# IPv6 Protocols & Standards

## ISP/IXP Workshops

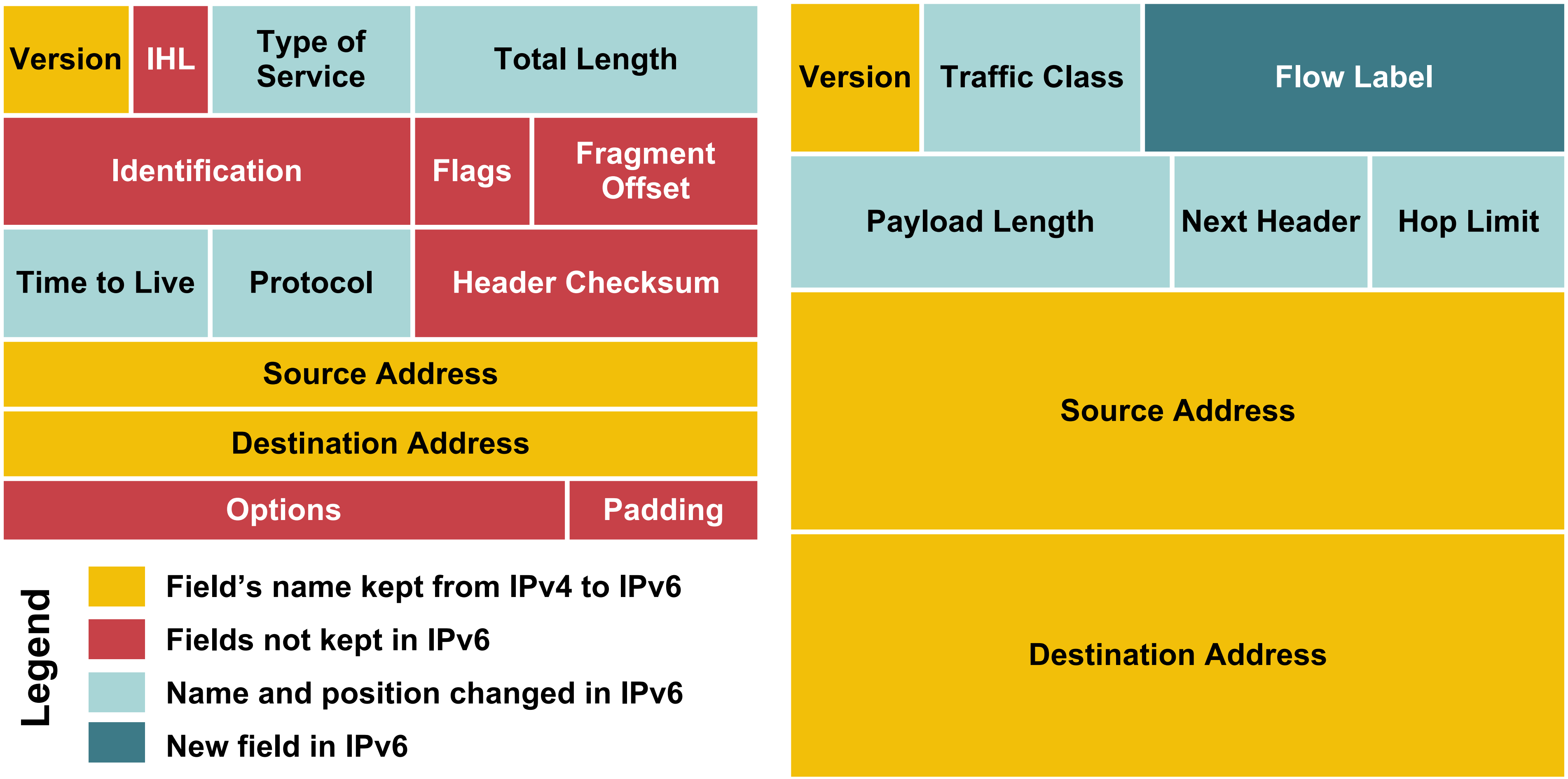
# So what has really changed?

