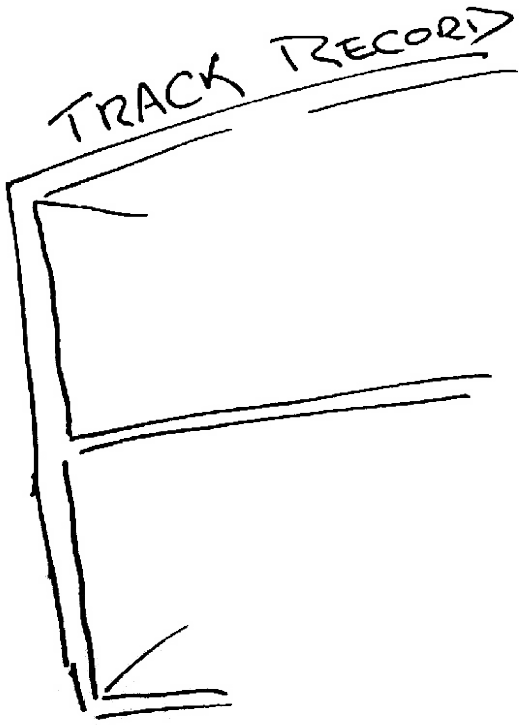
The State of IPv6

Geoff Huston

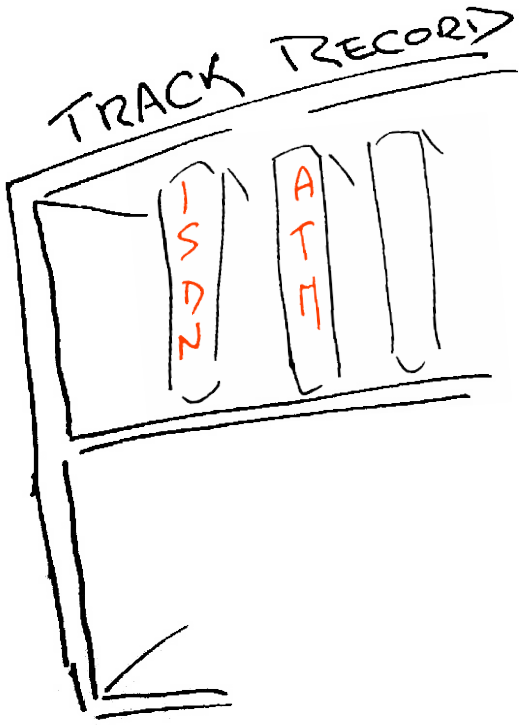
APNIC

The mainstream telecommunications industry has a rich history



The mainstream telecommunications industry has a rich history

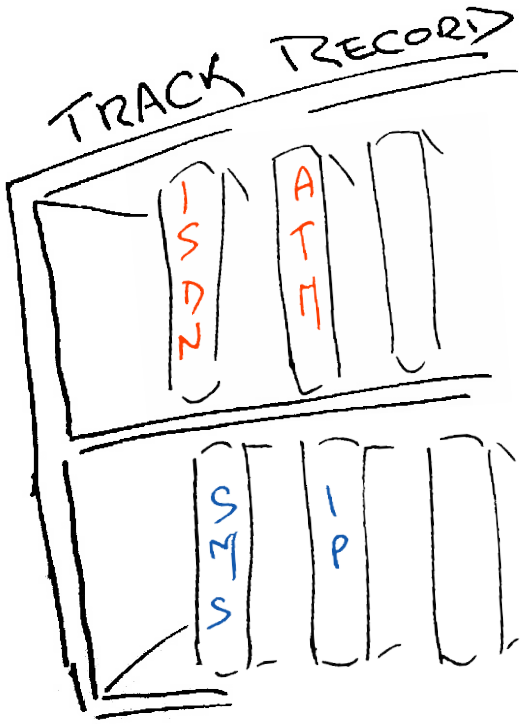
…of making very poor technology choices



The mainstream telecommunications industry has a rich history

…of making very poor technology guesses

and regularly being taken by surprise!



The Internet...

Has been a runaway success that has transformed not just the telecommunications sector, but entire social structures are being altered by the Internet

And now just as we are gearing up, we are about to stuff it up! We've used up most of the Internet's 32bit address pool and that's a huge problem!

The Internet...

Has been a runaway success, has transformed not just the telecommunications [illegible] but our entire social structure are being altered by the Internet

And now as we are gearing up, we are [illegible] to stuff it up! We've [illegible] most of the Internet's address pool and that's a huge problem!

This is should not be news - we've known about this looming IPocalypse for the past twenty years

IETF Meeting - August 1990

Internet Growth (Continued):
Continued Internet Growth

Frank Solensky
Racal InterLan
solensky@interlan.com

- A preliminary analysis of data presented earlier in the conference projects the "size" of the Internet on several metrics, assuming continued exponential growth.
  - NIC Assigned Network Numbers
  - NIC "Connected" Status Nets
  - BBN's snapshots
  - NSFnet Policy Routing DataBases
- As was mentioned during the discussion period, a logistic curve would likely be a more realistic model: This will be the subject of further analysis. Note, however, that the limit that this approaches may turn out to be beyond the capacity of the class A-B-C numbering scheme

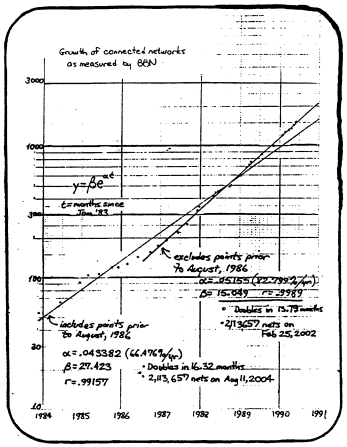
NIC

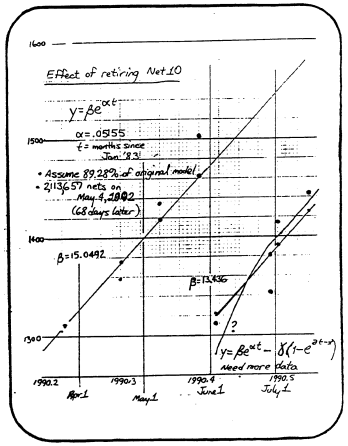
"Connected" IP Network Numbers

- Assigned Numbers RFC defines connected networks as connected to research and operational internet.
- Does not reflect whether the net is, in fact, entered in any routing table.

$y = \beta e^{\alpha t}$ where y = predicted number of nets, t = time (in months) since Jan. 1983

	Class A	Class B	Class C	Class A-B
β	12.069	24.412	887.879	3032.211
α	.012163	.040721	.011690	.013467
growth rate per yr.	15.613%	61.440%	14.497%	17.413%
y	125	16,382	2,097,150	49,147
$\hat{x}$	192.193	159.839	624.438	206.346
	Jan 6, 1999	Apr 26, 1996	May 14, 2038	Mar 27, 2000
r	.9293	.9870	.7942	.9548



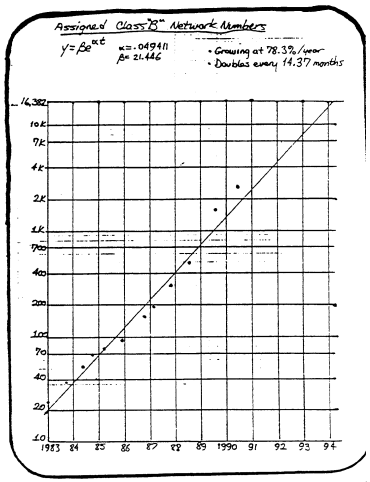


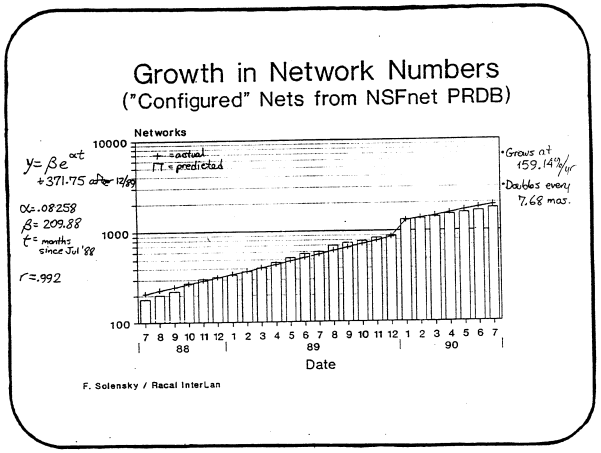
Assignment of IP Network Numbers

- Reflects organizations' desire for IP Address assignment; that is, to be listed in RFC-1166.
- Does not reflect "connectivity"

$y = \beta e^{\alpha t}$ where y = predicted number of nets, t = time (in months) since Jan '83

	Class A	Class B	Class C	Class A-B
β	11.883	21.446	1531.793	2899.462
α	.013175	.049411	.027187	.015587
growth rate per yr.	17.008%	78.389%	37.973%	20.394%
y	125	16,382	2,097,150	49,147
$\hat{x}$	178.605	134.35	265.64	181.58
	(Nov 19, 1997)	(Mar. 11, 1994)	(Feb. 18, 2005)	(Feb 17, 1998)
r	.9491	.9842	.9800	.9749





IETF Meeting - August 1990

Depletion Dates

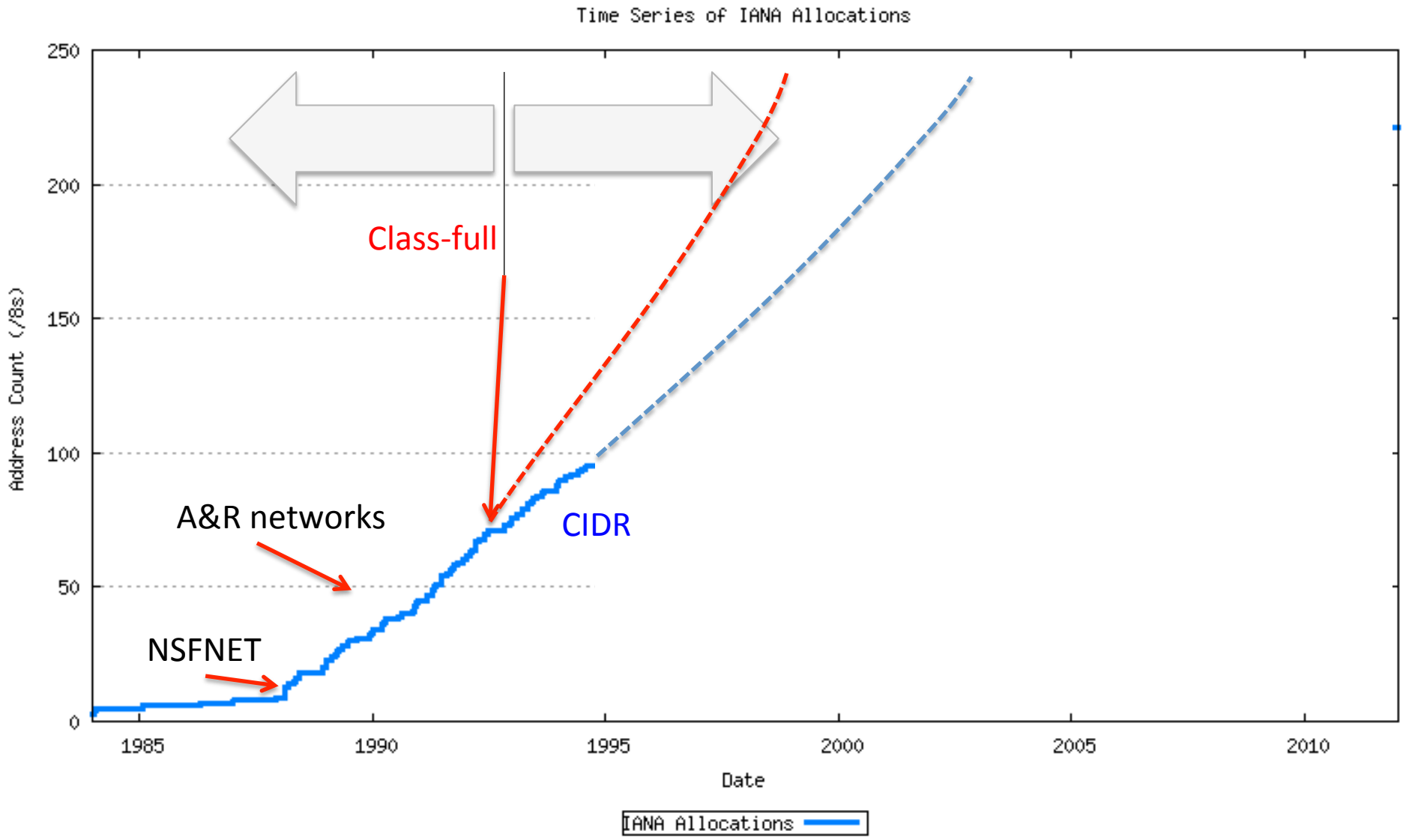
• Assigned Class "B" network numbers	Mar. 11, 1994
• NIC "connected" Class B network numbers	Apr. 26, 1996
• NSFnet address space*	Oct. 19, 1997
• Assigned Class "A-B" network numbers	Feb 17, 1998
• NIC "connected" Class A-B network numbers	Mar. 27, 2000
• BBN snapshots*	May 4, 2002

* all types: may be earlier if network class address consumption is not equal.

What did we do back in 1992?

We bought some time by removing the CLASS A, B, C address structure from IP addresses

The CIDR Fix


Time Series of IANA Allocations
Address Count (/8s)
250
200
150
100
50
0
1985
1990
1995
2000
2005
2010
Date
Class-full
A&R networks
CIDR
NSFNET
IANA Allocations

What else did we do back in 1992?

