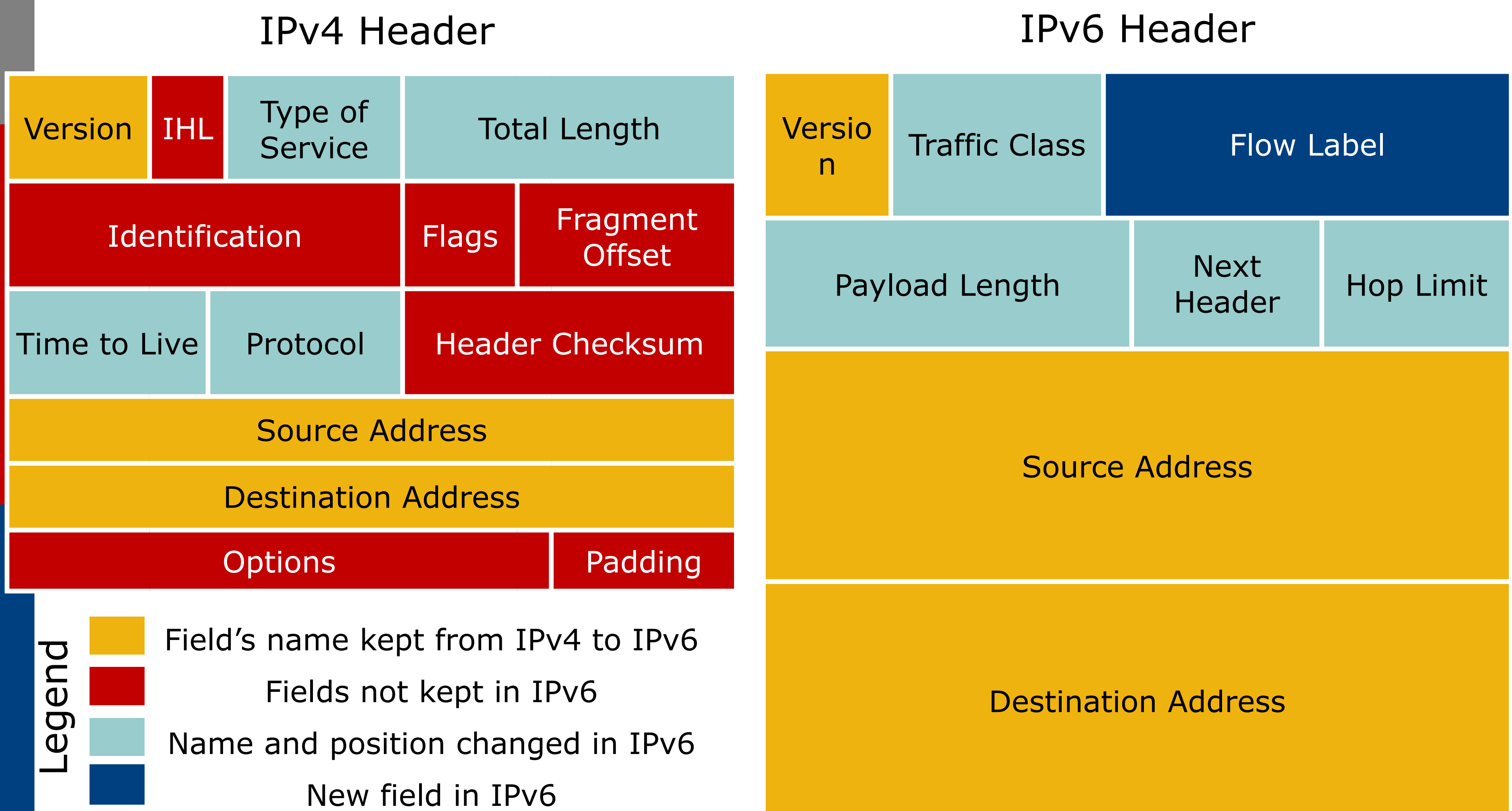
IPv6 Protocols & Standards

ISP Training Workshops

So what has really changed?

