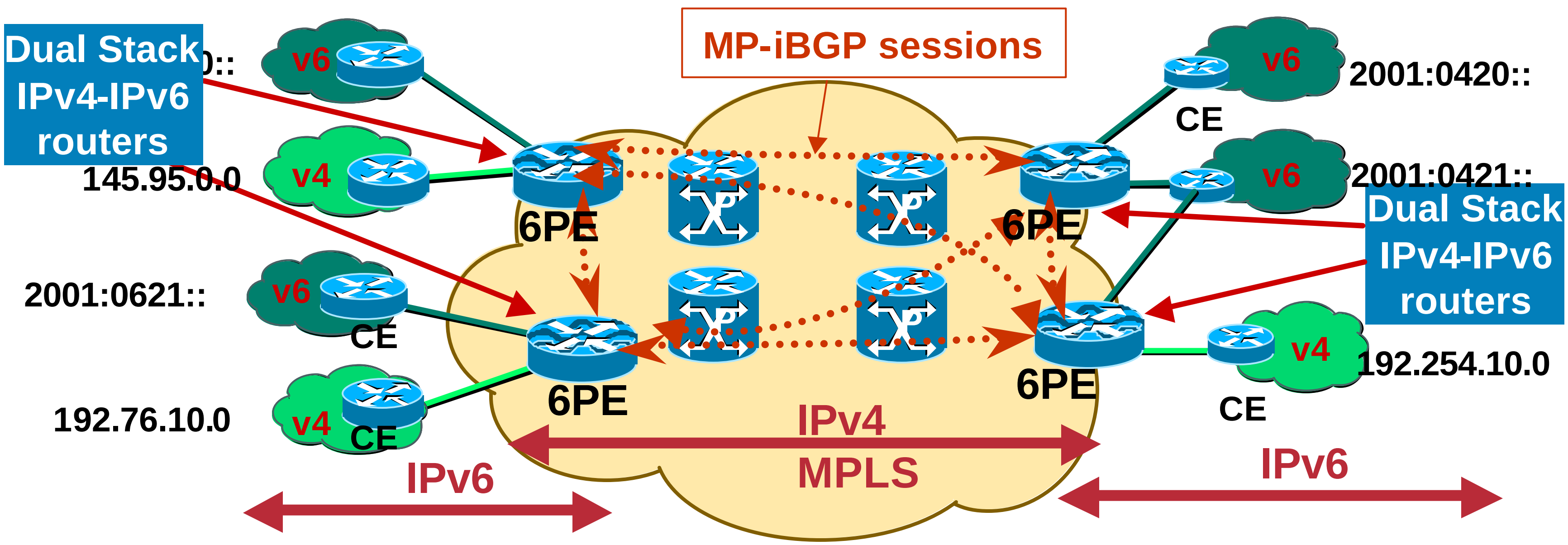


- IPv4 or MPLS Core Infrastructure is IPv6-unaware
- PEs are updated to support Dual Stack/6PE
- IPv6 reachability exchanged among 6PEs via iBGP
- IPv6 packets transported from 6PE to 6PE inside MPLS

Native IPv6-only Infrastructure?

- **Application's focus**

  When will the IPv6 traffic be important enough?

