IPv6 in Cellular Networks

(IPv6-only in non-cellular networks)
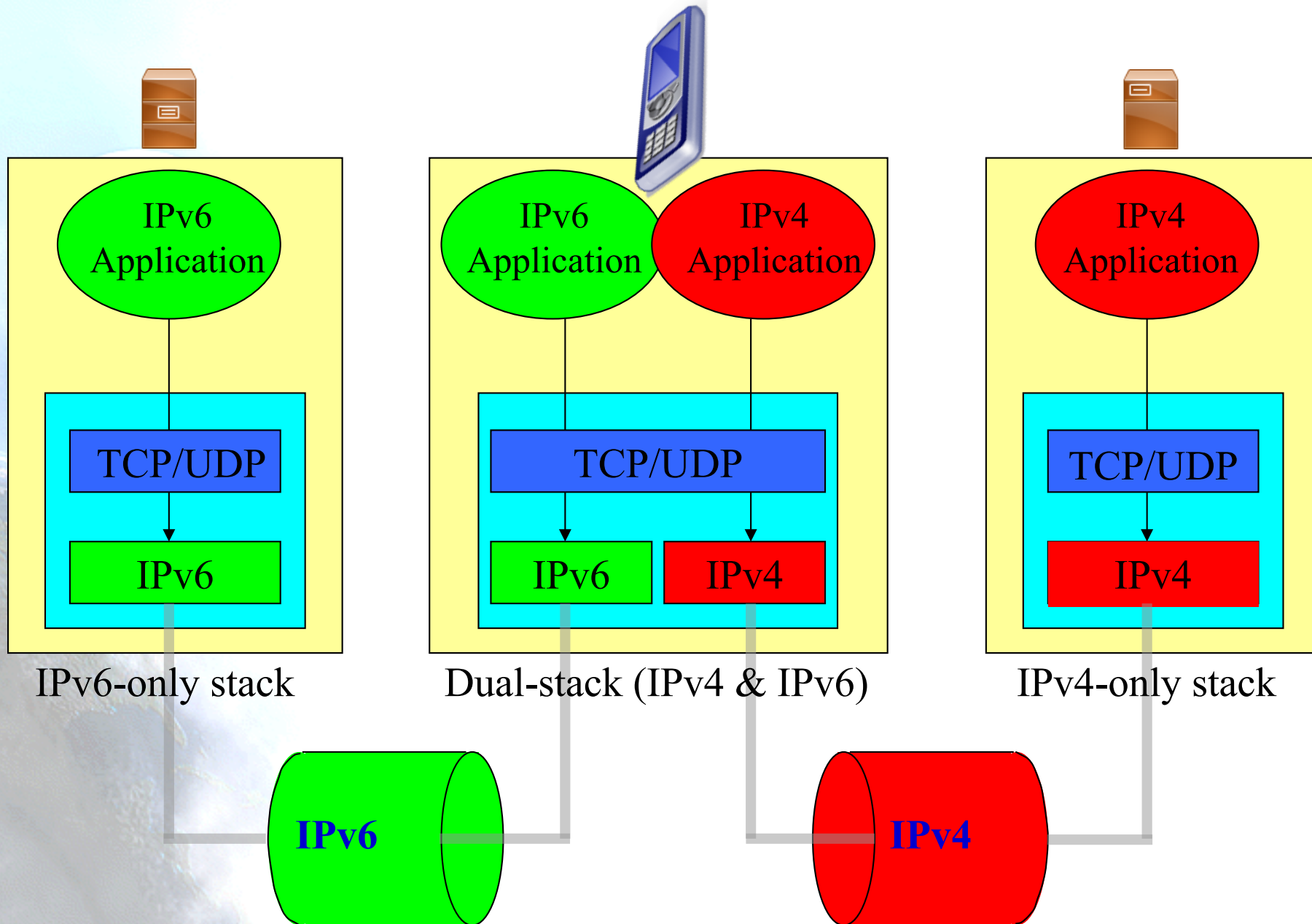
ESNOG 20
Madrid
October 2017

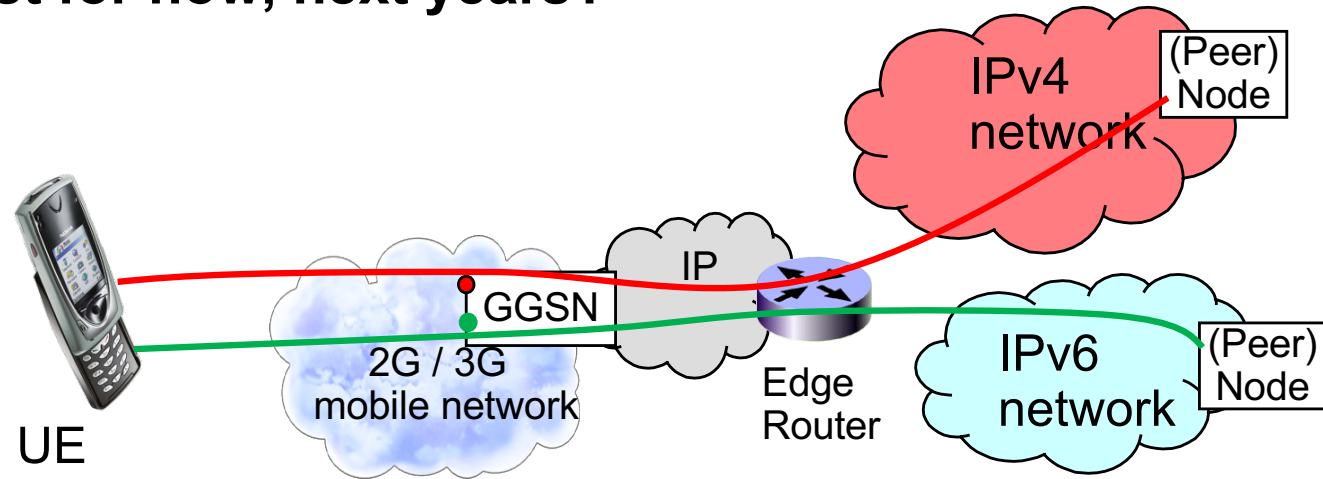**Jordi Palet (jordi.palet@theipv6company.com)**

Need to support IPv6

- IPv4 exhaustion
  - Sharing IPv4 (CGN) is not enough and is problematic
- Increase in number of users
- Increase in number of devices per user (and also tethering)
- Increase in number of addresses per device (VMs, other reasons)
- VoLTE/IMS
- IoT
- **LONG TERM STRATEGY**

The best solution: Dual-Stack!

IPv6-only stack | Dual-stack (IPv4 & IPv6) | IPv4-only stack

IPv6 Application — TCP/UDP — IPv6

IPv6 Application / IPv4 Application — TCP/UDP — IPv6 / IPv4

IPv4 Application — TCP/UDP — IPv4

IPv6

IPv4

Sure ?

- **Do you have enough IPv4 addresses?**
  - **Not just for now, next years?**

IPv4 network

(Peer) Node

IP

GGSN

Edge Router

2G / 3G mobile network

UE

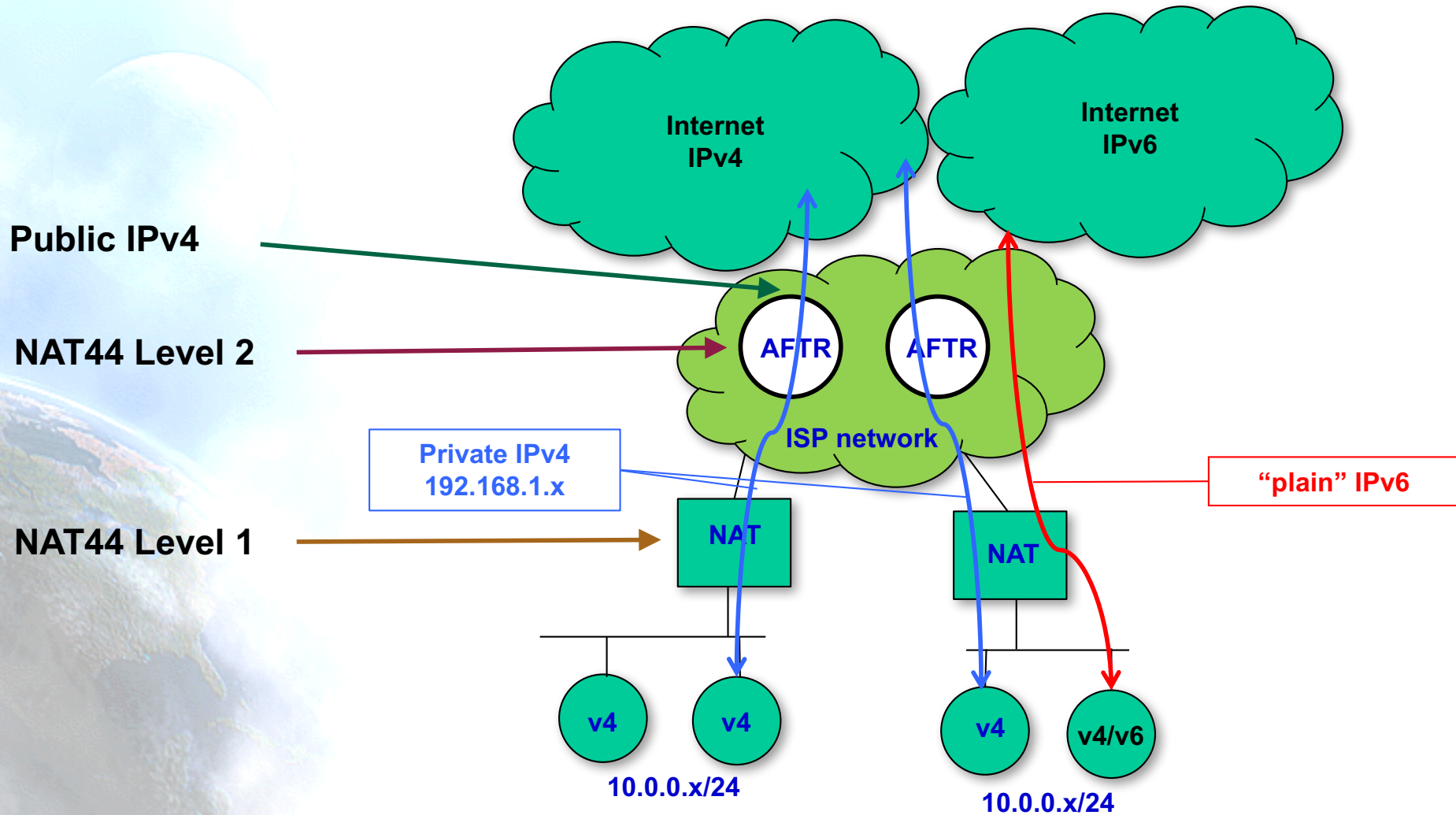IPv6 network

(Peer) Node

- **O&M cost?**
- **Call-center impact?**
- **Performance?**
- **Licenses?**
- **Issues authenticating 2 addresses?**

Alternatives to Dual-Stack

- **IPv6 + CGN**

- **IPv6-only**

- **IPv6-only with NAT64**

- **IPv6-only with NAT64 and DNS64**

- **464XLAT**

- **Other transition technologies**

NAT444 (CGN)

Internet IPv4

Internet IPv6

Public IPv4

NAT44 Level 2

AFTR

AFTR

ISP network

Private IPv4
192.168.1.x

"plain" IPv6

NAT44 Level 1

NAT

NAT

v4

v4

v4

v4/v6

10.0.0.x/24

10.0.0.x/24

CGN breaks …

- UPnP-IGD (Universal Plug & Play - Internet Gateway Device protocol)
- NAT-PMP (NAT Port Mapping Protocol)
- Other NAT Traversal mechs
- Security
- AJAX (Asyncronous Javascript And XML)
- FTP (big files)
- BitTorrent/Limewire (seeding – uploading)
- On-line gaming
- Video streaming (Netflix, Hulu, …)
- IP cameras
- Tunnels, VPN, IPsec, ...
- VoIP
- Port forwarding
- ...

How many ports per user?

