IPv6

Geoff Huston
APNIC

Why?

Because we ran out of IP addresses

Again.

We've been here before ...

The original ARPAnet design from 1969 used the NCP protocol, which used 8 bit addresses in the NCP packet header

- Maximum network span of 256 nodes
- Enough?

- Well yes, because at the time computers were the size of entire rooms, cost many millions of dollars and there were only a few thousand in the entire world.
- At the time the entire concept of shrinking the computer to something you could hold in one hand and trying to connect billions of them together was just too far into the future to worry about

Transition V1.0

- Turns out that 8 bits of addresses was not enough for the next generation of mini-computers
- ARPAnet undertook a transition from NCP to a new protocol: TCP/IP
  - Expansion from 8-bit to 32-bit addresses
  - Flag Day: 1 January 1983
  - Shutdown and reboot every node into the new protocol!

Vint Cerf, APRICOT, Feb 2011

"This time, for sure!" *

* Actually Vint Cerf did not say that!

* Actually Vint didn't say this!

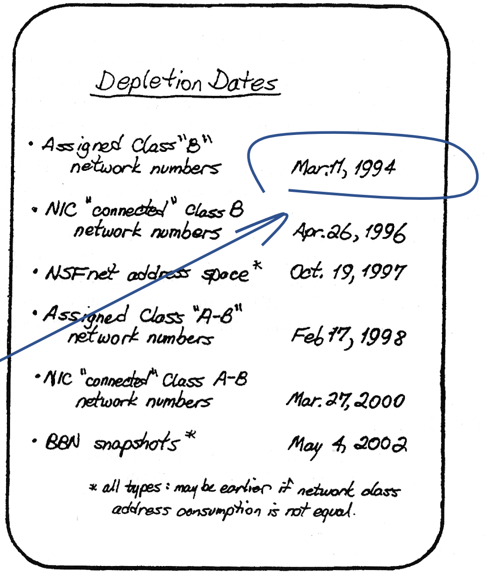
IP Version 4

- 32-bit address field
  - That’s 4,294,967,296 addresses
- In 1983 that looked like a HUGE number of computers

Digital Pressures

- Through the 1980's computers changed from large expensive pieces of ironware to desktop consumer products
  - And the market changed from thousands to tens of millions
- And the prospect was smaller, cheaper and more
  - So by 1990 that 4 billion address space was looking pretty small
  - And it was not going to last much longer!

Frank Solensky – IETF 1990
Presentation on IPv4 Address Depletion Predictions



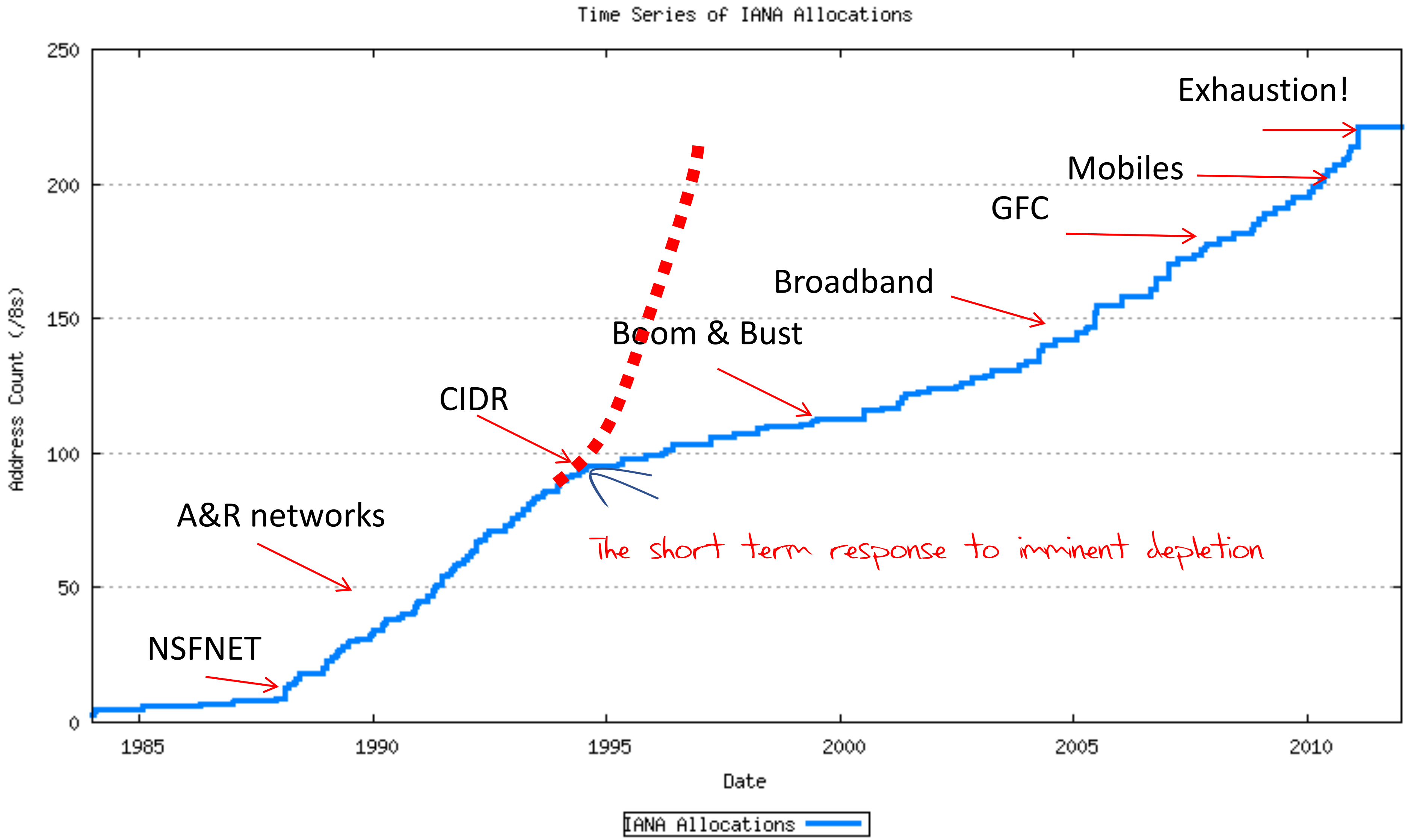
IPocalypse?