- **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**

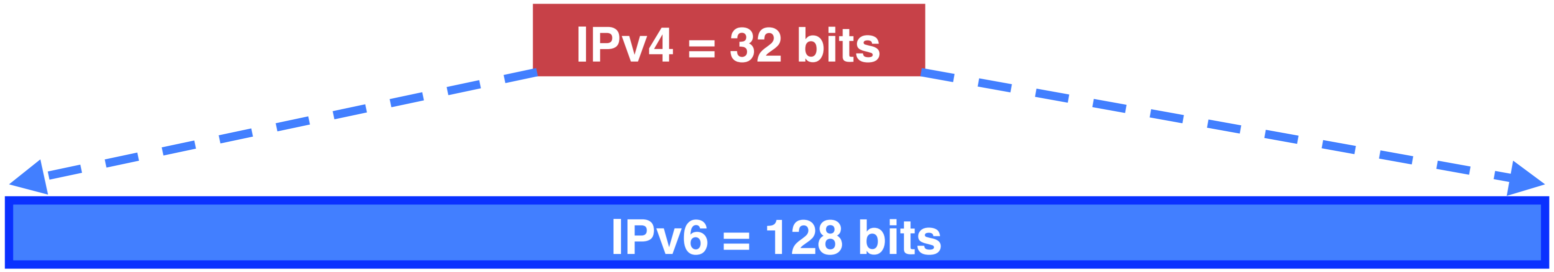
# IPv4 and IPv6 Header Comparison

## 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 x $10^{38}$ possible addressable devices**

**= 340,282,366,920,938,463,463,374,607,431,768,211,456**

**~ 5 x $10^{28}$ addresses per person on the planet**

# How was the IPv6 Address Size Chosen?

- **Some wanted fixed-length, 64-bit addresses**
  - Easily good for $10^{12}$ sites, $10^{15}$ nodes, at .0001 allocation efficiency (3 orders of magnitude more than IPv6 requirement)
  - Minimizes growth of per-packet header overhead
  - Efficient for software processing
- **Some wanted variable-length, up to 160 bits**
  - Compatible with OSI NSAP addressing plans
  - Big enough for auto-configuration using IEEE 802 addresses
  - Could start with addresses shorter than 64 bits & grow later
- **Settled on fixed-length, 128-bit addresses**

# IPv6 Address Representation

- **16 bit fields in case insensitive colon hexadecimal representation**

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

- **Leading zeros in a field are optional:**

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

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

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

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

  **0:0:0:0:0:0:0:1 → ::1** (loopback address)

  **0:0:0:0:0:0:0:0 → ::** (unspecified address)

# IPv6 Address Representation

- IPv4-compatible (not used any more)

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

  = ::192.168.30.1

  = ::C0A8:1E01

- In a URL, it is enclosed in brackets (RFC2732)

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

  Cumbersome for users

  Mostly for diagnostic purposes

  Use fully qualified domain names (FQDN)

- ⇒ The DNS has to work!!

# IPv6 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

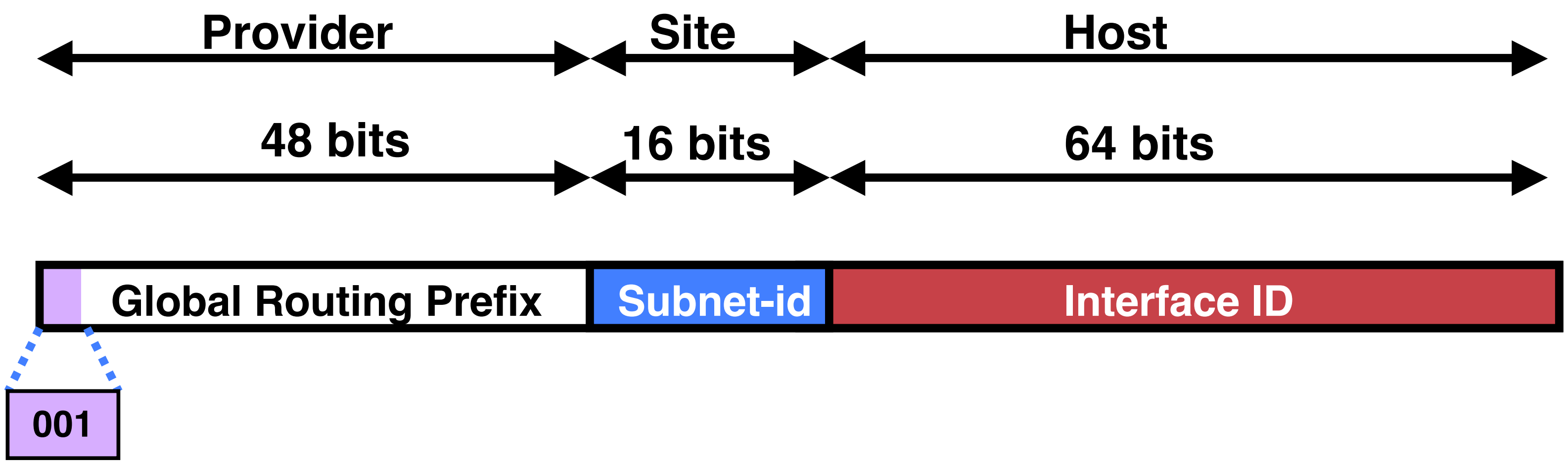
- A single interface may be assigned multiple IPv6 addresses of any type (unicast, anycast, multicast)

