



IPv6

Stateless Operations Explored

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IPv6 Stateless Operation Goals

- Simple
 - Plug-and-play
 - Quick
 - No manual addressing of hosts
 - Generate routable address (es)
- Automate network address renumbering
- Self Healing / Maintenance-free
- IT SHOULD JUST WORK!

Can't I do this today with IPv4?

IPv4 a victim of its own Success

- IPv4 addresses consumed at an alarming rate
- IPv4 System administration
 - Manual configuration of Addresses or use of Dynamic Host Configuration Protocol (DHCP)
 - Labor intensive and error prone
 - Not easy to setup and maintain
 - Not simple!
 - Usually requires NAT
- Security is optional; no single standard

IPv6 Addresses Explored

- Addresses assigned to interfaces (*)
- Interfaces typically have multiple addresses
- Subnets associated with single link (*)
- IPv6 addresses have scope and lifetime
- (*) No change from IPv4 model
- Unicast: For a single I/F
- Multicast: For a set of I/F
 - A packet is delivered to ALL interfaces identified by this address
- Anycast: For a set of I/F
 - A packet is delivered to ONE of the interfaces identified by this address
- Unlike IPv4, IPv6 does not define a broadcast address
 - Use multicast

IPv6 Addresses Explored

- IPv6 supports notion of “**scoped**” addresses
- Scoped unicast addresses
 - Link scope, site scope



- Scoped multicast addresses
 - 16 scopes including node, link, site, organization, and global

- Addresses
 - Are leased to an interface
 - Have a Valid and Preferred **lifetime**
- Router advertises “preferred” and “valid” lifetimes
 - “Preferred” address - Unrestricted use
 - “Deprecated” address - Use is discouraged

Preferred Lifetime

Valid Lifetime

← Preferred → ← Deprecated →

IPv6 Automatic Connectivity

- Provides Network plug-and-play
 - Link Local Address Creation
 - No Router or Server required
 - Stateless mechanism
 - Router advertisements provide prefix
 - Stateful mechanism
 - Server provides address
- Simplified Network Administration
 - Lower network maintenance
- Easy Renumbering - Designed to happen!
 - Improved Competition and an end of ISP "lock in"!

IPv6 Neighbor Discovery

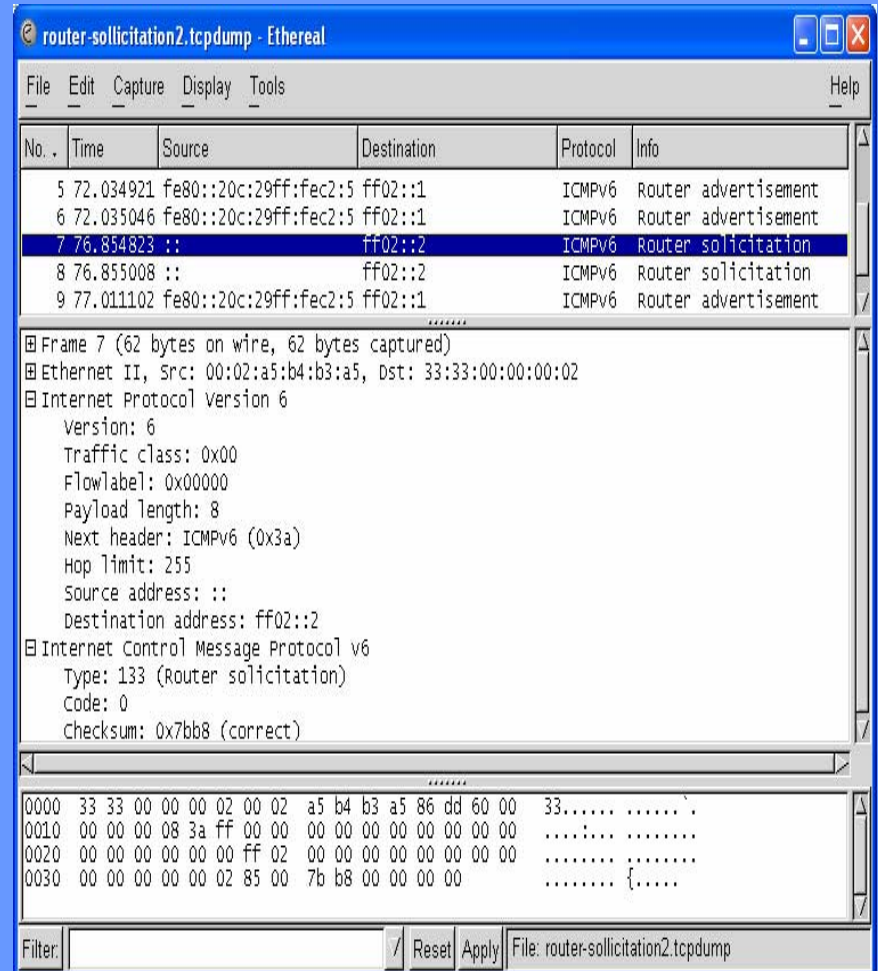
- Used to:
 - Discover presence of other nodes on the Link
 - Determine datalink-layer addresses for other nodes
 - Find routers
 - Maintain reachability information about the paths to active neighbors
 - Obtain link configuration parameters
- Integral part of IPv6
 - Must be implemented on every node

