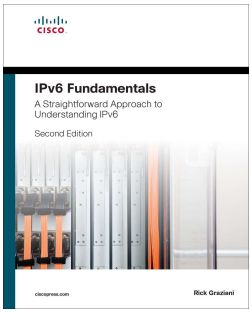

IPv6 Fundamentals, by Rick Graziani

Address Representation and Address Types

Prepared by **Alvaro Barradas** for Redes II
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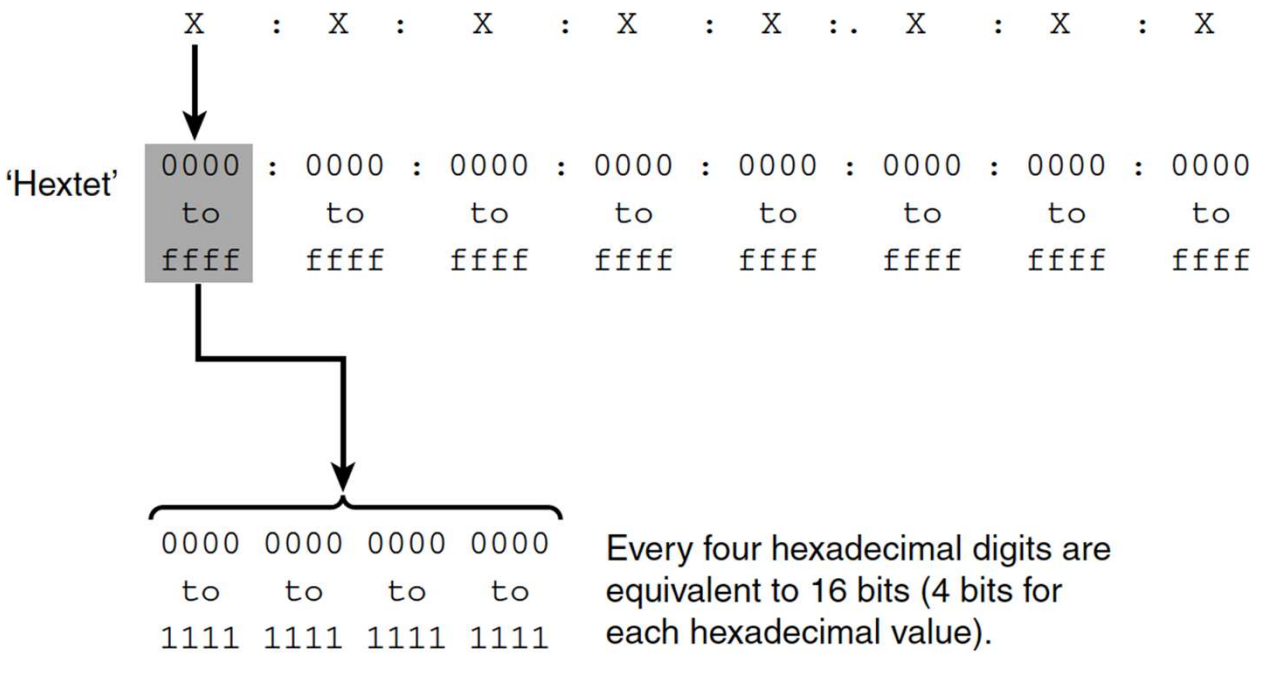
Chapter 4

IPv6 Address Representation and Address Types

IPv6 Address Representation

- Most obvious difference:
  - IPv4, 32-bit addresses expressed in doted-decimal notation.
  - IPv6, 128-bit addresses expressed in hexadecimal.
- IPv6 includes new address types, and changes to familiar address types.
- RFC 4291 describes the *preferred form* x:x:x:x:x:x:x:x
  - each *x* is a 16-bit section represented by 4 hexadecimal digits
  - Section are separated by colons



```
Windows-OS> ipconfig

Ethernet adapter Local Area Connection:
   Connection-specific DNS Suffix  . :
   IPv6 Address. . . . . . . . . . . : 2001:db8:cafe:1:d0f8:9ff6:4201:7086  ! IPv6 GUA
   Link-local IPv6 Address . . . . . : fe80::d0f8:9ff6:4201:7086%11         ! IPv6 Link-Local
   IPv4 Address. . . . . . . . . . . : 192.168.1.100
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : fe80::1%11                           ! IPv6 Default Gateway
                                       192.168.1.1
-------------------------------------------------------------------------------------------------
Mac-OS$ ifconfig

en1: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
          ether 60:33:4b:15:24:6f
          inet6 fe80::6233:4bff:fe15:246f%en1 prefixlen 64 scopeid 0x5          ! IPv6 Link-Local
          inet 192.168.1.111 netmask 0xffffff00 broadcast 192.168.1.255
          inet6 2001:db8:cafe:1:4bff:fe15:246f prefixlen 64 autoconf            ! IPv6 GUA
          Graphics: autoselect
          status: active
```