So we hit the wall - right?

Panic!

- This was a brutal wakeup call
- We had hardly started with the internet and its demise was just 4 years away!
- So we rapidly worked on short term responses to push this exhaustion date out
- To give us more time to work on the longer term solutions
- So:
  - We dropped the classful address plan
  - We introduced NATs to allow address sharing
  - We worked on a new protocol

It worked!



Time Series of IANA Allocations
250
200
150
100
50
0
Address Count (/8s)
1985
1990
1995
2000
2005
2010
Date
IANA Allocations
Exhaustion!
Mobiles
GFC
Broadband
Boom & Bust
CIDR
A&R networks
NSFNET
The short term response to imminent depletion

That longer term plan

- Was to develop a new IP protocol
- And then transition the Internet over to use this new protocol

What are we transitioning to?

IPv6!

IPv6 is…

- IPv4 with larger address fields
- Not much else changed
  - It’s still an address-based stateless datagram forwarding protocol
  - It still has decoupled forwarding, routing, naming, transport
  - The interfaces to the underlying media protocols are largely unchanged
- So transition to IPv6 should be easy

So transition should be easy?

Right?

So transition should be easy?

Well, no, not really!

Why is this taking so long?

IPv6 was a minimal change to IPv4

- So early adopters found little in the way of an early adoption benefit

IPv6 was not backward compatible with IPv4

- IPv6 adopters still had to support IPv4
- EVERYONE has to transition to dual stack BEFORE we can drop IPv4

Transition, the second time around

- A “Flag Day” switchover is impossible
- Piecemeal replacement won’t work either, as IPv6 is not backward compatible with IPv4
- So, we need to run both protocols in tandem “for a while”
- But bear in mind that one protocol has already run out of addresses
- And network growth continues at record levels

Transition, the second time around

We need to :

- deploy IPv6 in parallel with IPv4
- deploy ever more stringent IPv4 address conservation measures within the network
- allow the network to expand at an ever-increasing rate

All at the same time!

Transition is more like this!


Savage Chickens
by Doug Savage
CHAINSAW JUGGLING? THAT'S EASY! I JUGGLE ANGRY FERRETS!
BUT, TO BE FAIR, THEY DON'T START OFF ANGRY
www.savagechickens.com

Or this!

"The Internet" does not exist

- The Internet is not a singly managed entity
- Noone is in control
- Noone is there to tell anyone else what they can (or cannot) do
- The Internet is a collection of markets (Goods and services, Transmission and switching, Technologies, …)
- We find it impossible to orchestrate collective synchronised actions across all these distinct activities
- So the status quo accumulates a huge amount of inertial momentum
- Which makes it terribly hard to change direction in an orderly manner!

Its now 2022 and we are still in this transition

We underestimated the awesome ability of NATs to squeeze out address efficiencies – the past decade of massive growth on the Internet has been largely based on various forms of NAT usage

NATs expanded the usable IPv4 address capacity by a further ~20 bits

- Each bit of increased address size doubles the total capacity of the space
- So it's taken us much longer than we though to fill up these additional address bits

So how is this transition going?

- Slowly!

Let's look at progress so far

2012 – no significant deployment of IPv6

Let's look at progress so far

2012 2014 – still very little movement in the larger environment

Let's look at progress so far

2012 2014 2017 – India IPv6 deployment

Let's look at progress so far

2012 2014 2017 2019 – stirring in China

Where are we in 2022?

- 11 years after the depletion of the central IPv4 address pools we are still sitting on some 30% of the Internet user base with Dual Stack (IPv4 + IPv6) support
  - The other 3 billion uses are on IPv4 only
- How much longer will it take before we can call this transition “completed”?