Max 30 Connections

Max 15 Connections
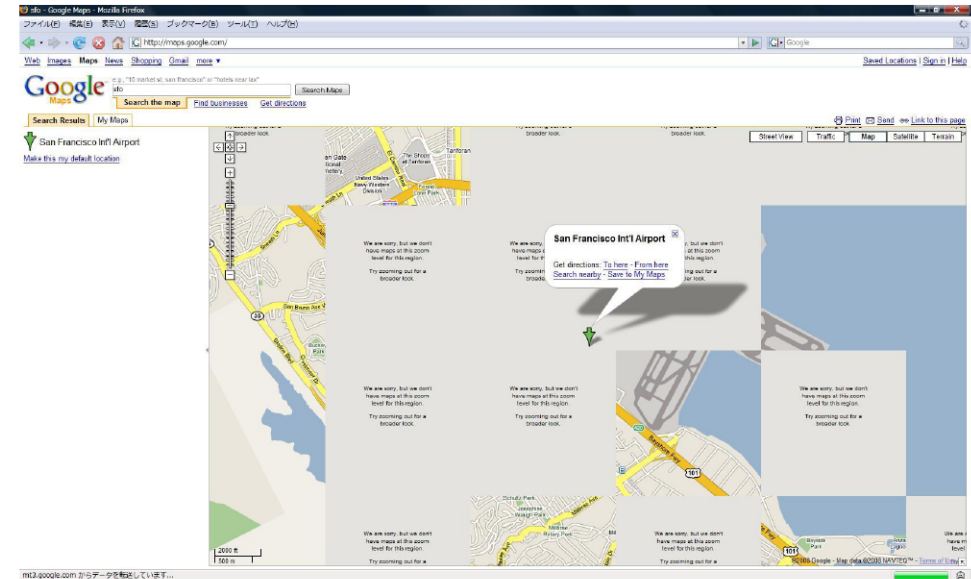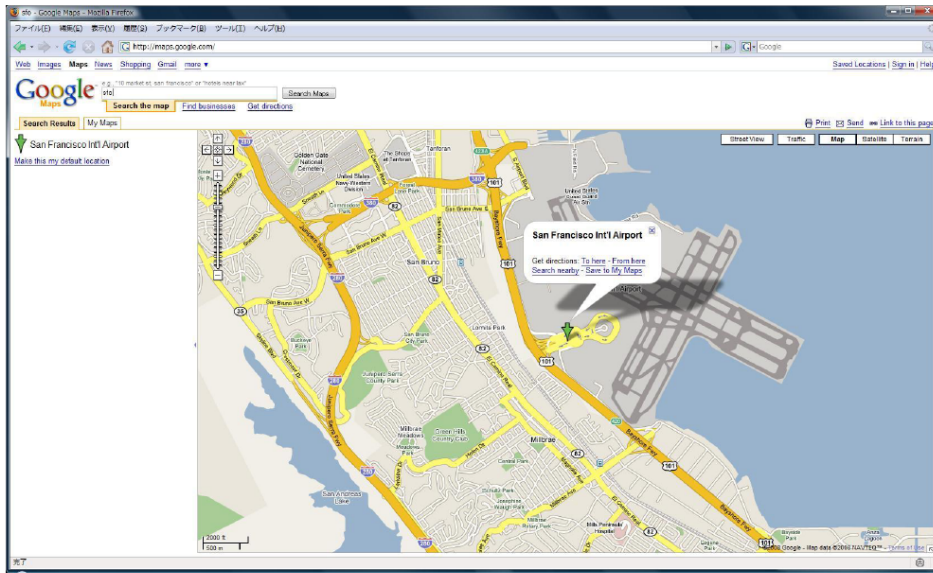
- **Possibly a minimum of 300 per user behind each CPE**
  - **More as AJAX/similar technologies usage increase**
  - **Times average number of users behind each NAT**
  - **And going up**

- **Be aware of IP/port sharing implications …**

So … IPv6-only?

- **Many examples in content providers**

- **FaceBook is one of them**

- **Datacenters are IPv6-only**
  - Started in 2014, internal traffic was 90% IPv6
  - +100 Terabits per second
  - 100% IPv6 in June 2015
  - Allows using FaceBook in IPv6-only networks and clients
  - IPv4 (from Internet) terminated in the IPv6-only clusters
    - RFC1918 space for IPv4 BGP sessions
    - Later on use RFC5549
      - Advertising IPv4 Network Layer Reachability Information with an IPv6 Next Hop
    - IPv4 in IPv6 tunneling, for IPVS (IP Virtual Server)
    - IPv4 link-local (169.254.0.0/16) for Linux and switches
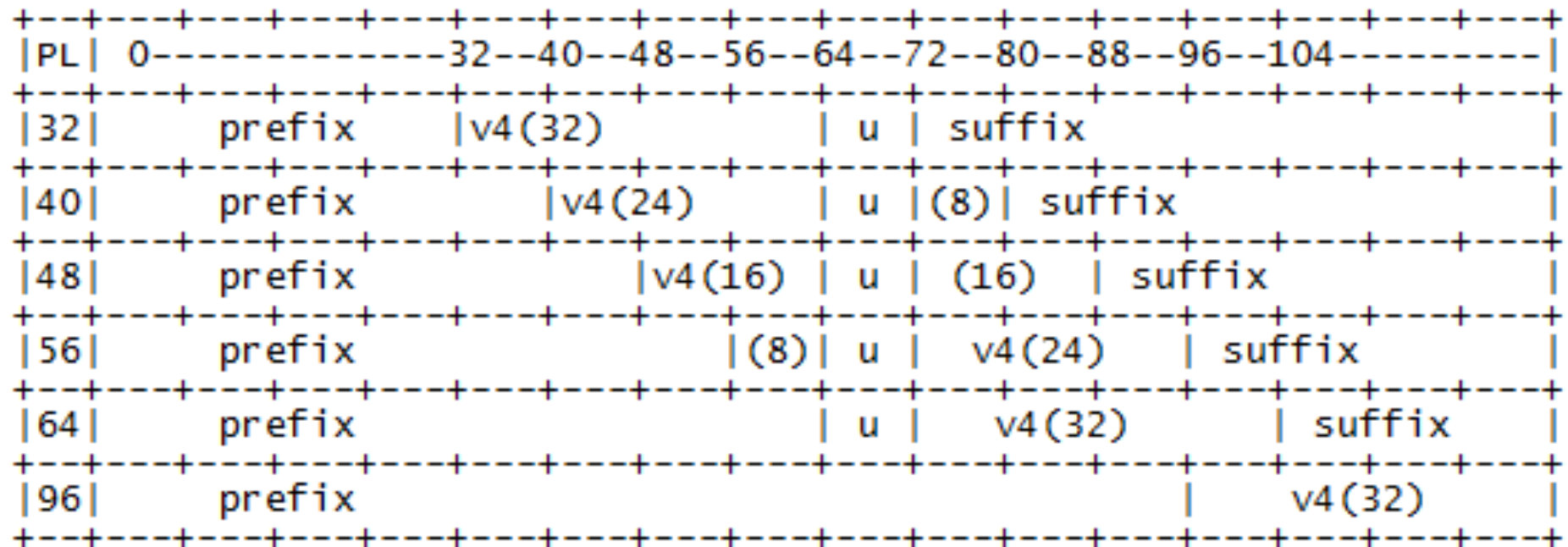
IPv6-only in the cellular net

- Not an option today

- Users will be able to access IPv6-only contents and apps
    - However no access to IPv4-only ones
    - IPv4-only tethered devices will not work

NAT64 (1)

- Problem: When ISPs only provide IPv6 connectivity or devices are IPv6-only (cellular)
  - but there are still IPv4-only contents/apps in Internet

- Similar idea as NAT-PT, but working better
- Several **IPv6-only** nodes share a public IPv4 address to access IPv4 Internet
- NAT64 is a mechanism to translate IPv6 packets to IPv4 and vice versa
- Translation is carried out in packet headers following the IP/ICMP Translation Algorithm [RFC7915][RFC6146]
- Current specification only defines how NAT64 translates unicast TCP, UDP, and ICMP packets
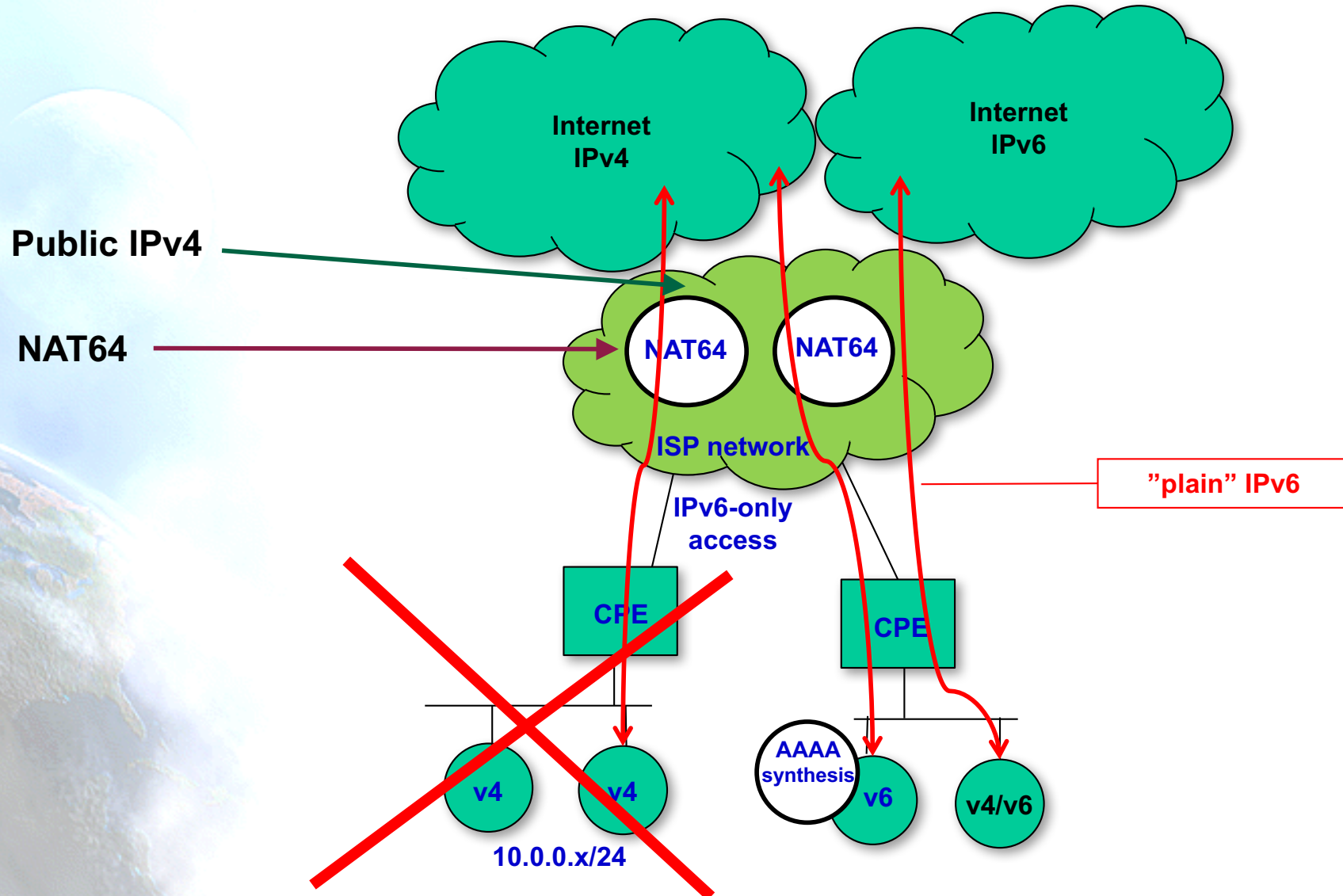
NAT64 (2)

