IPv6:: It's Happening!

CISCO Live!

Nathan Sherrard
Systems Architect

BRKIPV-2191

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1. Find this session in the Cisco Live Mobile App
2. Click "Join the Discussion"
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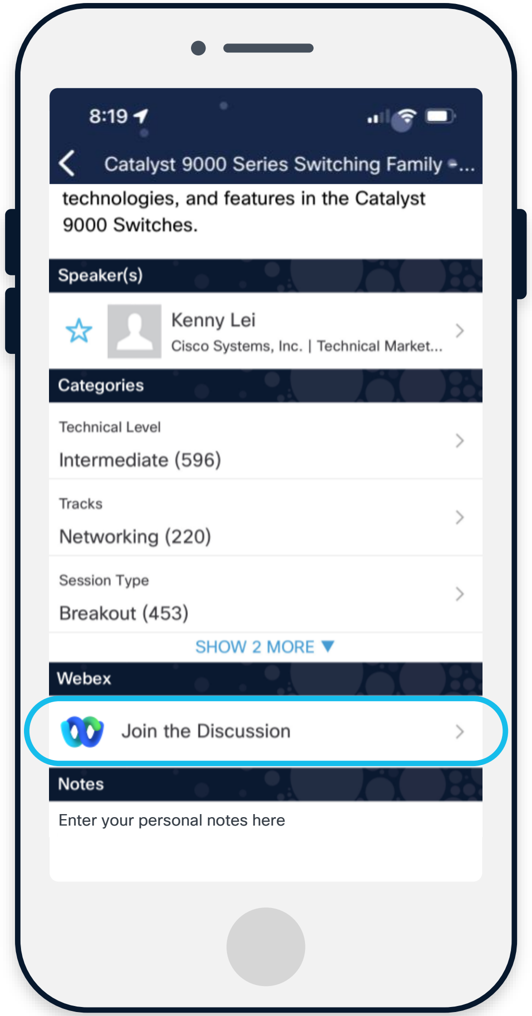
4. Enter messages/questions in the Webex space

Webex spaces will be moderated by the speaker until June 13, 2025.



FULL CONFERENCE IT LEADERSHIP

IPv6:: It's Happening! - BRKIPV-2191

Nathan Sherrard, Systems Architect, Cisco - **Distinguished Speaker**

You are a Speaker **Tuesday, Jun 10 | 11:00 AM - 12:30 PM PDT**

IPv6 has had a long and winding history, with many organizations ignoring it. Yet in recent years its use has exploded, and we are now at a point where everyone needs to take it seriously and get ready for an IPv6-only future. If you're looking at the steps toward enabling IPv6, and are wondering where and how to start, this is the session for you. We will look at recent adoption trends and government mandates that are forcing the issue, do a walkthrough on the protocol itself, and finally explore some best practices around addressing plans and transition technologies. This session is targeted for enterprise, commercial, and public sector customers who are only just beginning their IPv6 adoption. We will not be discussing issues relating to service provider and mobile network providers. No IPv6 knowledge is required to attend, though basic familiarity with IPv4 networking is assumed. If you attended the TECIPV Technical Seminars, you do not need to attend this session.

