RIPE NCC
RIPE NETWORK COORDINATION CENTRE

Basic IPv6

RIPE 86 - Tutorial

22 May 2023

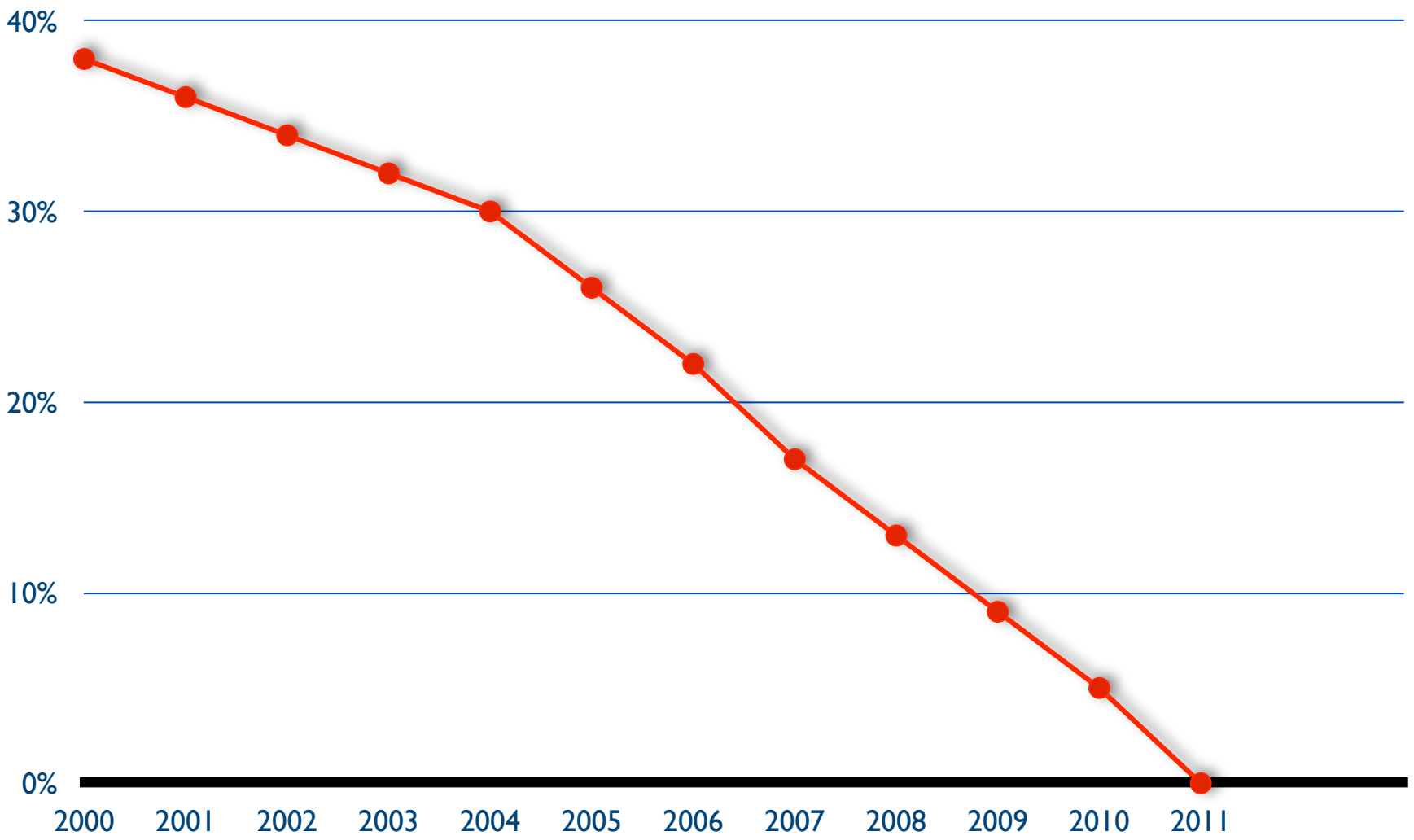
Overview

- Introduction
- IPv6 Address Basics
- IPv6 Protocol Basics
- Addressing Plan
- IPv6 Packets
- Deploying IPv6
- Transition Mechanisms
- 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.”

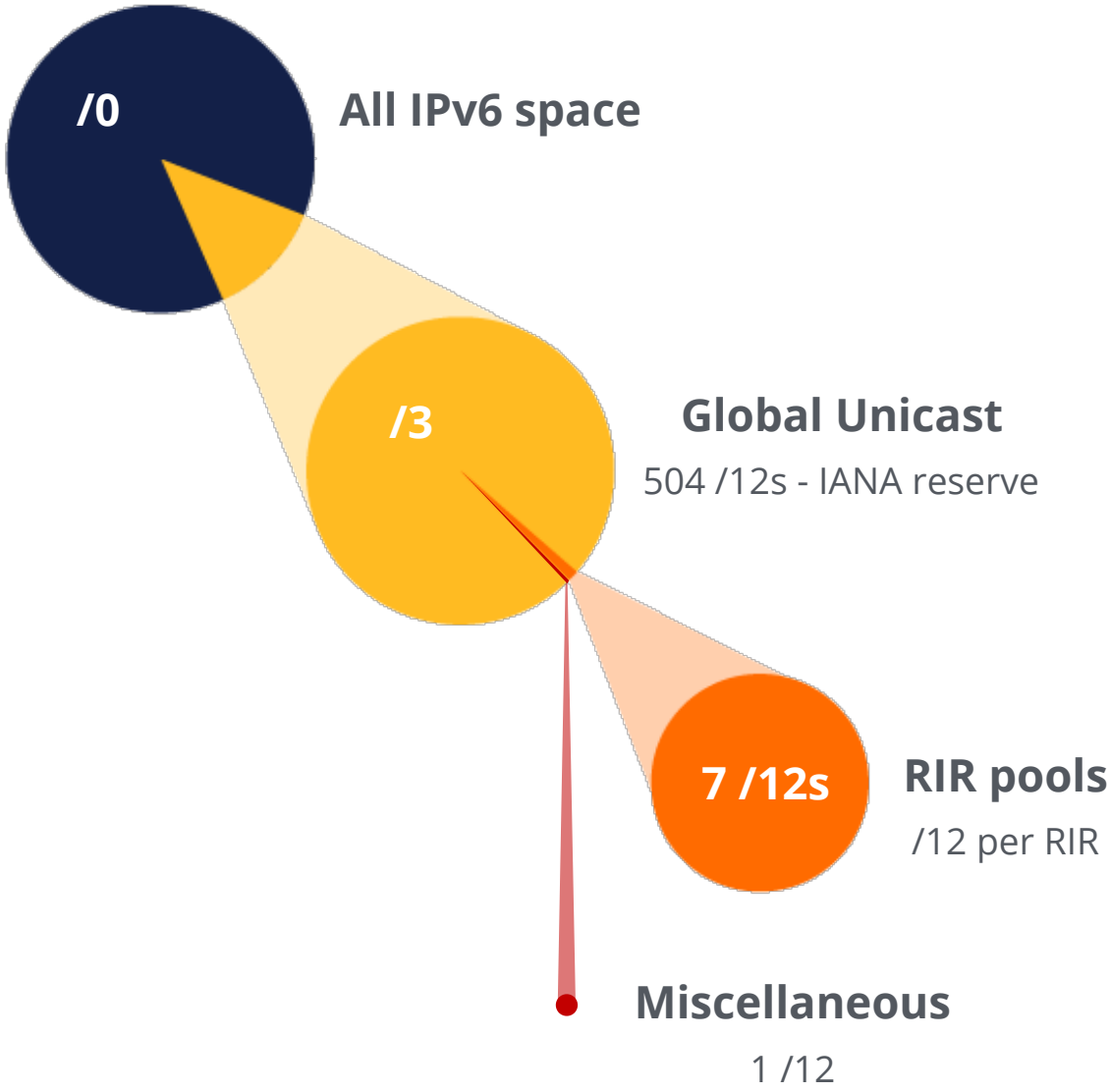
Our Reality: The Waiting List

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

IPv6 Address Basics

Section 2

IP Address Distribution



RIR Pools

October 2006

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

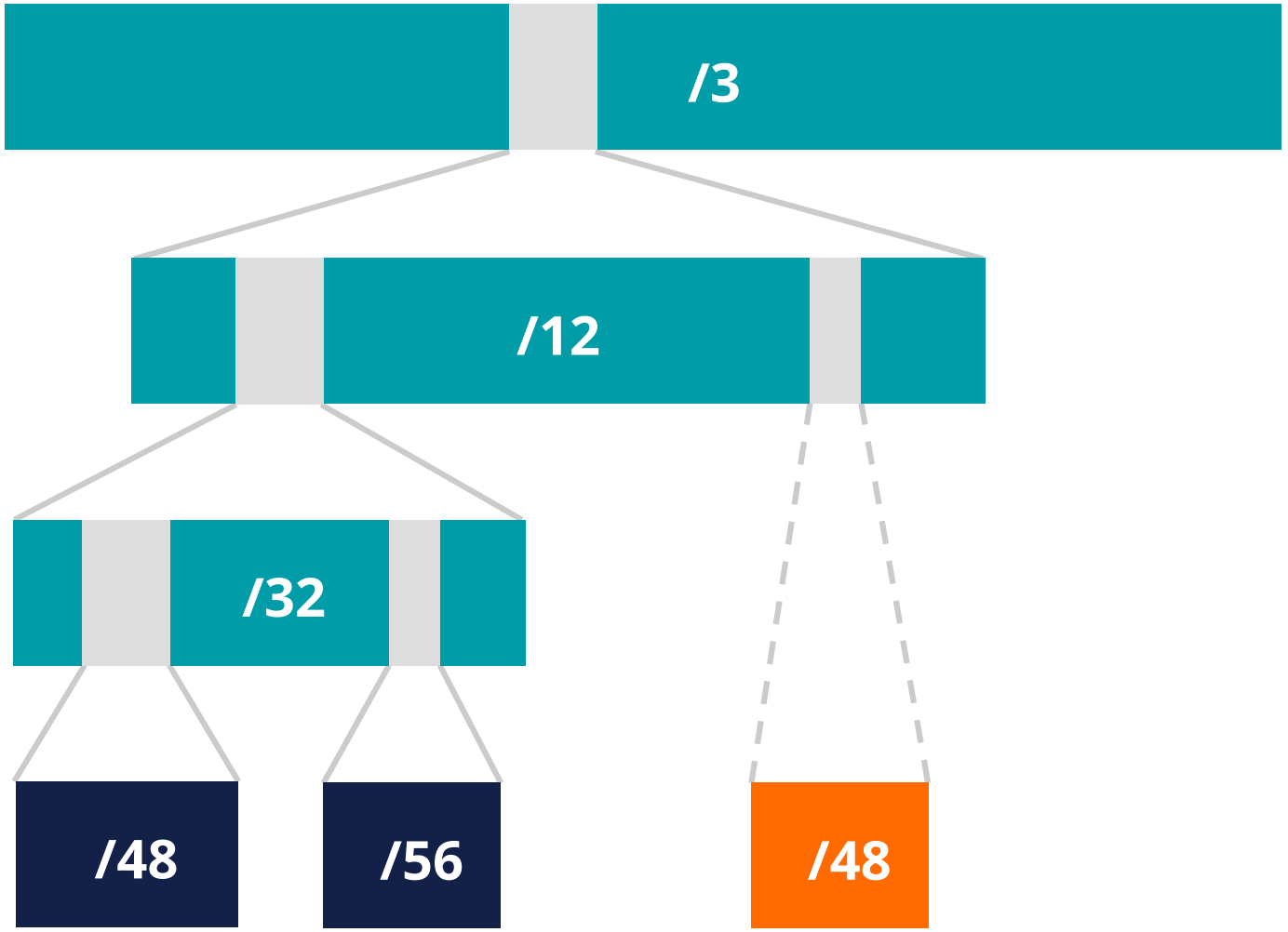
June 2019

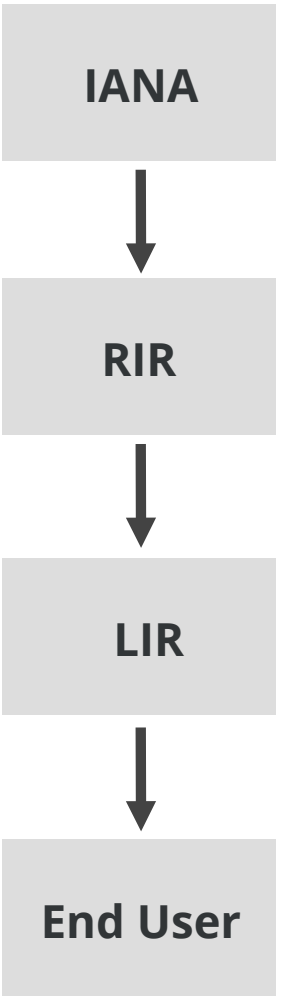
RIPE NCC	2A10:0000::/12

November 2019

ARIN	2630:0000::/12

IP Address Distribution





Allocation PA Assignment PI Assignment

IPv6 Address Basics

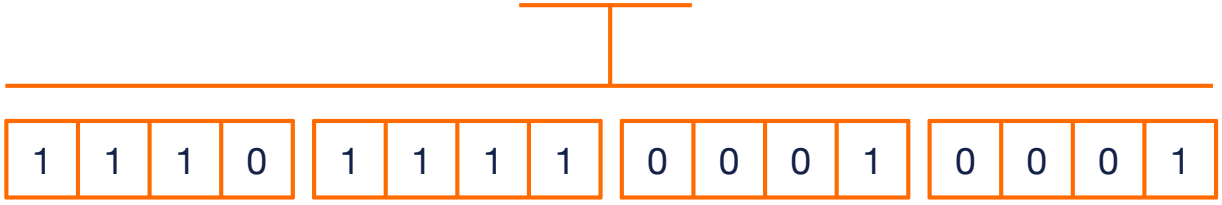
- IPv6 address: **128 bits**
  - 32 bits in IPv4
- Every subnet should be a **/64**
- Customer assignments (sites) between:
  - **/64** (1 subnet)
  - **/48** (65,536 subnets)
- Minimum allocation size **/32**
  - 65,536 /48s
  - 16,777,216 /56s