Figure 4-1 *Preferred Form of IPv6 Address*

IPv6 Address Representation

0000:0000:0000:0000:0000:0000:0000:0000
0000:0000:0000:0000:0000:0000:0000:0001
ff02:0000:0000:0000:0000:0000:0000:0001
fe80:0000:0000:0000:a299:9bff:fe18:50d1
2001:0db8:1111:000a:00b0:0000:9000:0200
2001:0db8:0000:0000:abcd:0000:0000:1234
2001:0db8:cafe:0001:0000:0000:0000:0100
2001:0db8:cafe:0001:0000:0000:0000:0200

IPv6 Address Representation

How to shorten IPv6 addresses?

- **Rule 1:** Omit Leading Zeros
  - This rule applies only to leading 0s
  - Not for trailing 0s
  - Being able to omit both leading and trailing 0s would cause the address to be ambiguous.

Table 4-1 *Examples of Omitting Leading 0s in a Hextet**

Format	IPv6 Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0000
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 0 or 0:0:0:0:0:0:0:0
Preferred	0000:0000:0000:0000:0000:0000:0000:0001
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 1 or 0:0:0:0:0:0:0:1
Preferred	ff02:0000:0000:0000:0000:0000:0000:0001
Leading 0s omitted	ff02: 0: 0: 0: 0: 0: 0: 1 or ff02:0:0:0:0:0:0:1

Format	IPv6 Address
Preferred	fe80:0000:0000:0000:a299:9bff:fe18:50d1
Leading 0s omitted	fe80:0:0:0:a299:9bff:fe18:50d1 or fe80:0:0:0:a299:9bff:fe18:50d1
Preferred	2001:0db8:1111:000a:00b0:0000:9000:0200
Leading 0s omitted	2001:db8:1111:a:b0:0:9000:200 or 2001:db8:1111:a:b0:0:9000:200
Preferred	2001:0db8:0000:0000:abcd:0000:0000:1234
Leading 0s omitted	2001:db8:0:0:abcd:0:0:1234 or 2001:db8:0:0:abcd:0:0:1234

Preferred	2001:0db8:aaaa:0001:0000:0000:0000:0100
Leading 0s omitted	2001:db8:aaaa:1:0:0:0:100 or 2001:db8:aaaa:1:0:0:0:100
Preferred	2001:0db8:aaaa:0001:0000:0000:0000:0200
Leading 0s omitted	2001:db8:aaaa:1:0:0:0:200 or 2001:db8:aaaa:1:0:0:0:200

IPv6 Address Representation

- **Rule 1:** Omit Leading Zeros (not tralling zeros)
  - 0s omitted:

    `2001:db8:100:a:0:bc:abcd:d0b`
  - Incorrect (trailling 0s):

    `2001:db8**0**:100**0**:a**000**:**0000**:bc**00**:abcd:d0b**0**`
  - Correct (leading zeros)

    `2001:**0**db8:**0**100:**000**a:**0000**:**00**bc:abcd:**0**d0b`

IPv6 Address Representation

How to shorten IPv6 addresses?

- **Rule 2:** Omit All-0s Hextets
  - You can use a double colon (::) to represente any single, contiguous string of two or more hextets (16-bit segments) consisting of all 0s.

Table 4-2 *Examples of Omitting a Single Contiguous String of All-0s Hextets*

Format	IPv6 Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0000
(::) All-0s segments	::
Preferred	0000:0000:0000:0000:0000:0000:0000:0001
(::) All-0s segments	::0001
Preferred	ff02:0000:0000:0000:0000:0000:0000:0001
(::) All-0s segments	ff02::0001
Preferred	fe80:0000:0000:0000:a299:9bff:fe18:50d1
(::) All-0s segments	fe80::a299:9bff:fe18:50d1
Preferred	2001:0db8:1111:000a:00b0:0000:0200
(::) All-0s segments	2001:0db8:1111:000a:00b0::0200

Falta um hexteto

Preferred	2001:0db8:0000:0000:abcd:0000:0000:1234
(::) All-0s segments	2001:0db8::abcd:0000:0000:1234
Preferred	2001:0db8:aaaa:0001:0000:0000:0000:0100
(::) All-0s segments	2001:0db8:aaaa:0001::0100
Preferred	2001:0db8:aaaa:0001:0000:0000:0000:0200
(::) All-0s segments	2001:0db8:aaaa:0001::0200

IPv6 Address Representation

- **Rule 2:** Omit All-0s Hextets
  - 0nly a single contiguous string of all-0s segments can be represented with a double-colon; otherwise the address would be ambiguous.

