

IPv6 Protocols & Standards

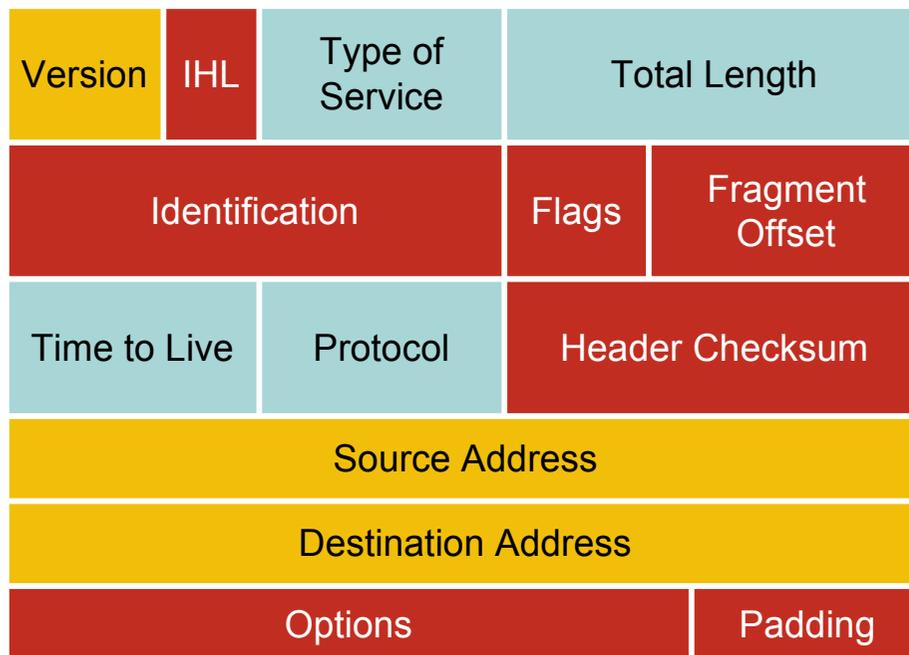
ISP/IXP Workshops

So what has really changed?

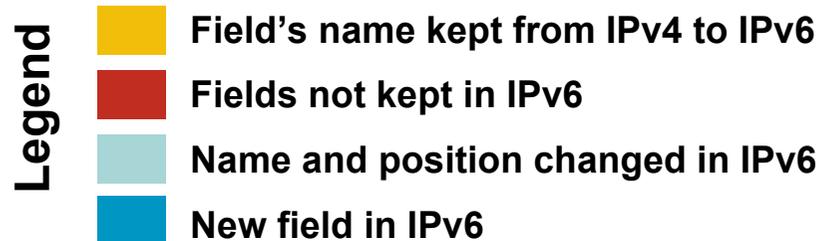
- Expanded address space
 - Address length quadrupled to 16 bytes
- Header Format Simplification
 - Fixed length, optional headers are daisy-chained
 - IPv6 header is twice as long (40 bytes) as IPv4 header without options (20 bytes)
- No checksum at the IP network layer
- No hop-by-hop segmentation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

IPv4 and IPv6 Header Comparison

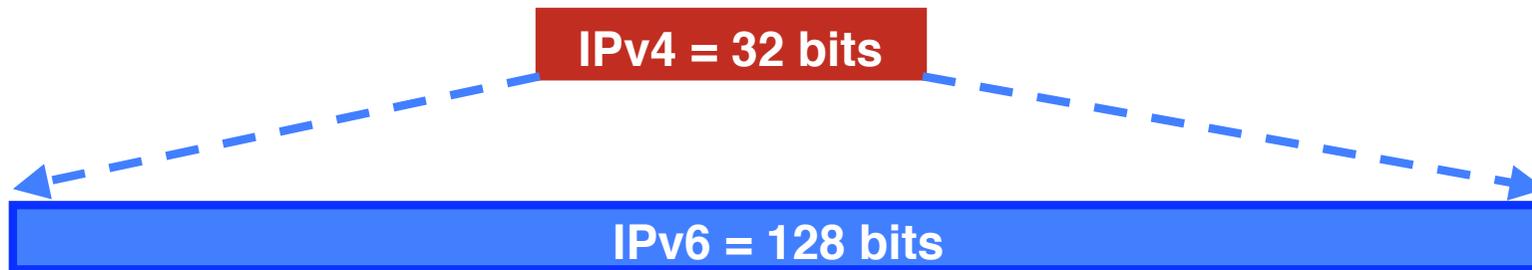
IPv4 Header



IPv6 Header



Larger Address Space



IPv4

32 bits

= 4,294,967,296 possible addressable devices

IPv6

128 bits: 4 times the size in bits

= 3.4×10^{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

- 16 bit fields in case insensitive colon hexadecimal representation

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

- Leading zeros in a field are optional:

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

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

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

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



0:0:0:0:0:0:0:1 → ::1

(loopback address)

0:0:0:0:0:0:0:0 → ::

(unspecified address)

IPv6 Address Representation

- IPv4-compatible (not used any more)

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

= ::192.168.30.1

= ::C0A8:1E01

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

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

Cumbersome for users

Mostly for diagnostic purposes

Use fully qualified domain names (FQDN)

- ⇒ The DNS has to work!!

