

# The IPv6 Protocol & IPv6 Standards



ISP Workshops

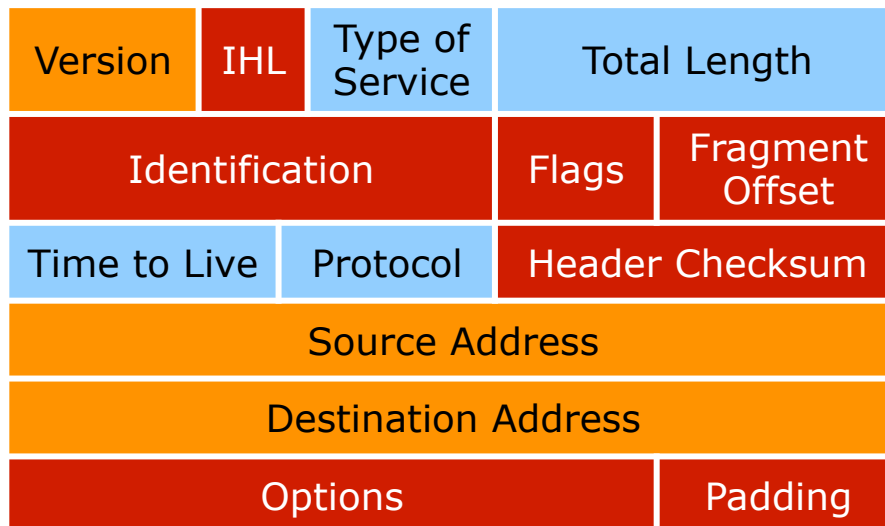
# So what has really changed?

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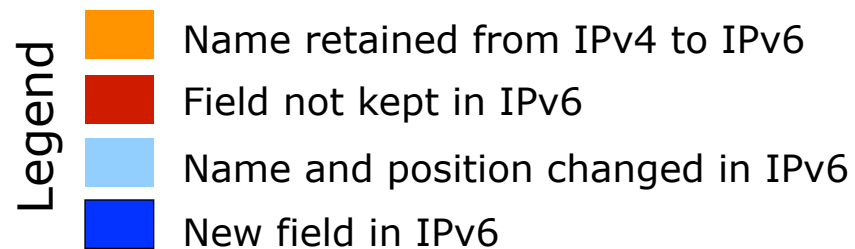
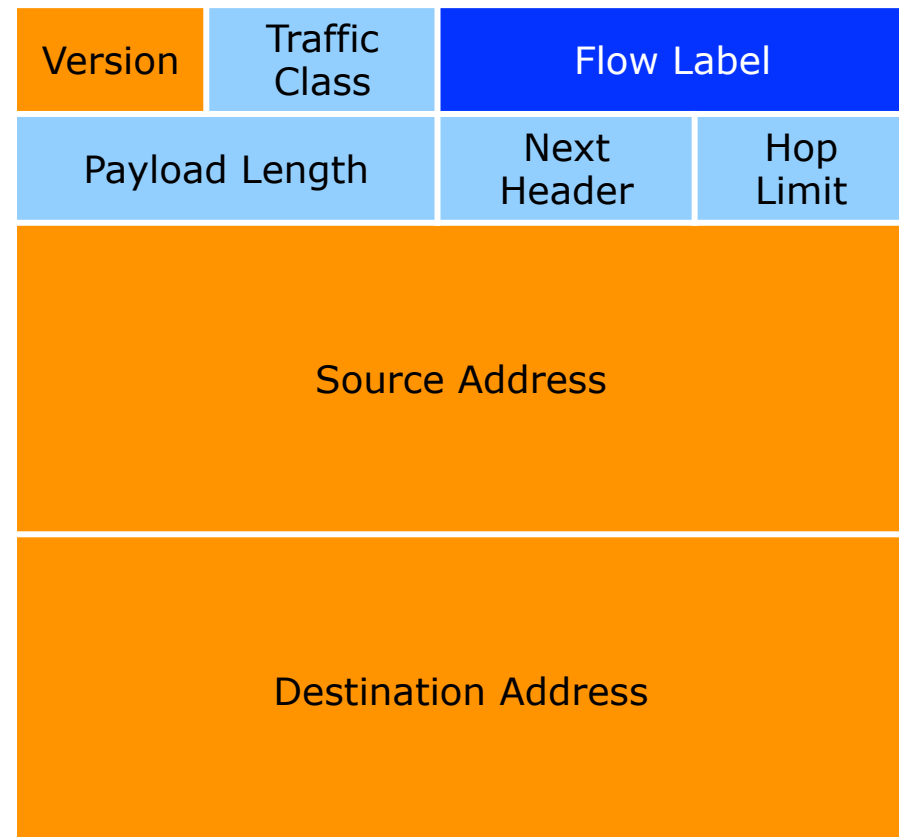
- ❑ Expanded address space
  - Address length quadrupled to 16 bytes
- ❑ Header Format Simplification
  - Fixed length, optional headers are daisy-chained
  - IPv6 header is twice as long (40 bytes) as IPv4 header without options (20 bytes)
- ❑ No checksum at the IP network layer
- ❑ No hop-by-hop fragmentation
  - 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