- Incorrect address using two double colons:

  `2001::abcd::1234`

- Possible ambiguous choices:

`2001:0000:0000:0000:0000:abcd:0000:1234`
`2001:0000:0000:0000:abcd:0000:0000:1234`
`2001:0000:0000:abcd:0000:0000:0000:1234`
`2001:0000:abcd:0000:0000:0000:0000:1234`

IPv6 Address Representation

What if you have more than one contiguous string of all-0s hextets?

- RFC 5952
  - The double colon should represente the longest string of all-0s hextets.
  - If the strings are of equal length, the first string should use the double colon (::) notation.

IPv6 Address Representation

Combining Rule 1 and Rule 2

- **Compressed Format:**
  - We can combine the two rules just discussed to reduce an address even further.

Table 4-3 *Examples of Applying Both Rule 1 and Rule 2*

Format	IPv6 Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0000
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 0
(::) All-0s segments	::
Preferred	0000:0000:0000:0000:0000:0000:0000:0001
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 1
(::) All-0s segments	::1

Format	IPv6 Address
Preferred	ff02:0000:0000:0000:0000:0000:0000:0001
Leading 0s omitted	ff02: 0: 0: 0: 0: 0: 0: 1
(::) All-0s segments	ff02::1
Preferred	fe80:0000:0000:0000:a299:9bff:fe18:50d1
Leading 0s omitted	fe80: 0: 0: 0:a299:9bff:fe18:50d1
(::) All-0s segments	fe80::a299:9bff:fe18:50d1
Preferred	2001:0db8:1111:000a:00b0:0000:9000:0200
Leading 0s omitted	2001: db8:1111: a: b0: 0:9000: 200
(::) All-0s segments	2001:db8:1111:a:b0::9000:200
Preferred	2001:0db8:0000:0000:abcd:0000:0000:1234
Leading 0s omitted	2001: db8: 0: 0:abcd: 0: 0:1234
(::) All-0s segments	2001:db8::abcd:0:0:1234

Preferred	2001:0db8:aaaa:0001:0000:0000:0000:0100
Leading 0s omitted	2001: db8:aaaa: 1: 0: 0: 0: 100
(::) All-0s segments	2001:db8:aaaa:1::100
Preferred	2001:0db8:aaaa:0001:0000:0000:0000:0200
Leading 0s omitted	2001: db8:aaaa: 1: 0: 0: 0: 200
(::) All-0s segments	2001:db8:aaaa:1::200

Table 4-4 *IPv6 Address Preferred and Compressed Formats*

Preferred Format	Compressed Format
0000:0000:0000:0000:0000:0000:0000:0000	::
0000:0000:0000:0000:0000:0000:0000:0001	::1
ff02:0000:0000:0000:0000:0000:0000:0001	ff02::1
fe80:0000:0000:0000:a299:9bff:fe18:50d1	fe80::a299:9bff:fe18:50d1
2001:0db8:1111:000a:00b0:0000:0000:0200	2001:db8:1111:a:b0::200
2001:0db8:0000:0000:abcd:0000:0000:1234	2001:db8::abcd:0:0:1234
2001:0db8:aaaa:0001:0000:0000:0000:0100	2001:db8:aaaa:1::100
2001:0db8:aaaa:0001:0000:0000:0000:0200	2001:db8:aaaa:1::200

Prefix Length Notation

- IPv4
  - The prefix (network portion) of the address can be identified by a dotted-decimal netmask, the *subnet mask*.
  - 255.255.255.0 indicates that the network portion of the address is the leftmost 24 bits.
  - This can also be written in CIDR notation as /24.
- IPv6
  - Address prefixes are represented like in IPv4 with CIDR notation.

Prefix Length Notation

- IPv6
  - **ipv6-address/prefix-length**
  - Where prefix-length is a decimal value indicating the number of leftmost contiguous bits in the address.
  - The prefix-length identifies the prefix (the network portion) of the address.
  - It is used with unicast addresses to separate the prefix portion of the address from the Interface ID.

Each hexadecimal digit is 4 bits; a hextet is a 16-bit segment.

```
2001:db8:aaaa:1111::100/64

2001 : 0db8 : aaaa : 1111 : 0000 : 0000 : 0000 : 0100
```

