

Introduction to IPv6

Structure and function of IPv6 addresses

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Collaborative Project

- India Internet Engineering Society (IIEsoc) and Industry Network Technology Council (INTC)
- Funding: Grant from ISIF Asia
- Thank you!



<https://www.iiesoc.in/>

<https://industry.netcouncil.org/>

Vision

Multi-year project: IPv6 deployment at enterprises.

Collaboration with American Registry for Internet Numbers (ARIN)

- Provide training,
- Analysis of security and application conversion,
- Help enterprises plan their IPv6 deployment.

Classes

- Introduction to IPv6 : Feb 4, 2021
- Lab: IPv6 basics : Feb 11, 2021
- Neighbor Discovery: March 4, 2021
- Lab: Neighbor Discovery: March 18, 2021
- IPv6 Address Planning: April 8, 2021
- Lab: IPv6 Address Planning: April 15, 2021
- IPv6 Transition Mechanisms: May 6, 2021
- Lab: IPv6 Transition Mechanisms: May 13, 2021

- DHCPv6: June 3, 2021
 - Lab: DHCPv6: June 10, 2021
 - IPv6 and Cloud: June 17, 2021
 - Lab: IPv6 and Cloud: June 24, 2021
 - Introduction to IPv6 Security July 8, 2021
- The next sessions are sponsored by a generous grant from ARIN.
- Trace Reading: August 12, 2021
 - Troubleshooting: August 19, 2021

A few words about me

- President: Industry Network Technology Council
- Founder & CEO: Inside Products, Inc.
- Advisory Board: India Internet Engineering Society
- RFCs: RFC8250 (Embedded performance and diagnostics for IPv6) and others
- Product developer (OEMed by IBM and others)
- Working with IPv6 for 15 years
- Working with network management, diagnostic, performance issues at large brick-and-mortar enterprises for over 30 years



Agenda

- Introduction to addressing
- Overview of Binary, Hexadecimal, decimal addressing concepts
- Zero compression
- Address changes from IPv4 to IPv6
- Public and private addresses
- IPv6 Prefixes
- IPv6 Address Structure
- IPv6 Interface ID
- IPv6 Addressing and Address Allocation Methods (stateless, stateful)
- Address types, unicast, multicast, anycast
- Address categories: global, site local, link local
- Unique Local Unicast addresses
- Special addresses (loopback, unspecified, IPv4 mapped IPv6)
- Broadcast address elimination

Network Addresses

Each one needs one!



Let's look at an address

What is this?



1600 Pennsylvania Ave
NW Washington, DC 20500



Private vs. Public Addresses



Public:

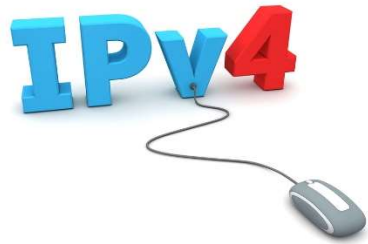
1600 Pennsylvania Ave
NW, Washington, DC 20500



Private:

P.O. Box 27624
Washington, D.C. 20500

Sample IPv4 Addresses

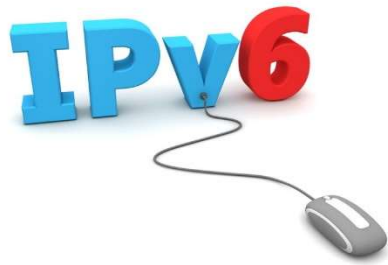


192.168.1.1

10.12.15.201

201.23.5.104

Sample IPv6 Addresses



3FFE:52AB:2:ABC:123:56:DE:1
2001::2:ABC:123
FE80::1234:1
FF01::2
::

Sample Private Addresses

192.168.1.1

- IPv4
- Private

FE80::1234:1

- IPv6
- Private (limited)

Sample Public Addresses

201.23.5.104

- IPv4
- Public

2001::2:ABC:123

- IPv6
- Public

TCP/IP Network

Addresses



192.168.1.100
2001:5c0:8fff:3::100



192.168.1.101
2001:5c0:8fff:3::101



192.168.1.102
2001:5c0:8fff:3::102

Addressing Concepts

Decimal notation (IPv4)

1.2.3.4

Hexadecimal notation (IPv6)

00 - FF

Binary

1 byte = 8 bits

Important IPv6 Prefix Notations

/8

```
11111111xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
```

00xx::
FFxx::

/16

```
1111111111111111xxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
```

0000::
FFFF::

/32

```
1111111111111111.1111111111111111.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
```

0000:0000::
FFFF:FFFF::

/48

```
1111111111111111.1111111111111111.
1111111111111111xxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
```

0000:0000:0000::
FFFF:FFFF:FFFF::

/56

```
1111111111111111.1111111111111111.
1111111111111111.1111111xxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
```