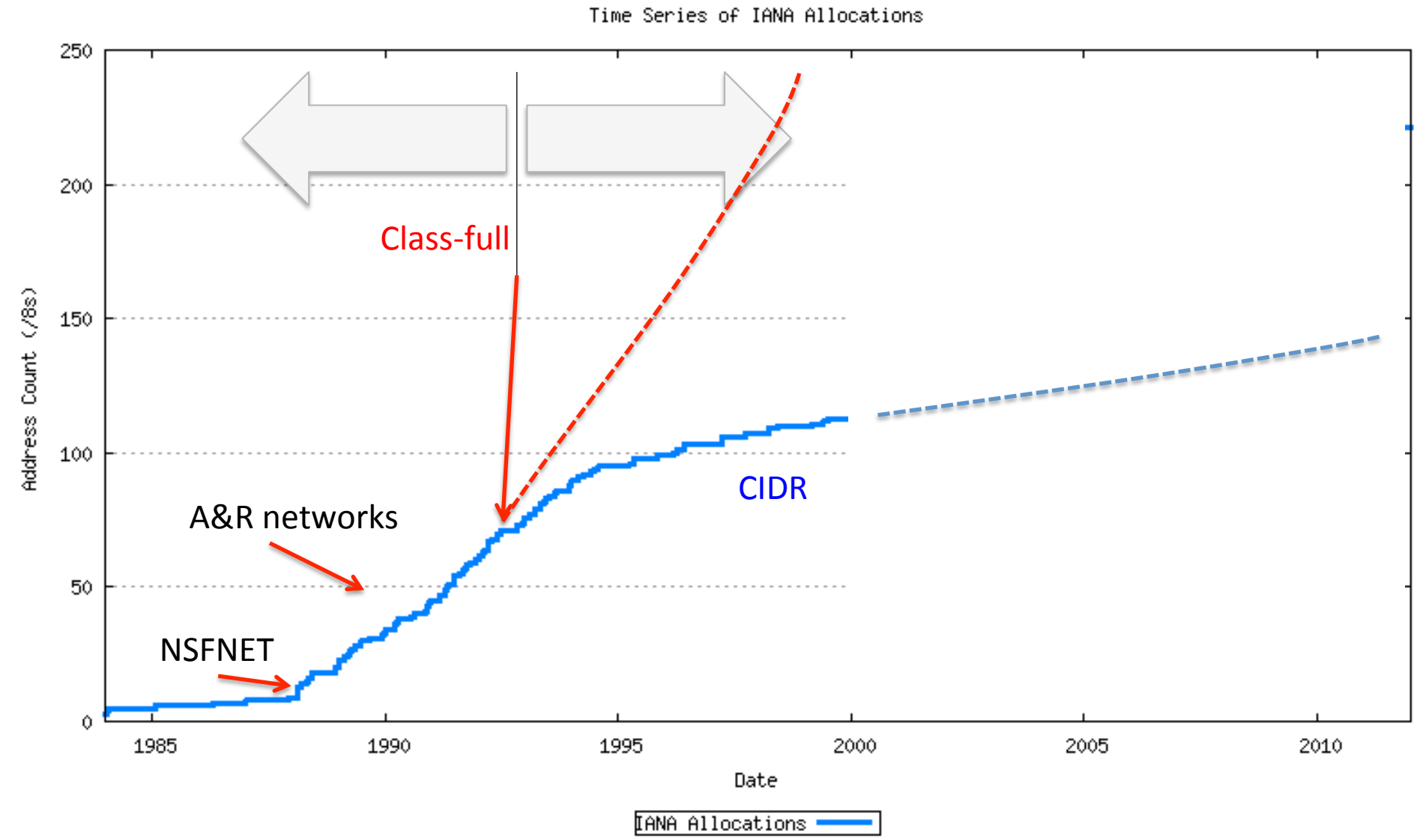
And we started working on a new Internet Protocol - to become IPv6 - to replace IPv4

We left the task of transition until after we had figured out what this new protocol would look like

zzzzzz

For a while this did not look to be an urgent problem...

CIDR worked!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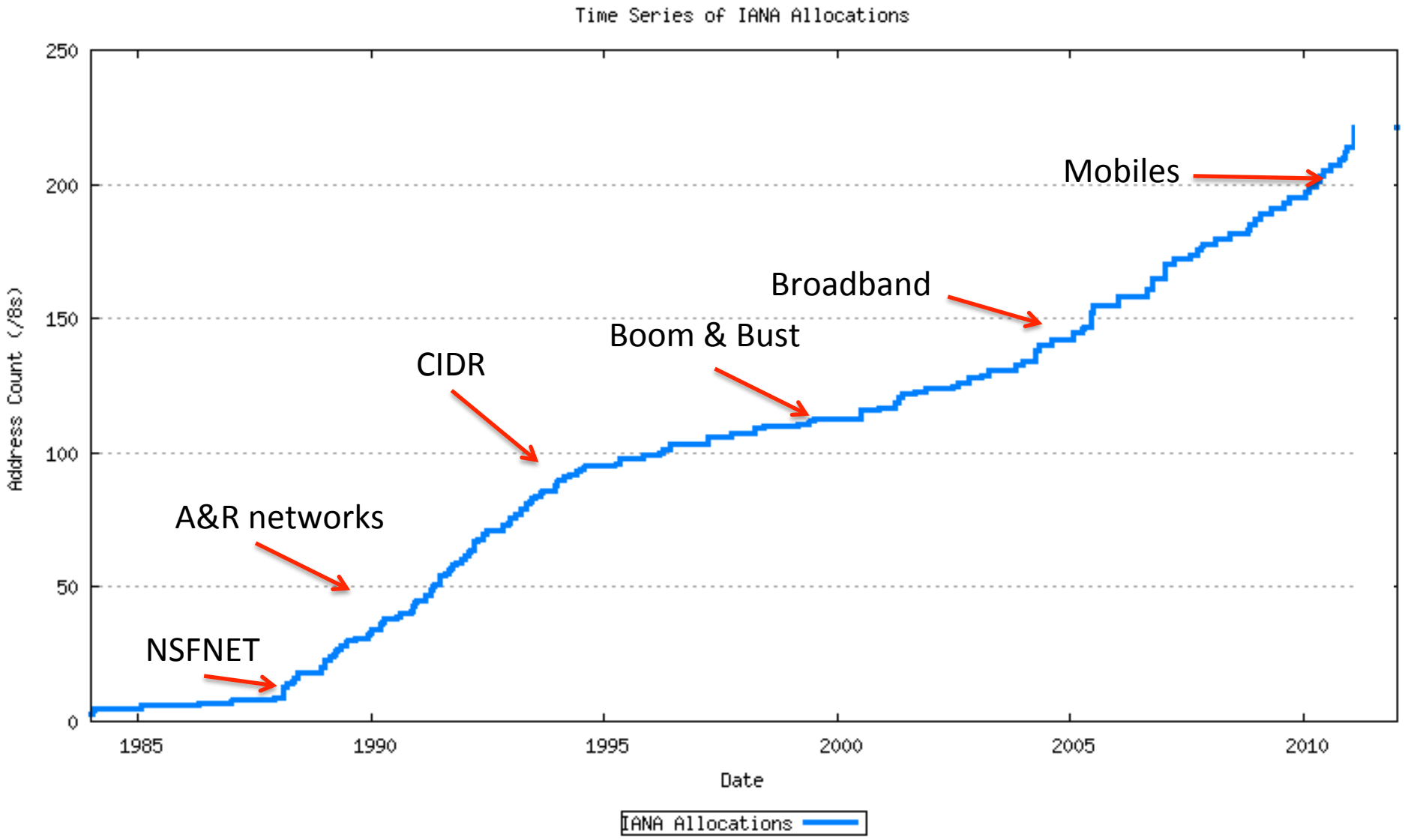
A&R networks
NSFNET
IANA Allocations

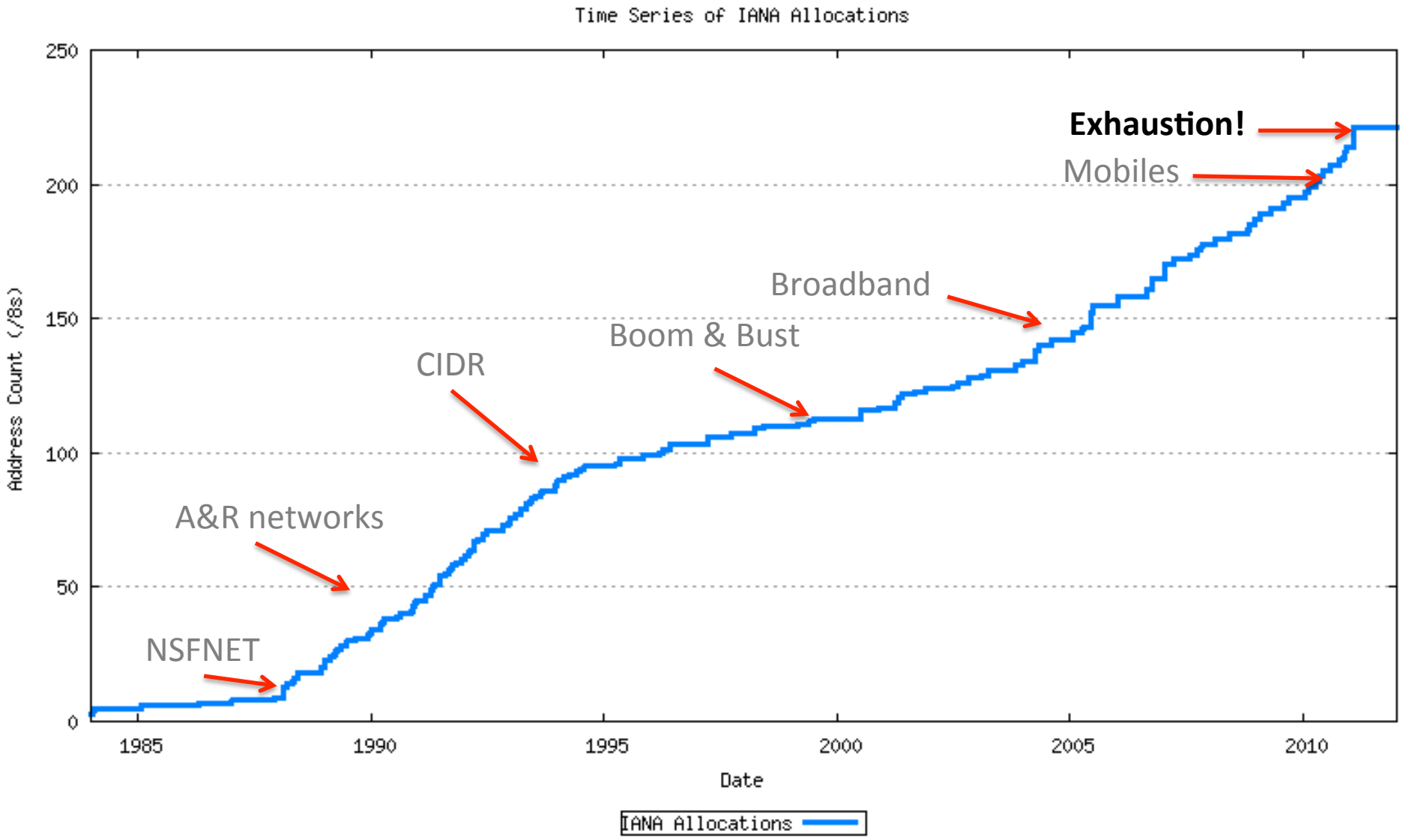
Meanwhile, we continued to build (IPv4) networks



The rude awakening

Until all of a sudden the IPv4 address piggy bank was looking extremely empty...

IPv4 Address Allocations



3 February 2011

Free Pool of IPv4 Address Space Depleted

IPv6 adoption at critical phase

Montevideo, 3 February 2011 – The Number Resource Organization (NRO) announced today that the free pool of available IPv4 addresses is now fully depleted. On Monday, January 31, the Internet Assigned Numbers Authority (IANA) allocated two blocks of IPv4 address space to APNIC, the Regional Internet Registry (RIR) for the Asia Pacific region, which triggered a global policy to allocate the remaining IANA pool equally between the five RIRs. Today IANA allocated those blocks. This means that there are no longer any IPv4 addresses available for allocation from the IANA to the five RIRs.

IANA assigns IPv4 addresses to the RIRs in blocks that equate to 1/256th of the entire IPv4 address space. Each block is referred to as a "/8" or "slash-8". A global policy agreed on by all five RIR communities and ratified in 2009 by ICANN, the international body responsible for the IANA function, dictated that when the IANA IPv4 free pool reached five remaining /8 blocks, these blocks were to be simultaneously and equally distributed to the five RIRs.

"This is an historic day in the history of the Internet, and one we have been anticipating for quite some time," states Raúl Echeberría, Chairman of the Number Resource Organization (NRO), the official representative of the five RIRs. "The future of the Internet is in IPv6. All Internet stakeholders must now take ... action to deploy IPv6."