    No Broadcast Address → Use Multicast

# Addressing

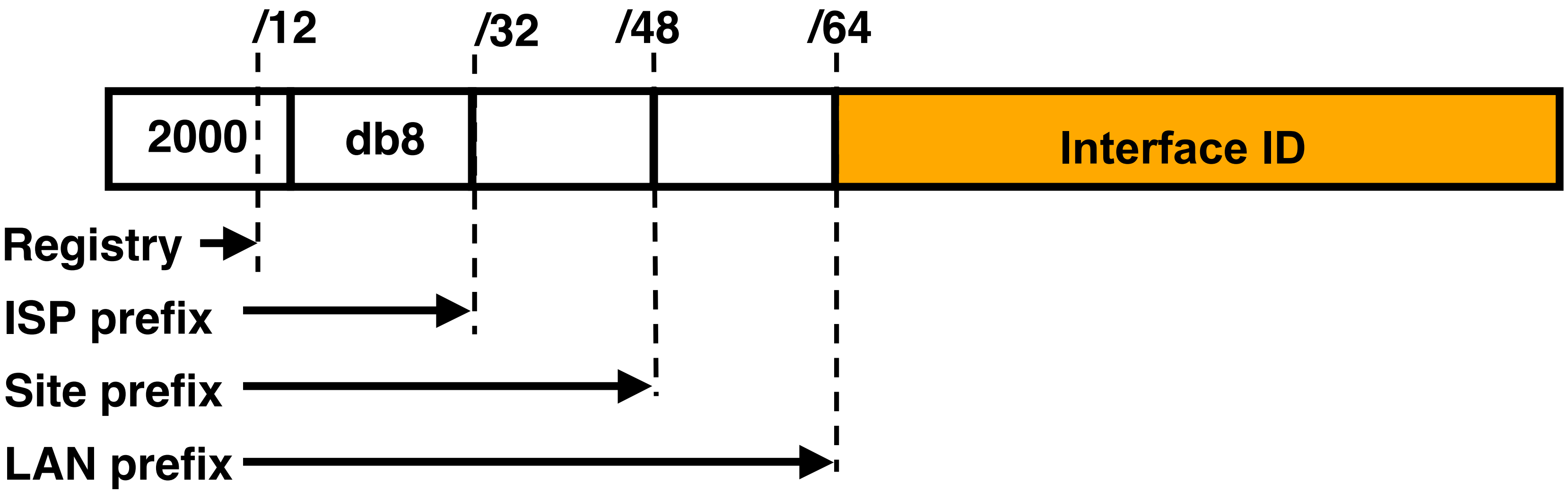
| Type | Binary | Hex |
|---|---|---|
| Unspecified | 000…0 | ::/128 |
| Loopback | 000…1 | ::1/128 |
| Aggregatable Global Unicast Address | 0010 | 2000::/3 |
| Link Local Unicast Address | 1111 1110 10 | FE80::/10 |
| Unique Local Unicast Address | 1111 1100<br>1111 1101 | FC00::/7 |
| Multicast Address | 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 16 hosts per IPv4 subnet)**