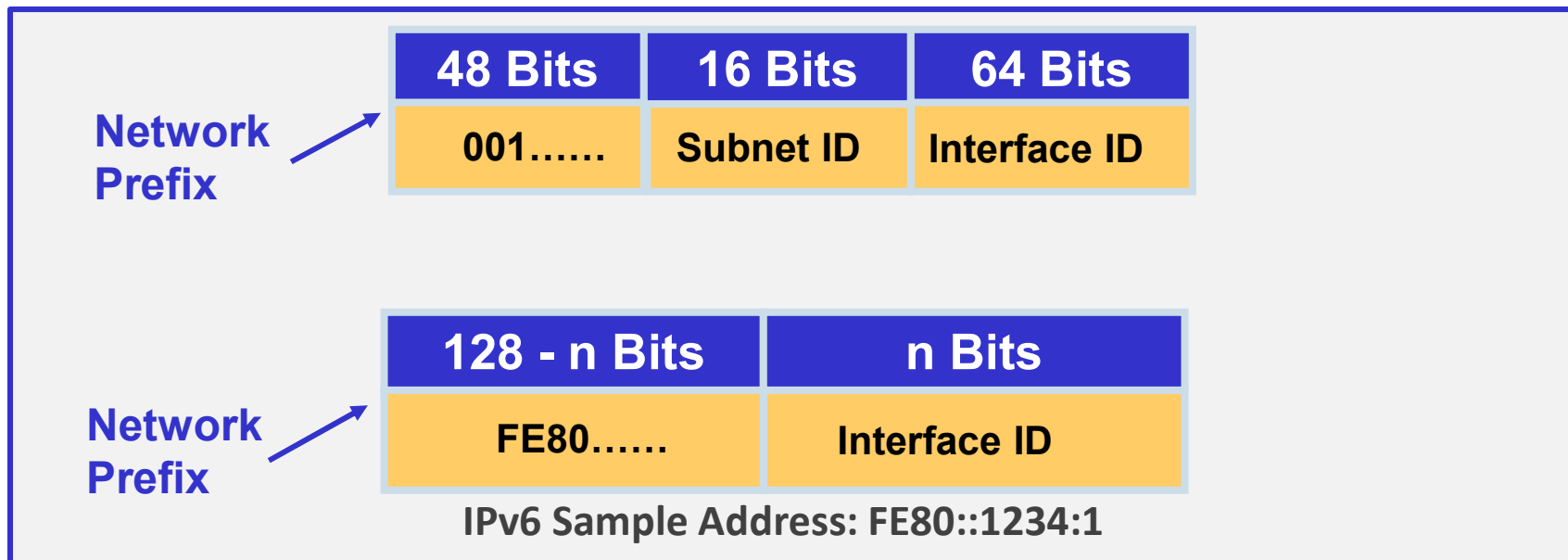
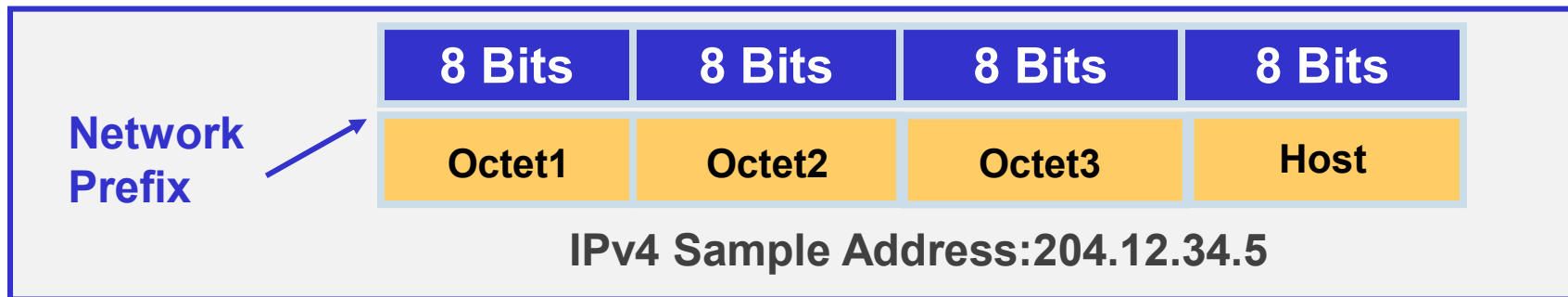
0000:0000:0000:00xx::
FFFF:FFFF:FFFF:FFxx::

/64

```
1111111111111111.1111111111111111.
1111111111111111.1111111111111111.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx.
```

0000:0000:0000:0000::
FFFF:FFFF:FFFF:FFFF::

IPv4 / IPv6 Address Structure



IPv6 Address Representation

IPv4 Address : 32 bits – IPv6 address : 128 bits

- IPv6 address : 8 sections of 4 hex digits (16 bits)
 - 1111:2222:3333:4444:5555:6666:7777:8888
- Zero-compression
 - 1111:2222:**0:0**:5555:6666:7777:8888
 - 1111:2222::**5555:6666:7777:8888**
- Prefix length
 - 1111:2222::**5555:6666:7777:8888 /64**
- Prefix alone
 - 1111:2222::**/64**

Zero Compression

- IPv6 addresses are zero compressed.
- Double colon can appear only once.
- Zero compression of special addresses.

