



**RIPE NCC**  
RIPE NETWORK COORDINATION CENTRE

# Basic IPv6

SEE11 - Tutorial

March 2023

# Overview



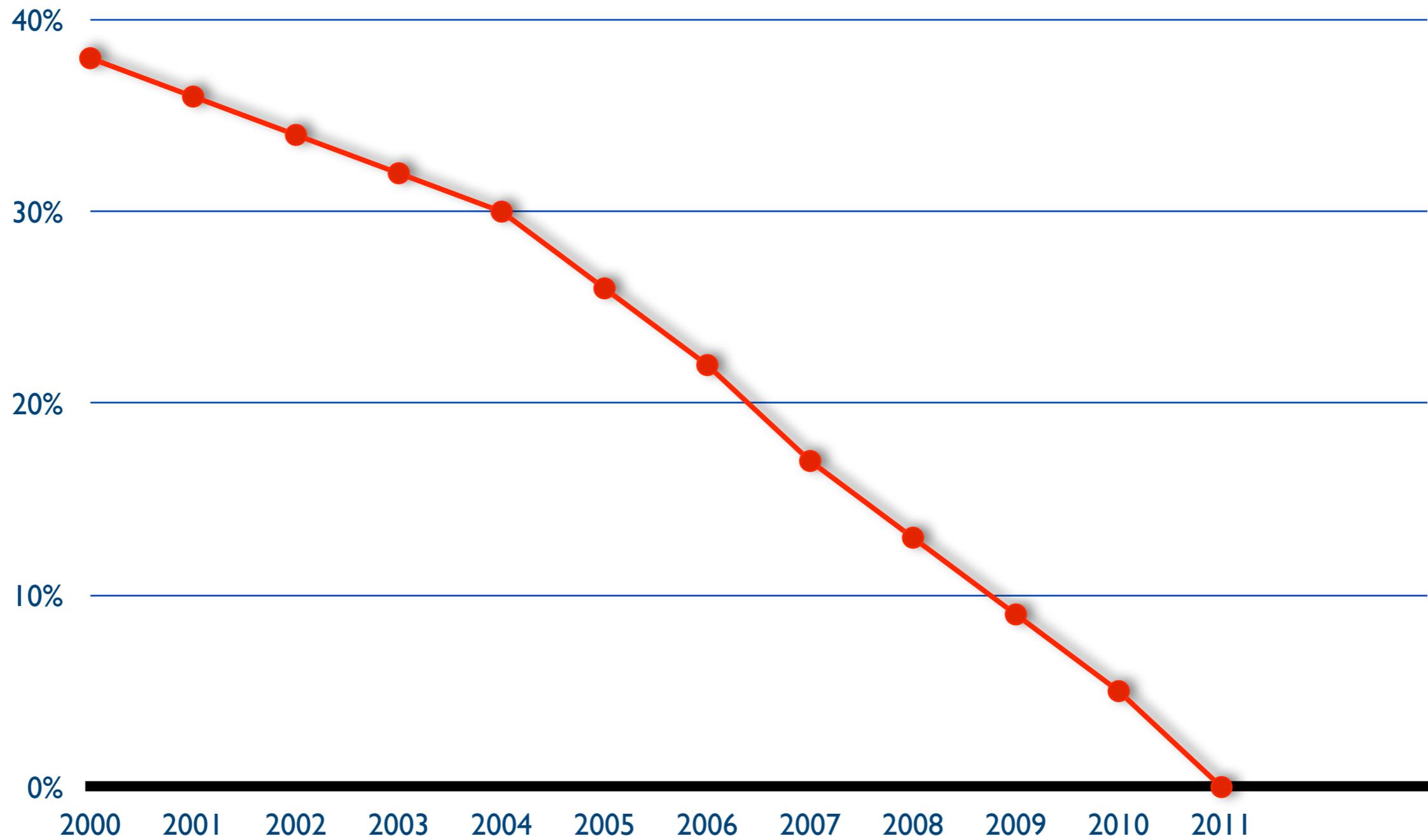
- Introduction
- IPv6 Address Basics
- Getting it
- IPv6 Protocol Basics
- Addressing Plan
- IPv6 Packets
- Deploying IPv6
- Tips



# IPv4?

## Section 1

# IANA IPv4 Pool



# IPv4 run-out



**“Today, at 15:35 (UTC+1) on 25 November 2019, we made our final /22 IPv4 allocation from the last remaining addresses in our available pool. We have now run out of IPv4 addresses.”**



# Our Reality: The Waiting List



1. Submit the IPv4 allocation request form at the LIR Portal (/24)
2. Wait

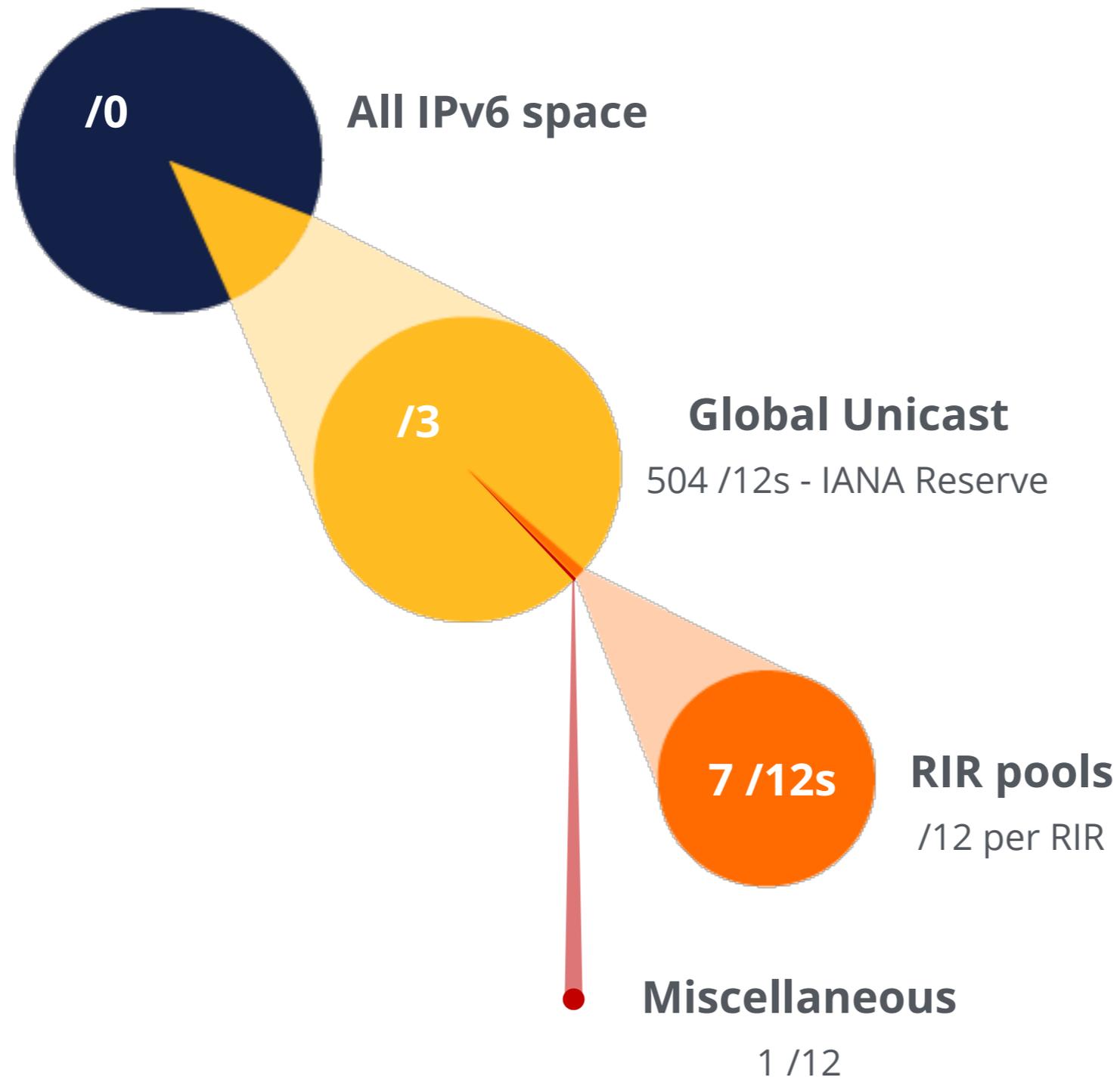




# IPv6 Address Basics

## Section 2

# IP Address Distribution



# RIR Pools



October 2006

RIR	IPv6 Range
<b>AFRINIC</b>	2C00:0000::/12
<b>APNIC</b>	2400:0000::/12
<b>ARIN</b>	2600:0000::/12
<b>LACNIC</b>	2800:0000::/12
<b>RIPE NCC</b>	2A00:0000::/12

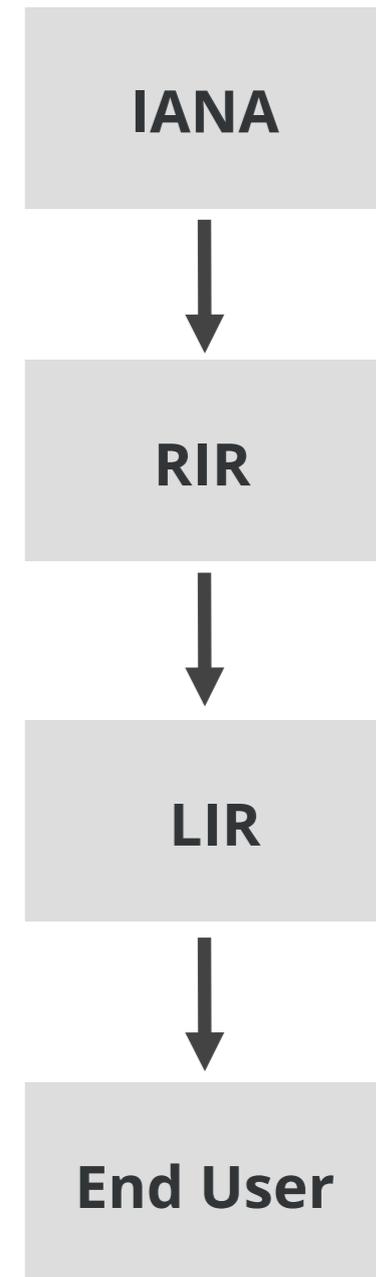
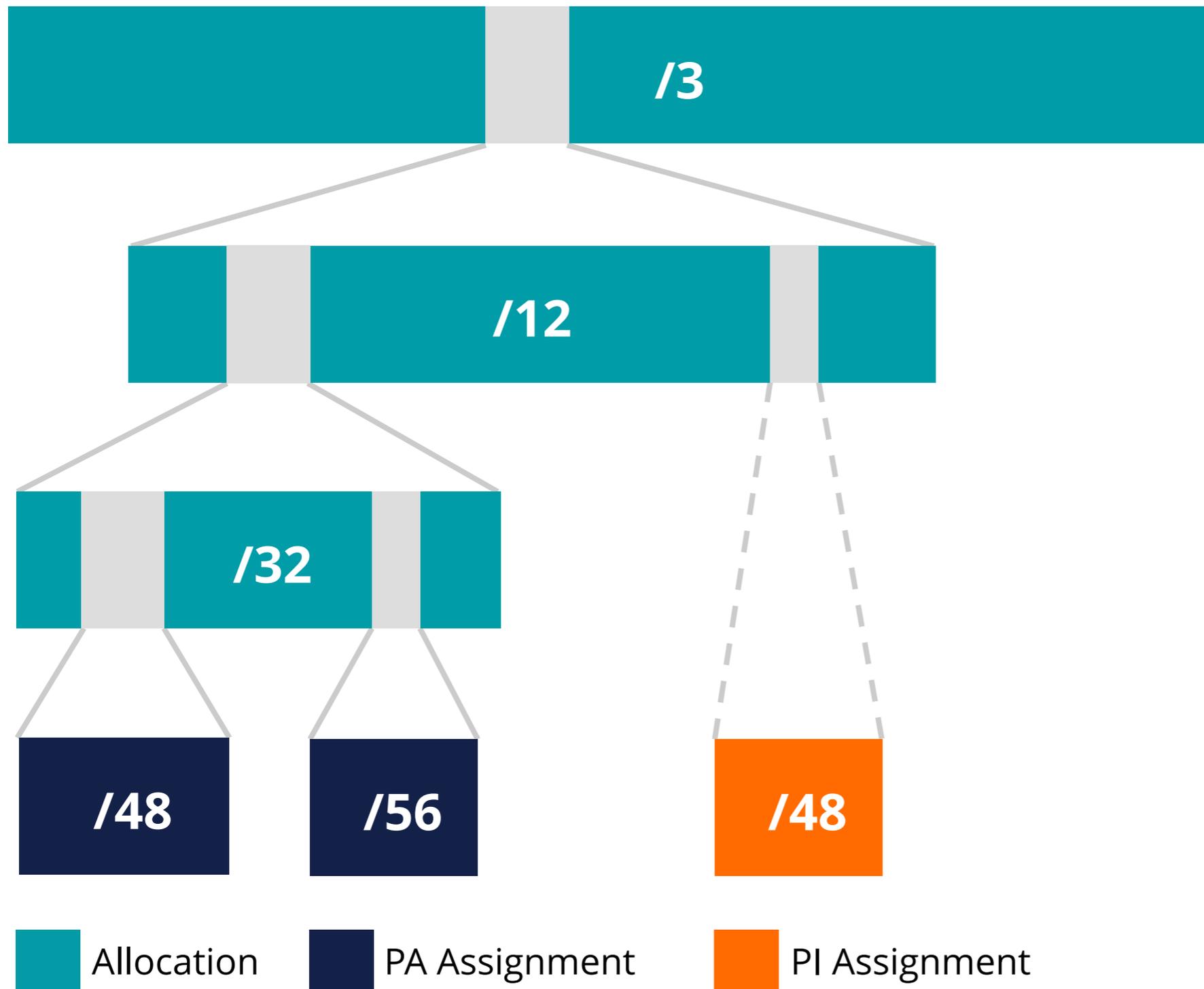
June 2019