# IPv6 Header

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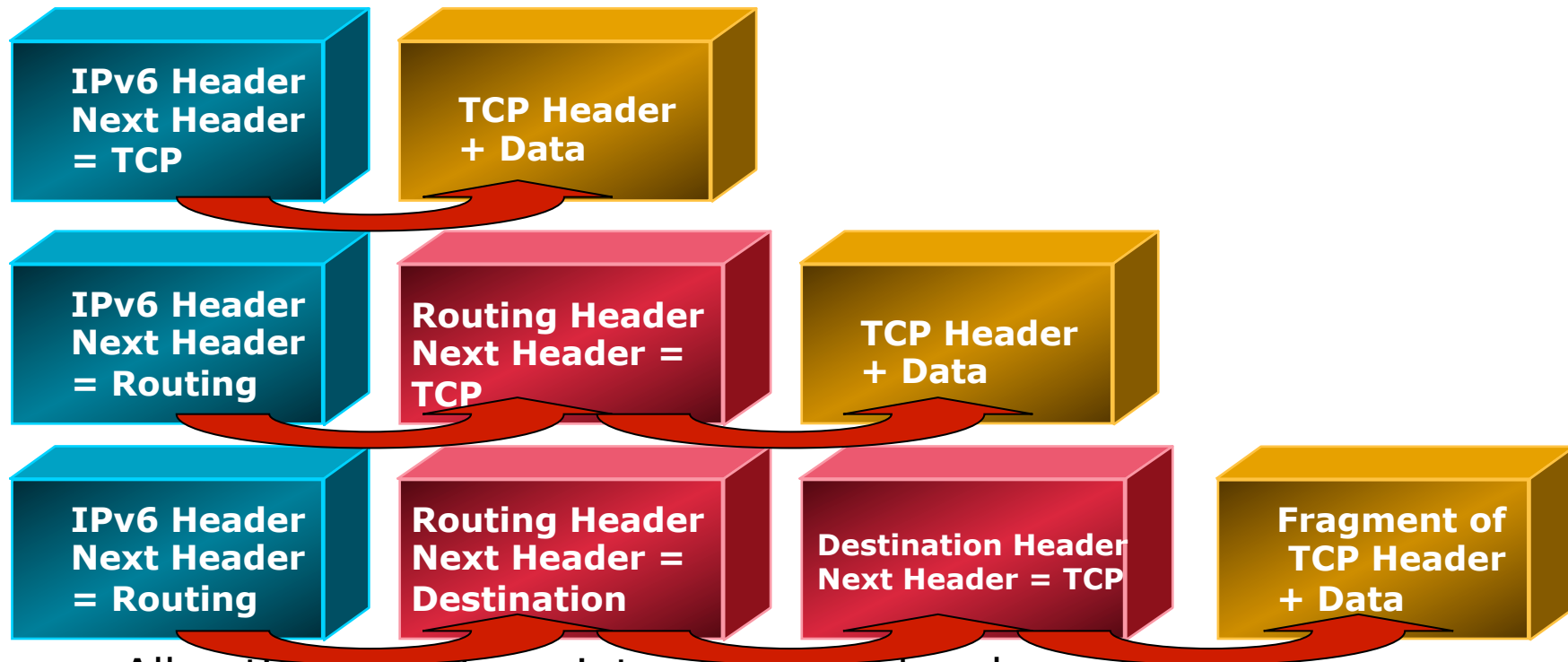
- ❑ Version = 4-bit value set to 6
- ❑ Traffic Class = 8-bit value
  - Replaces IPv4 TOS field
- ❑ Flow Label = 20-bit value
- ❑ Payload Length = 16-bit value
  - The size of the rest of the IPv6 packet following the header – replaces IPv4 Total Length
- ❑ Next Header = 8-bit value
  - Replaces IPv4 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

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- 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

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- 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