805B:2D9D:DC28:0:0:FC57:0:0



805B:2D9D:DC28::FC57:0:0

or

805B:2D9D:DC28:0:0:FC57::

FF00:4501:0:0:0:0:0:32

FF00:4501::32

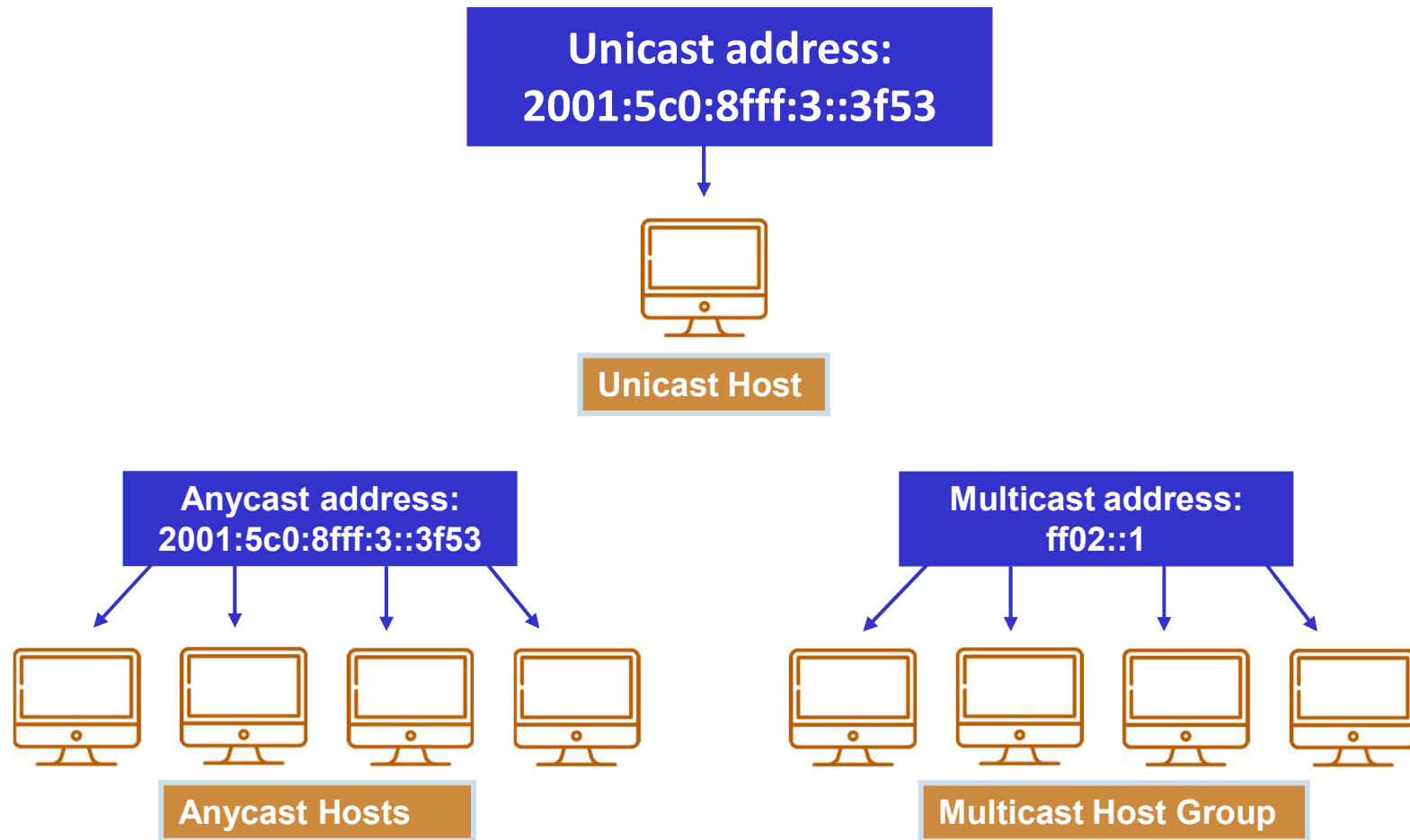
0:0:0:0:0:0:0:1

::1

0:0:0:0:0:0:0:0

::

IPv6 Address Types



Anycast addresses appear the same as unicast addresses

Importance of IPv6 Network Prefix

- First part of network prefix important!
- Example: **2001**:5c0:8fff:3::3f53
- Learn:
 - Can you go out on the internet with it,
 - What devices can you talk to,
 - Is it for special function.

