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IPv6:

The Protocol

Tim Martin

BRKIP6-2191

cisco Live!

Barcelona | January 27-31, 2020

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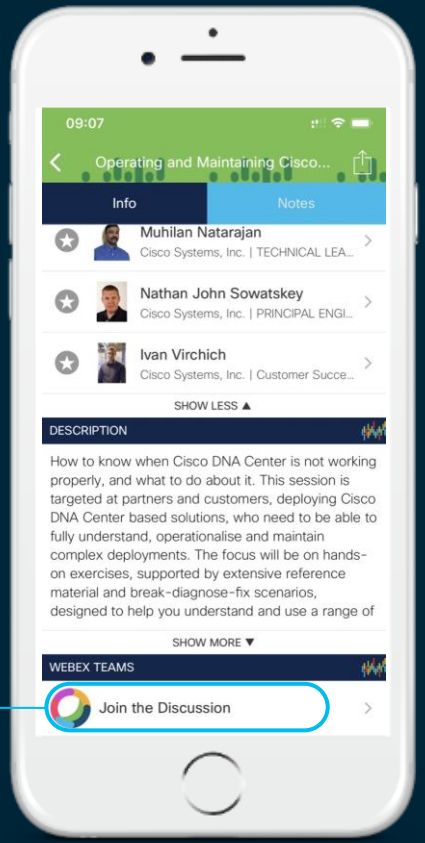
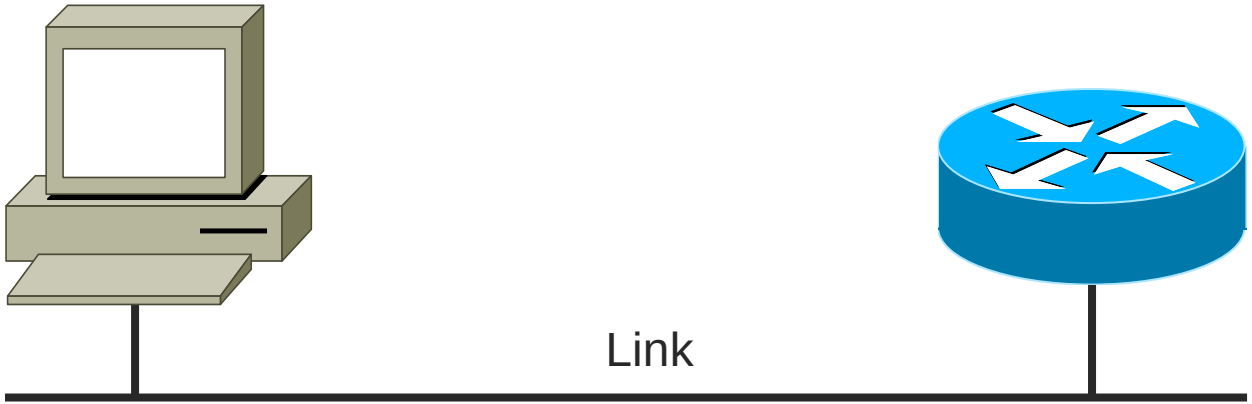


Agenda

- **IPv6 Addresses & Headers**
- IPv6 Address Assignment
- IPv6 Link Operations
- IPv6 Host Address Acquisition
- Conclusion

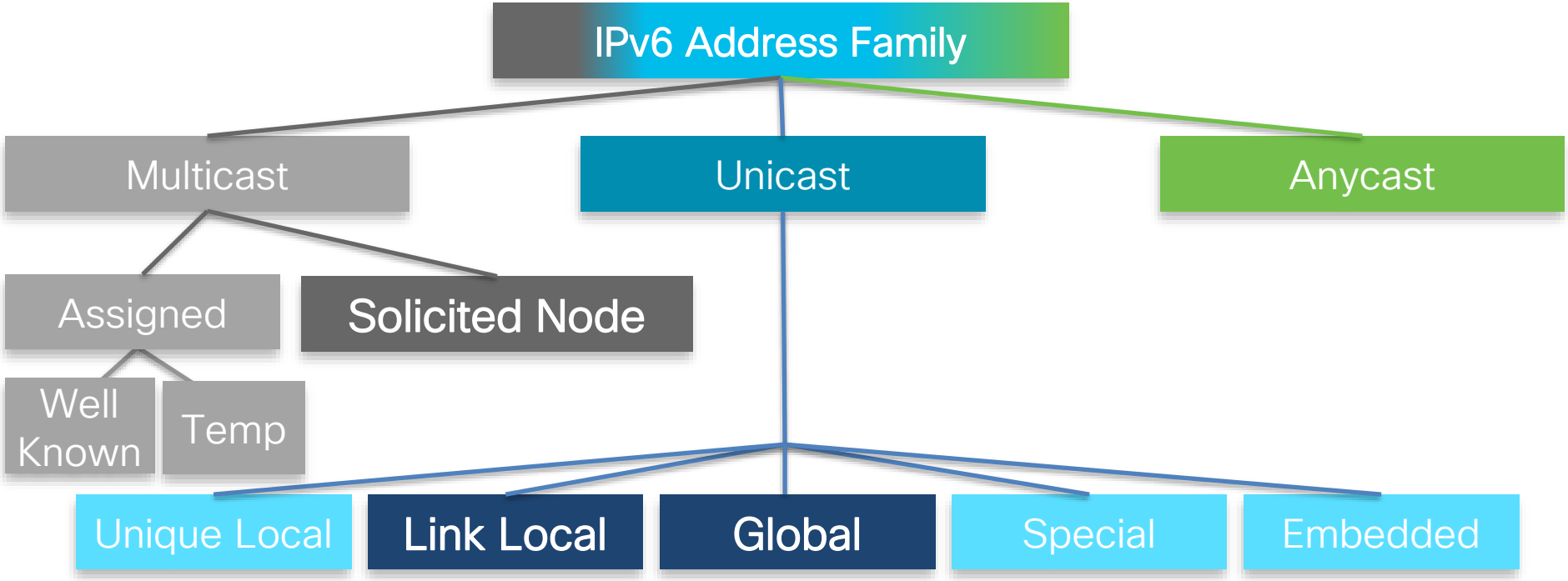
IPv6 Node Types

- Node: Any device that implements an IPv6 protocol stack
- Host: A device with one or more interfaces participating in IPv6 network
- Router: A device that forwards packets and provides provisioning services