Session Type: Breakout

Technical Level: Intermediate

Technology: IPv6

Track: Networking

Agenda

Introduction

State of the Industry

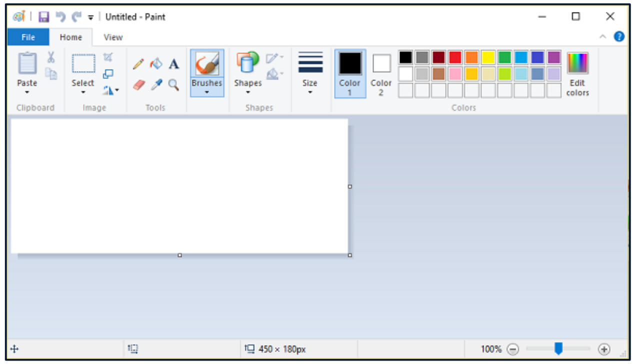
Protocol Primer

Addressing Plans

Transition Technologies

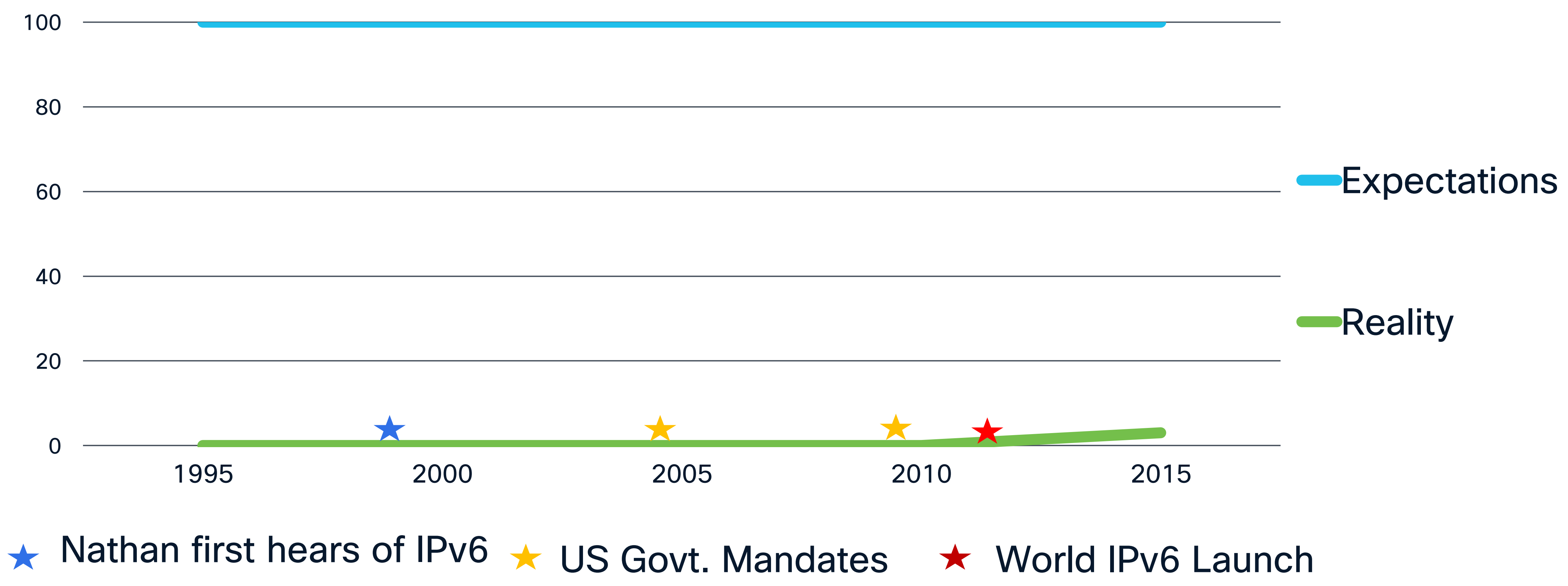
Next Steps

About Nathan



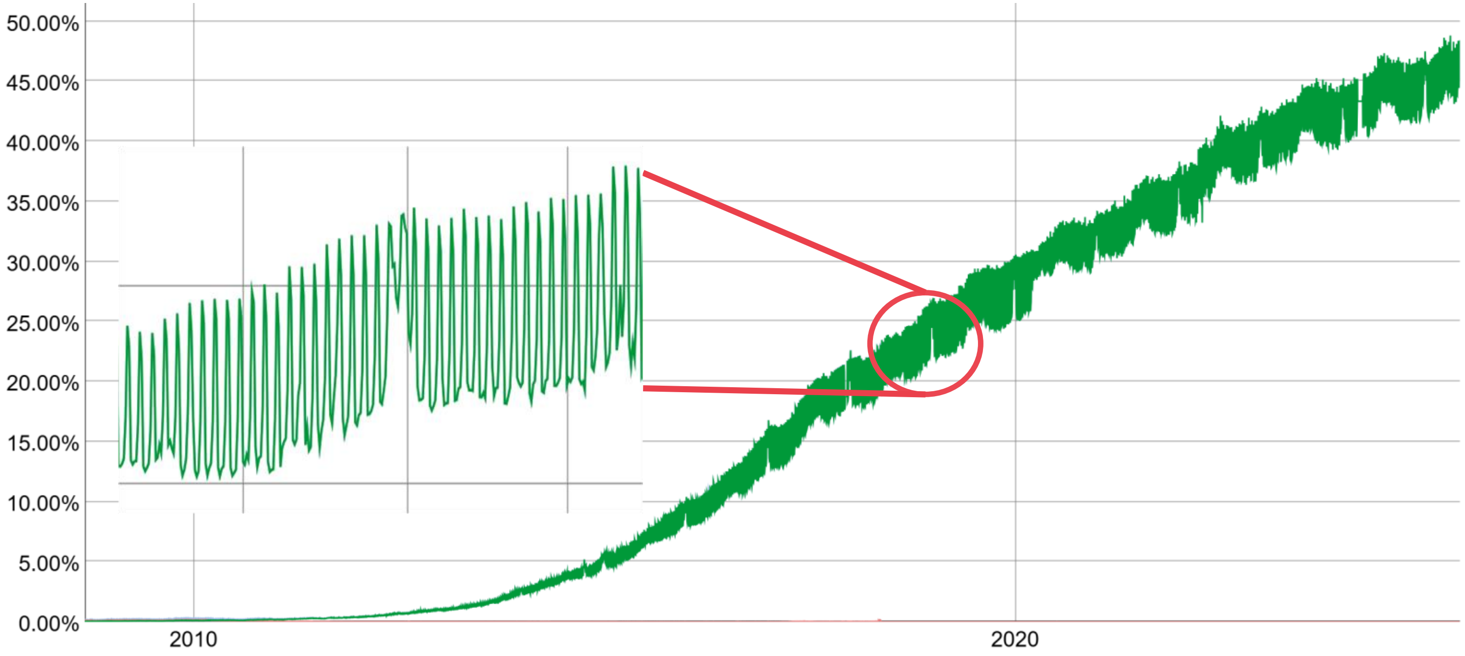
IPv6::
State of the Industry

IPv6 Adoption

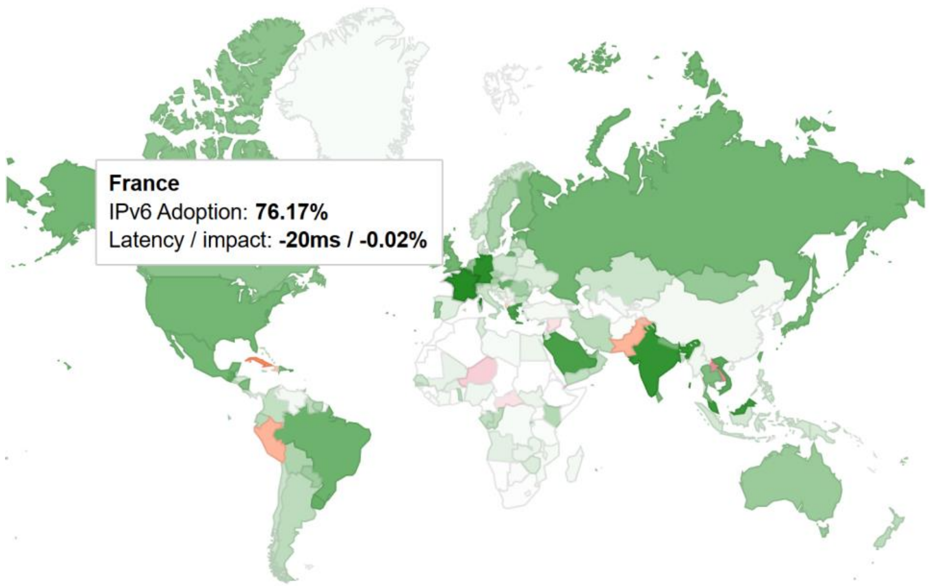


Global IPv6 Stats

Google Global Traffic %

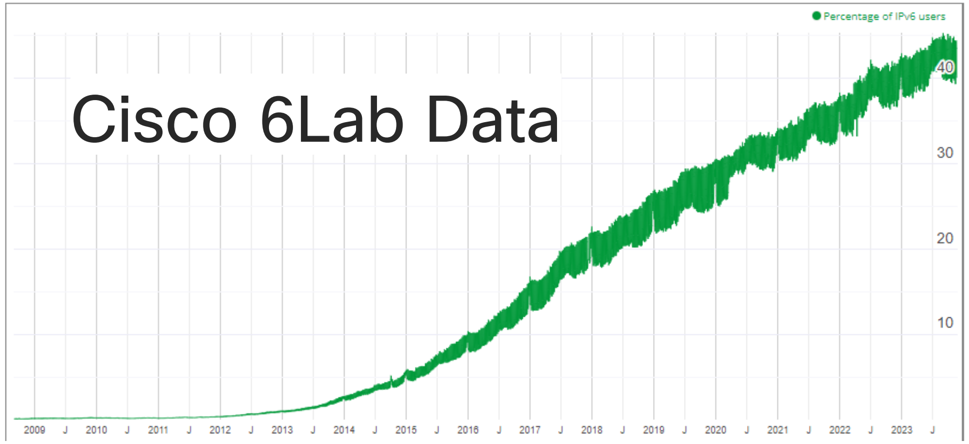


Google Per-country adoption

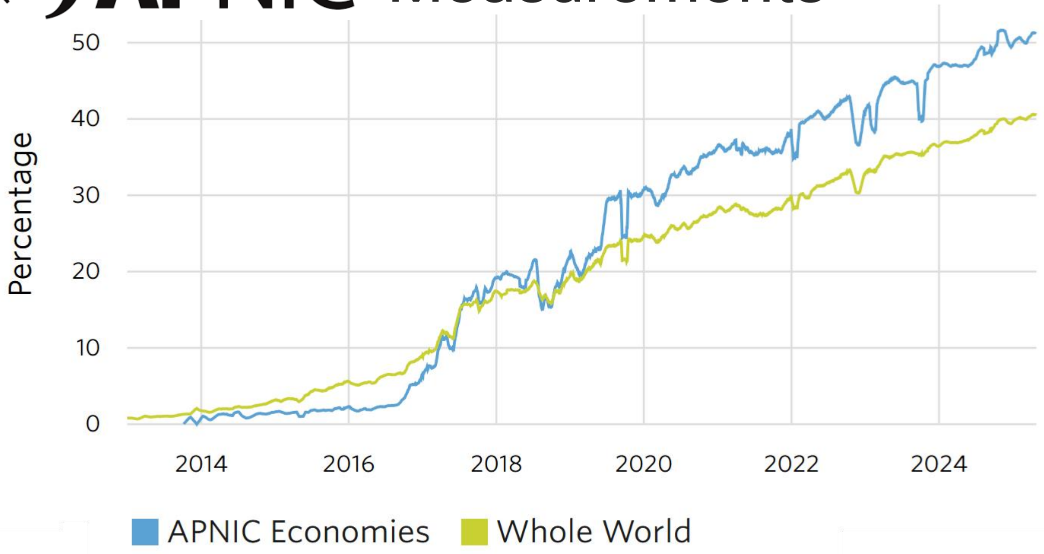


https://www.google.com/intl/en/ipv6/statistics.html

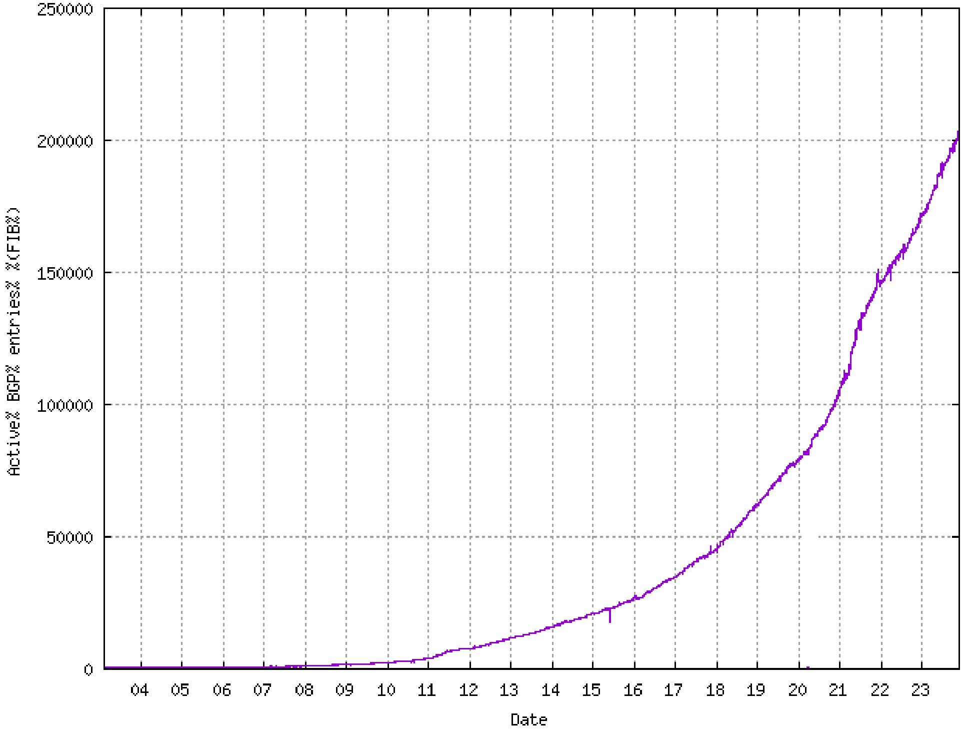
Global IPv6 Stats



APNIC Measurements



IPv6 Prefixes in Global Table



https://6lab.cisco.com/stats/cible.php?country=world&option=users
https://www.cidr-report.org/v6/as2.0/#General_Status
https://blog.apnic.net/2025/04/23/ipv6-capability-reaches-50-in-the-asia-pacific-region/

Global IPv6 Stats

Facebook US: 61%

Akamai US: 52%

Cisco Live US: 47%

Cisco Live Melbourne: 54%

Cisco Live EMEA (external): 51%

Cisco Live EMEA (internal): 76%

PNLNMS-1035

https://www.facebook.com/ipv6/?tab=ipv6_country
https://www.akamai.com/internet-station/cyber-attacks/state-of-the-internet-report/ipv6-adoption-visualization

State of Affairs – pre-2012 (World IPv6 Launch)

A Vicious Cycle

https://commons.wikimedia.org/wiki/File:Mexican_Standoff.jpg (Author: Martin SoulStealer). This file is licensed under the Creative Commons Attribution 2.0 Generic license.

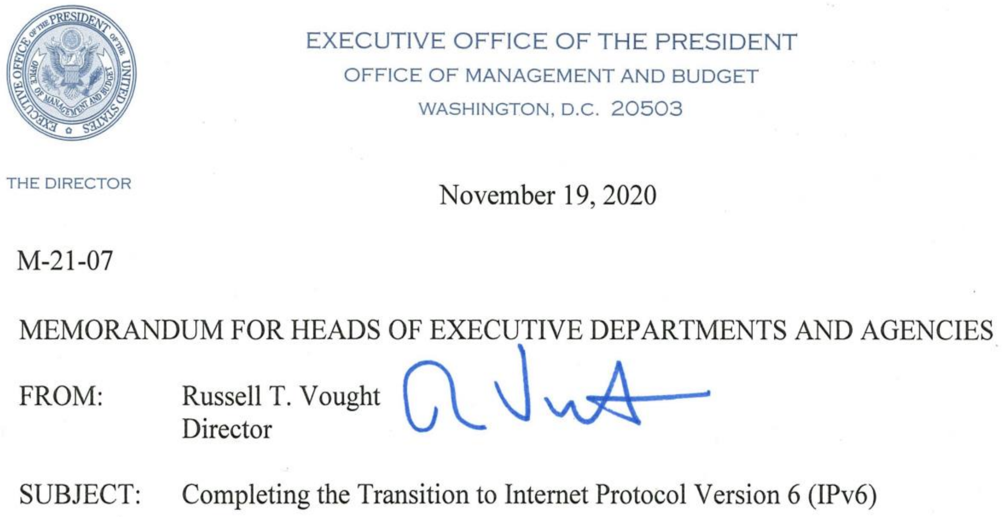
Driving Factors

- IPv4 address exhaustion
  - Limited availability / costly
  - NAT use … is complicated
- More IPv6 support
  - Clients
  - Networks
  - Web Content
  - Cloud Providers
  - Standards
- Mobile Devices, IOT, Containers
- Organizational mandates
- Alternate Business Models

https://commons.wikimedia.org/wiki/File:US_Navy_110519-N-VA590-457_Sailors_participate_in_the_three-person,_four-legged_race_during_Sports_Day_at_Nong_Prue_Municipality_Sports_Field.jpg
This image was released by the United States Navy with the ID 110519-N-VA590-457

IPv6 2021 OMB Memorandum

- “The strategic intent is for the Federal government to deliver its information services, operate its networks, and access the services of others using **only IPv6**.”
- Regarding **dual-stack**: “in recent years it has become clear that this approach is overly complex to maintain and unnecessary.”



EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

THE DIRECTOR

November 19, 2020

M-21-07

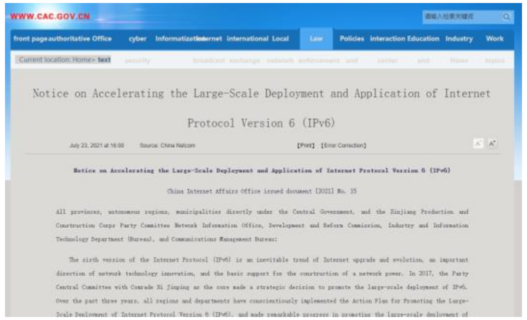
MEMORANDUM FOR HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: Russell T. Vought
Director

SUBJECT: Completing the Transition to Internet Protocol Version 6 (IPv6)

https://www.whitehouse.gov/wp-content/uploads/2020/11/M-21-07.pdf

IPv6 requirements around the world



Notice on Accelerating the Large-Scale Deployment and Application of Internet Protocol Version 6 (IPv6)

July 23, 2021 at 16:00 Source: China Netcom [Print] [Error Correction]

Notice on Accelerating the Large-Scale Deployment and Application of Internet Protocol Version 6 (IPv6)

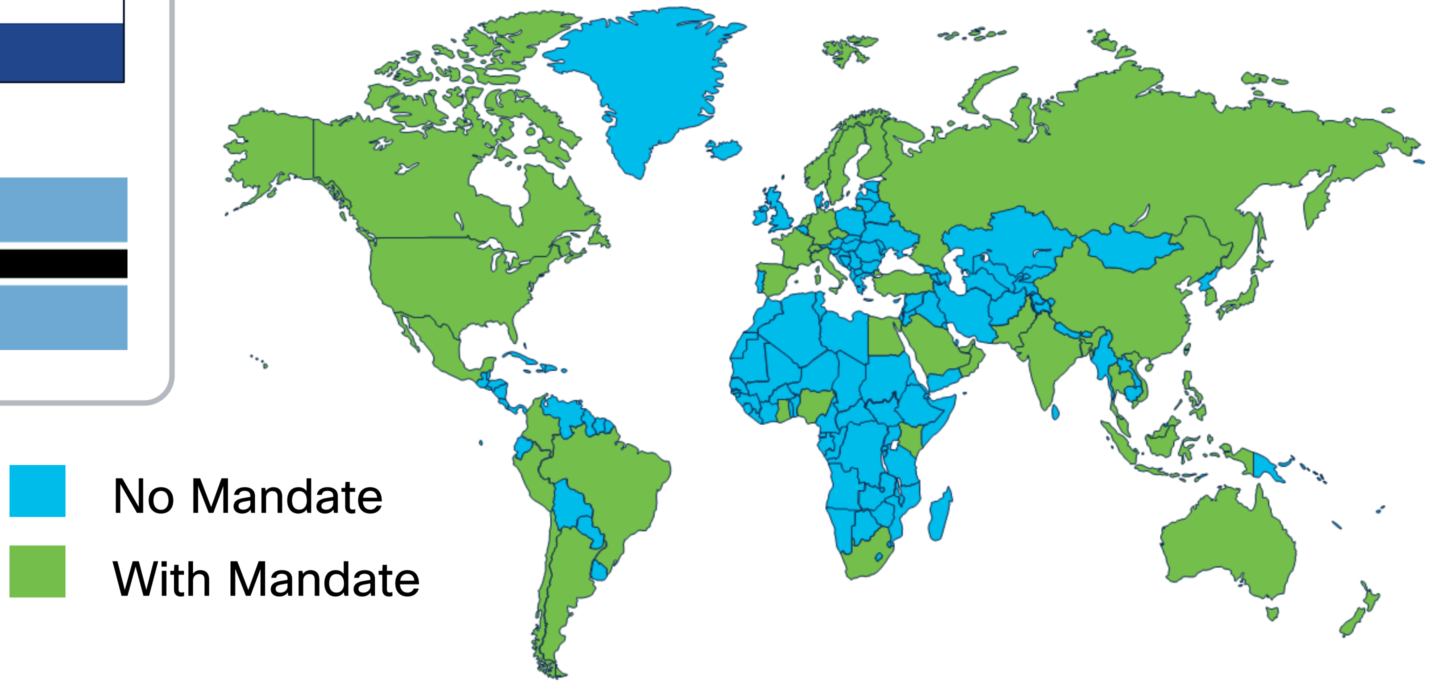
China Internet Affairs Office issued document [2021] No. 15

All provinces, autonomous regions, municipalities directly under the Central Government, and the Xinjiang Production and Construction Corps Party Committee Network Information Office, Development and Reform Commission, Industry and Information Technology Department (Bureau), and Communications Management Bureau:

The sixth version of the Internet Protocol (IPv6) is an inevitable trend of Internet upgrade and evolution, an important direction of network technology innovation, and the basic support for the construction of a network power. In 2017, the Party Central Committee with Comrade Xi Jinping as the core made a strategic decision to promote the large-scale deployment of IPv6. Over the past three years, all regions and departments have conscientiously implemented the Action Plan for Promoting the Large-Scale Deployment of Internet Protocol Version 6 (IPv6), and made remarkable progress in promoting the large-scale deployment of

China:

- No new private IPv4 as of 2023
- Fully IPv6-only by 2030
- 95% there by 2025



Pay to Stay… on Legacy

AWS News Blog

New – AWS Public IPv4 Address Charge + Public IP Insights

by Jeff Barr | on 28 JUL 2023 | in Amazon EC2, Announcements, Launch, News | Permalink | Share

0:00 / 0:00

Voiced by Amazon Polly

Public IP Address Type	Current Price/Hour (USD)	New Price/Hour (USD) (Effective February 1, 2024)
In-use Public IPv4 address (including Amazon provided public IPv4 and Elastic IP) assigned to resources in your VPC, Amazon Global Accelerator, and AWS Site-to-site VPN tunnel	No charge	$0.005
Additional (secondary) Elastic IP Address on a running EC2 instance	$0.005	$0.005
Idle Elastic IP Address in account	$0.005	$0.005

Azure:

Type	Standard (ARM)
Dynamic IPv4 address	N/A
Static IPv4 address	**$0.005**/hour
Public IPv4 prefix[2]	**$0.006** per IP/hour[3]

GCP:

SKU ID	SKU Description	SKU List Price (USD) *(Previous)*	SKU List Price (USD) *(New)*
C054-7F72-A02E	External IP Charge on a Standard VM	$0.004	$0.005
4AF8-7C1F-39C4	External IP Charge on a Spot Preemptible VM	$0.002	$0.0025

IPv6 is an IETF Standard (RFC 8200/STD86)