<b>RIPE NCC</b>	2A10:0000::/12
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November 2019

<b>ARIN</b>	2630:0000::/12
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# IP Address Distribution





# IPv6 Address Basics

- IPv6 address: **128 bits**
  - 32 bits in IPv4
- Every subnet should be a **/64**
- Customer assignments (sites) between:
  - **/64** (1 subnet)
  - **/48** (65,536 subnets)
- Minimum allocation size **/32**
  - 65,536 /48s
  - 16,777,216 /56s

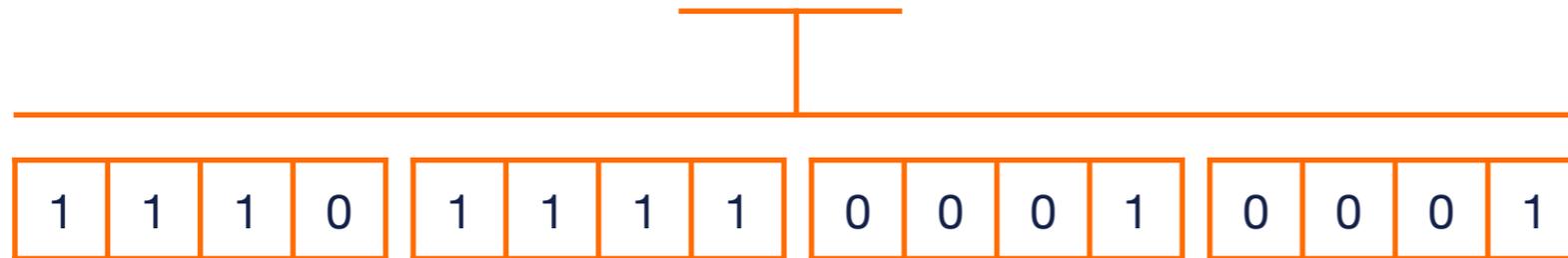
# Address Notation



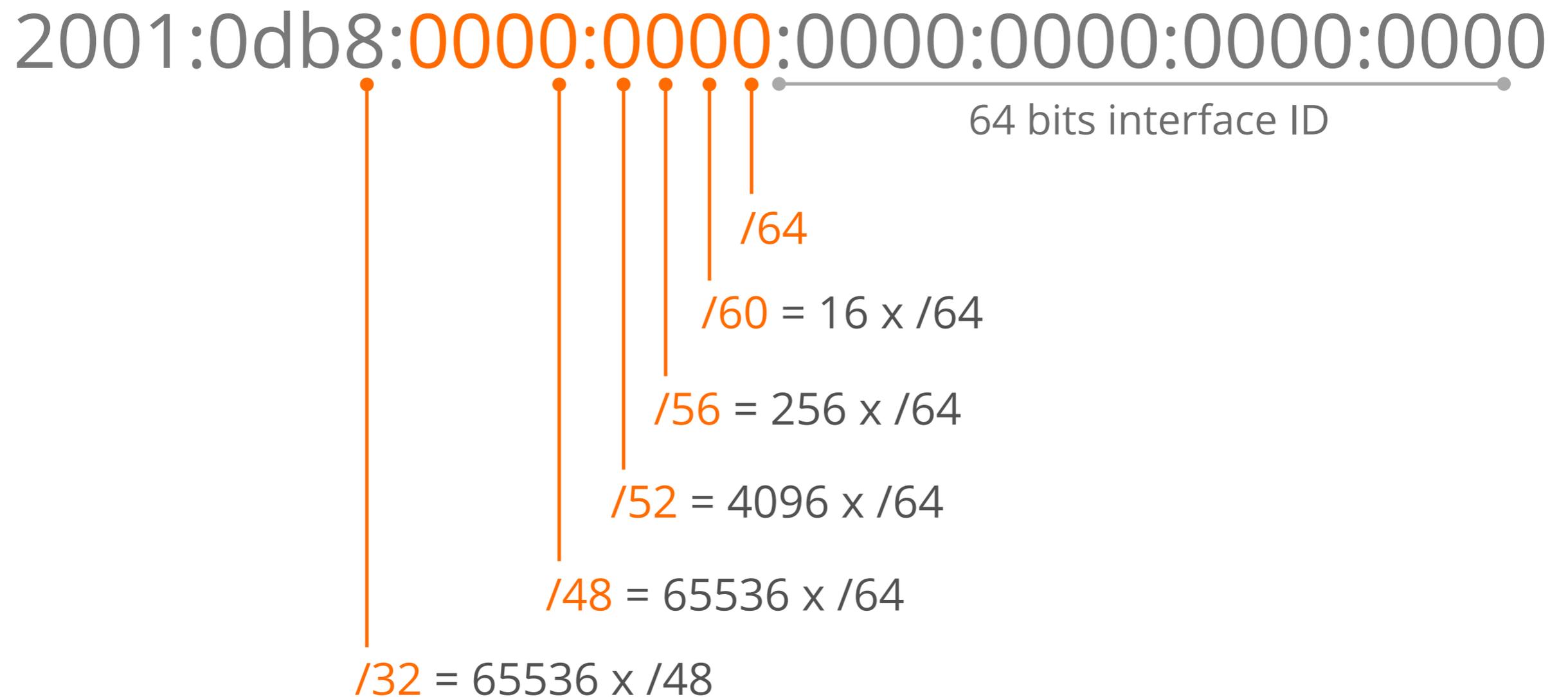
2001:0db8:003e:ef11:0000:0000:c100:004d

2001:0db8:003e:ef11:0000:0000:c100:004d

2001:db8:3e:ef11:0:0:c100:4d



# IPv6 Subnetting



# Multiple address types



Addresses	Range	Scope
Unspecified	::/128	n/a
Loopback	::1	host
IPv4-Embedded	64:ff9b::/96	n/a
Discard-Only	100::/64	n/a
Link Local	fe80::/10	link
<b>Global Unicast</b>	<b>2000::/3</b>	<b>global</b>
Unique Local	fc00::/7	global
Multicast	ff00::/8	variable





# Getting It

## Section 3



# Getting an IPv6 allocation

- To qualify, an organisation **must**:
  - Be an LIR
  - Have a plan for making assignments within two years
- Minimum allocation size **/32**
  - **Up to a /29** without additional justification
  - More if justified by customer numbers and network extension
  - Additional bits based on hierarchical and geographical structure, planned longevity and security levels



# Customer Assignments

- Give your customers enough addresses
  - **Minimum /64**
  - Up to /48
- Originally, for more than /48, send in request form
  - *RIPE Policy Proposal 2019-06 - LIR can create assignments larger than /48 without a request*
- Every assignment **must be registered** in the RIPE Database

# Comparison IPv4 and IPv6 status



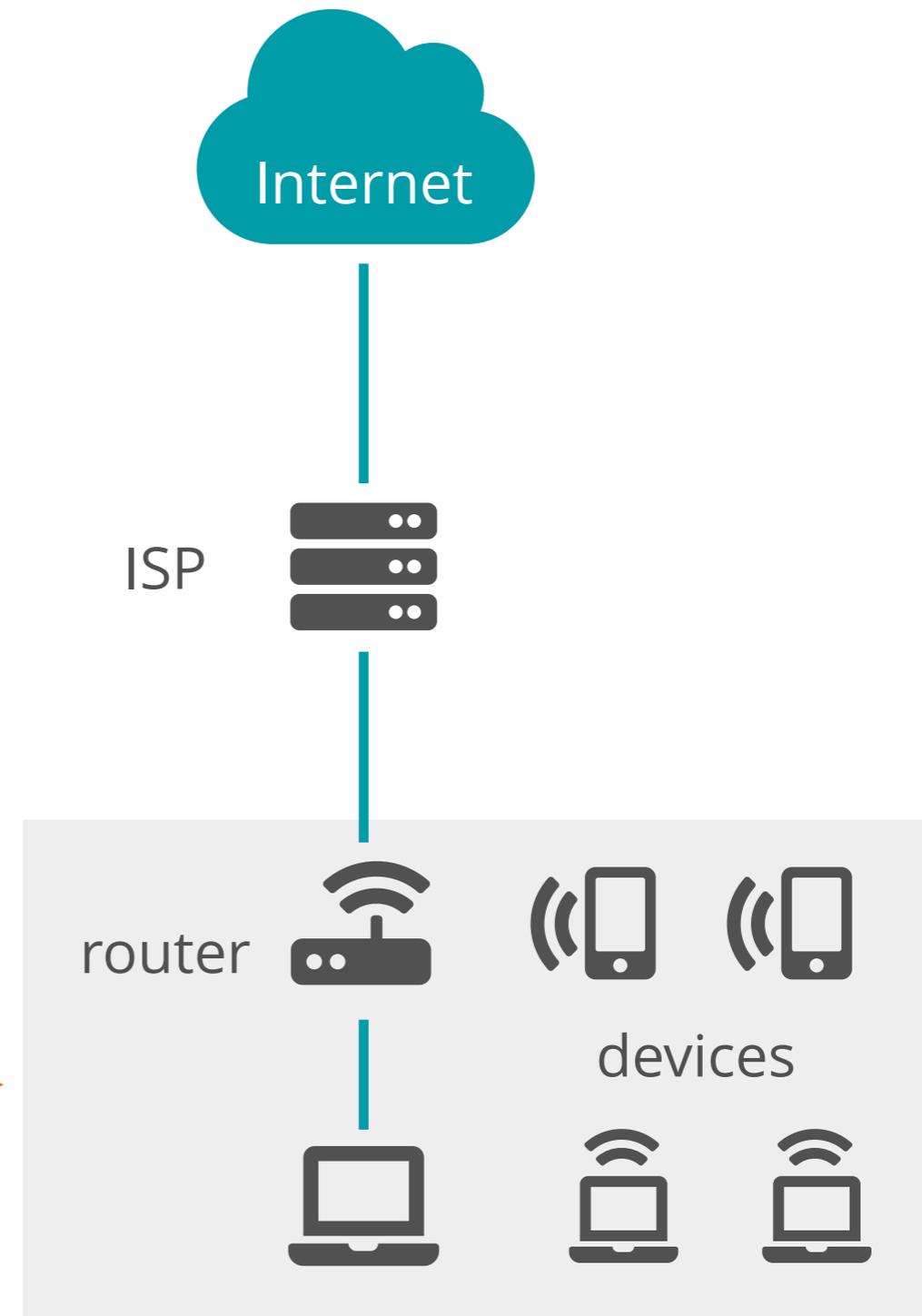
IPv4		IPv6
ALLOCATED PA	<b>Allocation</b>	ALLOCATED-BY-RIR
ASSIGNED PA	<b>Assignment</b>	ASSIGNED
	<b>Group of Assignments</b>	AGGREGATED-BY-LIR
SUB-ALLOCATED PA	<b>Sub-Allocation</b>	ALLOCATED-BY-LIR
ASSIGNED PI	<b>PI Assignment</b>	ASSIGNED PI