Address Notation

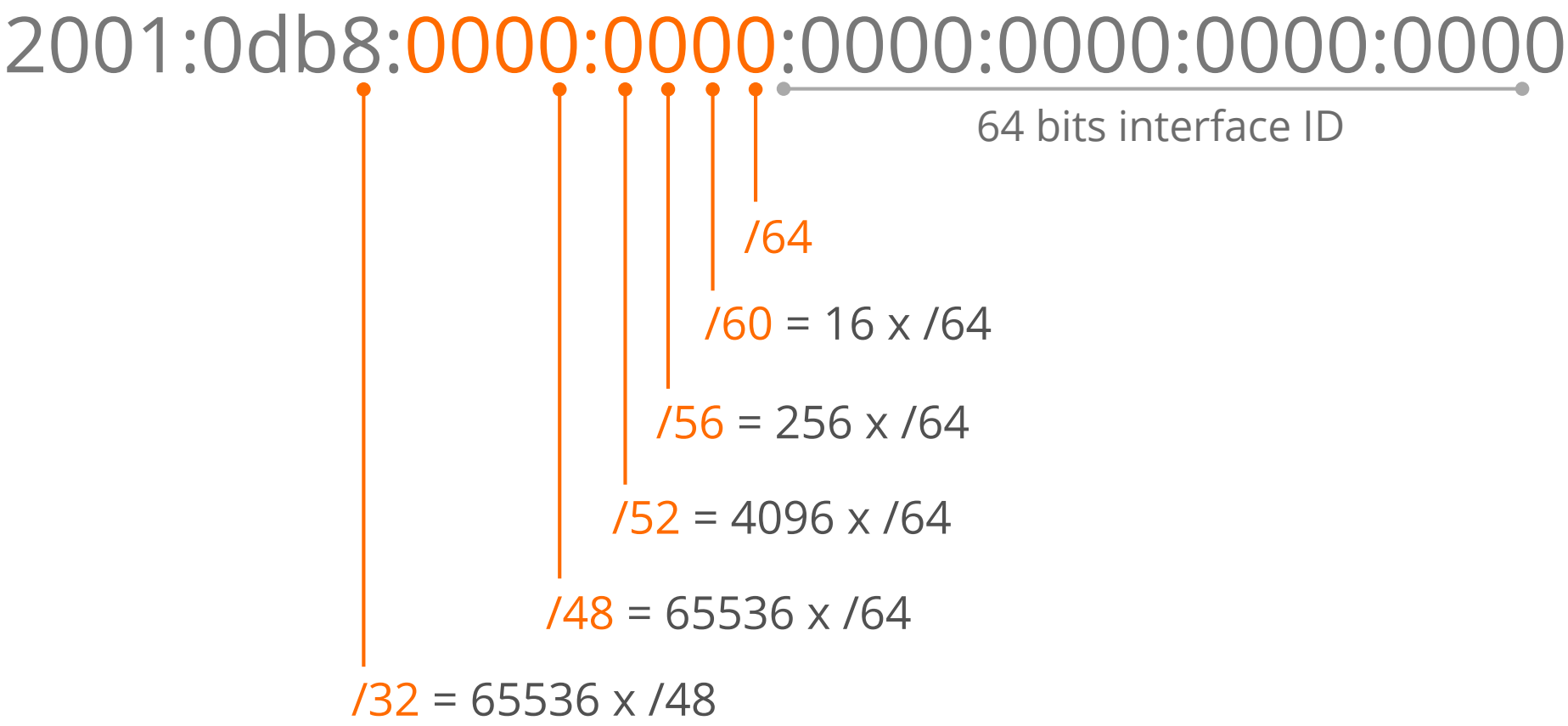
2001:0db8:003e:ef11:0000:0000:c100:004d

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

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



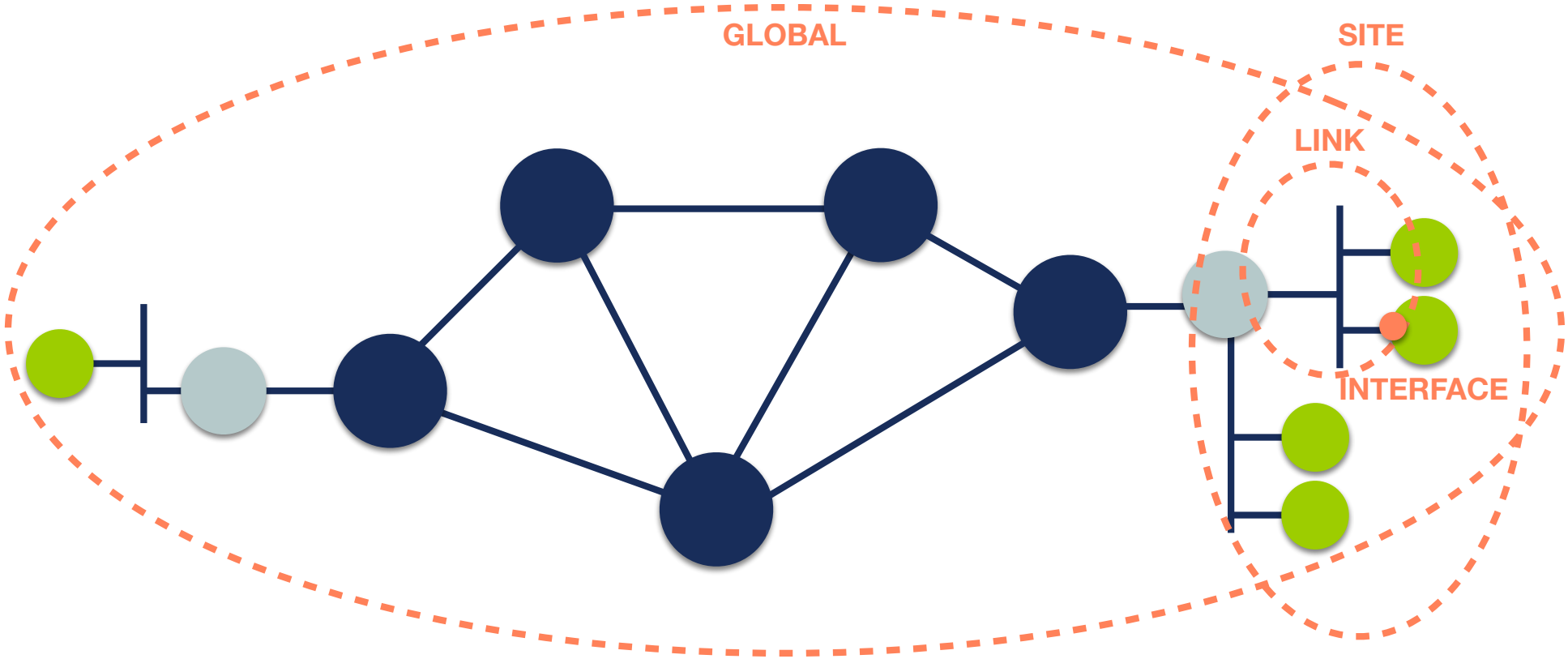
IPv6 Subnetting



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
Global Unicast	2000::/3	global
Unique Local	fc00::/7	global
Multicast	ff00::/8	variable