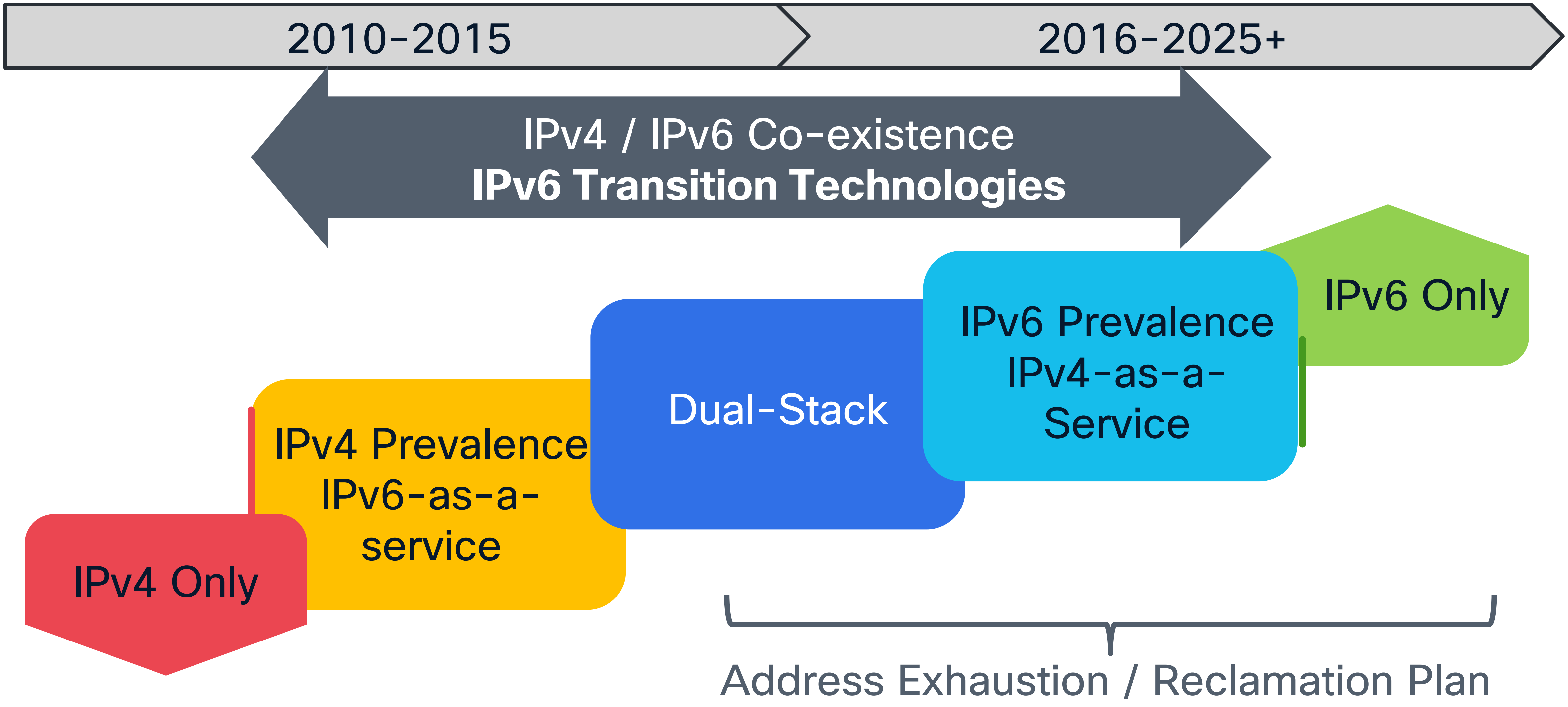
- **RFC 8200** rolls up all the previous disparate RFCs about IPv6 into a single RFC
  - Obsoletes 2460 and 1883

- There are more RFCs around **security and best practices** (e.g., RFC 9099)
  - See BRKSEC-2044 - Secure Operations for an IPv6 Network

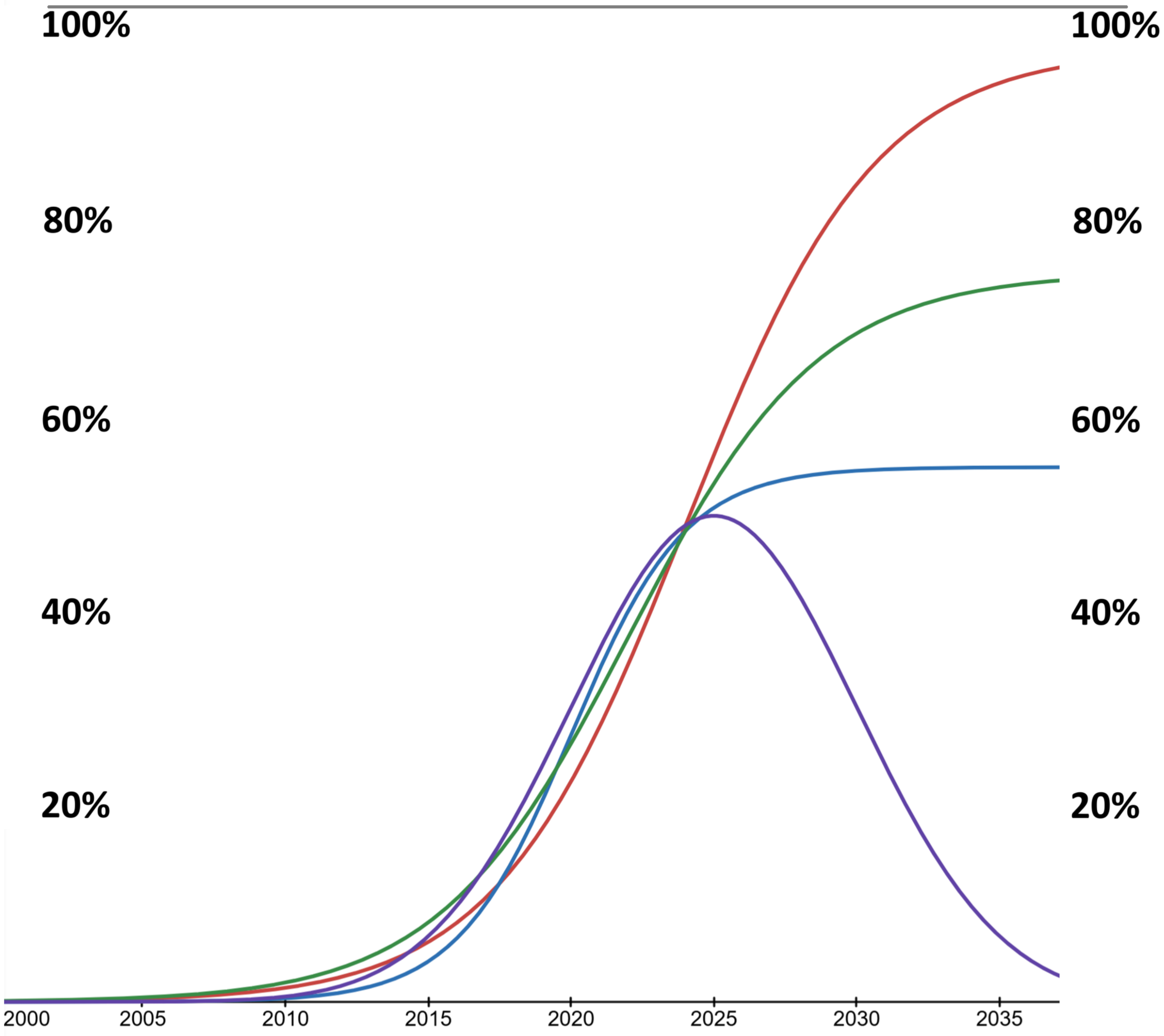
- **IPv6 is ready** to be validated and tested in your environment
  - You can start planning deployment, adoption, and operations

- https://www.system.de/ipv6-rfc/
- https://www.rfc-editor.org/rfc-index.html

IPv6 Multi-Year Evolution



Any guesses?



100%
80%
60%
40%
20%
100%
80%
60%
40%
20%
2000
2005
2010
2015
2020
2025
2030
2035

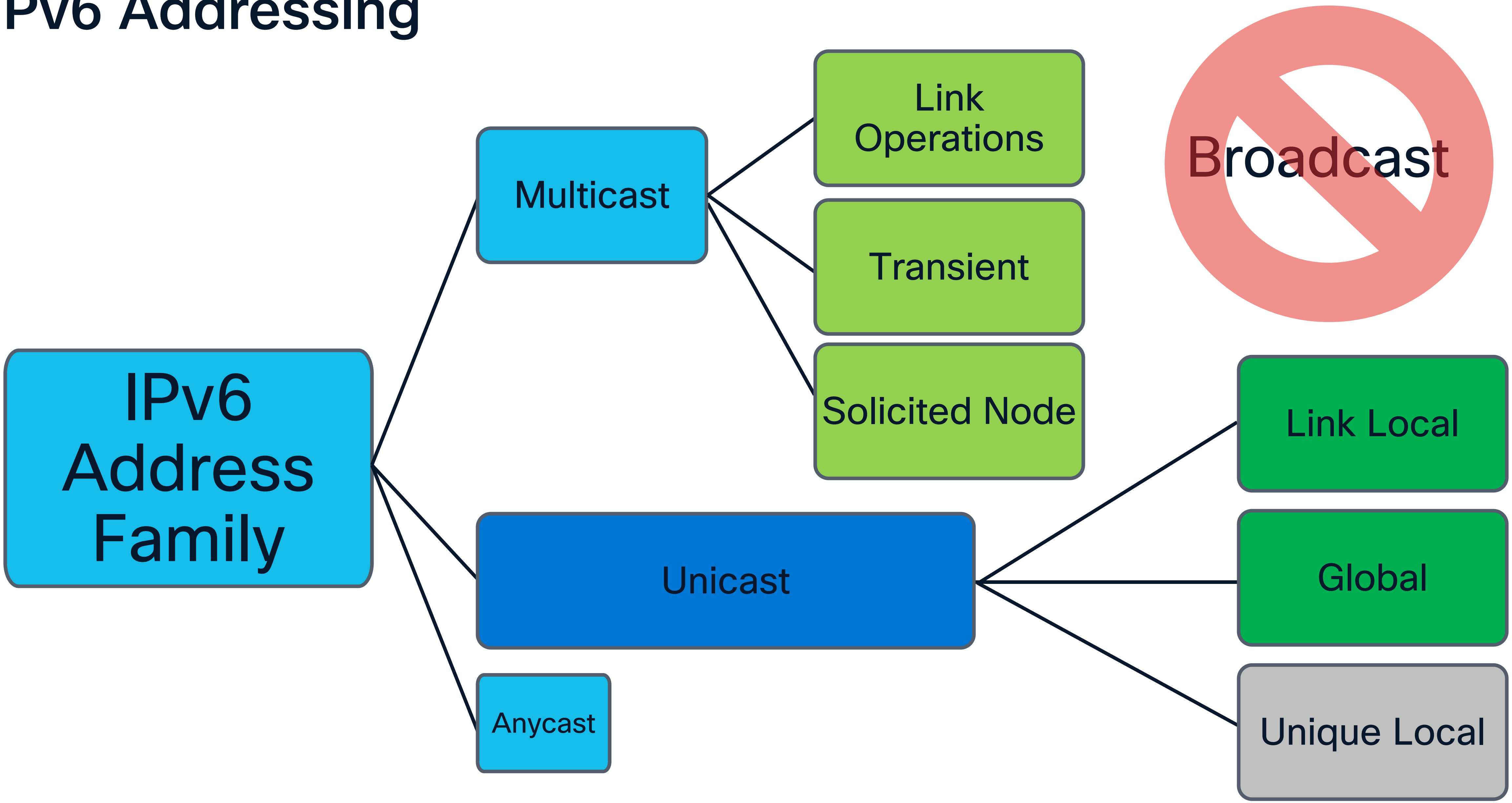
“How did you go bankrupt?”
Bill asked.
“Two ways,”
Mike said.
“Gradually and then suddenly.”

The Sun Also Rises

Ernest Hemingway

IPv6::
The Protocol

IPv6 Addressing



Hexadecimal Is Really Not That Difficult

For Your Reference

- Widely used in computing and programming
  - Hex is a base 16 numerical system
  - Typically expressed by 0x, i.e. 0x34
- Every nibble is a Hex character
  - 4 bits have 16 combinations
  - Easier than high school algebra

100s	10's	1's
0	5	2
1	7	2
5	8	9

256's	16's	1's
	3	4
	a	c
2	4	d

Binary	Hex	Decimal
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A	10
1011	B	11
1100	C	12
1101	D	13
1110	E	14
1111	F	15

IPv6 Address Format

- IPv6 addresses are 128 bits long (32 hex characters)
  - 8 groups (words, quads, hextets) of 16 bits separated by (:)
  - RFC5952 - lower case, leading zeros, zero compression

2001:0db8:0046:a1d1:0000:0000:0000:0001

2001:db8:46:a1d1:0:0:0:1

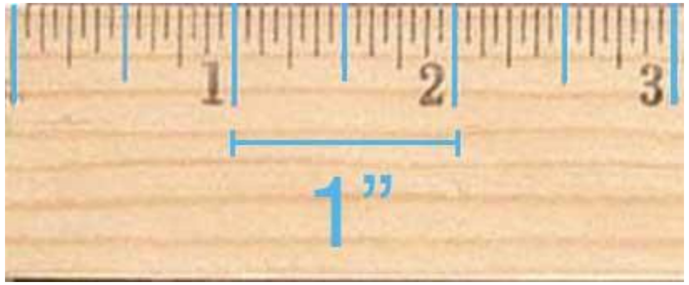
2001:db8:46:a1d1::1

Prefix | **Interface Id**

2001	0db8	0046	a1d1	0000	0000	0000	0001
16 bits	16 bits	16 bits	16 bits	16 bits	16 bits	16 bits	16 bits

