Deploying IPv6-Mostly Access Networks

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List of countries by IPv4 address allocation

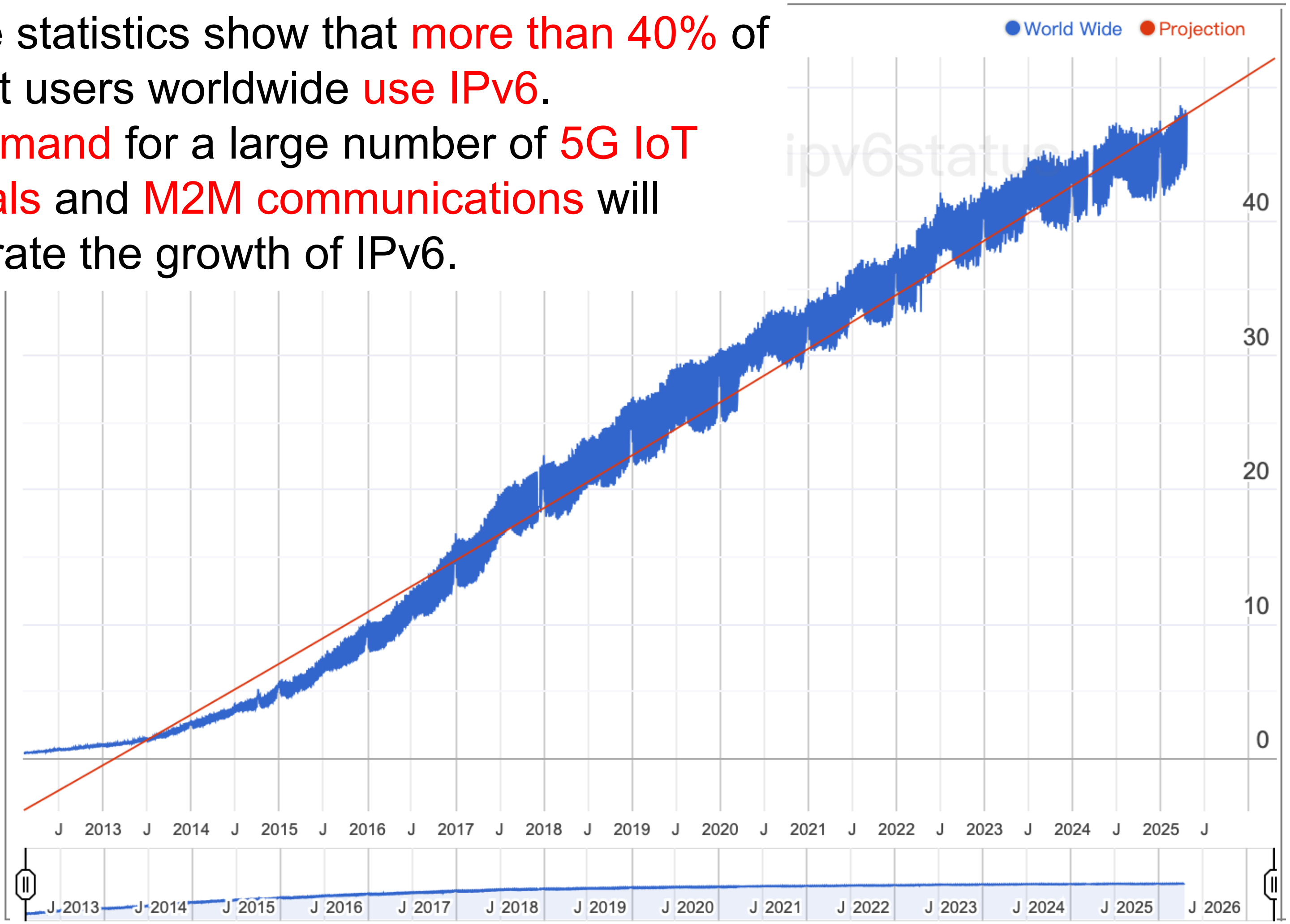
#	Location	IP addresses [3]	%	Population [4][a]	IP addresses per 1000
	(total world allocation)	3,686,475,740	100	8,091,734,930	456
1	United States	1,611,297,420	43.71	343,477,335	4,691
2	China	343,125,576	9.31	1,422,584,933	241
3	Japan	189,145,768	5.13	124,370,947	1,521
4	United Kingdom	134,054,832	3.64	68,682,962	1,952
5	Germany	124,185,676	3.37	84,548,231	1,469
6	South Korea	112,495,296	3.05	51,748,739	2,174
7	Brazil	87,096,200	2.36	211,140,729	413
8	France	82,053,600	2.23	66,438,822	1,235
9	Canada	67,921,556	1.84	39,299,105	1,728
10	Italy	54,020,088	1.47	59,499,453	908
11	Netherlands	48,112,552	1.31	18,092,524	2,659
12	Australia	46,444,728	1.26	26,451,124	1,756
13	Russia	44,859,860	1.22	145,440,500	308
14	India	41,624,148	1.13	1,438,069,596	29
15	Taiwan	35,715,484	0.97	23,317,145	1,532
16	Spain	32,317,160	0.88	47,911,579	675