IPv6 Neighbor Discovery Comparison with IPv4

- Combines features
IPv4 ARP + ICMP Router Discovery + ICMP Redirect
- Provides improvements over IPv4:
 - Router Discovery is part of the base protocol set
 - Neighbor Unreachability Detection
 - Address resolution at ICMP layer above the IP layer
 - Can use IPsec mechanisms
 - Router Advertisements Carry
 - link-layer addresses, prefixes for a link
 - advertise an MTU for hosts to use on the link

IPv6 Router Solicitation

- Host sends a multicast Router solicitation when an interface is enabled
 - To discover IPv6 routers present on the link
 - To request an immediate Router advertisement
 - Sent to All-Router Multicast Address
 - Source link layer address of sender may be sent as an option



The screenshot shows a Wireshark capture window titled "router-solicitation2.tcpdump - Ethereal". The main display area shows a list of captured packets. Packet 7 is highlighted, showing an ICMPv6 Router solicitation. The packet details pane shows the following information:

| No. | Time | Source | Destination | Protocol | Info |
|-----|-----------|-----------------------|-------------|----------|----------------------|
| 5 | 72.034921 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 6 | 72.035046 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 7 | 76.854823 | :: | ff02::2 | ICMPv6 | Router solicitation |
| 8 | 76.855008 | :: | ff02::2 | ICMPv6 | Router solicitation |
| 9 | 77.011102 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |

Packet 7 details:

- Frame 7 (62 bytes on wire, 62 bytes captured)
- Ethernet II, Src: 00:02:a5:b4:b3:a5, Dst: 33:33:00:00:00:02
- Internet Protocol Version 6
 - Version: 6
 - Traffic class: 0x00
 - Flowlabel: 0x00000
 - Payload length: 8
 - Next header: ICMPv6 (0x3a)
 - Hop limit: 255
 - Source address: ::
 - Destination address: ff02::2
- Internet Control Message Protocol v6
 - Type: 133 (Router solicitation)
 - Code: 0
 - Checksum: 0x7bb8 (correct)

The packet bytes pane shows the raw data in hexadecimal and ASCII:

```
0000 33 33 00 00 00 02 00 02 a5 b4 b3 a5 86 dd 60 00 33.....
0010 00 00 00 08 3a ff 00 00 00 00 00 00 00 00 00 00 .....
0020 00 00 00 00 00 00 ff 02 00 00 00 00 00 00 00 00 .....
0030 00 00 00 00 00 02 85 00 7b b8 00 00 00 00 ..... {.....
```