IPv6 Address Representation

- Prefix Representation

Representation of prefix is 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

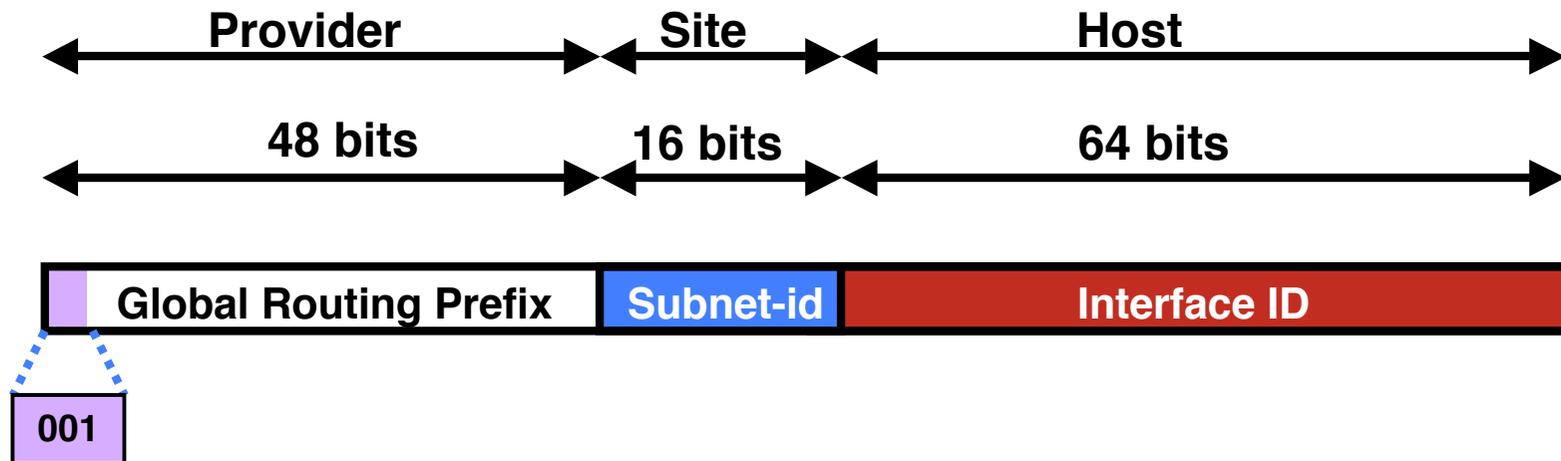
IPv6 Addressing

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

IPv6 Addressing

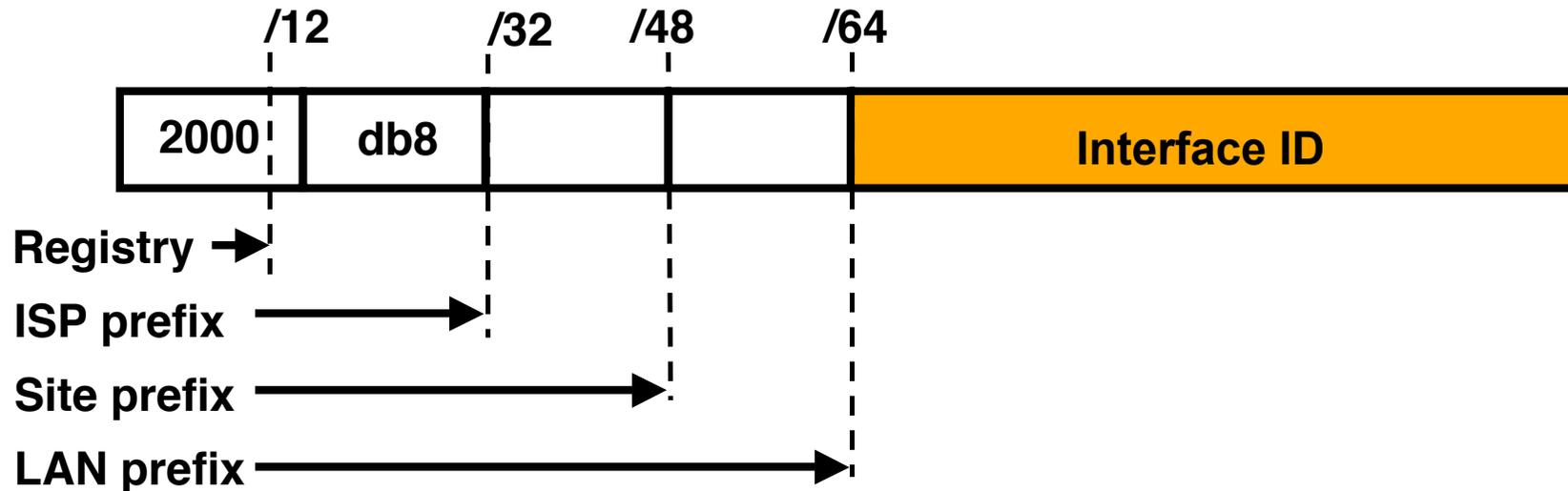
Type	Binary	Hex
Unspecified	000...0	::/128
Loopback	000...1	::1/128
Global Unicast Address	0010	2000::/3
Link Local Unicast Address	1111 1110 10	FE80::/10
Unique Local Unicast Address	1111 1100 1111 1101	FC00::/7
Multicast Address	1111 1111	FF00::/8