IPv6 Address Scope



fe80::A:b:100

ff01::2

2001:67c:2e:1::c1

FD00:A:B::100

FF05::1:3

ff02::1

IPv6 Protocol Basics

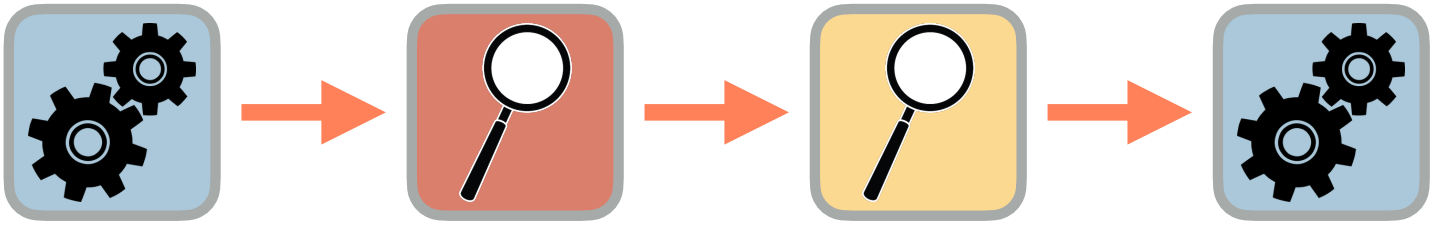
Section 3

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

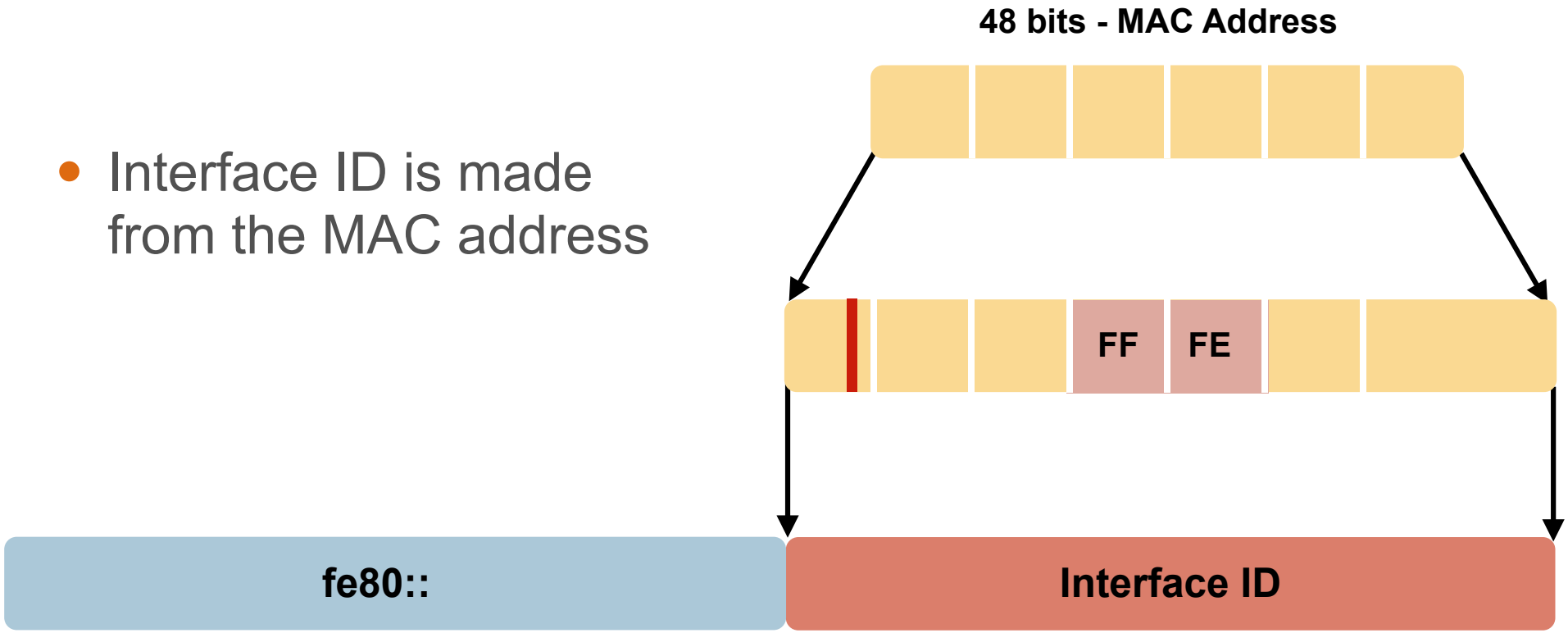
The Autoconfiguration Process

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

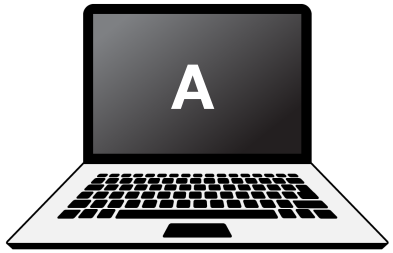


- fe80:: + Interface ID = Link-Local address for the host

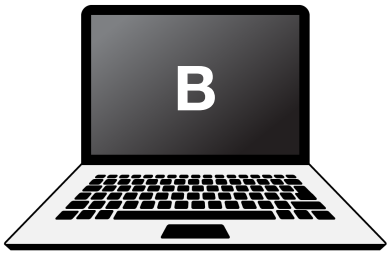
Checking for Duplicates

Neighbor Solicitation

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



Neighbor Advertisement

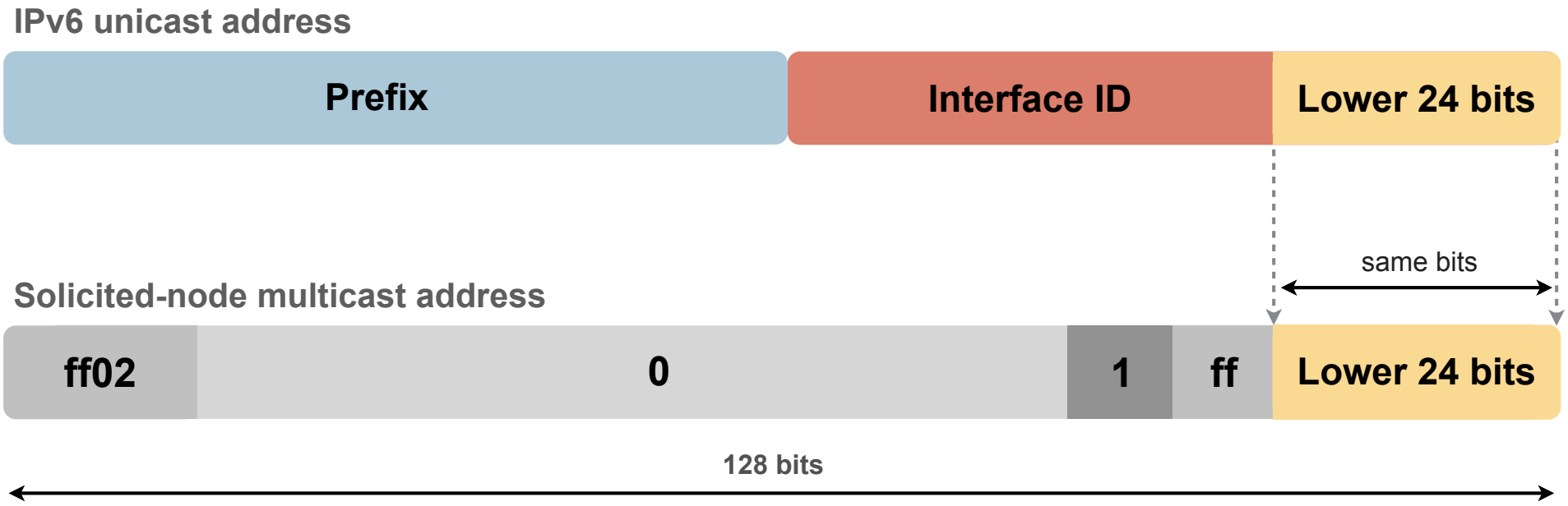


Hello! Yes, I'm using that IPv6 address.
My MAC address is 72:D6:0C:2F:FC:01

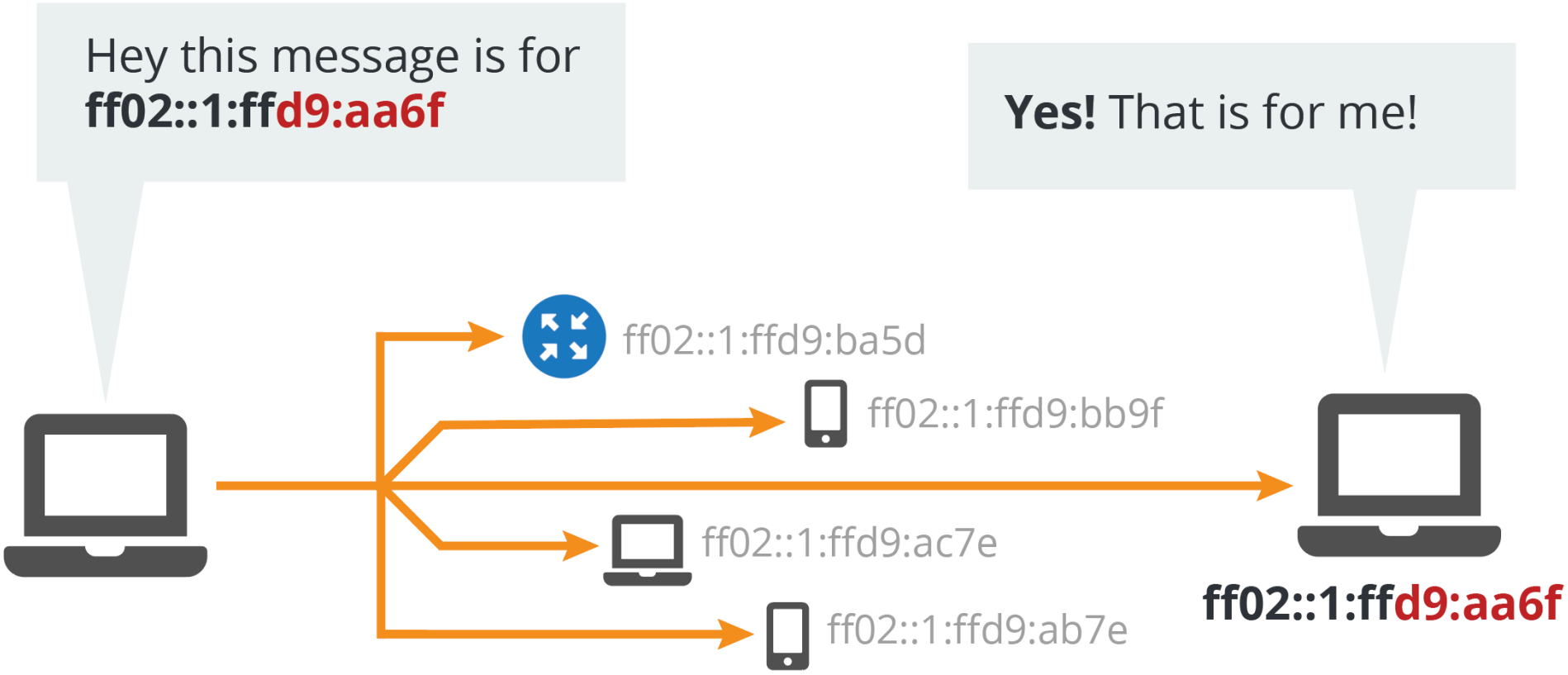
If nobody replies to the Neighbor Solicitation, the host uses the generated link-local address

Solicited Node Multicast Address

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



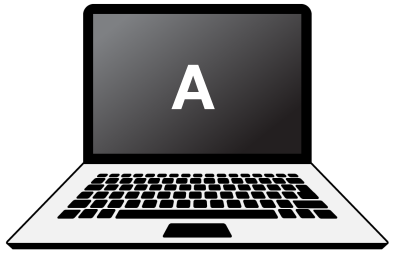
Solicited Node Multicast Address



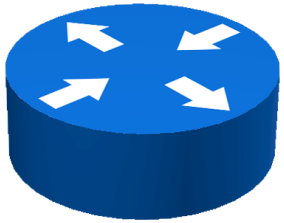
Searching for Routers

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)

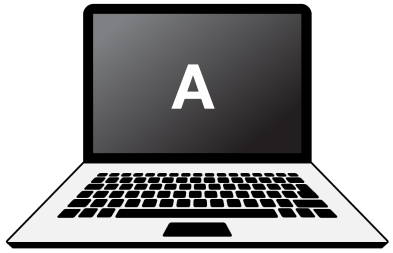
Interfaces Will Have Multiple Addresses

- 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

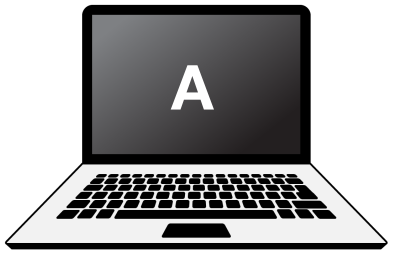
Hello! Yes, I'm still online.
My MAC address is 72:D6:0C:2F:FC:01

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

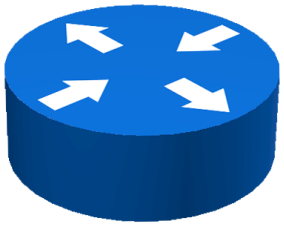
Redirects

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 4

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

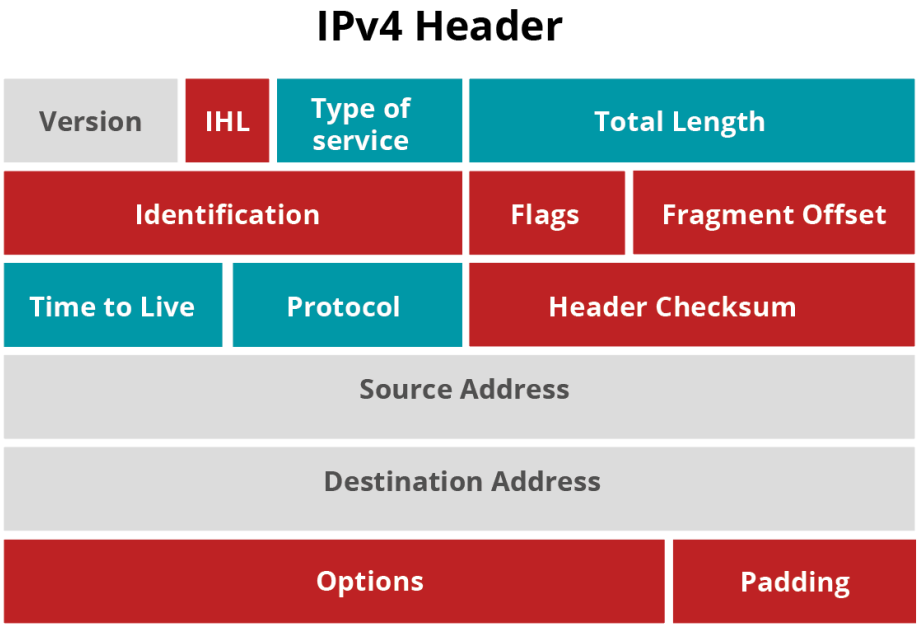
Section 5

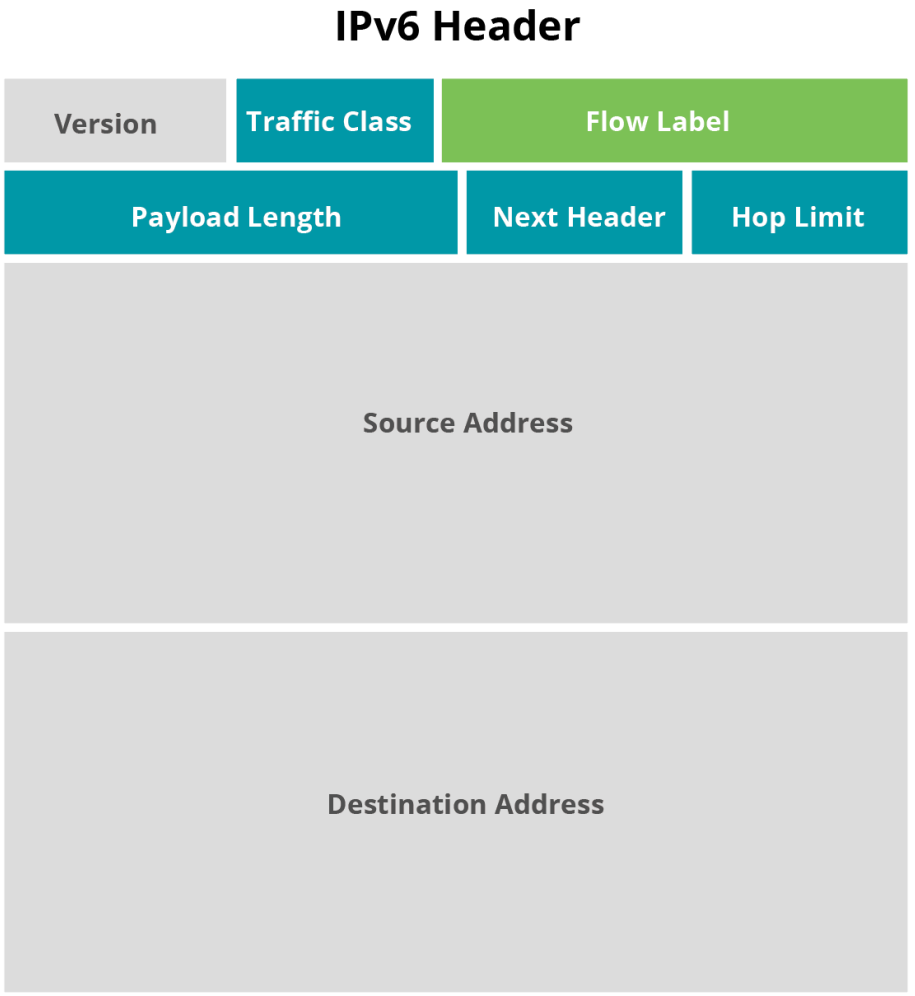
IPv6 Header Format

- Fixed length
  - Optional headers are daisy-chained

- IPv6 header is twice as long (40 bytes) as IPv4 header without options (20 bytes)