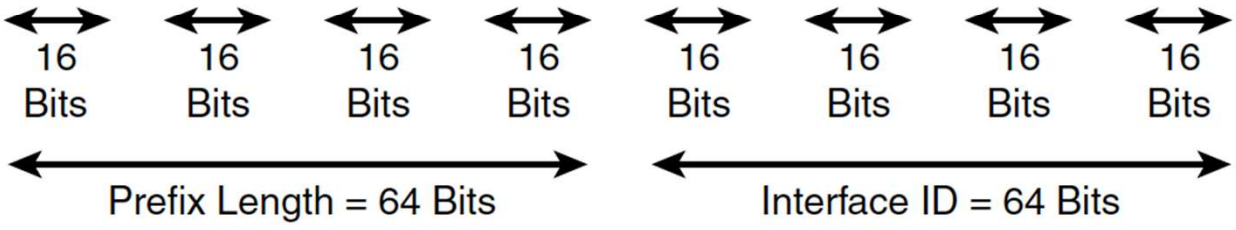


Figure 4-2 *IPv6 Prefix and Prefix Length*

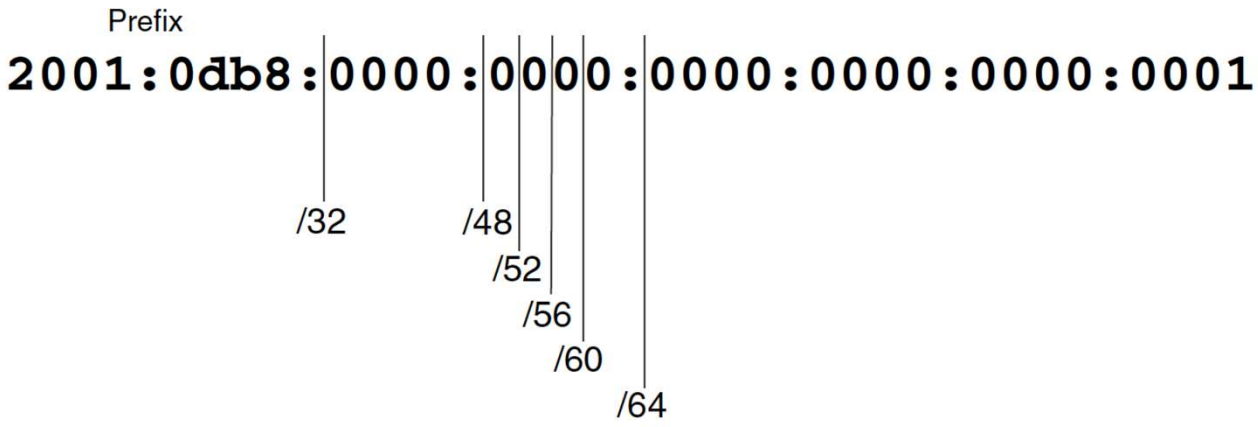


Figure 4-3 *IPv6 Prefix Length Examples*

IPv6 Address Types

- A brief look at the address space

- Unicast addresses
- Multicast addresses
- Anycast addresses

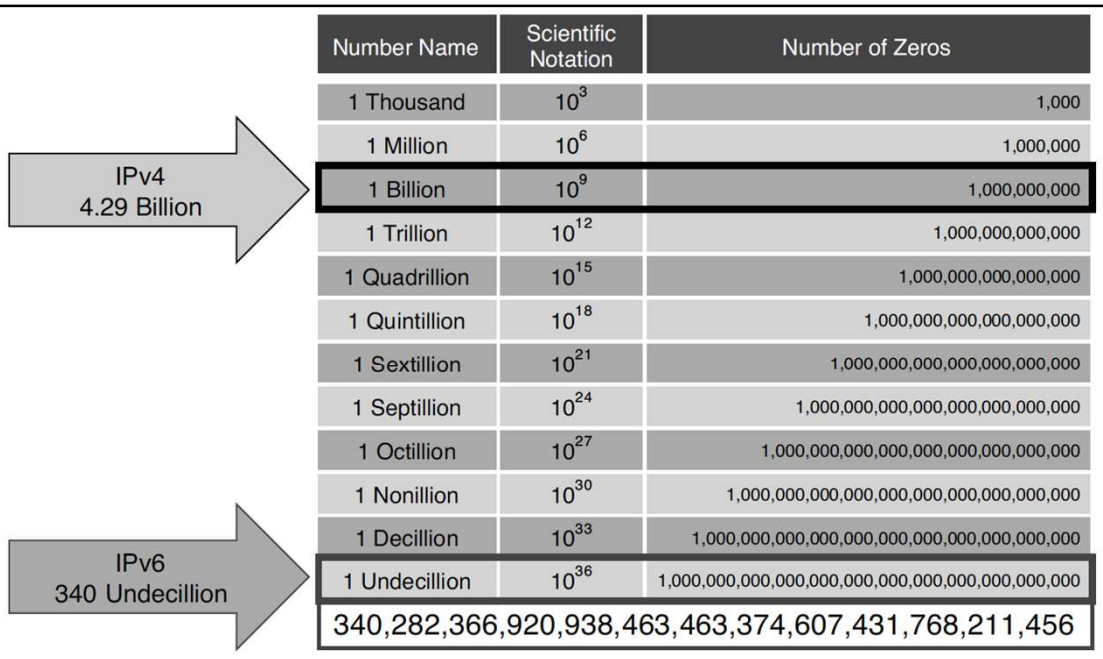
IPv6 Address Space

IPv4 provides 4 billion addresses 4,294,967,296

- IPv6 provides **340 undecillion** addresses

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

- Common analogies:
  - The number of grains of sand on Earth.
  - 10 nonillion addresses assigned to every person on Earth.
  - 3,911,873,538,269,506,102 addresses per m^2 of the surface of the planet Earth.