- IPv4 addresses of hosts is algorithmically translated to/from IPv6 addresses using a specific algorithm [RFC6052]
- It's based on statically configured information, including a well known prefix
- A well-known prefix is defined (64:ff9b::/96), another could be used

```
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|PL|  0--------------32--40--48--56--64--72--80--88--96--104---------|
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|32|     prefix    |v4(32)            | u | suffix            |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|40|     prefix       |v4(24)         | u |(8)| suffix        |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|48|     prefix          |v4(16) | u | (16)  | suffix         |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|56|     prefix             |(8)| u |  v4(24)  | suffix        |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|64|     prefix             | u |   v4(32)    | suffix         |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|96|     prefix                          |   v4(32)           |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

NAT64 (3)

- It's known that there are things that doesn't work:
  - Everything out of TCP,UDP, or ICMP: Multicast, Stream Control Transmission Protocol (SCTP), the Datagram Congestion Control Protocol (DCCP), and IPSEC

  - Applications that carry layer 3 information in the application layer: FTP [RFC6384], SIP/H323

  - Some apps: online gaming, skype, etc.
    - Peer-to-peer using IPv4 "references"
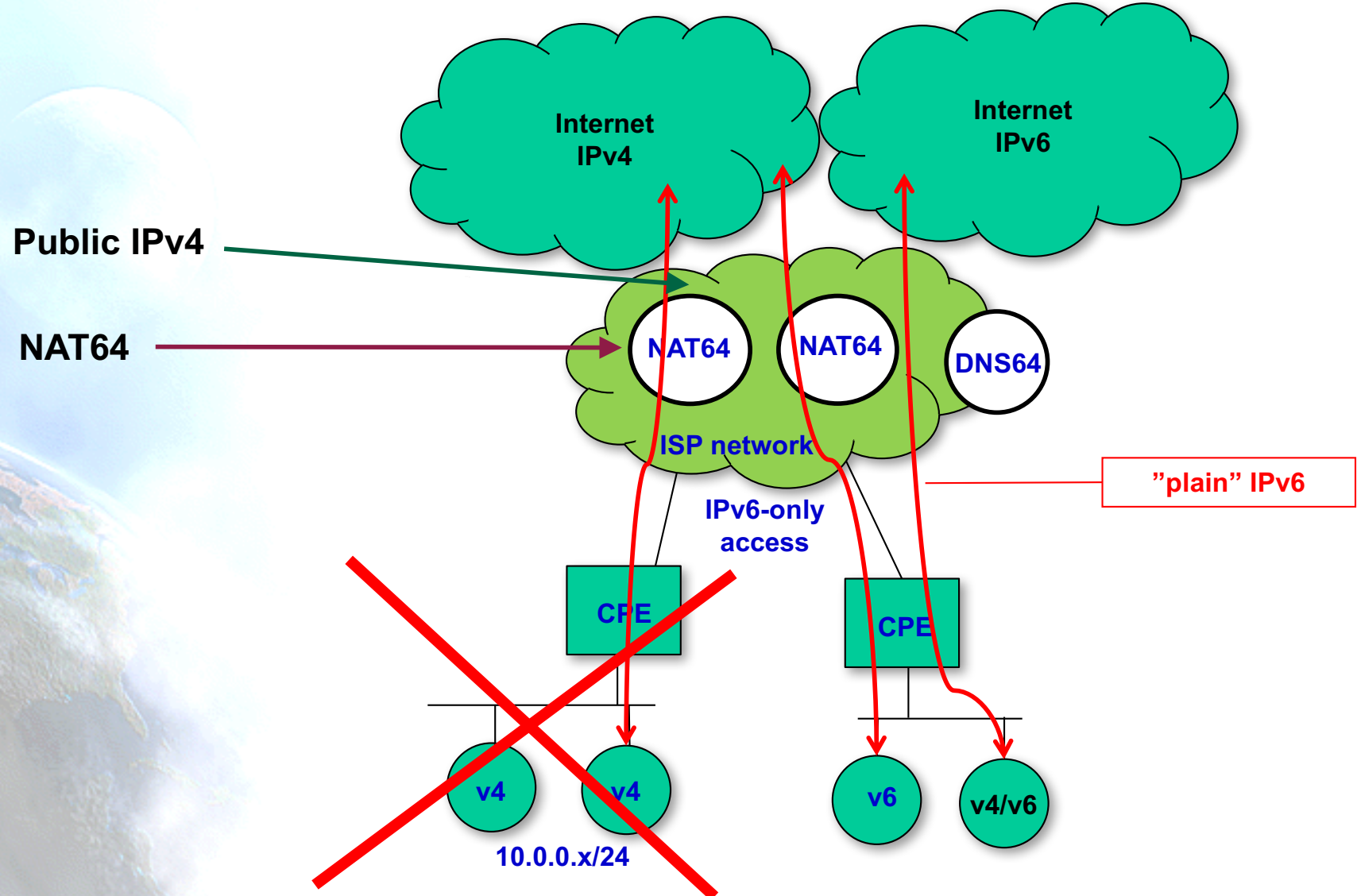
  - Literal addresses

  - Socket APIs

NAT64

Internet IPv4

Internet IPv6

Public IPv4

NAT64

NAT64   NAT64

ISP network

"plain" IPv6

IPv6-only access

CPE   CPE

v4   v4   AAAA synthesis   v6   v4/v6

10.0.0.x/24

IPv6-only with NAT64

- ## Only valid if UE supports it
  - – By means of "built-in" AAAA synthesis
    - • RFC7050 (Discovery of the IPv6 Prefix Used for IPv6 Address Synthesis) + RFC6052 (IPv6 Addressing of IPv4/IPv6 Translators)
      - – Happy Eyeballs v2 includes it

- ## For the rest of the cases
  - – Users will be able to access IPv6-only contents and apps
    - • However no access to IPv4-only ones
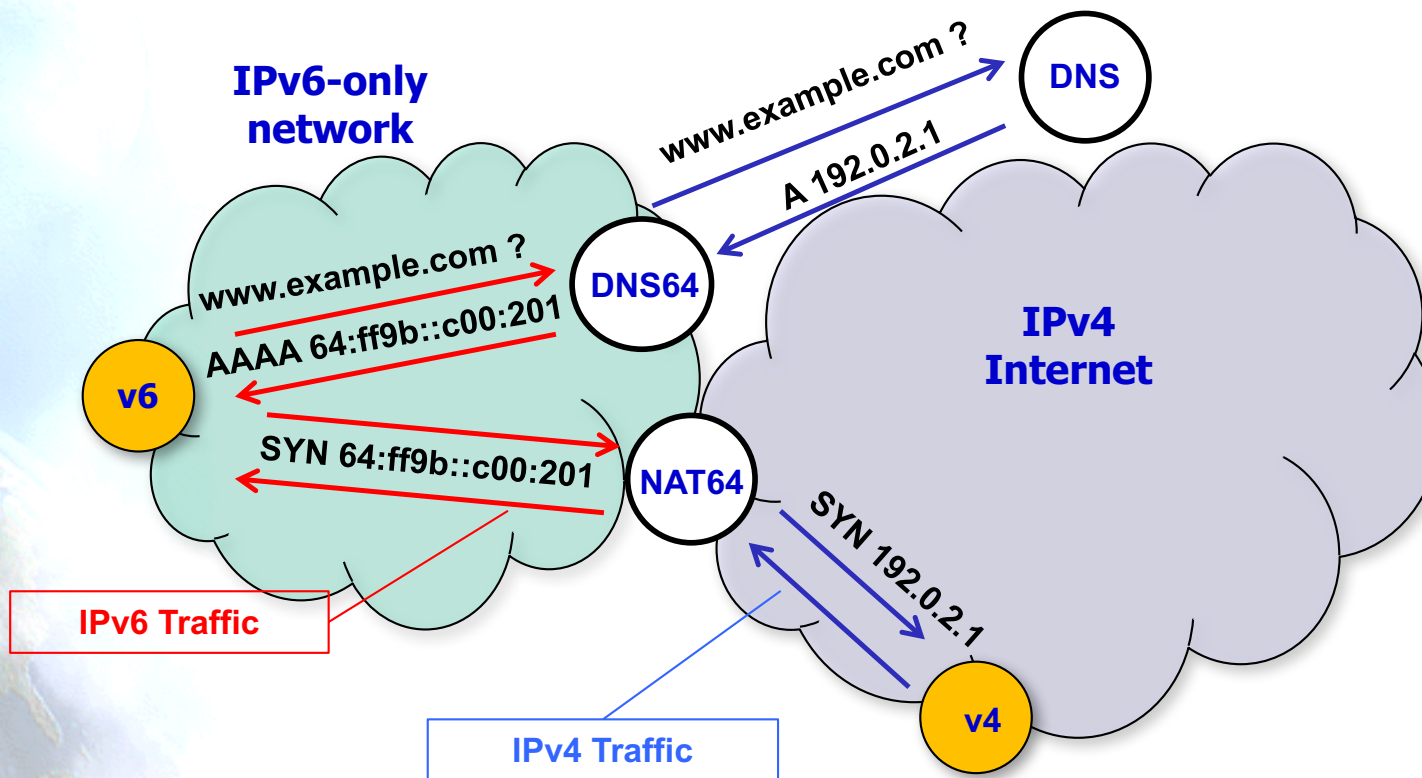   - • IPv4-only tethered devices will not work

DNS64

- DNS64 is a mechanism to synthesize RRs of type AAAA from A RRs [RFC6147]

- IPv6 addresses in synthesized AAAA is generated from IPv4 address and the IPv6 prefix assigned to the NAT64 device [RFC6052]

- When there is an AAAA query, it asks outside for A and AAAA RRs. If only receives an A, converts it into an AAAA

- Hosts see the host as IPv6 reachable, with the synthesized IPv6 address

NAT64+DNS64

Stateful NAT64

- Allow an IPv6-only network to connect to IPv4 Internet

IPv6-only network

www.example.com ?

A 192.0.2.1

DNS

www.example.com ?

AAAA 64:ff9b::c00:201