Source: https://en.wikipedia.org/wiki/List_of_countries_by_IPv4_address_allocation

- Although the United States holds nearly half of all allocated IPv4 addresses globally, it is also one of the most proactive countries in promoting IPv6 adoption.
  - Not all of the IPv4 address space assigned to the U.S. has been allocated to end users.
  - On average, the number of IPv4 addresses per person is still insufficient to meet basic connectivity needs—for example, for mobile phones, tablets, computers, and wearable devices.
- Countries with large populations such as China, India, Russia, and Brazil have fewer than one IP address per person.

IPv6 is becoming more popular and traffic is growing rapidly

- Google statistics show that more than 40% of Internet users worldwide use IPv6.
- The demand for a large number of 5G IoT terminals and M2M communications will accelerate the growth of IPv6.



Source: https://www.vyncke.org/ipv6status/project.php?metric=p&timeforward=365&timebackward=365&country=ww

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Why Are We Talking About IPv6-Mostly?

- IPv4 addresses are running out
- IPv6 solves the address shortage but many apps still need IPv4
- IPv6-Mostly prefers IPv6 but keeps IPv4 as backup
- Helps move to full IPv6 safely and gradually

What is an IPv6-Mostly Network?

- Supports IPv6-only, dual-stack, and IPv4-only devices
- Tries to use IPv6 first, but offers IPv4 if needed
- Avoids multiple network setups
- Makes network management easier and future-proof

Important Technologies

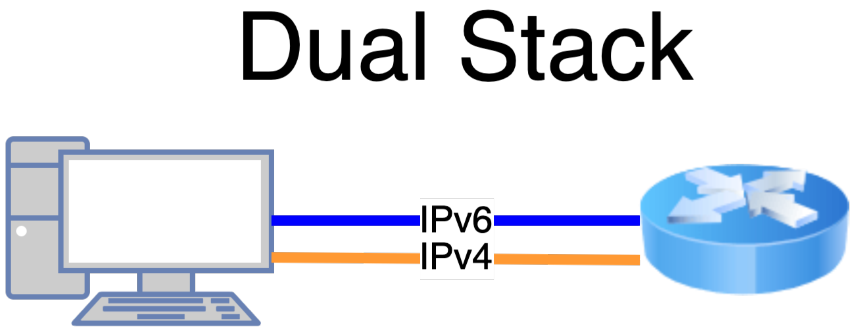
- NAT64: Helps IPv6-only devices talk to IPv4
- DNS64: Helps IPv6-only devices reach IPv4-only websites
- DHCP Option 108: Device says it doesn't need IPv4
- PREF64: Router tells devices how to use NAT64

The endless transition to IPv6

- IPv6 is slowly being deployed
- IPv4 is still the protocol of the Internet
- There are simply not enough IPv4 addresses
  - repurposing 240/4, 127/8 or 0/8 will not help
- There are many transition mechanisms, two of which are special:
  - Dual stack: Running both protocols at the same time
  - NAT64: Allowing limited access from unmodified IPv6-only hosts to IPv4 resources

Dual Stack

- IPv4-only and IPv6-only resources directly accessible
- IPv6 preferred for dual-stack resources
- Problems with IPv6 masked by Happy Eyeballs algorithm
- But it does not address IPv4 shortage



IPv6-Mostly vs Dual-Stack

- Dual-stack uses both IPv4 and IPv6 always
- IPv6-Mostly uses IPv6 first, saves IPv4 addresses
- Easier to spot and fix IPv6 problems
- NAT64 replaces NAT44 with no extra network load