Why is this taking so long?

- If we designed the IPv6 protocol 30 years ago
- And we’ve been running the IPv4 Internet on empty for many years
- Then why isn’t the Internet an all-IPv6 Internet today?

Why is this taking so long?

NATs are just too good!

- NATs drive every part of today’s internet, and we’ve adapted the entire IP infrastructure and application space to work in a NAT environment
- We’ve pushed the role of service identification to the name space
- And changed the architecture of the Internet into a client/server model
- And clients don’t need permanently assigned public addresses
- So NATs have allowed us to build a network with some 40 billion connected devices – and we are confident that we can grow further

Why is this taking so long?

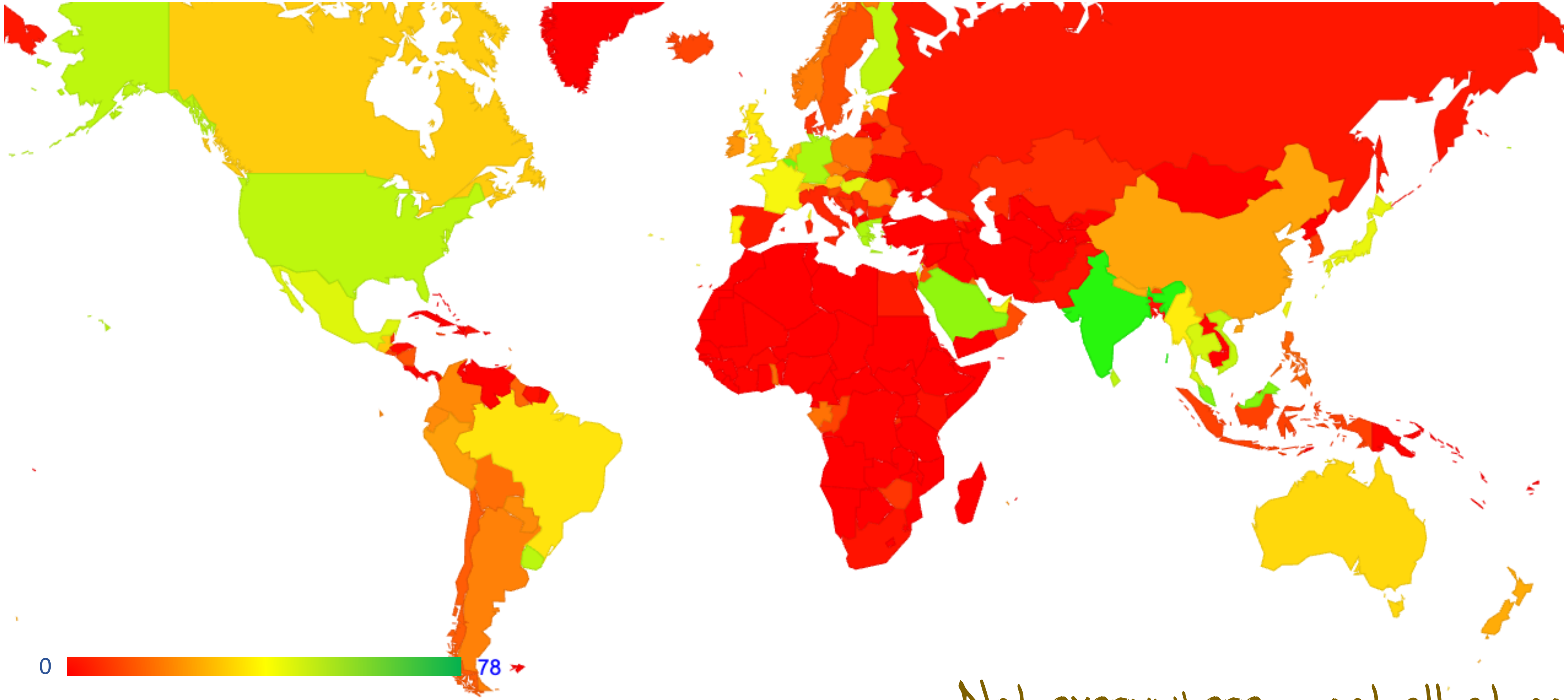
IPv6 is not different enough

- IPv6 is just IPv4 with larger addresses
- It does not make packet switching any cheaper, so it does not give early adopters any advantage
- And IPv6 not backward compatible with IPv4, so early adopters still have to run IPv4 as well