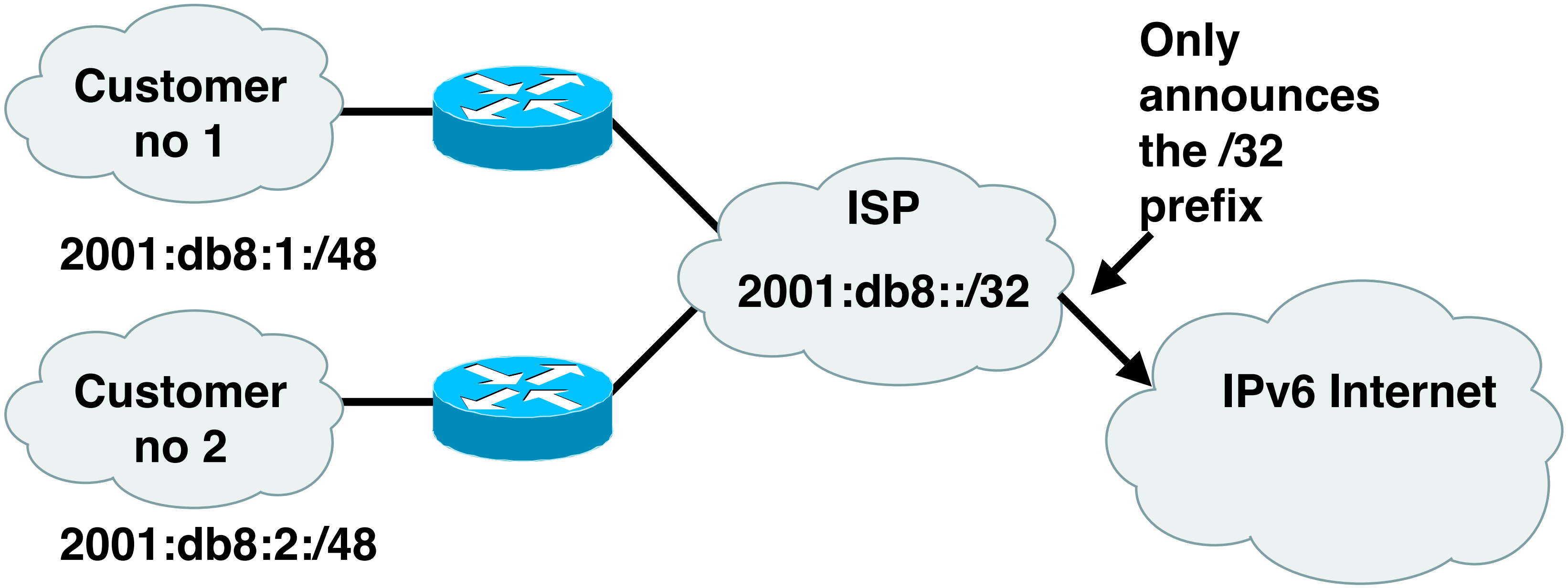
# IPv6 Addressing Scope

- **16 bits reserved for the 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)
- **32 bits reserved for service providers**
  - Possibility of $2^{32}$ service providers
  - i.e. 4 billion discrete service provider networks
    - Although some service providers already are justifying more than a /32
  - Equivalent to the size of the entire IPv4 address space

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

# Aggregation benefits




- **Larger address space enables:**

  **Aggregation of prefixes announced in the global routing table**

  **Efficient and scalable routing**

  **But current Internet multihoming solution breaks this model**

# Interface IDs

- **Lowest order 64-bit field of unicast address may be assigned in several different ways:**