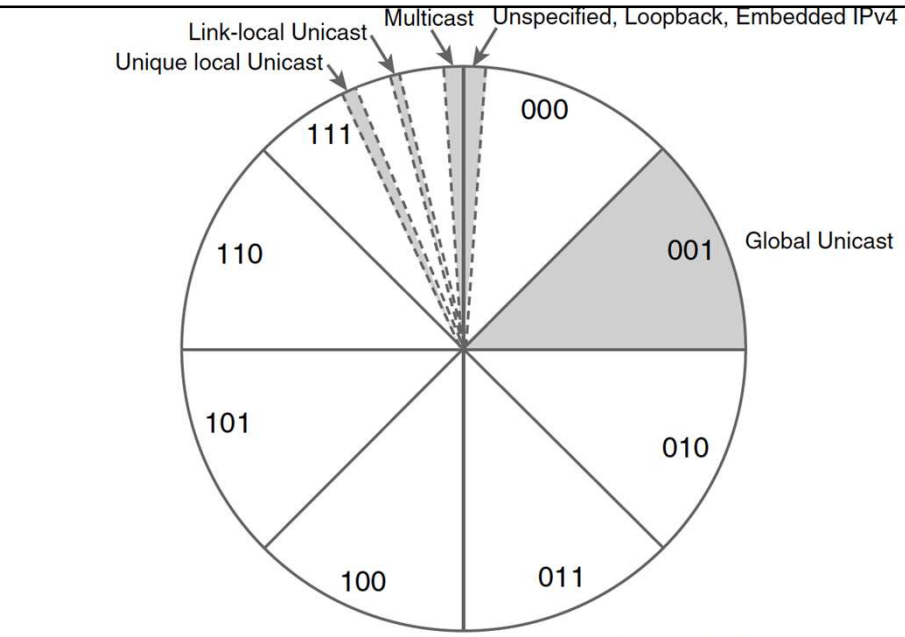
Number Name	Scientific Notation	Number of Zeros
1 Thousand	10^3	1,000
1 Million	10^6	1,000,000
1 Billion	10^9	1,000,000,000
1 Trillion	10^{12}	1,000,000,000,000
1 Quadrillion	10^{15}	1,000,000,000,000,000
1 Quintillion	10^{18}	1,000,000,000,000,000,000
1 Sextillion	10^{21}	1,000,000,000,000,000,000,000
1 Septillion	10^{24}	1,000,000,000,000,000,000,000,000
1 Octillion	10^{27}	1,000,000,000,000,000,000,000,000,000
1 Nonillion	10^{30}	1,000,000,000,000,000,000,000,000,000,000
1 Decillion	10^{33}	1,000,000,000,000,000,000,000,000,000,000,000
1 Undecillion	10^{36}	1,000,000,000,000,000,000,000,000,000,000,000,000
340,282,366,920,938,463,463,374,607,431,768,211,456		

Figure 4-4 *Powers of 10: Comparing IPv4 and IPv6 Address Space*

Table 4-5 *IANA's Allocation of IPv6 Address Space**

Leading Bits	Address	Range of First Hextet	Allocation	Fraction of Space
000x		0000 1fff		1/8
0000 0000	0000::/8	0000 00ff	Unspecified, loopback, embedded	1/256
0000 0001 through 0001 xxxx	0000::/3	0100 1fff	Reserved by IETF	Remaining 1/8
001x	2000::/3	2000 3fff	Global unicast	1/8
010x	4000::/3	4000 5fff	Reserved by IETF	1/8
011x	6000::/3	6000 7fff	Reserved by IETF	1/8
100x	8000::/3	8000 9fff	Reserved by IETF	1/8
101x	a000::/3	a000 bfff	Reserved by IETF	1/8
110x	c000::/3	c000 dfff	Reserved by IETF	1/8
111x				1/8
1110 xxxx	e000::/4	e000 efff	Reserved by IETF	1/16
1111 0xxx	f000::/5	f000 f7ff	Reserved by IETF	1/32
1111 10xx	f800::/6	f800 fbff	Reserved by IETF	1/64
1111 110x	fc00::/7	fc00 fdff	Unique local unicast	1/128
1111 1110 0	fe00::/9	fe00 fe74	Reserved by IETF	1/512
1111 1110 10	fe80::/10	fe80 febf	Link-local unicast	1/1024
1111 1110 11	fec0::/10	fec0 feff	Reserved by IETF; previously site-local (deprecated)	1/1024
1111 1111	ff00::/8	ff00 ffff	Multicast	1/256

* In this table, the "Range of First Hextet" column does not show the complete range of the address space. For example, the actual range of the global unicast address space would be 2000:: through 3fff:ffff:ffff:ffff:ffff:ffff:ffff:ffff.