Perspective

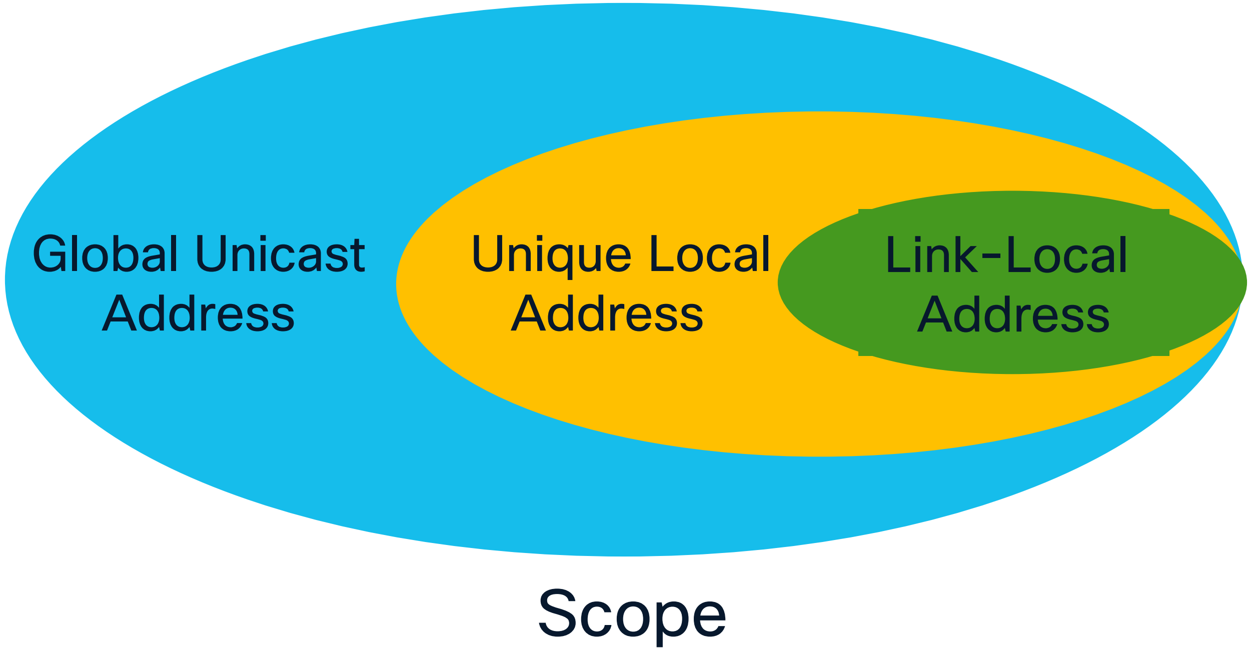
- Total # of IPv4 addresses:
  4,294,967,296
- Total # of IPv6 addresses:
  340,282,366,920,938,463,463,374,607,431,768,211,456



- Don’t bring IPv4 thinking into a IPv6 world!
- We now have the space to do things better

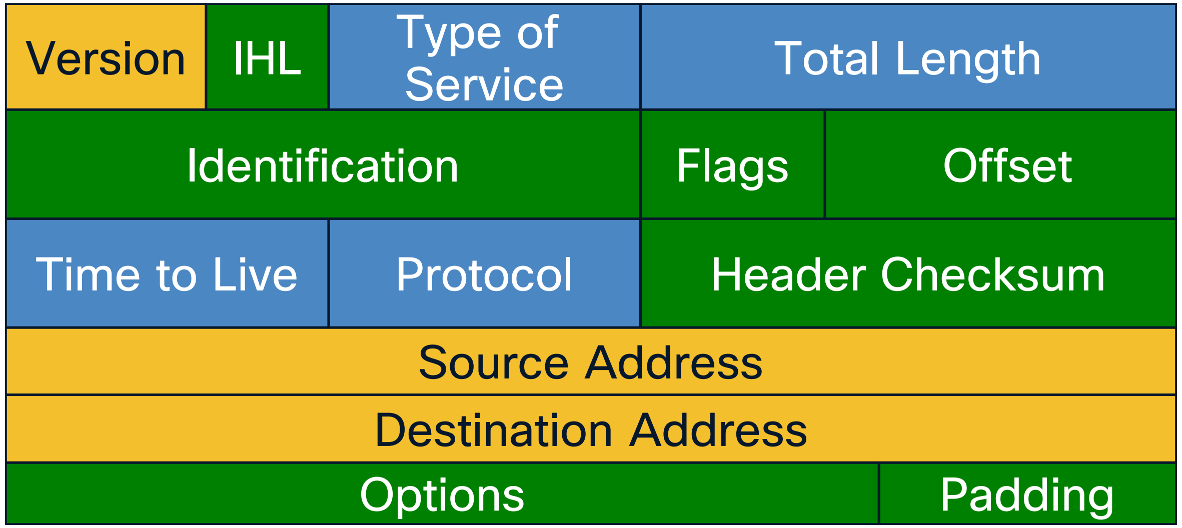
IPv6 Unicast Address Types

- Link-Local Address (LLA)
  - **fe80::/10** range
  - Locally significant to LAN segment
  - Used in many aspects of IPv6 operation
- Unique Local Address (ULA)
  - Routable within administrative domain
  - Poor comparison to RFC1918 IPv4 Addressing
  - **fc00::/7**
  - Avoid if possible!
- Global Unicast Address (GUA)
  - Routable on the Internet
  - **2000::/3**



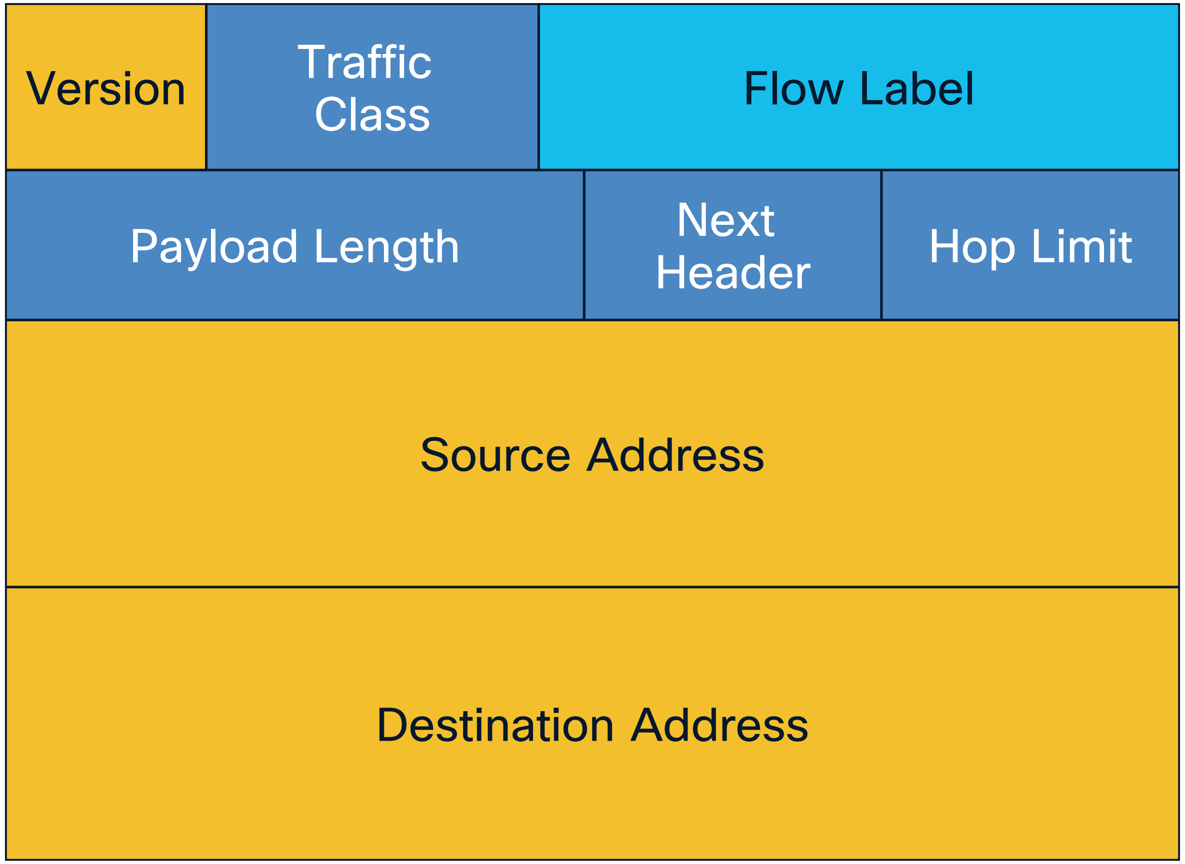
IPv4 and IPv6 Header Comparison

IPv4 Header (20-60)



- Length was variable
- Fields in green are removed
- Options appear in extension headers

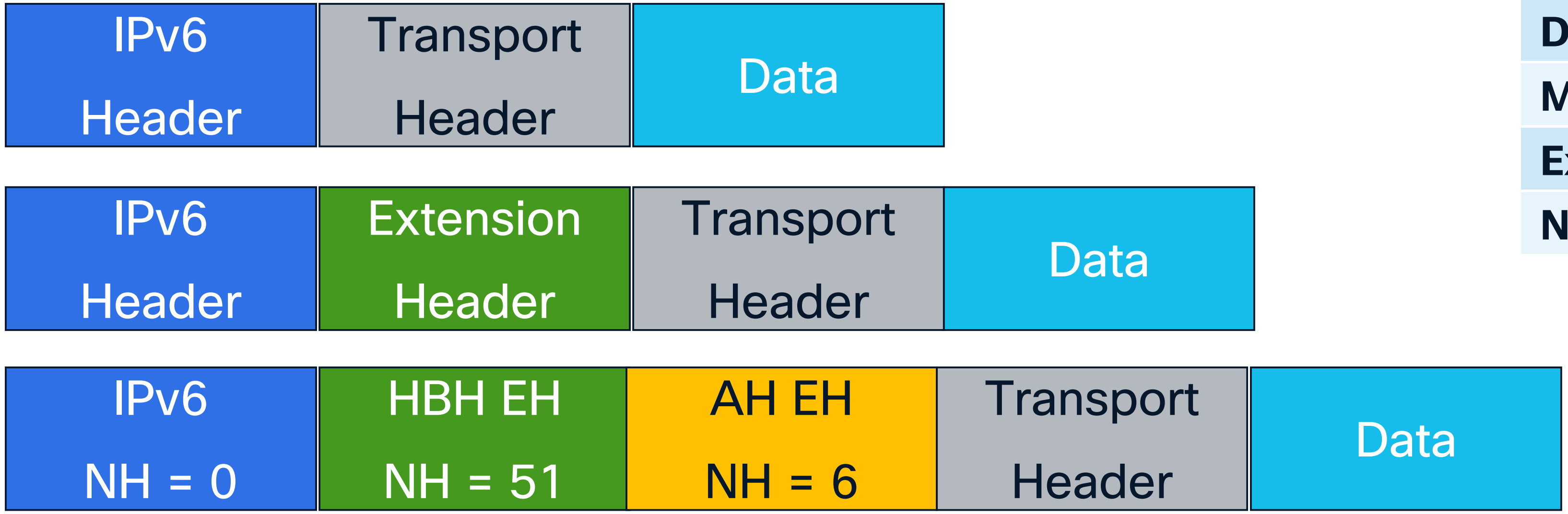
IPv6 Header (40)



Extension Headers (EH) ~ Layer 3.5

- EH are daisy chained, processed in order
- EHs have a Next Header field
- Length is variable, ends on 64-bit boundary
- All EHs and Upper-Layer Headers must be in the initial fragment

Extension Header	Type
Hop-by-Hop Options	0
Destination Options	60
Routing Header	43
Fragment Header	44
Authentication Header	51
ESP Header	50
Destination Options	60
Mobility Header	135
Experimental	253,254
No Next Header	59



IPv6 over Ethernet

- IPv6 has a specific Ethertype ID

Destination Ethernet Address	**Source Ethernet Address**	**0x0800**	**IPv4 Header and Payload**

Destination Ethernet Address	**Source Ethernet Address**	**0x86DD**	**IPv6 Header and Payload**

IPv6 relies heavily on (Ethernet) Multicast

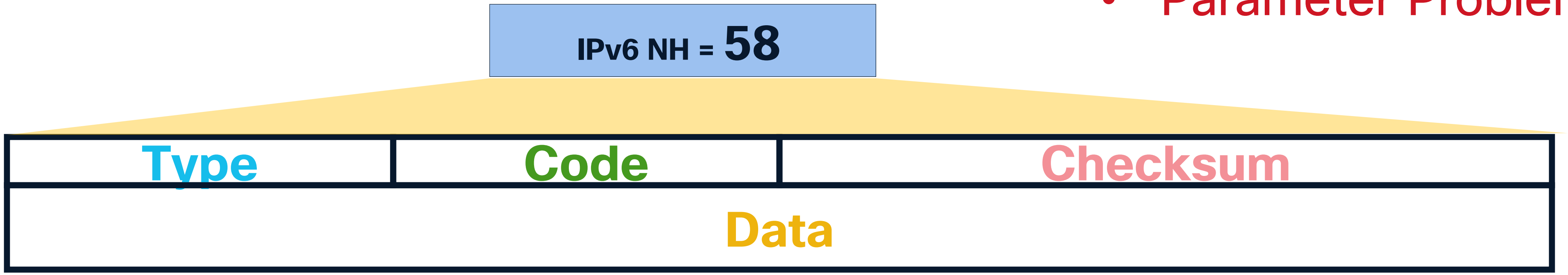
33	**33**	**xx**	**xx**	**xx**	**xx**

ICMPv6 Messages

See: RFC 4890

- Neighbor or router discovery (133-137)
- Multicast Listener Discovery (130-132, 143)
- Diagnostics using Ping, *Traceroute* (128, 129)

- Destination Unreachable (1)
- Packet Too Big (2)
- Time Exceeded (3)
- Parameter Problem (4)