Why is this taking so long

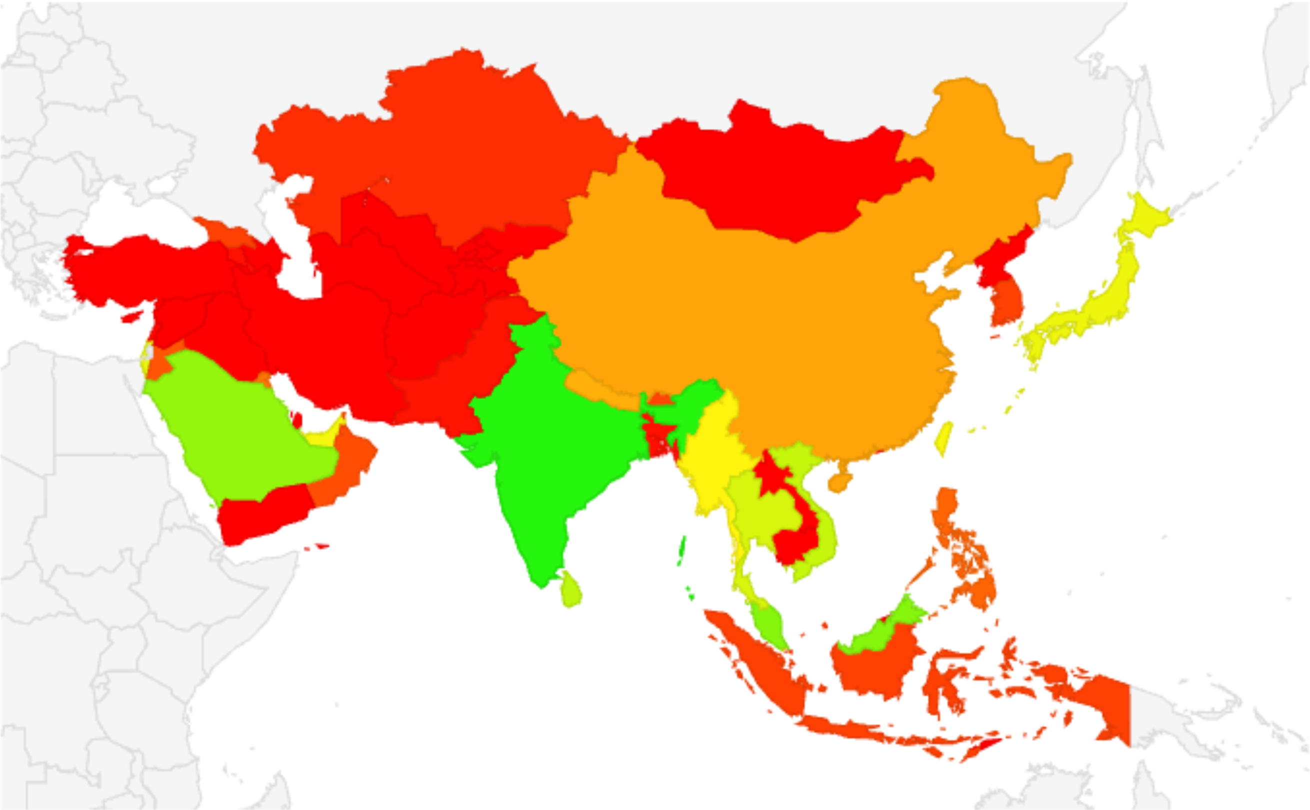
- The transition timetable is not being set by the early adopters
  - There is not enough competitive advantage for early adopters to drive the transition
- The transition timetable is not being set by the late adopters
  - At some point the last to adopt cannot impose a hold over everyone else
- So transition is a form of “majority” decision making
  - It’s a case of “critical mass” that will determine at what point dual stack service providers will contemplate dropping IPv4 and completing their part of the transition