IPv6 Router Advertisement

- Router multicasts periodically (or on demand) its availability
- Router advertisements carry
 - Lifetime as a default router
 - Managed flag to inform hosts how to perform Address Autoconfiguration
 - List of prefixes used for a link
 - Link-layer address
 - Advertise an MTU for hosts to use on the link

The screenshot shows a Wireshark capture of an IPv6 Router Advertisement packet. The packet list pane shows six packets, all of which are Router advertisements. The packet details pane shows the structure of the advertisement, including the ICMPv6 options section with three prefix information options. The packet bytes pane shows the raw data of the packet.

| No. | Time | Source | Destination | Protocol | Info |
|-----|-----------|-----------------------|-------------|----------|----------------------|
| 1 | 0.000000 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 2 | 0.000132 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 3 | 30.488813 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 4 | 30.488935 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 5 | 63.066934 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |
| 6 | 63.067057 | fe80::20c:29ff:fec2:5 | ff02::1 | ICMPv6 | Router advertisement |

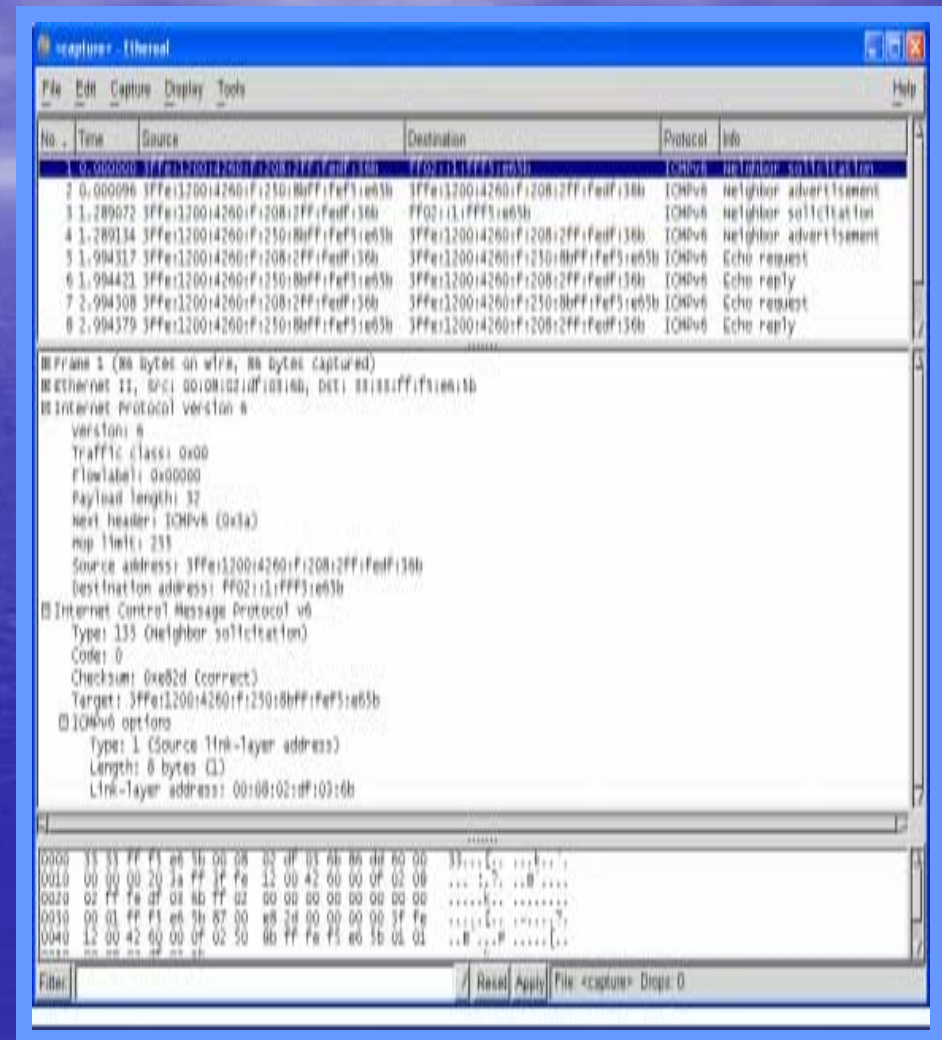
Frame 1 (110 on wire, 110 captured)