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

IPv4 and IPv6 Header Comparison



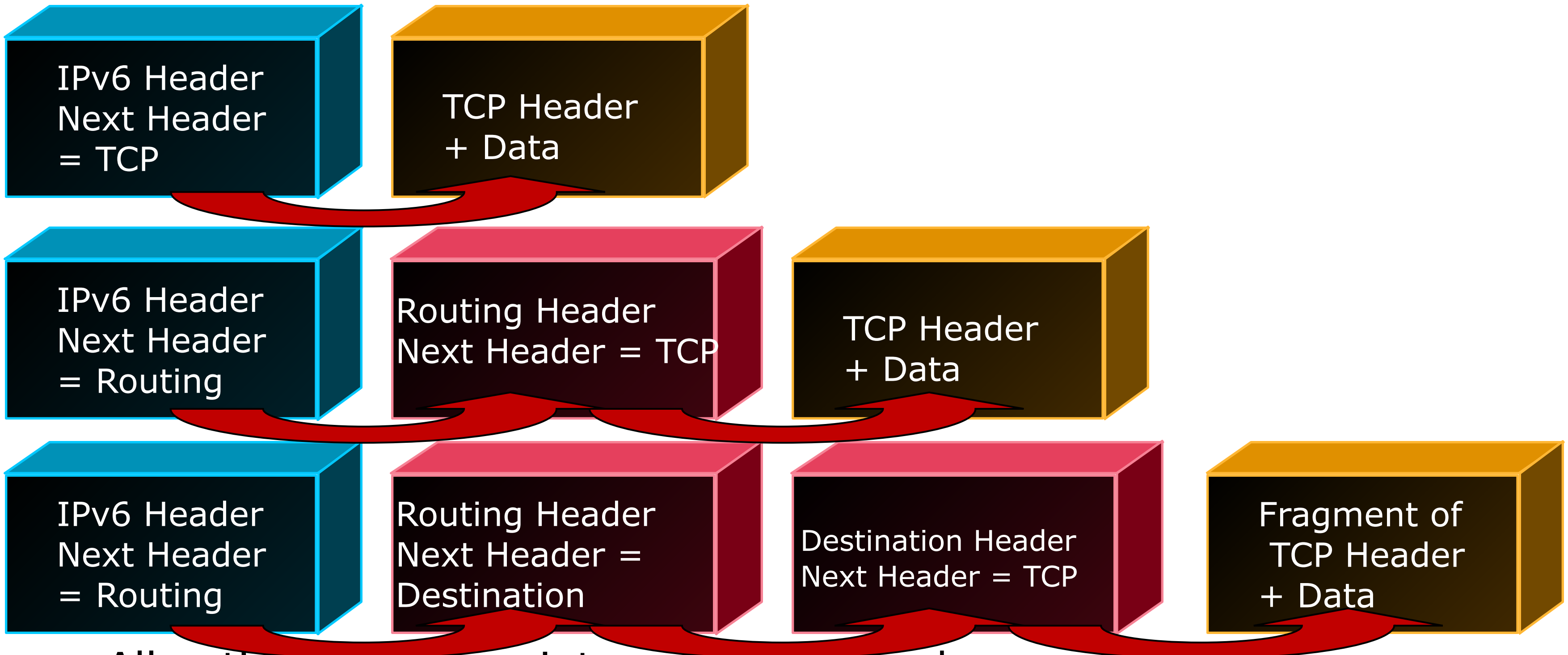
IPv6 Header

- Version = 4-bit value set to 6
- Traffic Class = 8-bit value
  - Replaces IPv4 TOS field
- Flow Label = 20-bit value
- Payload Length = 16-bit value
  - The size of the rest of the IPv6 packet following the header – replaces IPv4 Total Length
- Next Header = 8-bit value
  - Replaces IPv4 Protocol, and indicates type of next header
- Hop Limit = 8-bit value
  - Decreased by one every IPv6 hop (IPv4 TTL counter)
- Source address = 128-bit value
- Destination address = 128-bit value

Header Format Simplification

- Fixed length
  - Optional headers are daisy-chained
- 64 bits aligned
- IPv6 header is twice as long (40 bytes) as IPv4 header without options (20 bytes)
- IPv4 contains 10 basic header fields
- IPv6 contains 6 basic header fields
  - No checksum at the IP network layer
  - No hop-by-hop fragmentation

Header Format – Extension Headers



- All optional fields go into extension headers
- These are daisy chained behind the main header
  - The last 'extension' header is usually the ICMP, TCP or UDP header
- Makes it simple to add new features in IPv6 protocol without major re-engineering of devices
- Number of extension headers is not fixed / limited

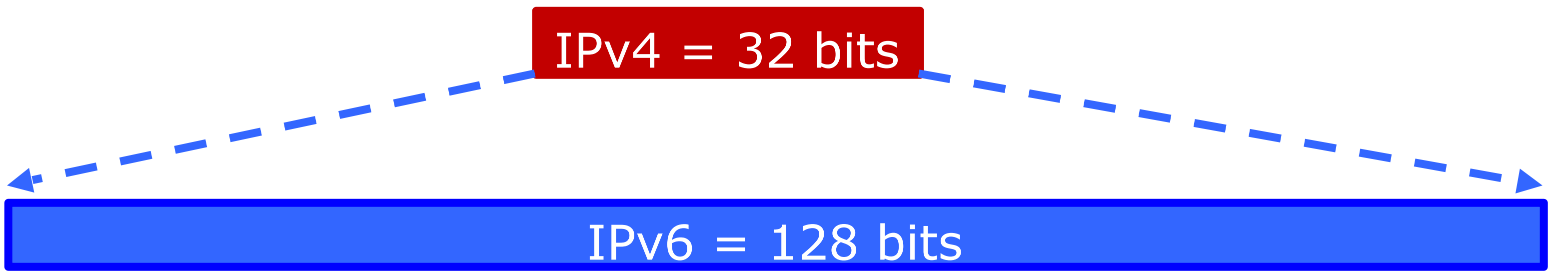
Header Format – Common Headers

- Common values of Next Header field:
  - 0 Hop-by-hop option (extension)
  - 2 ICMP (payload)
  - 6 TCP (payload)
  - 17 UDP (payload)
  - 43 Source routing (extension)
  - 44 Fragmentation (extension)
  - 50 Encrypted security payload (extension, IPSec)
  - 51 Authentication (extension, IPSec)
  - 59 Null (No next header)
  - 60 Destination option (extension)

Header Format – Ordering of Headers

- Order is important because:
  - Hop-by-hop header has to be processed by every intermediate node
  - Routing header needs to be processed by intermediate routers
  - At the destination fragmentation has to be processed before other headers
- This makes header processing easier to implement in hardware