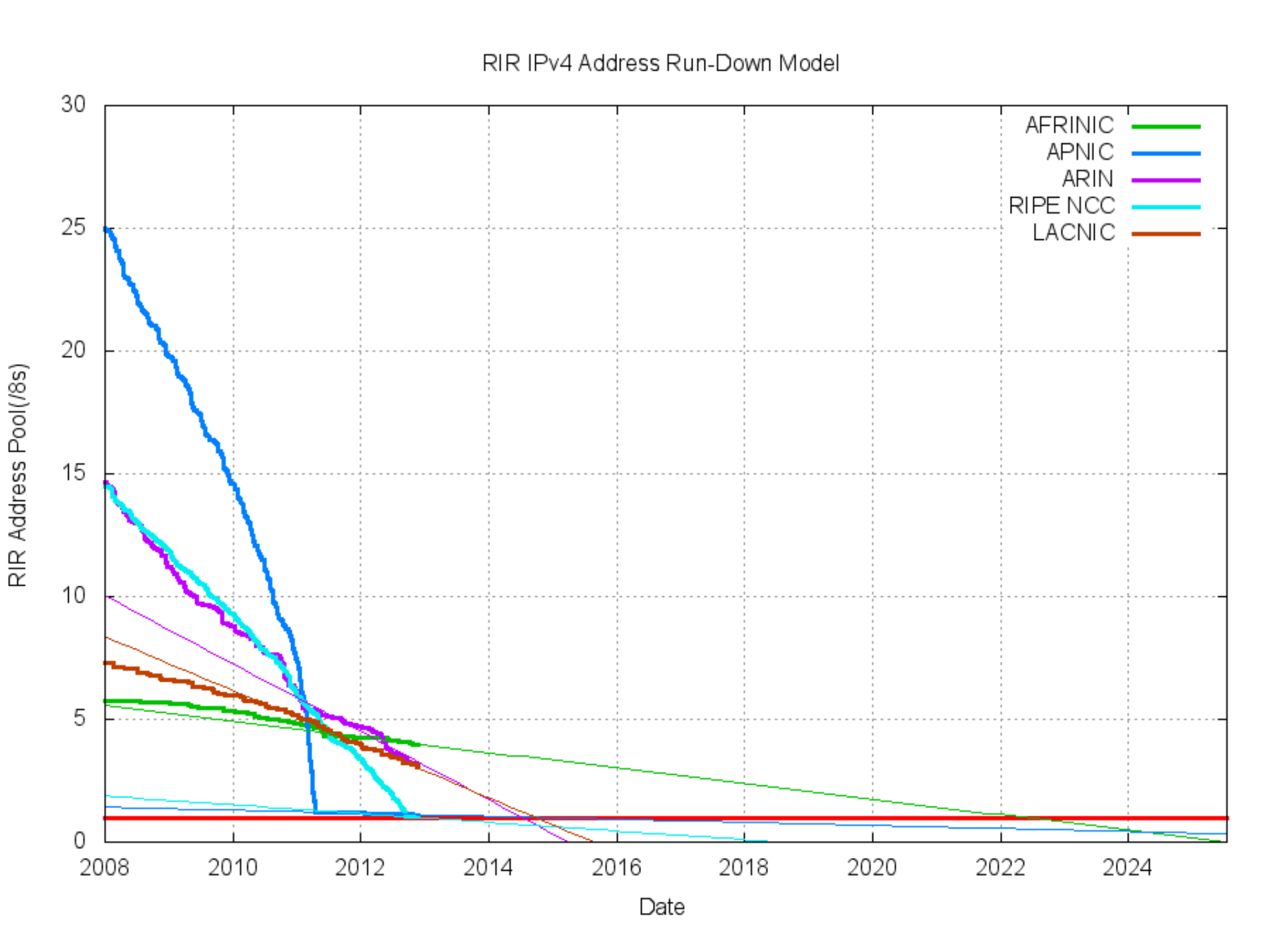
Ooops!

"This is truly a major turning point in the ... ," said Rod Beckstrom, ICANN's President and Chief Executive Officer. "Nobody was caught ... this ... Internet technical community has been planning for IPv4 depletion for quite some time. But it means the adoption of IPv6 is now of paramount importance, since it will allow the Internet to continue its amazing growth and foster the global innovation we've all come to expect."

IPv6 is the "next generation" of the Internet Protocol, providing a hugely expanded address space and allowing the Internet to grow into the future. "Billions of people world wide use the Internet for everything from sending tweets to paying bills. The transition to IPv6 from IPv4 represents an opportunity for even more innovative applications without the fear of running out of essential Internet IP addresses," said Vice President of IANA Elise Gerich.

Adoption of IPv6 is now vital for all Internet stakeholders. The RIRs have been working with network operators at the local, regional, and global level for more than a decade to offer training and advice on IPv6 adoption and ensure that everyone is prepared for the exhaustion of IPv4.

"Each RIR will have its final full /8 from IANA, plus any existing IP address holdings to distribute. Depending on address space requests received, this could last each RIR anywhere from a few weeks to many months. It's only a matter of time before the RIRs and Internet Service Providers (ISPs) must start denying requests for IPv4 address space. Deploying IPv6 is now a requirement, not an option," added Echeberría. IPv6 address space has been available since 1999. Visit http://www.nro.net/ipv6/ for more information on IPv6, or

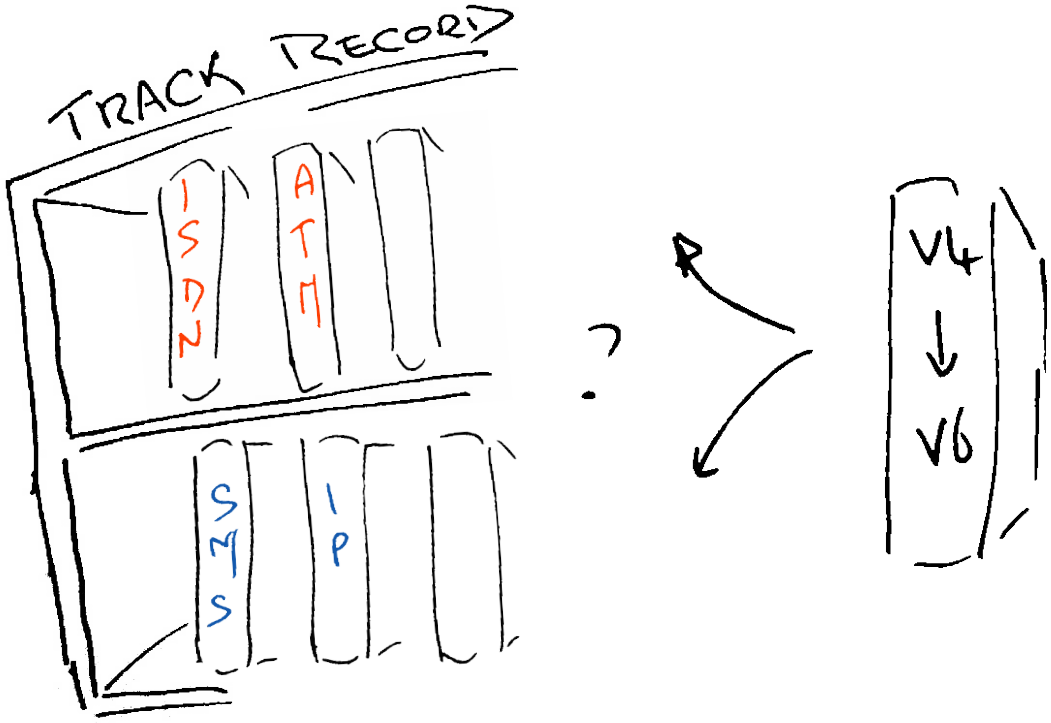

RIR IPv4 Address Run-Down Model
RIR Address Pool(/8s)
Date
AFRINIC
APNIC
ARIN
RIPE NCC
LACNIC
0
5
10
15
20
25
30
2008
2010
2012
2014
2016
2018
2020
2022
2024

The rude awakening

Until all of a sudden the IPv4 address piggy bank was looking extremely empty...

And transition to IPv6 is suddenly a very important topic!

So, how are we going with the IPv4 to IPv6 transition?



Do we really need to worry about this?

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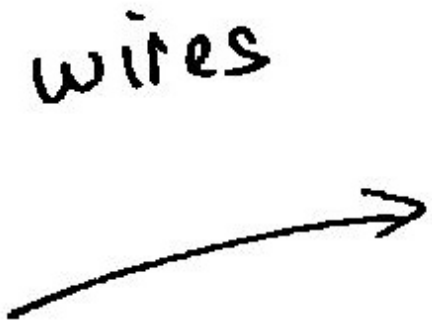
Surely IPv6 will just happen – its just a matter of waiting for the pressure of IpV4 address exhaustion to get to sufficient levels of intensity.

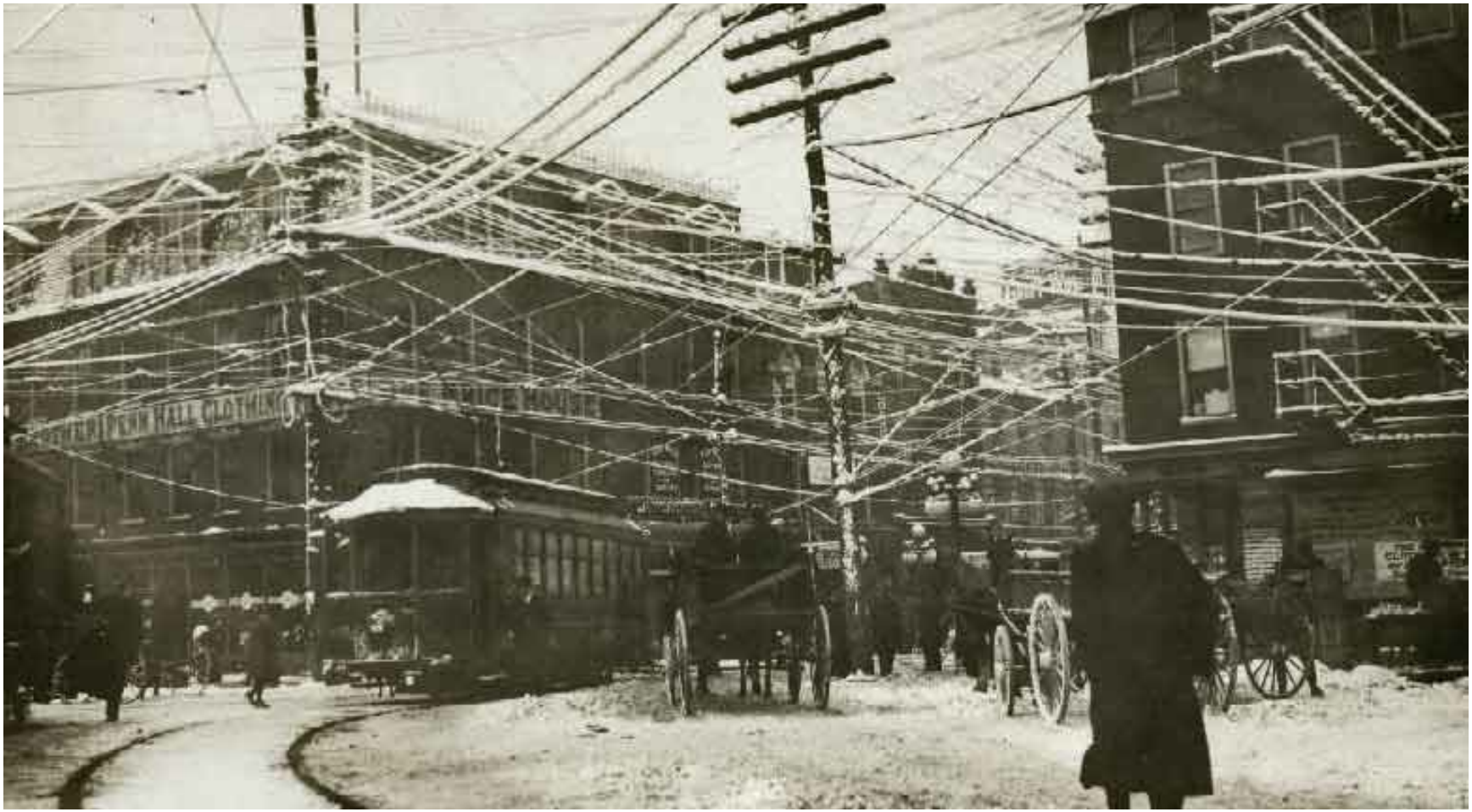
Do we really need to worry about this?

Surely IPv6 will just happen – its just a matter of waiting for the pressure of IpV4 address exhaustion to get to sufficient levels of intensity.

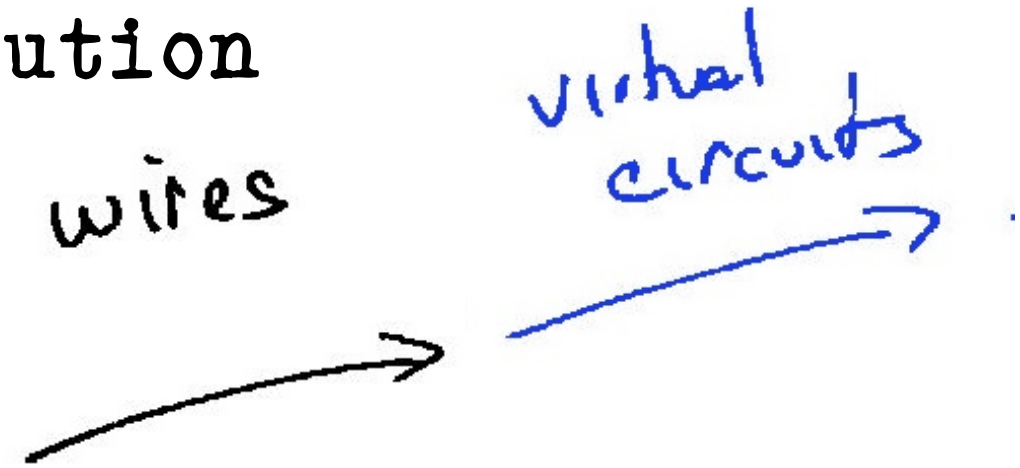
Or maybe not – let's look a bit closer at the situation ...