IPv6 Global Unicast Addresses



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

IPv6 Address Allocation



- The allocation process is:

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

Each registry gets a /12 prefix from the IANA

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

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

IPv6 Addressing Scope

- 64 bits reserved for the interface ID

 - Possibility of 2^{64} hosts on one network LAN

 - Arrangement to accommodate MAC addresses within the IPv6 address

- 16 bits reserved for the end site

 - Possibility of 2^{16} networks at each end-site

 - 65536 subnets equivalent to a /12 in IPv4 (assuming 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

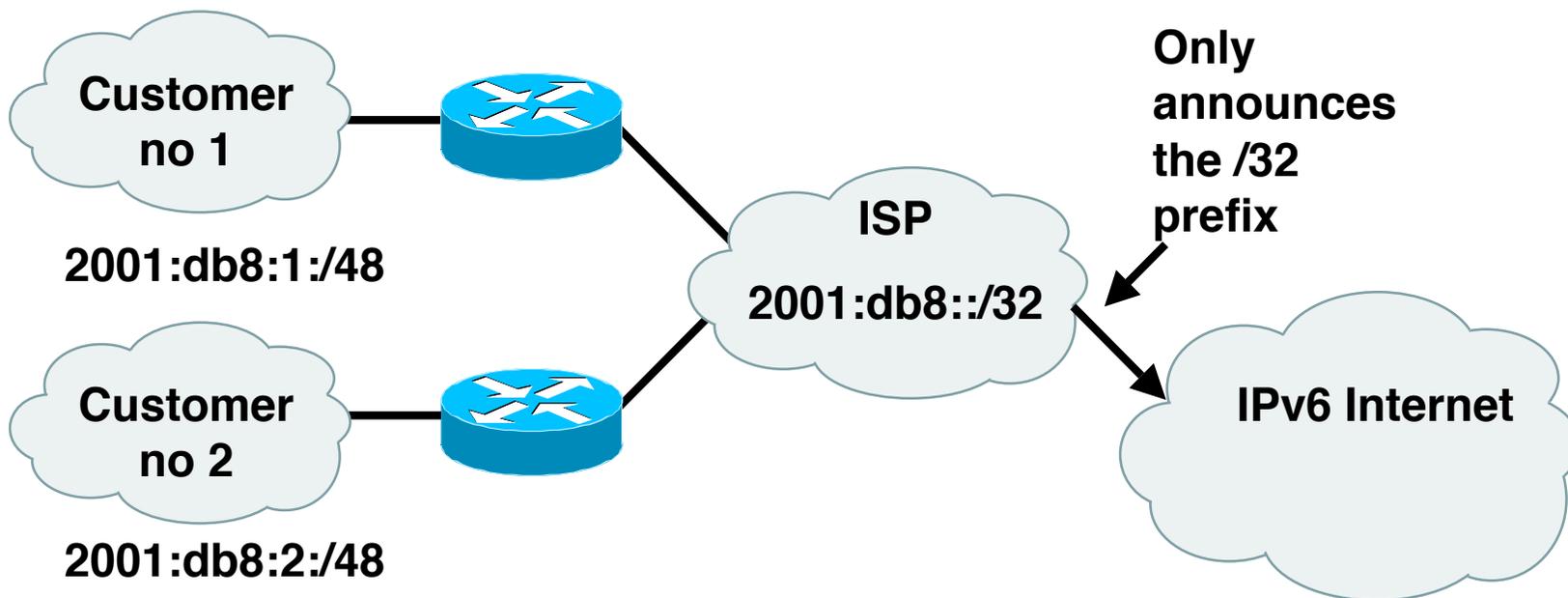
i.e. 500 million discrete service provider networks

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
- (6Bone)
Was the IPv6 experimental network since the mid 90s
Now retired, end of service was 6th June 2006 (RFC3701)