Address's & Headers

IPv6 Addressing



*IPv6 does not use broadcast addressing

Hexadecimal Is Really Not That Difficult

- 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	256's	16's	1's
0	5	2		3	4
1	7	2		a	c
5	8	9	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) 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

Explaining BIG Numbers With Math

- The standard LAN size has been set at a /64
  - 18,446,744,073,709,600,000 IPv6 addresses
- Let's attempt to exhaust all of the available addresses
  - We will allocate 10,000,000 addresses per second
  - Hint: there are 31,536,000 seconds per year
  - 10,000,000 x 31,536,000 = 315,360,000,000,000

18,446,744,073,709,600,000

/ 315,360,000,000,000

= 58,494 years

Attribution: Ed Horley

IPv6 Unicast Address Types

Link-Local – Non routable exists on a layer 2 domain (**fe80**::/10)

fe80:0000:0000:0000:xxxx:xxxx:xxxx:xxxx

Unique-Local – Routable within administrative domain (**fc**00::/7)

fc00:~~~~:~~~~:**:**xxxx:xxxx:xxxx:xxxx**

fd00:~~~~:~~~~:**:**xxxx:xxxx:xxxx:xxxx**

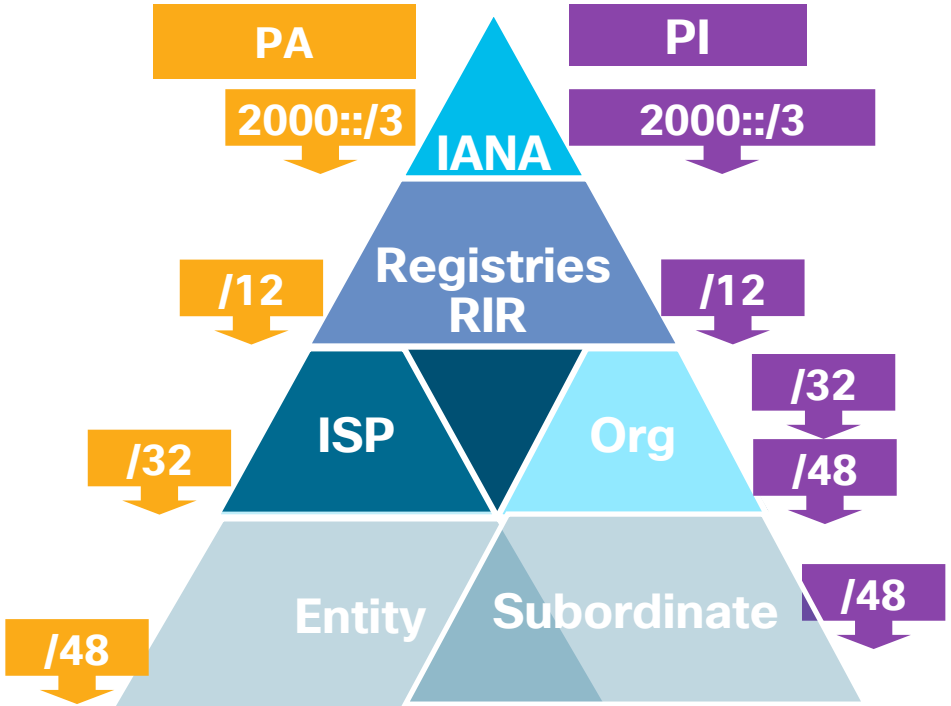
Global – Routable across the Internet (**2000::/3**)

2000:**:****:****:**xxxx:xxxx:xxxx:xxxx**

3fff:**:****:****:**xxxx:xxxx:xxxx:xxxx**

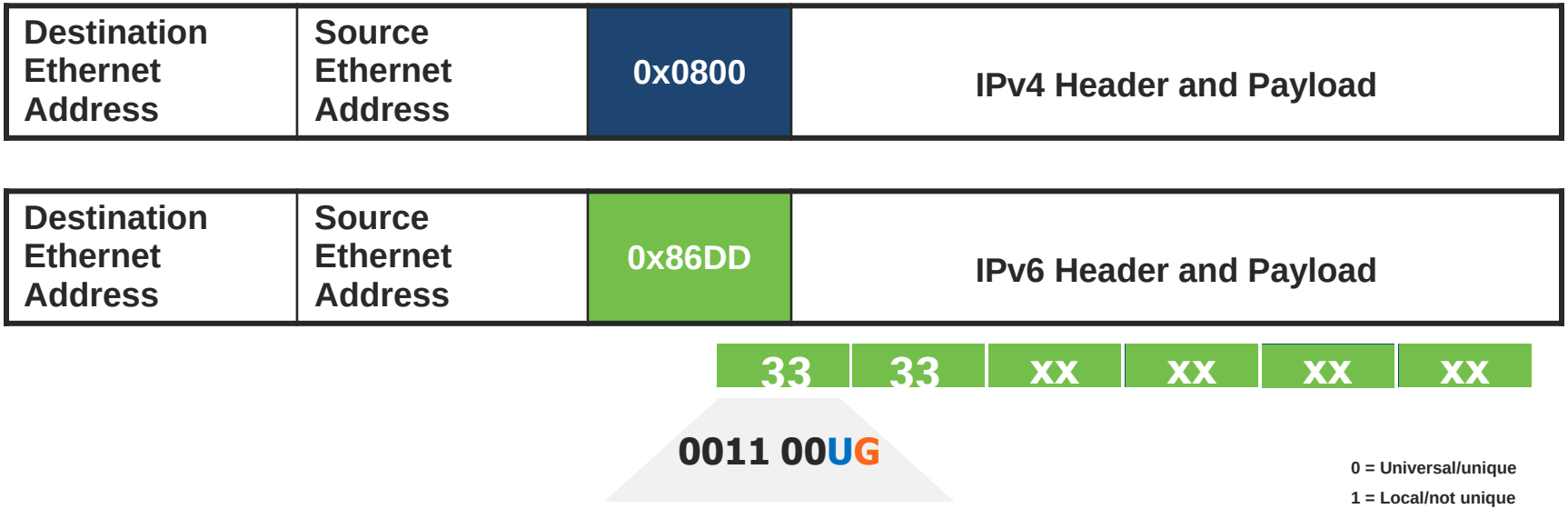
Global Address Assignment

- Provider Allocated (PA)
  - From your ISP, single homed
  - /48 - /60
- Provider Independent (PI)
  - Multi home, Multi provider
  - /32 - /48
- Local Internet Registry (LIR)
  - Regional registry member
  - Acquire & manage space
  - /29 - /48