DNS64

v6

SYN 64:ff9b::c00:201

NAT64

IPv4 Internet

IPv6 Traffic

SYN 192.0.2.1

IPv4 Traffic

v4

IPv6-only with NAT64+DNS64

- All good ?

- NOT really …
  - Will break if apps use:
    - Literal addresses
    - Socket APIs
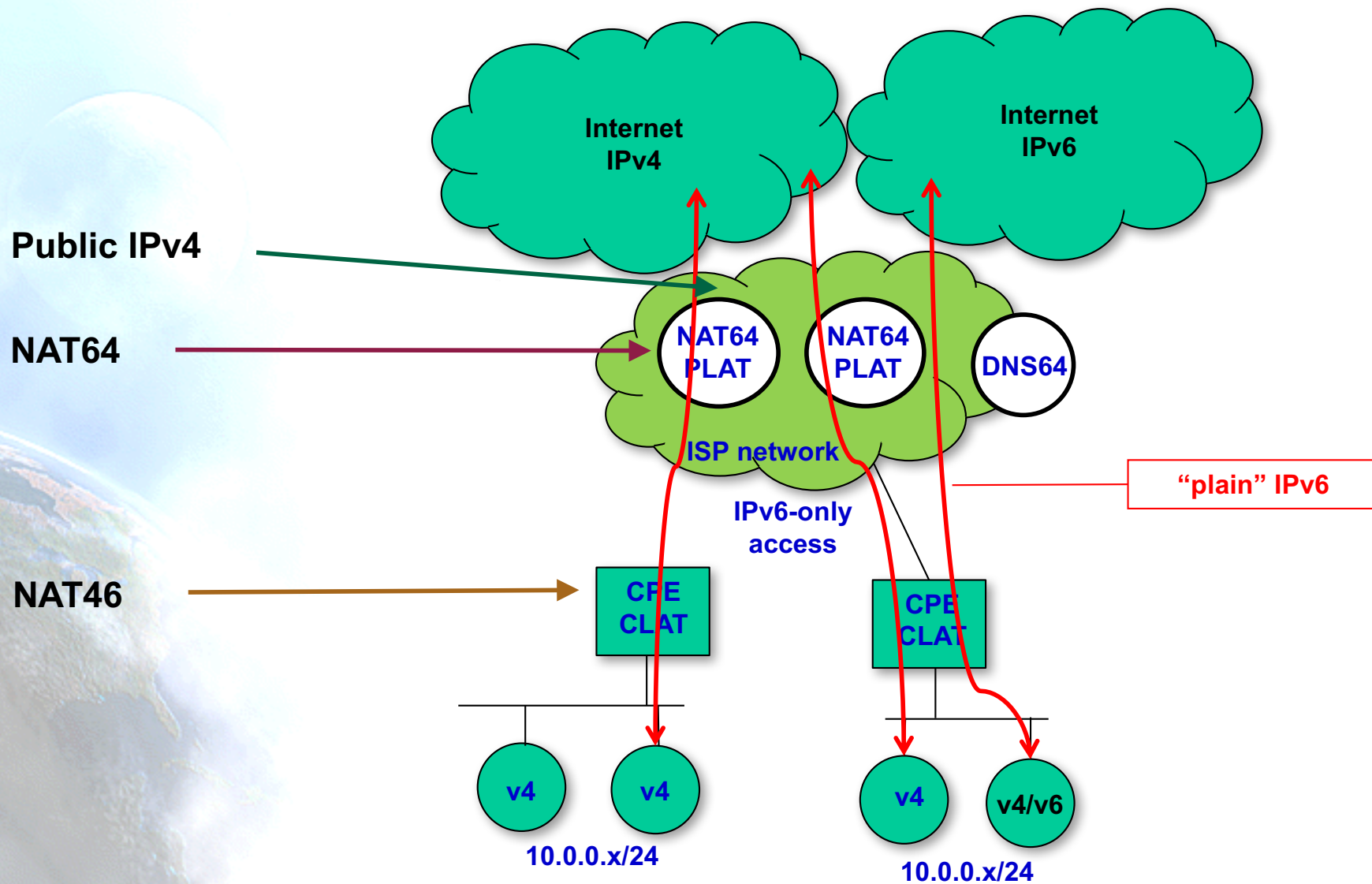 - IPv4-only tethered devices will not work

NAT64 breaks …

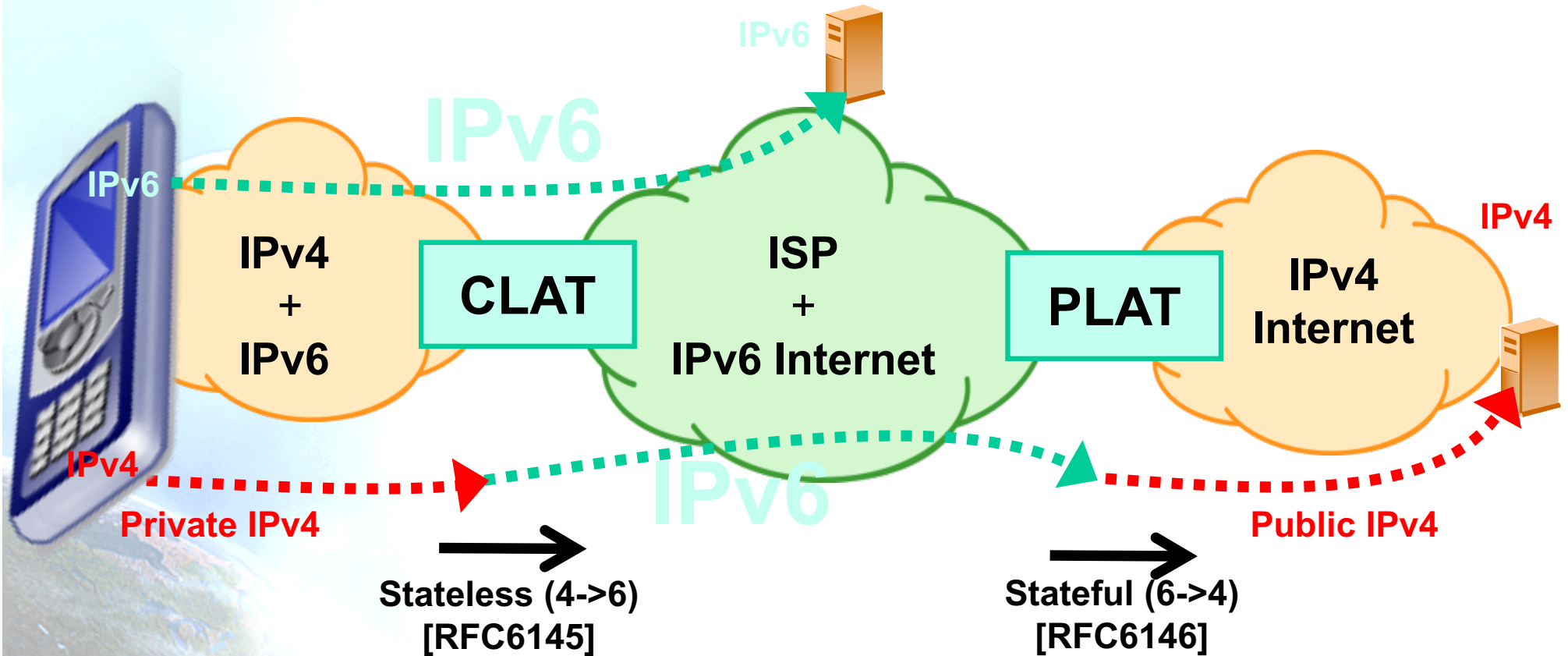| App Name	Functionality	Version	464XLAT Fixed
connection tracker	Broken	NA	NA
DoubleTwist	Broken	1.6.3	YES
Go SMS Pro	Broken	NA	YES
Google Talk	Broken	4.1.2	YES
Google+	Broken	3.3.1	YES
IP Track	Broken	NA	NA
Last.fm	Broken	NA	YES
Netflix	Broken	NA	YES
ooVoo	Broken	NA	YES
Pirates of the Caribean	Broken	NA	YES
Scrabble Free	Broken	1.12.57	YES
Skype	Broken	3.2.0.6673	YES
Spotify	Broken	NA	YES
Tango	Broken	NA	YES
Texas Poker	Broken	NA	YES
TiKL	Broken	2.7	YES
Tiny Towers	Broken	NA	YES
Trillian	Broken	NA	YES
TurboxTax Taxcaster	Broken	NA	
Voxer Walkie Talkie	Broken	NA	YES
Watch ESPN	Broken	1.3.1	
Zynga Poker	Broken	NA	YES
Xabber XMPP	Broken	NA	

*T-Mobile

464XLAT

- 464XLAT (RFC6877): RFC6145 + RFC6146
- Very efficient use of scarce IPv4 resources
  - N*65.535 flows per each IPv4 address
  - Network growth not tied to IPv4 availability
- IPv4 basic service to customers over an-IPv6 only infrastructure
  - **WORKS** with applications that use socket APIs and literal IPv4 addresses (Skype, etc.)
- Allows traffic engineering
  - Without deep packet inspection
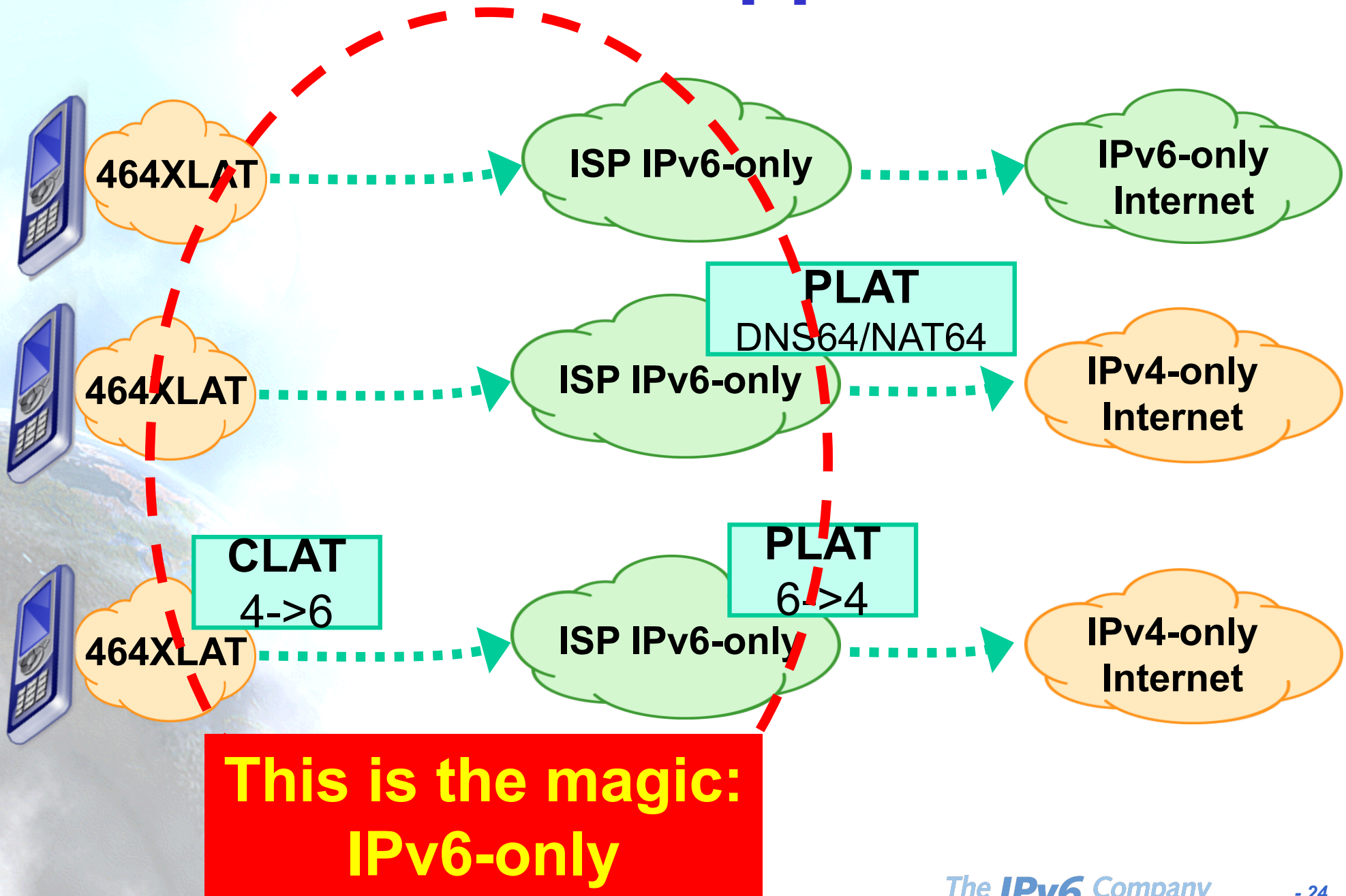- Easy to deploy and available
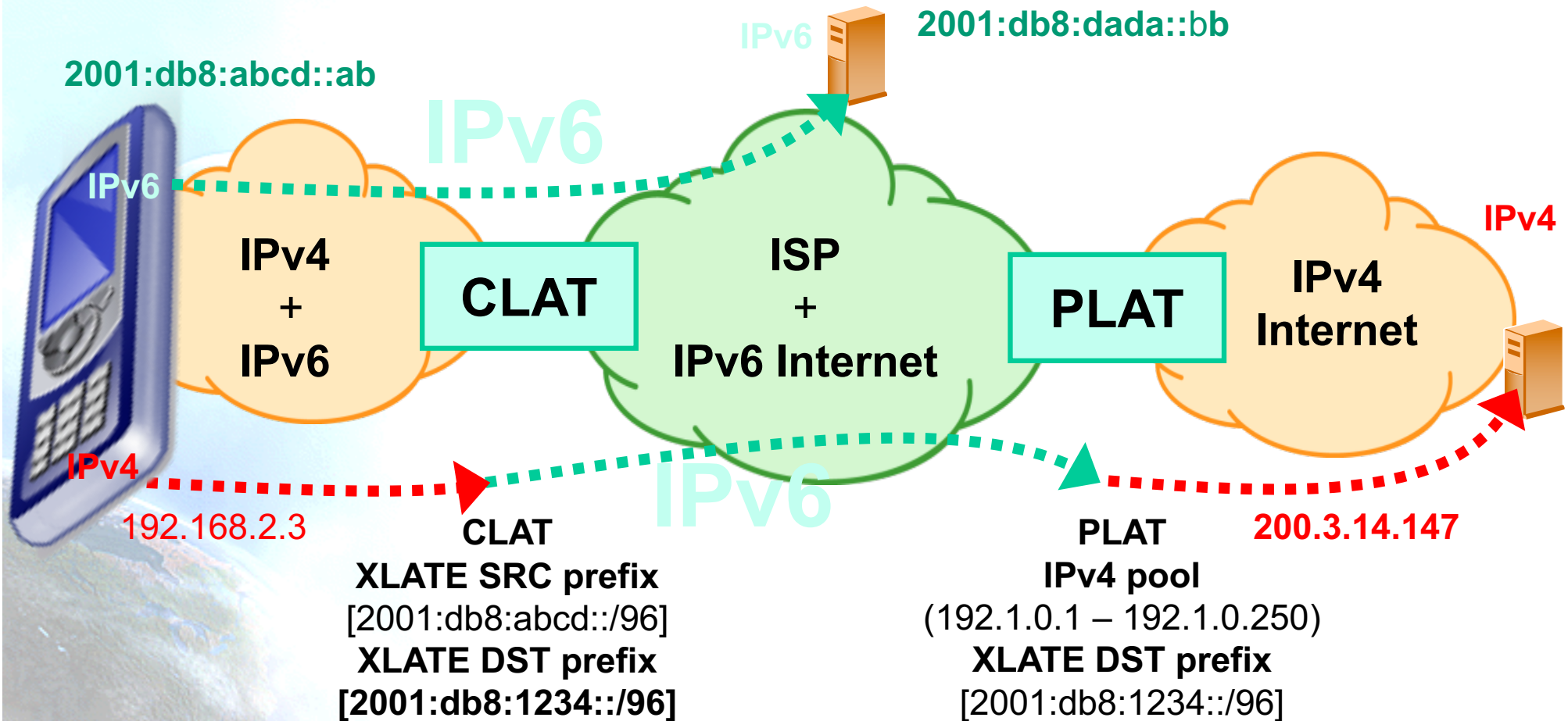 - Commercial solutions and open source

464XLAT

Public IPv4

NAT64

NAT46

Internet IPv4

Internet IPv6

NAT64 PLAT

NAT64 PLAT

DNS64

ISP network

IPv6-only access

"plain" IPv6

CPE CLAT

CPE CLAT

v4

v4

v4

v4/v6

10.0.0.x/24

10.0.0.x/24

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How it works 464XLAT?

CLAT: Customer side translator (XLAT)
PLAT: Provider side translator (XLAT)

Stateless (4->6) [RFC6145]

Stateful (6->4) [RFC6146]

Possible "app" cases

464XLAT → **ISP IPv6-only** → **IPv6-only Internet**

464XLAT → **ISP IPv6-only** → **IPv4-only Internet**

PLAT DNS64/NAT64

CLAT 4->6

464XLAT → **ISP IPv6-only** → **IPv4-only Internet**

PLAT 6->4

This is the magic: IPv6-only

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464XLAT Addressing

2001:db8:dada::bb

2001:db8:abcd::ab

IPv6

IPv6

IPv6

IPv4 + IPv6

CLAT

ISP + IPv6 Internet

PLAT

IPv4 Internet

IPv4

IPv4

192.168.2.3

CLAT
XLATE SRC prefix
[2001:db8:abcd::/96]
XLATE DST prefix
[2001:db8:1234::/96]

200.3.14.147

PLAT
IPv4 pool
(192.1.0.1 – 192.1.0.250)
XLATE DST prefix
[2001:db8:1234::/96]

IPv4 SRC
192.168.2.3
IPv4 DST
200.3.14.147

Stateless
XLATE
[RFC6145]

IPv6 SRC
2001:db8:abcd::192.168.2.3
IPv6 DST
2001:db8:1234::200.3.14.147

Stateful
XLATE
[RFC6146]

IPv4 SRC
192.1.0.1
IPv4 DST
200.3.14.147

Simplicity