# Examples ASSIGNED

- One single network
- An individual customer
- Your own infrastructure

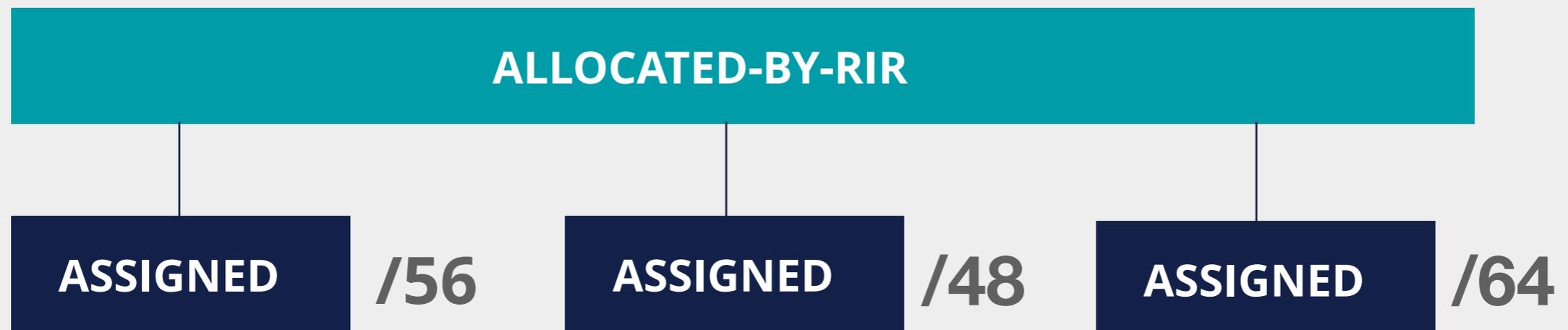
One assignment  
= 'ASSIGNED'



# Using ASSIGNED



- Represents one assignment
- Minimum assignment size is a /64



# Using ASSIGNED - Example Object



**inet6num: 2001:db8:1000::/48**

netname: CUSTOMER-NET

country: NL

admin-c: ADM321-RIPE

tech-c: NOC123-RIPE

**status: ASSIGNED**

mnt-by: LIR-MNT

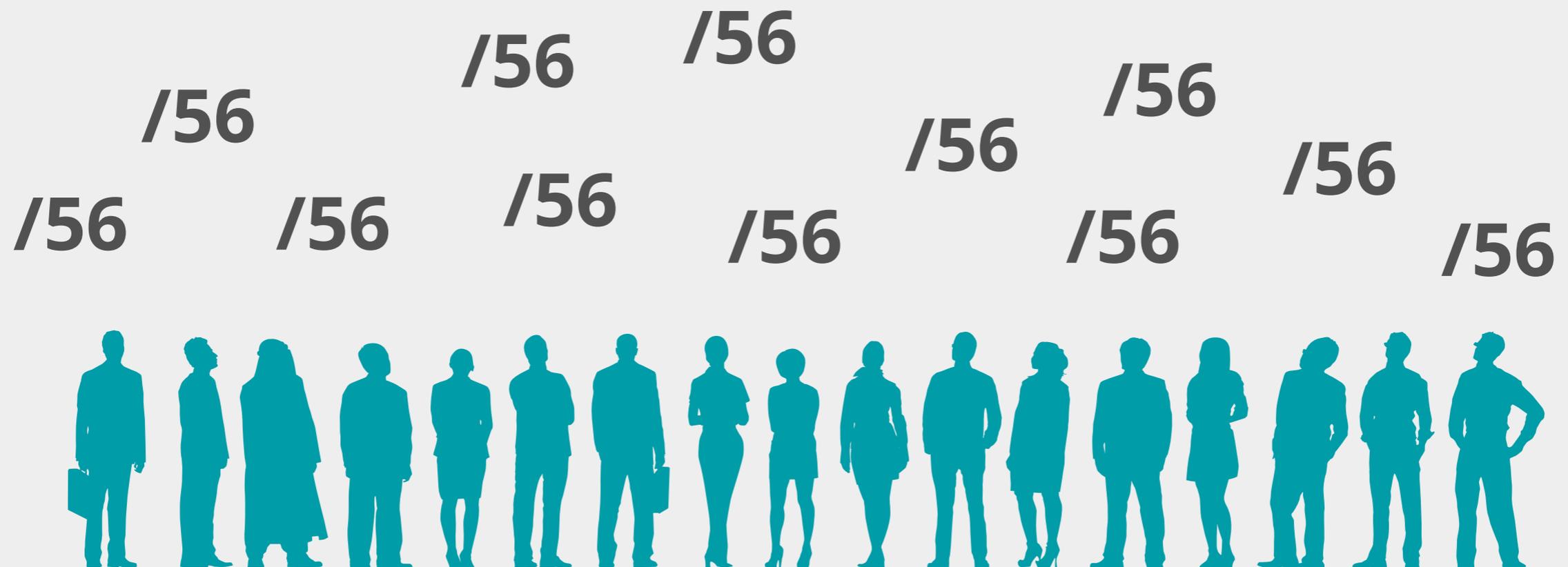
created: 2015-05-31T08:23:35Z

last-modified: 2015-05-31T08:23:35Z

# Examples AGGREGATED-BY-LIR



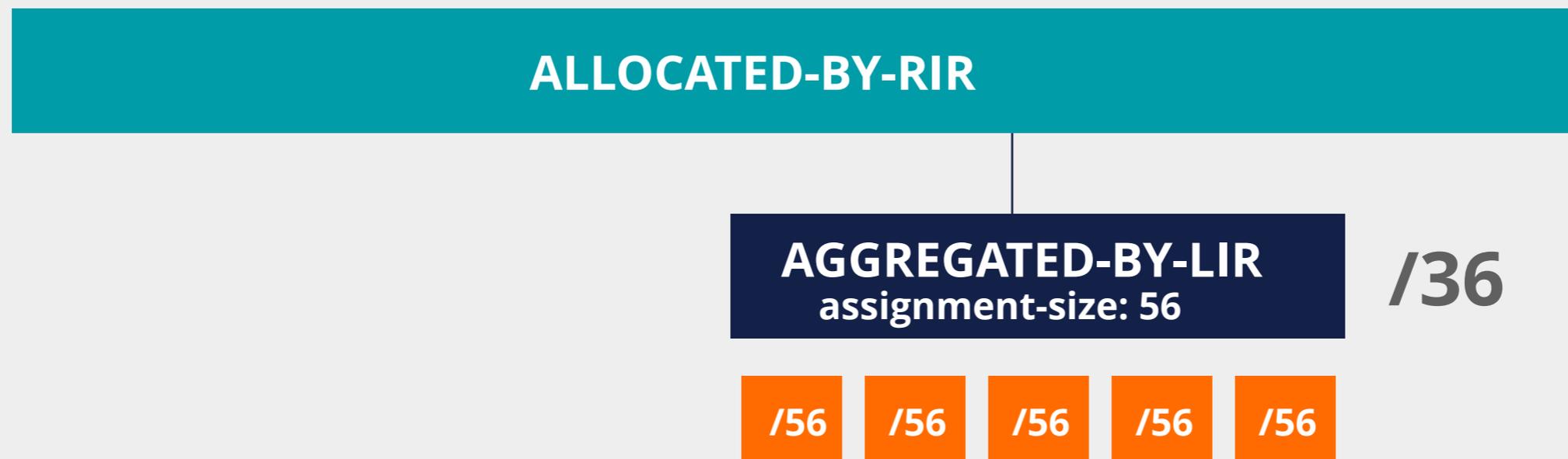
- Group of customers
- Same assignment size





# Using AGGREGATED-BY-LIR

- Can be used to group customers
  - For example: Residential broadband customers
- **“assignment-size:”** = assignment of each customer



# Using AGGREGATED-BY-LIR - Example



<b>inet6num:</b>	<b>2001:db8:1000::/36</b>
netname:	DSL-Broadband-Pool
country:	NL
admin-c:	ADM321-RIPE
tech-c:	NOC123-RIPE
<b>status:</b>	<b>AGGREGATED-BY-LIR</b>
<b>assignment-size:</b>	<b>56</b>
mnt-by:	LIR-MNT
notify:	noc@example.net
created:	2015-05-31T08:23:35Z
last-modified:	2015-05-31T08:23:35Z
source:	RIPE