IPv6 Adoption today



Not everywhere – not all at once
~1 B iPv6 users out of 4B

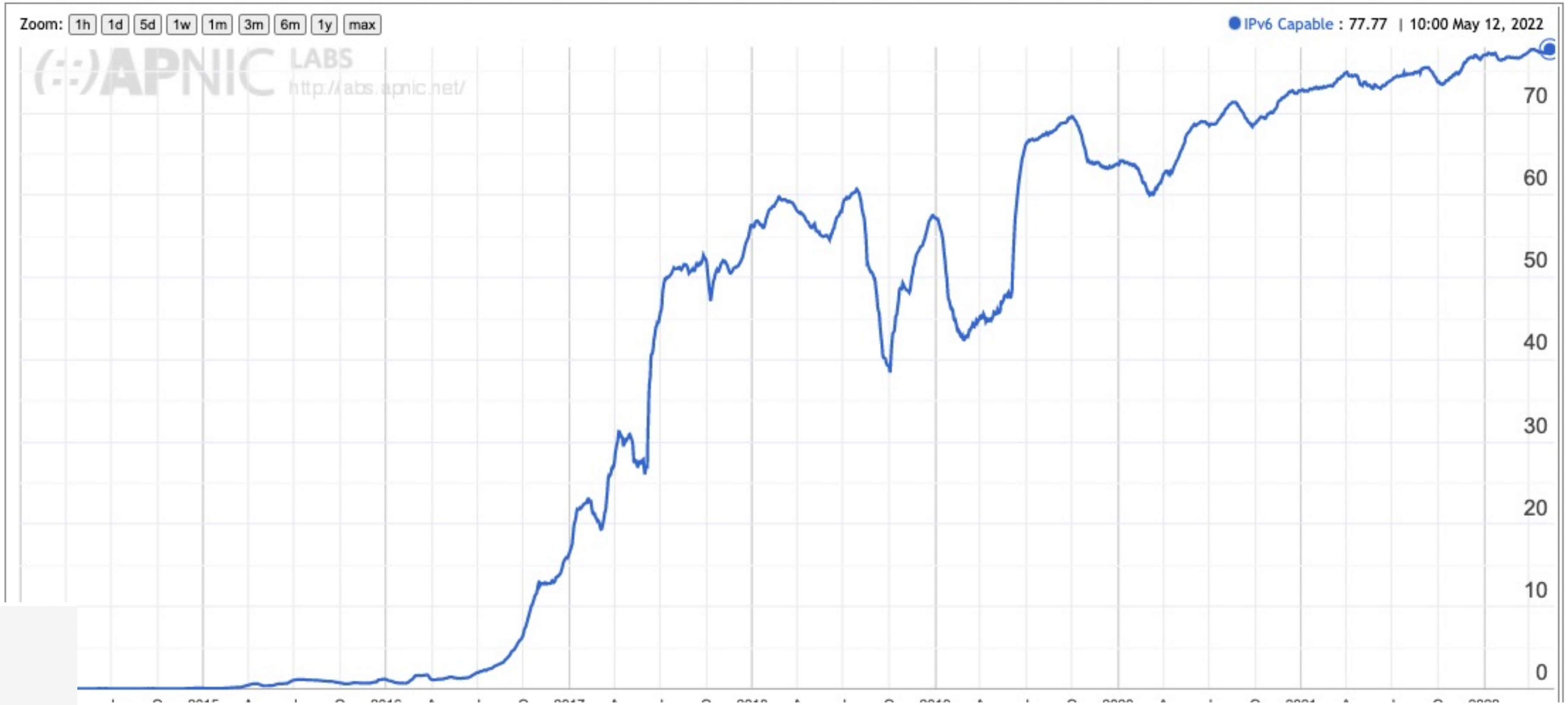
Asia