  **auto-configured from a 64-bit EUI-64, or expanded from a 48-bit MAC address (e.g., Ethernet address)**

  **auto-generated pseudo-random number (to address privacy concerns)**

  **assigned via DHCP**

  **manually configured**

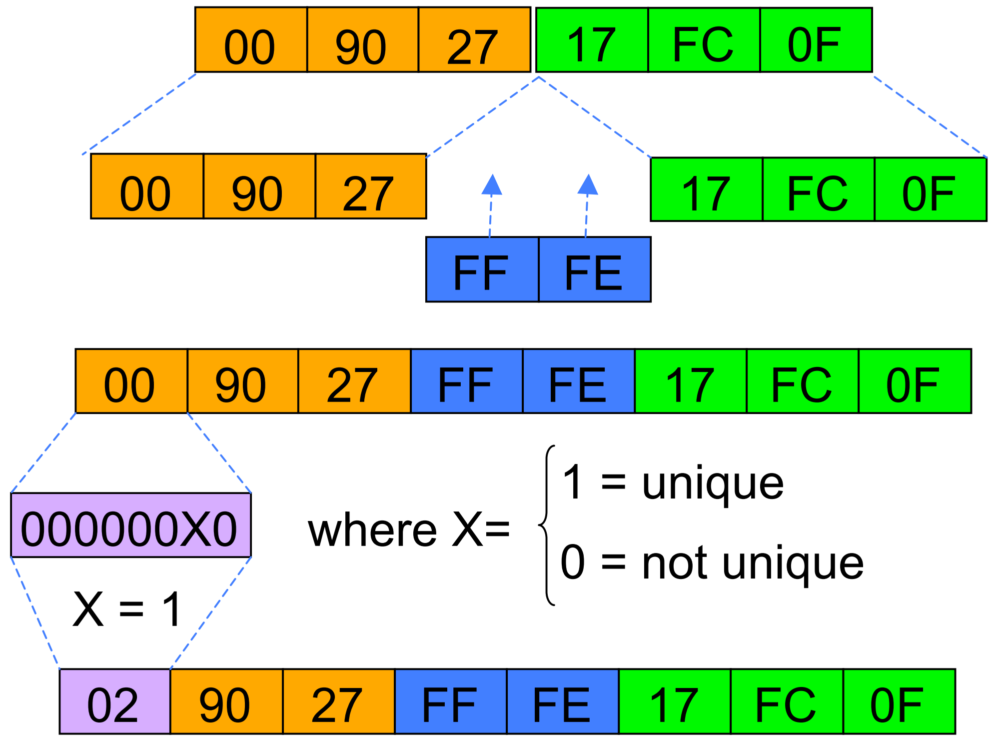
# EUI-64

**Ethernet MAC address (48 bits)**

**64 bits version**

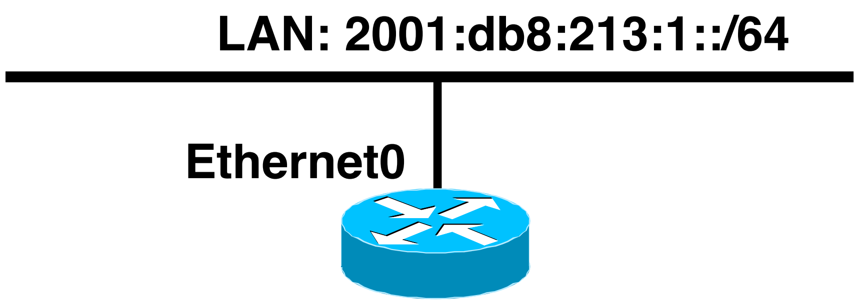
**Uniqueness of the MAC**

**Eui-64 address**




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

# IPv6 Addressing Examples

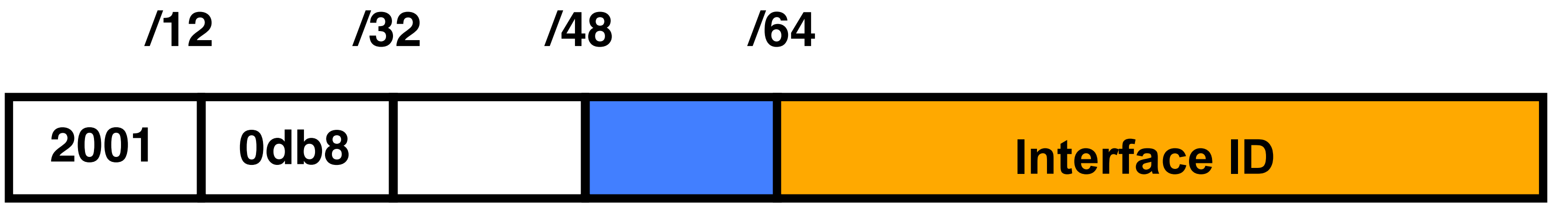



```
interface Ethernet0
 ipv6 address 2001:db8:213:1::/64 eui-64
```

**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 3041)




- **Temporary addresses for IPv6 host client application, e.g. Web browser**
  - **Inhibit device/user tracking but is also a potential issue**
    - **More difficult to scan all IP addresses on a subnet but port scan is identical when an address is known**
  - **Random 64 bit interface ID, run DAD before using it**
  - **Rate of change based on local policy**
  - **Implemented on Microsoft Windows XP**
  - **From RFC 3041: “…interface identifier …facilitates the tracking of individual devices (and thus potentially users)…”**