- Ethernet II
- Internet Protocol Version 6
- Internet Control Message Protocol v6
 - Type: 134 (Router advertisement)
 - Code: 0
 - Checksum: 0xa011 (correct)
 - Cur hop limit: 64
 - Flags: 0x00
 - Router lifetime: 120
 - Reachable time: 0
 - Retrans time: 0
 - ICMPv6 options
 - Type: 3 (Prefix information)
 - Length: 32 bytes (4)
 - Prefix length: 64
 - Flags: 0xc0
 - Valid lifetime: 0x00278d00
 - Preferred lifetime: 0x00093a80
 - Prefix: 3ffe:1200:4260:f::

0000 33 33 00 00 00 01 00 0c 29 c2 52 ff 86 dd 60 00 33.....).R...
0010 00 00 00 38 3a ff fe 80 00 00 00 00 00 02 0c ...8:.....
0020 29 ff fe c2 52 ff ff 02 00 00 00 00 00 00 00)...R...
0030 00 00 00 00 00 01 86 00 a0 11 40 00 00 78 00 00@..x..
0040 00 00 00 00 00 00 03 04 40 c0 00 27 8d 00 00 09@.....

IPv6 Neighbor Solicitation

- Sent to request the Link Layer address of a target host
- Unicast-ed to target host during Neighbor Unreachability Detection (NUD)
- Multicast-ed to target host during address resolution
- Used for Duplicate Address Detection (DAD)



IPv6 Neighbor Advertisement

- Sent as a response to a Neighbor Solicitation
- Sent as needed in order to update other host neighbor cache

The screenshot shows a Wireshark capture of network traffic. The main pane displays a list of captured packets. Packet 4 is selected, showing its details in the right pane. The packet is an IPv6 Neighbor Advertisement (NA) packet, which is a response to a Neighbor Solicitation (NS) packet. The details pane shows the following information:

- Ethernet II, Src: 00:10:00:00:00:00, Dst: 00:10:00:00:00:00
- Internet Protocol version 6
 - version: 6
 - Traffic class: 0x00
 - Flow label: 0x00000
 - Payload length: 32
 - Next header: ICMPv6 (0x3a)
 - Hop limit: 255
 - Source address: ffe1:2001:4260:f201:0fff:fe5:ae5b
 - Destination address: ffe1:2001:4260:f201:0fff:fe5:ae5b
- Internet Control Message Protocol v6
 - Type: 136 (Neighbor advertisement)
 - code: 0
 - checksum: 0xf72a (correct)
 - Flags: 0x60000000
 - Target: ffe1:2001:4260:f201:0fff:fe5:ae5b
 - ICMPv6 options
 - Type: 2 (Target link-layer address)
 - Length: 8 bytes (1)
 - Link-layer address: 00:10:00:00:00:00

The packet bytes pane at the bottom shows the raw data of the packet in hexadecimal and ASCII format.