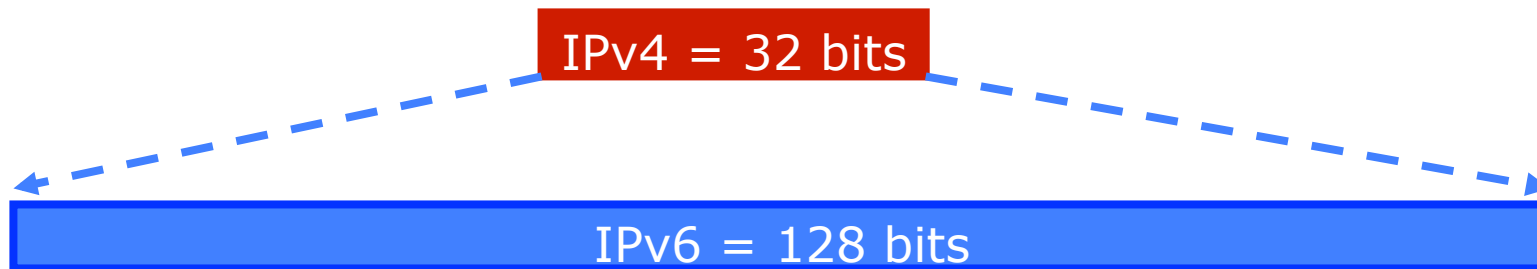
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- Order is important because:
  - Hop-by-hop header has to be processed by every intermediate node
  - Routing header needs to be processed by intermediate routers
  - At the destination fragmentation has to be processed before other headers
- This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



# Larger Address Space

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- IPv4
  - 32 bits
  - = 4,294,967,296 possible addressable devices
- IPv6
  - 128 bits: 4 times the size in bits
  - =  $3.4 \times 10^{38}$  possible addressable devices
  - = 340,282,366,920,938,463,463,374,607,431,768,211,456
  - $\sim 5 \times 10^{28}$  addresses per person on the planet


# How was the IPv6 Address Size Chosen?

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- 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)

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- 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)

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- `::` 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](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)

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## □ 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

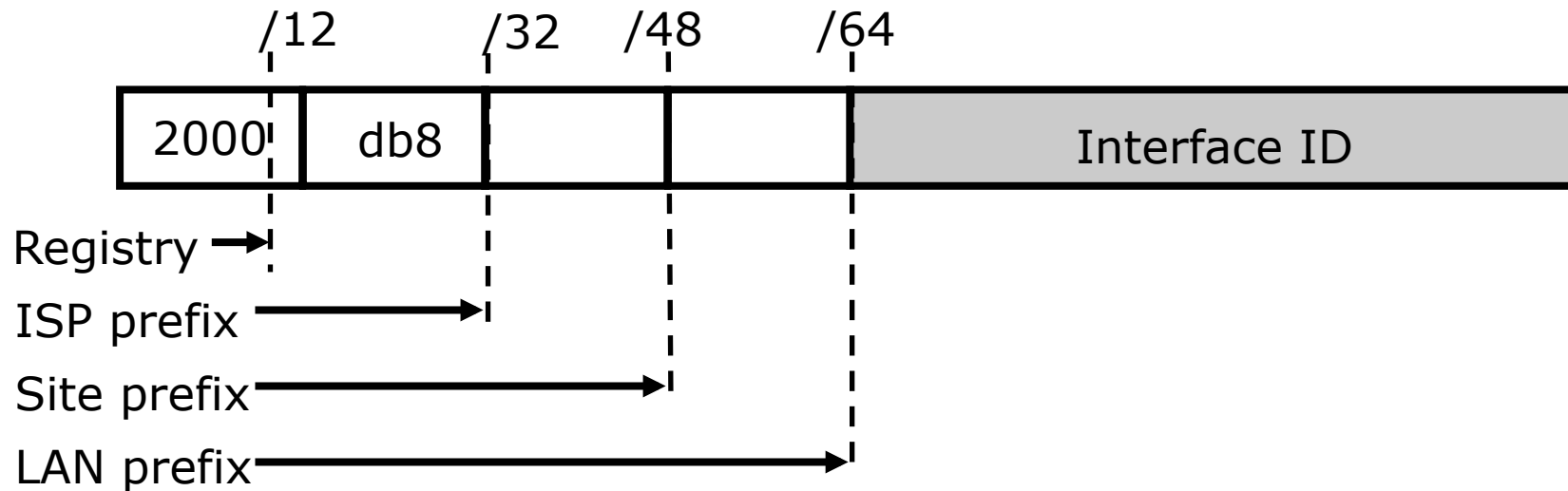
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- IPv6 Addressing rules are covered by multiple RFCs
  - Architecture defined by RFC 4291
- Address Types are :
  - Unicast : One to One (Global, Unique Local, Link local)
  - Anycast : One to Nearest (Allocated from Unicast)
  - Multicast : One to 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

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- 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