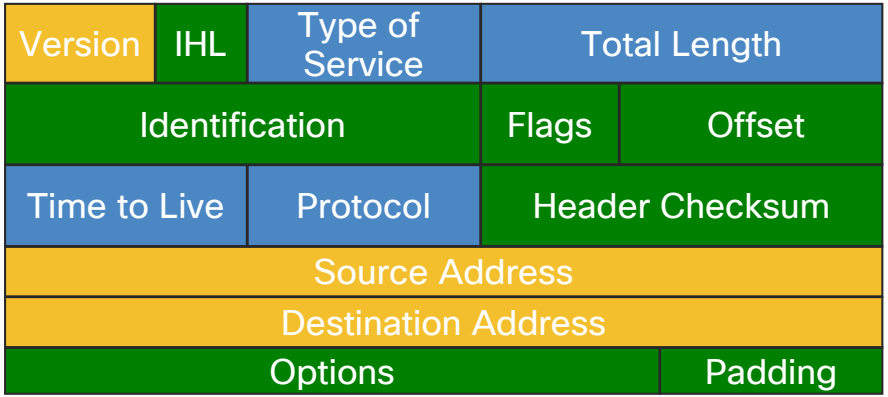
IPv6 over Ethernet

- IPv6 has a specific Ether type id
- IPv6 relies heavily on Multicast

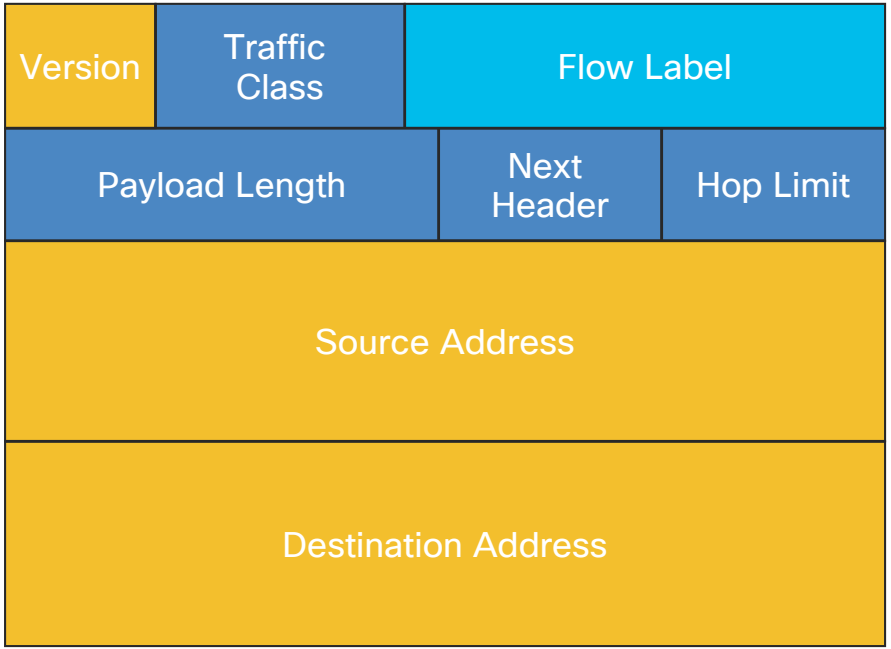


IPv4 and IPv6 Header Comparison

IPv4 Header (20-60)



IPv6 Header (40)

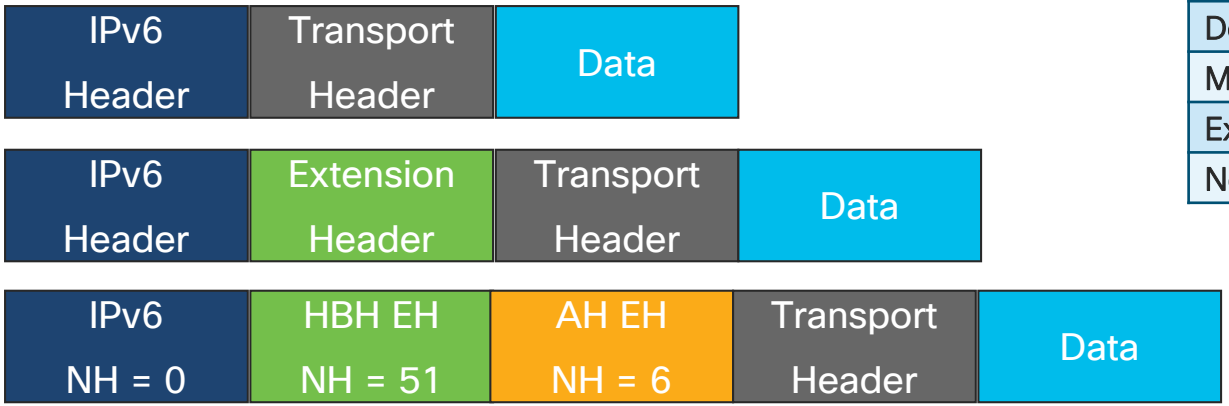


- Length was variable
- Fields in green are removed
- Options appear in extension headers
- Upper layer checksums use Pseudo Header format: SRC/DST + Next Header

Extension Headers (~ Layer 3.5)

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

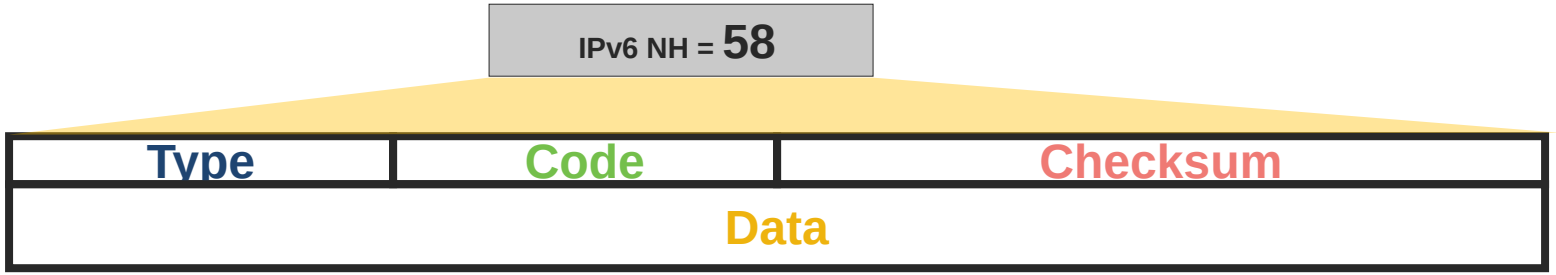
Extension Header	Type
Hop-by-Hop Options	0
Destination Options	60
Routing Header	43
Fragment Header	44
Authentication Header	51
ESP Header	50
Destination Options	60
Mobility Header	135
Experimental	253,254
No Next Header	59