FE80 = Link Local

FFxx = Multicast

2001 = Global Unicast

0000 = Special

Addressing Changes

- No broadcast addressing in IPv6
- IPv6 multicast addressing used

IPv4 Broadcast Addresses

~~192.168.1.255
255.255.255.255~~

Addressing Planning

- IPv6 address planning is different from IPv4
- IPv4: 0 address is network, .1 address is gateway, 255 is broadcast (generally)
- IPv4 and IPv6 subnet structure is different
- Basically, you do not lose three addresses per subnet

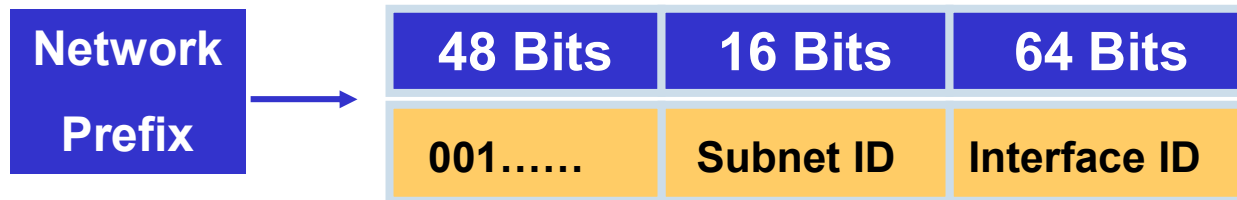
IPv4 Subnet

192.168.1.1
(network)

192.168.1.255
(broadcast)



Types of Unicast Addresses



Global Unicast Address

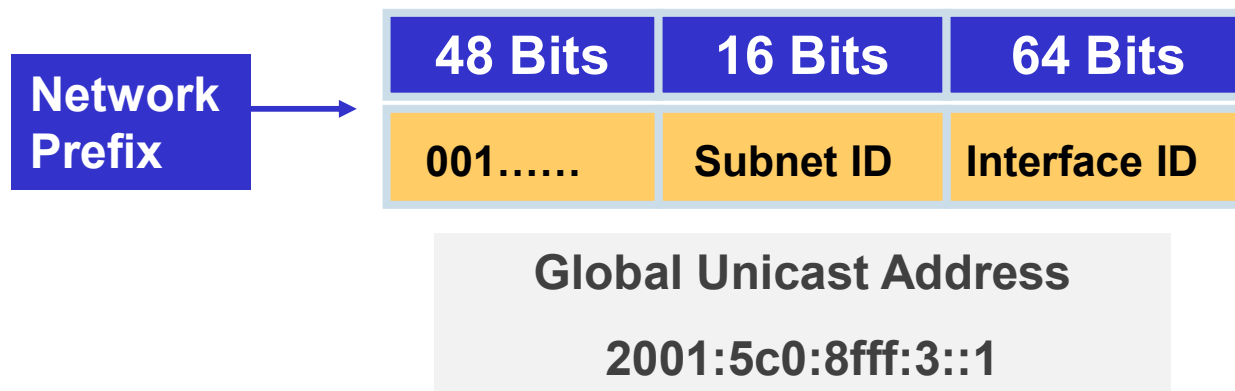
2001:5c0:8fff:3::3f53

Types of IPv6 unicast addresses:

- global unicast,
- link-local unicast, and
- site-local unicast.