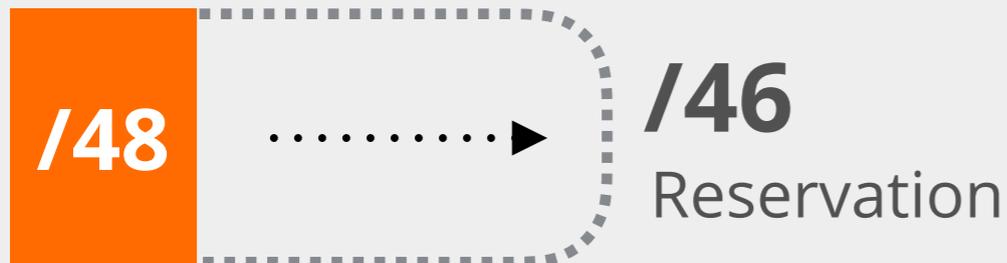
# Examples ALLOCATED-BY-LIR



## Reservation for a large customer



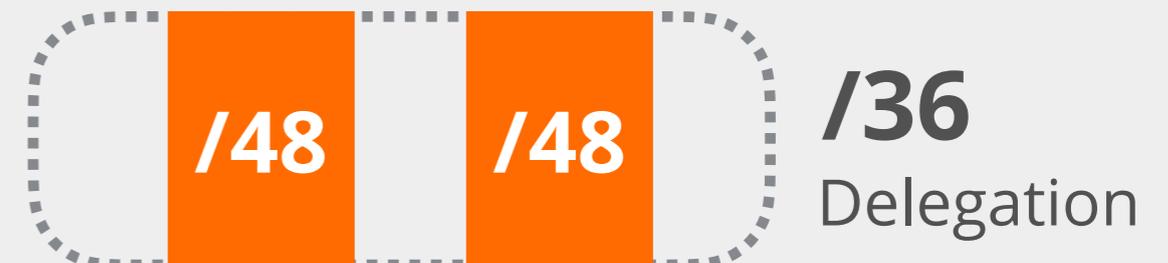
Large Customer



## Branch office or department



Branch Office

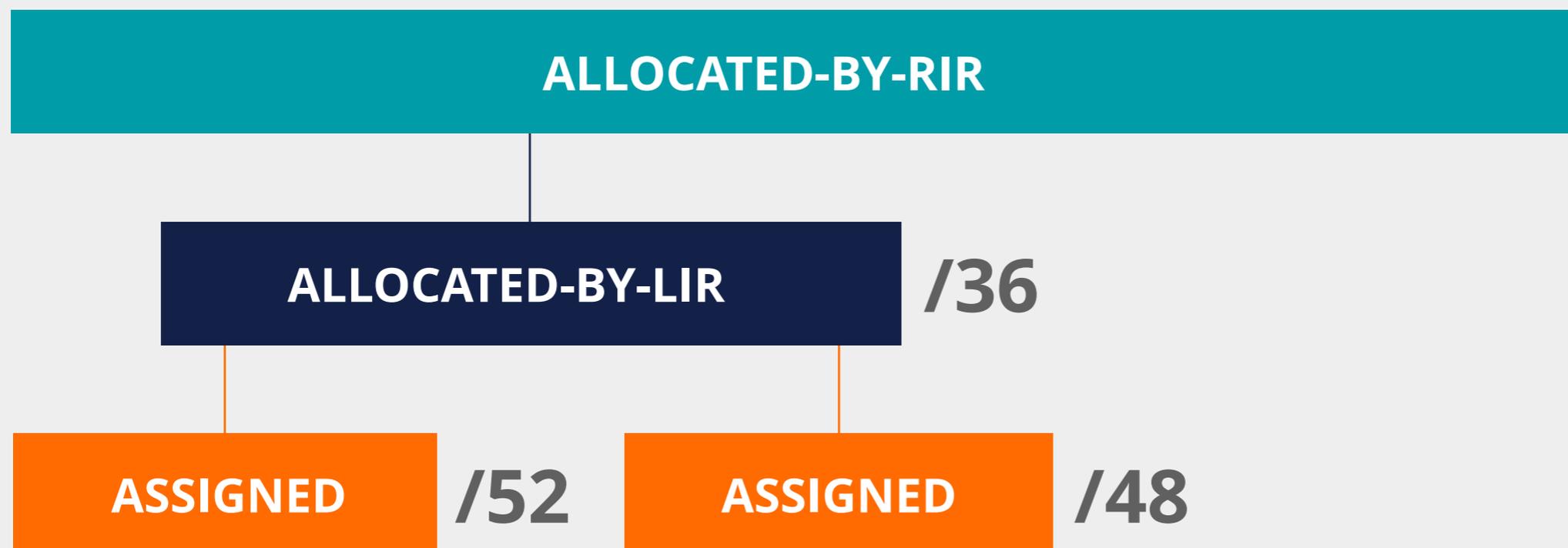


# Using ALLOCATED-BY-LIR



Can be used for customers with **potential for growth**

- Or for your own infrastructure
- Or to delegate address space to a downstream ISP



# Using ALLOCATED-BY-LIR - Example



**inet6num: 2001:db8:50::/44**

netname: Branch-Office-Network

country: NL

admin-c: ADM321-RIPE

tech-c: NOC123-RIPE

**status: ALLOCATED-BY-LIR**

**mnt-by: LIR-MNT**

**mnt-lower: BRANCH-OFFICE-MNT**

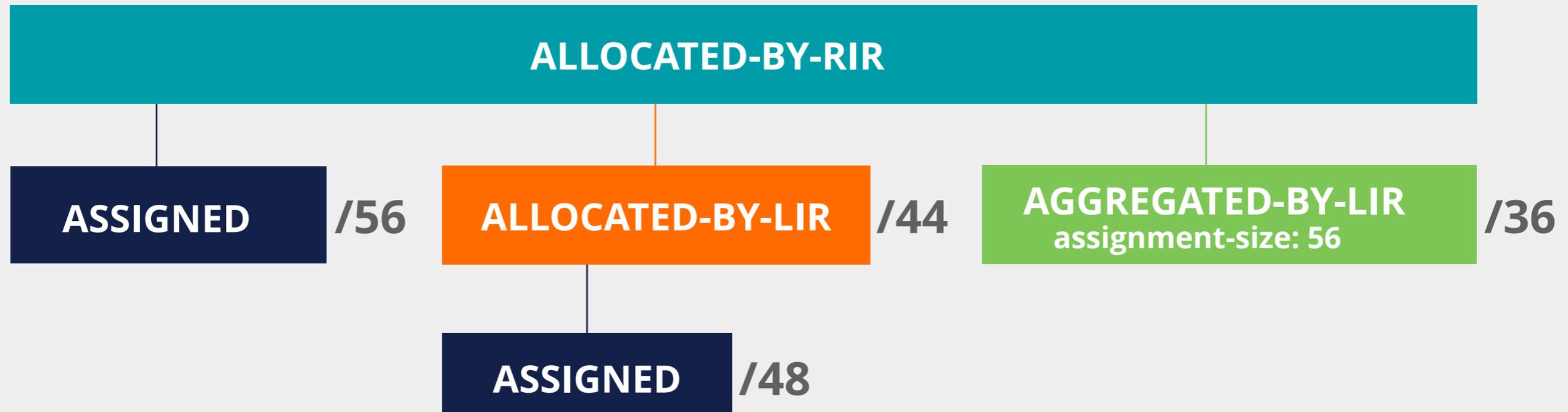
notify: noc@example.net

created: 2015-05-31T08:23:35Z

last-modified: 2015-05-31T08:23:35Z

source: RIPE

# Overview





# Getting IPv6 PI Address Space

- To qualify, an organisation must:
  - **Meet** the contractual **requirements** for provider independent resources
  - LIRs must demonstrate special **routing requirements**
- Minimum assignment size: **/48**
- PI space **cannot** be used for sub-assignments



# IPv6 Protocol Basics

## Section 4

# IPv6 Protocol Functions

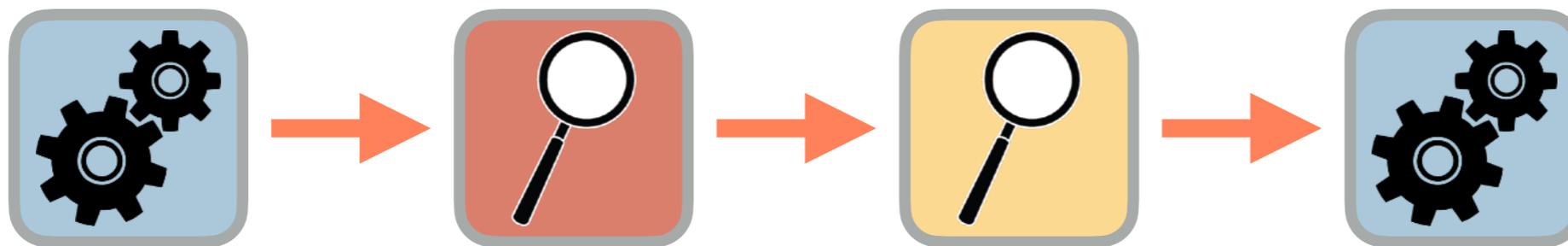


- Address Autoconfiguration
  - Supported by Neighbor Discovery
  - Stateless - with SLAAC
  - Stateful - with DHCPv6
- Neighbor Discovery Protocol
  - Replaces ARP from IPv4
  - Uses ICMPv6 and Multicast
  - Finds the other IPv6 devices on the link
  - Keeps track of reachability

# The Autoconfiguration Process



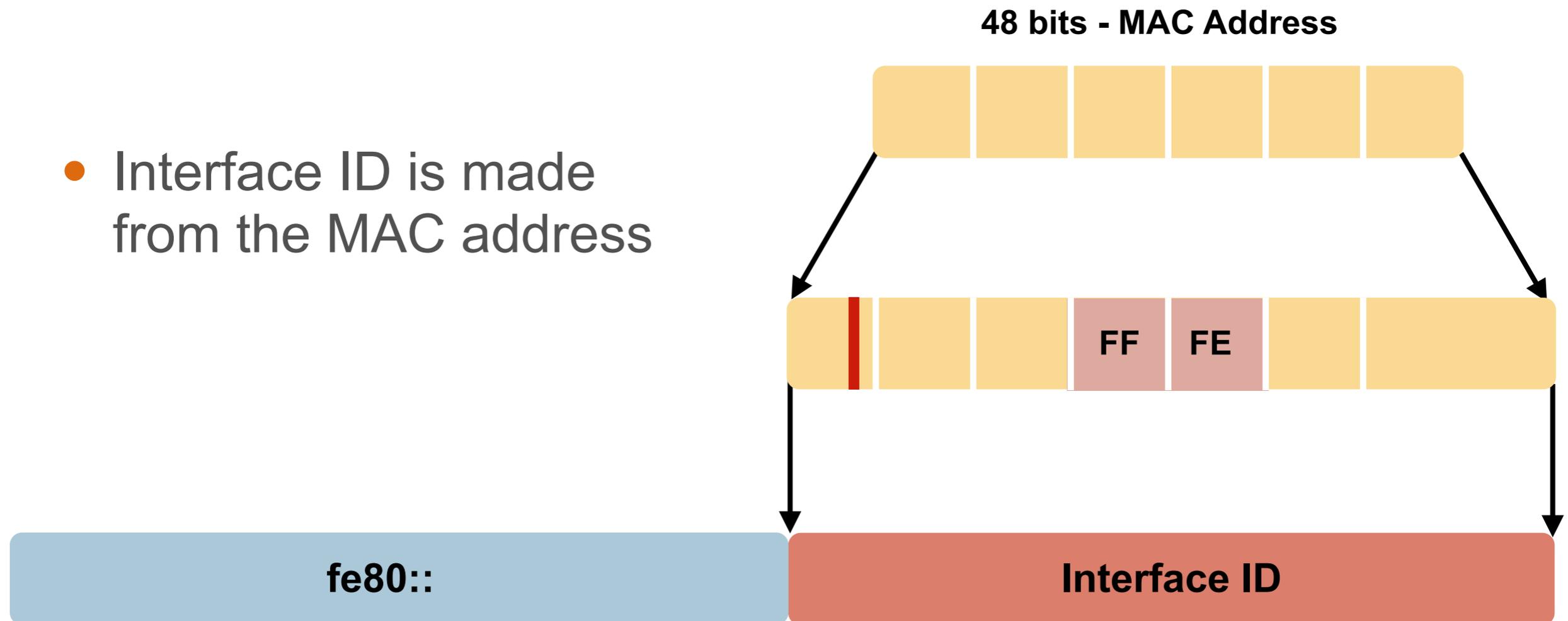
1. Make a Link-Local address
2. Check for duplicates on the link
3. Search for a router
4. Make a Global Unicast address



# Making a Link-Local Address



- Interface ID is made from the MAC address



- fe80:: + Interface ID = Link-Local address for the host

# Checking for Duplicates



## Neighbor Solicitation

Hello! Is this IPv6 address in use?  
Can you tell me your MAC address?