IPv6 Header



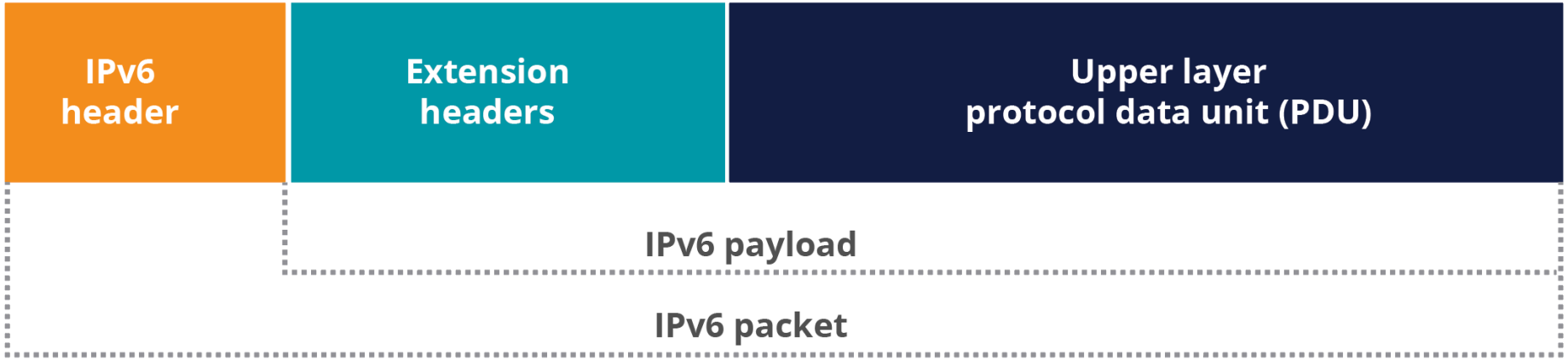


LEGEND

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

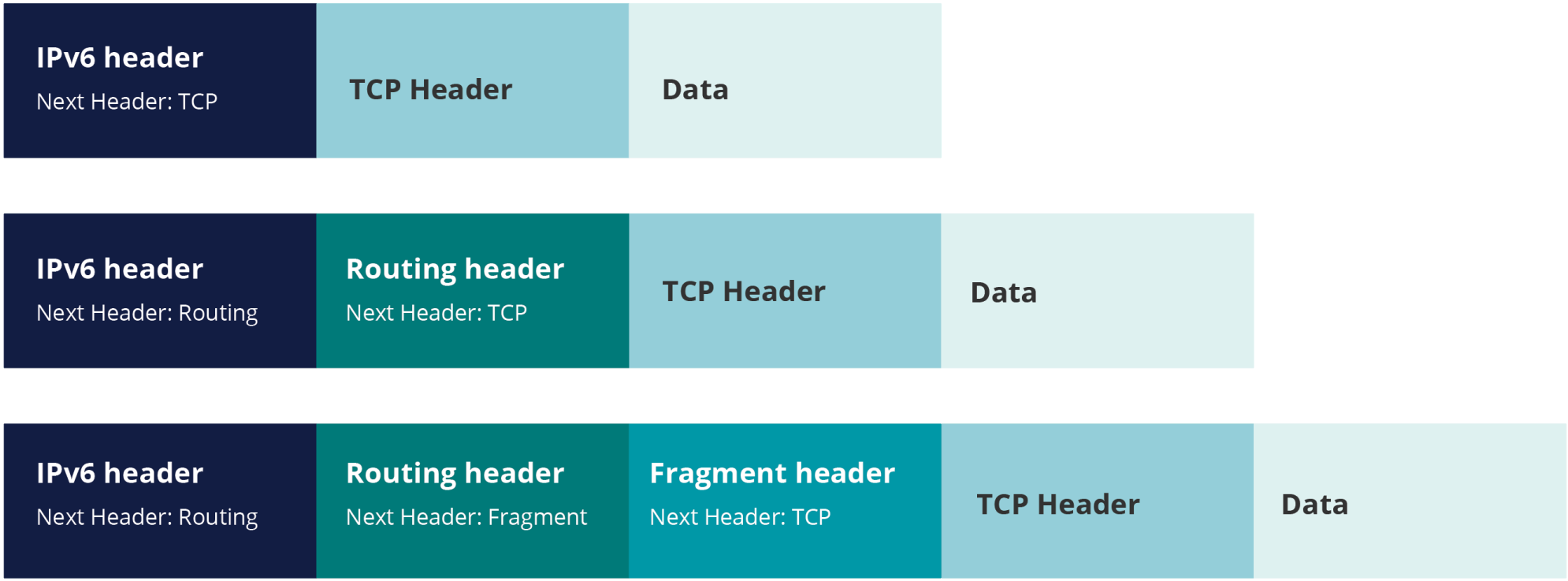
IPv6 Header

- Optional fields go into extension headers



IPv6 Header

- Daisy-chained after the main header

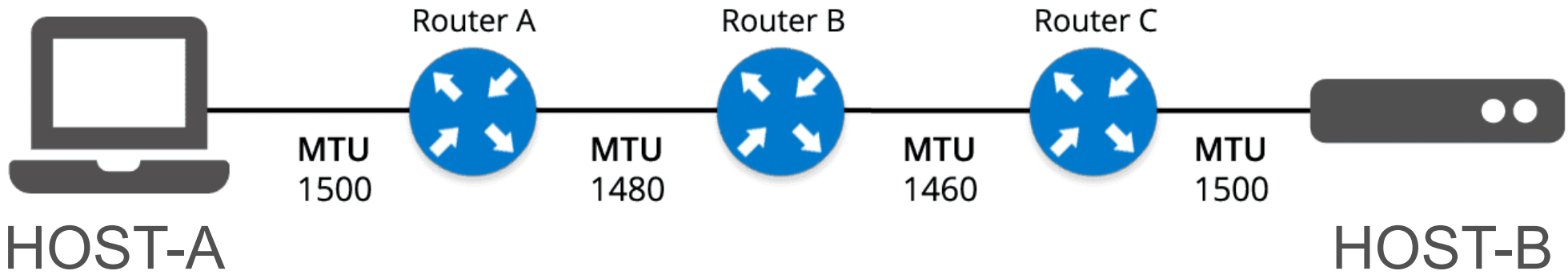


Fragmentation

- 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

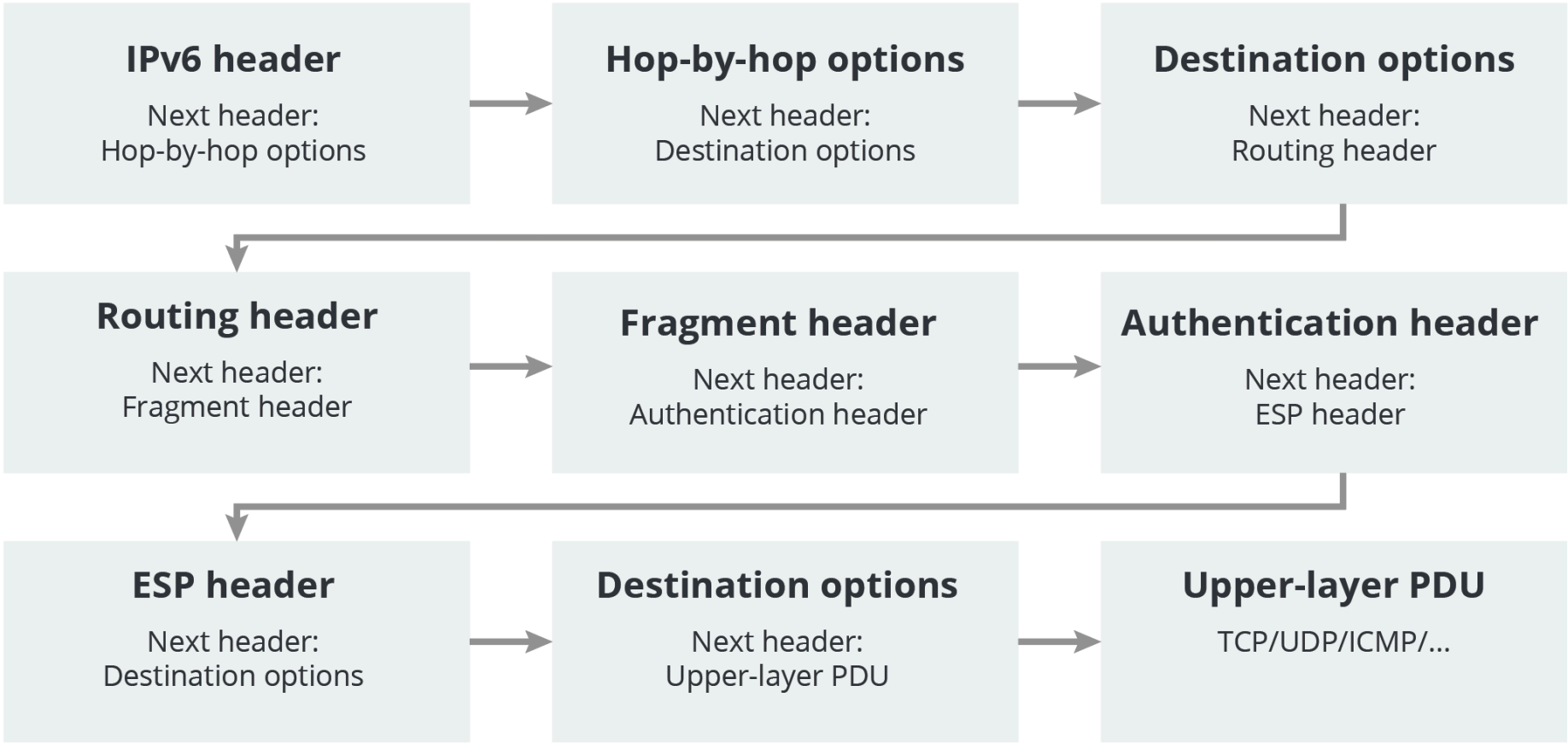
- A sender who gets this “message-too-big” ICMPv6 error tries again with a smaller packet
  - A hint of size is in the error message
  - This is called Path MTU Discovery



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

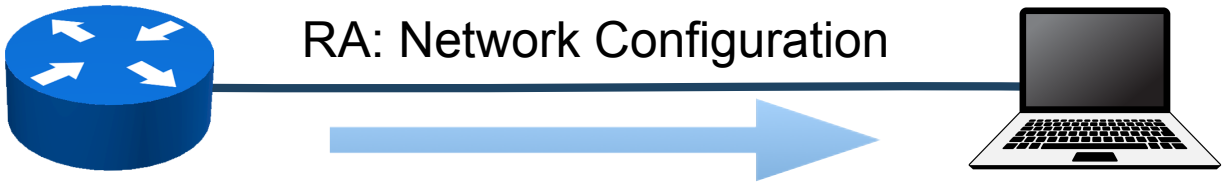
Section 6

Assigning Addresses

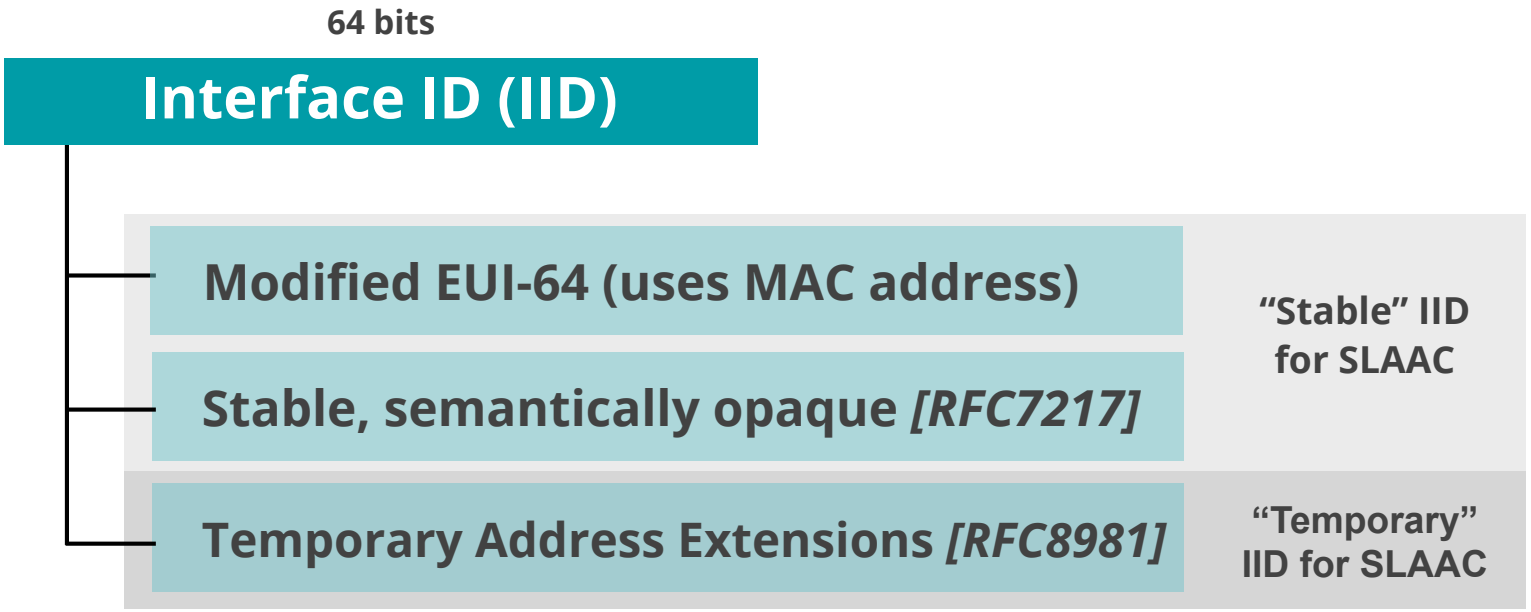
- Routers influence how hosts connect to network
- Several options:
  - Manual configuration
  - Router Advertisement only (SLAAC)
  - RA + DHCPv6 (‘M’ flag on)
  - RA + DHCPv6 (‘O’ flag on)
  - RA (‘A’ flag off) + DHCPv6 (‘M’ flag on)
- Gateway is always provided by the RA