The
"inevitability"
of technological
evolution





The "inevitability" of technological evolution



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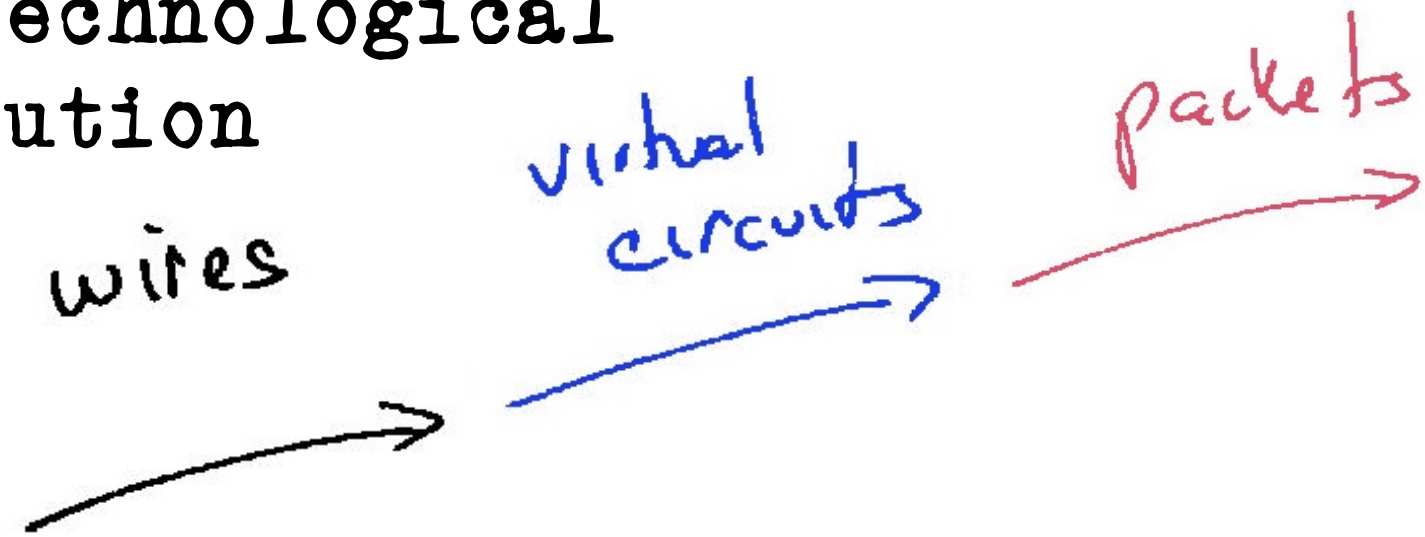
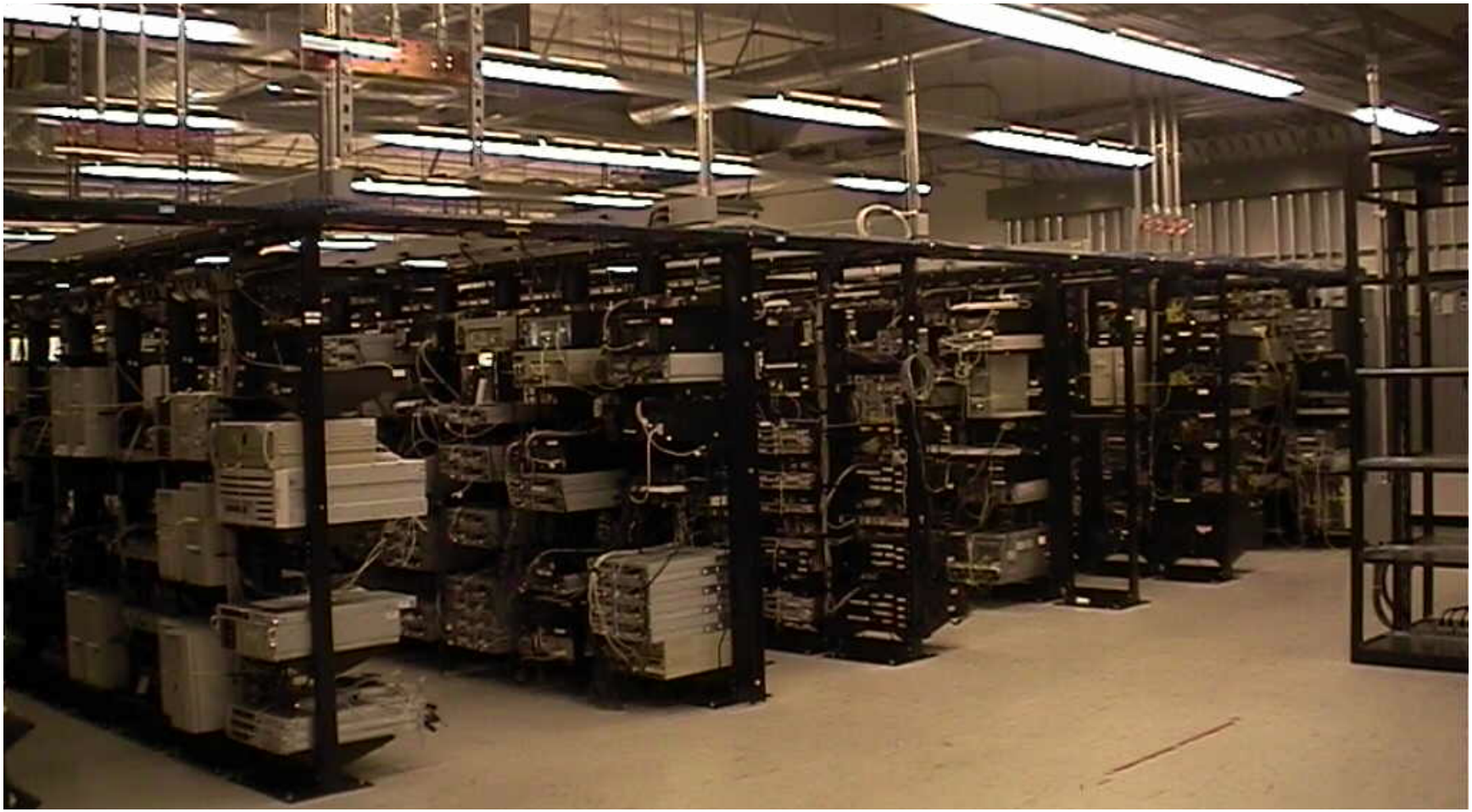
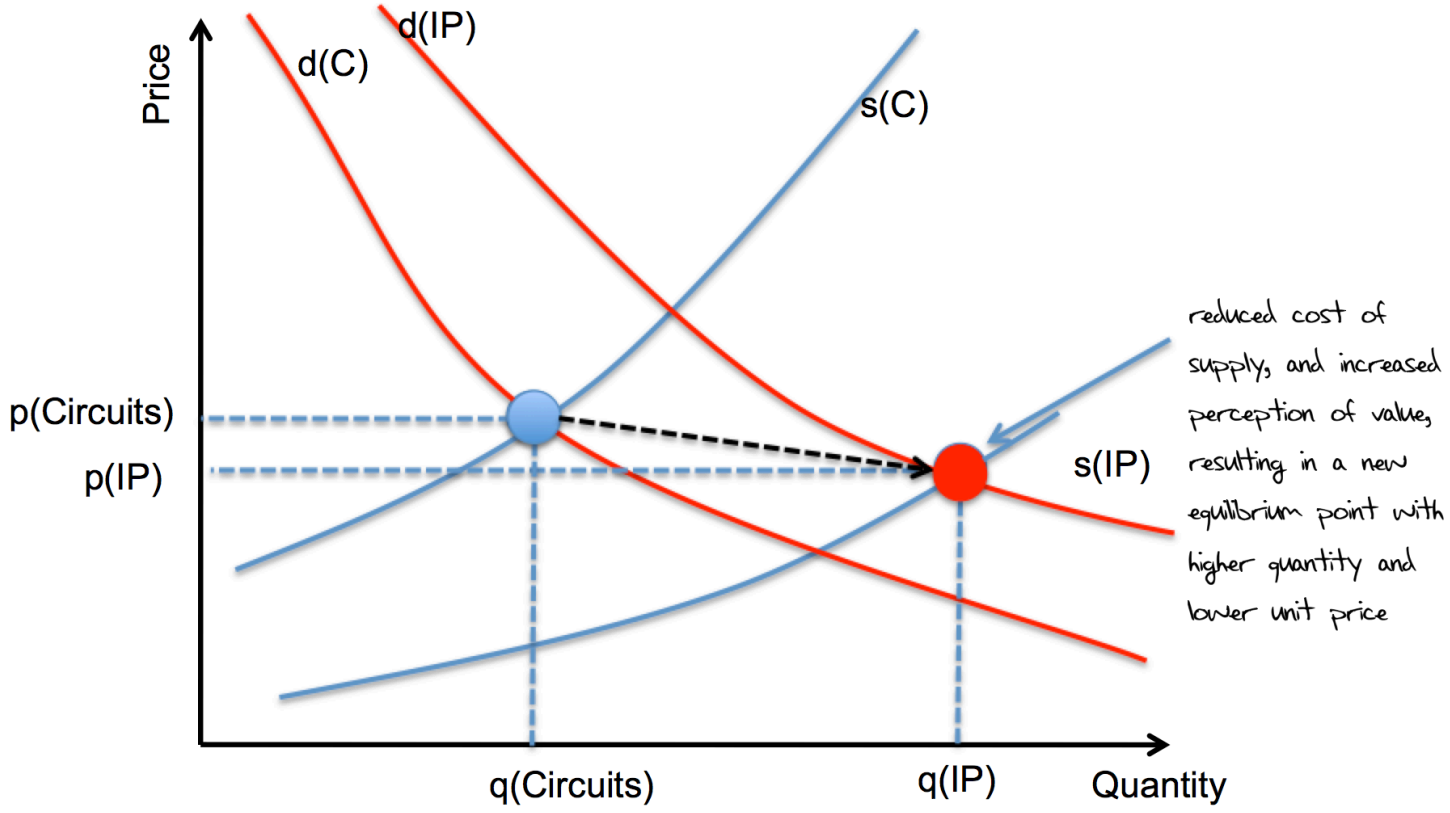




The "inevitability" of technological evolution

Each time we shifted the technology base of the networks, the cost efficiencies of the "new" technology in effect motivated the shift from the older technology to the new

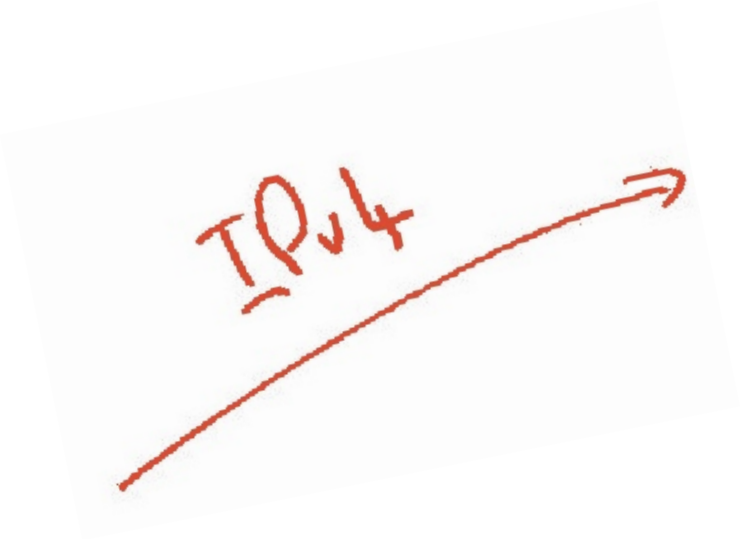
The "inevitability" of technological evolution: Its just economics!



The "inevitability" of technological evolution

Now lets look at something a little more topical to today!

The
"inevitability"
of technological
evolution?