## Neighbor Advertisement



Hello! Yes, I'm using that IPv6 address.  
My MAC address is 72:D6:0C:2F:FC:01



If nobody replies to the Neighbor Solicitation,  
the host uses the generated link-local address

# Solicited Node Multicast Address



- Used in Neighbor Discovery Protocol for obtaining the layer 2 link-layer (MAC) addresses

IPv6 unicast address



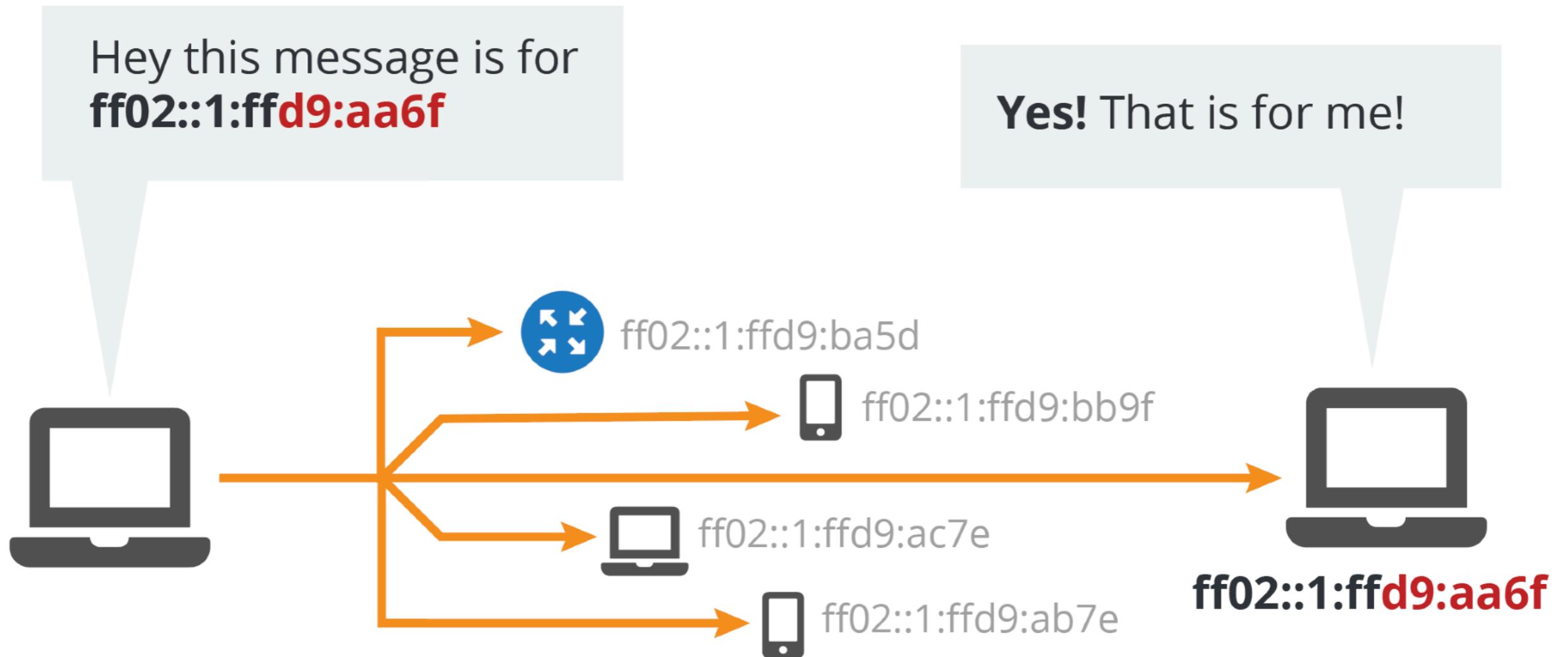
Solicited-node multicast address



128 bits



# Solicited Node Multicast Address



# Searching for Routers

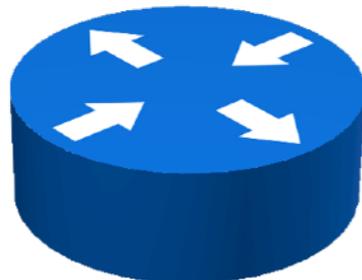


## Router Solicitation

Hello! Is there a router out there?



## Router Advertisement



Hello! I'm a router and I have some information for you...



The Router Advertisement gives the host more information to get an IPv6 address and set up a connection

# Stateless Address Auto-Configuration



- **The Router Advertisement message tells the host:**
  - Router's address
  - Zero or more link prefixes
  - SLAAC allowed (yes/no)
  - DHCPv6 options
  - MTU size (optional)

**Link Prefix**

**Interface ID**

Global Unicast IPv6 Address

# Interfaces will have multiple addresses



- Unicast

- Link Local `fe80::5a55:caff:fef6:bdbf/64`
- Global Unicast `2001::5a55:caff:fef6:bdbf/64` (multiple)

- Multicast

- All Nodes `ff02::1` (scope: link)
- Solicited Node `ff02::1:fff6:bdbf` (scope: link)

- Routers

- All Routers `ff02::2` (scope: link)

# Verifying Reachability



## Neighbor Solicitation

Hello! Are you still out there?  
Is your MAC address still valid?



## Neighbor Advertisement



Hello! Yes, I'm still online.  
My MAC address is 72:D6:0C:2F:FC:01



If the target does not reply to the Neighbor Solicitation,  
the sender removes the MAC address from the cache

# Redirects

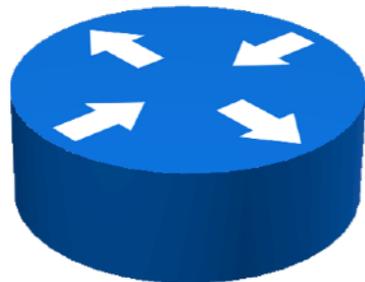


## IPv6 Packet

This packet is for an IPv6 host.



## Redirect



Hello! That destination you wanted?  
I know a better way to reach it.



- Hosts can be redirected to a better first-hop router
- They can also be informed that the destination is a neighbor on the link



# Addressing Plans

## Section 5

# Why Create an Addressing Plan?



- **Benefits of an IPv6 addressing plan**
  - Mental health during implementation (!)
  - Easier implementation of security policies
  - Efficient addressing plans are scalable
  - More efficient route aggregation

# IPv6 Address Management



- **Your spreadsheet might not scale**
  - There are 65.536 /64s in a /48
  - There are 65.536 /48s in a /32
  - There are 524.288 /48s in a /29
  - There are **16.777.216** /56s in a /32
  - There are **134.217.728** /56s in a /29
- Find a suitable IPAM solution

# Addressing plans



- /64 for each subnet
- Number of hosts in a /64 is irrelevant
- Multiple /48s per pop can be used
  - separate blocks for infrastructure and customers
  - document address needs for allocation criteria
- Use one /64 block per site for loopbacks

# The /64 story



- “Every interface ID must be a /64” (RFC 4291)
- Because of SLAAC
- Other RFCs followed this
  
- The **only** exception is a /127 for point-to-point links



# IPv6 Packets

## Section 6

# IPv6 Header Format

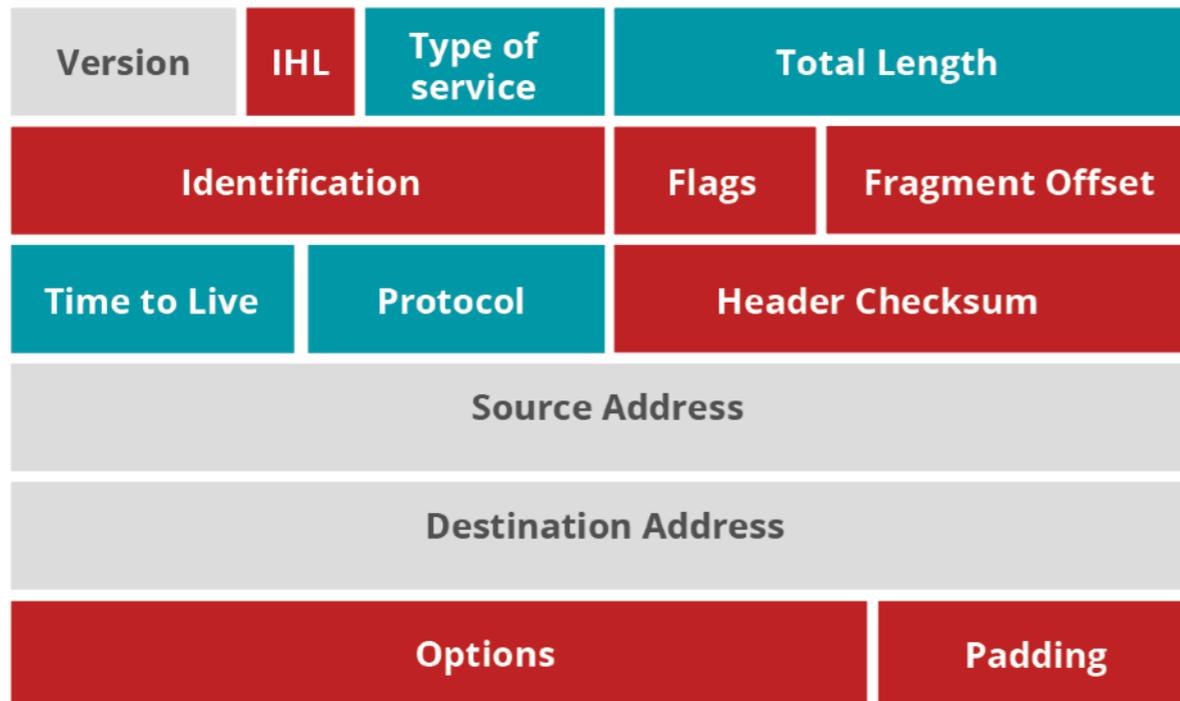


- Fixed length
  - Optional headers are daisy-chained
- IPv6 header is twice as long (40 bytes) as IPv4 header without options (20 bytes)