Aggregation hopes



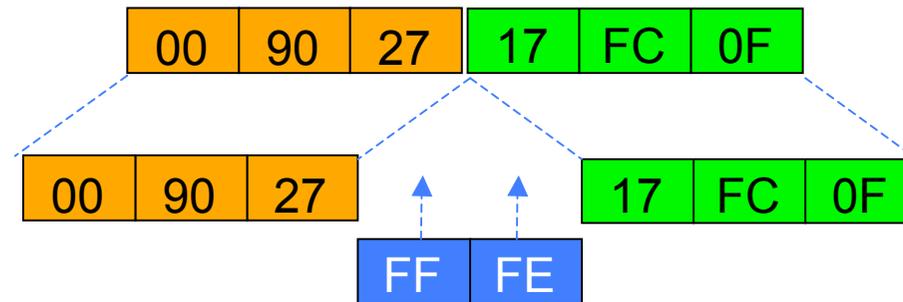
- Larger address space enables aggregation of prefixes announced in the global routing table
- Idea was to allow efficient and scalable routing
- **But current Internet multihoming solution breaks this model**

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

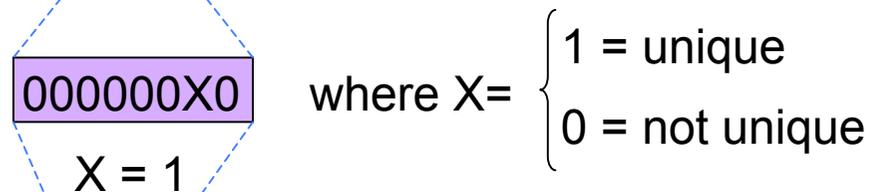