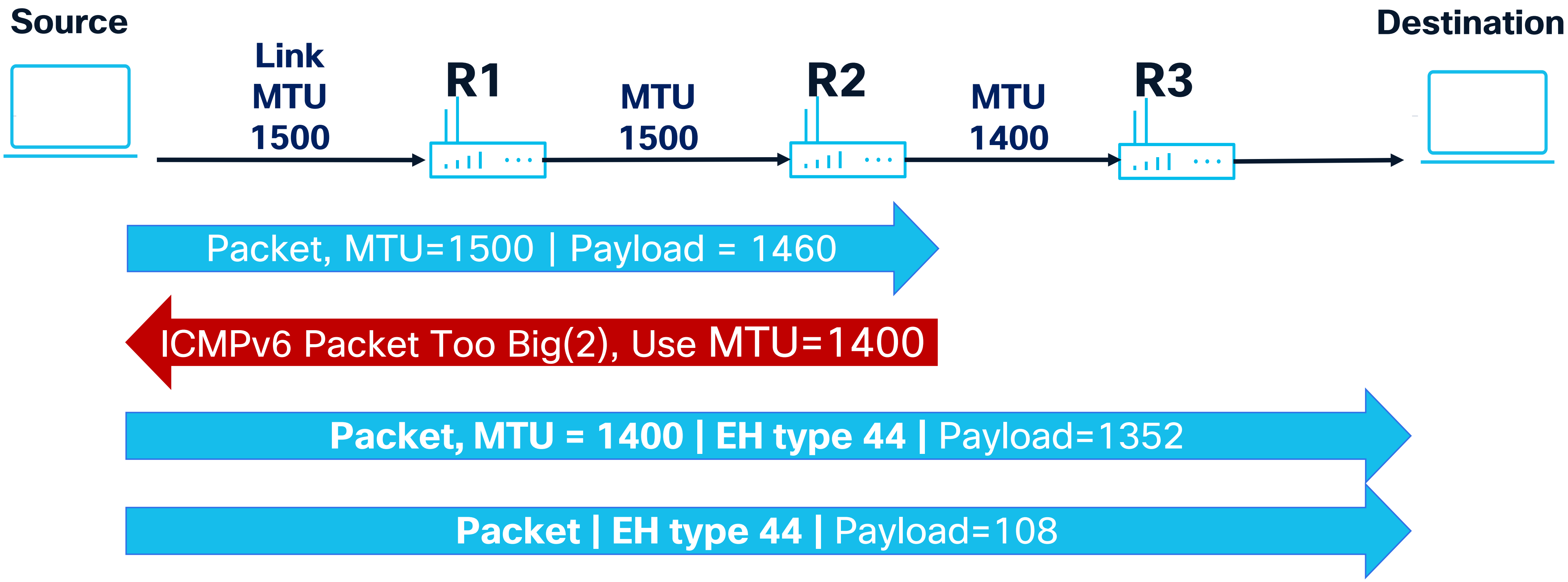


- **Type –** (0-127) = Error messages, (128-255) = Informational messages
- **Code –** More granularity within the type
- **Checksum –** Computed over the entire ICMPv6 & pseudo header
- **Data** – Contents of “offending”, filled to 1280 bytes (error) or specific message format (info)

Path MTU Discovery

Fragmentation Header:

Next Header	Reserved	Fragment Offset	Res	M
Identification				



IPv6 Multicast Address (RFC 4291)

- Prefix ff00::/8
- Changes based on flag settings

8-bits	4-bits	4-bits	112-bits
1111 1111	0 R P T	Scope	Variable format

Flags	
O	Reserved
R = 0 R = 1	No embedded RP Embedded RP
P = 0 P = 1	Without Prefix Address based on Prefix
T = 0 T = 1	Well Known Address Transient address

Scope	
1	Node
2	Link
3	Realm
4	Admin
5	Site
8	Organization
e	Global

LL Groups	
::1	All Nodes
::2	All Routers
::5	OSPF
::6	OSPF DR
::a	EIGRP
::fb	mDNSv6
::1:2	DHCPv6

Special Use Addresses (RFC 5156)

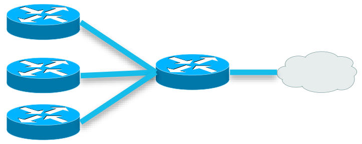
For Your Reference

- Localhost

  0:0:0:0:0:0:0:1=> ::1

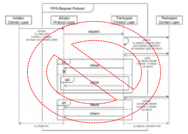
- Default Route

  ::/0



- Unspecified address

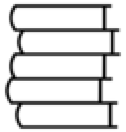
  0:0:0:0:0:0:0:0=> 0::0 => :: => ::/128



- Documentation Prefix

  2001:0db8::/32

  3fff::/20 (NEW!)

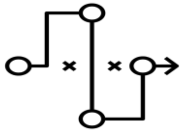


- Discard Prefix

  100::/64

- SRv6

  5f00::/16

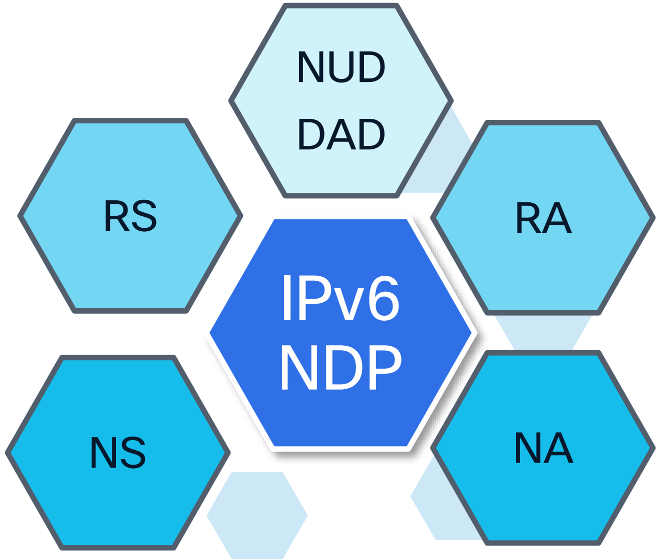


IPv6::
The Protocol

Link Operations

Neighbor Discovery Protocol – (NDP)

Informational



Using

Solves the following problems:

- Router discovery
- Prefix discovery
- Parameter discovery
- Address autoconfiguration
- Address resolution
- Next-hop determination
- Neighbor unreachability detection
- Duplicated address detection
- Redirects

Using 5 ICMPv6 packet types:

Router solicitation (133)
Router advertisement (134)
Neighbor solicitation (135)
Neighbor advertisement (136)
Redirect (137)

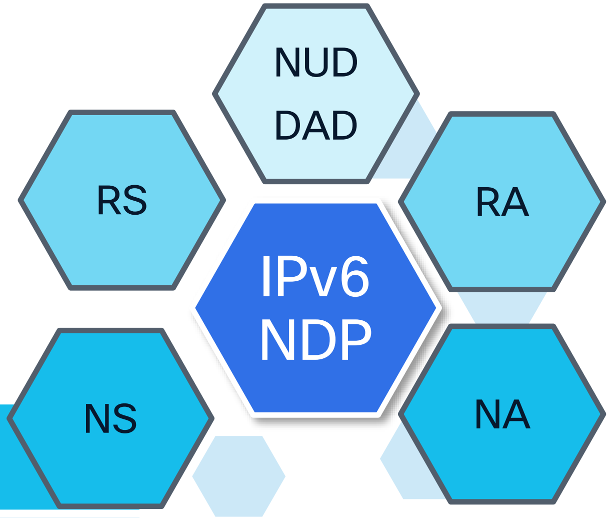
BRKIPV-1616
BRKENT-3002

Containing

Option Name	Type
Source Link Layers Address	1
Target Link-Layer Address	2
Prefix Information	3
Redirected Header	4
MTU	5
RDNSS	25
DNS Search List	31

Neighbor Discovery Protocol – (NDP)

Informational



- Should use Link Local (fe80::/64) as its source
- Hop Limit must be set to 255
  - Generalized TTL Security Mechanism

IPv4	IPv6
ARP Request	Neighbor Solicitation
ARP Reply	Neighbor Advertisement
Broadcast	All-Nodes Multicast or Solicited Node Multicast
Default Gateway via DHCP	Default Gateway via Router Advertisement
Address Assignment via DHCP	Address assignment via Router Advertisement + SLAAC OR DHCPv6

Solicited Node Multicast

Informational

- Required & special form of multicast used for neighbor resolution
- Every interface with an IPv6 Unicast address must:
  - Create corresponding solicited node multicast (**ff02::1:ff00:0/104**)
- All Layer 3 IPv6 multicast packets must:
  - Map to corresponding Layer 2 multicast (**33-33-xx-xx-xx-xx**)

IPv6 Unicast Address	`fe80::aaaa:bbbb:cc55:deca`
IPv6 Solicited Node Multicast Address	`ff02::0000:0001:ff55:deca`
Ethernet Multicast MAC	33-33-FF-55-DE-CA

Solicited Node Multicast Example

Informational

```
R1#sh ipv6 int e0
Ethernet0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::200:CFF:FE3A:8B18
  Global unicast address(es):
      2001:DB8:46:1234::1 subnet is 2001:DB8:46:1234::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::1:FF00:1
    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 router advertisements are sent every 200 seconds
```

← Solicited-Node Multicast Addresses

***If** EUI format is used then the 1st solicited node mcast addr is used for both the LL & GU

Neighbor Solicitation & Advertisement

Informational

- Node A needs to resolve node B's link-layer address (Map L3 to L2)
- Multicast for resolution (new), Unicast for reachability (cached)
- Node B will add node A to its neighbor cache during this process w/o sending NS

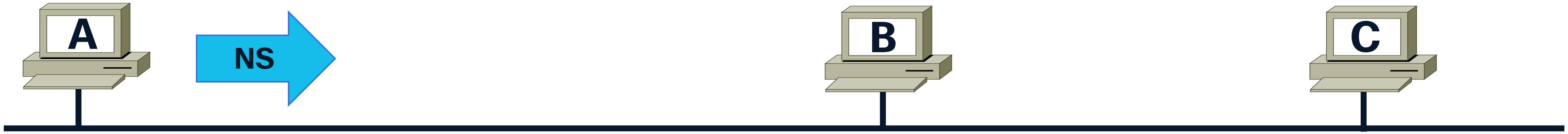
ICMPv6 Type	**135 NS**
IPv6 Source	fe80::a
IPv6 Destination	**ff02::1:ff**00:b
Hop Limit	255
Target Address	2001:db8:46:46::b
Query	**What is B link layer address?**
Opt. 1 SLLA	A's Link Layer Address

ICMPv6 Type	**136 NA**
IPv6 Source	fe80::b
IPv6 Destination	fe80::a
Target Address	2001:db8:46:46::b
Option 2 TLLA	**B's Link Layer Address**
***Flags**	R = Router S = Response to Solicitation O = Override cache information

Duplicate Address Detection (DAD)

Informational

- Unspecified Source (::), No Option 1 SLLA
- Probing the local link to verify address uniqueness
- Most vendors now use Optimistic DAD



ICMPv6 Type	135 NS
IPv6 Source	UNSPEC = ::
IPv6 Dest.	A's Solicited Node Multicast ff02::1:ffab:cdef
Query	Anyone Using "fe80::1234:5678:90ab:cdef"

Router Solicitation and Advertisement

- Router Solicitations (RS) are sent by nodes at boot up
- Router Advertisements (RA) go out in response to RS *and* at regular intervals
- Routers forward packets as well as provide provisioning services

RS	
ICMP Type	133
IPv6 Source	fe80::a
IPv6 Destination	ff02::2
Opt. 1 SLLA	SRC Link Layer Address

RA	
ICMP Type	134
IPv6 Source	fe80::1
IPv6 Destination	fe80::a
Data	Options, subnet prefix, lifetime, autoconfig flag

Router Advertisement

- M-Flag – Stateful DHCPv6 to acquire IPv6 address
- O-Flag – Stateless DHCPv6 in addition to SLAAC
- Preference Bits – Low, Med, High
- Router Lifetime – Must be >0 for Default Router
- Options – Prefix Information, Length, Flags
- L bit – Only way a host get a On Link Prefix
- A bit – SLAAC (Stateless Autoconfiguration)
  - Typically opposite of ‘M’ flag

Type: 134 (RA)
Code: 0
Checksum: 0xff78 [correct]
Cur hop limit: 64
∞ Flags: 0x84
1... .... = Managed **(M flag)**
.0.. .... = Not other **(O flag)**
..0. .... = Not Home (H flag)
...0 1... = Router pref: High
Router lifetime: (s)**1800**
Reachable time: (ms) 3600000
Retrans timer: (ms) 1000
ICMPv6 Option 3 (Prefix Info)
Prefix length: 64
∞ Flags: 0x84
1... .... = On link (L Bit)
.... 0... = No Auto (A Bit)
Prefix: 2001:0db8:4646:1234::/64