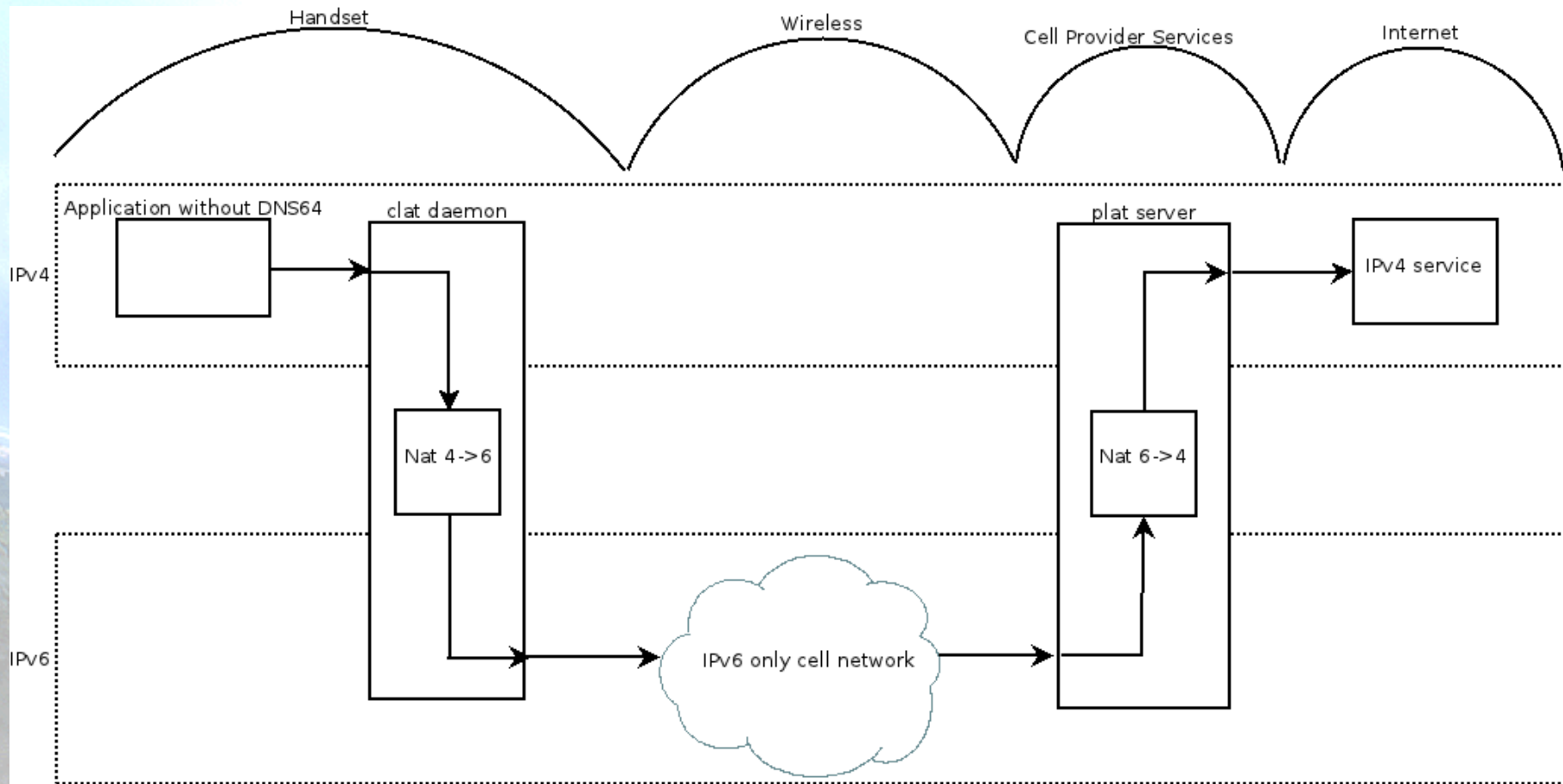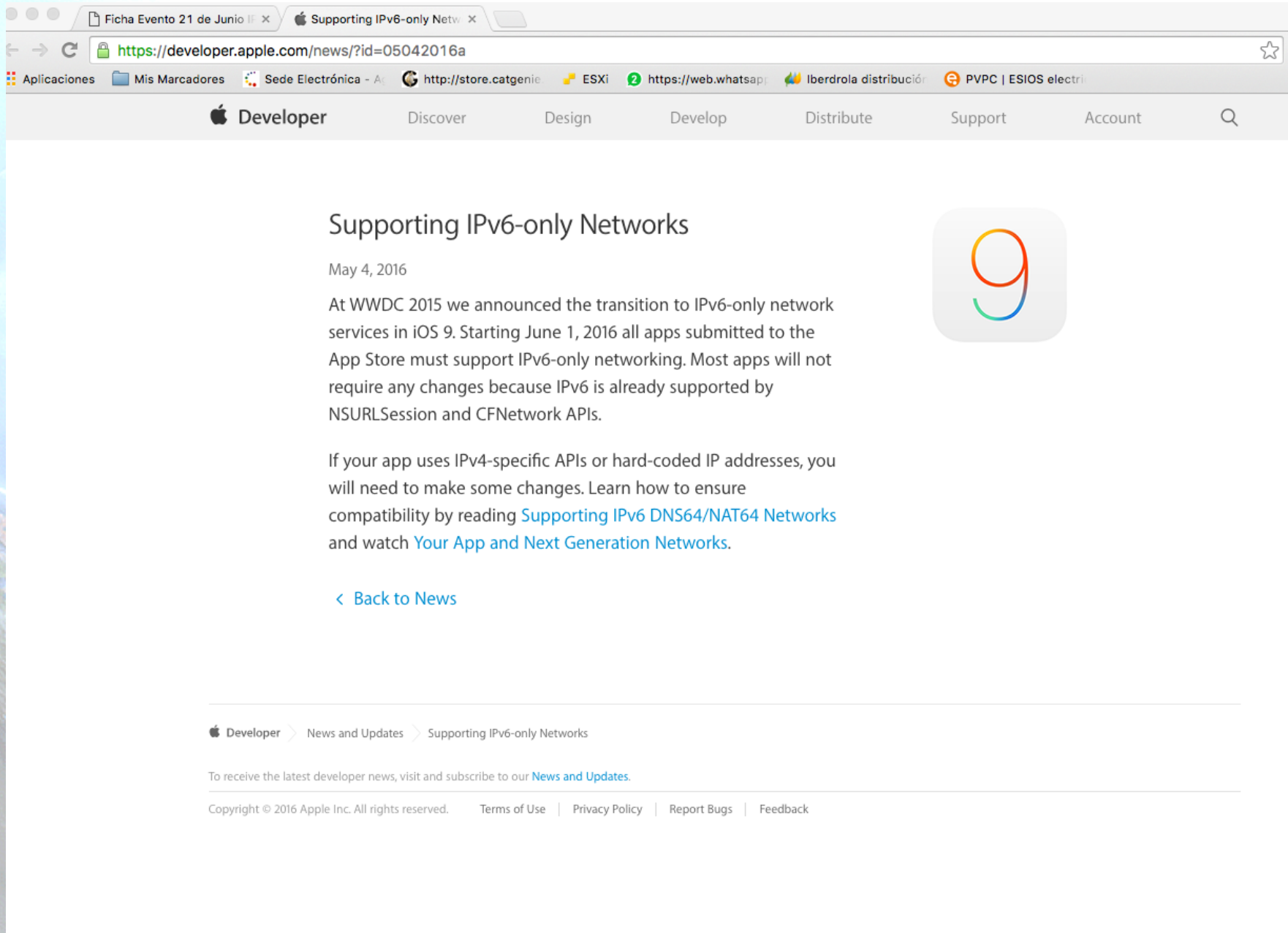
* Dan Drown

Apple vs Android & Windows

- Apple long-term strategy
  - Mandate IPv6 in AppStore
    - Announced in June 2015
    - Enforced for new Apps in Junes 2016
    - Older Apps reviewed after September 2016
  - Doesn't include CLAT support
    - Sort-of, is Bump-in-the-Host [RFC6535] implemented in Happy Eyeballs v2) - IPv6-only since iOS 10.2

- Android & Windows Phone
  - Both included CLAT support
    - Since 2013

Apple Announcement

Availability and Deployment

- NAT64:
  - A10
  - Cisco
  - F5
  - Juniper
  - NEC
  - Huawei
  - Jool, Tayga, Ecdsys, Linux, OpenBSD, …

- CLAT
  - Android (since 4.3)
  - Nokia
  - Windows (now also Windows 10 - Creator Update, Windows Server 2016, since July 2017)
  - NEC
  - Linux
  - Jool
  - OpenWRT
  - Apple (sort-of, is Bump-in-the-Host [RFC6535] implemented in Happy Eyeballs v2) - IPv6-only since iOS 10.2

- Commercial deployments:
  - T-Mobile US: +68 Millions of users
  - Orange
  - Telstra
  - SK Telecom
  - …
  - Big trials in several ISPs

DNSSEC Considerations

- DNS64 modifies DNS answers and DNSSEC is designed to detect such modifications, DNS64 can break DNSSEC

- In general, DNS servers with DNS64 function, by default, will not synthesize AAAA responses if the DNSSEC OK (DO) flag was set in the query. In this case, as only an A record is available, it means that the CLAT will take the responsibility, as in the case of literal IPv4 addresses, to keep that traffic flow end-to-end as IPv4, so DNSSEC is not broken

- Today no apps in cellular that use DNSSEC, but you should be ready for that
  - Consider apps used by means of tethering
  - Very relevant for non-cellular networks

Other Transition Technologies

- 6RD

- DS-Lite

- MAP-E or MAP-T

- ...

- No way!

  – Not implemented in smartphones

  – Require using lots of IPv4 addresses

  – Heavy setup and network overhead, require DHCP

  – Take less advantage of "multiplexing" IPv4 addresses & ports, than stateful NAT64

Performance

US Mobile Performance – Dual Stack Provider iOS

- iPhone 6 on LTE only
- No Instrumentation of the client
- Examining Client Last Byte Time
  - Time it takes for the device to read the response
  - Read all the data for a newsfeed

Time of HTTP GET completion
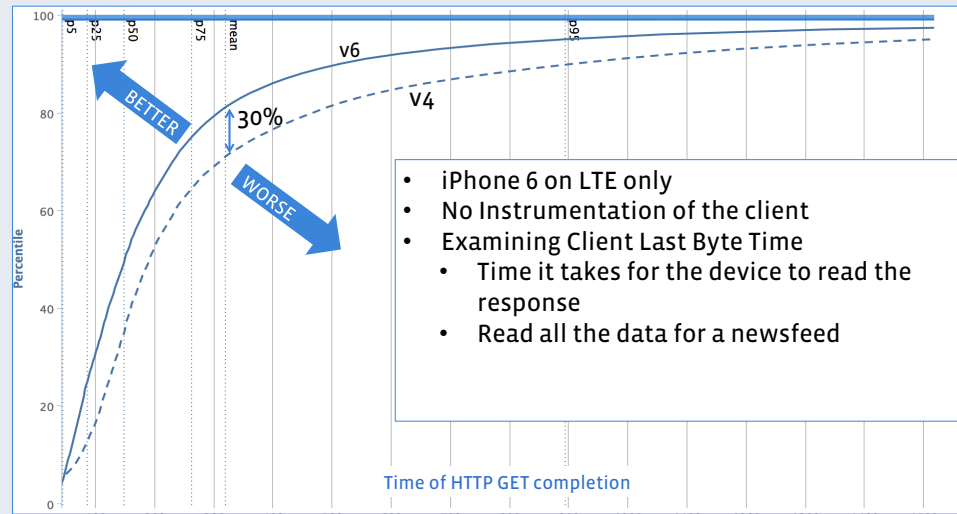
US Mobile Performance – Dual Stack Provider Android

- Android 4/5
- Galaxy S5 on LTE only
- No Instrumentation of the client
- Examining Client Last Byte Time
  - Time it takes for the device to read the response
  - Read all the data for a newsfeed

Time of HTTP GET completion

US Mobile Performance – Dual Stack Provider iOS

- iPhone 6
- Client instrumentation
- No A/B testing
- Mobile Proxygen
- Examining Total Request Time
  - Similar to Client Last Byte Time

Total Request Time
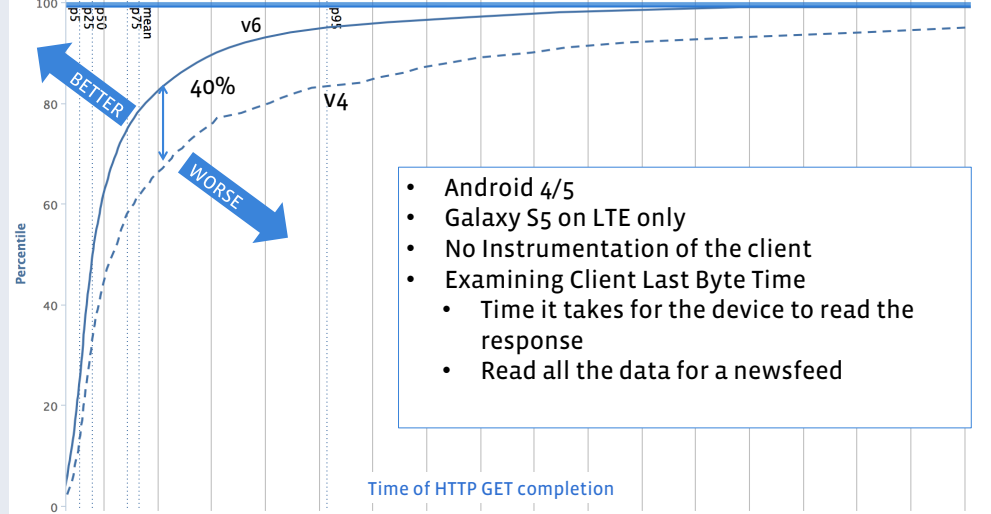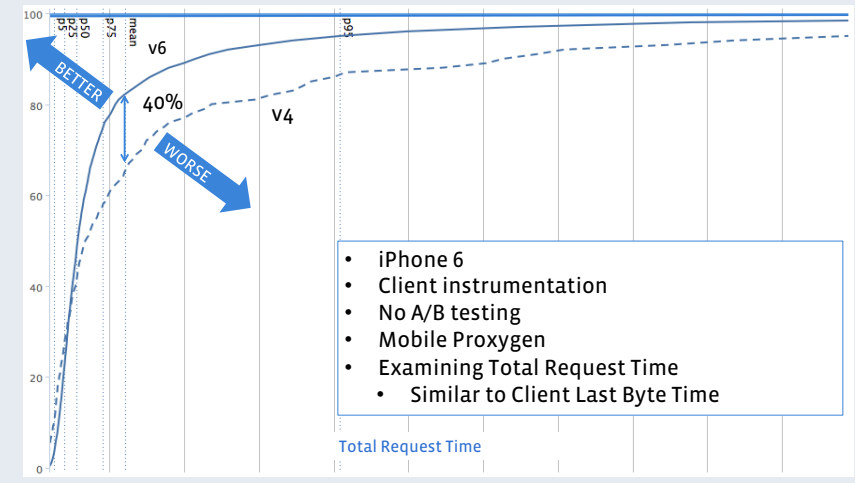