**Ethernet MAC address
(48 bits)**



64 bits version



Uniqueness of the MAC

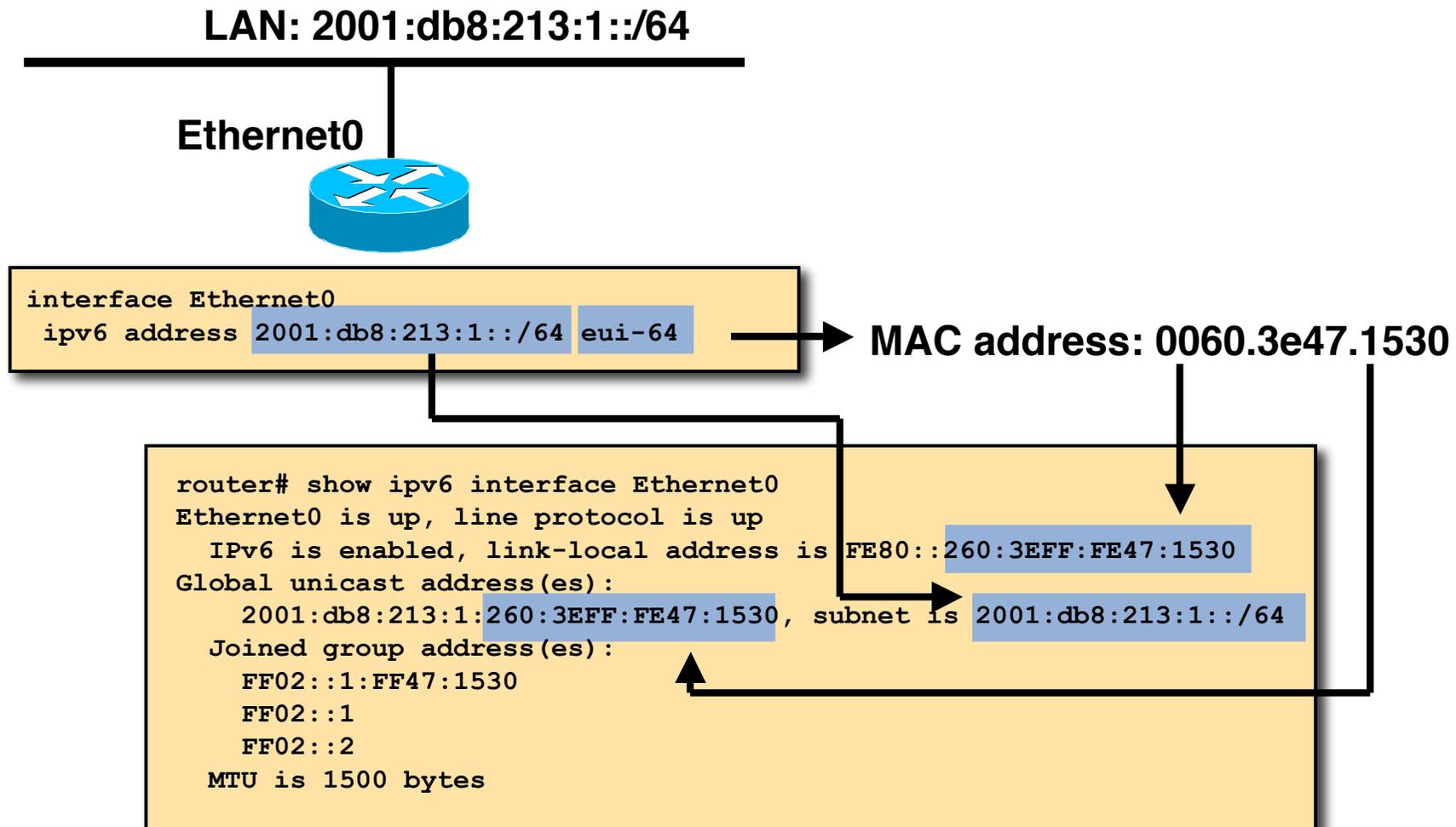


Eui-64 address

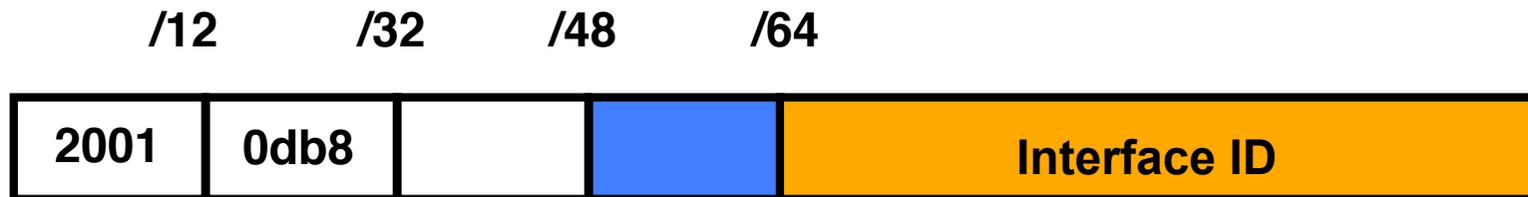


- EUI-64 address is formed by inserting FFFE and OR'ing a bit identifying the uniqueness of the MAC address

IPv6 Addressing Examples



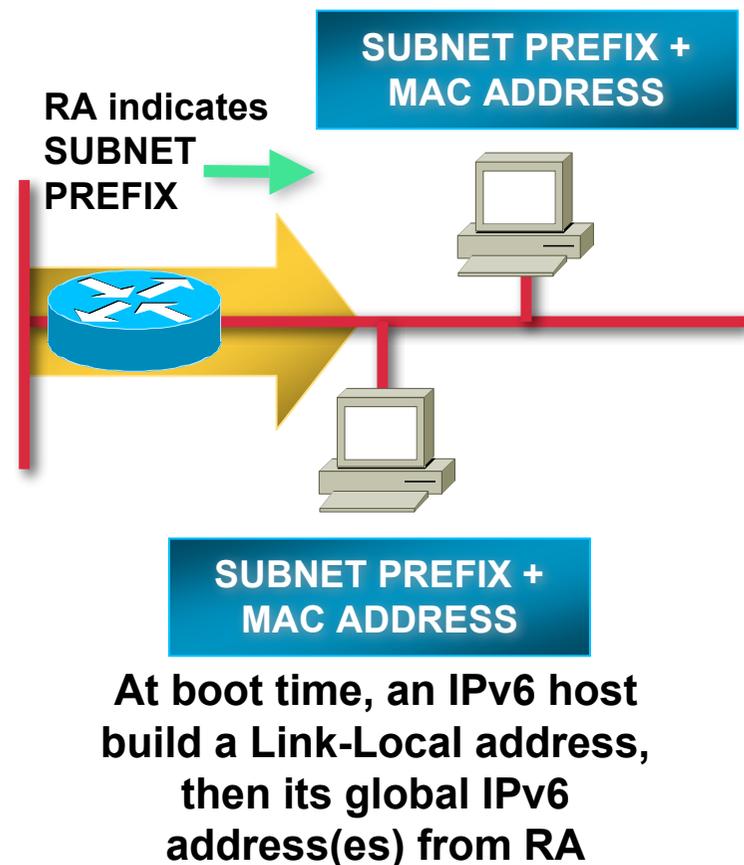
IPv6 Address Privacy (RFC 4941)