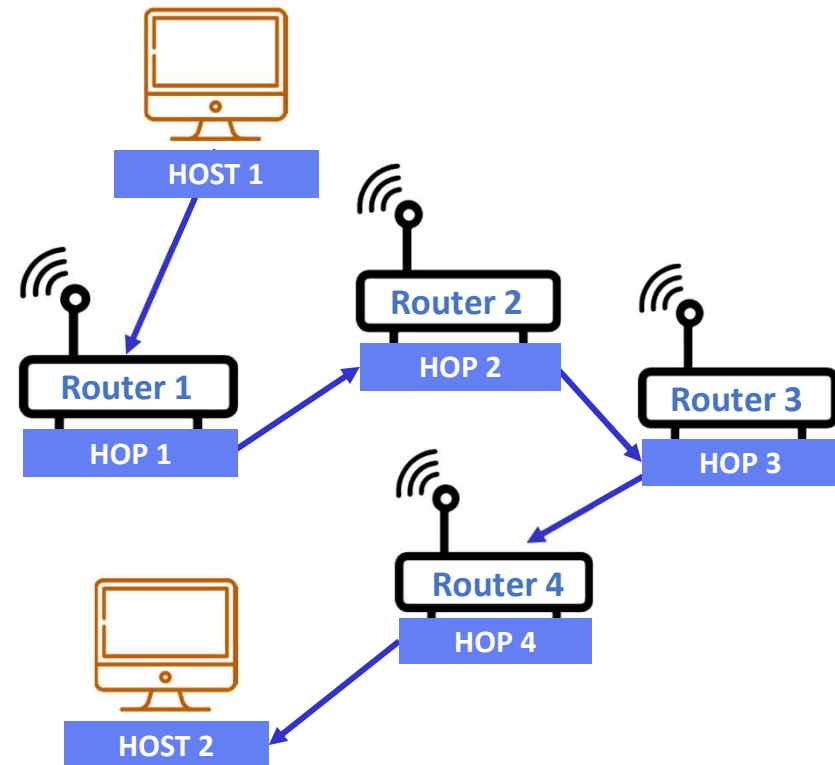
IPv6 Global Unicast Address

- Global unicast address: 48-bit network prefix, 16-bit subnet ID, 64 bit interface ID
- Router interface: 64 bits
- Current global unicast address allocation: 2000::/3 (binary 001)



IPv6 Global Unicast Address

- IPv6 global unicast address (like) IPv4 global unicast address
- Plan network in hierarchy
- Limit routing table entries



Windows IP Configuration

Ethernet adapter Ethernet:

Media State : Media disconnected
Connection-specific DNS Suffix . :

Wireless LAN adapter Local Area Connection* 2:

Media State : Media disconnected
Connection-specific DNS Suffix . :

Wireless LAN adapter Local Area Connection* 13:

Media State : Media disconnected
Connection-specific DNS Suffix . :

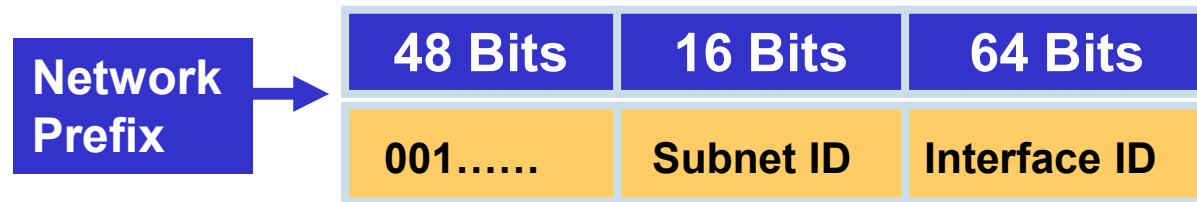
Wireless LAN adapter Wi-Fi:

Connection-specific DNS Suffix . :
IPv6 Address. : 2601:642:c201:bd::478d
IPv6 Address. : 2601:642:c201:bd:fcde:f576:4c8d:11f7
Temporary IPv6 Address. : 2601:642:c201:bd:c5f4:62a3:c9cd:500b
Link-local IPv6 Address : fe80::fcde:f576:4c8d:11f7%9
IPv4 Address. : 10.0.0.118
Subnet Mask : 255.255.255.0
Default Gateway : fe80::5a19:f8ff:fef4:a74e%9
10.0.0.1

Ethernet adapter Bluetooth Network Connection:

Media State : Media disconnected
Connection-specific DNS Suffix . :

Global Unicast Network Prefix



Global Unicast Address

2001:5c0:8fff:3::3f53

- Network Prefix: First part of an IPv6 address.
- Best practices: 48 bits

Global Unicast Subnet Prefix

- Subnet prefix: standard is 16 bits
- 65,535 subnets



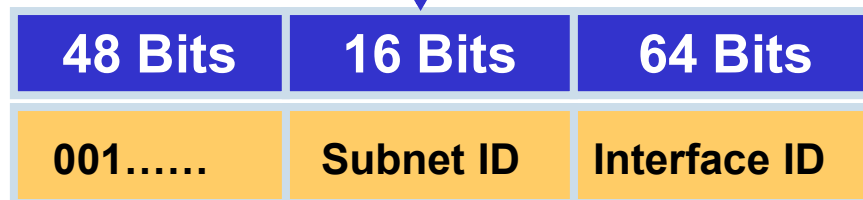
| | | |
|----------------|----------------|----------------|
| 48 Bits | 16 Bits | 64 Bits |
| 001..... | Subnet ID | Interface ID |

Global Unicast Address

2001:5c0:8fff:0003::35f3

Global Unicast Interface ID (IID)

- IID is for an interface
- IID must be unique
- IID: standard is 64 bits



Global Unicast Address

2001:5c0:8fff:3::3f53

EUI-64 Format

- IID: based on the link-layer (MAC) address
- EUI-64 format : OUI field + FFFE + Serial Number