ICMPv6 Messages

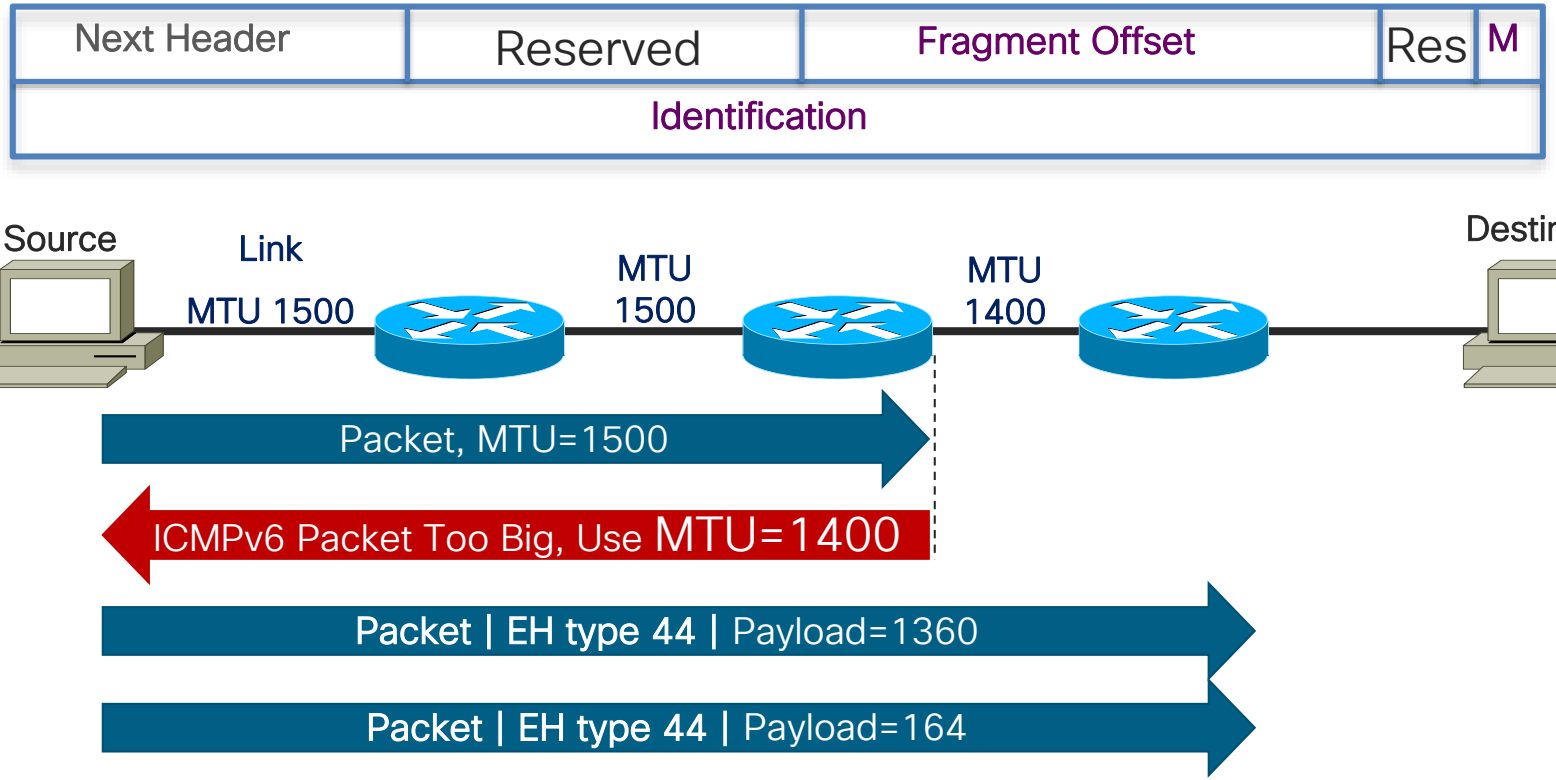
- Neighbor or router discovery (133-137)
- Multicast Listener Discovery (130-132, 143)
- Diagnostics using Ping, Traceroute (128, 129)

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



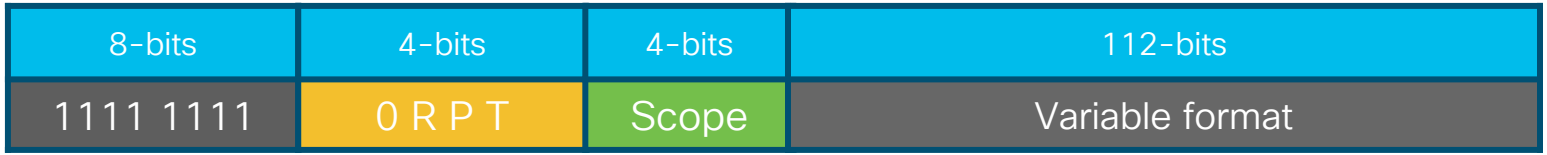
- Type – (0-127) = Error messages, 128-255 Informational messages
- Code – More granularity within the type
- Checksum – Computed over the entire ICMPv6 & pseudo header
- Data – Contents of “offending”, filled to 1280B (error) or specific message format (info)

Path MTU Discovery



IPv6 Multicast Address (RFC 4291)

- Prefix ff00::/8
- Changes based on flag settings
  - Typically the last 32 bits of host's unicast address



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 Temporary address

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

Unicast:
2001:db8:46::426:c001

Multicast:
ff0e::426:c001

Special Use Addresses (RFC 5156)