IPv6-Mostly vs IPv6-Only Networks

- IPv6-only networks are harder to manage
- IPv6-Mostly balances old and new devices
- No need for multiple SSIDs or VLANs
- Helps IT teams plan future upgrades

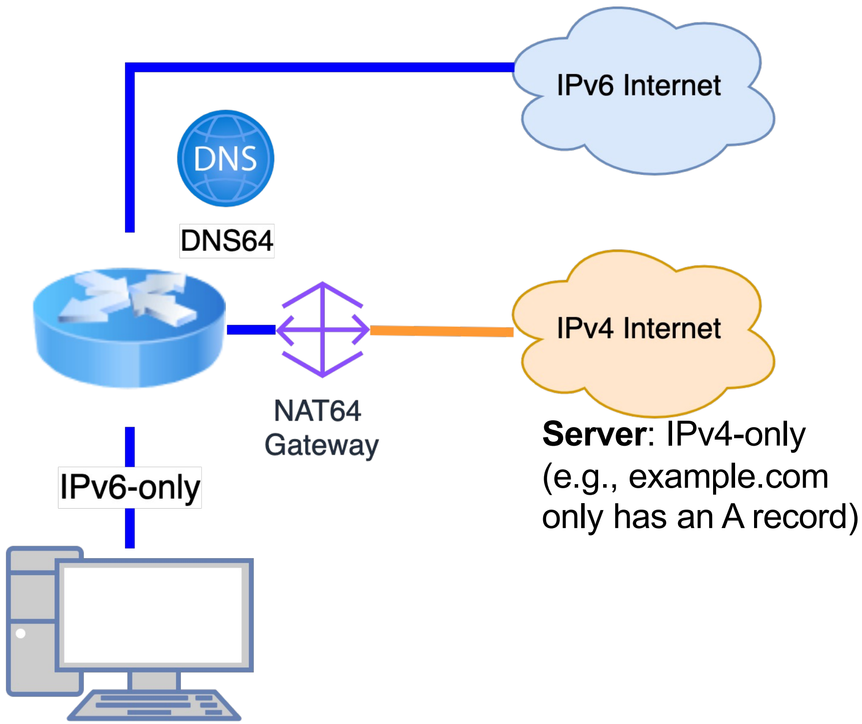
What are NAT64 and DNS64?

- NAT64 translates IPv6 to IPv4
- DNS64 works with NAT64 to fake IPv6 addresses
- IPv6-only devices can reach IPv4 sites

NAT64 allows IPv6-only networks

- IPv6 accessible natively
- IPv4 is translated into part of IPv6 address space
- Together with DNS64, everything seems to be accessible over IPv6
- But sometimes you run into…
  - IPv4 literals
  - Legacy software opening IPv4-only sockets
  - Dual-stack servers with broken IPv6

Step 2: DNS64 handles the query
DNS64 → Public DNS: query for example.com A record
→ Response: A = 93.184.216.34
Step 3: DNS64 synthesizes an AAAA record
DNS64 Synthesize: 64:ff9b::5d:b8:d8:22 (mapped from 93.184.216.34)
Client Receives: example.com AAAA = 64:ff9b::5d:b8:d8:22