Example on Windows PC: result of IPConfig

Ethernet adapter Local Area Connection:

Description : Realtek Family Fast Ethernet NIC

Physical Address : 00-11-D8-39-29-2B

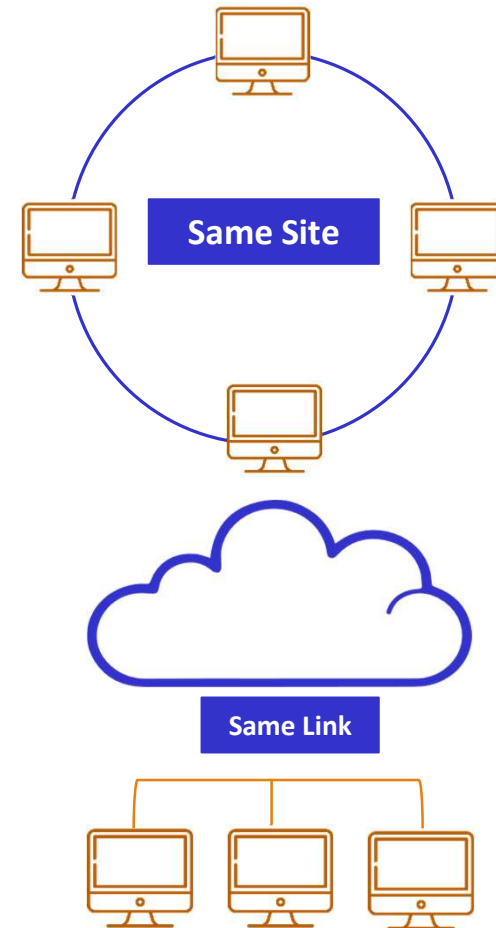
Autoconfiguration Enabled . : Yes

IP Address : fe80::211:d8ff:fe39:292b%4

IPv6 Private Addresses

- Link-local or site-local
- Never routed outside a company or link
- Start with hex FE then 8 to F (1111 1110 1)
- Most common: FE80 (link-local)

FE8n – FEFn = Private Addresses



Link-Local Unicast Address

- IPv6 devices always have link-local address
- IPv6 devices use link-local to communicate with 'on-link' devices
- IPv6 routers must not forward link-local packets

| 10 Bits | 54 Bits | 64 Bits |
|------------|---------|--------------|
| 1111111010 | zeroes | Interface ID |

Sample Link-Local Address

fe80::211:d8ff:fe39:292b

Link-Local Address Explained

- Why do you need link-local addresses?
- How do you get a link-local address?

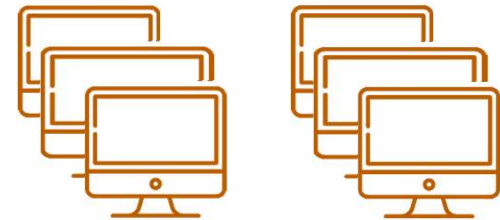
Who am I? IPv6 Stateless autoconfiguration



FE8n - FEBn = Link Local

Site-Local Unicast Addresses

- IPv4 site-local private addresses = 10.0.0.0/80.0/12 or 192.168.0.0/16
- Site-local address + NAT used for topology hiding
- **IPv6 site-local unicast deprecated**
- Site scope multicast still available



FECn - FEFn = Site Local

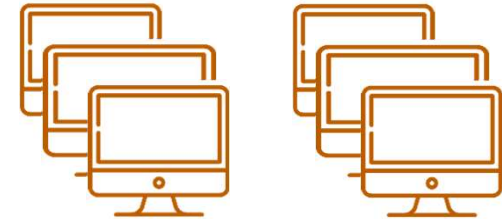
| IPv6 Prefix | Allocation | Reference |
|-------------|----------------------|-----------|
| 0000::/8 | Reserved by IETF | [RFC3513] |
| 0100::/8 | Reserved by IETF | [RFC3513] |
| 0200::/7 | Reserved by IETF | [RFC4048] |
| 0400::/6 | Reserved by IETF | [RFC3513] |
| 0800::/5 | Reserved by IETF | [RFC3513] |
| 1000::/4 | Reserved by IETF | [RFC3513] |
| 2000::/3 | Global Unicast | [RFC3513] |
| 4000::/3 | Reserved by IETF | [RFC3513] |
| 6000::/3 | Reserved by IETF | [RFC3513] |
| 8000::/3 | Reserved by IETF | [RFC3513] |
| A000::/3 | Reserved by IETF | [RFC3513] |
| C000::/3 | Reserved by IETF | [RFC3513] |
| E000::/4 | Reserved by IETF | [RFC3513] |
| F000::/5 | Reserved by IETF | [RFC3513] |
| F800::/6 | Reserved by IETF | [RFC3513] |
| FC00::/7 | Unique Local Unicast | [RFC4193] |
| FE00::/9 | Reserved by IETF | [RFC3513] |
| FE80::/10 | Link Local Unicast | [RFC3513] |
| FEC0::/10 | Reserved by IETF | [RFC3879] |
| FF00::/8 | Multicast | [RFC3513] |

IPv6 Address Space Allocations



DeFacto Site-Local Unicast

- ULA (Unique Local Unicast) addresses
- Large address space!
- Conflicts?