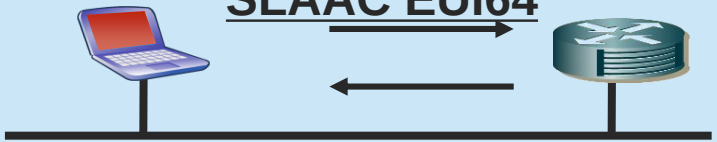
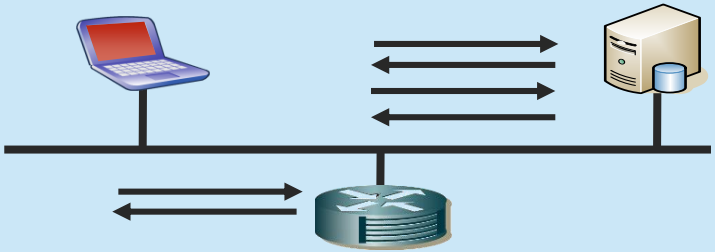
- Localhost
  - 0:0:0:0:0:0:0:1=> ::1
- Unspecified address
  - 0:0:0:0:0:0:0:0=> 0::0 => :: => ::/128
- Documentation Prefix
  - 2001:0db8::/32
- Discard Prefix
  - 0100::/64
- 6to4 Automatic Tunneling
  - 2002::/16
- Default Route
  - ::/0





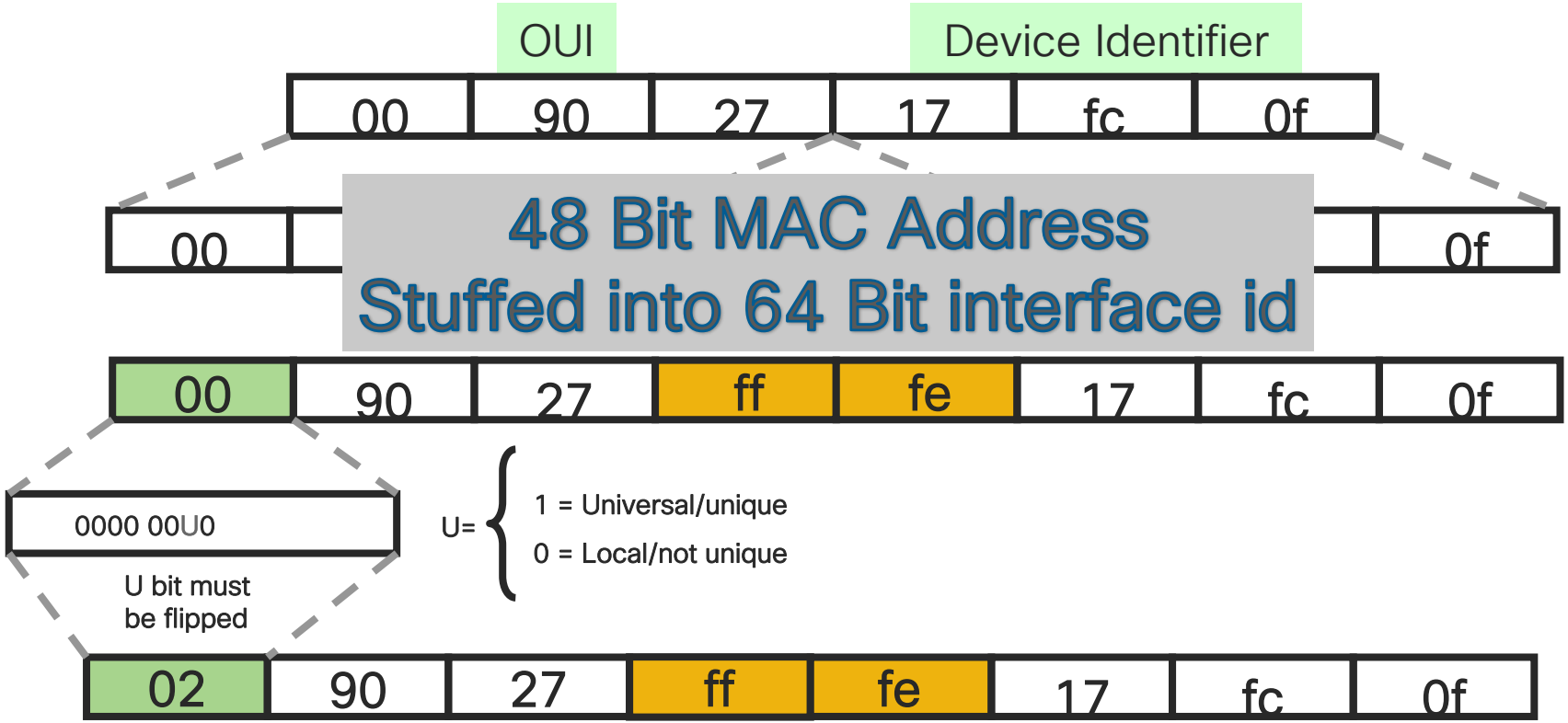

Interface ID’s

IPv6 Interface id Assignment

Similar to IPv4	New in IPv6
Manually configured 	StateLess Address AutoConfiguration SLAAC EUI64 
Assigned via DHCPv6 	SLAAC Privacy Extensions 

*Secure Neighbor Discovery SeND

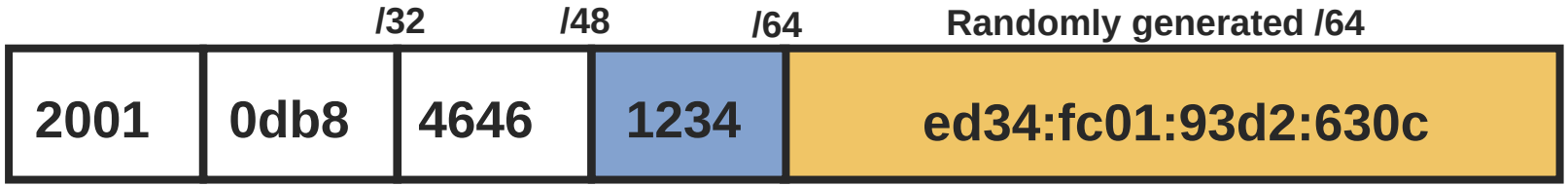
Extended Unique Identifier (EUI64)



IPv6 Privacy Extensions (RFC 4941)

- Generated on unique 802 using MD5, then stored for next iteration
- Enabled by default in Windows, Android, iOS, Mac OS/X, Linux
- Temporary or Ephemeral addresses for client application (web browser)