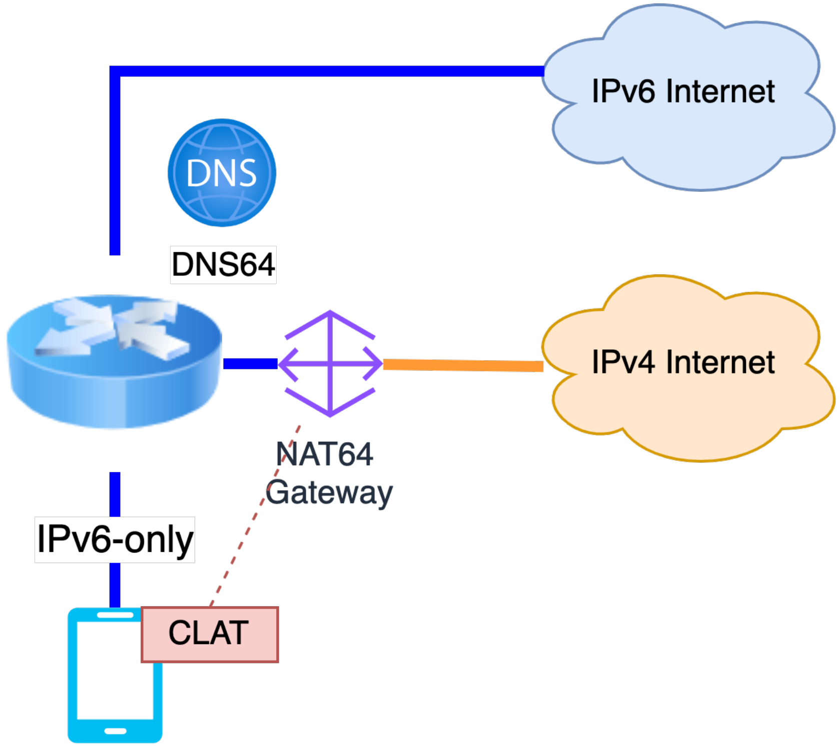
Step 1: Client sends a DNS query
Client → DNS64: query for example.com AAAA record
Step 4: Client initiates IPv6 connection
Client → 64:ff9b::5d:b8:d8:22 (TCP SYN, port 80)

What are 464XLAT and CLAT?

- 464XLAT helps old IPv4-only apps work on IPv6 networks
- CLAT (Customer-side Translator) gives the device a fake IPv4 feel
- Data goes over IPv6 using NAT64
- Great for phones and other mobile devices

Mobiles are ready

- Apple forces all iOS apps to work well on IPv6-only networks with NAT64
- There is Happy Eyeballs 2.0 for IPv4 literals or broken IPv6 on dual stack servers
- Finally CLAT is used for tethering to a computer
- Android uses just CLAT (464XLAT)
  - so IPv4 is accessible via two translations



Desktops suffer on IPv6-only

- No Happy Eyeballs 2.0 implementation outside Apple
  - and even on Apple, only high-level APIs support it (eg. Safari, not Firefox)
  - Chrome has “Use NAT64 translation for IPv4 literals” feature
- No CLAT in Windows, Linux or ChromeOS
- Well known small problems:
  - Legacy applications using IPv4-only sockets
  - IPv4 literals do not work (except Chrome)
  - Dual-stack servers where IPv6 is broken do not work
  - Legacy Happy Eyeballs doesn’t help since there's no IPv4 to fall back to
  - Most corporate VPNs do not work (often just a configuration issue)

IPv6-only support on other platforms

- Windows 11 pledged to implement CLAT and DHCP Option 108
- Linux has some support for DHCP Option 108
  - NetworkManager
  - systemd-networkd
  - dhcpcd
- Proper CLAT for Linux is still missing
  - Not supported by the kernel itself
  - eBPF might be the way forward