The remaining portions of IPv6 address space are reserved by IETF for future use.

Figure 4-5 *IANA's Allocation of IPv6 Address Space in 1/8 Sections*

IPv6 Address Types

- Unicast
  - Global Unicast
  - Link Local
  - Loopback
  - Unspecified
  - Unique Local
  - Embeded IPv4
- Multicast
  - Well-Known
  - Transient
  - Solicited-Node
- Anycast

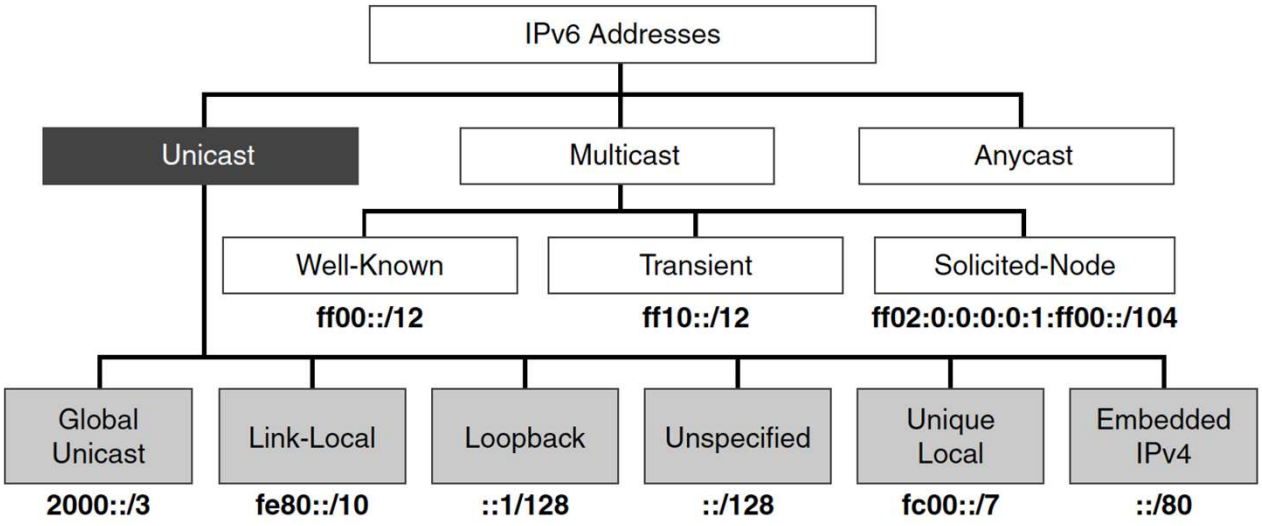


Figure 4-6 *IPv6 Address Types: Unicast Addresses*

Unicast Addresses

- **Global Unicast**
  - A routable address in IPv6 Internet (similar to public IPv4 address).
- **Link Local**
  - Used only to communicate with devices on the same link.
- Loopback
  - Not assigned to any physical interface. Used to send a packet to itself.
- Unspecified
  - Used only as a source. Indicates the absence of na IPv6 address.
- Unique Local
  - Not intended to be routable in the IPv6 Internet (similar to a private IPv4 address).
- IPv4 embeded
  - Na IPv6 address that carries na IPv4 address.

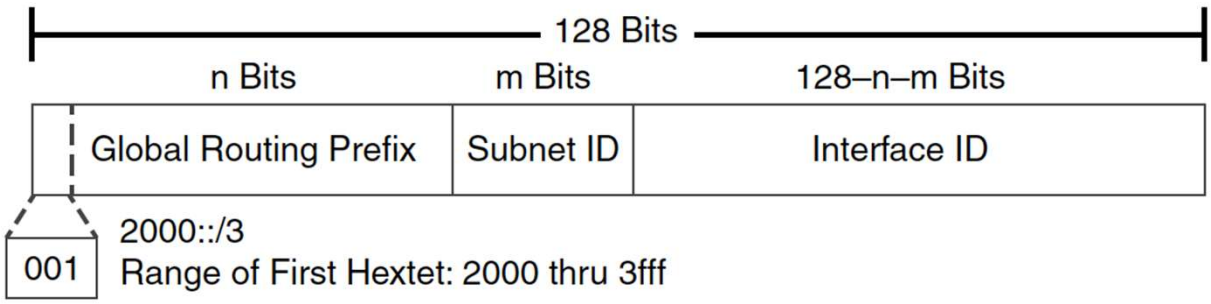


Figure 4-7 *Structure of a GUA Address*

Global Unicast Address

- Global Routing Prefix
  - The prefix (network) portion of the address assigned by the provider to the customer site.
- Subnet ID
  - A separate field for allocating subnets within the customer site.
- Interface ID
  - Identifies the interface on the subnet.