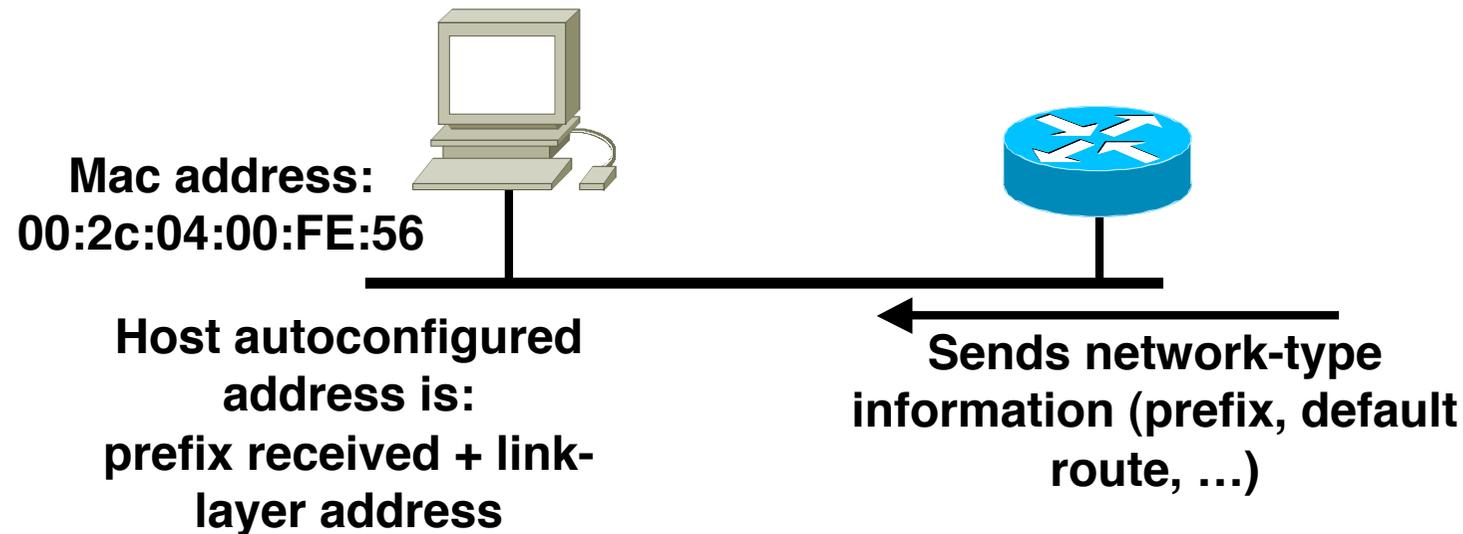
- Temporary addresses for IPv6 host client application, e.g. Web browser
- Intended to inhibit device/user tracking but is also a potential issue
 - More difficult to scan all IP addresses on a subnet
 - But port scan is identical when an address is known
- Random 64 bit interface ID, run DAD before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