How to Start Using IPv6-Mostly

1. Enable PREF64 in routers
2. Set up DHCP to support Option 108
3. Turn on Option 108 on compatible devices

- Test in small networks first
- Use short lease times for safe rollbacks

PREF64 RA Option

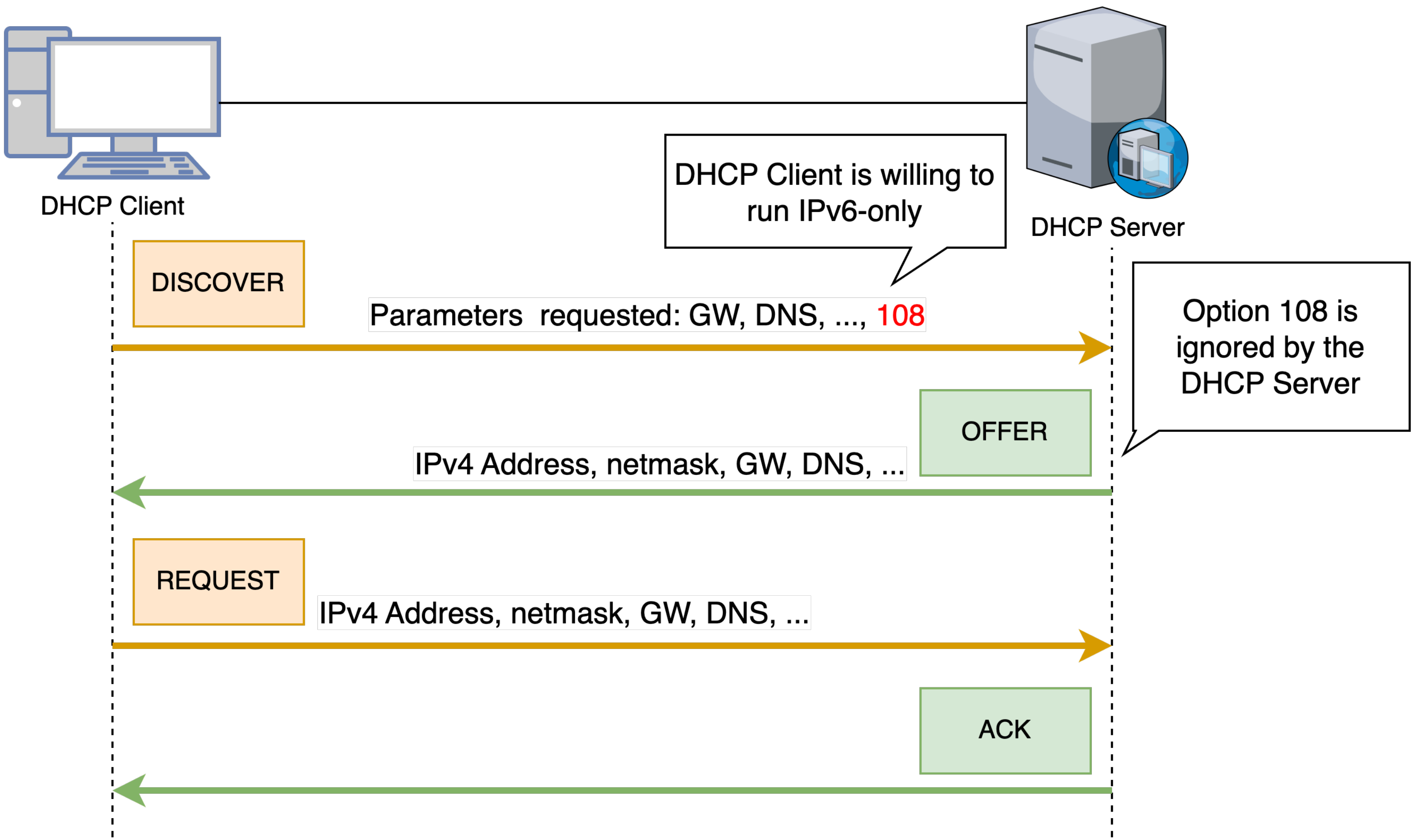
- A Router Advertisement option carrying NAT64 prefix
- Needed for CLAT configuration, local DNS64 or Happy Eyeballs 2.0 (dealing with IPv4 literals)
- Shares fate with other configuration parameters
  - can be trusted a bit more than DNS64
- Supported by recent Android, iOS and macOS

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     |     Scaled Lifetime     | PLC |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|              Highest 96 bits of the Prefix                    |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