*FaceBook data

(17/3/2015)

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NAT64 (464XLAT) vs CGN

- NAT64 has much lower CapEx/OpEx
  - No need to buy CGN
    - NAT64 scales better, you have open source solutions, lower cost
  - No need to buy IPv4
  - Doesn't extend the IPv4 usage
- Progressive deployment:
  - New phones
  - Not impacting existing users
  - Naturally increase your IPv6 traffic
    - Decrease IPv4 one
  - Lower logging cost
    - Less and less IPv4 logging
  - IPv6 deployment with persistent prefixes
    - Avoid the need for logging
- Billing
  - Trunking IPv6 adresses in CDRs
  - Hash IPv6 addresses in IPv4 records

KISS … for LEA

- Keep It Simply Stupid concept ;-)
  - Law Enforcement Agencies require to identify the source address
  - Having a SINGLE IP source protocol is easier
  - IPv4 is gone, we can use only IPv6
  - IPv6-only is not feasible today
  - 464XLAT allows "IPv4 as a service" in the customer LANs: the simpler choice
    - So, only need to identify the source IPv6 address/prefix
    - No need to identify source ports anymore
    - No need to look inside of traffic (DPI)

Roaming

- Use PCRF (Policy and Charging Control Function) to selectively enable IPv6 in roaming customers sessions
  - Depending on "roaming partner"

- RFC7445
  - Analysis of Failure Cases in IPv6 Roaming Scenarios

Overall IPv6 3G/4G Architecture
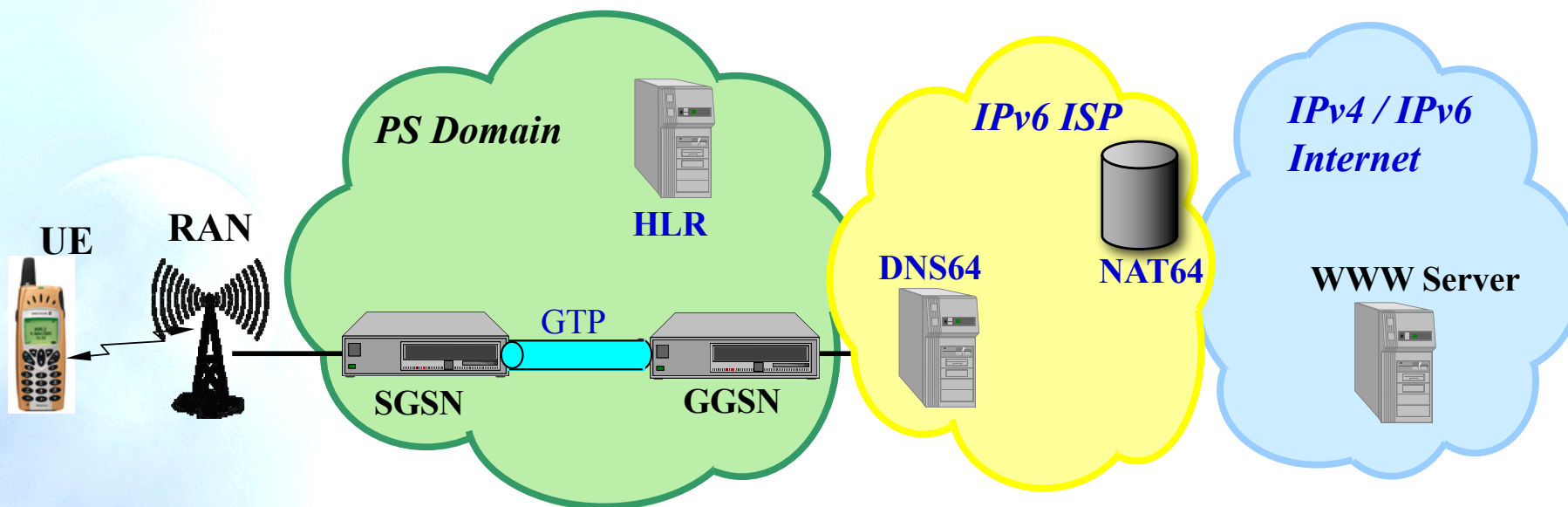
- RFC6459: IPv6 in 3rd Generation Partnership Project (3GPP) Evolved Packet System (EPS)
- UE: User Equipment
- RAN: Radio Access Network (UTRAN, LTE, …)
- SGSN/MME: Serving GPRS Support Node/Mobility Management Entity
  - Acts as a "switch"
- GTP: GPRS Tunneling Protocol
- HLR: Home Location Register
- GGSN/EPG: Gateway GPRS Support Node/Evolved Packet Gateway
  - Acts as a "router"

User plane vs. transport plane

- User and transport planes are completely independent:

  - The transport plane can run on a different IP version than the user plane

- RAN and Core Network transport can also run on different IP versions
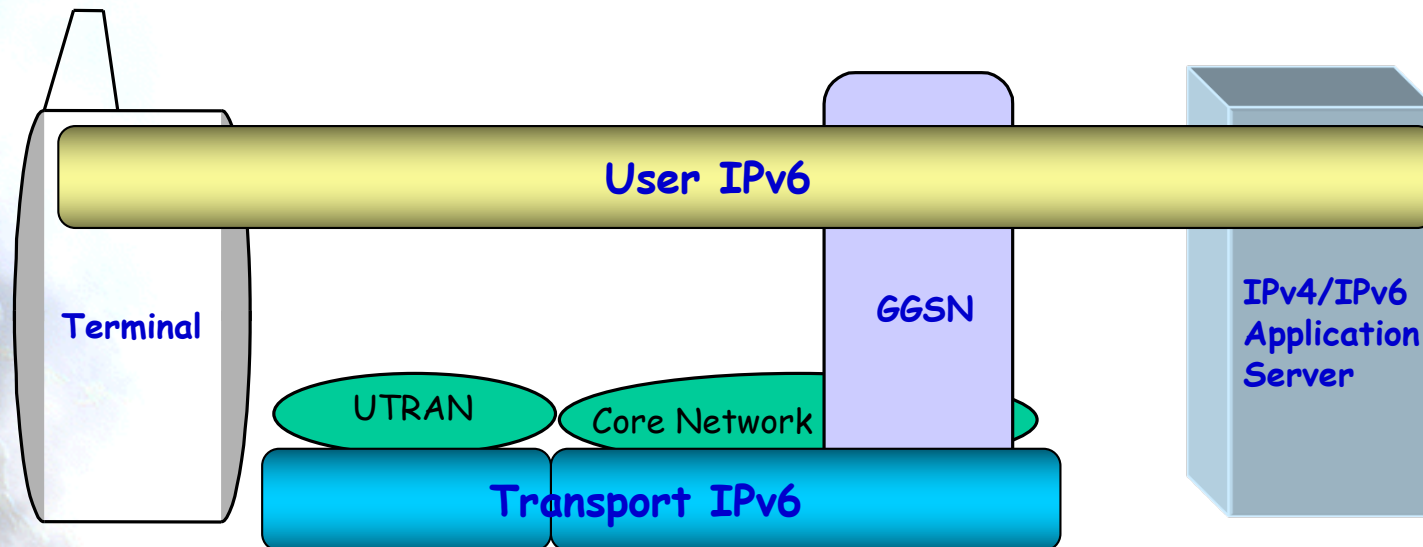
Transport of user IP packets

- IP packets to/from the UE are tunneled through the cellular network.
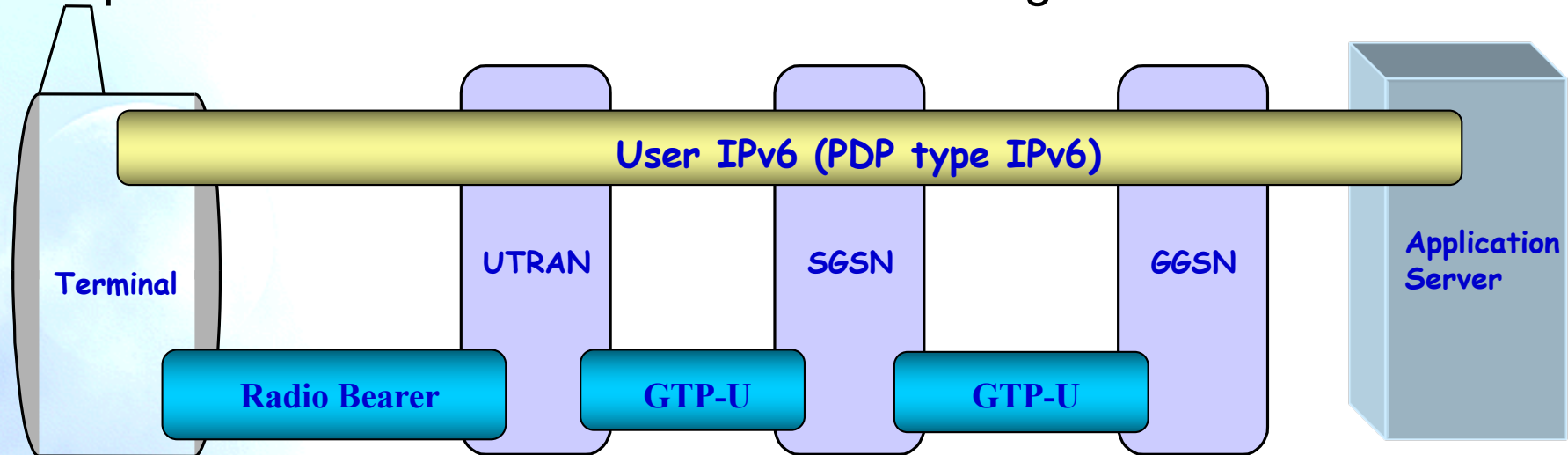
- When an UE attaches to the Network, the SGSN creates a Mobility Management context containing information pertaining to e.g., mobility and security for the MS.
- At PDP Context Activation (PDP - Packet Data Protocol), the SGSN and GGSN create a PDP context, containing information about the session (e.g. IP address, QoS, routing information , etc.).
- Each Subscriber may activate several PDP Contexts towards the same or different GGSNs.
- When activated towards the same GGSN, they can use the same or different IP addresses.

The PDP Context
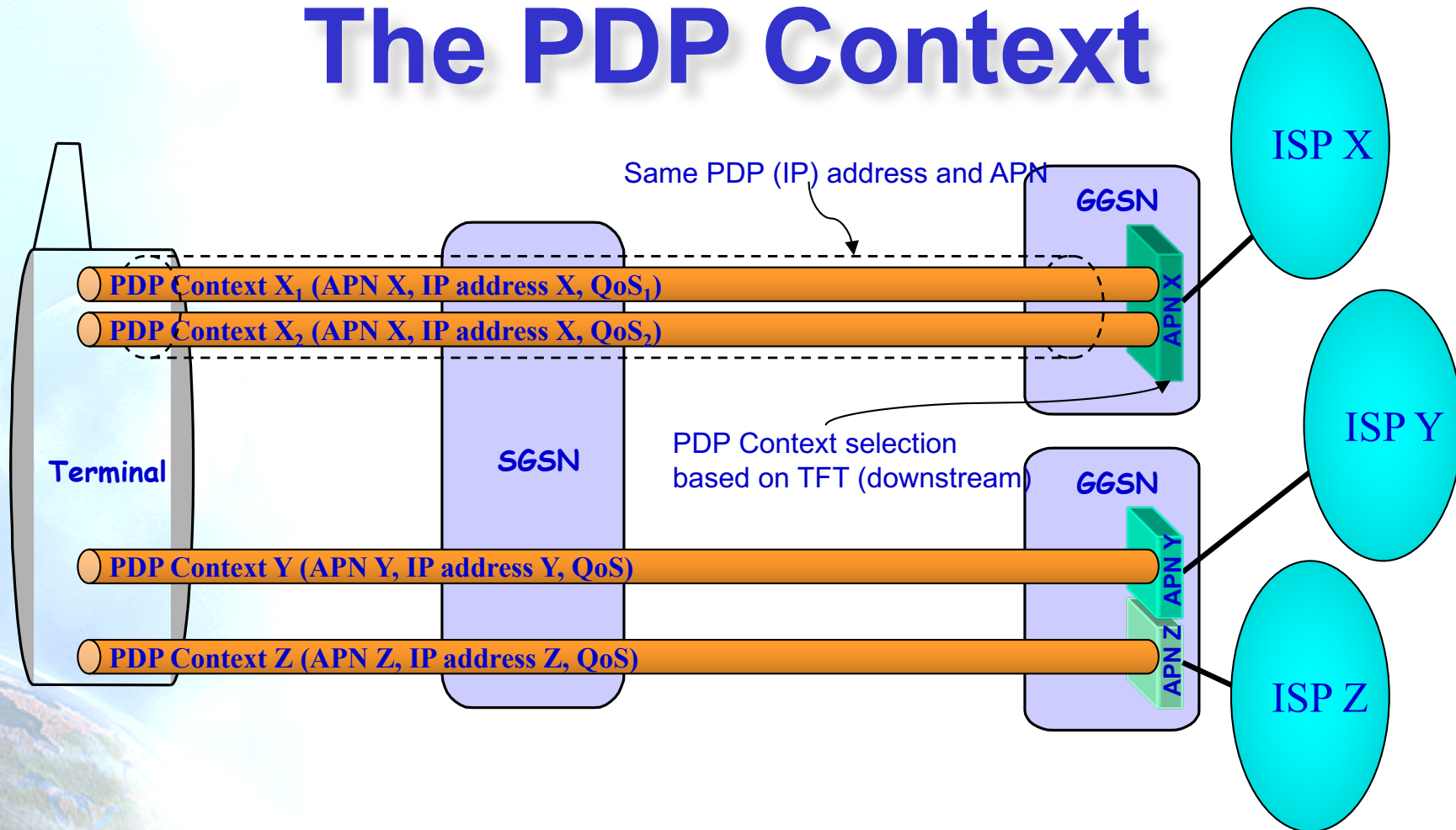
- PDP context can be IPv4-only (IPv4), IPv6-only (IPv6) or dual-stack (IPv4v6)