The
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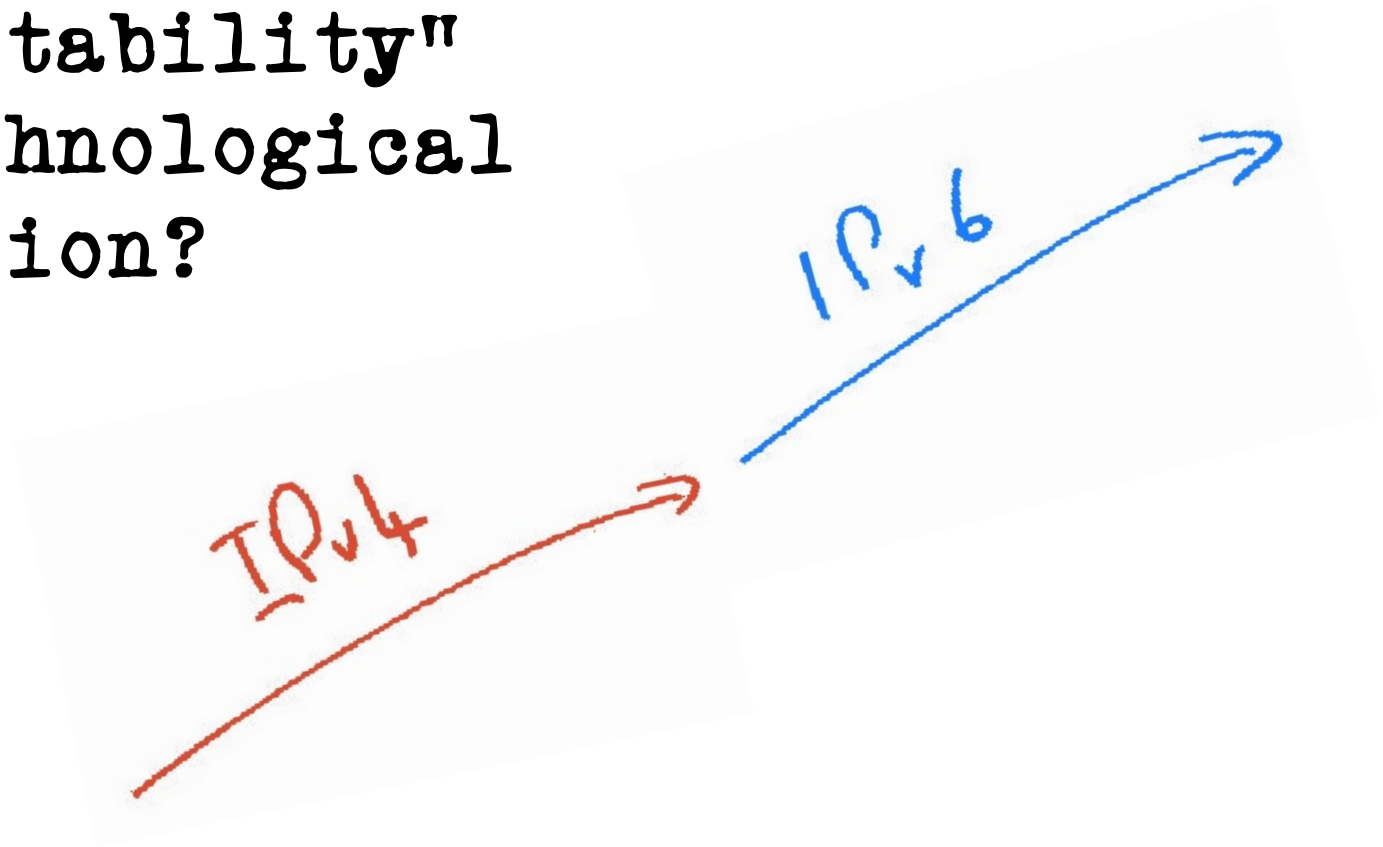
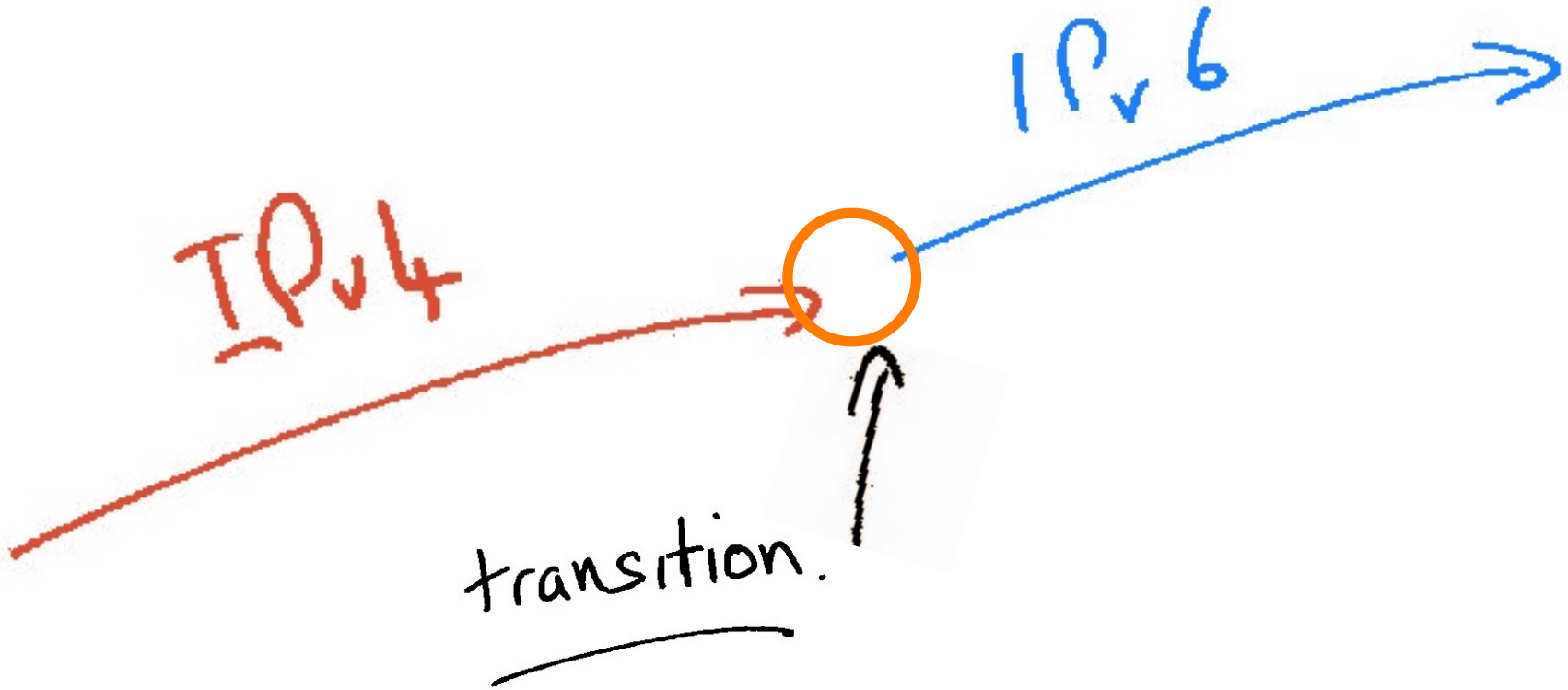
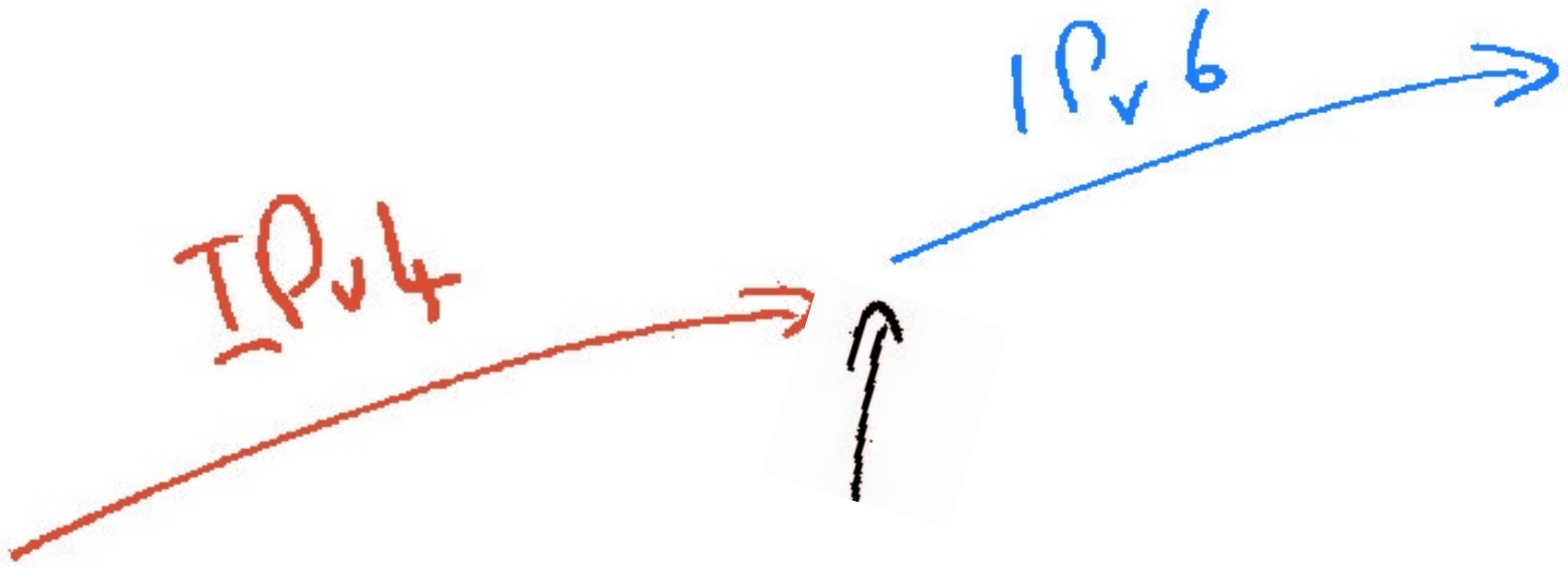


The challenge often lies in managing the transition from one technology to another



Option 1: Flag Day!



We all agree to turn off IPv4 and turn on IPv6 EVERYWHERE

All at the same time! All over the Internet!

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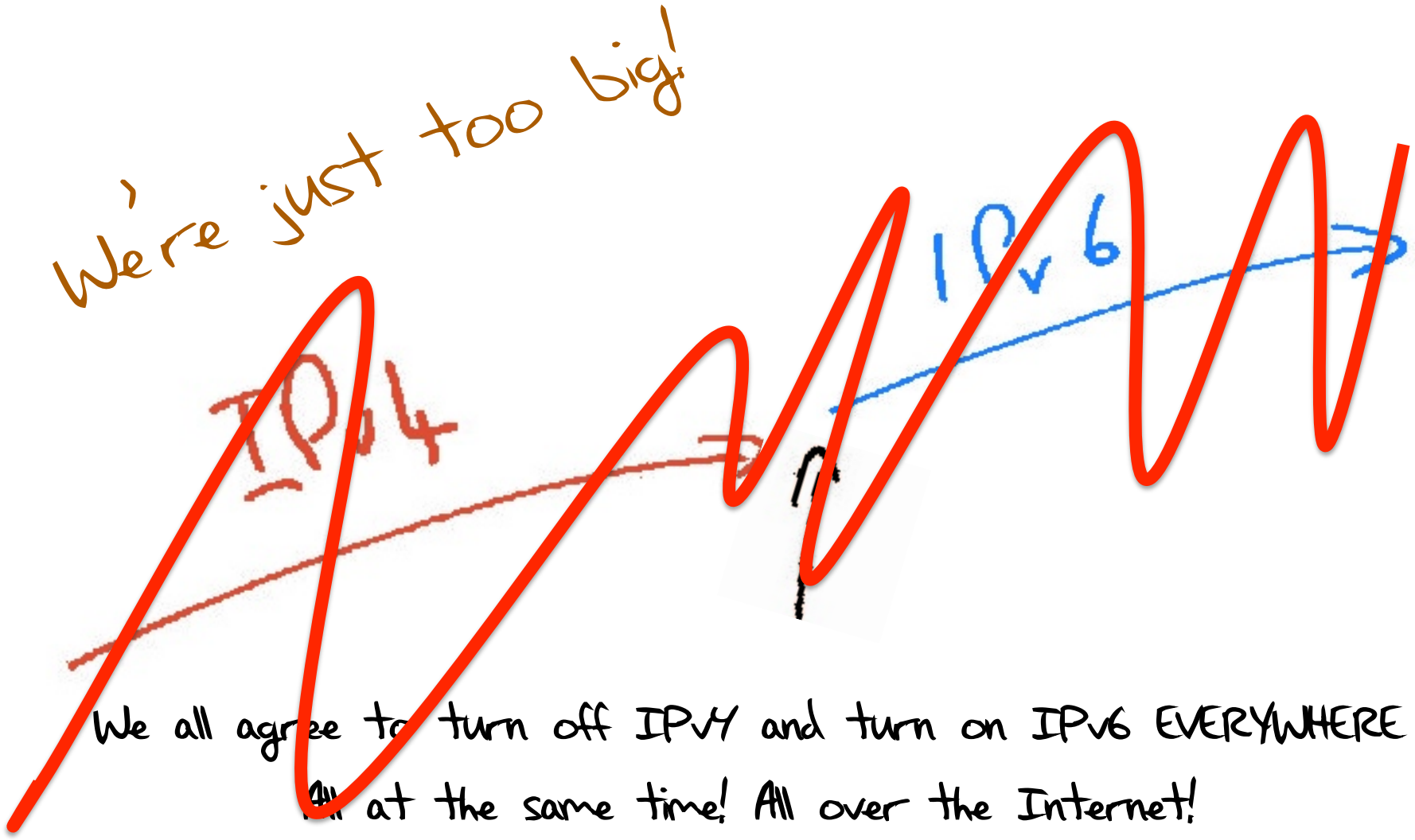