IPv6::
The Protocol

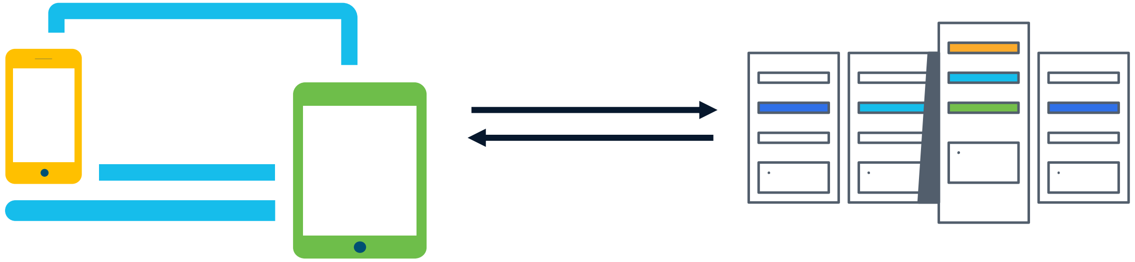
Interface ID’s

IPv6 interface ID Assignment

Similar to IPv4

Statically configured

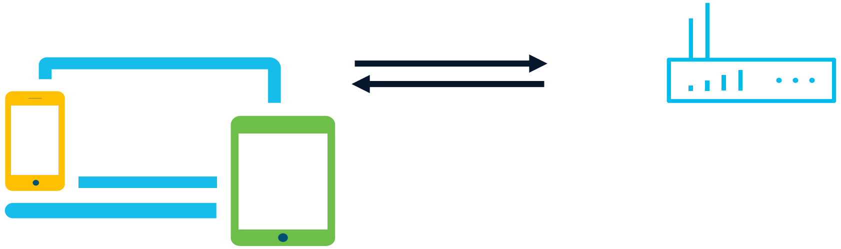
Assigned via DHCPv6



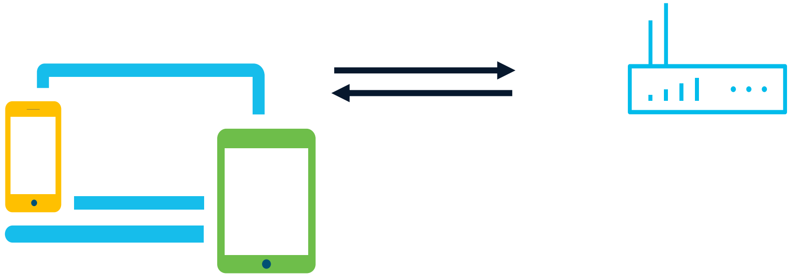
IPv6 interface ID Assignment

New to IPv6

StateLess Address Auto Configuration
SLAAC EUI64

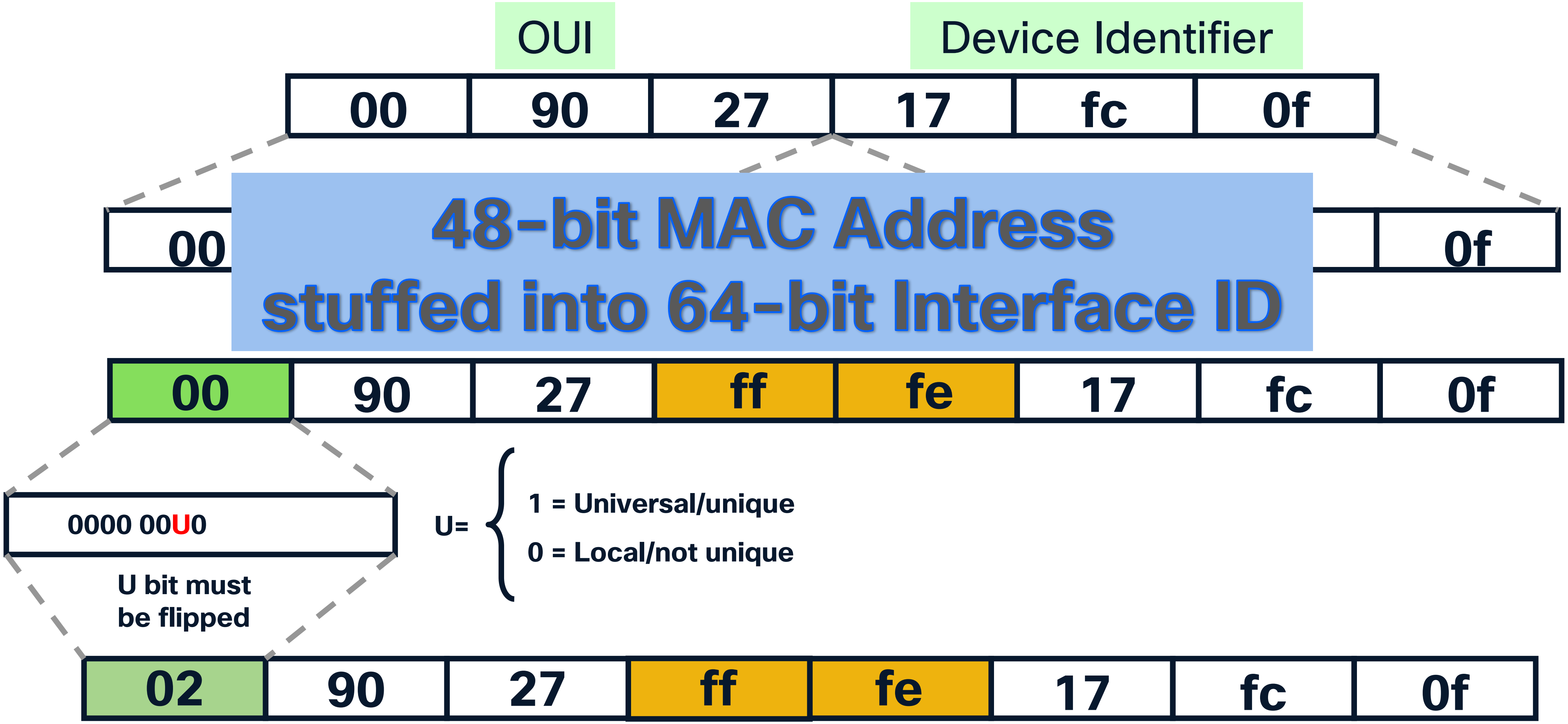


SLAAC RFC 8981
Temporary Address Extensions for Stateless Address Autoconfiguration in IPv6 (formerly Privacy Extensions)



Extended Unique Identifier (EUI64)

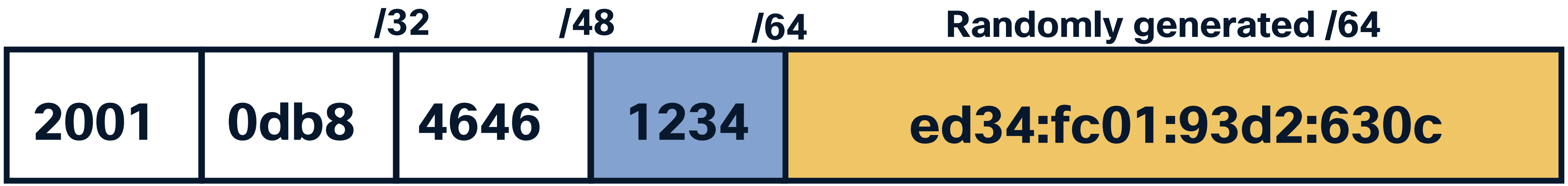
No longer used by most Host OS's



IPv6 Privacy Extensions (RFC 8981)

- Randomly generated for each interface
- Enabled by default in Windows, Android, iOS, Mac OS/X, Linux
- Temporary address rotation in addition

- RFC 7217
- Generate IID's that are Stable/Constant for each subnet
- IID's Change As Hosts Move From One Network to Another



DHCPv6

Stateful

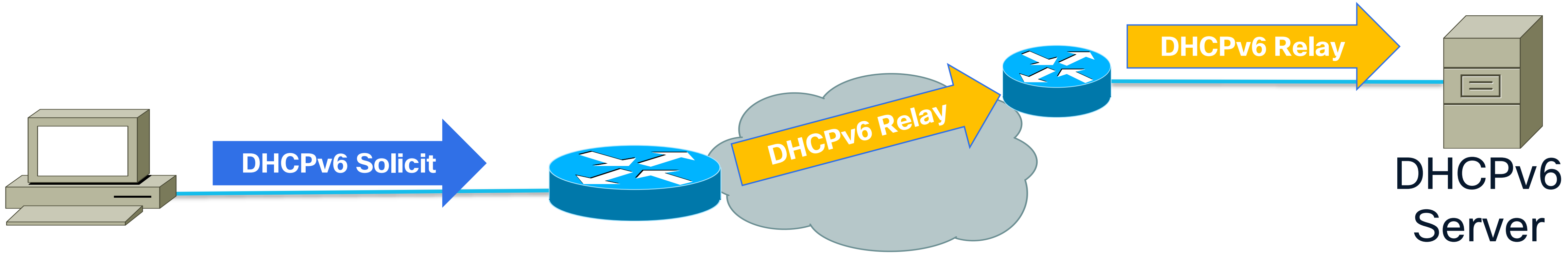
SOLICIT (any servers) →

← **ADVERTISE** (want this address)

REQUEST (I want that address) →

← **REPLY** (It's yours)

- Source – fe80::1234, Destination – ff02::1:2
- Client UDP 546, Server UDP 547
- DUID – Different from v4 (not MAC!), used to identify clients
- Original Multicast encapsulated in unicast (relay)



DHCPv6

Stateless

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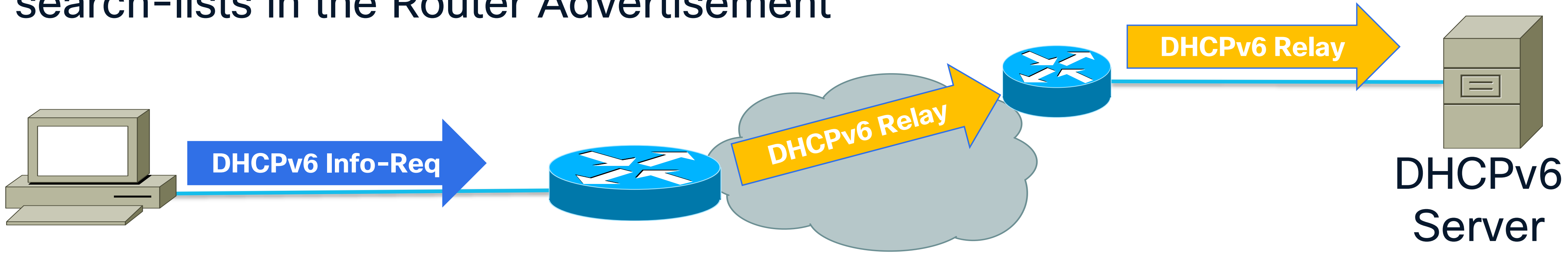
- Use SLAAC for address, but still desire extra information
- Same source/dest addresses and ports as Stateful
- Managed flag = 0
- O flag = 1

INFORMATION-REQUEST (any servers) →
Option Requests

← **REPLY** (Here is your config parameters)

- **RDNSS** allow DNS recursive servers and DNS search-lists in the Router Advertisement



Router Advertisement on the wire

```
> Ethernet II, Src: Arcadyan_a2:2c:05 (b8:f8:53:a2:2c:05), Dst: IPv6mcast_01 (33:33:00:00:00:01)
> Internet Protocol Version 6, Src: fe80::baf8:53ff:fea2:2c05, Dst: ff02::1
v Internet Control Message Protocol v6
    Type: Router Advertisement (134)
    Code: 0
    Checksum: 0xa04a [correct]
    [Checksum Status: Good]
    Cur hop limit: 64
  > Flags: 0x40, Other configuration, Prf (Default Router Preference): Medium
    Router lifetime (s): 900            0... .... = Managed address configuration: Not set
    Reachable time (ms): 0
    Retrans timer (ms): 0
  v ICMPv6 Option (Prefix information : 2600:4040:46c7:500::/64)
      Type: Prefix information (3)
      Length: 4 (32 bytes)
      Prefix Length: 64
    > Flag: 0xc0, On-link flag(L), Autonomous address-configuration flag(A)
      Valid Lifetime: 7200
      Preferred Lifetime: 7200
      Reserved
      Prefix: 2600:4040:46c7:500::
  > ICMPv6 Option (Route Information : High 2600:4040:46c7:500::/56)
  > ICMPv6 Option (Recursive DNS Server 2600:4040:46c7:500::1)
  > ICMPv6 Option (MTU : 1500)
  > ICMPv6 Option (Source link-layer address : b8:f8:53:a2:2c:05)
```

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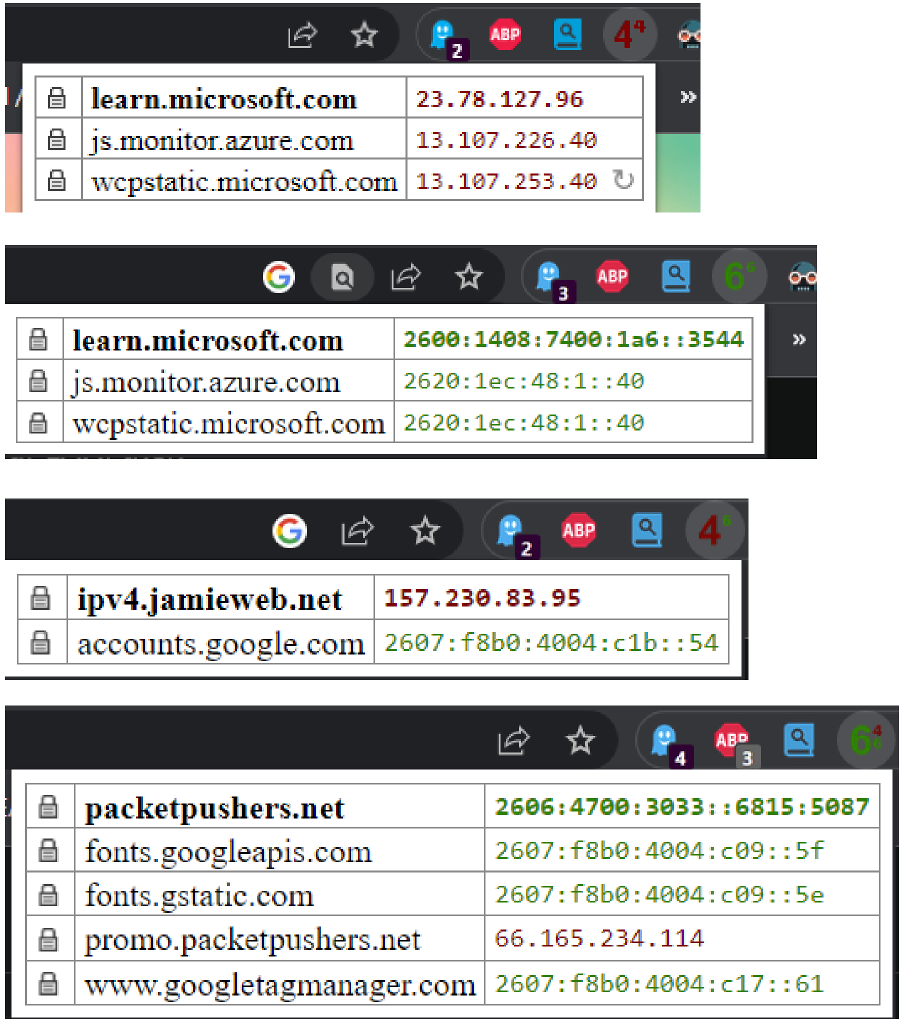
Endpoint Validation

```
natha  ~  80ms  ipconfig /all                                   pwsh  100%  09:37:02

Wireless LAN adapter Wi-Fi:

   Connection-specific DNS Suffix  . : myfiosgateway.com
   Description . . . . . . . . . . . : Killer(R) Wi-Fi 6 AX1650s
   Physical Address. . . . . . . . . : 04-6C-59-0D-95-8A
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   IPv6 Address. . . . . . . . . . . : 2600:4040:46c7:500:f813:a911:3d11:334b(Preferred)
   Temporary IPv6 Address. . . . . . : 2600:4040:46c7:500:c35:d878:d18b:78ee(Preferred)
   Link-local IPv6 Address . . . . . : fe80::ff1c:1776:bf67:54ba%14(Preferred)
   IPv4 Address. . . . . . . . . . . : 192.168.1.177(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Lease Obtained. . . . . . . . . . : Wednesday, May 10, 2023 12:02:00 PM
   Lease Expires . . . . . . . . . . : Saturday, May 20, 2023 8:46:36 AM
   Default Gateway . . . . . . . . . : fe80::baf8:53ff:fea2:2c05%14
                                       192.168.1.1
   DHCP Server . . . . . . . . . . . : 192.168.1.1
   DHCPv6 IAID . . . . . . . . . . . : 151284825
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-2B-76-54-14-04-6C-59-0D-95-8A
   DNS Servers . . . . . . . . . . . : 2600:4040:46c7:500::1
                                       192.168.1.1
   NetBIOS over Tcpip. . . . . . . . : Enabled

natha  ~  271ms  netsh int ipv6 show int 14

Interface Wi-Fi Parameters
----------------------------------------------
Link MTU                            : 1500 bytes
```