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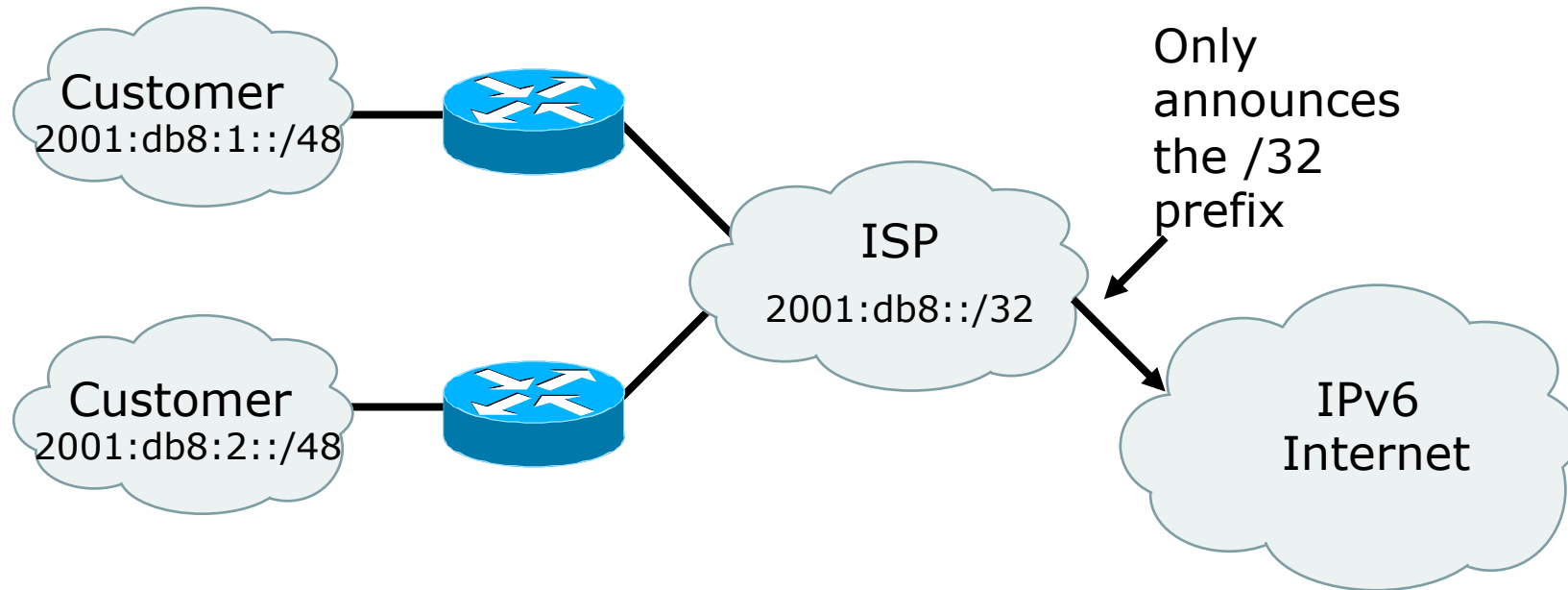
- 16 bits reserved for each service provider
  - Possibility of  $2^{16}$  end-sites per service provider
  - 65536 possible customers: equivalent to each service provider receiving a /8 in IPv4 (assuming a /24 address block per customer)
- 29 bits reserved for all service providers
  - Possibility of  $2^{29}$  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?

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- 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**

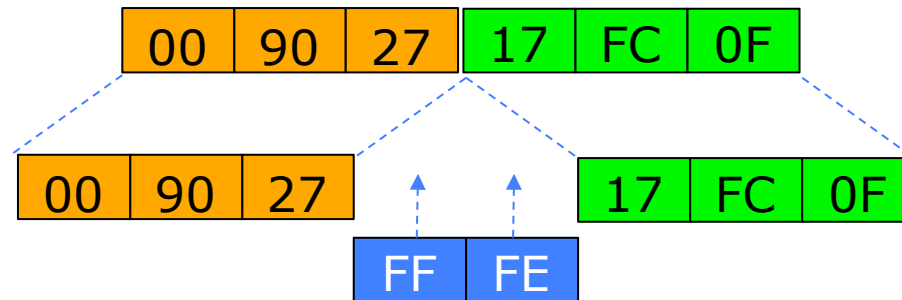
# Interface IDs

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- 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

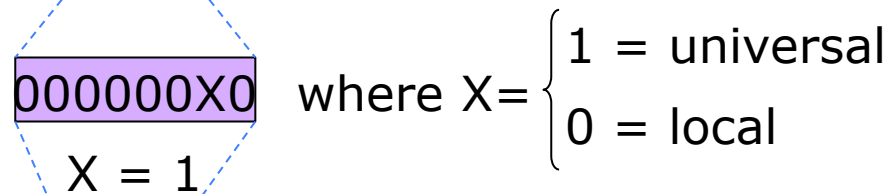
Ethernet MAC address  
(48 bits)