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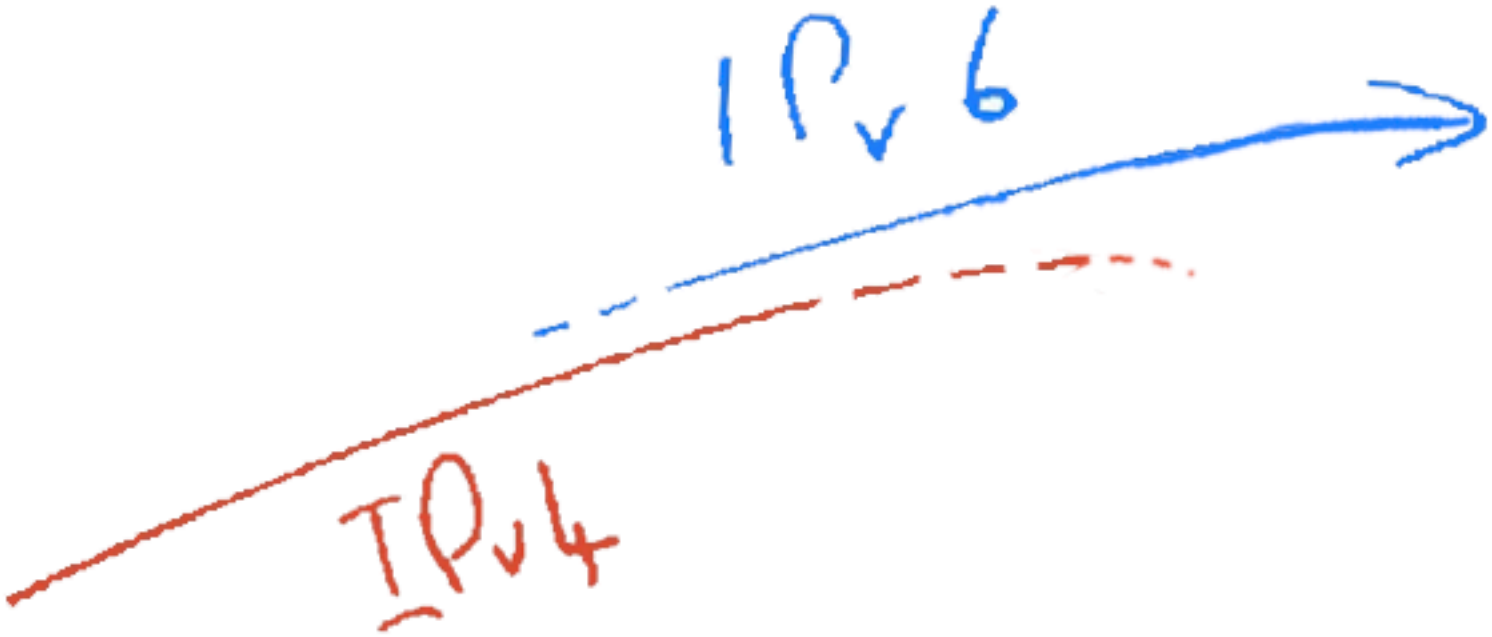
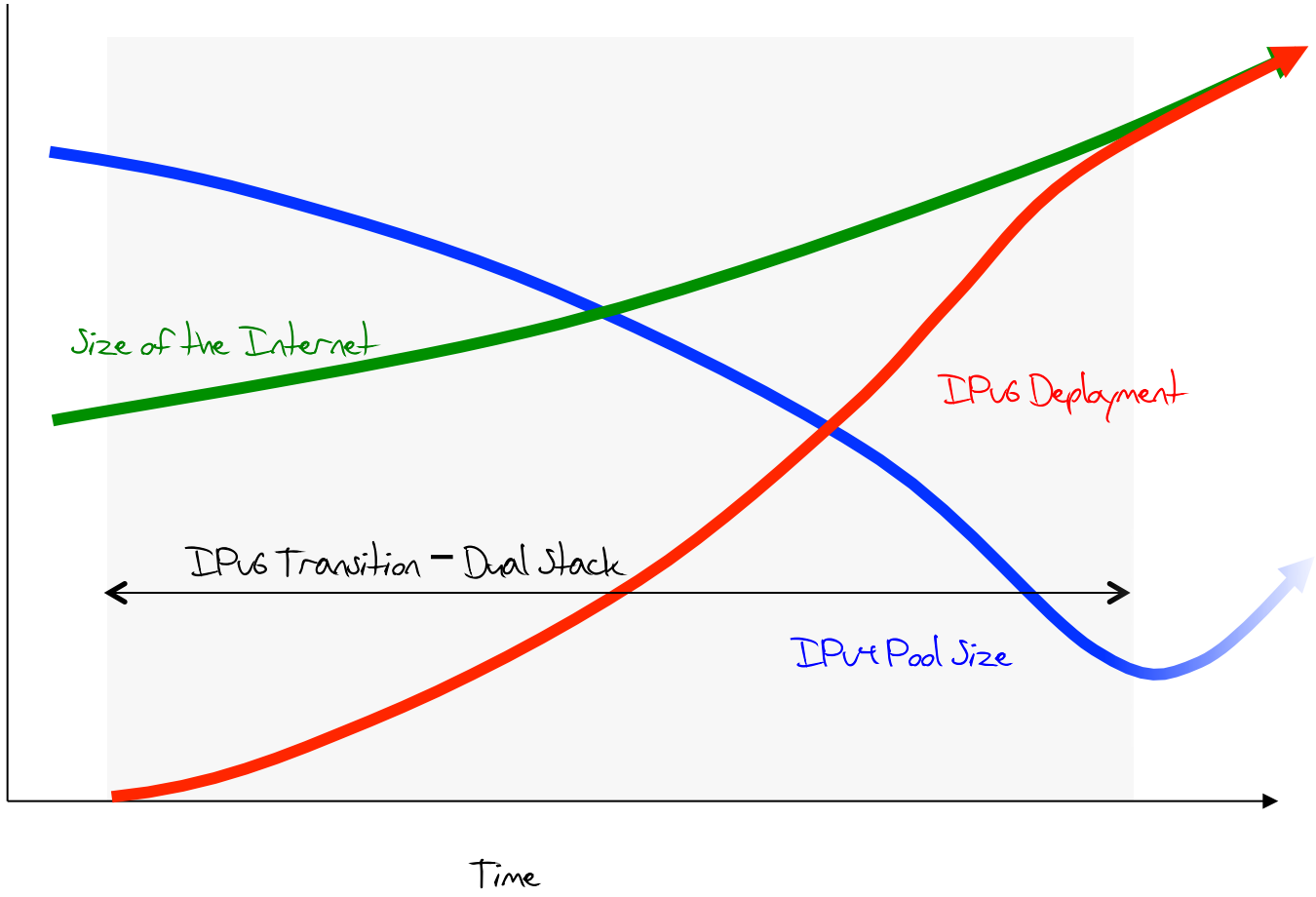
Option 2: Parallel Transition!



We start to slide in IPv6 in parallel with IPv4

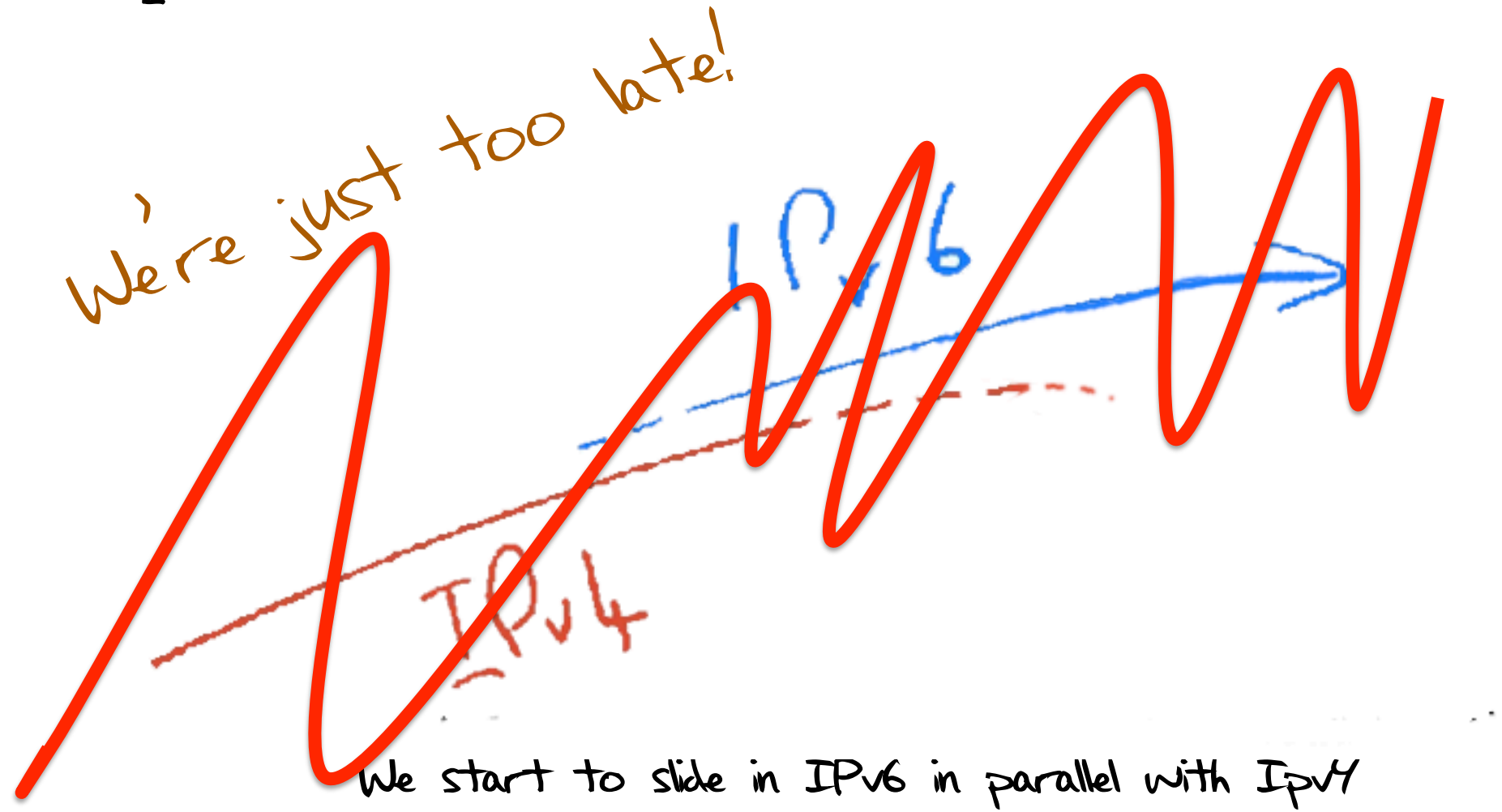
Then we gradually phase out IPv4

Option 2: Parallel Transition!



For this to work we have to start early and finish BEFORE IPv4 address pool exhaustion

Option 2: Parallel Transition!



We start to slide in IPv6 in parallel with IpV4

Then we gradually phase out IPv6

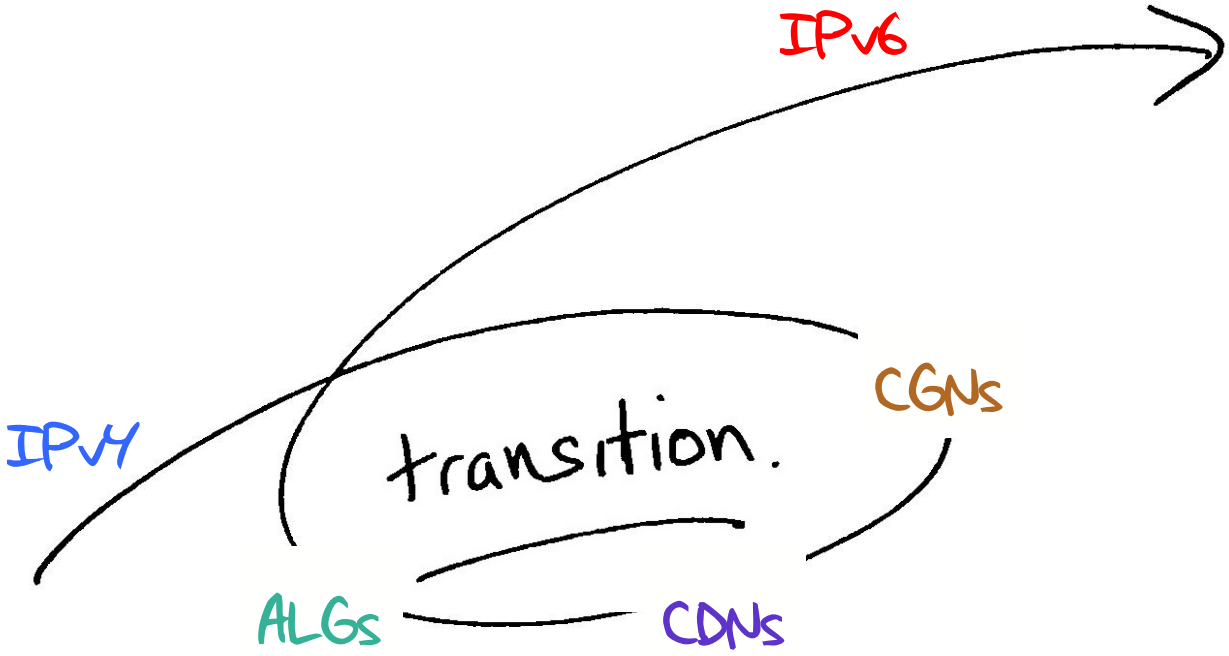
The small print: It's incredibly difficult for markets to plan without clear price signals, and we never managed to price future scarcity into the Internet model. Our chosen address distribution model was one that deliberately avoided any form of price-based market signaling. We sort of hoped that operators would price future risks. We were very wrong!

Hybrid IPv4

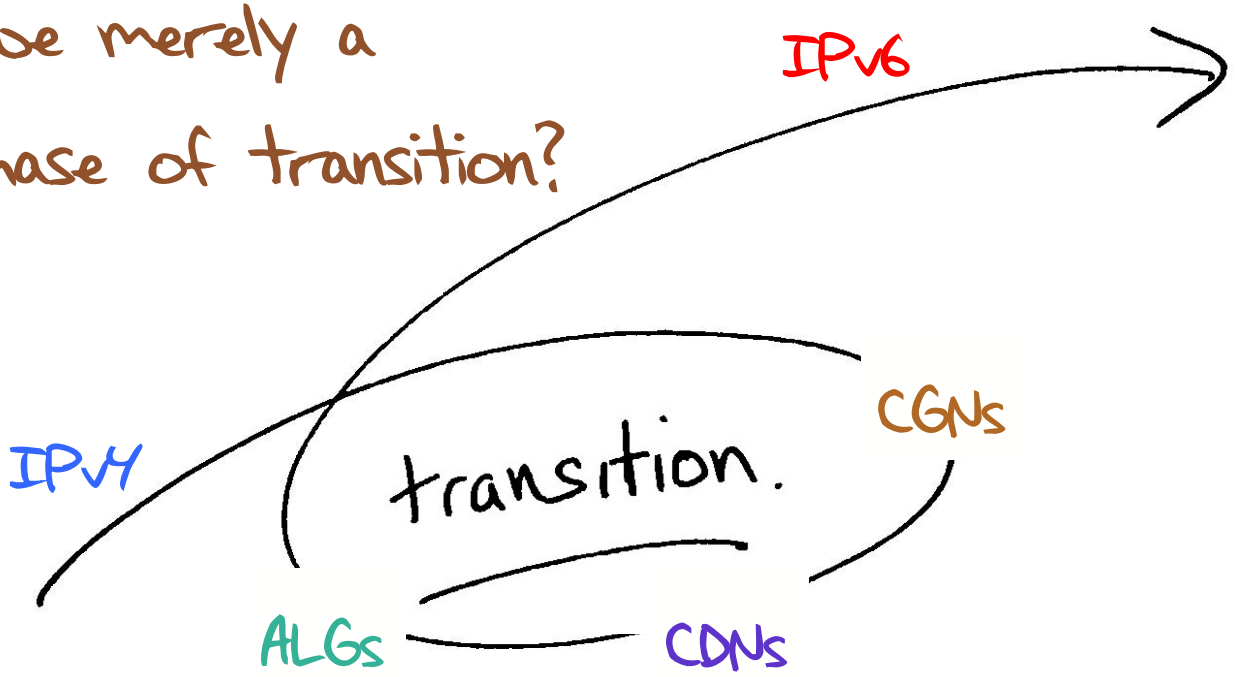
The increasing scarcity of IPv4 will force carriage providers to add address sharing mechanisms into the IPv4 network