Router Redirect

- Sent by a router to inform a host of a better first hop on the path to the destination
- Used to inform if the destination is a neighbor

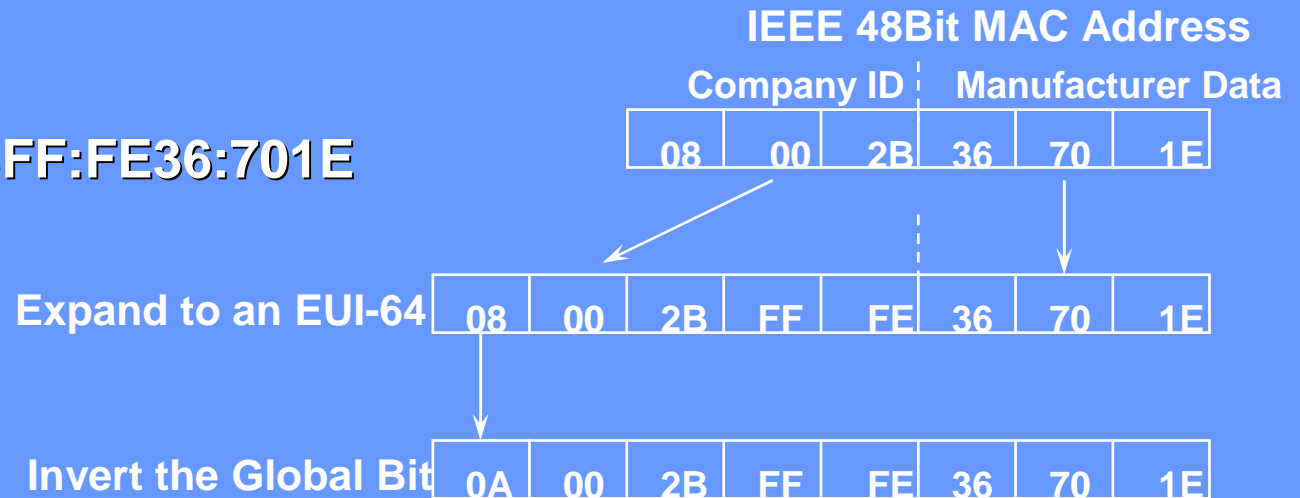
Address Autoconfiguration Process

1. Create a Link Local Address
 - No router or server required
2. Determine whether Addresses should be obtained via Stateless or Stateful mechanism or both
 - Stateless mechanism
 - Router advertisements provide prefix
 - Stateful mechanism
 - Server provides address (for example via DHCPv6)

IPv6 Link Local Address Creation

- Link-Local address is formed by appending token to the architecturally defined Link-Local prefix FE80::/10
 - See IPv6-over-x specs for details on how to form the Interface Identifier
- Interface ID based on EUI-64
 - Constructed from a Global Token E.g. IEEE 48-bit MAC Address With the “global” bit inverted

FE80::0A00:2BFF:FE36:701E



IPv6 Stateless Address Autoconfiguration

- Routers advertise prefixes that identify the subnet(s) associated with a link
- Hosts generate an "interface token" that uniquely identifies an interface on a subnet.
- An address is formed by combining the two.

IPv6 Stateful Address Autoconfiguration

- Clients obtain address and / or configuration from a DHCP server
- DHCP server maintains the database and has a tight control over address assignments.
- Host sends DHCP Solicit
 - DHCPv6 Multicast Address
- Agent replies with DHCP Advertisement

Policy Stateless or Stateful?