# IPv6 Auto-Configuration

- **Stateless (RFC2462)**

  **Host autonomously configures its own Link-Local address**

  **Router solicitation are sent by booting nodes to request RAs for configuring the interfaces.**

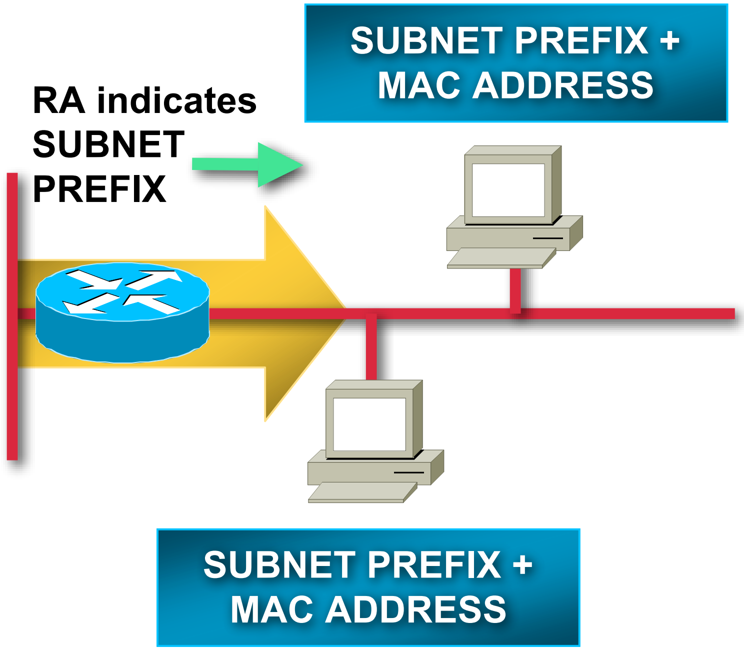
- **Stateful**

  **DHCPv6 – required by most enterprises**

- **Renumbering**

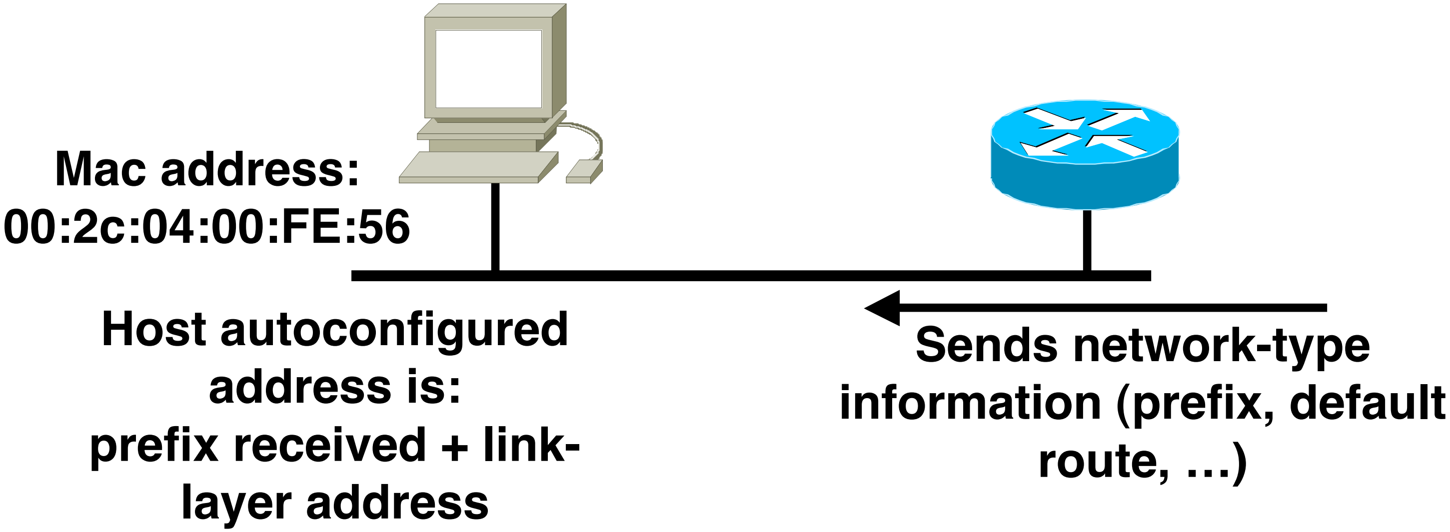
  **Hosts renumbering is done by modifying the RA to announce the old prefix with a short lifetime and the new prefix**

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




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

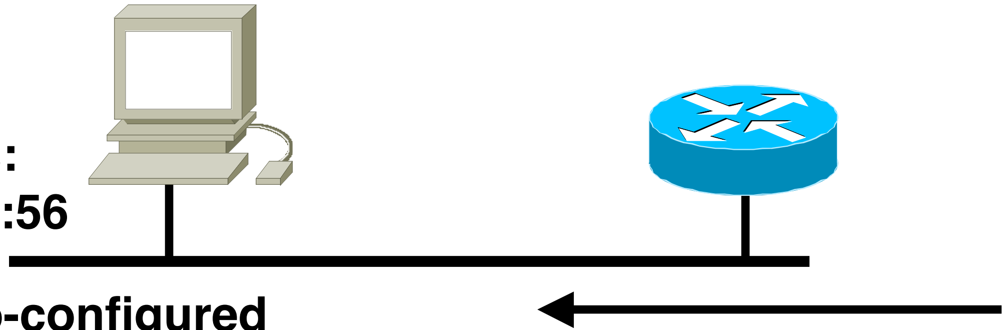
# Auto-configuration




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

# Renumbering

Mac address:
00:2c:04:00:FE:56



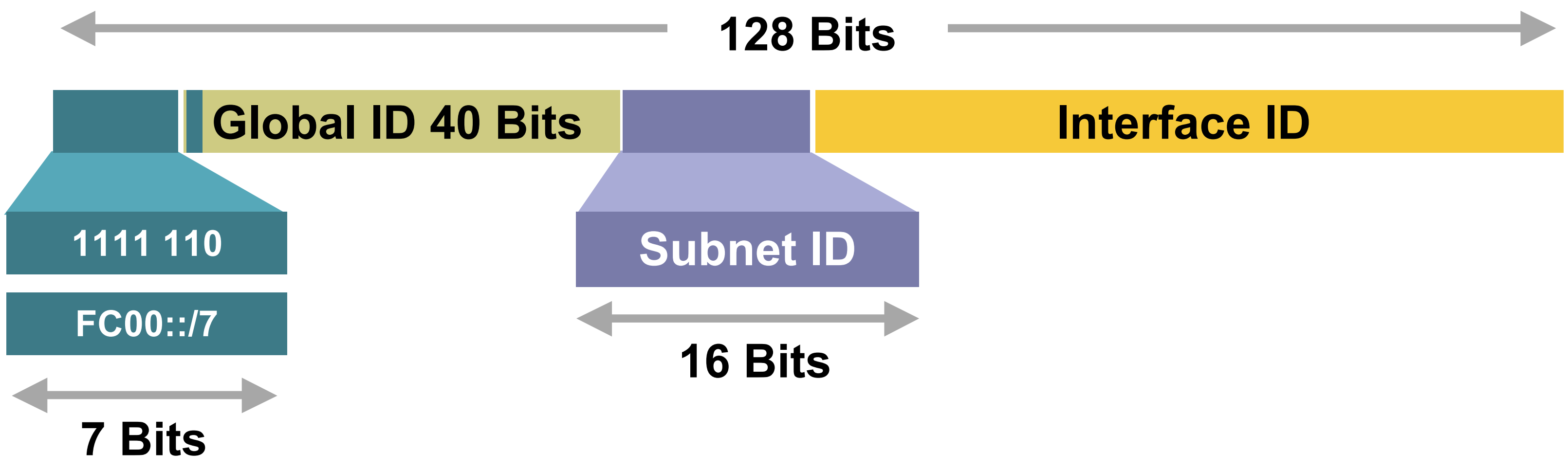
Host auto-configured address is:
*NEW* prefix received + SAME link-layer address