IPv
Foo

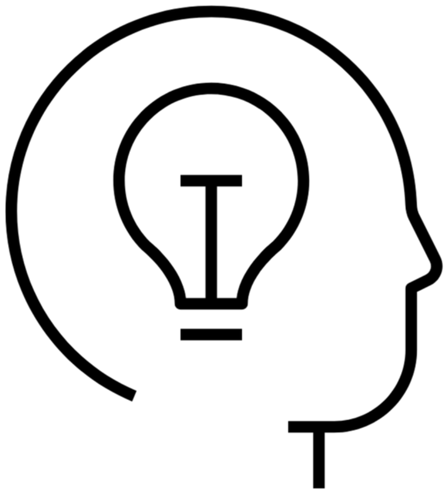


Numerous 'netsh', 'ip' and 'ifconfig' commands for Windows, Linux and Mac

IPv6::
Addressing Plans

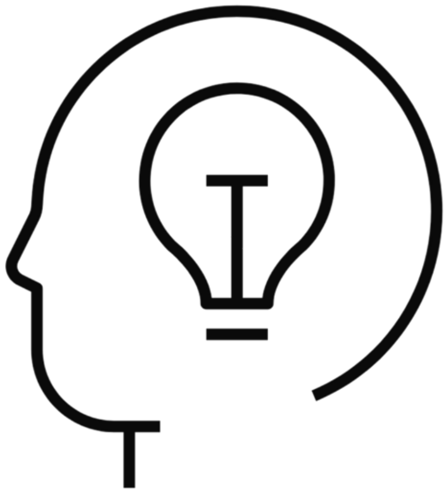
A shift in thinking...

IPv4



Addresses

IPv6



Subnets

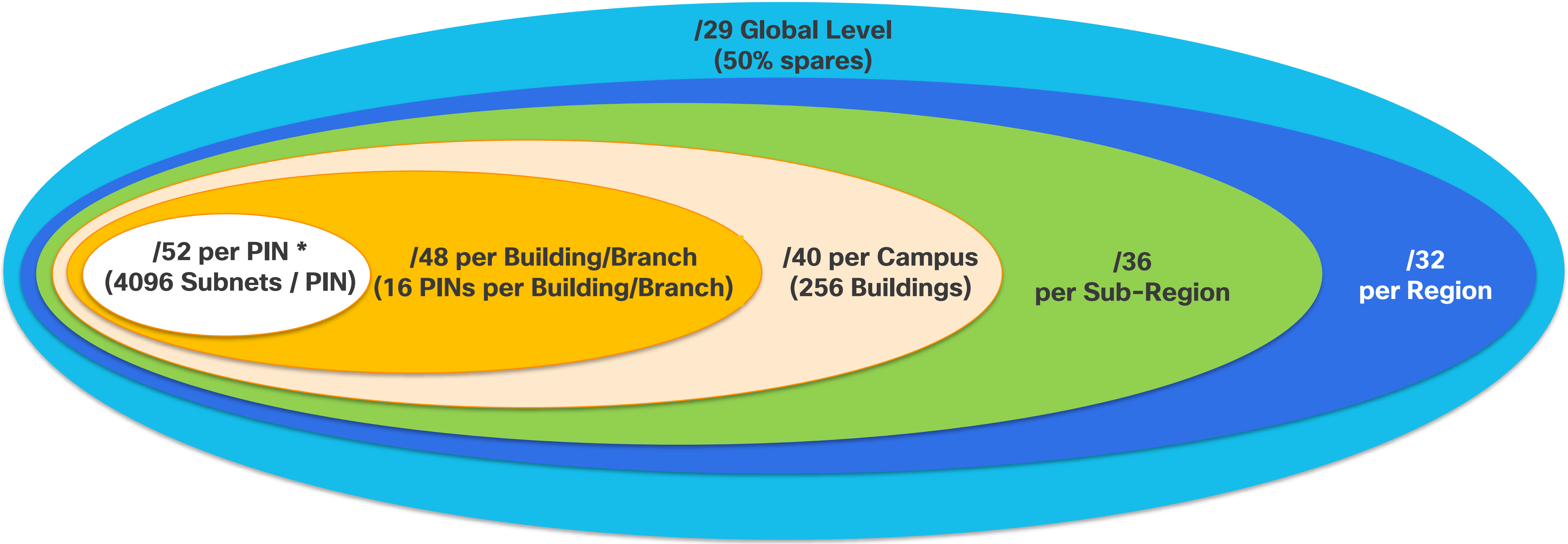
IPv6 Address Space - PA vs. PI

- **Provider Aggregatable ("Assigned") (PA)**
  - Original intention for all
  - Residential and small business
  - Prefixes may change (DHCPv6-PD)
- **Provider Independent (PI)**
  - Now more common in Enterprises
  - Control and stability
  - Requires AS and extra cost
  - Often used with BGP (though not always)

- **Considerations**
  - Local breakout (DIA) at sites?
  - Will my ISP run BGP with me at each of my sites?
  - Should I get 1 PI block or per-RIR?
  - Will I be multihoming?

Address Overview Example

Breaking down the /28



Nibble Boundaries!

* PIN = Place In the Network - A framework to classify functional areas of the network e.g., Lab, Desktop, DC, DMZ, etc.

Address Planning Continued

More Examples

2001:0db8::/32 – allocated from RIR

`PPPP:PPPP:CGGG:LLSS ::/64`

- P = Global Prefix from RIR (2001:0db8)
- C = Campus vs. Cloud vs. Colo
- G = Geographic breakdown
- L = Logical/Functional breakdown (PIN)
- S = Subnet

`PPPP:PPPP:CGGG:LSSS ::/64`

`PPPP:PPPP:CGGL:LSSS ::/64`

`PPPP:PPPC:GGGL:LSSS ::/64`

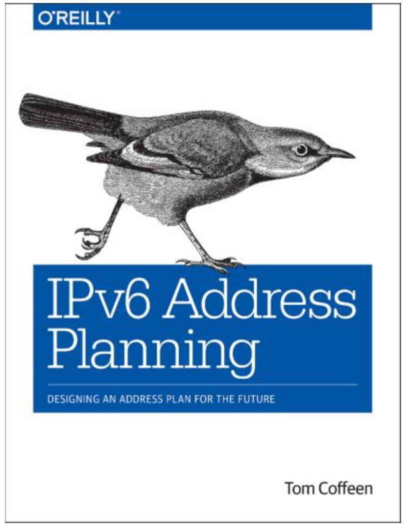
`PPPP:PPPC:GGGG:LLSS ::/64`

~~`PPPP:PPPP:CGGG:GLSS ::/64`~~

/48 is longest prefix allowed in global routing tables

Address Planning Continued

Template Addressing Example



(13th Nibble) Functional Identifier

'Site' Identifier

PIN (16)

Subnets / PIN (4096)

/48	/52	/64

2001:0db8:729c::/48

- 0 = *Reserved*
- 2 = Infrastructure
- 4 = Desktop (wired)
- 6 = Wireless (corp)
- 8 = Guest Wi-fi
- A = Lab
- C = Building DC
- E = DMZ
- F = *Reserved*
- *'Even' = Future Use*

2001:0db8:729c:4000::/52 - Desktop PIN

2001:0db8:729c:4200::/64 – Desktop VLAN 200

2001:0db8:729c:4201::/64 – Desktop VLAN 201

2001:0db8:029c:a000::/52 - Lab PIN

2001:0db8:029c:a004::/64 – Lab Subnet 4

2001:0db8:029c:a005::/64 – Lab Subnet 5

Address Planning: The 4 Rules

1. SIMPLE
   - You don’t want to spend weeks explaining it!
2. Embed Information
   - To help troubleshooting and operation of the network
   - Examples: location, country, PIN, VLAN, IPv4 addresses in Link Local and/or Global Addresses
3. Build-in Reserve
   - Cater for future growth, mergers & acquisitions, new locations
   - Reserved vs. assigned
4. Aggregatable
   - Good aggregation is essential, just one address block (per location), we can take advantage of this (unlike in IPv4!)
   - Ensures scalability and stability

IPv6::
Transition Technologies

Dual-Stack (former recommendation)

- Transition from IPv4 to Dual-stack

  Then IPv6-only / IPv6-mostly can be introduced after

- Node has both IPv4 and IPv6 addresses

  Clients, servers, network, services

- IPv6 is preferred over IPv4

  RFC 6724 – Host Address Selection

  RFC 8305 - Happy Eyeballs

https://commons.wikimedia.org/wiki/File:Ships_that_pass_in_the_night,_Atlantic_City,_New_Jersey.png (Author: Unknown) (public domain)

Dual-Stack – Pros and Cons

Pros

- Classic standard solution model
- Supports legacy (IPv4) applications
- Widely available
- Once services are on IPv6, IPv4 can simply be discontinued

Cons

- Doesn't solve IPv4 exhaustion
- Increased CapEx+OpEx
- Scalability concerns
- Policy synchronization
- Security: larger attack surface
- Hidden brokenness

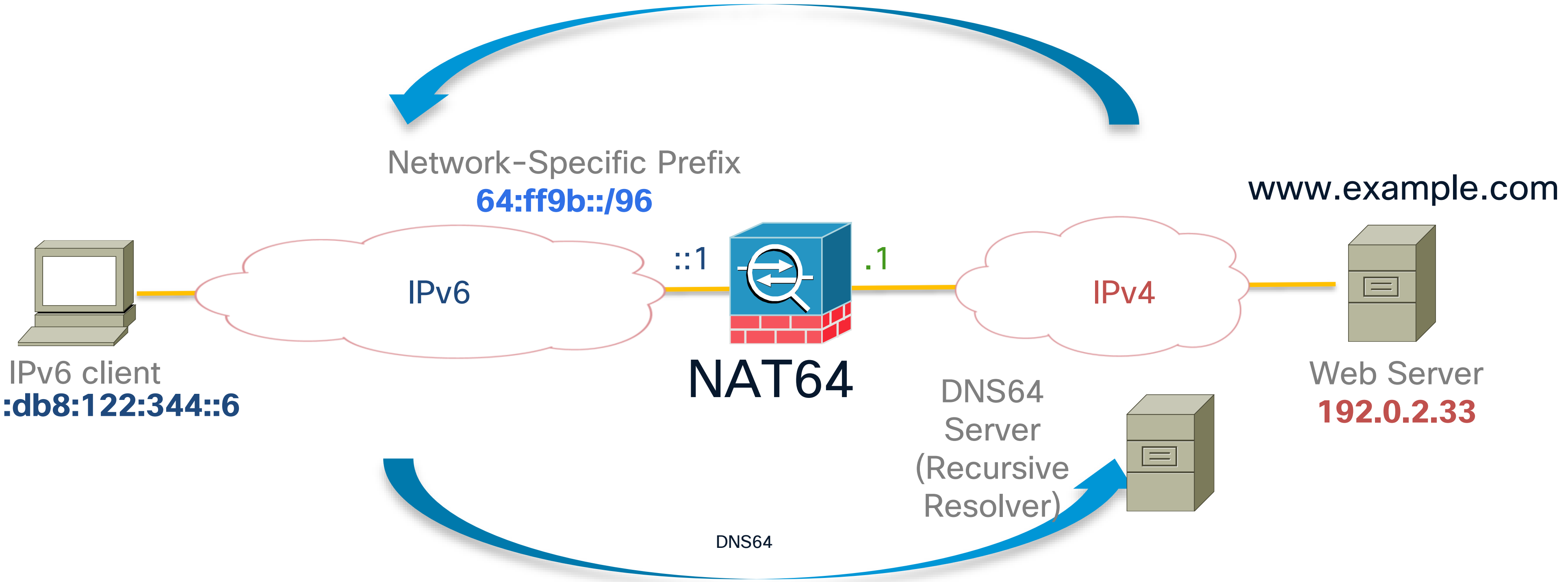
IPv6-only Transition Technologies

- **Dual-Stack** (former go-to, now only when necessary)
- **NAT64 + DNS64**
  - Allows access to IPv4 resources from IPv6 clients
  - Common in enterprise
- **SLB64**
  - Easy; common for data center / servers
  - Presents IPv6 address to outside
- **464XLAT**
  - mobile service provider ... and now Enterprise
- MAP-T / MAP-E / DS-Lite / lw4o6 – access provider
- 6rd – legacy access provider
- Teredo/ISATAP/6to4 – legacy tunnels