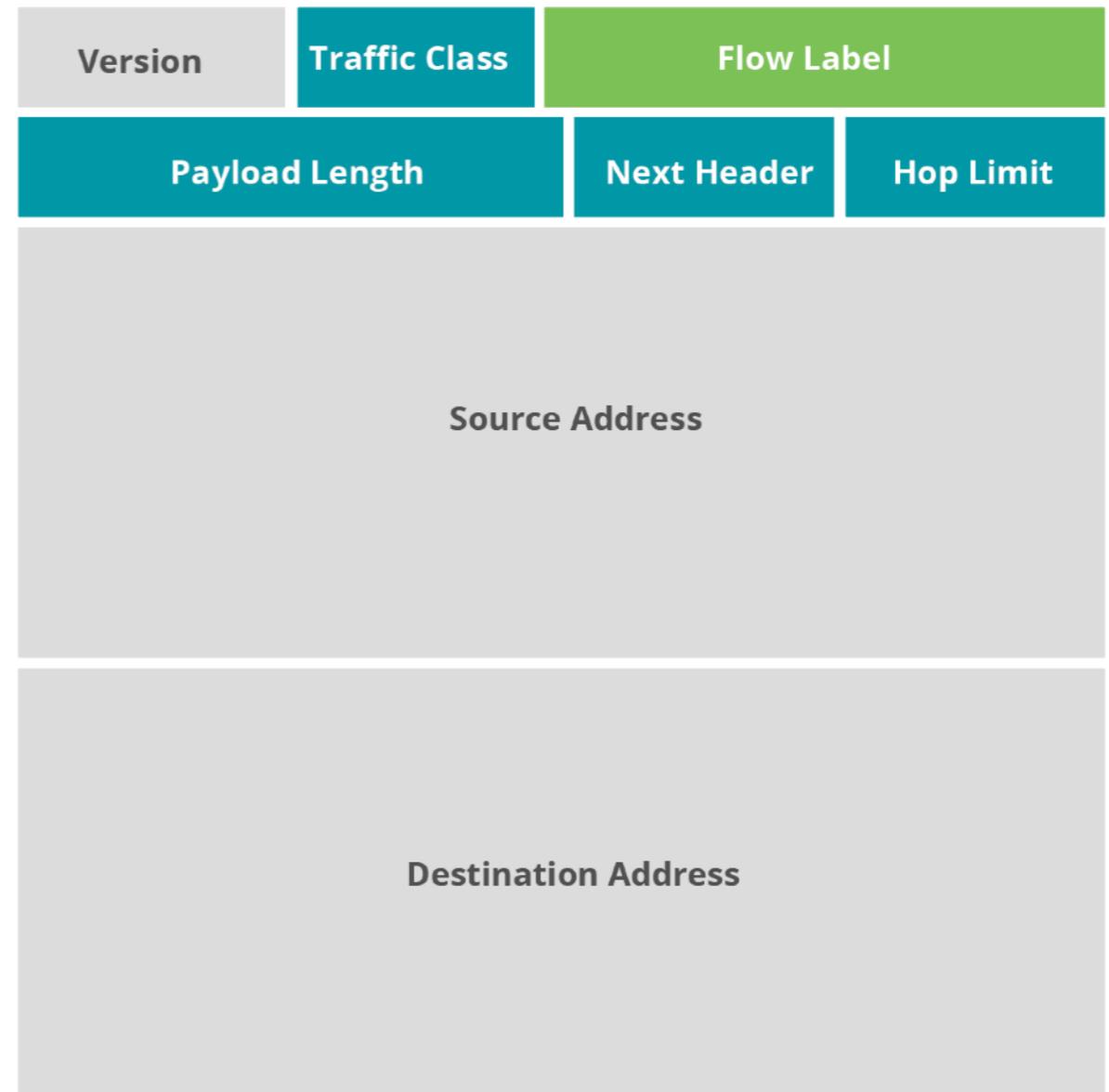
# IPv6 Header



## IPv4 Header



## IPv6 Header



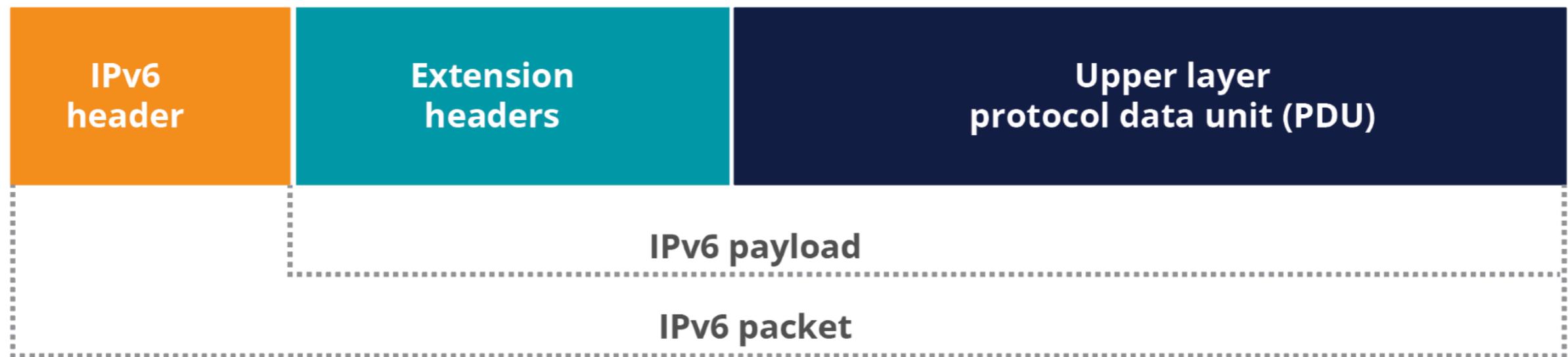
### LEGEND

- Field's name kept from IPv4 to IPv6
- Field not kept in IPv6
- Name and position changed in IPv6
- New field in IPv6

# IPv6 Header



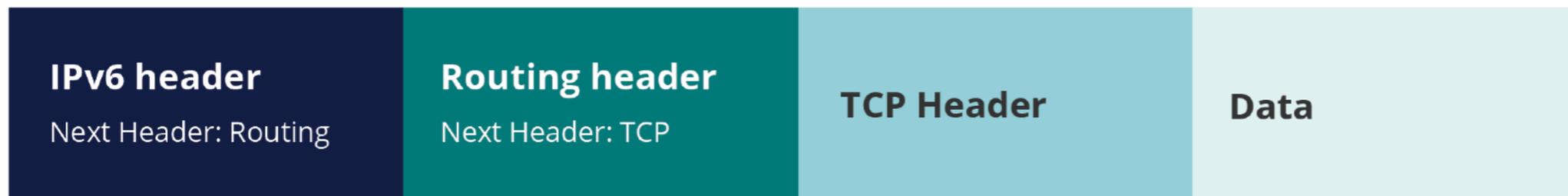
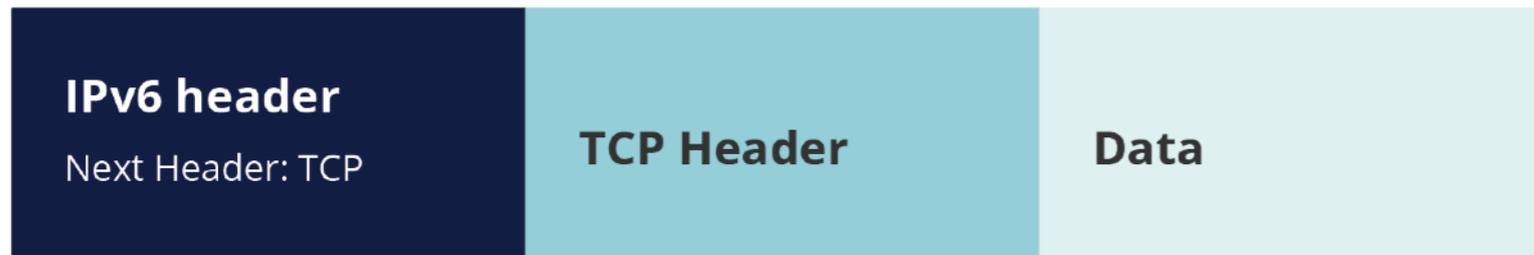
- Optional fields go into extension headers



# IPv6 Header



- Daisy-chained after the main header





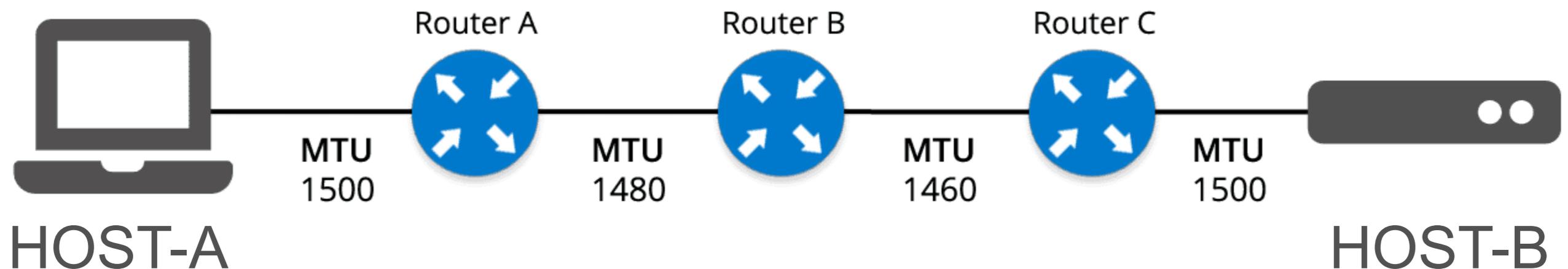
# Fragmentation

- Routers don't fragment packets with IPv6
  - More efficient handling of packets in the core
  - Fragmentation is being done by host
  
- If a packet is too big for next hop:
  - "Packet too big" error message
  - This is an ICMPv6 message
  - Filtering ICMPv6 causes problems

# Path MTU Discovery



- A sender who gets this “message-too-big” ICMPv6 error tries again with a smaller packet
  - A hint of size is in the error message
  - This is called Path MTU Discovery

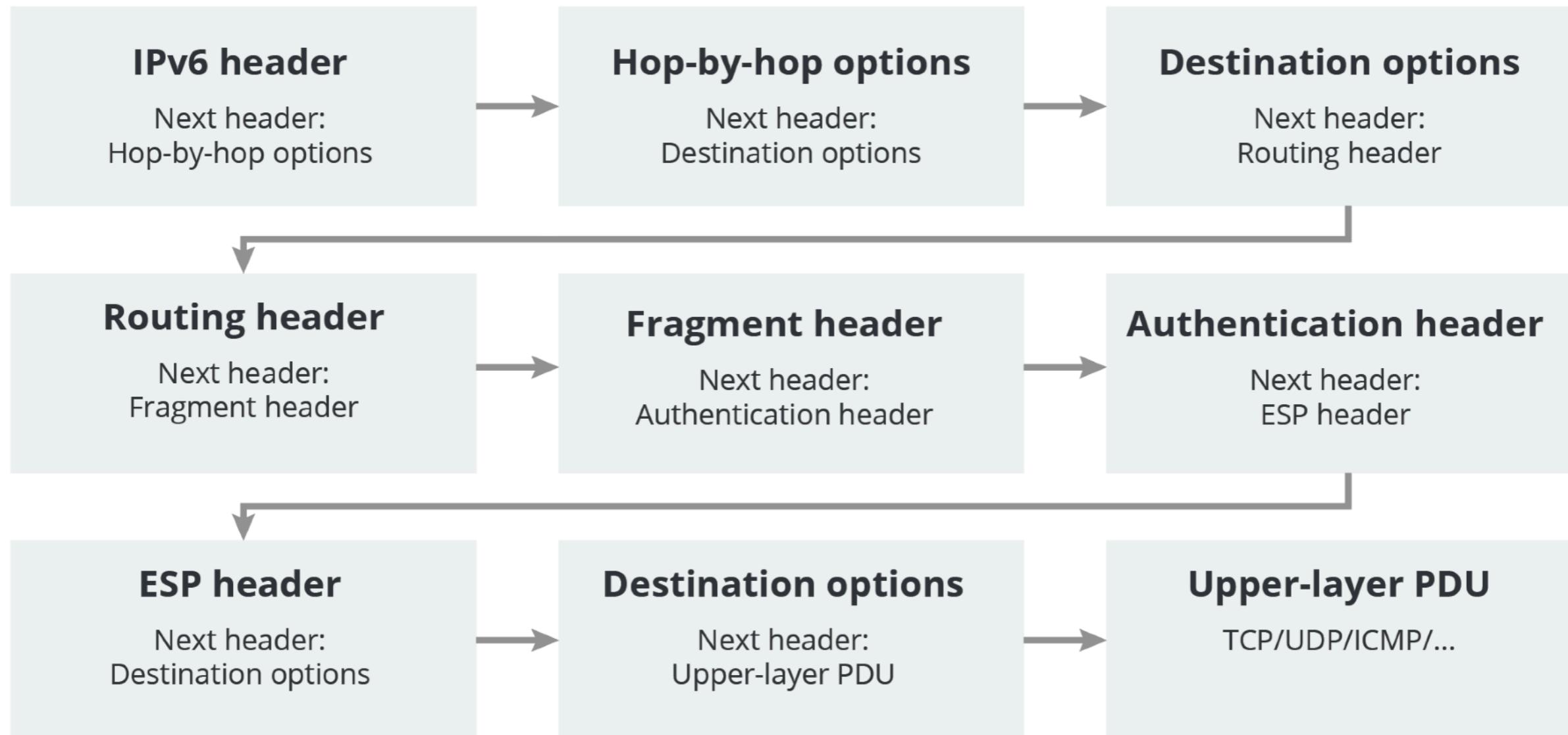


# Ordering of Headers



- Order is important:
  - Only hop-by-hop header has to be processed by every node
  - Routing header needs to be processed by every router
  - Fragmentation has to be processed before others at the destination

# Ordering of Headers



# Broadcast



- IPv6 has no broadcast
- There is an “all nodes” multicast group
  - ff02::1
- Disadvantages of broadcast:
  - It wakes up all nodes
  - Only a few devices are involved
  - Can create broadcast storms