Larger Address Space



- IPv4
  - 32 bits
  - = 4,294,967,296 possible addressable devices
- IPv6
  - 128 bits: 4 times the size in bits
  - = 3.4×10^{38} possible addressable devices
  - = 340,282,366,920,938,463,463,374,607,431,768,211,456
  - ~ 5×10^{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 (1)

- 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 (2)

- :: representation
  - RFC5952 recommends that the rightmost set of :0: be replaced with :: for consistency
    - 2001:db8:0:2f::5 rather than 2001:db8::2f:0:0:0:5
- IPv4-compatible (not used any more)
  - 0:0:0:0:0:0:192.168.30.1
  - = ::192.168.30.1
  - = ::C0A8:1E01
- In a URL, it is enclosed in brackets (RFC3986)
  - http://[2001:db8:4f3a::206:ae14]:8080/index.html
  - Cumbersome for users, mostly for diagnostic purposes
  - Use fully qualified domain names (FQDN)
  - ⇒ The DNS has to work!!

IPv6 Address Representation (3)

- Prefix Representation
  - Representation of prefix is just like IPv4 CIDR
  - In this representation you attach the prefix length
  - Like IPv4 address:
    - 198.10.0.0/16
  - IPv6 address is represented in the same way:
    - 2001:db8:12::/40

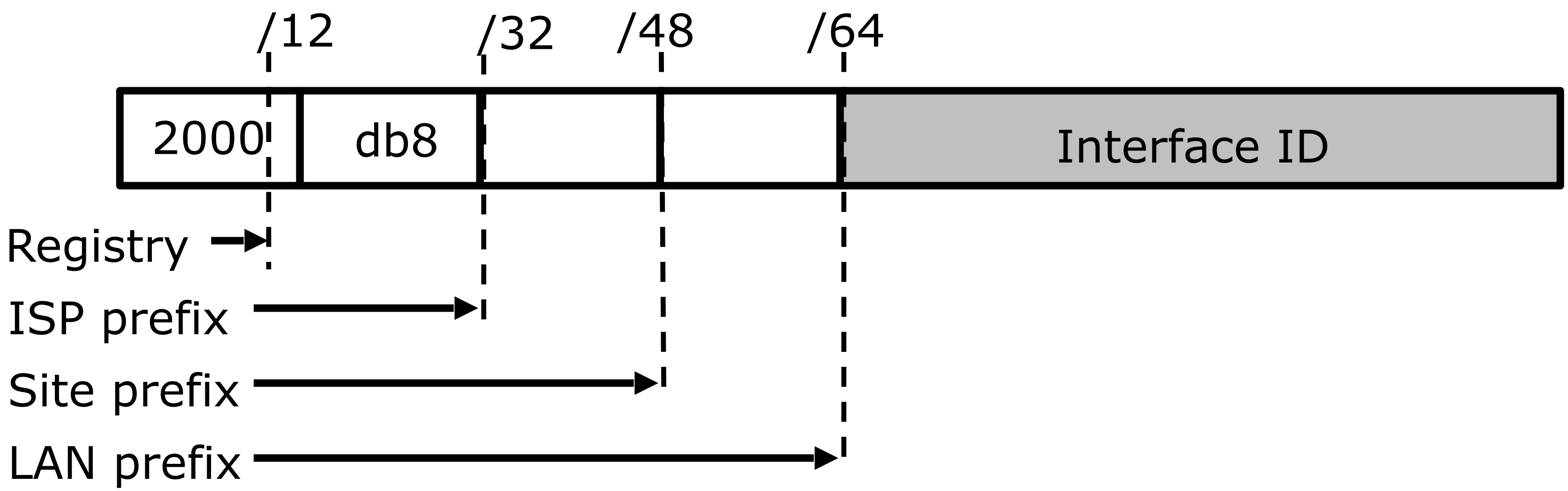
IPv6 Addressing

- IPv6 Addressing rules are covered by multiple RFCs
  - Architecture defined by RFC 4291
- Address Types are :
  - Unicast : One to One (Global, Unique Local, Link local)
  - Anycast : One to Nearest (Allocated from Unicast)
  - Multicast : One to Many
- A single interface may be assigned multiple IPv6 addresses of any type (unicast, anycast, multicast)
  - No Broadcast Address → Use Multicast

IPv6 Addressing

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

IPv6 Address Allocation



- The allocation process is:
  - The IANA is allocating out of 2000::/3 for initial IPv6 unicast use
  - Each registry gets a /12 prefix from the IANA
  - Registry allocates a /32 prefix (or larger) to an IPv6 ISP
  - Policy is that an ISP allocates a /48 prefix to each end customer

IPv6 Addressing Scope

- 64 bits reserved for the interface ID
  - Possibility of 2^{64} hosts on one network LAN
  - In theory 18,446,744,073,709,551,616 hosts
  - Arrangement to accommodate MAC addresses within the IPv6 address
- 16 bits reserved for the end site
  - Possibility of 2^{16} networks at each end-site
  - 65536 subnets equivalent to a /12 in IPv4 (assuming a /28 or 16 hosts per IPv4 subnet)