- **Requires**

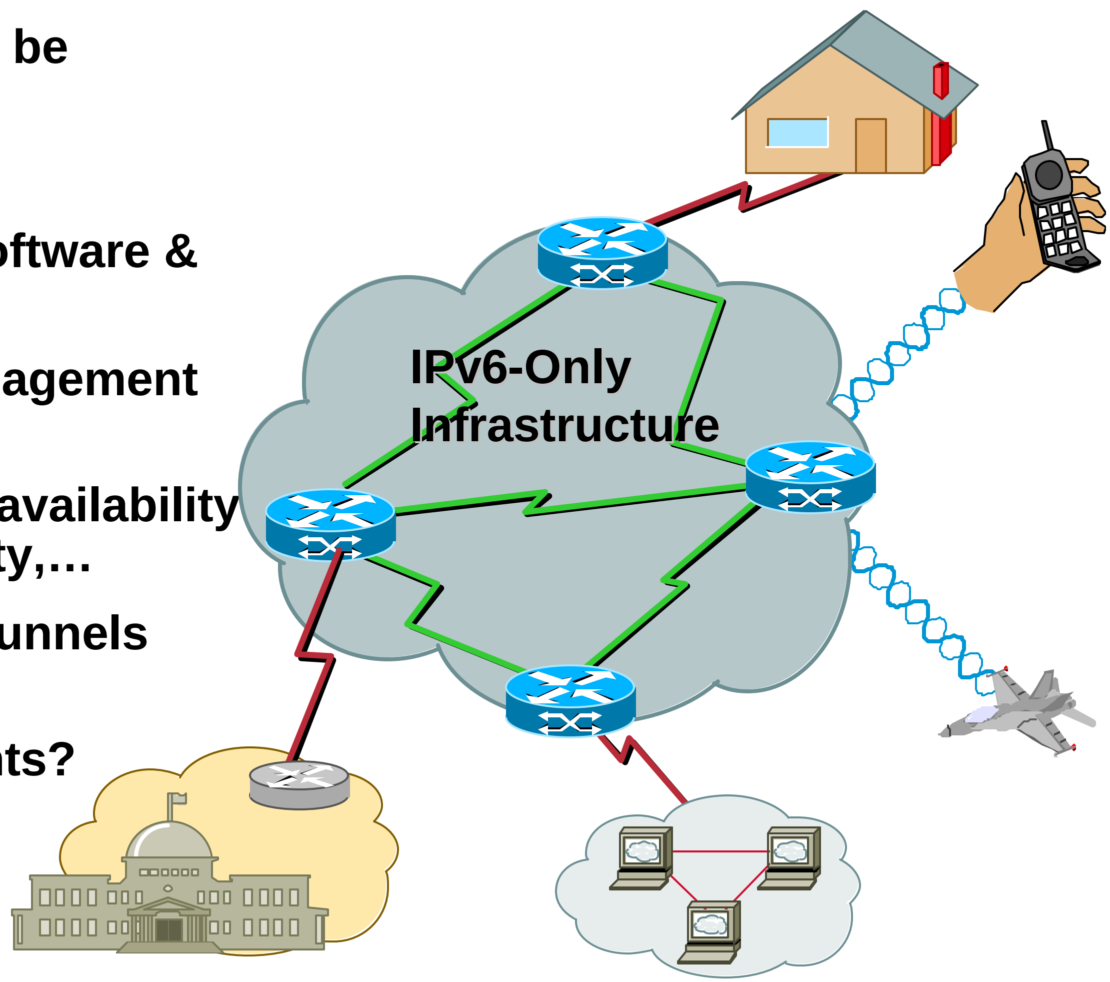
  Full Network upgrade (software & potentially hardware)

  Native IPv6 Network Management Solutions

  Enhanced IPv6 services availability
  Multicast, QoS, security,…

  Transport IPv4 through tunnels over IPv6

  IPv4 traffic requirements?