# Neighbor Discovery

- ND is used by nodes:
  - For address resolution
  - To find neighboring routers
  - To track address changes
  - To check neighbor reachability
  - To do Duplicate Address Detection
  
- ND uses 5 different ICMPv6 packet types



# Deploying IPv6

## Section 7



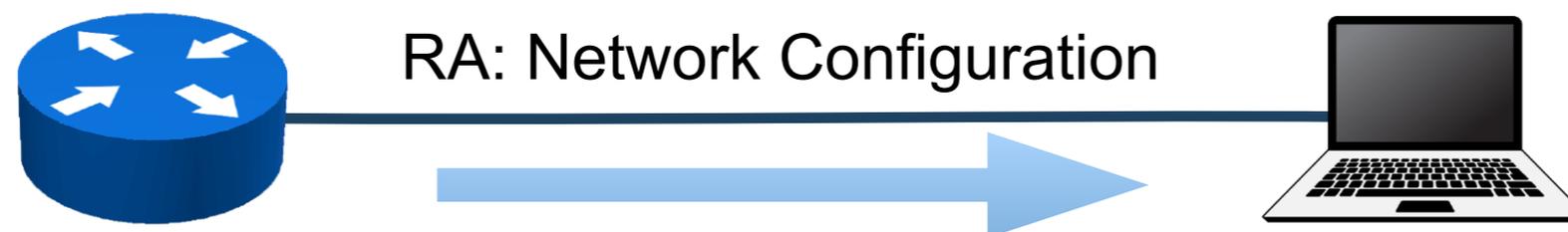
# Assigning Addresses

- Routers influence how hosts connect to network
- Several options:
  - Manual configuration
  - Router Advertisement only (SLAAC)
  - RA + DHCPv6 ('M' flag on)
  - RA + DHCPv6 ('O' flag on)
  - RA ('A' flag off) + DHCPv6 ('M' flag on)
- Gateway is always provided by the RA

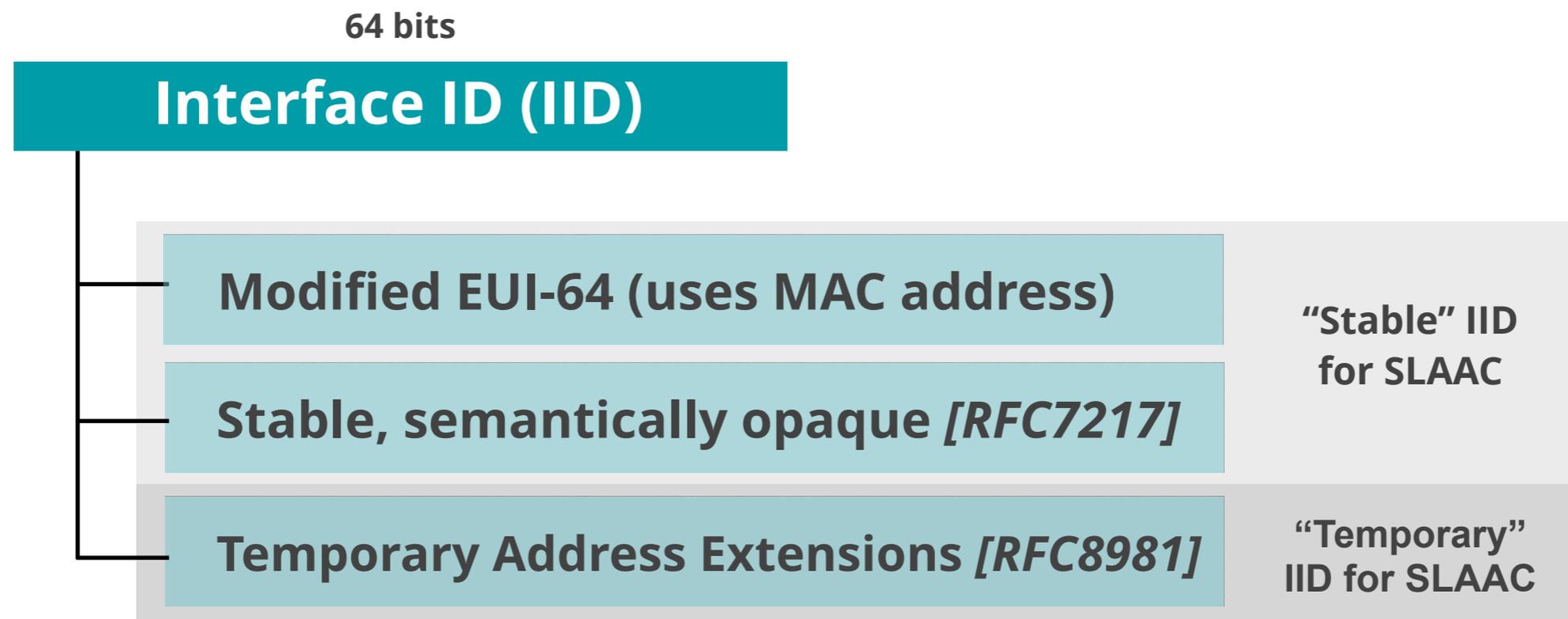
# Router Advertisement Options



- RA message is used to provide configuration info
  - Default gateway address
  - Which prefix(es) to use on the link? Prefix length?
  - Is SLAAC allowed?
  - Is DHCPv6 available? For address/options? Only options?
  - What is the preference of a router on the link?
  - DNS servers / Domain (optional)
  - MTU size (optional)



# SLAAC IID Generation Options



# Stable, Semantically Opaque IID



- Consider IID bits “**opaque**”, no value or meaning *[RFC7136]*

## How to generate IIDs *[RFC7217]*

Different for each interface in the same network prefix

Not related to any fixed interface identifier

Always the same when same interface connected to same network

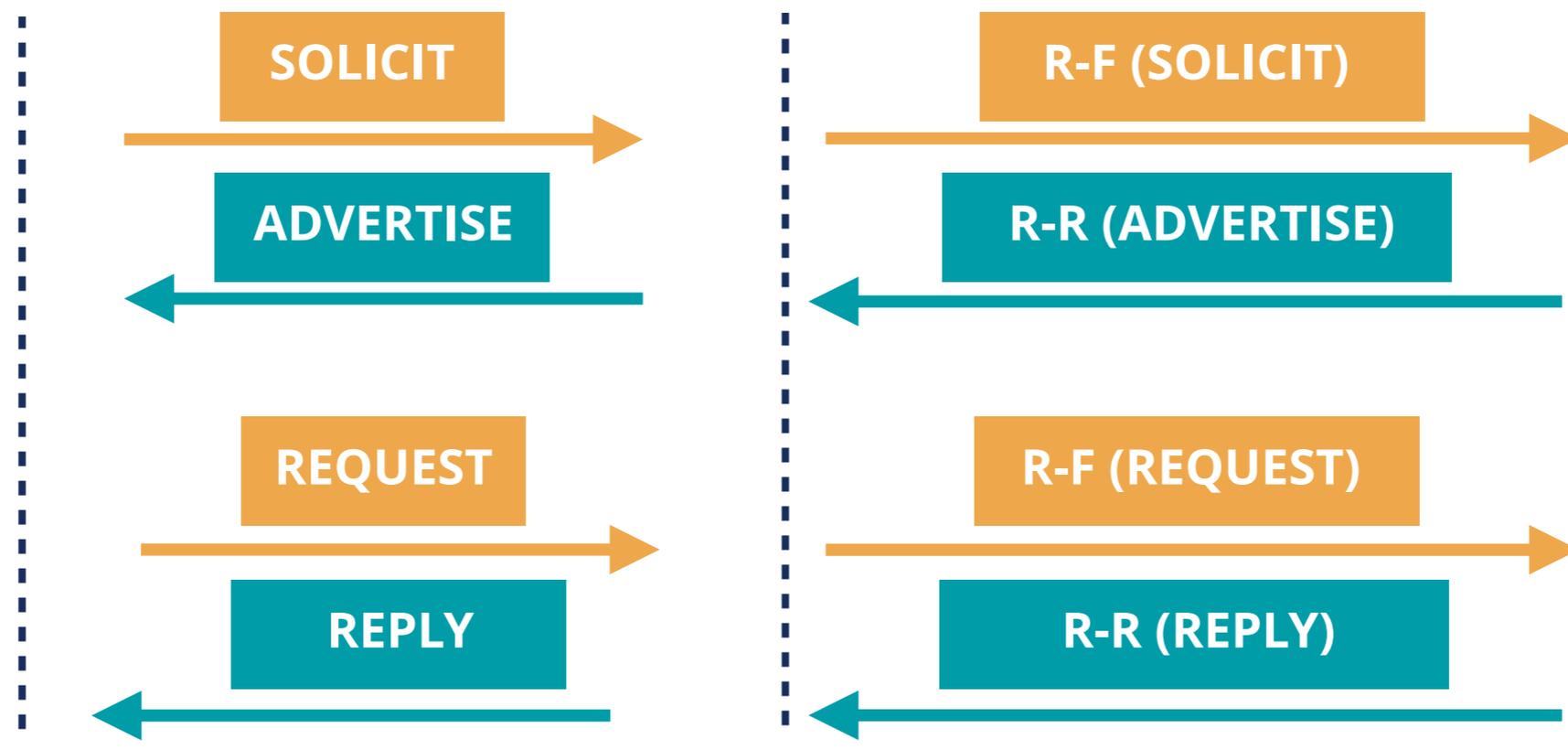
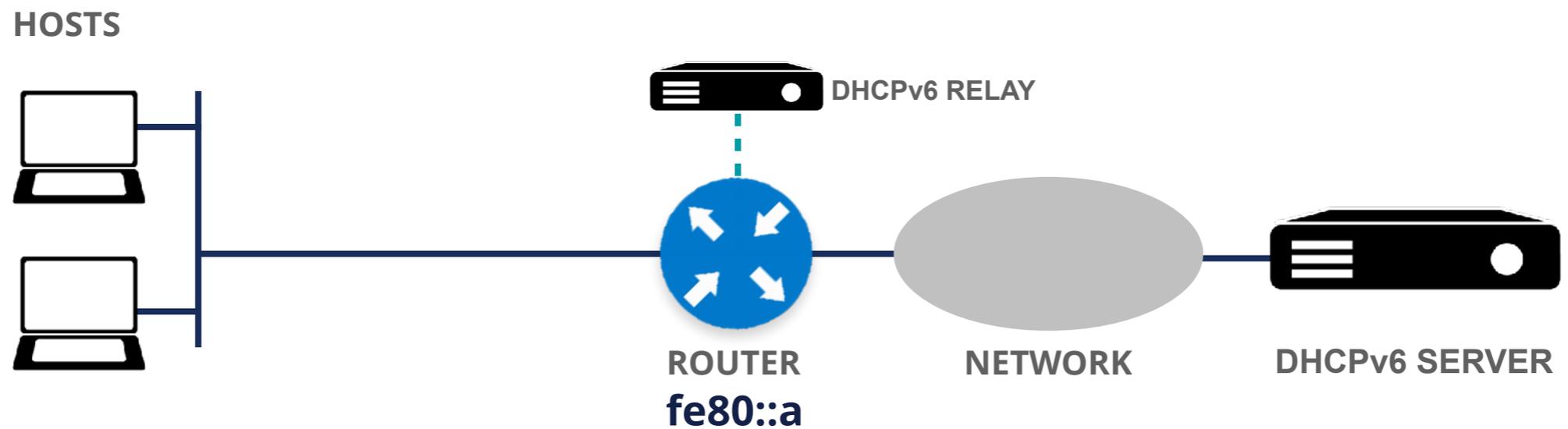
- Widely used and standardised for “stable” addresses *[RFC8064]*