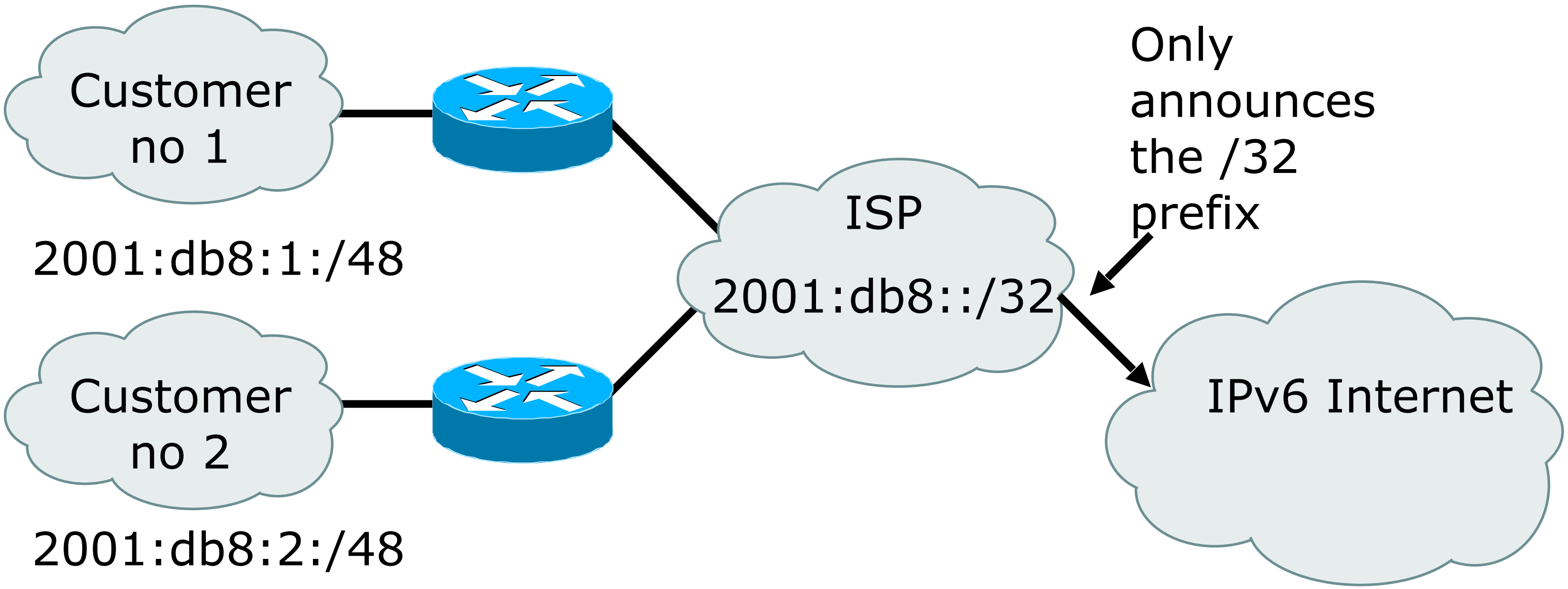
IPv6 Addressing Scope

- 16 bits reserved for each service provider
  - Possibility of 2^{16} end-sites per service provider
  - 65536 possible customers: equivalent to each service provider receiving a /8 in IPv4 (assuming a /24 address block per customer)
- 29 bits reserved for all service providers
  - Possibility of 2^{29} service providers
  - i.e. 536,870,912 discrete service provider networks
    - Although some service providers already are justifying more than a /32

How to get an IPv6 Address?

- IPv6 address space is allocated by the 5 RIRs:
  - AfriNIC, 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
  - Last resort only and now mostly useless
- (6Bone)
  - Was the IPv6 experimental network since the mid 90s
  - Now retired, end of service was 6th June 2006 (RFC3701)

Aggregation hopes



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

Interface IDs

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

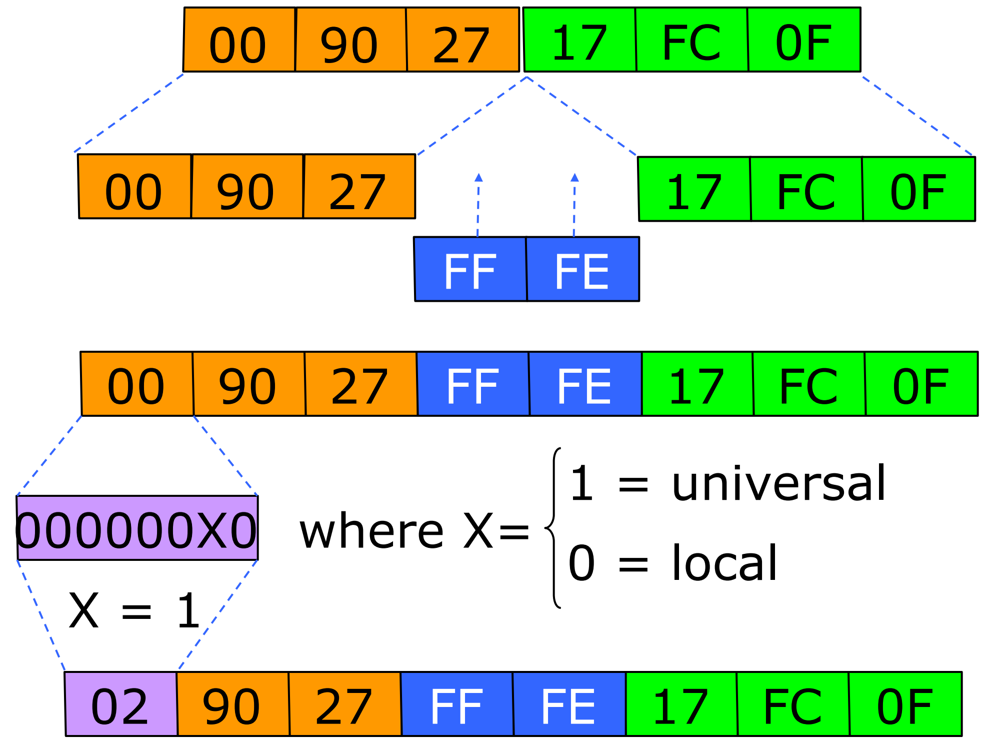
EUI-64

Ethernet MAC address
(48 bits)