- Configuration options:
  - Manually configured
  - Address Autoconfiguration
  - DHCPv6

Example 4-1 *Viewing IPv6 Addresses on Windows and Mac OS*

```
Windows-OS> ipconfig
Ethernet adapter Local Area Connection:
   Connection-specific DNS Suffix  .  :
   ! IPv6 GUA
   IPv6 Address. . . . . . . . . . . : 2001:db8:cafe:1:d0f8:9ff6:4201:7086
   ! IPv6 Link-Local
   Link-local IPv6 Address . . . . . : fe80::d0f8:9ff6:4201:7086%11
   IPv4 Address. . . . . . . . . . . : 192.168.1.100
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   ! IPv6 Default Gateway
   Default Gateway . . . . . . . . . : fe80::1%11
                                       192.168.1.1
-------------------------------------------------------------------------------
Mac-OS$ ifconfig
en1: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
   ether 60:33:4b:15:24:6f
   ! IPv6 Link-Local
   inet6 fe80::6233:4bff:fe15:246f%en1 prefixlen 64 scopeid 0x5
   inet 192.168.1.111 netmask 0xffffff00 broadcast 192.168.1.255
   ! IPv6 GUA
   inet6 2001:db8:cafe:1:4bff:fe15:246f prefixlen 64 autoconf
   media: autoselect
   status: active
```

Link-Local Unicast Address

- To be na IPv6-enabled device, a device must have na IPv6 link-local address. It doesn't have to have a GUA.
- Link-local addresses are not routable. Routers do not forward packets with a link-local address.
- Only have to be unique on the link. It is common for a device to use the same link-local address on different interfaces.
- There can be only one link-local address per interface.
- Devices can use Duplicate Address Detection (DAD) to determine whether or not the link-local address is unique (ICMPv6 Neighbor Discovery).

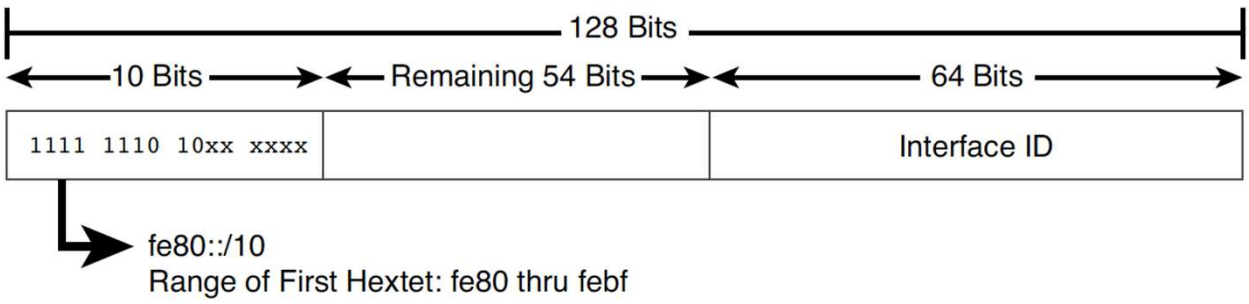


Figure 4-8 *Structure of a Link-Local Unicast Address*

Link-Local Unicast Address

- Some ways IPv6 devices use link-local addresses:
  - Upon startup, before obtaining a GUA, used as a source address to comunicate with other devices on the network, including the local router.
  - Devices use the router's link-local address as their default gateway address.
  - Routers Exchange IPv6 dynamic routing protocol messages from their link-local address.
  - IPv6 routing table entries populated from dynamic routing protocols use link-local addresses as the next-hop address.

Link-Local Unicast Address

- Configuration options:
  - Dynamically (automatically) created upon startup.
  - Manually configured.

Loopback Address

- Used by a node to send an IPv6 packet to itself, typically when testing the TCP/IP stack.

- Main characteristics:
  - Cannot be assigned to a physical interface.
  - A packet with a loopback address (source or destination) should never be sent beyond the device.
  - A router can never forward a packet with a destination address that is a loopback address.
  - The device must drop a packet received on na interface if the destination address is a loopback address.