IPv6 Auto-Configuration

- Stateless (RFC4862)
 - 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

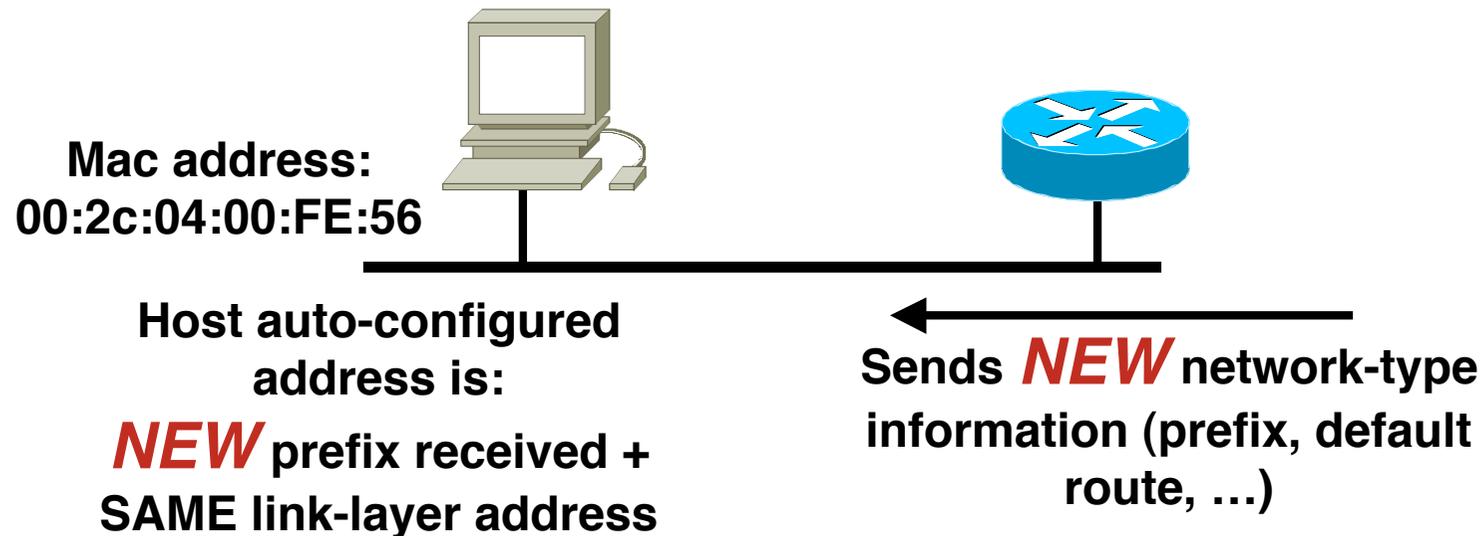


Auto-configuration



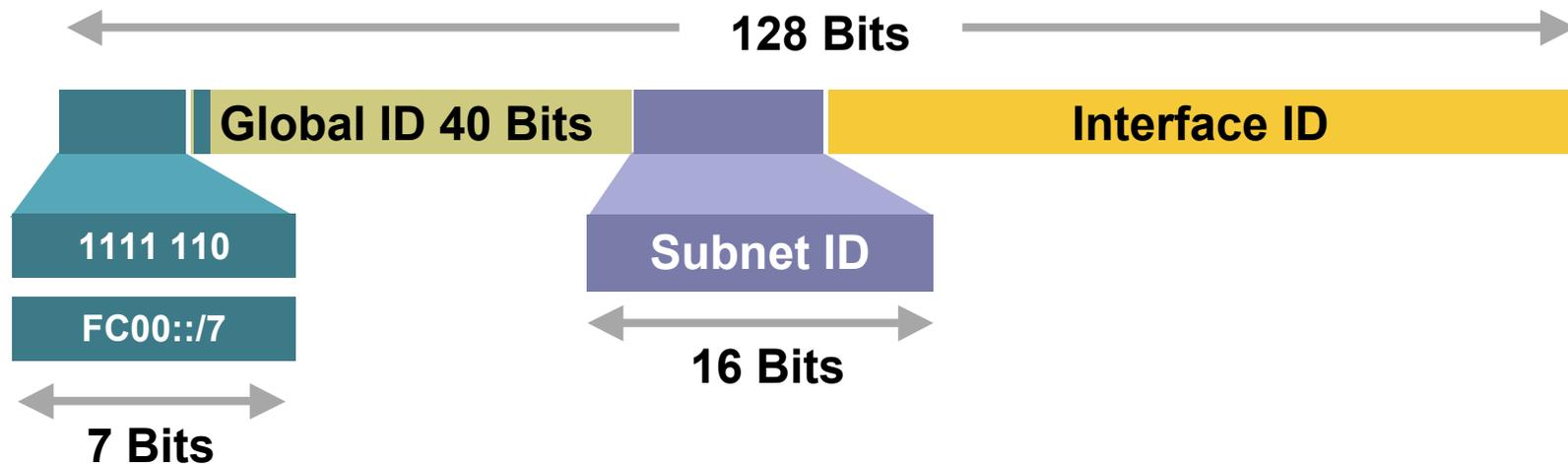
- PC sends router solicitation (RS) message
- Router responds with router advertisement (RA)
 - This includes prefix and default route
- PC configures its IPv6 address by concatenating prefix received with its EUI-64 address

Renumbering



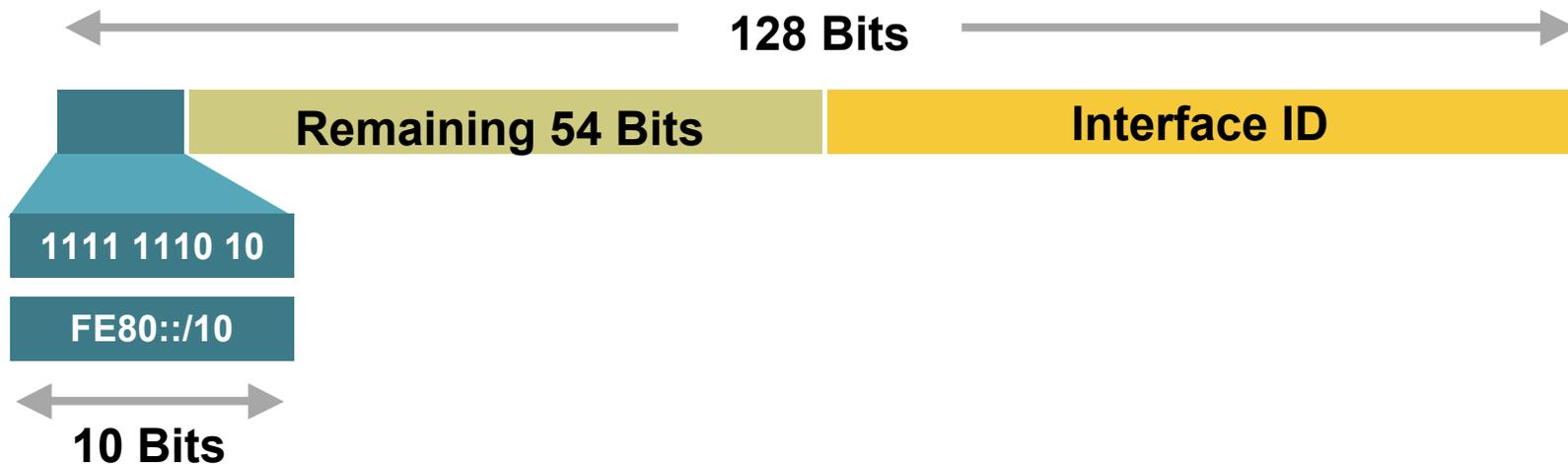
- Router sends router advertisement (RA)
 - This includes the new prefix and default route (and remaining lifetime of the old address)
- PC configures a new IPv6 address by concatenating prefix received with its EUI-64 address
 - Attaches lifetime to old address