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

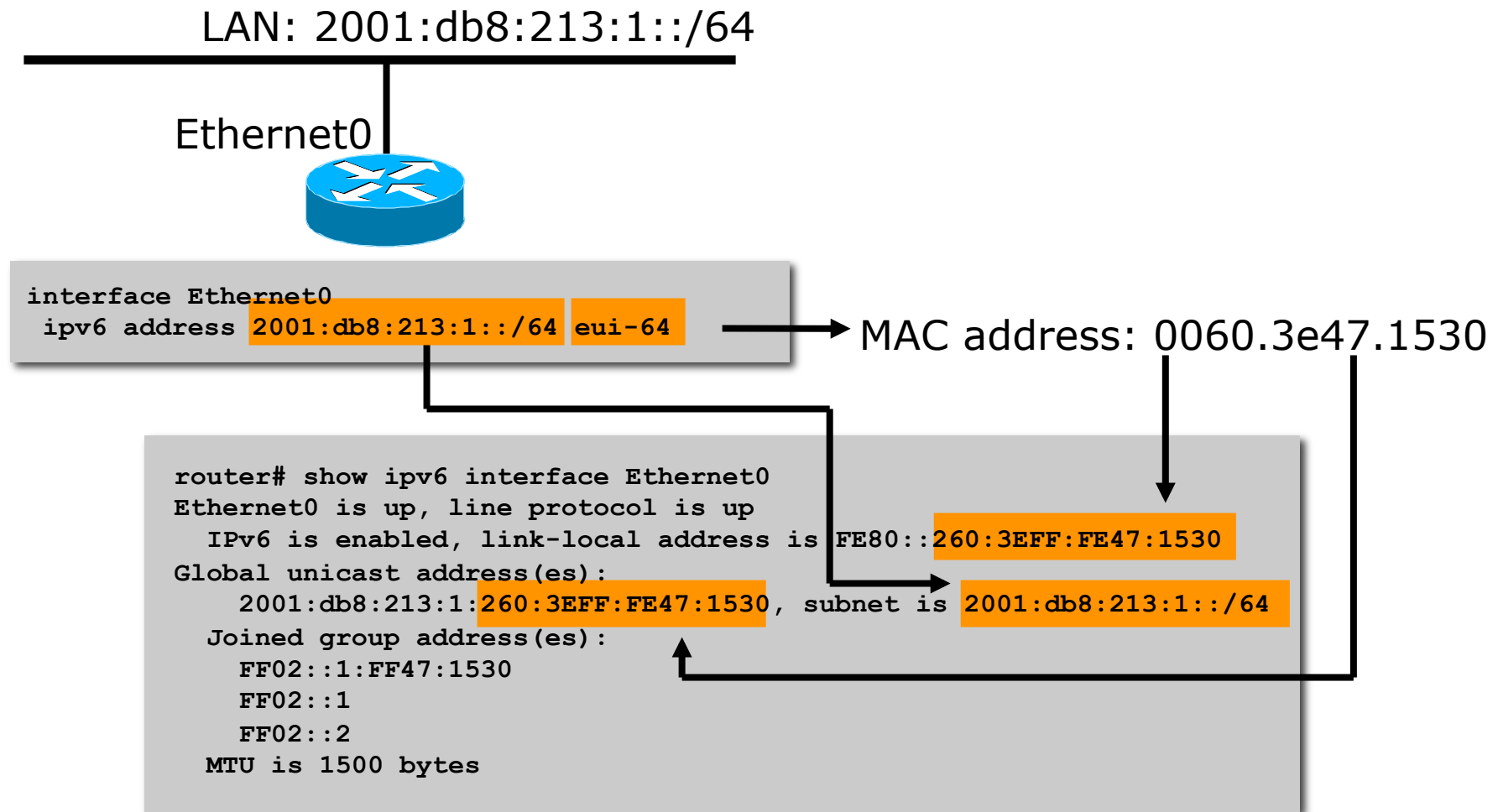
- Global scope: for IEEE 48-bit MAC
- Local scope: when no IEEE 48-bit MAC is available (eg serials, tunnels)

# EUI-64

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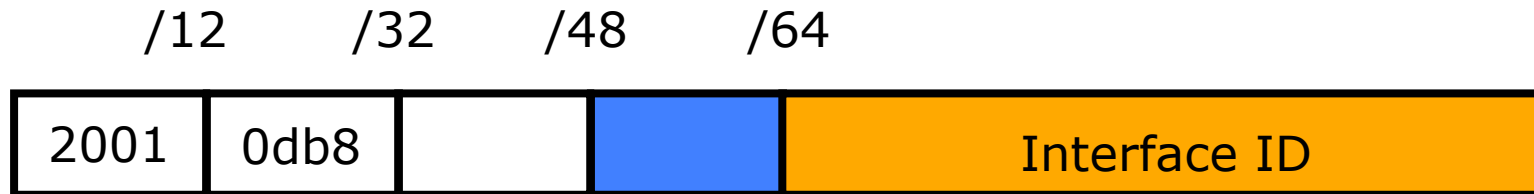
- Device MAC address is used to create:
  - Final 64 bits of global unicast address e.g.
    - 2001:db8:0:1:290:27ff:fe17:fc0f
  - Final 64 bits of link local address e.g.
    - fe80::290:27ff:fe17:fc0f
  - Final 24 bits of solicited node multicast address e.g.
    - ff02::1:ff17:fc0f
- Note that both global unicast and link local addresses can also be configured manually