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



DHCPv6

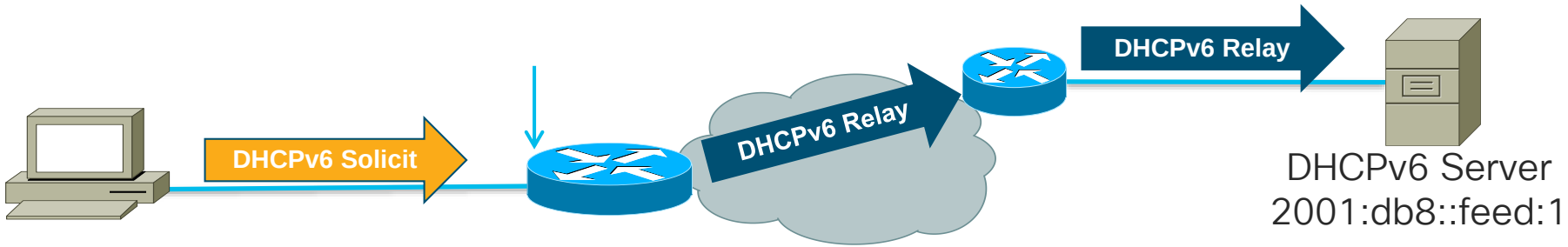
- Source – fe80::1234, Destination – ff02::1:2
- Client UDP 546, Server UDP 547
- DUID – Different from v4, used to identify clients
- Original Multicast encapsulated in unicast **(relay)**
- ***ipv6 dhcp relay destination*** 2001:db8::feed:1

SOLICIT (any servers) →

← ADVERTISE (want this address)

REQUEST (I want that address) →

← REPLY (It's yours)

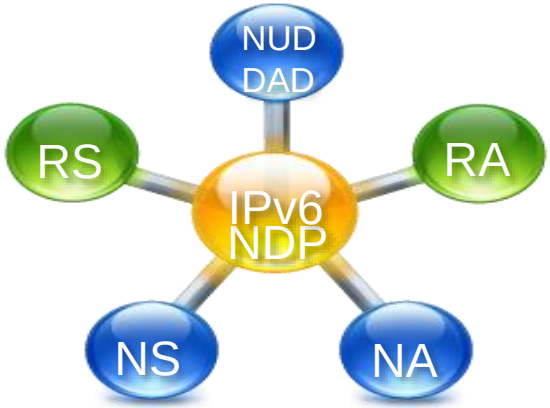


Link Operations

Neighbor Discovery Protocol – (NDP)

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

- Neighbor discovery messages
  - Router solicitation (ICMPv6 type 133)
  - Router advertisement (ICMPv6 type 134)
  - Neighbor solicitation (ICMPv6 type 135)
  - Neighbor advertisement (ICMPv6 type 136)
  - Redirect (ICMPv6 type 137)



IPv4	IPv6
ARP Request	Neighbor Solicitation
ARP Reply	Neighbor Advertisement
Broadcast	Solicited Node Multicast

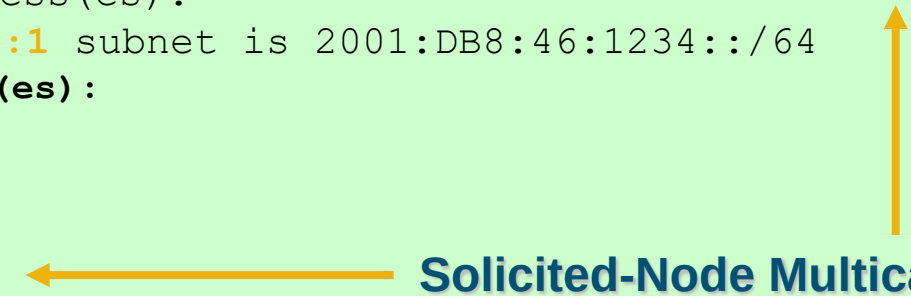
Solicited Node Multicast

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

IPv6 Source	fe80::04cb:57ff:fe**3c:deca**
IPv6 Destination	ff02::1:ff**3c:deca**
Ethernet Destination	33-33-FF-**3C-DE-CA**
Ethernet Source	02-CB-57-**3C-DE-CA**

Solicited Node Multicast Example

```
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
```



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

Neighbor Solicitation & Advertisement

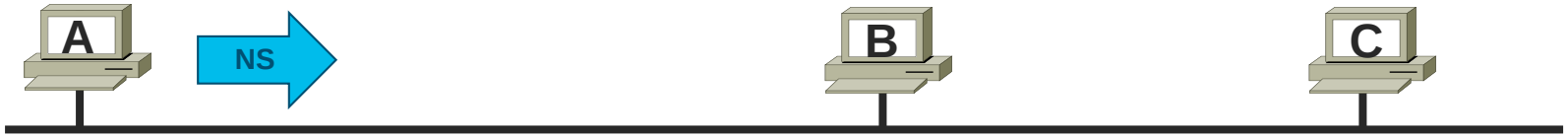
- Node A needs to resolve node B's link address, Map's L3 to L2
- Multicast for resolution (new), Unicast for reachability (cache)
- Node B will add node A to its neighbor cache during this process w/o sending NS

ICMPv6 Type	135 NS
IPv6 Source	fe80::a
IPv6 Destination	ff02::1:ff00: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)

- Unspecified Source (::), No Option 1 SLLA
- Probing the Local Link to Verify Address Uniqueness
- Microsoft uses a variant known as Optimistic DAD



ICMPv6 Type	135 NS
IPv6 Source	UNSPEC = ::
IPv6 Dest.	A Solicited Node Multicast ff02::1:ff00:a
Query	Anyone Using “a”

Node A can start using address A

Router Solicitation and Advertisement

- Router solicitations (RS) are sent by nodes at boot up
- 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
- Options – Prefix Information, Length, Flags
- L bit – Only way a host get a On Link Prefix
- A bit – Set to 0 for DHCP to work properly

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)
.... 1… = No Auto (A Bit)
Prefix: 2001:0db8:4646:1234::/64

Host OS’s

Router Advertisement Sent

```
▽ Internet Control Message Protocol v6
    Type: Router Advertisement (134)
    Code: 0
    Checksum: 0x1a4d [correct]
    Cur hop limit: 64
  ▽ Flags: 0x00
      0... .... = Managed address configuration: Not set
      .0.. .... = Other configuration: Not set
      ..0. .... = Home Agent: Not set
      ...0 0... = Prf (Default Router Preference): Medium (0)
      .... .0.. = Proxy: Not set
      .... ..0. = Reserved: 0
    Router lifetime (s): 180
    Reachable time (ms): 0
    Retrans timer (ms): 0
  ▷ ICMPv6 Option (Recursive DNS Server 2001:558:feed::1)
  ▽ ICMPv6 Option (Prefix information : 2601:
      Type: Prefix information (3)
      Length: 4 (32 bytes)
      Prefix Length: 64
    ▷ Flag: 0xc0
      Valid Lifetime: 300
      Preferred Lifetime: 300
      Reserved
      Prefix: 2601:
  ▷ ICMPv6 Option (Source link-layer address : 00:50:f1:00:00:00)
```