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	Organization
E	Global

IPv6 Multicast Address Examples

- RIPng

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

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

- OSPFv3

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

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

- EIGRP

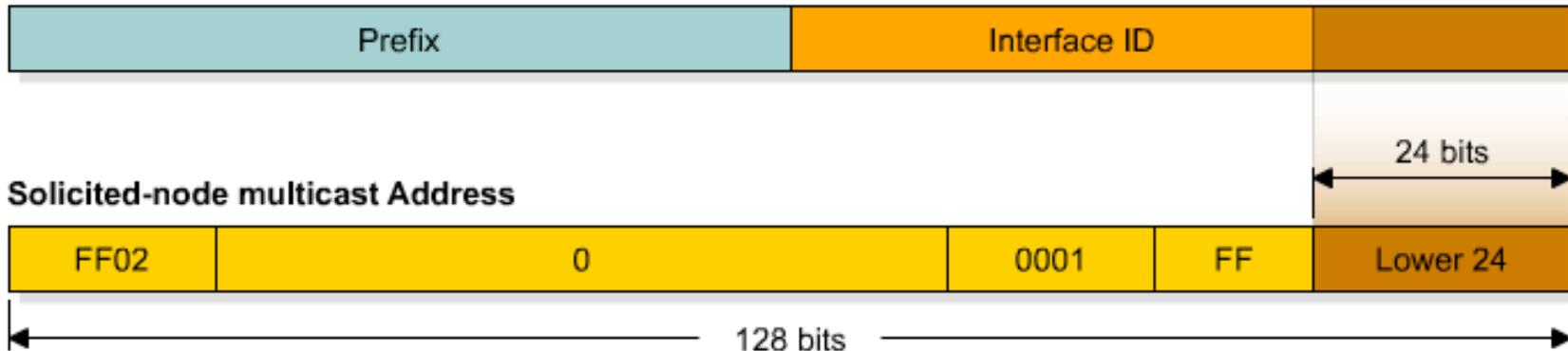
The multicast address **AllEIGRPRouters** is **FF02::A**

Solicited-Node Multicast

- Solicited-Node Multicast is used for Duplicate Address Detection as part of Neighbour Discovery
 - 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

IPv6 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 \leq 1280 octets
- A Hop-by-Hop Option supports transmission of “jumbograms” with up to 2^{32} octets of payload

Neighbour Discovery (RFCs 2461 & 4311)

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

IPv6 and DNS

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

IPv6 Technology Scope

<i>IP Service</i>	<i>IPv4 Solution</i>	<i>IPv6 Solution</i>
Addressing Range	32-bit, Network Address Translation	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: 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)
 - ICMPv6 (RFC4443)
 - RIP (RFC2080)
 - IGMPv6 (RFC2710)
 - Router Alert (RFC2711)
 - Autoconfiguration (RFC4862)
 - DHCPv6 (RFC3315 & 4361)
 - IPv6 Mobility (RFC3775)
 - GRE Tunnelling (RFC2473)
 - DAD for IPv6 (RFC4429)
 - ISIS for IPv6 (RFC5308)
 - Neighbour Discovery (RFC4861 & 4311)
 - IPv6 Addresses (RFC4291 & 3587)
 - BGP (RFC2545)
 - OSPF (RFC5340)
 - Jumbograms (RFC2675)
 - Radius (RFC3162)
 - Flow Label (RFC3697)
 - Mobile IPv6 MIB (RFC4295)
 - Unique Local IPv6 Addresses (RFC4193)
 - Teredo (RFC4380)
- IPv6 available over:
 - PPP (RFC5072)
 - FDDI (RFC2467)
 - NBMA (RFC2491)
 - Frame Relay (RFC2590)
 - IEEE1394 (RFC3146)
 - Facebook (RFC5514)
 - Ethernet (RFC2464)
 - Token Ring (RFC2470)
 - ATM (RFC2492)
 - ARCnet (RFC2497)
 - FibreChannel (RFC4338)

Recent IPv6 Hot Topics

- Transition/co-existence/IPv4 depletion debate
 - IANA IPv4 pool due to run out mid 2011
 - <http://www.potaroo.net/tools/ipv4/>
- Mobile IPv6
- Type 0 Routing Headers
- ULA and ULA-Central
- 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/IXP Workshops