64 bits version

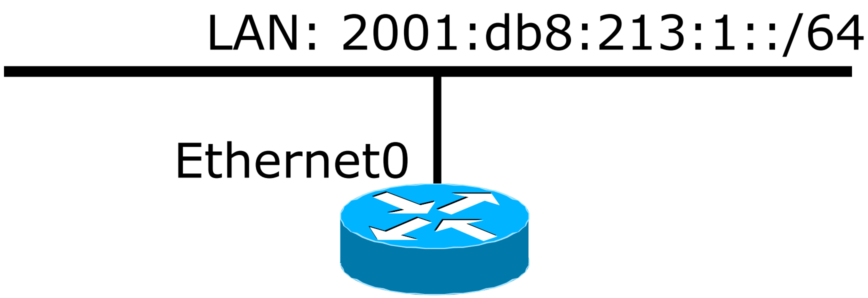
Scope of the EUI-64 id

EUI-64 address



- EUI-64 address is formed by inserting FFFE between the company-id and the manufacturer extension, and setting the "u" bit to indicate scope
  - Global scope: for IEEE 48-bit MAC
  - Local scope: when no IEEE 48-bit MAC is available (eg serials, tunnels)

IPv6 Addressing Examples

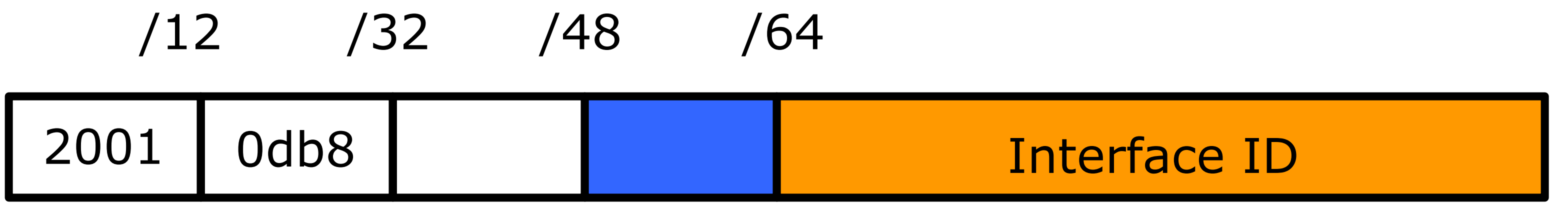



```
interface Ethernet0
 ipv6 address 2001:db8:213:1::/64 eui-64
```