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]*

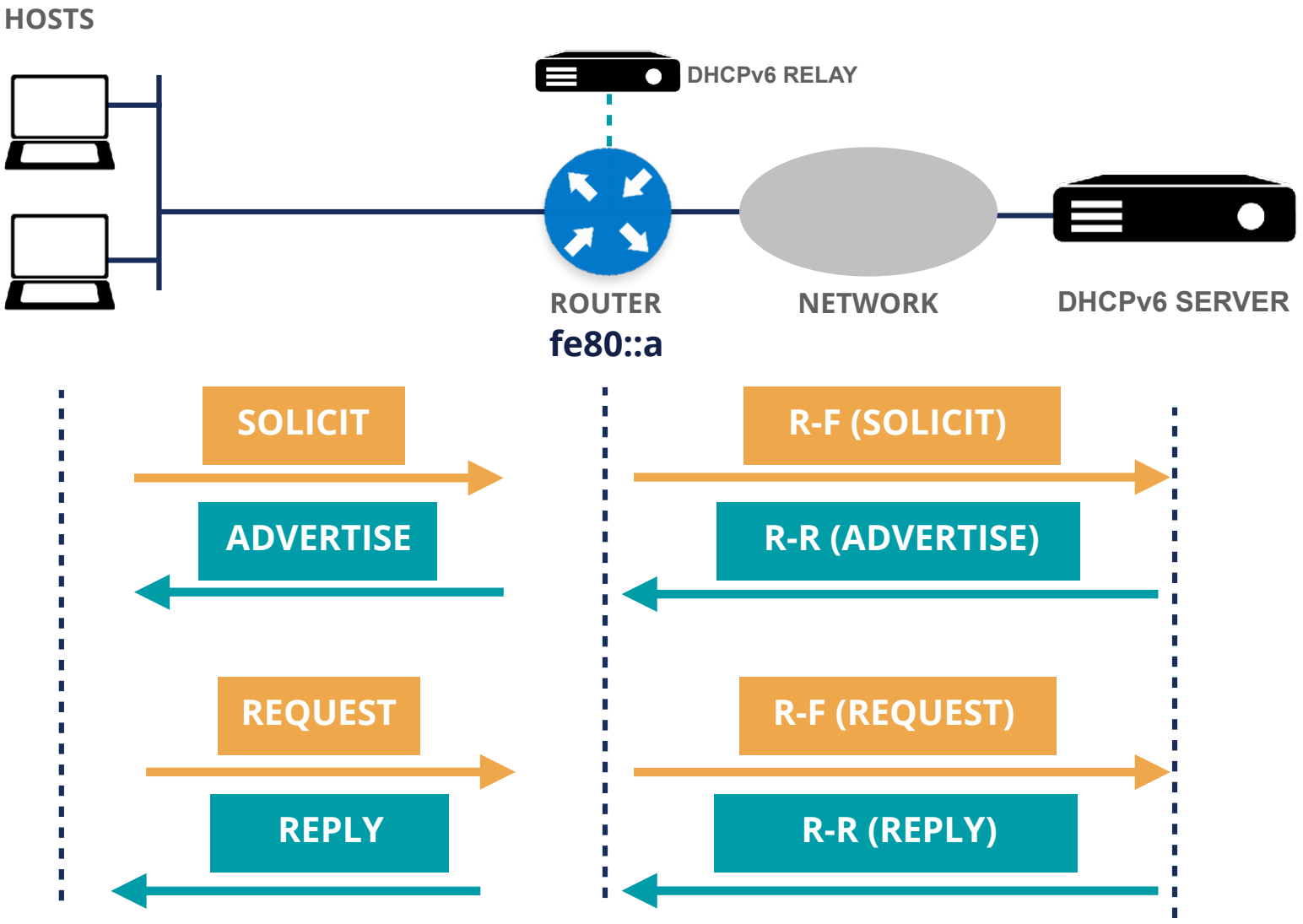
DHCPv6

- Used to give additional information like DNS servers or to manage the address pool

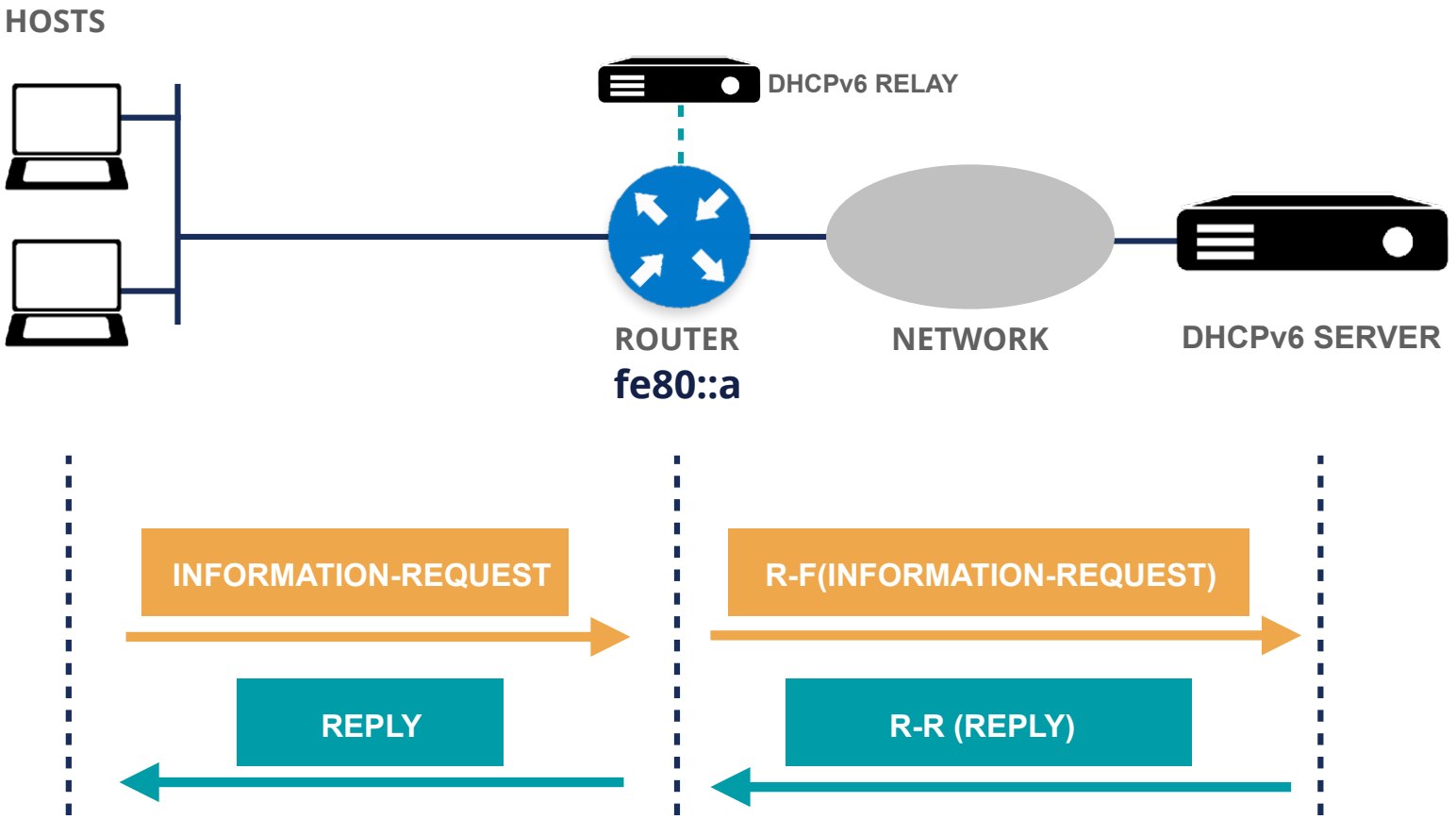
- Router Advertisement message contains hints
  - If “managed” flag = ‘1’ ⇒ can use DHCPv6 to get an address
  - Optionally provide the address of a DNS server (RFC 8106)

- Using additional flags, the network admin can disable SLAAC and force DHCPv6

DHCPv6 (M=1)


HOSTS
DHCPv6 RELAY
ROUTER
fe80::a
NETWORK
DHCPv6 SERVER
SOLICIT
R-F (SOLICIT)
ADVERTISE
R-R (ADVERTISE)
REQUEST
R-F (REQUEST)
REPLY
R-R (REPLY)

DHCPv6 (M=0, O=1)


HOSTS
DHCPv6 RELAY
ROUTER
fe80::a
NETWORK
DHCPv6 SERVER
INFORMATION-REQUEST
R-F(INFORMATION-REQUEST)
REPLY
R-R (REPLY)

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

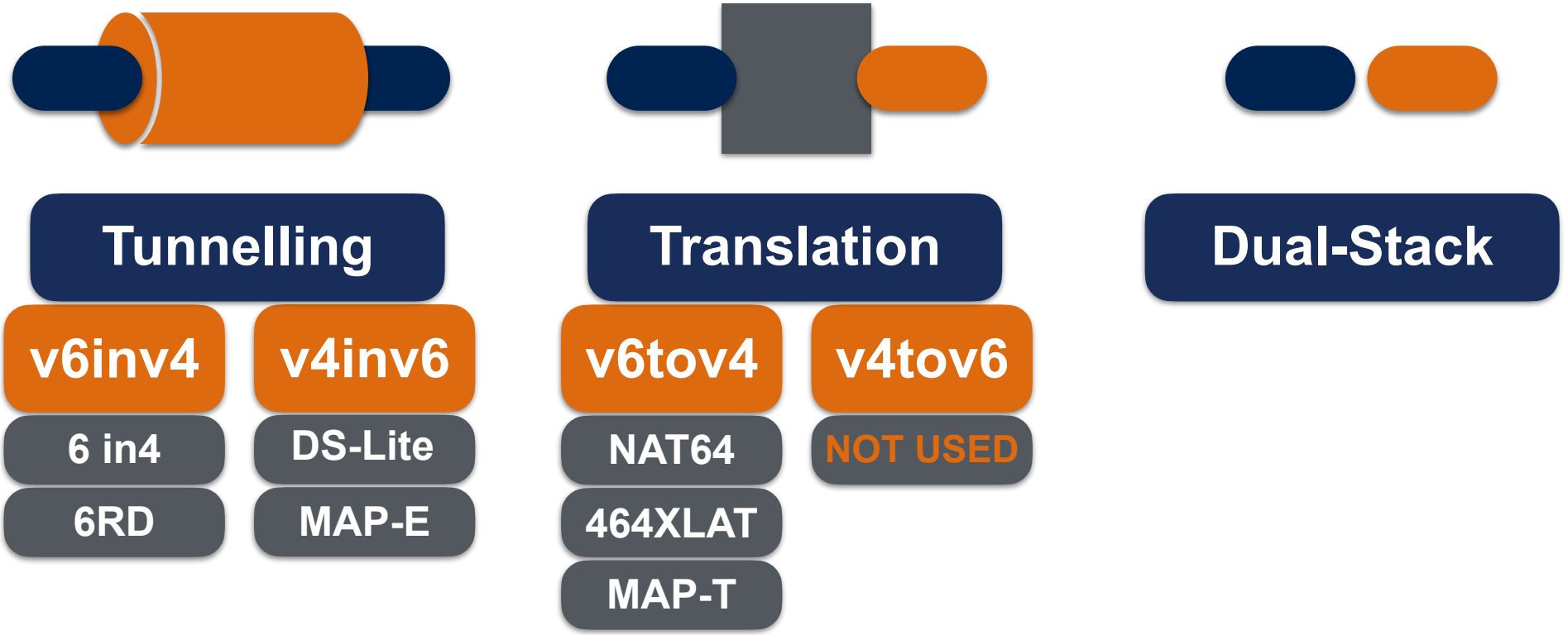
Transition Mechanisms

Section 7

Transitioning: Solving Two Problems

- Cope with the scarcity of IPv4 addresses
  - Our workarounds today: NAT/CGN/LSN
  - We need a better solution!
- Provide IPv6 connectivity to the host and to the network
  - We need to find a way to connect to the emerging IPv6-only networks