# 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/7 and Apple MacOS 10.7 onwards
  - Can be activated on FreeBSD/Linux with a system call

# Host IPv6 Addressing Options

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- 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

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## □ 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

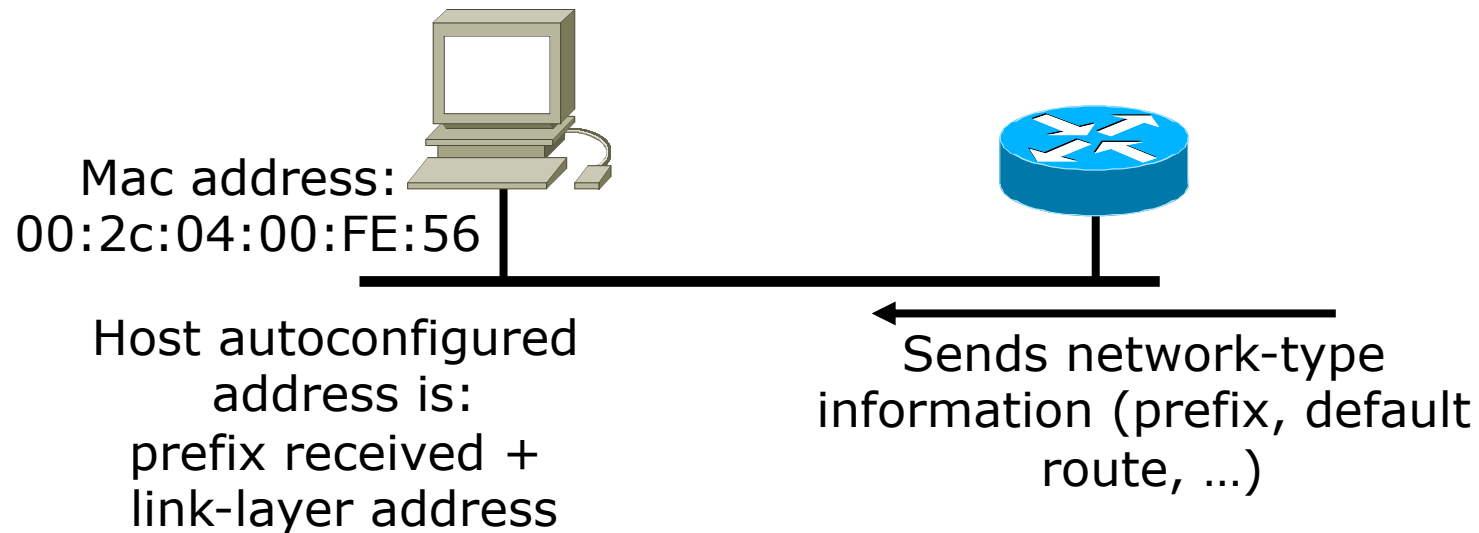
## □ Renumbering Routers

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

- **No known implementation!**