Sends *NEW* network-type information (prefix, default route, …)

- **Larger address space enables:**

  **Renumbering, using auto-configuration and multiple addresses**

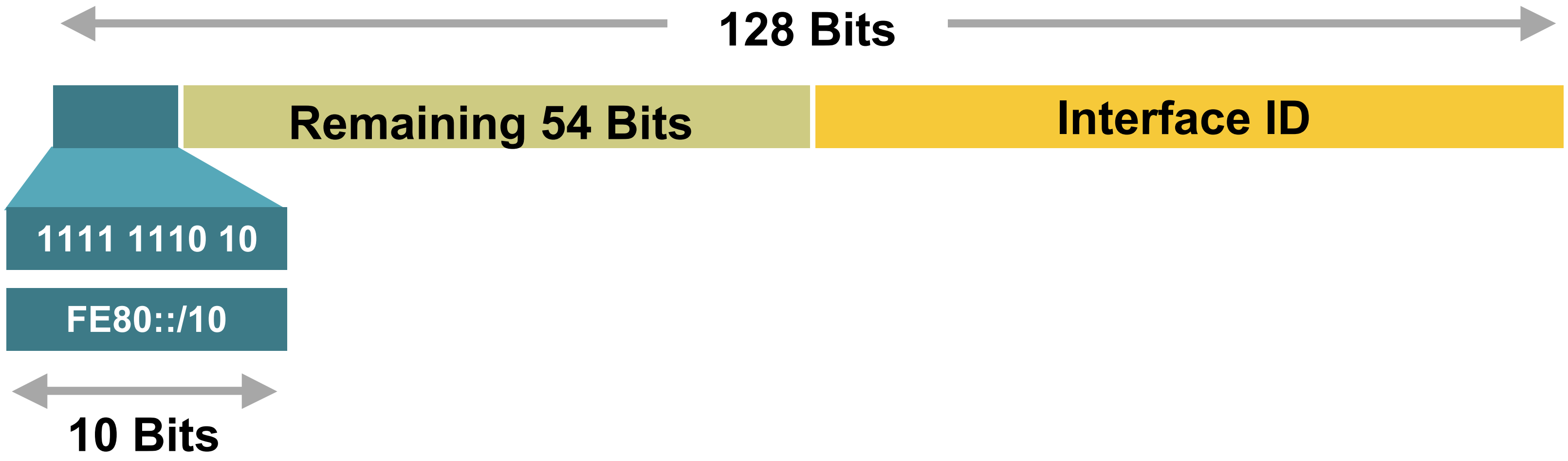
# Unique-Local




## Unique-Local Addresses Used For:

- Local communications
- Inter-site VPNs
- Not routable on the Internet

# Link-Local




**Link-Local Addresses Used For:**

- Mandatory Address for Communication between two IPv6 device (Like ARP but at Layer 3)
- Automatically assigned by Router as soon as IPv6 is enabled
- Also used for Next-Hop calculation in Routing Protocols
- 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 (1111 1111). 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 |