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:db8:213:1:260:3EFF:FE47:1530, subnet is 2001:db8:213:1::/64
  Joined group address(es):
    FF02::1:FF47:1530
    FF02::1
    FF02::2
  MTU is 1500 bytes
```

IPv6 Address Privacy (RFC 4941)



- Temporary addresses for IPv6 host client application, e.g. Web browser
- Intended to inhibit device/user tracking but is also a potential issue
  - More difficult to scan all IP addresses on a subnet
  - But port scan is identical when an address is known
- Random 64 bit interface ID, run DAD before using it
- Rate of change based on local policy
- Implemented on Microsoft Windows XP/Vista/7 and Apple MacOS 10.7 onwards
  - Can be activated on FreeBSD/Linux with a system call

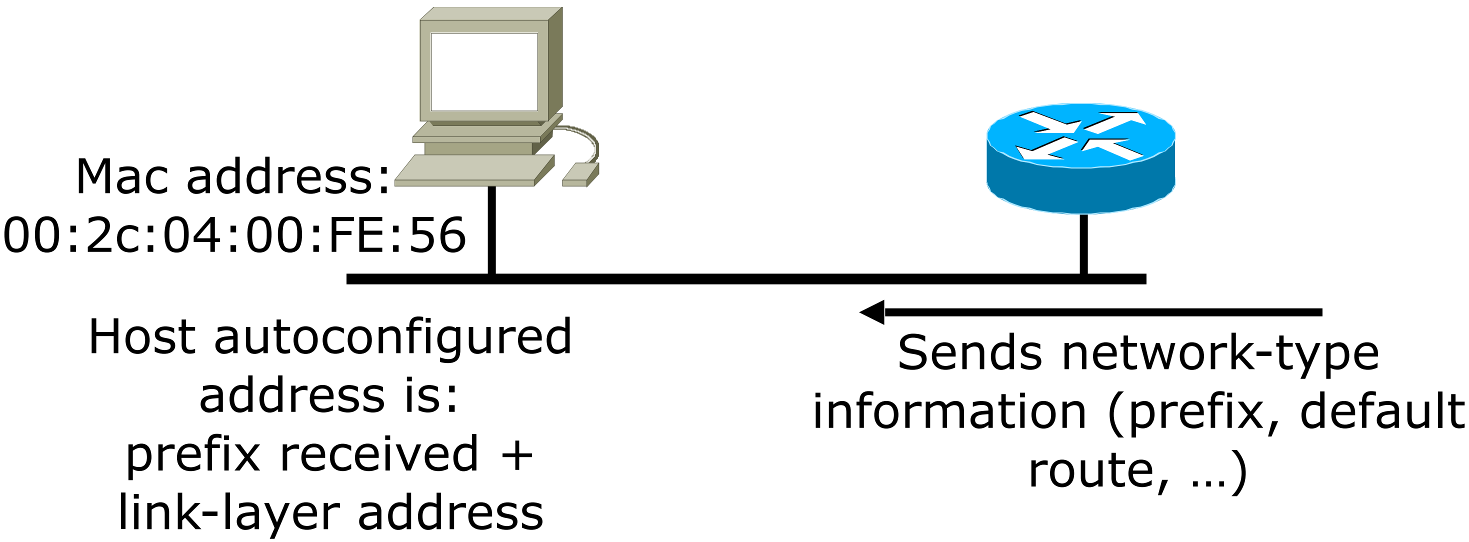
Host IPv6 Addressing Options

- Stateless (RFC4862)
  - SLAAC – Stateless Address AutoConfiguration
  - Booting node sends a "router solicitation" to request "router advertisement" to get information to configure its interface
  - Booting node configures its own Link-Local address
- Stateful
  - DHCPv6 – required by most enterprises
  - Manual – like IPv4 pre-DHCP
    - Useful for servers and router infrastructure
    - Doesn't scale for typical end user devices

IPv6 Renumbering

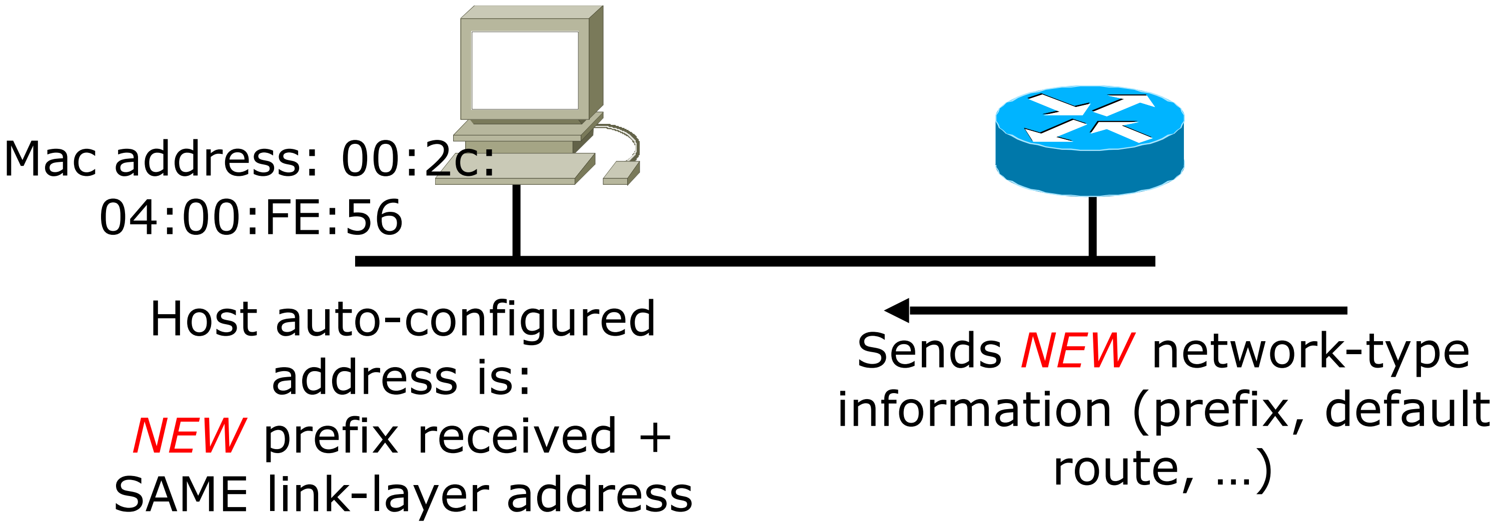
- Renumbering Hosts
  - Stateless:
    - Hosts renumbering is done by modifying the RA to announce the old prefix with a short lifetime and the new prefix
  - Stateful:
    - DHCPv6 uses same process as DHCPv4
- Renumbering Routers
  - Router renumbering protocol was developed (RFC 2894) to allow domain-interior routers to learn of prefix introduction / withdrawal
  - **No known implementation!**

Auto-configuration



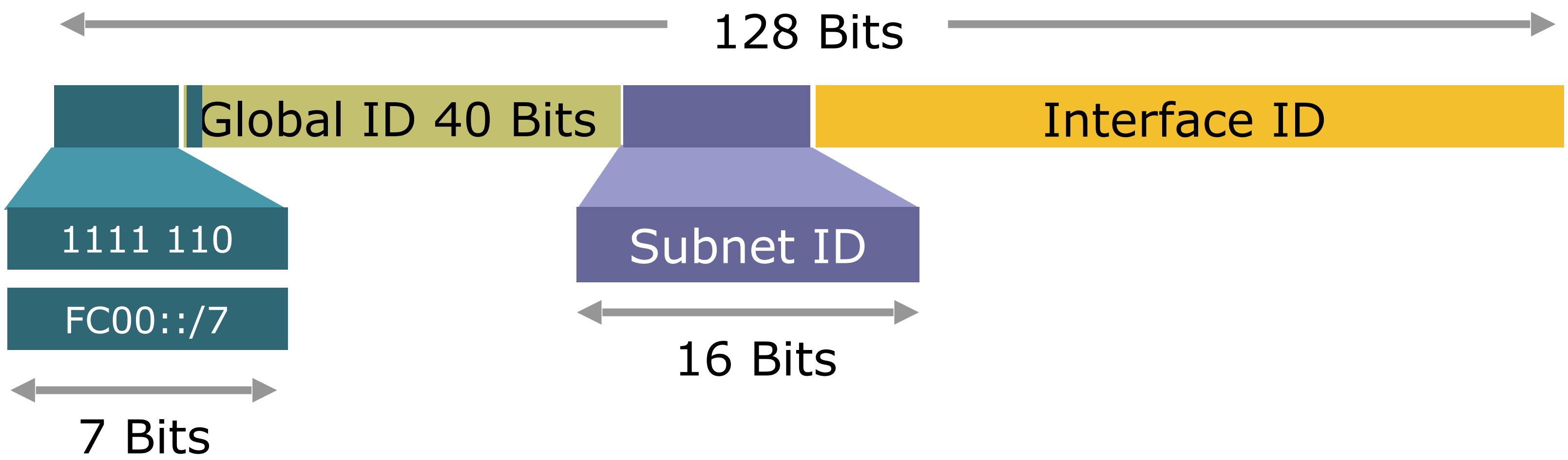
- PC sends router solicitation (RS) message
- Router responds with router advertisement (RA)
  - This includes prefix and default route
  - RFC6106 adds DNS server option
- PC configures its IPv6 address by concatenating prefix received with its EUI-64 address

Renumbering



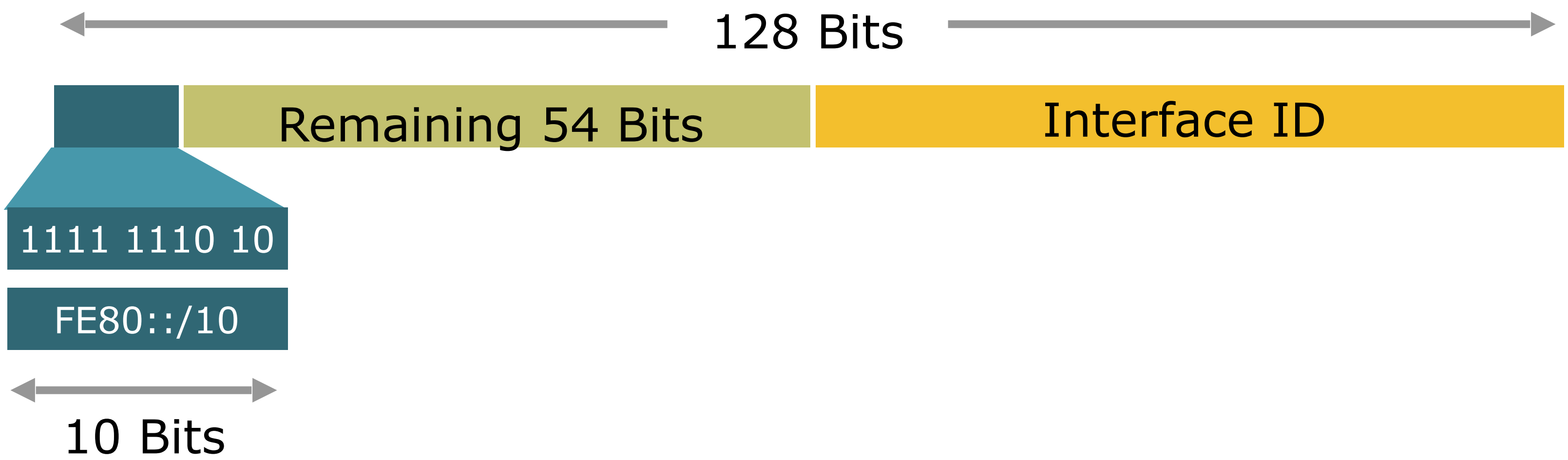
- Router sends router advertisement (RA)
  - This includes the new prefix and default route (and remaining lifetime of the old address)
- PC configures a new IPv6 address by concatenating prefix received with its EUI-64 address