- Dual-stack could also be provided with two PDP contexts (one each protocol, however it means 2 PDP context licenses)

- 464XLAT works with IPv6-only PDP context (long-term strategy)

The Access Point Name - APN

- The APN is a logical name referring to a GGSN. The APN also identifies an external network.

- The syntax of the APN corresponds to a fully qualified name.

- At PDP context activation, the SGSN performs a DNS query to find out the GGSN(s) serving the APN requested by the terminal.

- The DNS response contains a list of GGSN addresses from which the SGSN selects one address in a round-robin fashion (for this APN).

Single APN for Everyone

IPv4v6

IPv6

IPv4

RAN

IPv6 ISP

IPv4 / IPv6 Internet

IPv4v6 APN

DNS64   NAT64

WWW Server

GGSN
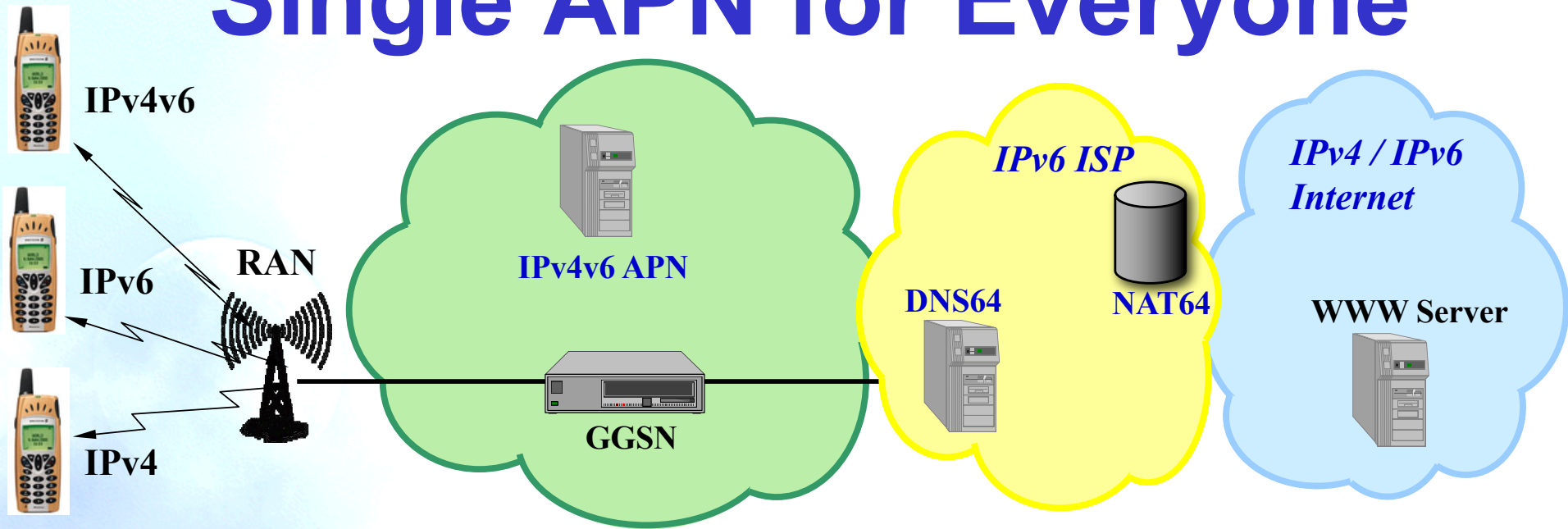
- ## Single APN
  - Supporting Dual-Stack and Single-Stack
  - Cellular IPv6 deployment is easy because the network supports whatever the UE ask.
  - Progressive deployment, as slow or fast as you want
    - One new phone, all new phones, then OTA old ones

- ## DNS supporting RFC7050
  - Discovery of the IPv6 Prefix Used for IPv6 Address Synthesis

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IPv6 Address Allocation Methods

- Stateless Address Autoconfiguration
  - Default, /64 for each PDP context
  - Introduced in GPRS R'99

- Stateful Address Autoconfiguration
  - DHCPv6 client in the terminal
  - Requires DHCPv6 relay agent in the GGSN

- GPRS-specific Address Configuration
  - Static Address Configuration
    - The UE provides its statically configured IPv6 address at PDP context activation
  - Dynamic Address Allocation
    - The IPv6 address is provided by the GGSN at PDP context activation

Stateless Address Auto-configuration

UE   **BSS/UTRAN**   **SGSN**   **GGSN**

1. Activate PDP Context Request (PDP type = IPv6, PDP Address = empty, APN, ...)

2. Create PDP Context Request

3. Create PDP Context Response (
   PDP address = **link-local address**, ...)

The UE extracts the Interface-ID from the link-local address

4. Activate PDP Context Accept (PDP Address = **link-local address**, ...)

5. Router Solicitation

The UE constructs its full IPv6 address

The GGSN shall be configured to advertise **only one network prefix**

6. Router Advertisement (M flag = 0, Network prefix, …)

7. Neighbor Solicitation

Neighbor Solicitation messages shall be discarded by the GGSN except if part of Neighbor Unreachability Detection

7. GGSN-Initiated PDP Context Modification Procedure

The GGSN updates the SGSN and MT with the full IPv6 address

Tethering

- RFC7278
    - Extending an IPv6 /64 Prefix from a Third Generation Partnership Project (3GPP) Mobile Interface to a LAN Link
    - The UE is switched from an IPv6 host mode to an IPv6 router-and-host mode

- If the UE is also a CLAT, it provides IPv4 service with private addresses to the "tethered" devices