FC00:: /7 = ULA

IPv6 Reserved Addresses

- Defined by the IETF

Includes:

- Unspecified,
- Loopback and
- IPv4 Embedded addresses

:: /8 = Reserved

See:

<http://www.iana.org/assignments/ipv6-address-space/ipv6-address-space.xml>

IPv6 Unspecified Address

- Who am I?
- IPv6 *unspecified address*.
- Stateless Autoconfiguration
- Represented as ::

0000 = Unspecified (::)

Who am I? (IPv4)

DHCP



Who am I? (IPv6)

Stateless Autoconfiguration

IPv6 Stateless Autoconfiguration

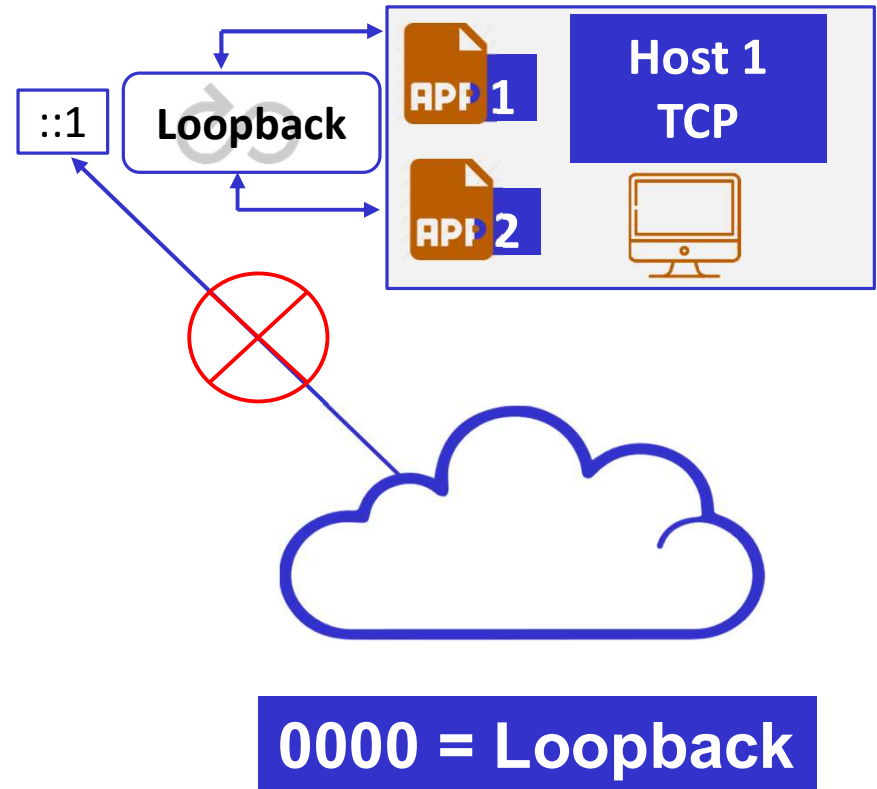
The image shows a Wireshark network traffic capture. The filter is set to 'icmpv6'. The packet list shows several ICMPv6 messages, with packet 40 selected. The packet details pane shows the following information:

- Frame 40 (78 bytes on wire, 78 bytes captured)
- Ethernet II, Src: 192.168.1.102 (00:13:d3:8d:61:fb), Dst: IPv6-Neighbor-Discovery_ff:8d:61:fb (33:33:ff:8d:61:fb)
 - Destination: IPv6-Neighbor-Discovery_ff:8d:61:fb (33:33:ff:8d:61:fb)
 - Source: 192.168.1.102 (00:13:d3:8d:61:fb)
 - Type: IPv6 (0x86dd)
- Internet Protocol Version 6
 - Version: 6
 - Traffic class: 0x00
 - Flowlabel: 0x00000
 - Payload length: 24
 - Next header: ICMPv6 (0x3a)
 - Hop limit: 255
 - Source address: ::
 - Destination address: ff02::1:ff8d:61fb
- Internet Control Message Protocol v6
 - Type: 135 (Neighbor solicitation)
 - Code: 0
 - Checksum: 0xe302 [correct]
 - Target: fe80::213:d3ff:fe8d:61fb

A red circle highlights the source IP address '192.168.1.102' in the Ethernet II section. A red arrow points to the target IPv6 address 'fe80::213:d3ff:fe8d:61fb' in the ICMPv6 section.