# Auto-configuration

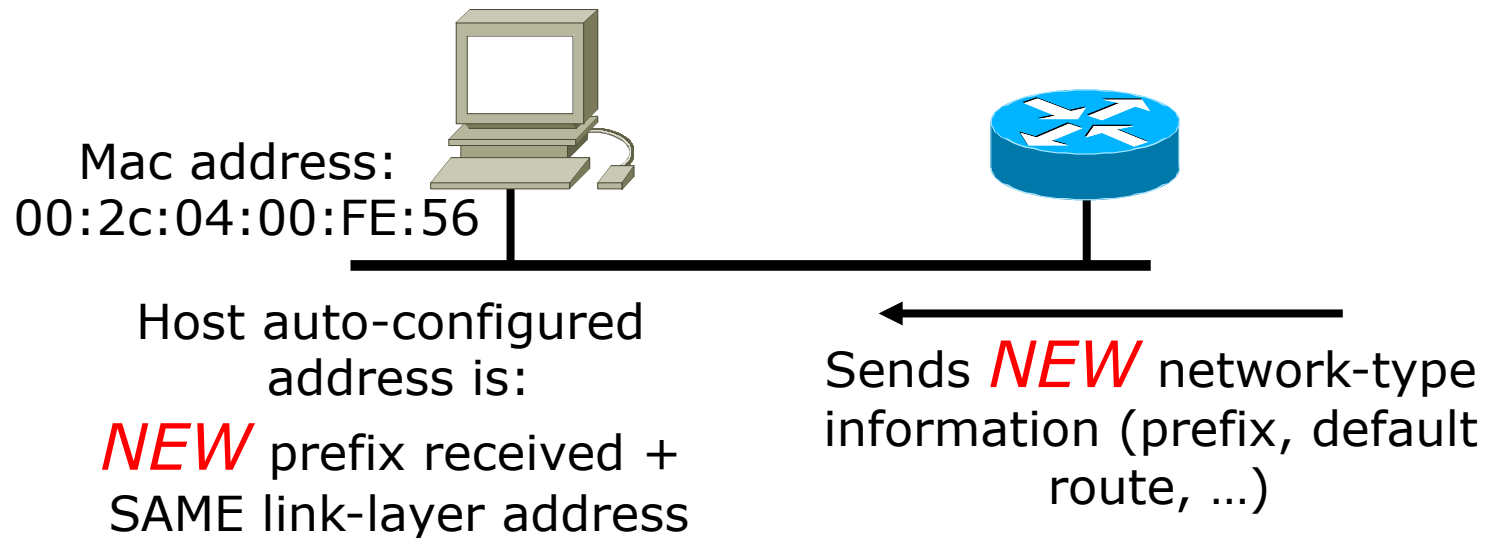
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- ❑ PC sends router solicitation (RS) message
- ❑ Router responds with router advertisement (RA)
  - This includes prefix and default route
  - RFC6106 adds DNS server option
- ❑ PC configures its IPv6 address by concatenating prefix received with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

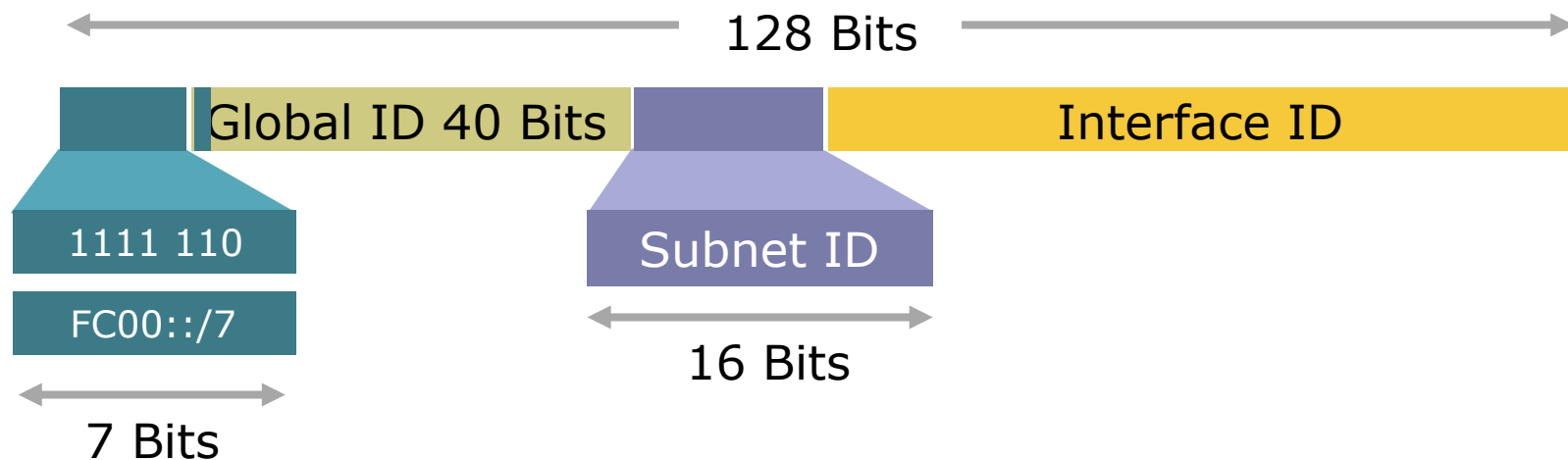
# Renumbering

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- 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