DNS64 Operation

←Step 5 Translates it to a **AAAA** record (embed IPv4 address on end of network-specific prefix)

←Step 4 DNS64 resolver receives **A** record for IPv4 server



Step 1→ **IPv6** client queries **AAAA** record for IPv4 server

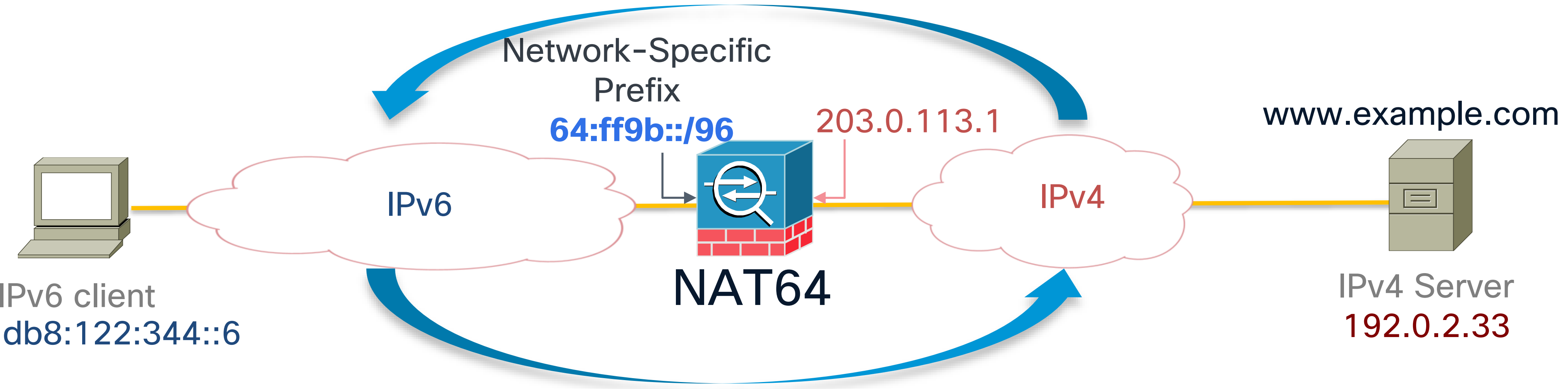
←Step 2 DNS64 receives "empty" **AAAA** record

Step 3→ DNS64 asks for **A** record of IPv4 server

NAT64 Operation

←Source IPv6 **64:ff9b**::c000:221 Dest. IPv6 2001:db8:122:344::6

←Source IPv4 192.0.2.33 Dest. IPv4 203.0.113.1



→ Source IPv6 2001:db8:122:344::6 Dest. IPv6 **64:ff9b**::c000:221

→Source IPv4 203.0.113.1 Dest. IPv4 192.0.2.33

IPv6-only Transition Technologies

- **Dual-Stack** (former go-to, now only when necessary)
- **NAT64 + DNS64** – common in enterprise
  - Allows access to IPv4 resources from IPv6 clients
- **SLB64** – easy; common for data center / servers
  - Presents IPv6 address to outside
- **464XLAT** – mobile service provider ... and now Enterprise
- MAP-T / MAP-E / DS-Lite / lw4o6 – access provider
- 6rd – legacy access provider
- Teredo/ISATAP/6to4 – legacy tunnels

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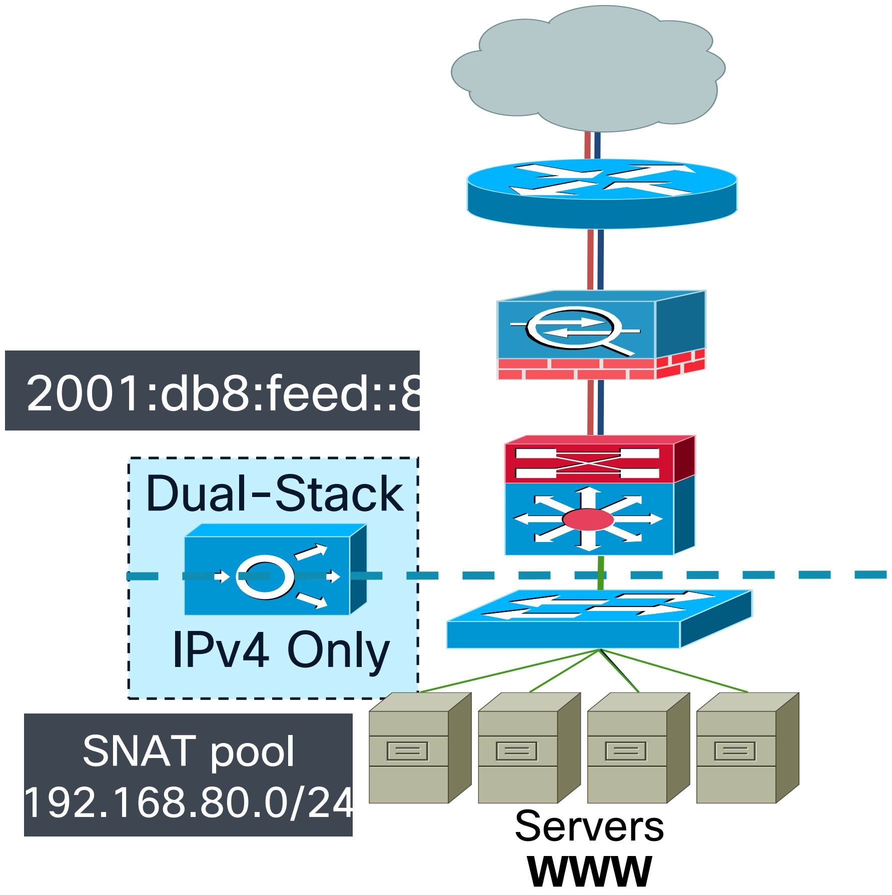
SLB64 Translation Technique

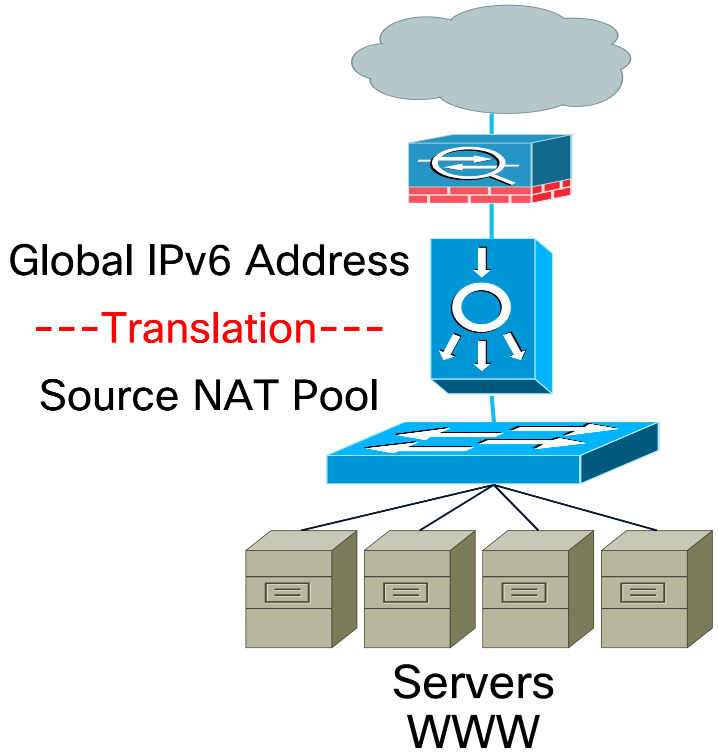
- Almost every network has some load balancing
- Router; ADC; Reverse Proxy
- Create Virtual IP (VIP)
  - Tie the VIP to servers (WWW)
  - Publish VIP AAAA record in DNS
- Establish a source NAT pool
  - Use as IPv4 source after translation
- Wide vendor support (on-prem and cloud)
- Very quick to deploy



X-Forwarded-For (XFF) / Forwarded Headers

- Web Server Logging for Geo Location, Analytics, Security
- Source IP of client requests will be logged as SNAT address
- Use X-Forwarded-For (or Forwarded) field of the HTTP header

```
GET / HTTP/1.1
Host: www.foo.org
User-Agent: Mozilla Firefox/3.0.3
Accept: text/html,application/xhtml+xml,application/xml
Accept-Language: en-us,en
Keep-Alive: 300
X-Forwarded-For: 2001:db8:ea5e:1:49fa:b11a:aaf8:91a5
Connection: keep-alive
```



IPv6::
More Next Steps

Network Validation

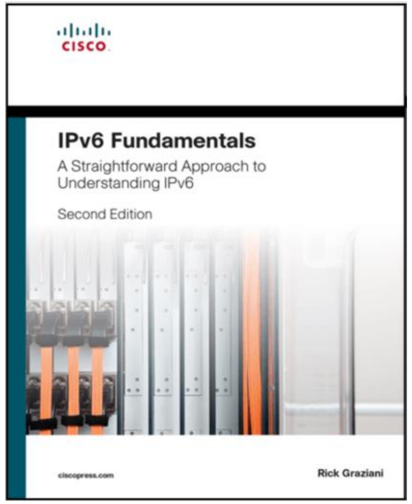
- NetFlow / IPFIX
  - What percentage of traffic is IPv4 vs IPv6?
  - Which network segments/subnets/VLANs are 100% IPv6, 100% IPv4?
  - Which servers are primarily IPv6, primarily IPv4?
  - Which clients are primarily IPv6, primarily IPv4?

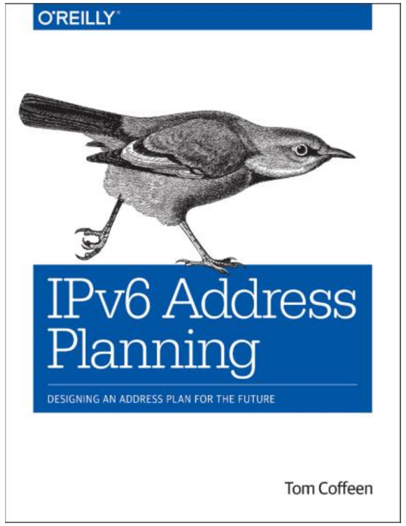
  - Secure Network Analytics (formerly StealthWatch)
  - Catalyst (DNA) Center Assurance

Be Aware of What's Changed

- **Deprecated**/rarely used: 6to4, Teredo, ISATAP, NAT-PT, SeND, Mobile IPv6
- Abandoning of **IPSec** as required for end-to-end connections
- Move from **EUI-64** to Privacy/Temporary addresses
- Rarity of **extension headers** (especially multiple!)
- Proliferation of **PI space** and the corresponding **larger allocations** readily available from the RIR's (i.e., no longer just /48's you get from your SP)

Resources





IPv6 Buzz Podcast - packetpushers.net/series/ipv6-buzz/

Infoblox IPv6 Center of Excellence - blogs.infoblox.com/category/ipv6-coe/

RIPE IPv6 Info Centre - www.ripe.net/publications/ipv6-info-centre

ARIN IPv6 Information - www.arin.net/resources/guide/ipv6/

APNIC IPv6 Information - www.apnic.net/community/ipv6/

RFC 9099: Operational Security Considerations for IPv6 Networks - www.rfc-editor.org/rfc/rfc9099

Cisco Live San Diego 2025 IPv6 Learning Map

Sunday–8th

TECIPV-2000 9:00
IPv6 in the Host and in the Local Network
Nathan Sherrard
Nicole Wajer
Steve Simlo

Monday–9th

BRKSEC-2044 13:00
Secure Operations for an IPv6 Network
Eric Vyncke

IBOIPV-1000 11:00
U.S. Government Mandate Driving to 80% IPv6-Only and beyond in 2025
Nathan Sherrard
David Prall

IBOIPV-2000 13:00
Sharing Experience on IPv6 Deployments
Eric Vyncke
Steve Simlo

BRKIPV-2186 13:00
IPv6 Networking in a Cloud Native World
Josh Halley

Tuesday–10th

CTF-1001 10:15
IPv6: The Internet's best kept secret!
Nicole Wajer

BRKIPV-2191 11:00
IPv6:: It's Happening!
Nathan Sherrard

BRKENT-2008 13:30
Goodbye Legacy, the Move to an IPv6-Only Enterprise
David Prall

BRKOPS-2223 14:00
The Network of the Future is Here - Let's Automate your IPv6 deployment with Python!
Nicole Wajer
Juulia Santala

Wednesday–11th

BRKIPV-2005 10:30
Riding the IPv6 Wave: Network Operations in an Increasingly IPv6 world
Jeffry Handal

BRKIPV-1616 13:00
IPv6 - What Do You Mean There Isn't a Broadcast?
Fish Fishburne

IBOENT-2811 14:30
Everything You Wanted to Know about IPv6 but Were Afraid to Ask
Nicole Wajer
Peter Paluch

BRKENT-3002 15:30
IPv6 Security in the Local Area with First Hop Security
Eric Vyncke

Thursday–12th

BRKIPV-2418 8:30
Deploying IPv6 Routing Protocols: Specifics and Considerations
Peter Paluch

BRKENT-3340 8:30
The Hitchhiker's Guide to Troubleshooting IPv6
Nicole Wajer

BRKEWN-2834 14:30
IPv6-Enabled Wi-Fi Access: Design and Deployment Strategies
Vinay Saini

Walk in Labs

LABIPV-1639	IPv6 Foundations: A Dive into Basic Networking Concepts
LABIPV-2640	IPv6 Deep Dive: Beyond Basics to Brilliance
LABMPL-1201	SRv6 Basics
LABSP-2129	SRv6 Micro-Segment Basics
LABCRT-2005	CCNP Service Provider SPRI – Implement Segment Routing v6

Instructor-led Labs

LTRIPV-2000	IPv6 deployment in Live IPv4 network
LTRENT-2016	Learning IPv6 in the Enterprise for Fun and (Fake) Profit: A Hands-On Lab

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Thank you

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