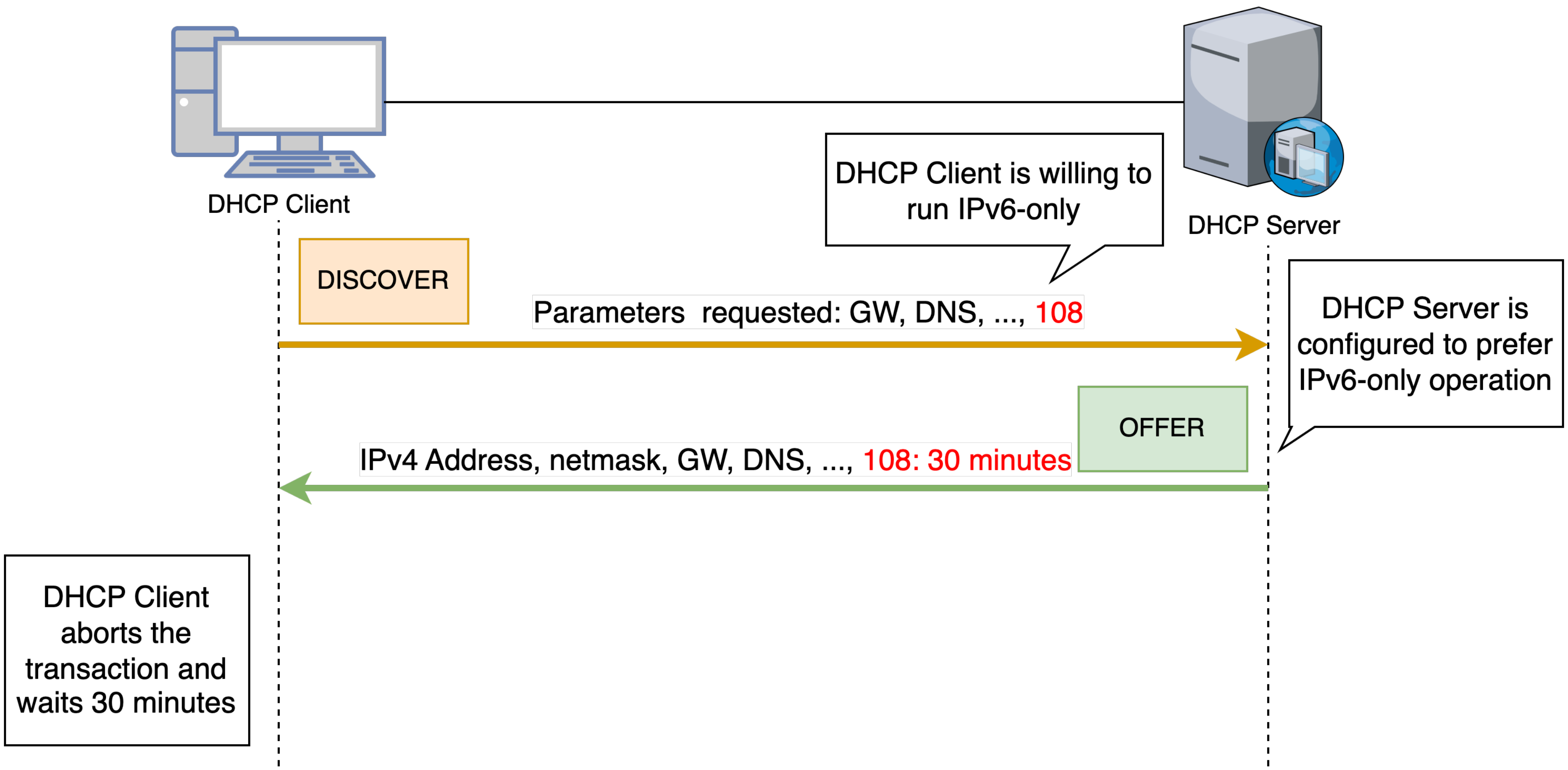
RFC 8925: IPv6-Only Preferred Option for DHCPv4

- Purpose
  - Defines DHCPv4 Option 108, enabling IPv6-capable hosts to prefer IPv6-only connectivity (such as NAT64 environments), thus avoiding unnecessary IPv4 address assignment and promoting IPv6-only deployments.
- How It Works
  - Client Behavior:
    - Includes Option 108 in DHCPDISCOVER or DHCPREQUEST messages.
    - If server replies with Option 108, client stops requesting an IPv4 address and temporarily disables DHCPv4 (default: 1800 seconds).
  - Server Behavior:
    - In IPv6-mostly networks, responds with Option 108 if requested by the client.
    - Does not assign an IPv4 address or assigns 0.0.0.0 as yiaddr.

IPv6-only Preferred option of DHCP



Using DHCP to turn IPv4 off



DHCP option 108 is easy

- Native support in the latest Kea
- Most DHCP servers support defining custom options
  - for instance: dnsmasq -O 108,0:0:1:2c
  - the option value represents duration for which the IPv4 stack should be disabled
- No special processing on the DHCP server side is required
- But there have to be free addresses in the IPv4 address pool
  - Otherwise the DHCP server will not respond