Option 3: Hybrid Transition

To get from "here" to "there" requires an excursion through an environment of CGNs, CDNs, ALGs and similar middleware 'solutions' to IPv4 address exhaustion

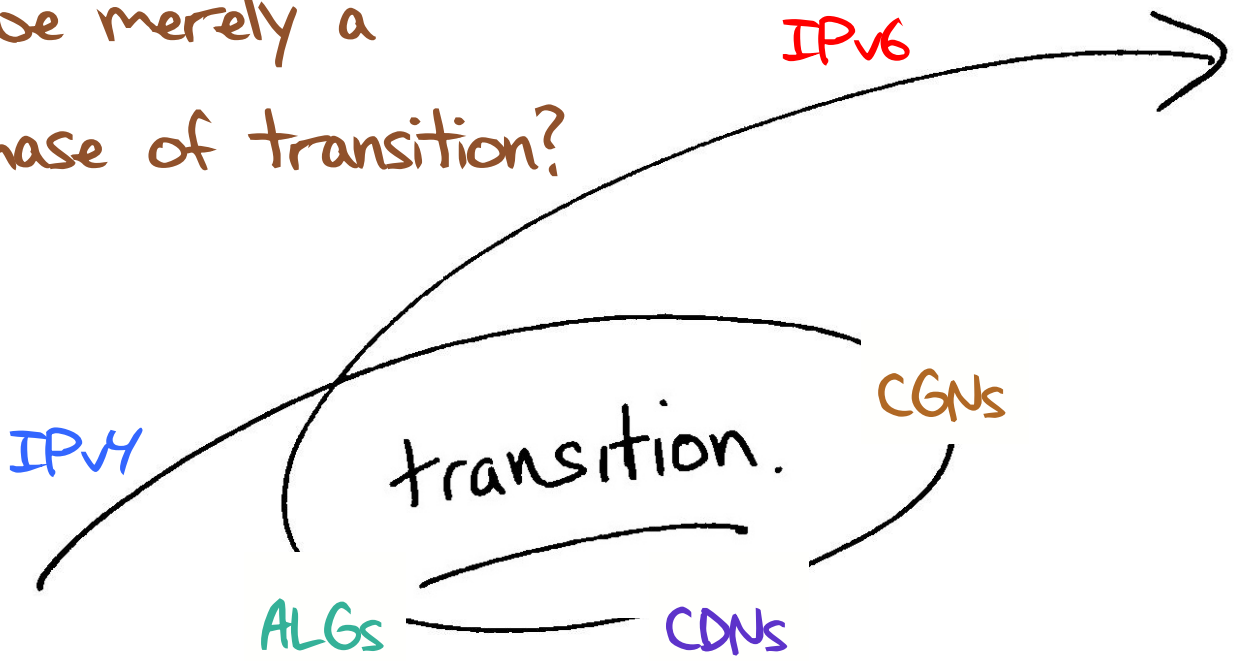


But will this be merely a temporary phase of transition?



Transition requires the network owner to undertake capital investment in network service infrastructure to support IPv4 address sharing/rationing.

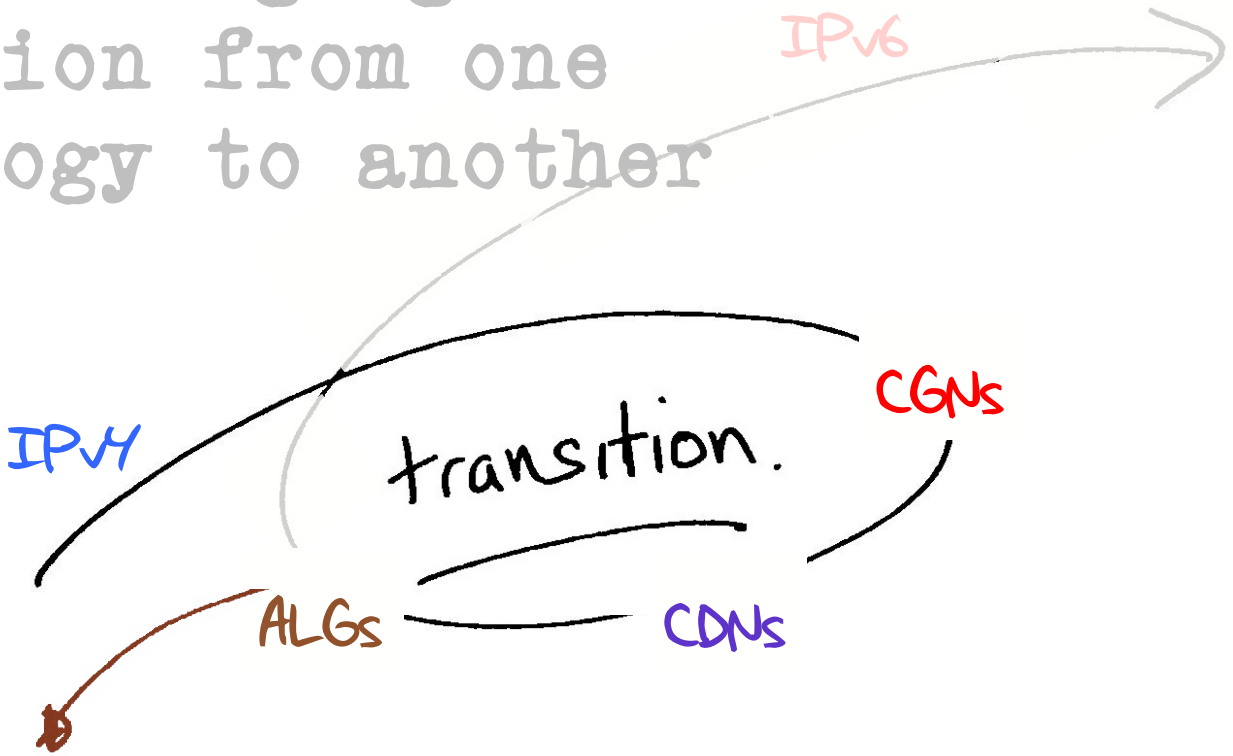
But will this be merely a temporary phase of transition?



Transition requires the network owner to undertake capital investment in network service infrastructure to support IPv4 address sharing/rationing.

What lengths will the network owner then go to to protect the value of this additional investment by locking itself into this "transitional" service model for an extended/indefinite period?

The challenge often lies in managing the transition from one technology to another



The risk in this transition phase is that the Internet carriage provider heads off in a completely different direction!

The problem is...

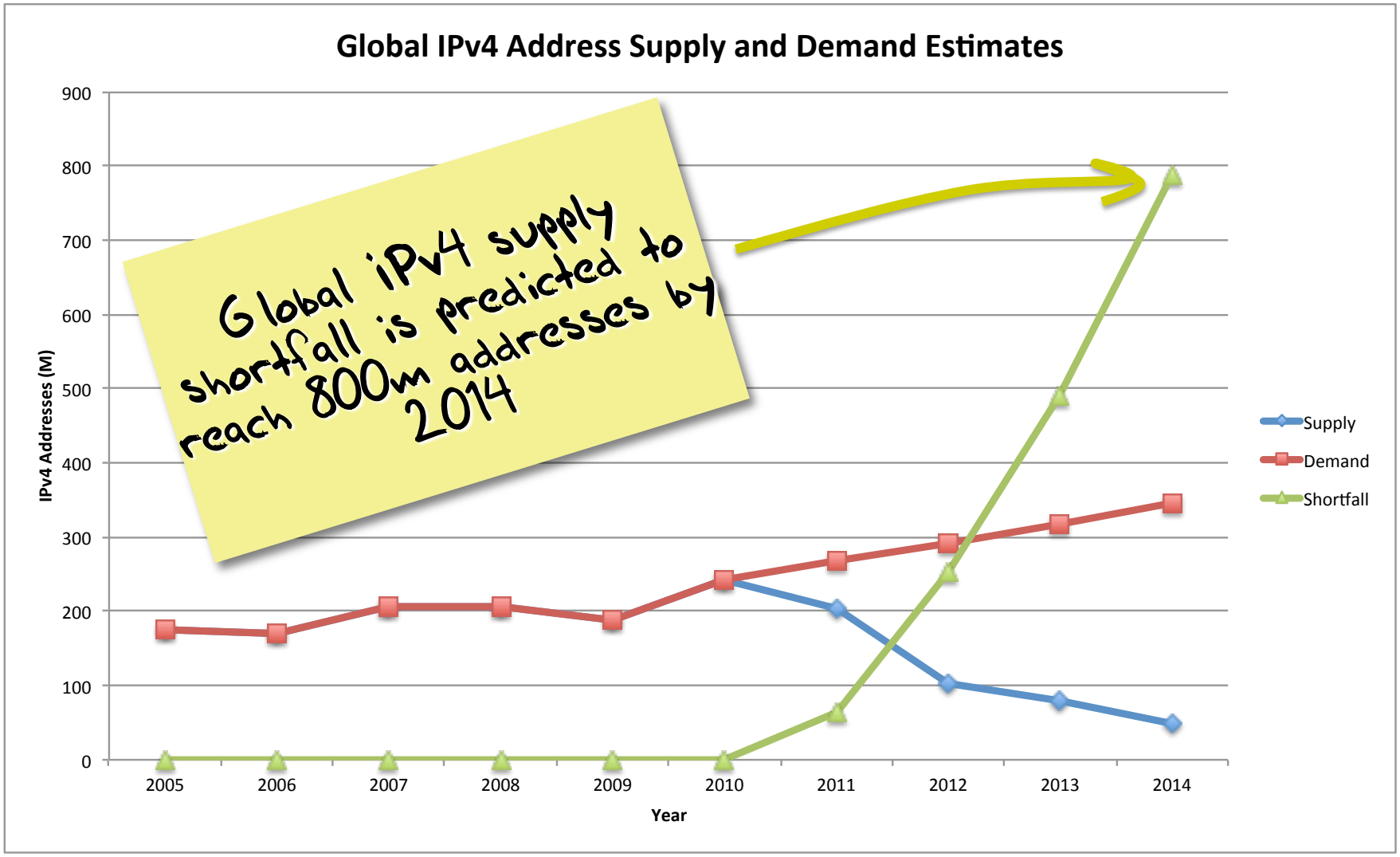
We now need to fuel an ever-expanding Internet:

- without any feed of more IPv4 addresses

and

- without sufficient IPv6 deployment to cut over

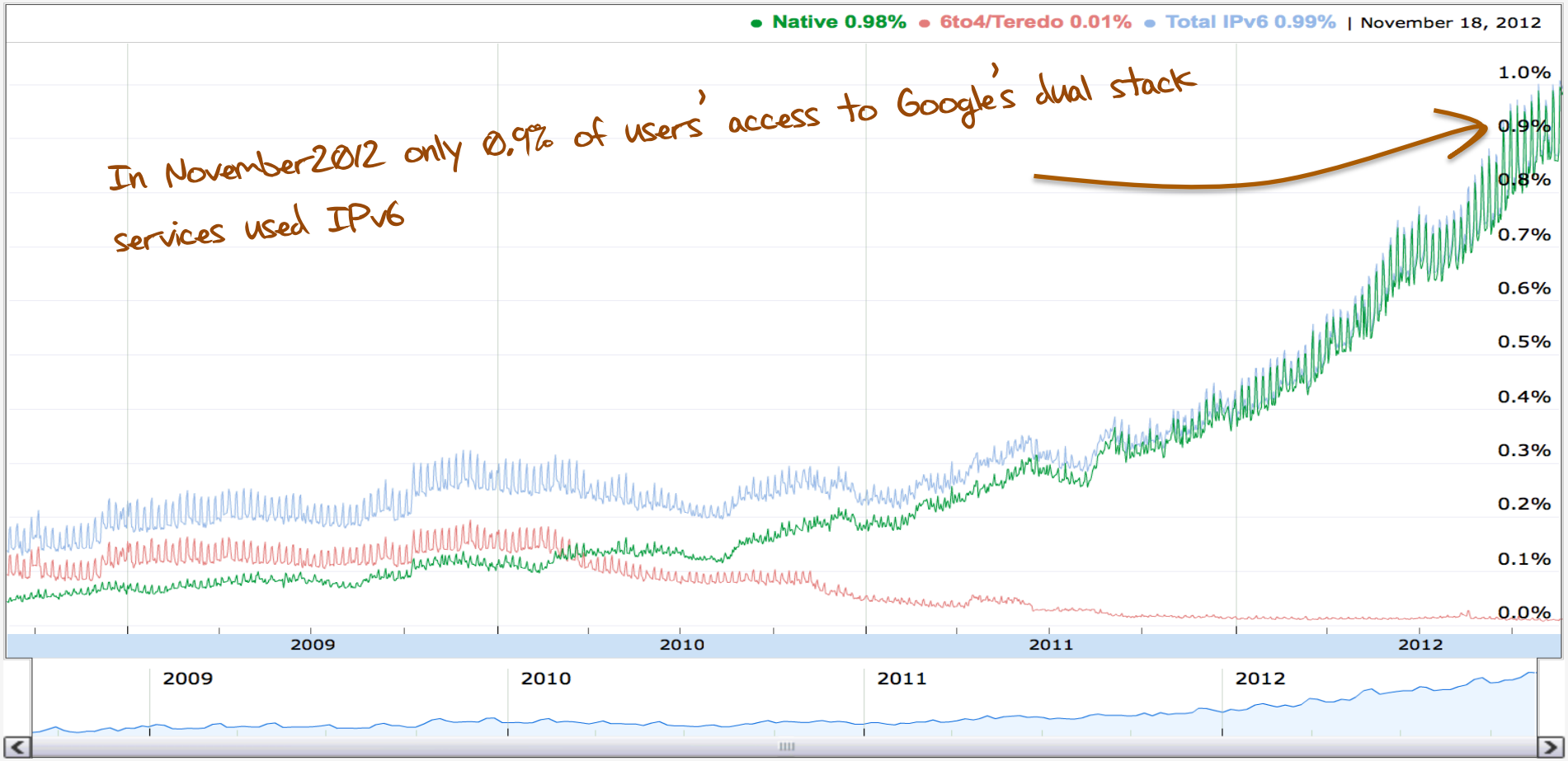
Coping with Demand



And it's not getting any easier...