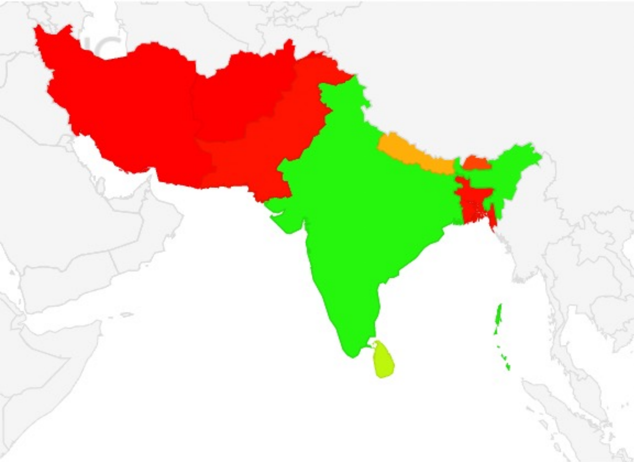


900M iPv6 users out of 2.3 B

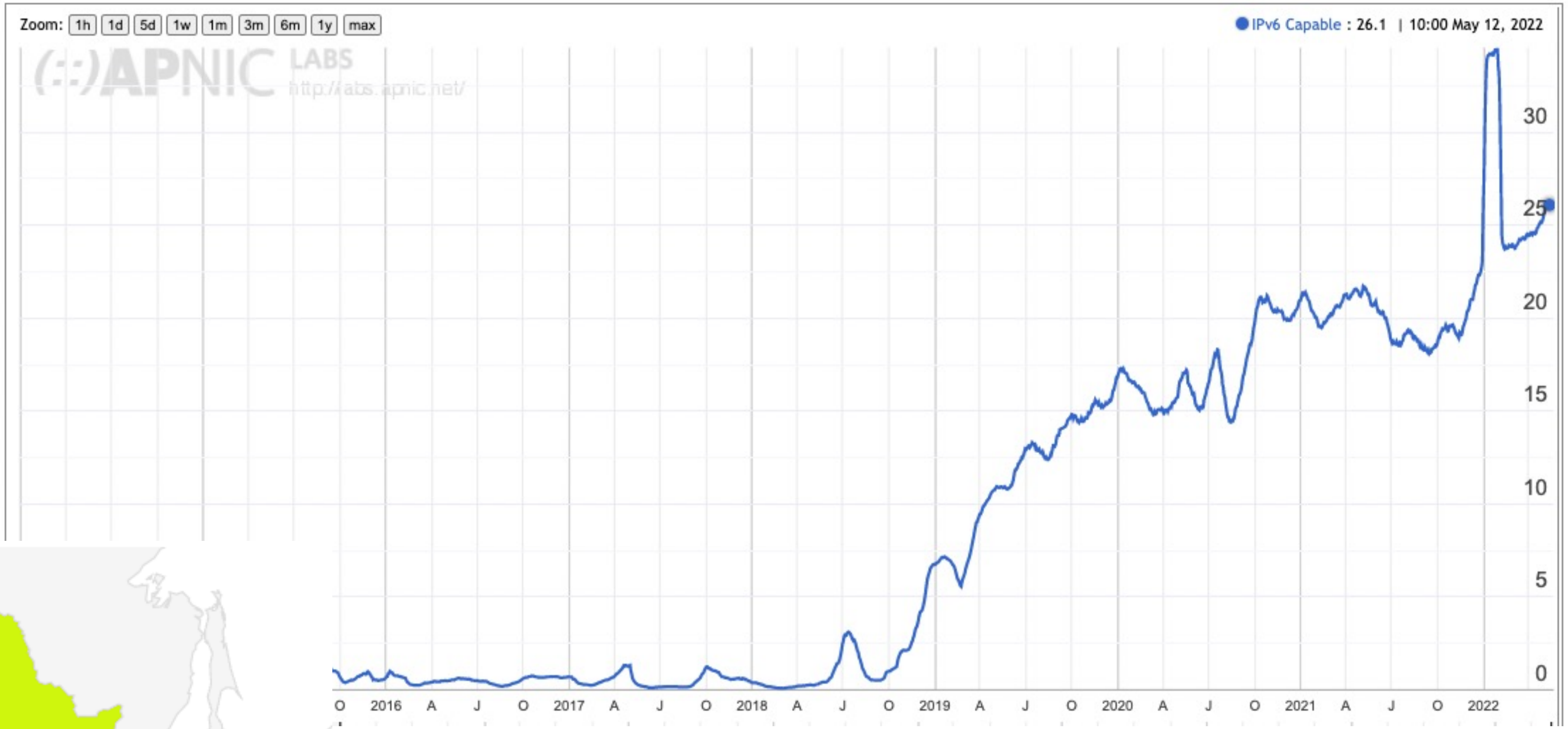
India

Use of IPv6 for India (IN)