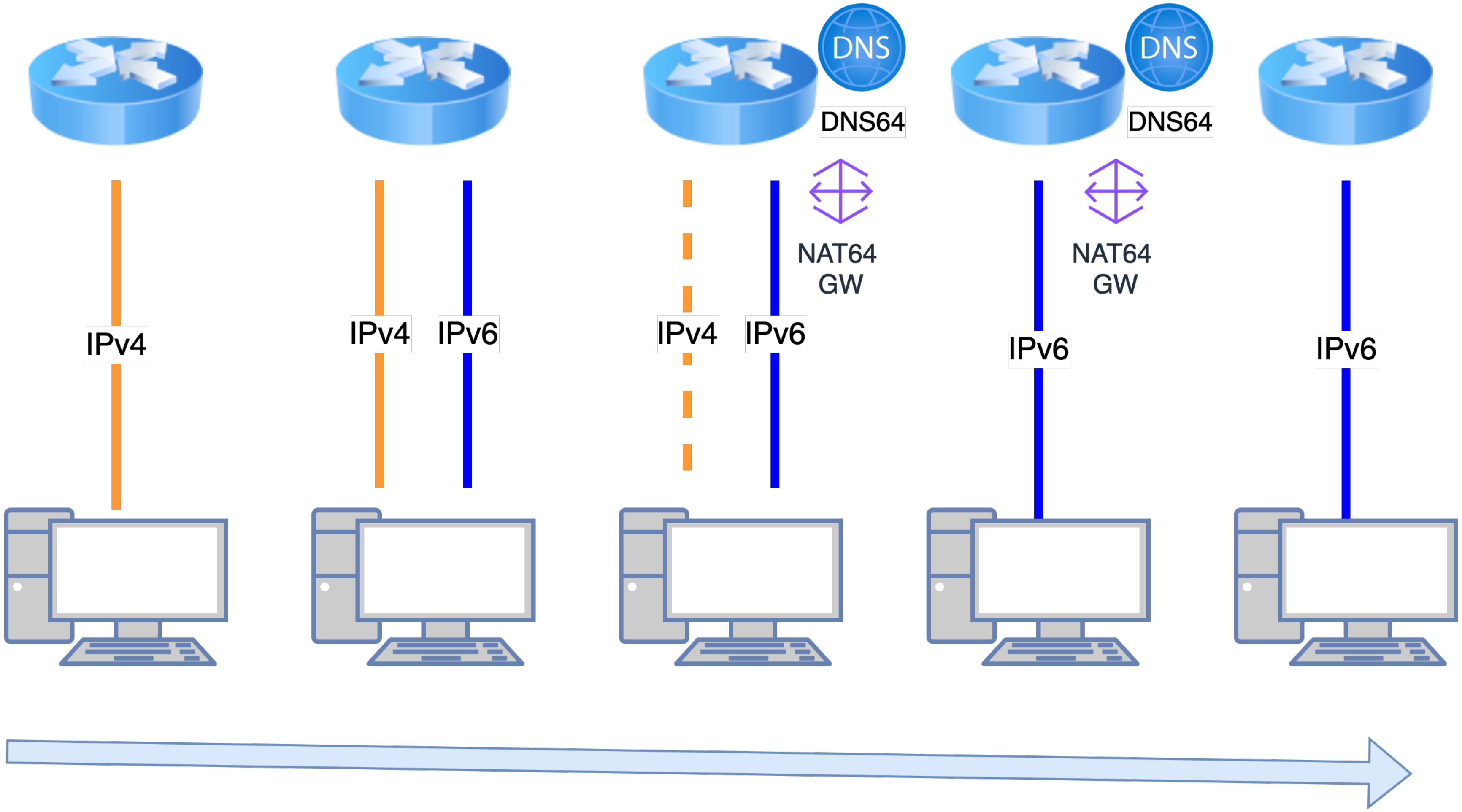
PREF64 RA option is harder

- No custom RA option support in routers
- Router vendors should really implement custom options similar to DHCP
  - Adoption is slowly increasing:
  - radvd (merged but unreleased)
  - odhcpd (used in OpenWRT)
  - rad (part of OpenBSD)
  - MikroTik RouterOS v7.8 beta2
  - BIRD 2.14 (as a part of custom router advertisement option)

When to consider IPv6-mostly

- You don't use NAT and your DHCP pool is filling up
- You do use NAT but are running out of private addresses
- There are mostly mobile or Apple devices in your network
- You already have NAT64 in place and want to gradually undeploy IPv4

Phased IPv6 transition



Summary

- IPv6-Mostly is a smart step toward full IPv6
- Works with new and old devices
- Easy to manage and upgrade
- Perfect for schools, companies, and public Wi-Fi

Reference

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Thank You