IPv6 Deployment Phases

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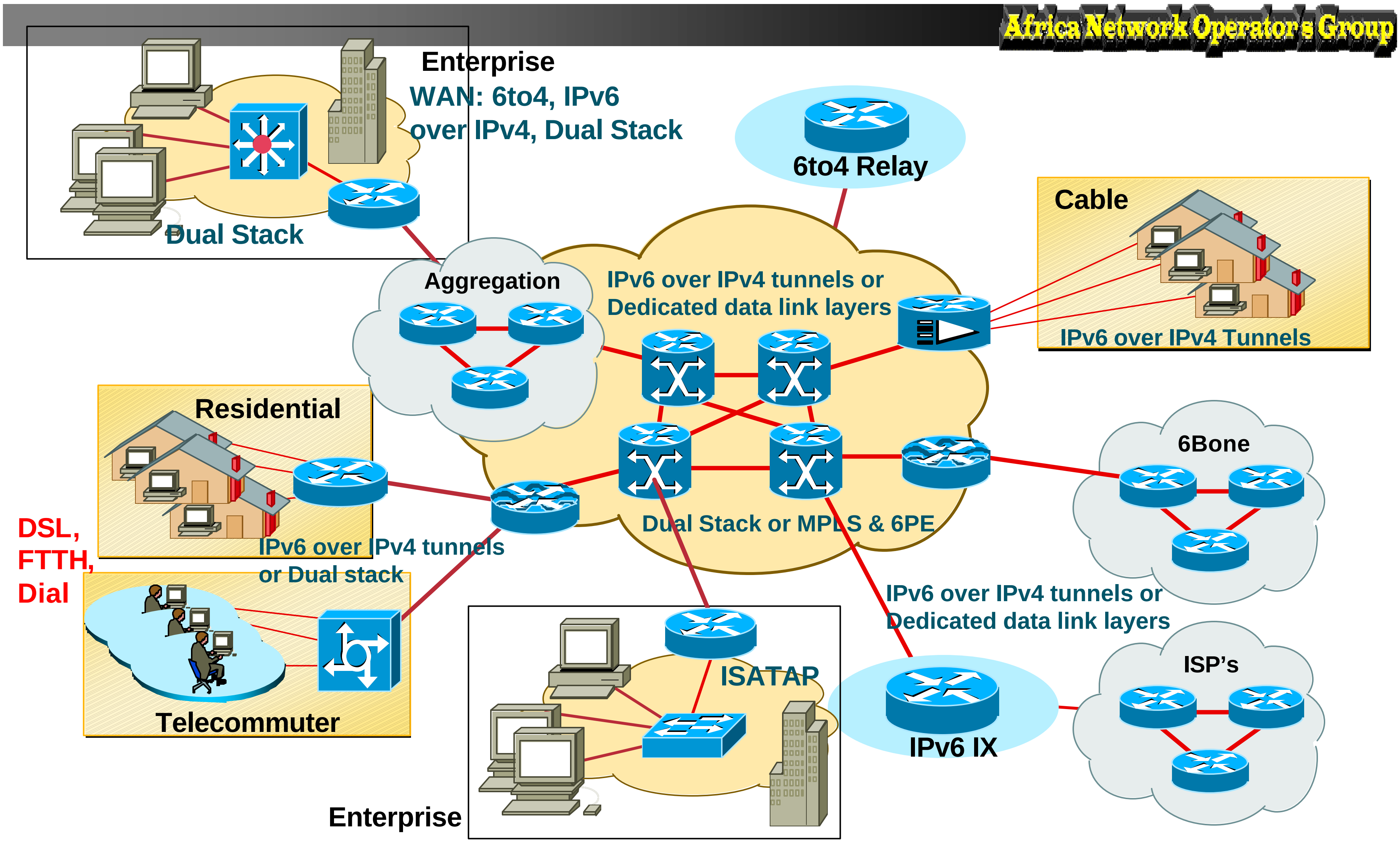
Phases	Benefits
IPv6 Tunnels over IPv4	Low cost, low risk to offer IPv6 services. No infrastructure change. Has to evolve when many IPv6 clients get connected.
Dedicated Data Link layers for Native IPv6	Natural evolution when connecting many IPv6 customers. Require a physical infrastructure to share 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



..a lot to do still..

Though IPv6 today has all the functional capability of IPv4:

- **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

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- Most of Operating Systems can deliver an IPv6 stack
- Internetworking vendors are committed on IPv6 support

  Interoperability events, eg. TAHI, UNH, ETSI,…
- For an update status, please check on

  http://playground.sun.com/pub/ipng/html/ipng implementations.2.html
- Applications IPv6 awareness (see www.hs247.com)

  Net Utilities (ping, finger, ifconfig....etc), NFS, Routing Daemons

  FTP, TELNET, WWW Server & Browser, Sendmail, SMTP

IPv6 Forum

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- 138 members (March 22nd, 2002)
  - Created in 1999
- Mission is to promote IPv6 not to specify it (IETF)
  - www.ipv6forum.com
- IPv6 Forum OneWorld working group
  - Australian, India, Korea, Mexico, Russian, UK,…
- Held 'IPv6 summit' around the World
  - Beijing – May 2002, Washington D.C. – June 2002

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
- **Upgrade your routers with IPv6 ready software**
- **Plan for IPv6 integration and IPv4-IPv6 co-existence**
  - Training, applications inventory, and IPv6 deployment planning

Questions?