Loopback Address

- IPv6 loopback address is 0:0:0:0:0:0:0:1 (:::1)
- Acts like IPv4 loopback.
 - Can't be assigned to physical interface.
 - Used by local applications
 - Can't travel outside node
 - Can't be forwarded by router



IPv4 Addresses in IPv6

- From reserved space (0000::/8)
- IPv4 Mapped (Embedded) IPv6 Addresses.
- Last 32 bits = IPv4 address
- Shown in IPv4 notation
- May see on IBM mainframe applications



IPv4 Mapped IPv6 Address

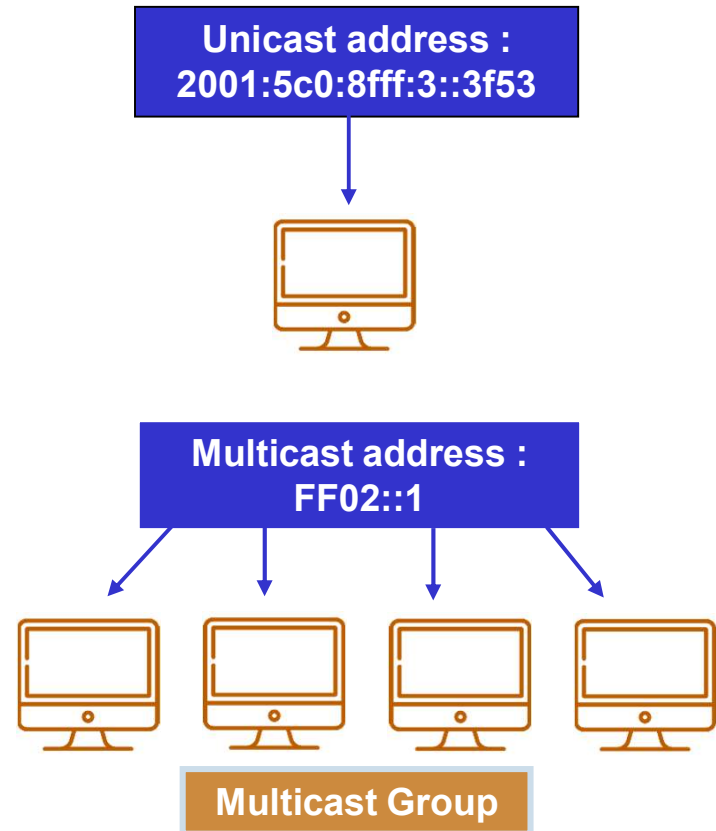
::ffff:192.168.0.1

~~IPv4 Compatible IPv6 Address~~

~~::192.168.0.1~~

IPv6 Multicast

- In IPv6, multicasting used widely
- Multicast is like a newsletter subscription.
- Devices belong to a multicast group
- IPv4 multicast uses Class D range: (224.xx.xx.xx – 239.xx.xx.xx)



IPv6 Multicast Scope

- IPv6 multicast addresses start with FF.
- Last 4 bits is scope. (Ex. FF01, FF02, etc).
- FF01:: means on same interface
- FF02:: means on same link
- FF05:: means in the same site
- FF0E:: means in the Internet.

(From RFC 4291)

Common IPv6 Multicast Groups

- Multicast addresses are registered with the Internet Assigned Numbers Authority (IANA).

See:

<http://www.iana.org/assignments/ipv6-multicast-addresses/ipv6-multicast-addresses.xml>

| <u>IPv6 multicast address</u> | <u>Description</u> |
|-------------------------------|--|
| FF02::1 | The all-nodes address |
| FF02::2 | The all-routers address |
| FF02::5 | The all-Open Shortest Path First (OSPF) routers address |
| FF02::6 | The all-OSPF designated routers address |

IPv6 Address Summary

- IPv6 is more than a bigger address!
- Many changes to protocol.

2001:5c0:8ff:ffe::1

2001::11:22:33:44

ff02::1



fe80::211:d8ff:fe39:292b

fe80::192:168:1:100

fe80::169.254.1.100

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Next Steps

- INTC Survey: Help Enterprise Advisory Council to decide on most important topics:

<https://www.surveymonkey.com/r/INTC-EACSurvey>

- Call for Participation: Enterprise IPv6 Survey

<https://www.surveymonkey.com/r/EnterpriseIPv6CallForParticipation>

- Call for Participation: Universities

<https://www.surveymonkey.com/r/UniversityIPv6CallForParticipation>



Questions?

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