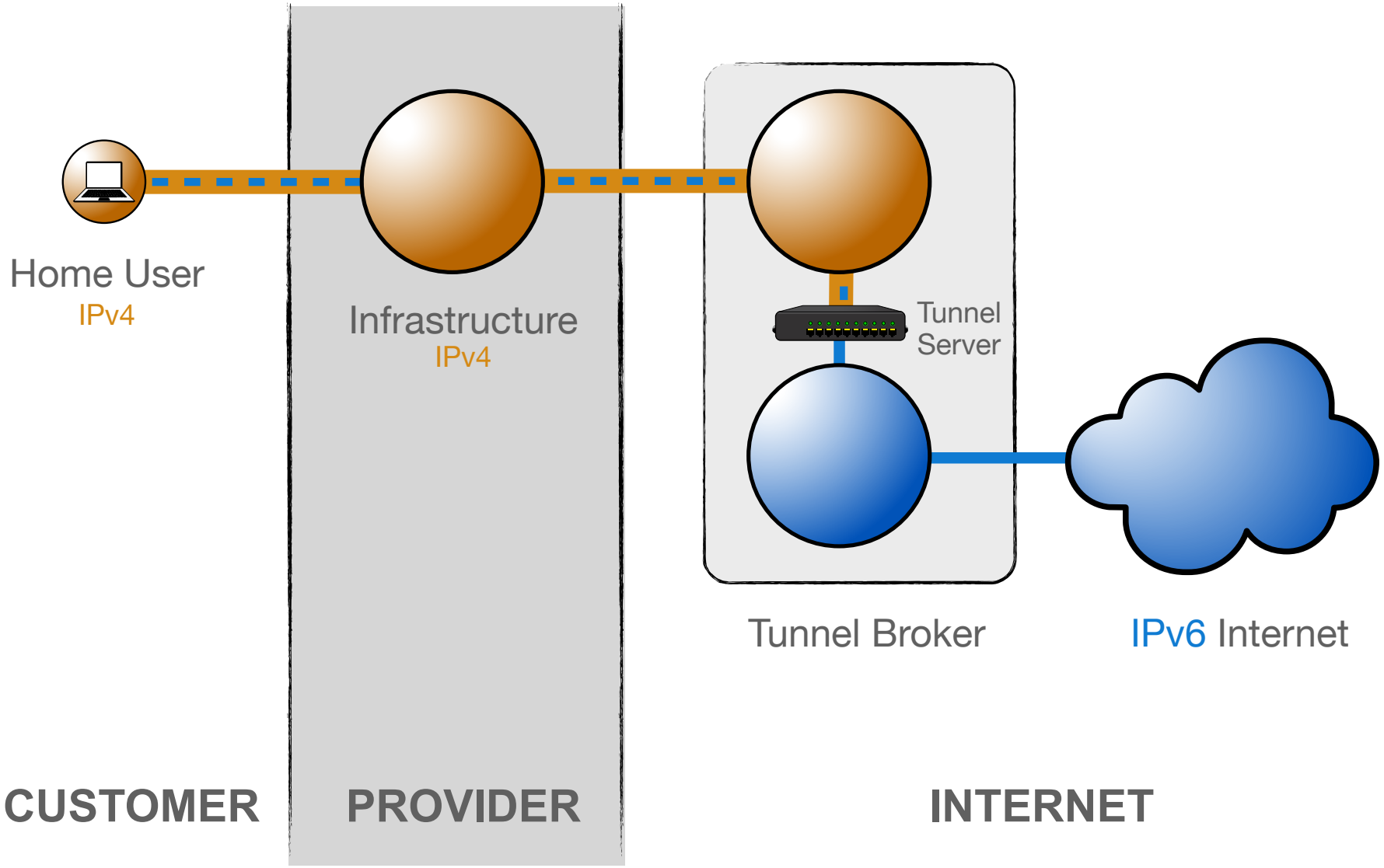
Three Different Types of Transition



Tunnelling - 6in4

- Manually configured tunnels towards a fixed tunnel broker like Hurricane Electric or your own system
- Stable and predictable but not easily deployed to the huge residential markets
- MTU might cause issues

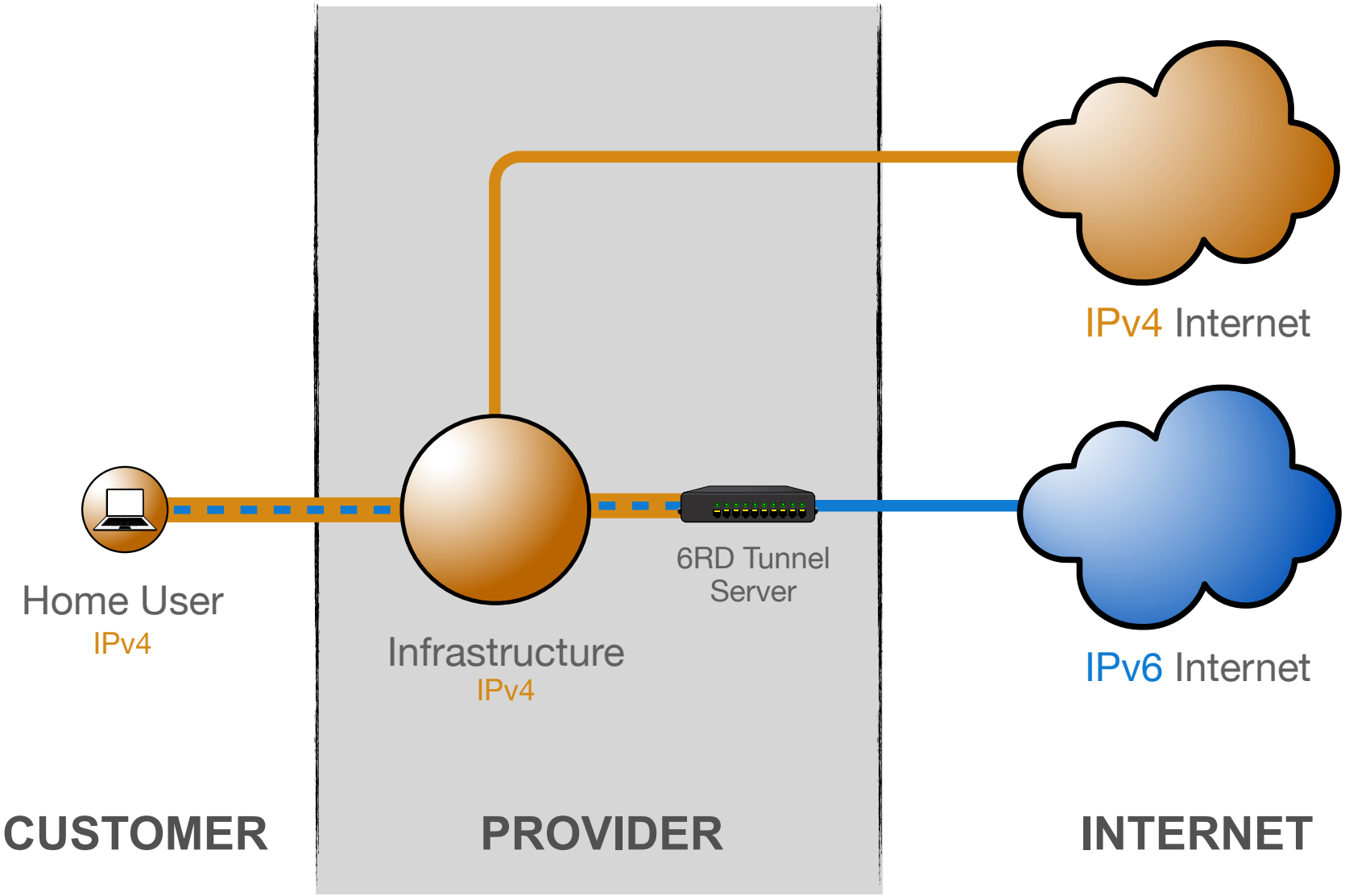
Tunnelling - 6in4



Tunnelling - 6RD

- Encodes the IPv4 address in the IPv6 prefix
- Uses address space assigned to the operator
- The operator has full control over the relay
- Can work with both public and private IPv4 space
- Needs additional software for signalling
- CPE should also support 6RD

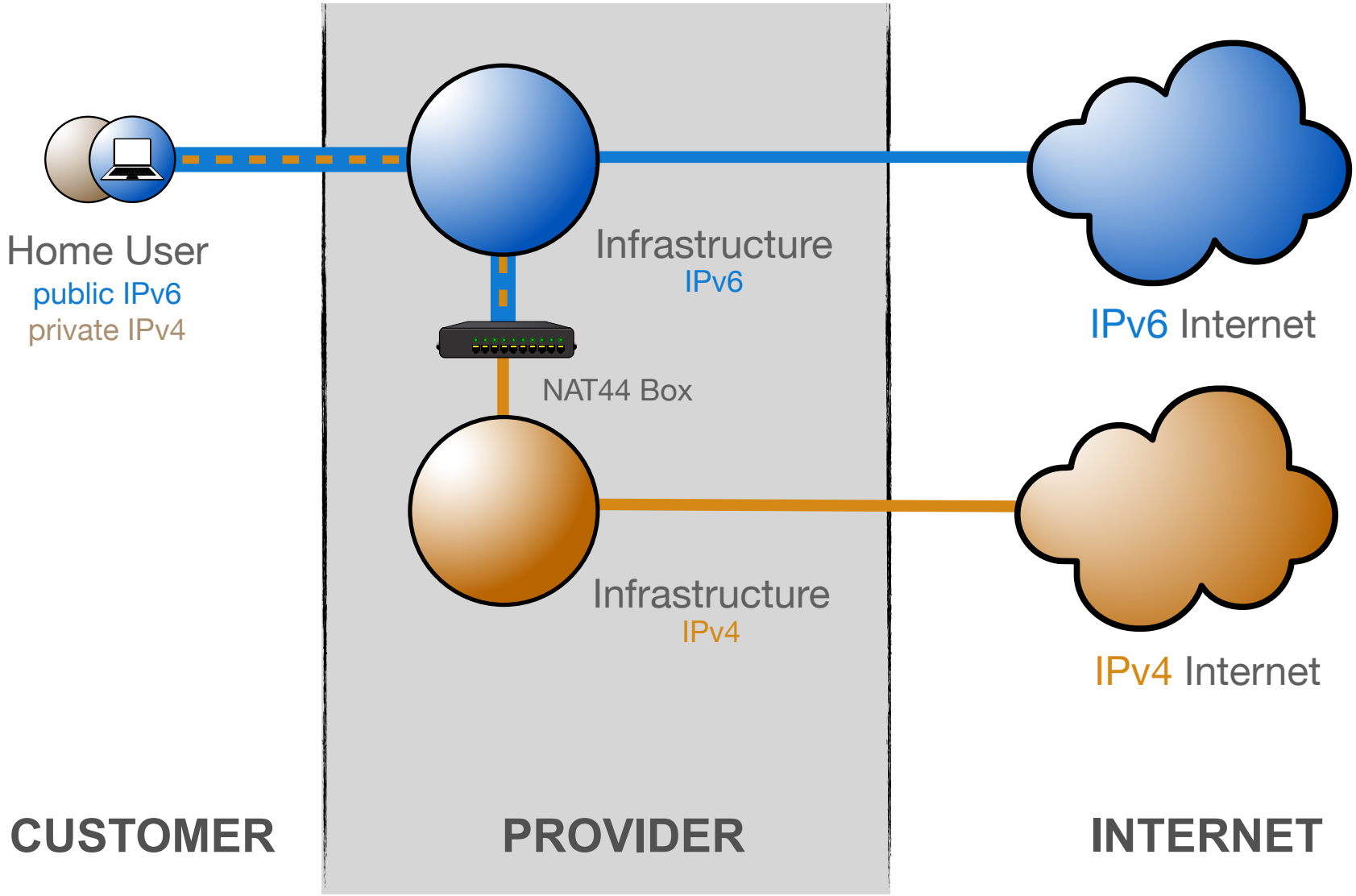
Tunnelling - 6RD



Tunnelling - DS-lite

- Tunnelling IPv4 over IPv6
- Allows clients to use RFC1918 addresses without doing NAT themselves
- NAT is centrally located at the provider
- Client's IPv6 address is used to maintain state and to keep clients apart
  - Allows for duplicate IPv4 ranges