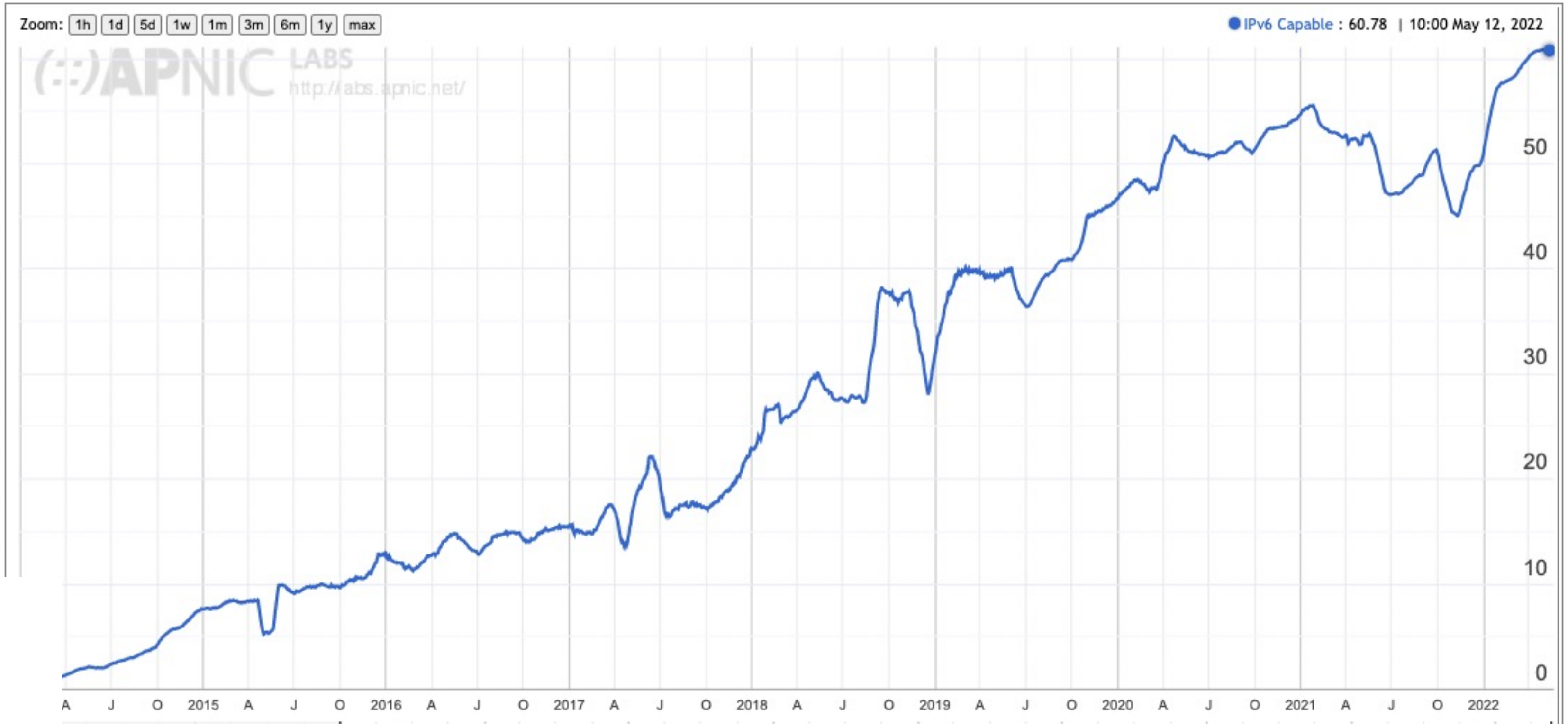




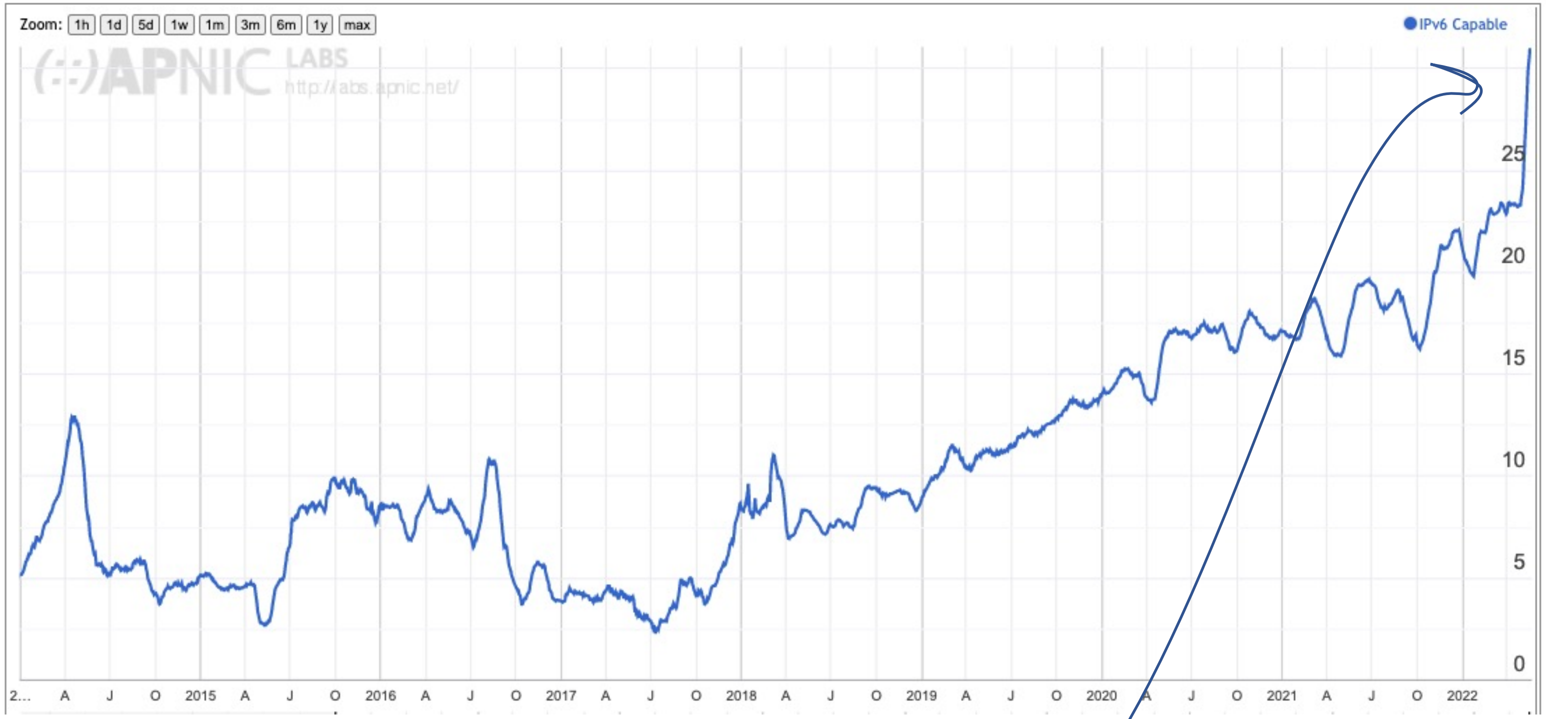
China

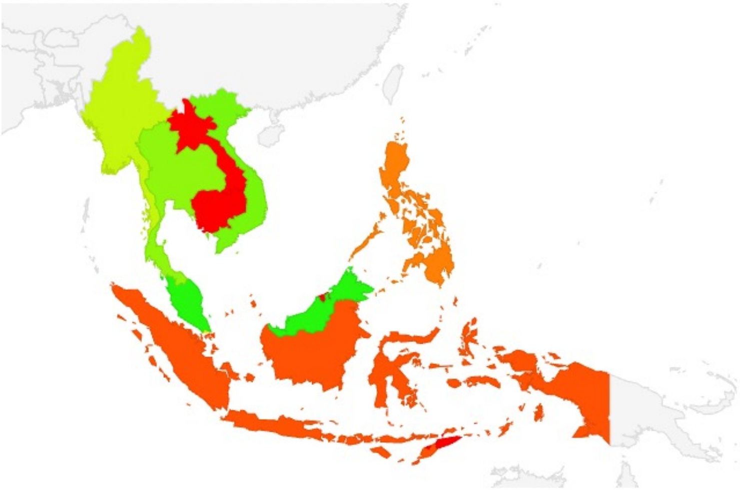

Zoom: 1h 1d 5d 1w 1m 3m 6m 1y max
IPv6 Capable : 26.1 | 10:00 May 12, 2022
(:::)APNIC LABS
http://labs.apnic.net/
30
25
20
15
10
5
0
O 2016 A J O 2017 A J O 2018 A J O 2019 A J O 2020 A J O 2021 A J O 2022

Malaysia


Zoom: 1h 1d 5d 1w 1m 3m 6m 1y max
IPv6 Capable : 60.78 | 10:00 May 12, 2022
(::)APNIC LABS
http://labs.apnic.net/
50
40
30
20
10
0
A J O 2015 A J O 2016 A J O 2017 A J O 2018 A J O 2019 A J O 2020 A J O 2021 A J O 2022

Singapore





What's this?

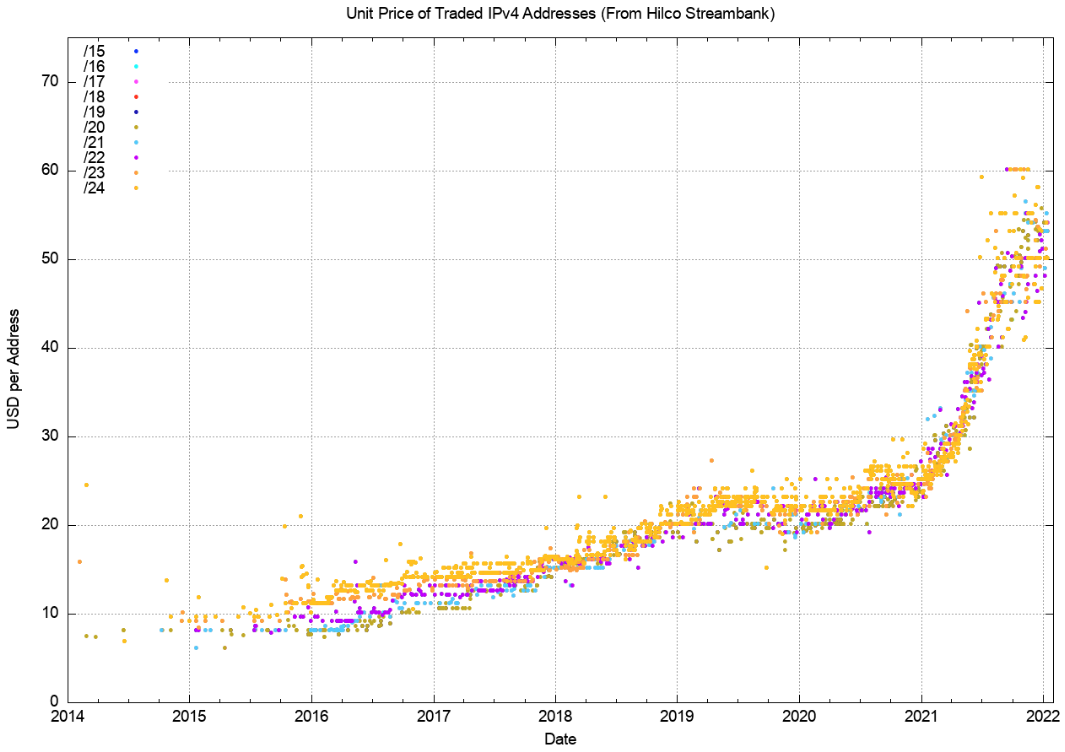
It's likely to be the combination of Cloudflare and Apple's recent Private Relay service

Those phones are iPhones running the latest version of Apple's iOS and the opt-in service called Private Relay. The iGiant bills Private Relay as a privacy enhancement because it obscures users' DNS lookups and IP addresses by funneling traffic over networks operated by Cloudflare, according to specs set by Apple.

https://www.theregister.com/2022/05/11/internet_has_shrunk/

Market Signals

The Price of IPv4 Addresses



Conclusions

- Is this transition was coming to an end the price of IPv4 addresses on the market would be collapsing
  - Instead it doubled over 2021!
  - So it seems that this transition will continue for some time yet
- There is no Plan B
  - There is no alternative to IPv6 out there, and continued growth of the silicon base continues to drain IPv4 resources
  - The escalating IPv4 price makes staying in IPv4-only less and less tenable
- So its not a case of “if” IPv6, but a case of “when” IPv6

Thanks!