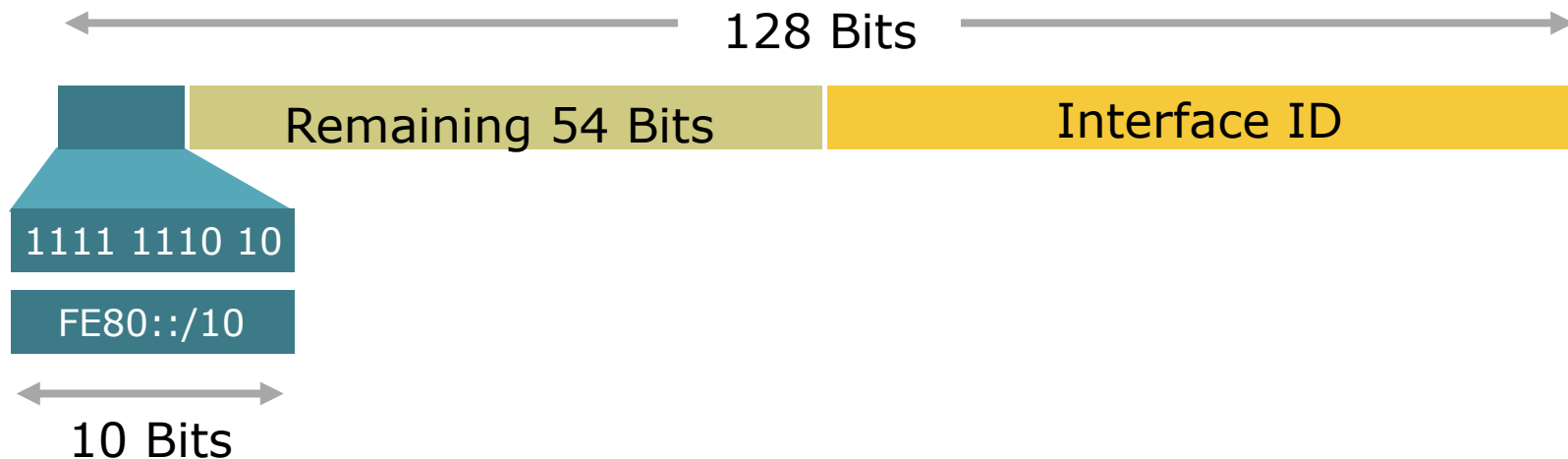
# Unique-Local



- 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

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- ❑ 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<sub>31</sub> value

# Multicast use

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- 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

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- 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

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## □ 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**

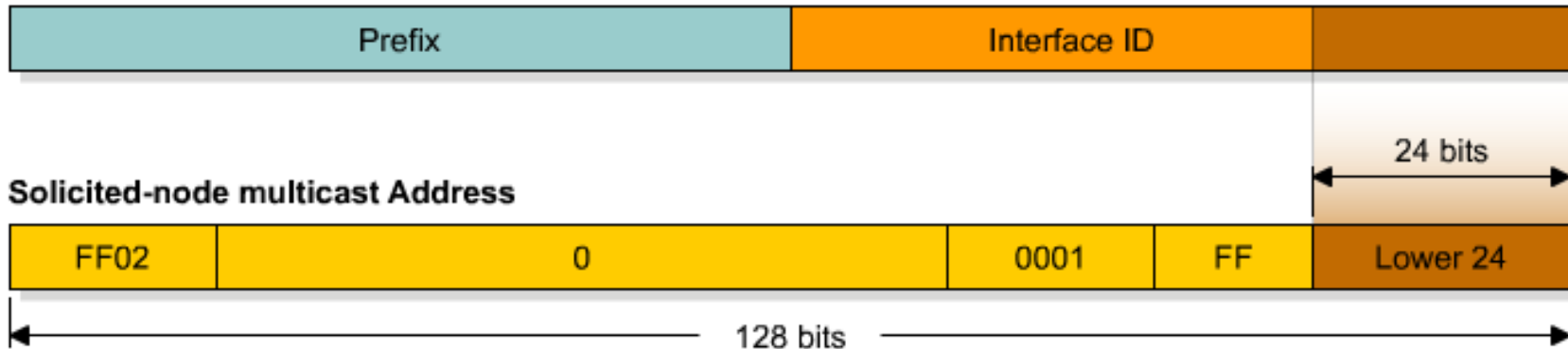
# Solicited-Node Multicast

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- 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

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

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- 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

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- 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

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- ❑ 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



# IPv6 Neighbour Discovery

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- 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

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- ❑ 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

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- 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

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## □ IP address to Hostname:

IPv4      1.30.168.192.in-addr.arpa.      PTR      www.abc.test.

IPv6      2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.0.0.0.8.1.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:

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## □ 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

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- ❑ 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

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- 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

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- 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

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- 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

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- 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

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- 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](http://www.ipv6tf.org)
- 3GPP UMTS Rel. 5 cellular wireless standards (2002) mandate IPv6; also being considered by 3GPP2

# IPv6 Status – Standardisation

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- 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)
  - IPv6 Addresses (RFC4291 & 3587)
  - BGP (RFC2545)
  - OSPF (RFC5340)
  - Jumbograms (RFC2675)
  - Radius (RFC3162)
  - Flow Label (RFC6436/7/8)
  - Mobile IPv6 MIB (RFC4295)
  - Unique Local IPv6 Addresses (RFC4193)
  - Teredo (RFC4380)
  - VRRP (RFC5798)
- 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

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- 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

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

# The IPv6 Protocol & IPv6 Standards



ISP Workshops