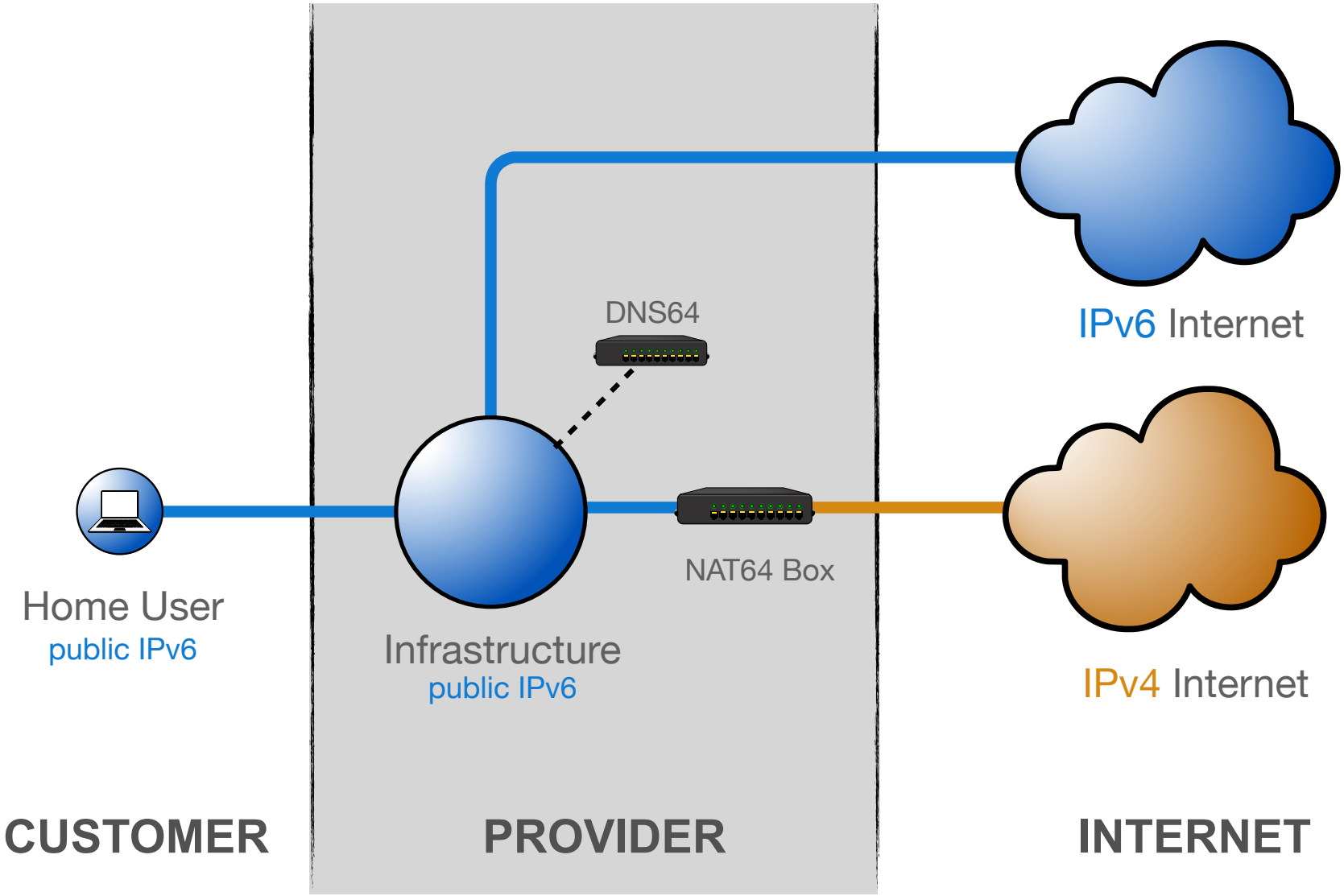
Tunnelling - DS-lite



Translation - NAT64 / DNS64

- Single-stack clients will only have IPv6
- Translator box will strip all headers and replace them with IPv4
- Requires some DNS “magic”
  - Capture responses and replace A with AAAA
  - Response is crafted based on target IPv4 address
- Usually implies address sharing on IPv4

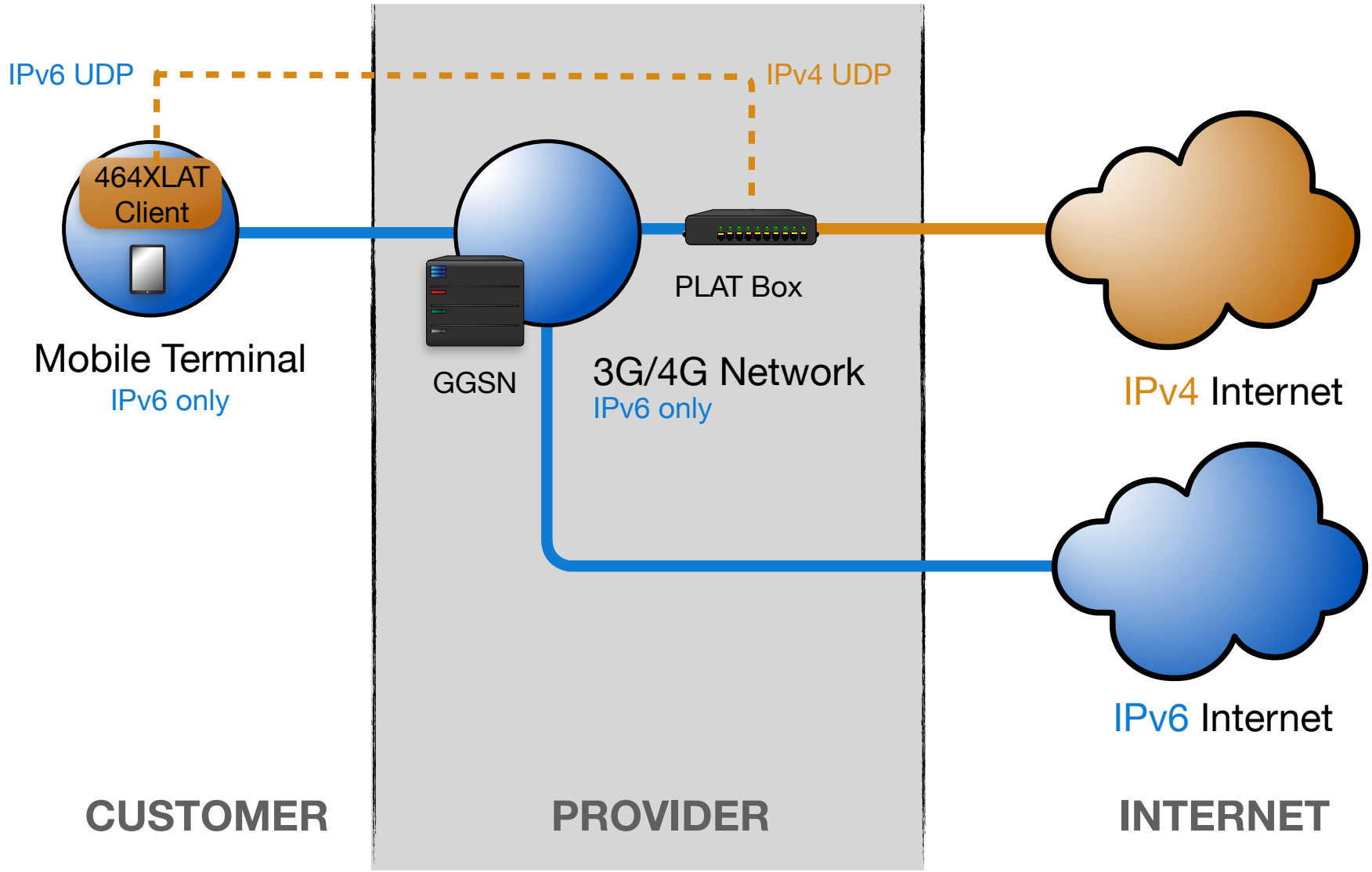
Translation - NAT64 / DNS64



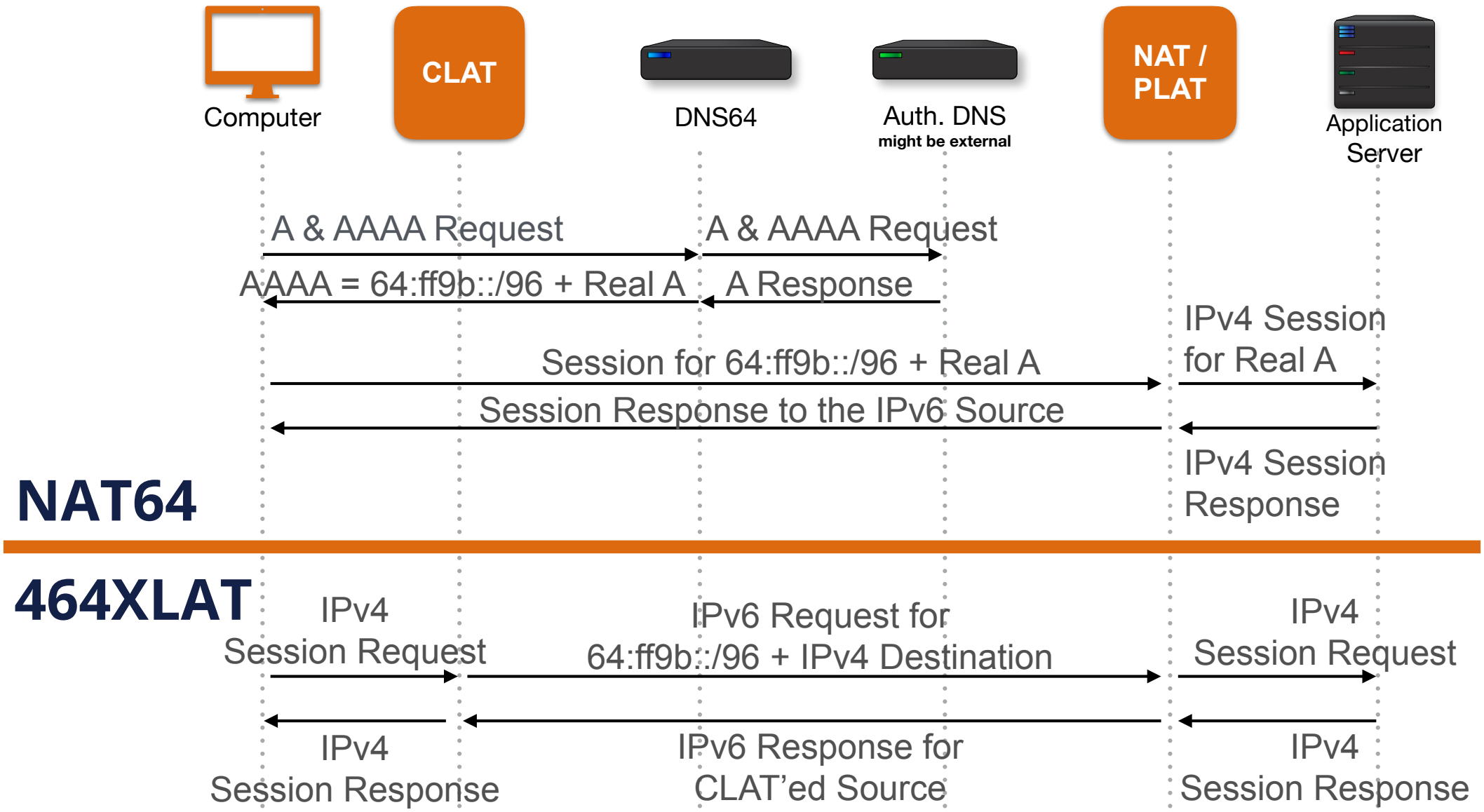
Translation - 464XLAT

- Extension to NAT64 to access IPv4-only applications (legacy applications)
- Handset pretends there is an IPv4 address and the CLAT translates IPv4 packets to IPv6
- Then in the PLAT translates from IPv6 to IPv4