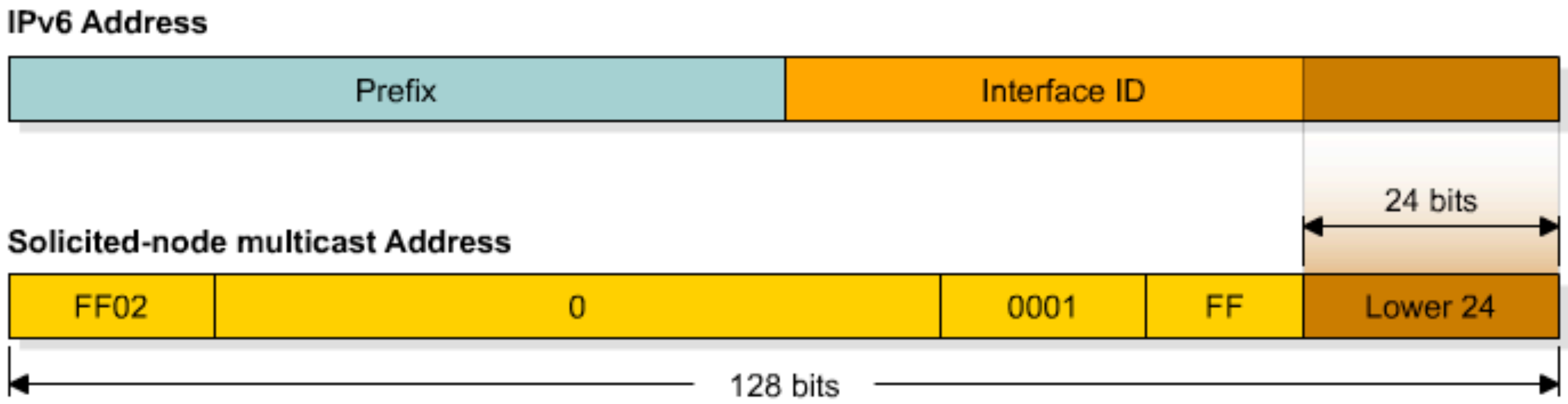
# IPv6 Multicast Address Examples

- **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 Address

- For each unicast and anycast address configured there is a corresponding solicited-node multicast
- This address is link local significance only
- This is specially used for two purpose, for the replacement of ARP, and DAD

# Solicited-Node Multicast Address




- **Used in neighbor solicitation messages**
- **Multicast address with a link-local scope**
- **Solicited-node multicast consists of prefix + lower 24 bits from unicast, FF02::1:FF:**

# Router Interface

```
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**

# Anycast

## Anycast Address Assignment

- Routers along the path to the destination just process the packets based on network prefix
- Routers configured to respond to anycast packets will do so when they receive a packet send to the anycast address
- Anycast allows a source node to transmit IP datagrams to a single destination node out of a group destination nodes with same subnet id based on the routing metrics

# 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 (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 3FFE:B00:C18:1::2 |
| IP address to hostname | **PTR record:** 1.30.168.192.in-addr.arpa. PTR www.abc.test. | **PTR record:** 2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.0.0.0.8.1.c.0.0.0.b.0.e.f.f.3.ip6.arpa PTR www.abc.test. |

# IPv6 Technology Scope

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

# What does IPv6 do for:

- **Security**

  **Nothing IPv4 doesn't do – IPSec runs in both**

  **but IPv6 mandates IPSec**

- **QoS**

  **Nothing IPv4 doesn't do –**

  **Differentiated and Integrated Services run in both**

  **So far, Flow label has no real use**

# IPv6 Security

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

# IP Quality of Service Reminder

Two basic approaches developed by IETF:

- “Integrated Service” (int-serv)

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

- “Differentiated Service” (diff-serv)

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

- Signaled diff-serv (RFC 2998)

  uses RSVP for signaling with course-grained qualitative aggregate markings

  allows for policy control without requiring per-router state overhead

# IPv6 Support for Int-Serv

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

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

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

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

# IPv6 Support for Diff-Serv

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

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

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

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

# IPv6 Standards

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

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

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

  mobile IPv6, header compression,...

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

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

# IPv6 Status – Standardisation

- Several key components on standards track…
  - Specification (RFC2460)
  - ICMPv6 (RFC4443)
  - RIP (RFC2080)
  - IGMPv6 (RFC2710)
  - Router Alert (RFC2711)
  - Autoconfiguration (RFC2462)
  - DHCPv6 (RFC3315 & 4361)
  - IPv6 Mobility (RFC3775)
  - GRE Tunnelling (RFC2473)
  - DAD for IPv6 (RFC4429)
  - Neighbour Discovery (RFC2461 & 4311)
  - IPv6 Addresses (RFC4291 & 3587)
  - BGP (RFC2545)
  - OSPF (RFC2740)
  - Jumbograms (RFC2675)
  - Radius (RFC3162)
  - Flow Label (RFC3697)
  - Mobile IPv6 MIB (RFC4295)
  - Unique Local IPv6 Addresses (RFC4193)
  - Teredo (RFC4380)
- IPv6 available over:
  - PPP (RFC2472)
  - FDDI (RFC2467)
  - NBMA (RFC2491)
  - Frame Relay (RFC2590)
  - IEEE1394 (RFC3146)
  - Ethernet (RFC2464)
  - Token Ring (RFC2470)
  - ATM (RFC2492)
  - ARCnet (RFC2497)
  - FibreChannel (RFC4338)

# Recent IPv6 “Hot Topics” in the IETF

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

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

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

# Status of other IPv6 related WGs in the IETF

- **V6ops**

  **Focuses on IPv6 operations**

- **SHIM6**

  **Focus on edge multihoming solution for IPv6**

# Conclusion

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

# IPv6 Protocols & Standards

## ISP/IXP Workshops