Table 4-6 *IPv6 Loopback Address Representations*

Representation	IPv6 Loopback Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0001
Leading 0s omitted	0:0:0:0:0:0:0:1
Compressed	::1

Unspecified Address

- Main characteristics:
  - It is an all-0s address.
  - Indicates the absence of an address.
  - It cannot be assigned to a physical interface.
  - It cannot be used as a destination address.
  - A router will never forward a packet that as an unspecified source address.

One example:

Used as a source address in ICMPv6 DAD, a process used by a device to ensure that its unicast address is unique in the local-link.

Table 4-7 *IPv6 Unspecified Address Representations*

Representation	IPv6 Unspecified Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0000
Leading 0s omitted	0:0:0:0:0:0:0:0
Compressed	::

Unique Local Address

Main characteristics:

- They can be used “just like” GUAs.
- They can be used for devices that never need access to or from the global Internet.
- They allow sites to be privately interconnected without address conflicts or without requiring addressing renumbering.
- They are independente of any ISP and can be used within a site even without having Internet connectivity.

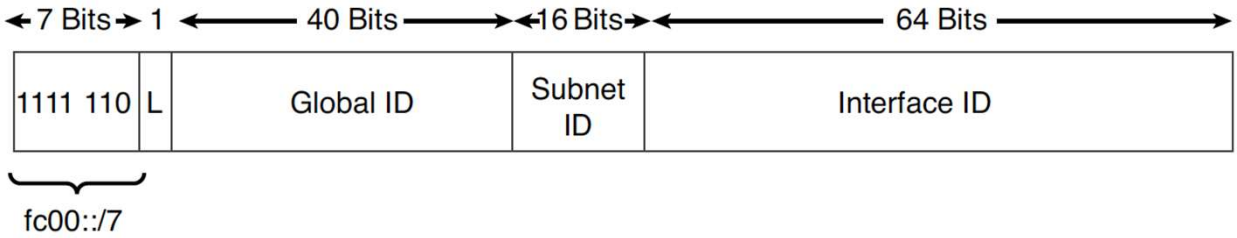


Figure 4-9 *Structure of a Unique Local Unicast Address*

Table 4-8 *Range of Unique Local Unicast Addresses*

Unique Local Unicast Address (Hexadecimal)	Range of First Hextet	Range of First Hextet in Binary
fc00::/7	fc00 to	**1111 110**0 0000 0000 to
	fdff	**1111 110**1 1111 1111

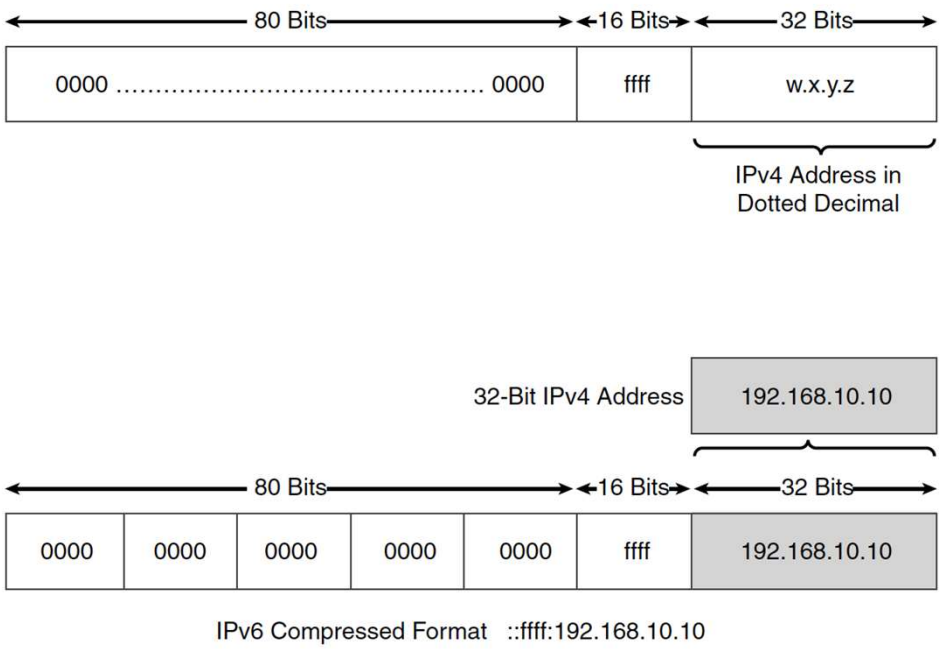


Figure 4-10 *IPv4-Mapped IPv6 Address*

Table 4-9 *IPv4-Mapped IPv6 Address Representations*

Representation	IPv4-Mapped IPv6 Address
Preferred	0000:0000:0000:0000:0000:0000:ffff:192.168.10.10
Leading 0s omitted	0:0:0:0:0:0:ffff:192.168.10.10
Compressed	::ffff:192.168.10.10