  - Attaches lifetime to old address

Unique-Local



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

Link-Local



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

Multicast use

- Broadcasts in IPv4
  - Interrupts all devices on the LAN even if the intent of the request was for a subset
  - Can completely swamp the network ("broadcast storm")
- Broadcasts in IPv6
  - Are not used and replaced by multicast
- Multicast
  - Enables the efficient use of the network
  - Multicast address range is much larger

IPv6 Multicast Address

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

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

Lifetime	
0	If Permanent
1	If Temporary

Scope	
1	Node
2	Link
5	Site
8	Organisation
E	Global

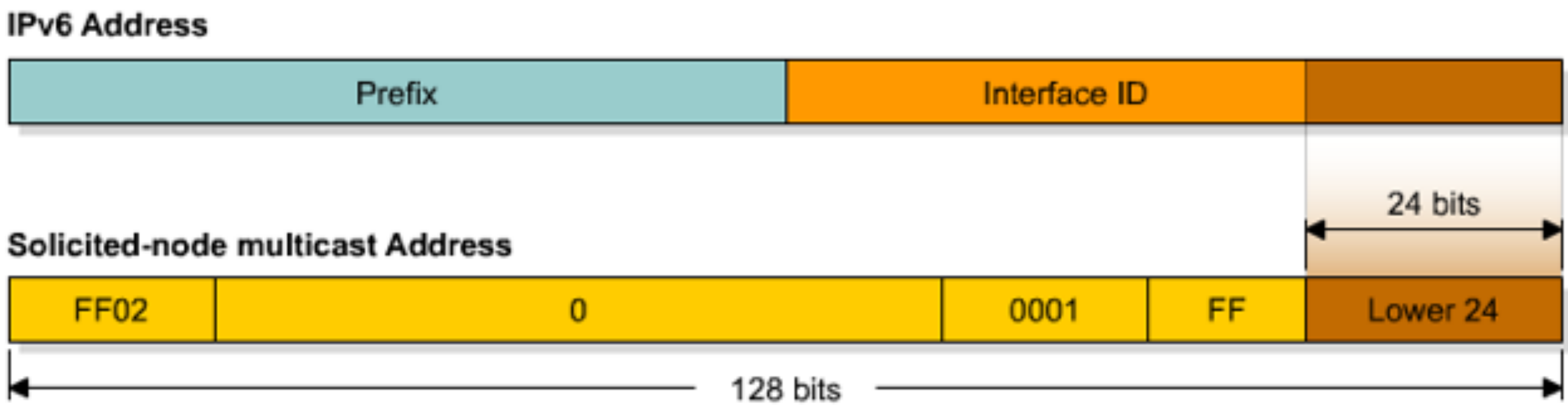
IPv6 Multicast Address Examples

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

Solicited-Node Multicast

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

Solicited-Node Multicast Address



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

Solicited-Node Multicast

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

Solicited-Node Multicast Address

IPv6 Anycast

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

Anycast on the Internet

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

MTU Issues

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

IPv6 Neighbour Discovery

- Protocol defines mechanisms for the following problems:
  - Router discovery
  - Prefix discovery
  - Parameter discovery
  - Address autoconfiguration
  - Address resolution
  - Next-hop determination
  - Neighbour unreachability detection
  - Duplicate address detection
  - Redirects

IPv6 Neighbour Discovery

- Defined in RFC 4861
- Protocol built on top of ICMPv6 (RFC 4443)
  - Combination of IPv4 protocols (ARP, ICMP, IGMP,…)
- Fully dynamic, interactive between Hosts & Routers
- Defines 5 ICMPv6 packet types:
  - Router Solicitation
  - Router Advertisement
  - Neighbour Solicitation
  - Neighbour Advertisement
  - Redirect

IPv6 and DNS

- Hostname to IP address:

IPv4	www.abc.test.	A	192.168.30.1
IPv6	www.abc.test	AAAA	2001:db8:c18:1::2

IPv6 and DNS

- IP address to Hostname:

IPv4	1.30.168.192.in-addr.arpa.	PTR	www.abc.test.