Dynamic Address Allocation

UE   BSS/UTRAN   SGSN   GGSN

1. Activate PDP Context Request (PDP type = IPv6, PDP Address = empty, APN, ...)

2. Create PDP Context Request

3. DHCP and/or RADIUS procedures

4. Create PDP Context Response (
   PDP address = **IPv6 address**, ...)

5. Activate PDP Context Accept (PDP Address = **IPv6 address**, ...)

For example the GGSN may use RADIUS for user authentication and IP address allocation, or it may use RADIUS for authentication and DHCP for IP address allocation.

Alternatively, the address may be allocated from a local pool of addresses in the GGSN.

Prefix Exclude Option

- If DHCPv6 is used, it may be interesting a single aggregated route/prefix for each customer, instead of using one prefix for the link between the delegating router and the requesting router and another prefix for the customer network.

- RFC6603
  - Prefix Exclude Option for DHCPv6-based Prefix Delegation

Declare Success

- Traffic moves from IPv4 to IPv6

- Customers never notice anything changed

IPv6 in Cellular/US

Major USA Mobile Networks IPv6 Deployment
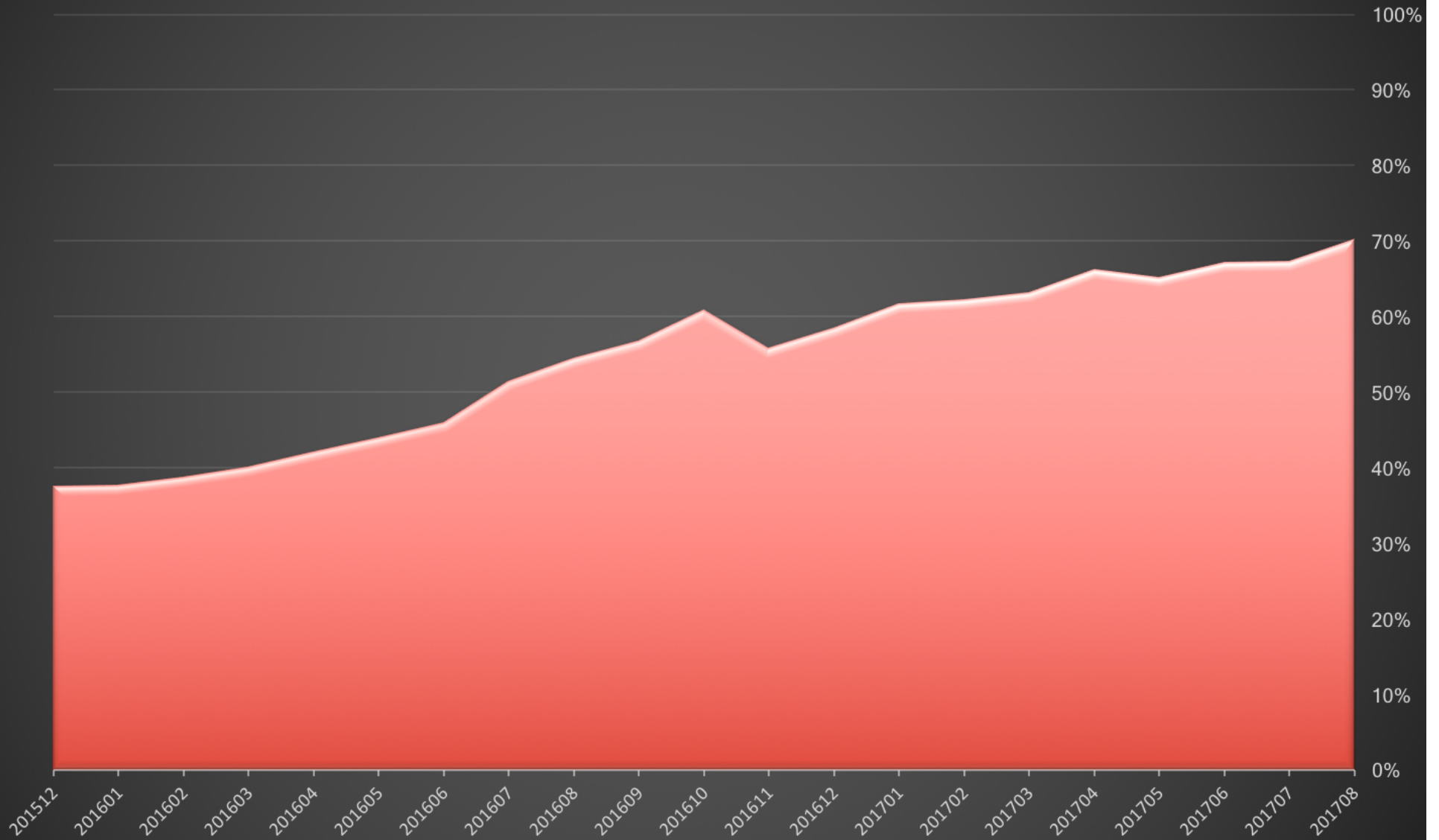
*ISOC/World IPv6 Launch data

Multiservice Network

464XLAT

Cellular network

PLAT
DNS64/NAT64

Corporate network

464XLAT Residential network

Example Residential Customer

Internet

IPv4 + IPv6
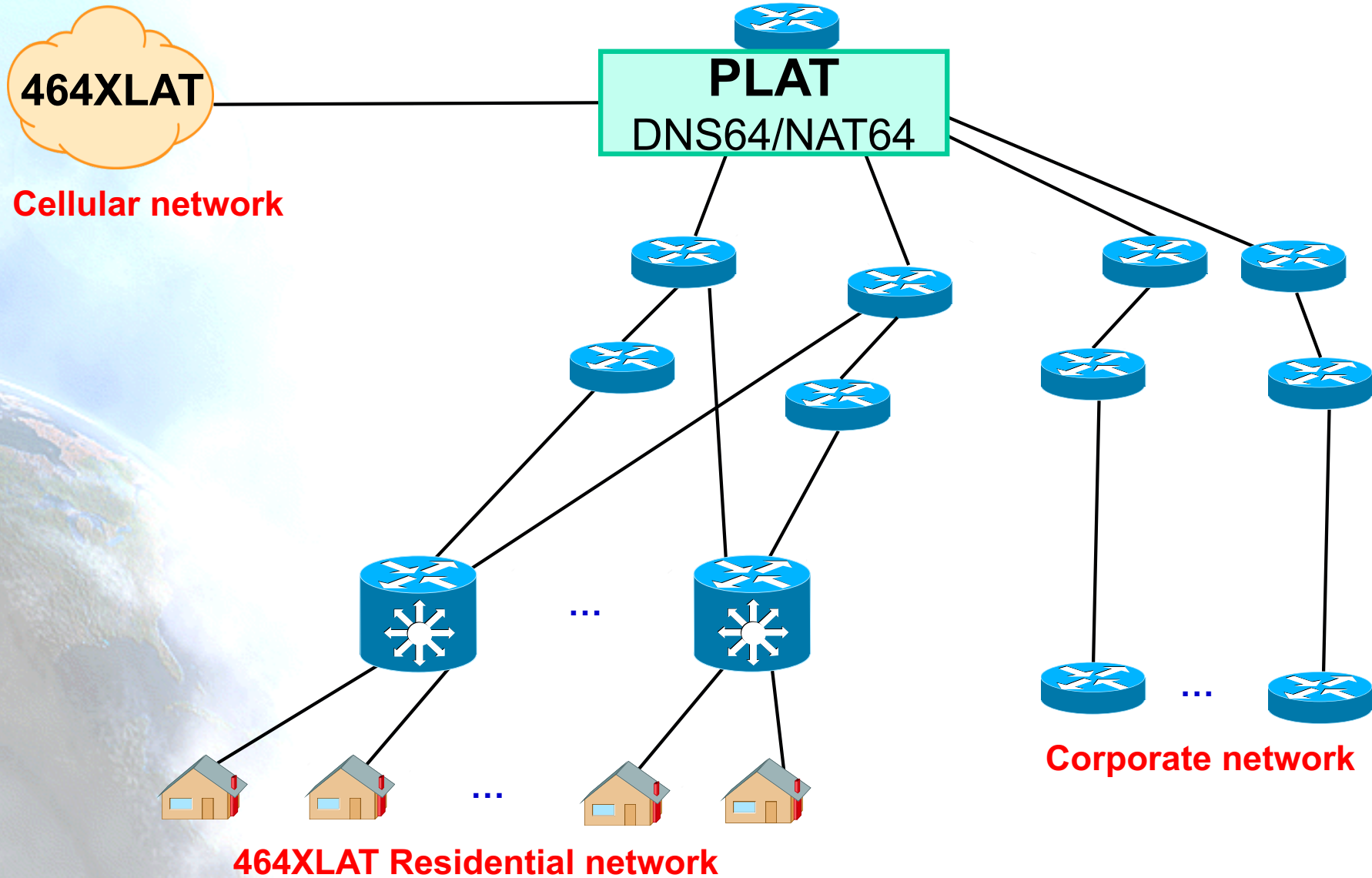2001:db8::/32

198.51.100.0/24
FE80::1/64

ISP Network

User Network

Eth0
198.51.100.10
2001:db8::10

**VM PLAT
(NAT64 + DNS64)**

Pool IPv4/NAT64:
198.51.100.11/32
Prefijo IPv6: 64:ff9b::/96

2001:db8:1::1
Eth1

Node 1

192.168.1.2/24
2001:db8:40::42/64

...

Node "n"

192.168.1.x/24
2001:db8:40::xx/64

Traffic Legend

Red: IPv6-only

Blue: IPv4-only

Green: Dual-stack

LAN Eth1
192.168.1.1
2001:db8:40::41

CPE (CLAT)

Pool IPv4/NAT46: 192.0.0.1/32
Pool IPv6: 2001:db8:2::40/128

2001:db8:1::2
WAN Eth0

BRAS

The **IPv6** Company

- 50

RIPE75 network with 464XLAT

RIPE 75 Network

SSID 464XLAT

Internet

Eth0
193.0.24.0/21
2001:67c:64::/48

**VM PLAT
(NAT64 + DNS64)**

Pool IPv4/NAT64: x.x.x.x/yy
Prefix IPv6: 64:ff9b::/96

DNS1:
2001:67c:64:53::53:1

DNS2:
2001:67c:64:53::53:2

2001:67c:64:101::1/64
Eth1

Node 1
192.168.11.x/24
2001:67c:64:ff01::xx/64

• • •

Node "n"
192.168.11.x/24
2001:67c:64:ff01::xx/64

LAN Eth1
192.168.11.1/24
2001:67c:64:ff01::1

CPE (CLAT)

Pool IPv4/NAT46: 192.0.0.1/24
Pool IPv6: 2001:67c:64:ff00::/120

2001:67c:64:101::2/64
WAN Eth0

Traffic Legend

Red: IPv6-only

Blue: IPv4-only

Green: Dual-stack

Some Related IETF Work

- https://datatracker.ietf.org/doc/draft-palet-v6ops-ipv6-only/

- https://datatracker.ietf.org/doc/draft-palet-v6ops-464xlat-deployment/

- https://datatracker.ietf.org/doc/draft-palet-v6ops-p2p-from-customer-prefix/

- https://datatracker.ietf.org/doc/draft-palet-v6ops-rfc7084-bis-transition/

Thanks!

Contact:

– **Jordi Palet:** **jordi.palet@theipv6company.com**