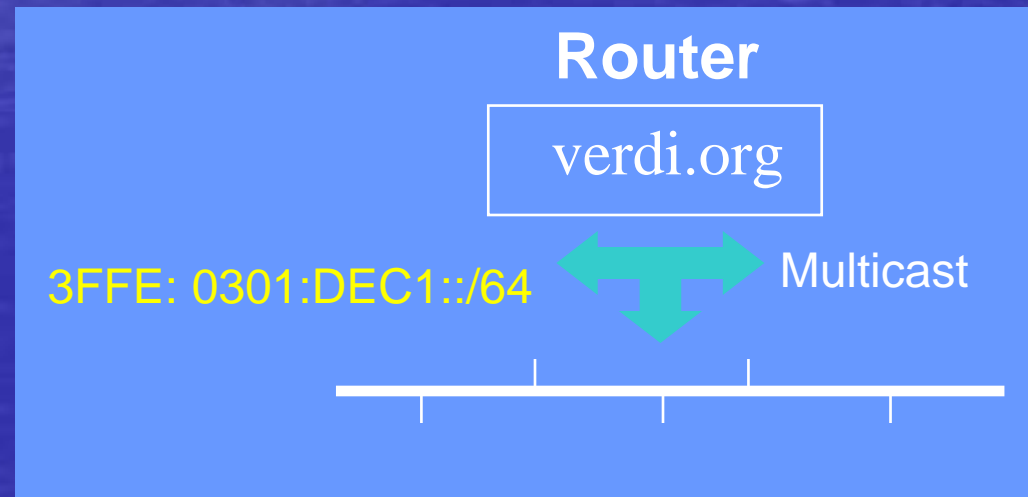
- Site administrator specifies which type of autoconfiguration to use
 - through setting / clearing a switch on the ICMPv6 Router Advertisement (M bit)
- Stateless and Stateful can Coexist
 - For example:
 - Addresses could come from Stateless
 - Additional Configuration Information could be provided by DHCPv6

IPv6 Stateless Operations Explored

- Prefix Advertisement
- Prefix Discovery
- Tentative Address Formation
- Duplicate Address Detection
- Address Resolution

Prefix Advertisement

- Router configured with the appropriate prefix(es)
 - & with associated lifetime for each prefix
- Router sends Router Advertisement
 - periodic and on-demand



Prefix Discovery

- Host sends Router Solicitation
 - To All-Routers Multicast Address
- Routers send Router Advertisement
 - Flags L bit (on-link), A bit (Autonomous)
 - Prefix(es) Information
 - Associated lifetimes
 - Preferred Lifetime
 - Valid Lifetime

Forming Tentative Address

- Host uses the prefix to form a tentative address
- For safety Duplicate address Detection algorithm should be performed

3FFE:0301:DEC1::/64



0A00:2BFF:FE36:701E

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IPv6 Address: 3FFE:0301:DEC1::0A00:2BFF:FE36:701E

Duplicate Address Detection (DAD)

- Used during Address Acquisition
- Stateless
 - DAD is performed only on Link-Local address
 - thus is not in critical path in large-scale-renumbering
- Stateful
 - all address should be tested for uniqueness.
- DAD can be disabled
 - But adds little or no overhead

DAD Operation

- Used to verify uniqueness of the tentative address
 - Host join All-Nodes-multicast (FF02::1) and Solicited-Node-multicast of the tentative address.
 - Transmit Neighbor solicitation with tentative address as a target address
 - If Neighbor Advertisement received
 - Address in use cannot be assigned to the interface
 - No response assume address is unique and available

Duplicate Address Detection Solicited Node Neighbor Solicitation

Ethernet Header

Dst Mac Address 33-33-FF-36-70-1E

IPv6 Header

Src Address ::

Dst Address FF02::1:FF36:701E

Hop Limit 255

ICMPv6 Header

Target Address FE80::0A00:2BFF:FE36:701E

Mac Address 08-00-FE-36-70-1E

Link Local (tentative)

FE80::0A00:2BFF:FE36:701E

All Nodes Multicast FF02::1

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Multicast Solicited Node Neighbor Solicitation

Mac Address 08-00-FE-36-70-1E

Mac Address Multicast 33-33-FF-36-70-1E

Link Local FE80::0A00:2BFF:FE36:701E

Solicited Node Multicast Address FF02::1:FF36:701E

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Duplicate Address Detection Multicast Neighbor Advertisement

| |
|--|
| Ethernet Header |
| Dst Mac Address 33-33-00-00-00-01 |
| IPv6 Header |
| Src Address FE80::0A00:2BFF:FE36:701E |
| Dst Address FF02::1 |
| Hop Limit 255 |
| ICMPv6 Header |
| Target Address FE80::0A00:2BFF:FE36:701E |