2001:db8:46:1::/64

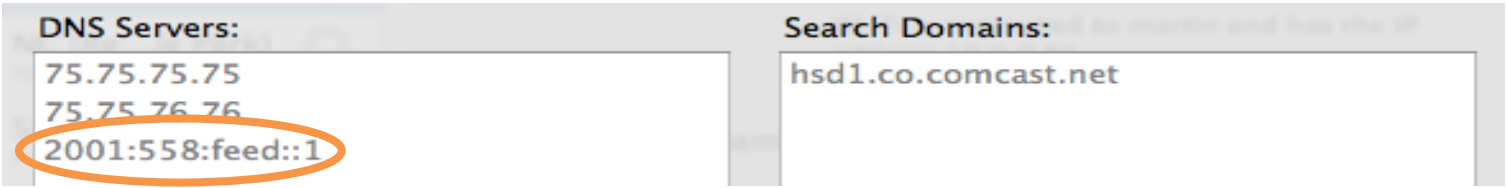
2001:db8:46:1::

(2001:db8:46:1::)

OSX Host Address Acquisition

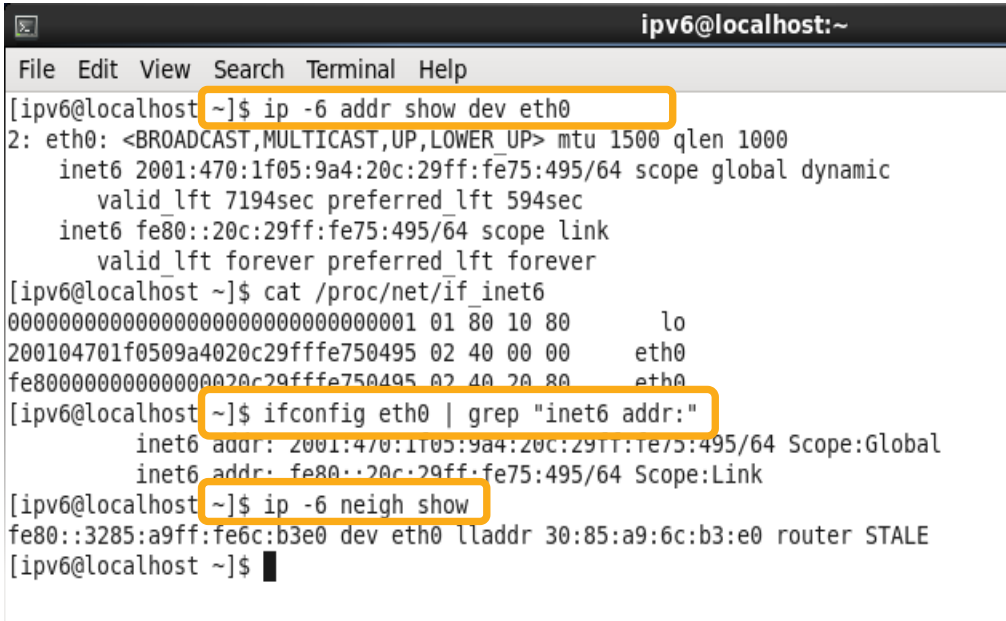
- Effect of the Router Advertisement from previous slide
  - Preferred & valid lifetimes
  - DNS server information

```
tmartin# ifconfig -L
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether b8:e8:56:19:f3:8a
        inet6 fe80::bae8:5642:ce19:f38a%en0 prefixlen 64 scopeid 0x4
        inet6 2001:db8:46:1:1809:5618:fa19:f38a prefixlen 64 autoconf pltime 267 vltime 267
        inet6 2001:db8:46:1:883e:b6a2:863:e31b prefixlen 64 autoconf temp pltime 267 vltime 267
        nd6 options=201<PERFORMNUD ,DAD>
```



Linux, Ubuntu IPv6 Basics

- Check an IPv6 address
  - ip -6 addr show dev eth0
- Check an IPv6 address
  - ifconfig eth0 | grep “inet6 addr:”
- Check for IPv6 neighbors
  - ip -6 neigh show
- Ping6 2001:db8:4:6::c001:d00d
  - Windows:> ping fe80::250:e1ff:fec3:1**%17**
  - Unix$ ping6 fe80::250:e1ff:fec3:1**%en0**



Windows Host Address Acquisition

```
C:\Documents and Settings\>netsh
netsh>interface ipv6
netsh interface ipv6>show address
Querying active state...
Interface 5: Local Area Connection
Addr Type  DAD State  Valid Life   Pref. Life   Address
---------  ---------- ------------ ------------ ----------------------------
Public     Preferred  29d23h58m25s  6d23h58m25s 2001:db8:4646:1:4f02:8a49:41ad:a136
Temporary  Preferred   6d21h48m47s       21h46m 2001:db8:4646:1:bd86:eac2:f5f1:39c1
Link       Preferred      infinite     infinite fe80::4f02:8a49:41ad:a136

netsh interface ipv6>show route
Querying active state...
Publish  Type       Met  Prefix                    Idx  Gateway/Interface Name
-------  --------  ----  ------------------------  ---  --------------------
no       Autoconf     8  2001:db8:4646:1::/64        5  Local Area Connection
no       Autoconf   256  ::/0                        5  fe80::20d:bdff:fe87:f6f9
```

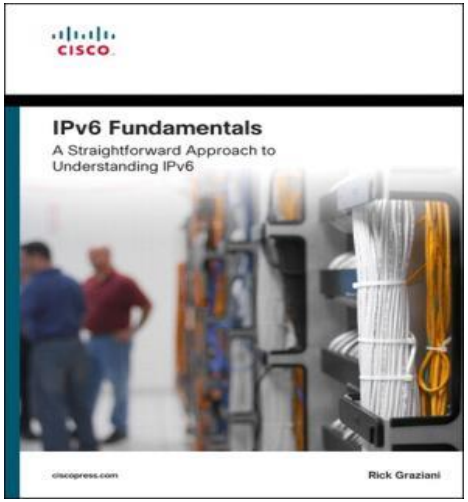
Agenda

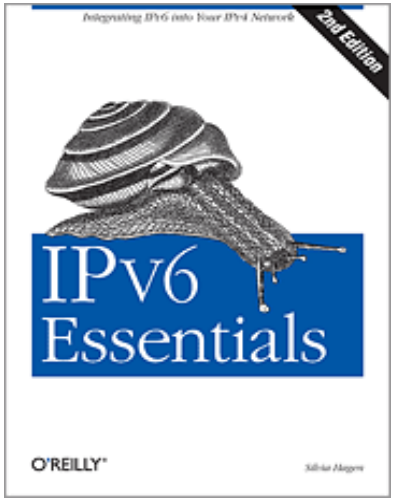
- IPv6 Addresses & Headers
- IPv6 Address Assignment
- IPv6 Link Operations
- IPv6 Host Address Acquisition
- Conclusion