# DHCPv6

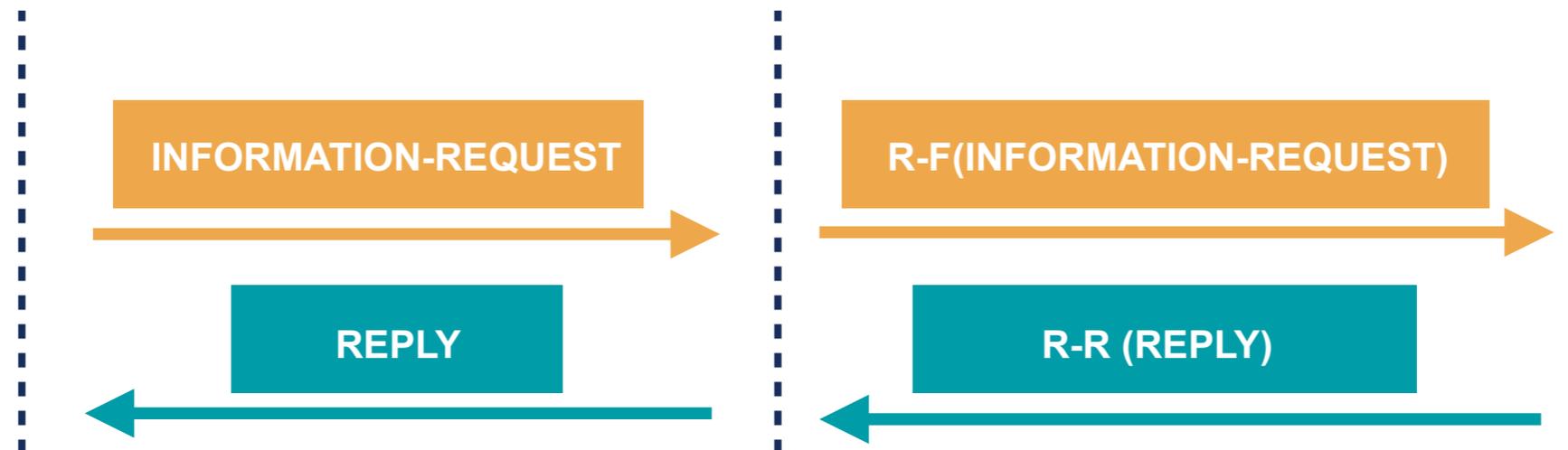
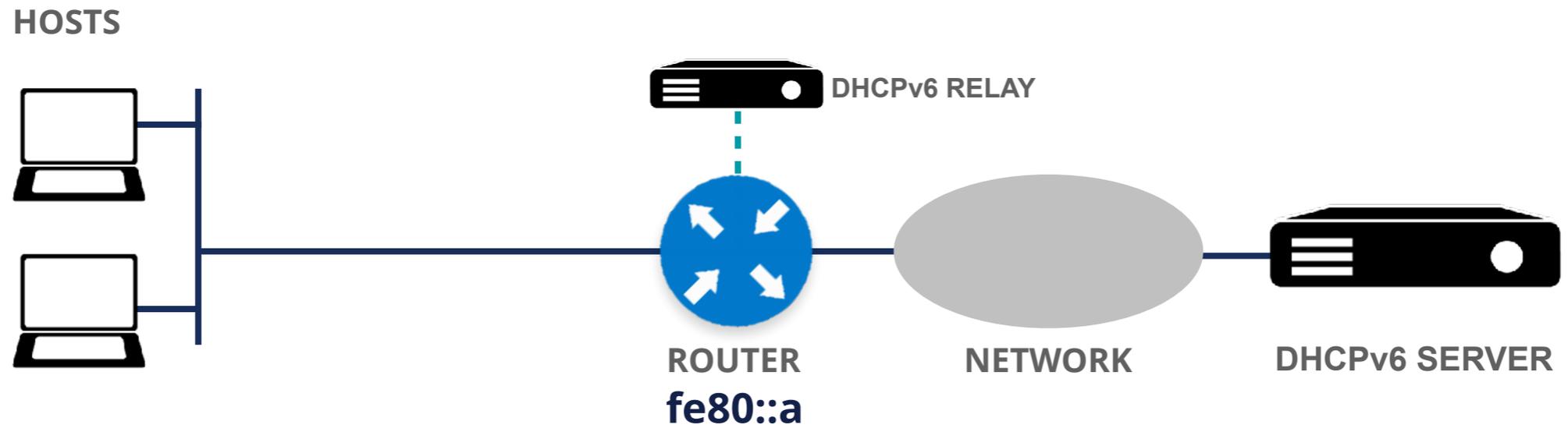


- Used to give additional information like DNS servers or to manage the address pool
- Router Advertisement message contains hints
  - If “managed” flag = ‘1’  $\Rightarrow$  can use DHCPv6 to get an address
  - Optionally provide the address of a DNS server (RFC 8106)
- Using additional flags, the network admin can disable SLAAC and force DHCPv6

# DHCPv6 (M=1)



# DHCPv6 (M=0, O=1)





# DNS in IPv6 is difficult?

- **DNS** is not IP layer dependent
- **A** record for **IPv4**
- **AAAA** record for **IPv6**
  
- Don't answer based on incoming protocol
- Only challenges are for translations
  - NAT64, proxies



# Tips

## Section 8



# How to get started

- Change purchasing procedure (feature parity)
- Check your current hardware and software
- Plan every step and test
- One service at a time
  - face first
  - core
  - customers

# RIPE-772 Document



- “Requirements for IPv6 in ICT Equipment”
  - Best Current Practice describing what to ask for when requesting IPv6 Support
  - Useful for tenders and RFPs
  - Original version was ripe-554
  - Ripe-554 Originated by the Slovenian Government
  - Adopted by various others (Germany, Sweden)

**Link to the document:**

**<https://www.ripe.net/publications/docs/ripe-772>**

# Troubleshooting for ISP Helpdesks



- Most ISP connectivity problems are not IPv6 related
- Helpdesks can get confused!
  - IPv6 is new for them
  - They don't have experience with IPv6 issues
- A generic troubleshooting guide can help!
- Based on the open source testipv6.com tool
- Customisable

<https://www.ripe.net/ripe/docs/ripe-631>





# Customers And Their /48

- Customers have no idea how to handle **65,536 subnets!**
- Provide them with information!



**Link to the document:**

<https://www.ripe.net/support/training/material/basicipv6-addressing-plan-howto.pdf>

# Don'ts



- Don't separate IPv6 features from IPv4
- Don't do everything in one go
- Don't appoint an IPv6 specialist
  - do you have an IPv4 specialist?
- Don't see IPv6 as a product
  - the Internet is the product!



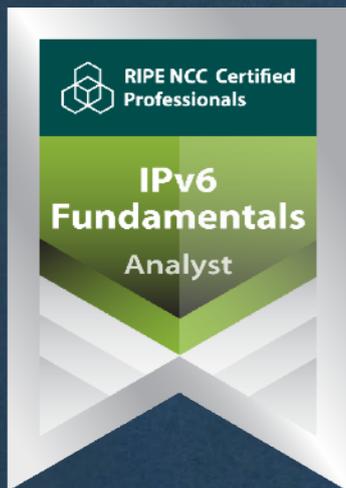
**RIPE NCC**  
Academy

Learn something new today!  
**[academy.ripe.net](https://academy.ripe.net)**

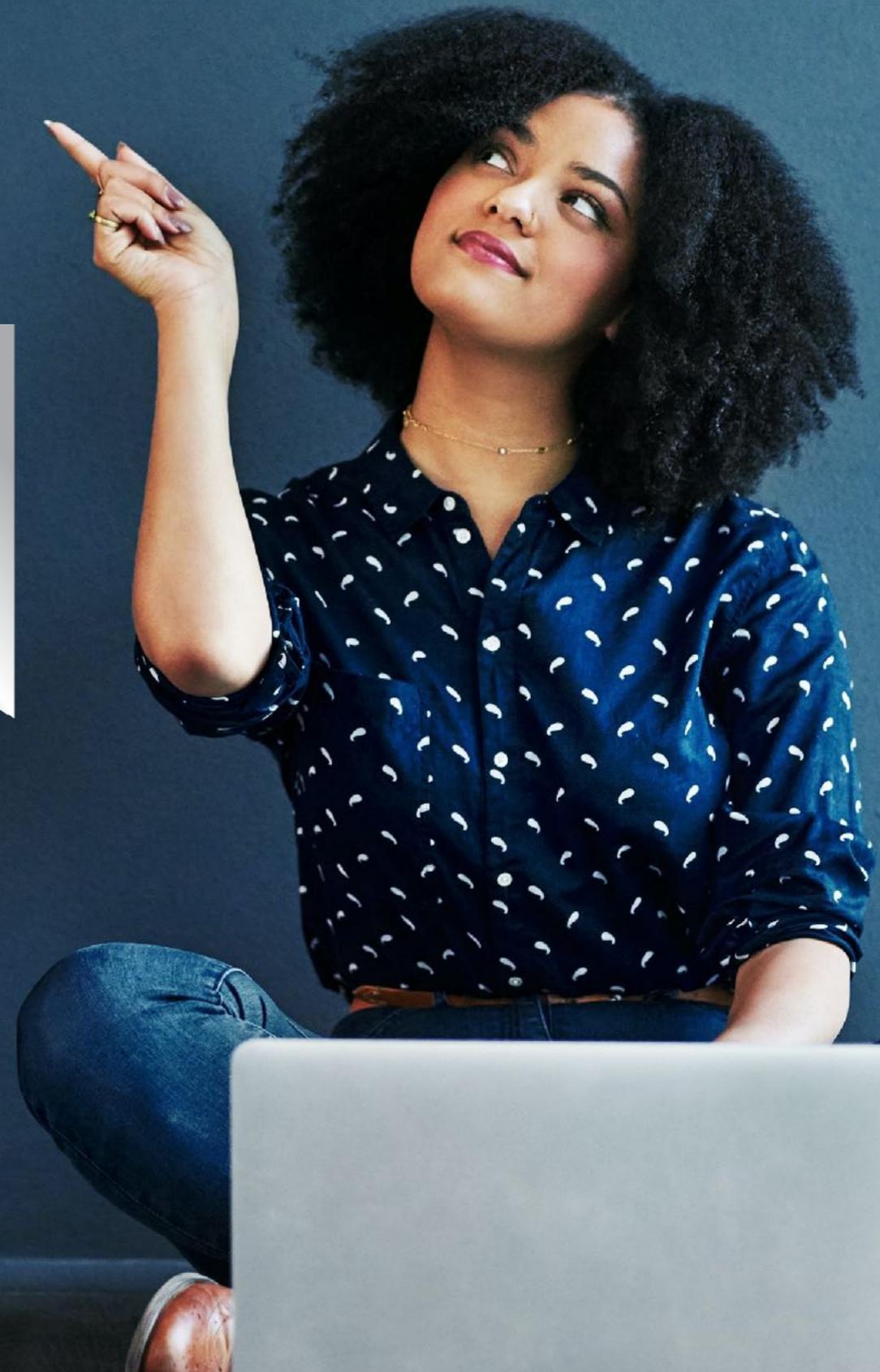




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<https://getcertified.ripe.net/>





# Questions



Änn      Соңы      An Críoch      پایان      Y Diwedd  
Vége      Endir      Finvezh      Ende      Koniec  
Son      டாசாஸ்ருலி      қтырз      Kінецъ      Finis  
Lõpp      Amaia      תסוה      Tmíem      Крај  
Sfârșit      Loppu      Slutt      Liðugt      Fund  
Kraj      النهاية      Конец      Konec      Τέλος  
Fine      Fin      Fí      Край      Pabaiga  
Slut      E inde      Fim      Beigas