Translation - 464XLAT



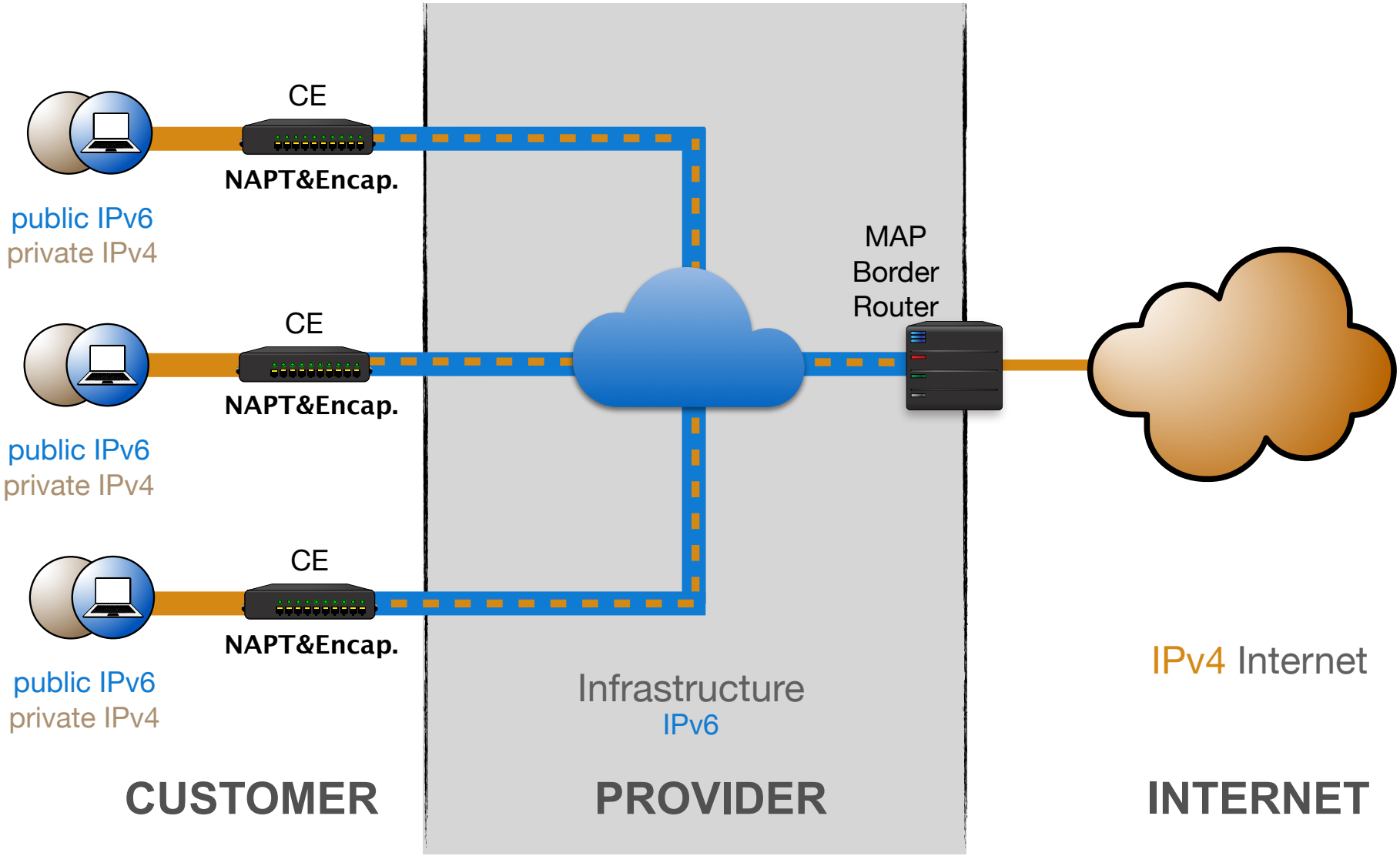
Translation - NAT64 & 464XLAT



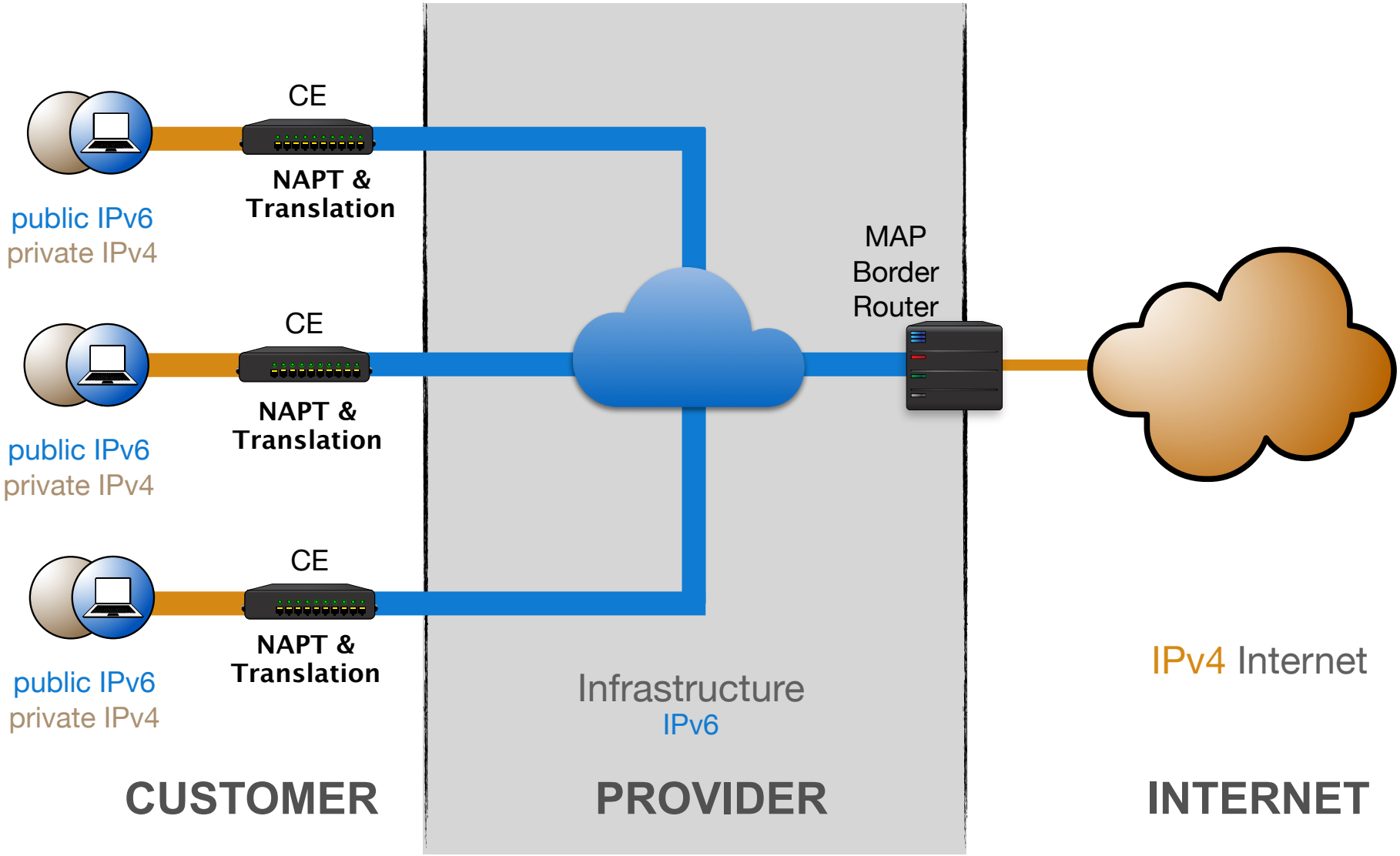
MAP-E / MAP-T

- IPv4 over IPv6 - **Encapsulated or Translated**
- Clients get private IPv4 and public IPv6
- IPv4 address/port mapped into IPv6 address
- **Stateless NAT44** allows traffic to flow asymmetrically in and out of MAP domain

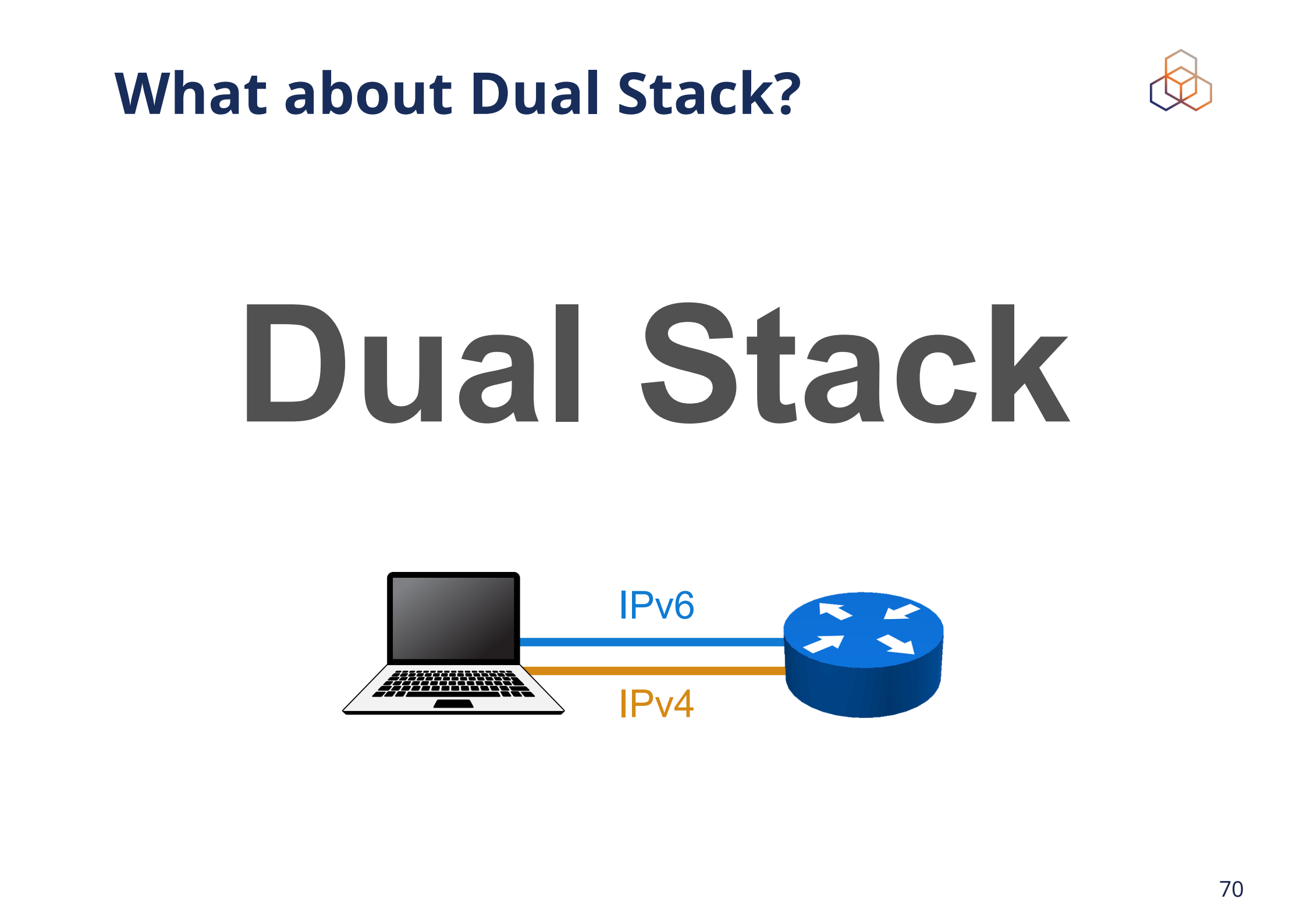
Tunnelling - MAP-E



Translation - MAP-T



What about Dual Stack?



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

- “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 to 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!

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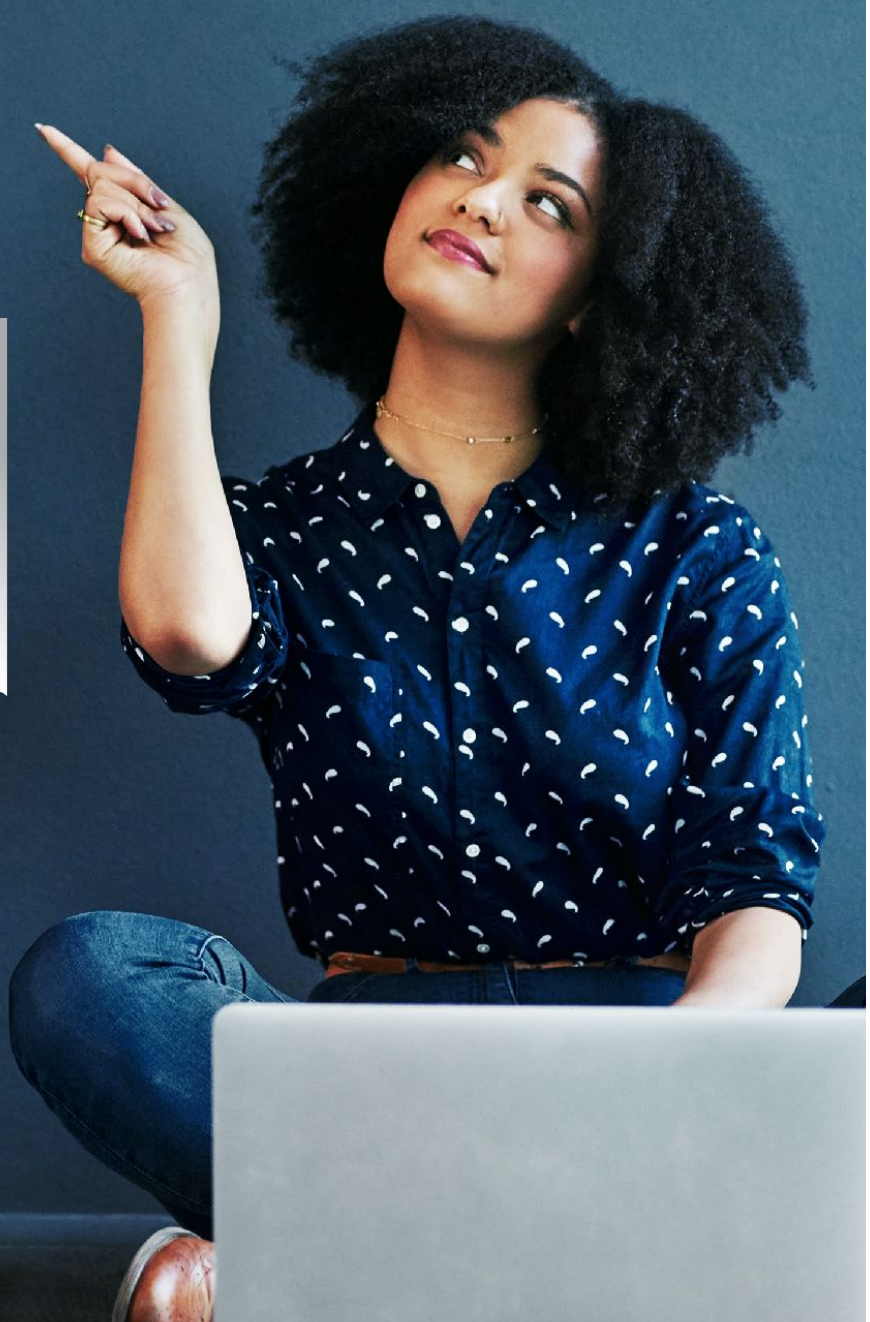

Questions


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D2