IPv6	2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.0.0.0.8.1.c.0.8.b.d. 0.1.0.0.2.ip6.arpa	PTR	www.abc.test.

IPv6 Technology Scope

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 signalling
  - "Differentiated Service" (diff-serv)
    - Coarse-grain (per-class), qualitative promises (e.g., higher priority), no explicit signalling
  - Signalled diff-serv (RFC 2998)
    - Uses RSVP for signalling 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)
- Originally standardised as RFC 3697

IPv6 Flow Label

- Flow label has not been used since IPv6 standardised
  - Suggestions for use in recent years were incompatible with original specification (discussed in RFC6436)
- Specification updated in RFC6437
  - RFC6438 describes the use of the Flow Label for equal cost multi-path and link aggregation in Tunnels

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: www.ipv6tf.org
- 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 (RFC4861)
  - ICMPv6 (RFC4443)
  - IPv6 Addresses (RFC4291 & 3587)
  - RIP (RFC2080)
  - BGP (RFC2545)
  - IGMPv6 (RFC2710)
  - OSPF (RFC5340)
  - Router Alert (RFC2711)
  - Jumbograms (RFC2675)
  - Autoconfiguration (RFC4862)
  - Radius (RFC3162)
  - DHCPv6 (RFC3315 & 4361)
  - Flow Label (RFC6436/7/8)
  - IPv6 Mobility (RFC3775)
  - Mobile IPv6 MIB (RFC4295)
  - GRE Tunnelling (RFC2473)
  - Unique Local IPv6 Addresses (RFC4193)
  - DAD for IPv6 (RFC4429)
  - Teredo (RFC4380)
  - ISIS for IPv6 (RFC5308)
  - VRRP (RFC5798)
- IPv6 available over:
  - PPP (RFC5072)
  - Ethernet (RFC2464)
  - FDDI (RFC2467)
  - Token Ring (RFC2470)
  - NBMA (RFC2491)
  - ATM (RFC2492)
  - Frame Relay (RFC2590)
  - ARCnet (RFC2497)
  - IEEE1394 (RFC3146)
  - FibreChannel (RFC4338)
  - Facebook (RFC5514)

Recent IPv6 Hot Topics

- IPv4 depletion debate
  - IANA IPv4 pool ran out on 3rd February 2011
    - http://www.potaroo.net/tools/ipv4/
- IPv6 Transition "assistance"
  - CGN, 6rd, NAT64, IVI, DS-Lite, 6to4, A+P…
- Mobile IPv6
- Multihoming
  - SHIM6 "dead", Multihoming in IPv6 same as in IPv4
- IPv6 Security
  - Security industry & experts taking much closer look

Conclusion

- Protocol is “ready to go”
- The core components have already seen several years field experience

IPv6 Protocols & Standards

ISP Training Workshops