Mac Address 08-00-FE-36-70-1E
Link Local (tentative)
FE80::0A00:2BFF:FE36:701E
All Nodes Multicast FF02::1

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Multicast Neighbor Advertisement

Mac Address 08-00-FE-36-70-1E
Mac Address Multicast 33-33-FF-36-70-1E
Link Local FE80::0A00:2BFF:FE36:701E
Solicited Node Multicast Address FF02::1:FF36:701E

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Address Resolution Neighbor Solicitation

Ethernet Header

Dst Mac Address 33-33-FF-36-70-1E

IPv6 Header

Src Address FE80::200:F8FF:FE21:E530

Dst Address FF02::1:FF36:701E

Hop Limit 255

ICMPv6 Header

Target Address FE80::0A00:2BFF:FE36:701E

Option Src Link Layer 00-00-FE-21-E5-30

Mac Address 00-00-FE-21-E5-30

Link Local

FE80::200:F8FF:FE21:E530

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Multicast Neighbor Solicitation

Mac Address 08-00-FE-36-70-1E

Mac Address Multicast 33-33-FF-36-70-1E

Link Local FE80::0A00:2BFF:FE36:701E

Solicited Node Multicast Address FF02::1:FF36:701E

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Address Resolution Neighbor Advertisement

Ethernet Header

Dst Mac Address 00-00-FE-21-E5-30

IPv6 Header

Src Address FE80::A00:2BFF:FE36:701E

Dst Address FF80::200:F8FF:FE21:E530

Hop Limit 255

ICMPv6 Header

Target Address FE80::0A00:2BFF:FE36:701E

Option Target Link Layer 00-00-FE-36-70-1E

Mac Address 00-00-FE-21-E5-30

Link Local

FE80::200:F8FF:FE21:E530

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Unicast Neighbor Advertisement

Mac Address 08-00-FE-36-70-1E

Mac Address Multicast 33-33-FF-36-70-1E

Link Local FE80::A00:2BFF:FE36:701E

Solicited Node Multicast Address FF02::1:FF36:701E

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Automatic Renumbering

- Renumbering IPv6 hosts is easy
 - Add a new prefix to the router
 - Reduce the lifetime of the old prefix
 - As nodes deprecate the old prefix, they begin using the new prefix for new connections
 - No network downtime
- Renumbering IPv6 routers
 - New protocol: Router Renumbering
- Use both to renumber entire site

Additional Considerations for Auto Configuration

- Privacy Extensions for Auto Configuration?
- Dynamic Updates to DNS?
- Link-Local Address Name Resolution?

IPv6 Benefit - Life Is Easier for Operations

- Better manageability
- IPv6 address scope
 - GLOBAL or LOCAL
- Configuration Policy Control
 - Stateless
 - Stateful (DHCPv6)
 - Routers dictating configuration policy and MTU size for the link

IPv6 Value Proposition

Engineered to Perform and Protect

IPv4

- Uses a 32-bit address
- Running out of internet addresses
- Security was an add-on
- System management is complex and slow
- Incredibly successful
- 20 + years old



IPv6

- Uses 128-bit addressing
- Enough address space to give every human on the planet a unique IP address
- Mandatory and effective IP security
- Less Infrastructure Maintenance and complexity required
- More efficient Mobile IP = seamless service availability
- Architecture of the future = Next Generation internet protocol

IPv6 Impact on the Communications Industry

- Complexity is reduced
- Optimal conditions for continued evolution of the Internet
 - To provide seamless Internet connectivity anytime, anywhere, always-on
 - To provide as many pervasive services as possible to as many users as possible
- New End-to-End Applications can now evolve again

Internet End-to-End
+ Pervasive Services
+ New Applications
+ Reduced Cost
= Profit



December 2003



“Remember TIMING is an important factor in any success story”

IPv6 Everything is possible

Questions?