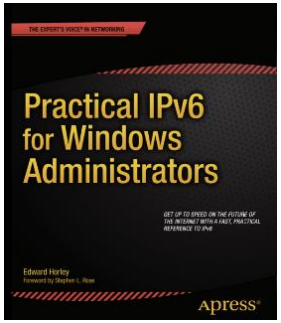
Key Take Away

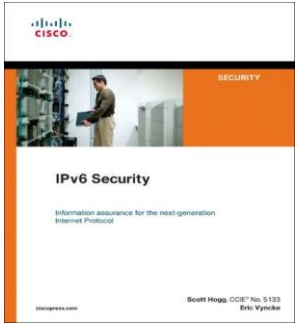
- Gain Operational Experience now
- Control IPv6 traffic as you would IPv4
- **Lead** your OT/LOB's into the Internet

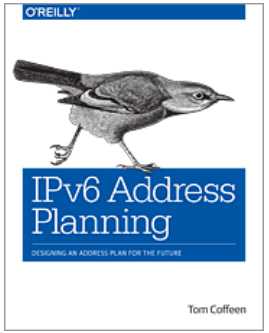
Recommended Reading











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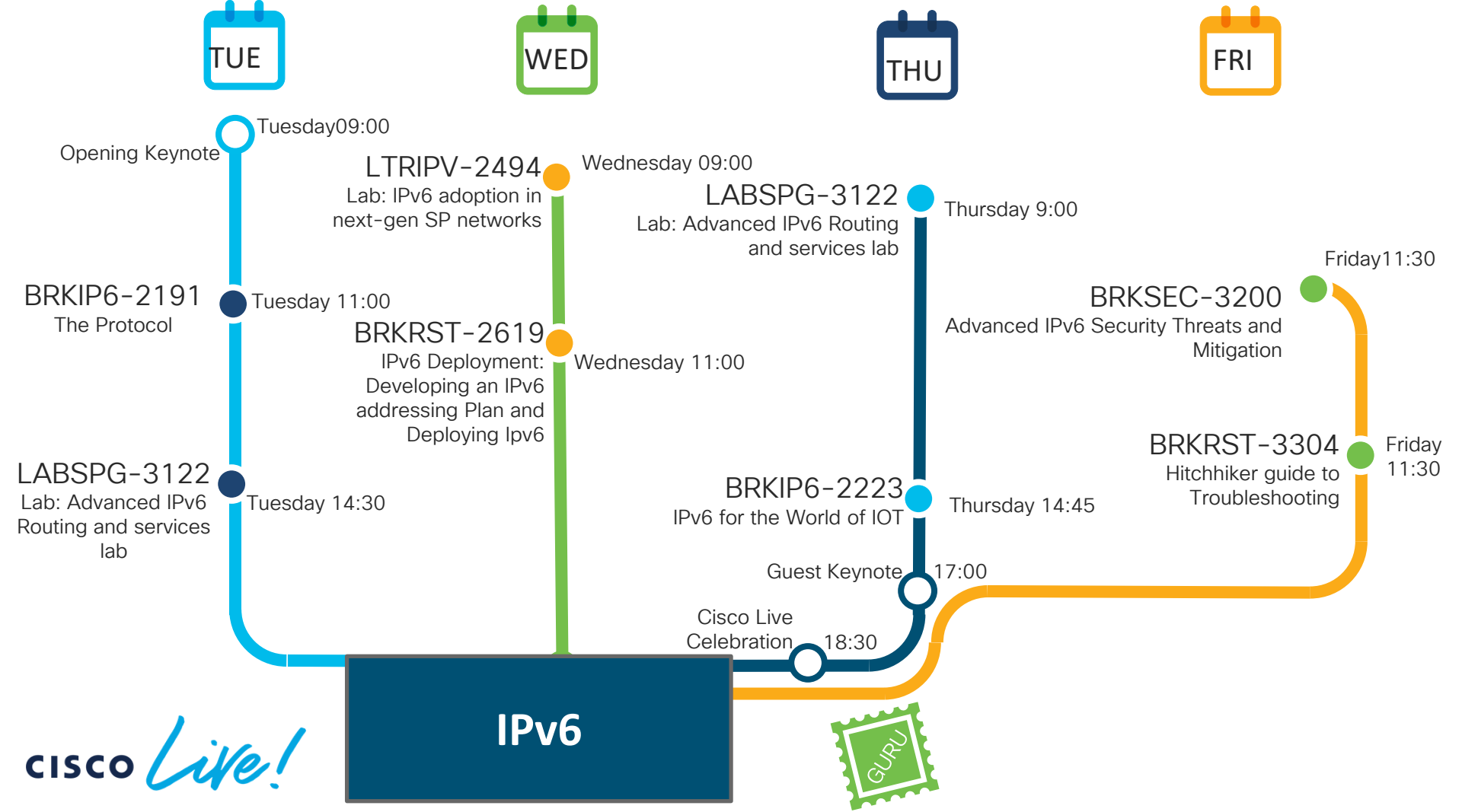
TUE
WED
THU
FRI
Tuesday09:00
Opening Keynote
LTRIPV-2494
Lab: IPv6 adoption in next-gen SP networks
Wednesday 09:00
LABSPG-3122
Lab: Advanced IPv6 Routing and services lab
Thursday 9:00
Friday11:30
BRKSEC-3200
Advanced IPv6 Security Threats and Mitigation
BRKIP6-2191
The Protocol
Tuesday 11:00
BRKRST-2619
IPv6 Deployment: Developing an IPv6 addressing Plan and Deploying Ipv6
Wednesday 11:00
BRKRST-3304
Hitchhiker guide to Troubleshooting
Friday 11:30
LABSPG-3122
Lab: Advanced IPv6 Routing and services lab
Tuesday 14:30
BRKIP6-2223
IPv6 for the World of IOT
Thursday 14:45
Guest Keynote
17:00
Cisco Live Celebration
18:30
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