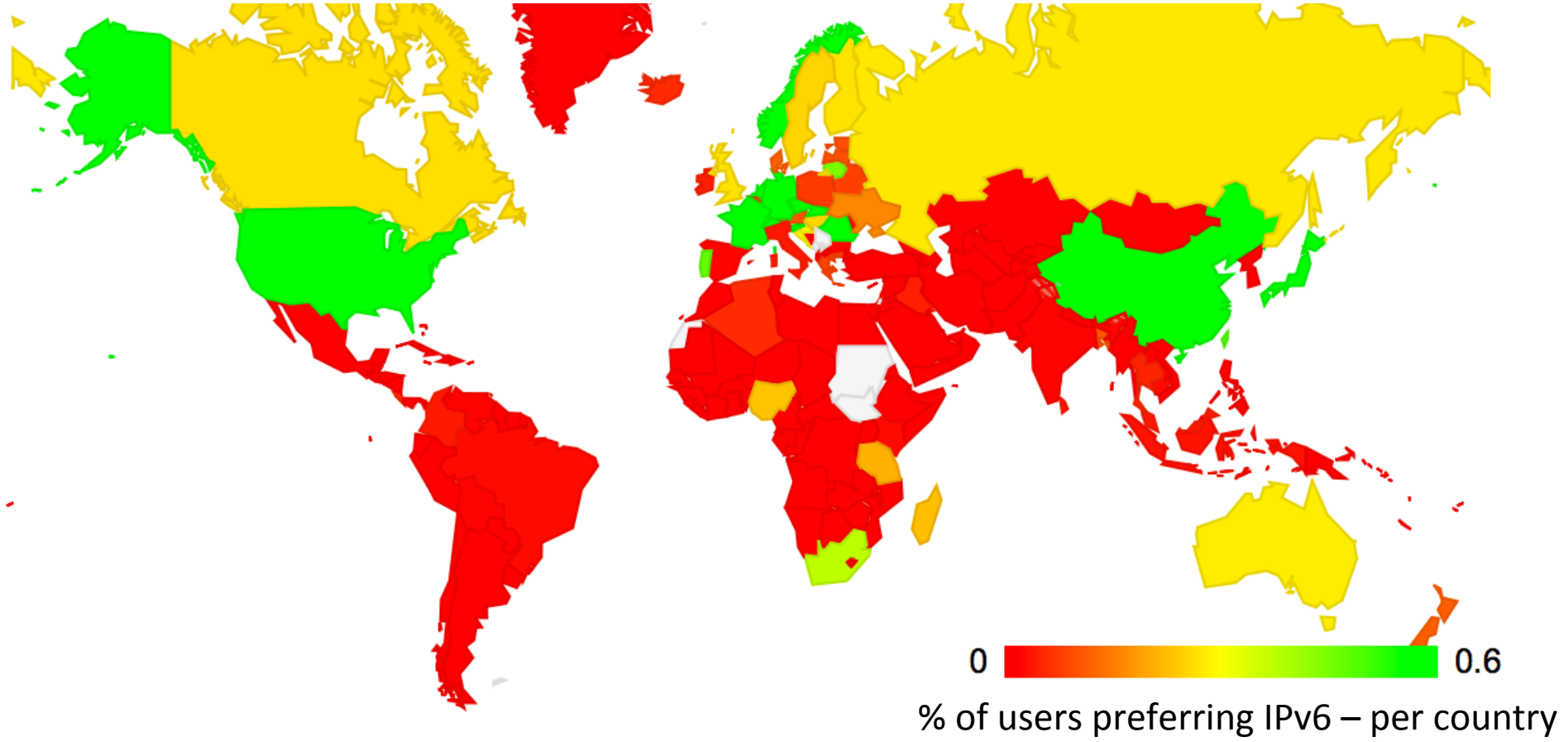
The metrics of IPv6 deployment could be a lot higher than they are today..

IPv6 capability, as seen by Google



http://www.google.com/intl/en/ipv6/statistics/

Where is it?



http://labs.apnic.net/index.shtml

Relatively, where is it?

APNIC

Contact us | Background | APNIC Research & Development | APNIC website

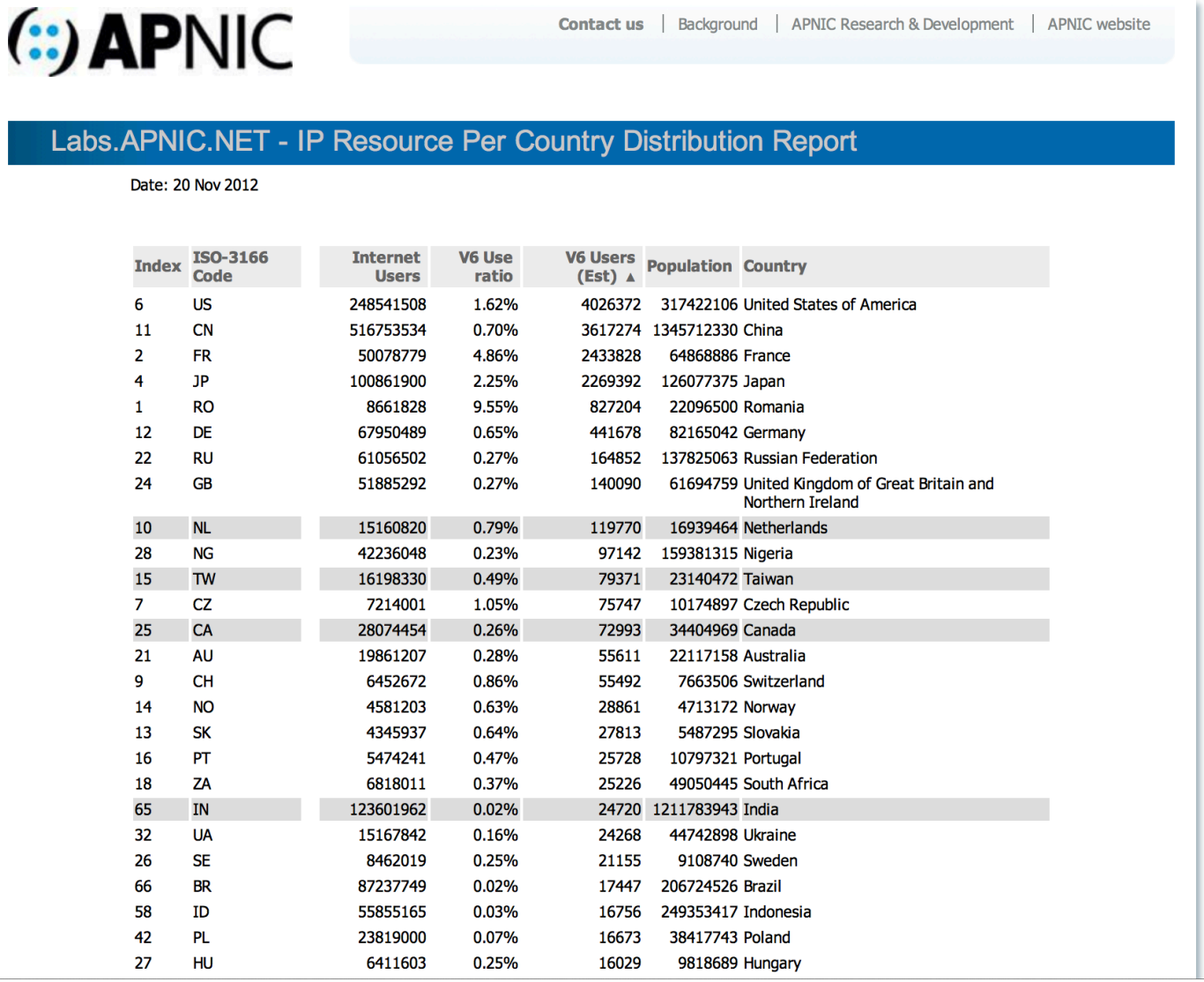
Labs.APNIC.NET - IP Resource Per Country Distribution Report

Date: 20 Nov 2012

Index	ISO-3166 Code	Internet Users	V6 Use ratio	V6 Users (Est)	Population	Country
1	RO	8661828	9.55%	827204	22096500	Romania
2	FR	50078779	4.86%	2433828	64868886	France
3	LU	467351	2.67%	12478	511326	Luxembourg
4	JP	100861900	2.25%	2269392	126077375	Japan
5	EU	0	1.95%	0	0	European Union
6	US	248541508	1.62%	4026372	317422106	United States of America
7	CZ	7214001	1.05%	75747	10174897	Czech Republic
8	SI	1417469	0.91%	12898	1996436	Slovenia
9	CH	6452672	0.86%	55492	7663506	Switzerland
10	NL	15160820	0.79%	119770	16939464	Netherlands
11	CN	516753534	0.70%	3617274	1345712330	China
12	DE	67950489	0.65%	441678	82165042	Germany
13	SK	4345937	0.64%	27813	5487295	Slovakia
14	NO	4581203	0.63%	28861	4713172	Norway
15	TW	16198330	0.49%	79371	23140472	Taiwan
16	PT	5474241	0.47%	25728	10797321	Portugal
17	LT	2095353	0.45%	9429	3521603	Lithuania
18	ZA	6818011	0.37%	25226	49050445	South Africa
19	BM	55146	0.30%	165	69279	Bermuda
20	HR	2652425	0.29%	7692	4480449	Croatia
21	AU	19861207	0.28%	55611	22117158	Australia
22	RU	61056502	0.27%	164852	137825063	Russian Federation
23	FI	4664889	0.27%	12595	5265112	Finland
24	GB	51885292	0.27%	140090	61694759	United Kingdom of Great Britain and Northern Ireland
25	CA	28074454	0.26%	72993	34404969	Canada
26	SE	8462019	0.25%	21155	9108740	Sweden

Internet Average

Absolutely, where is it?



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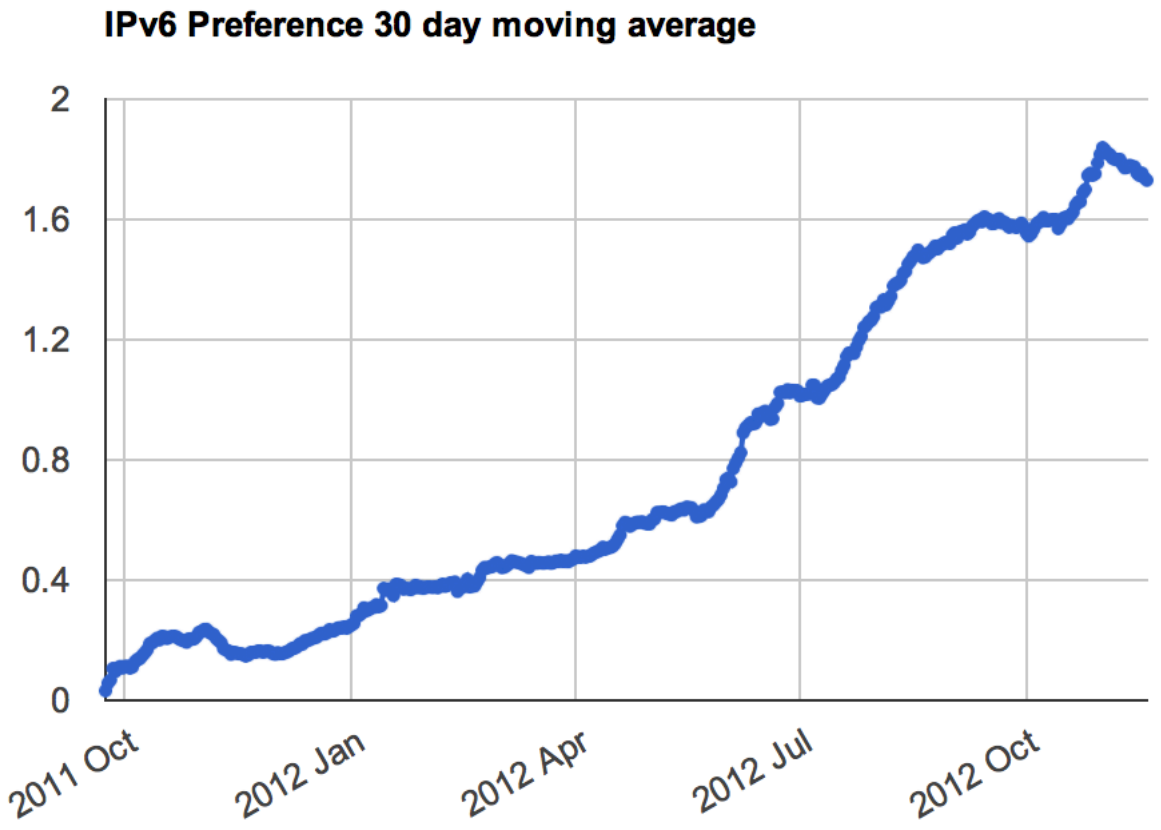
Labs.APNIC.NET - IP Resource Per Country Distribution Report

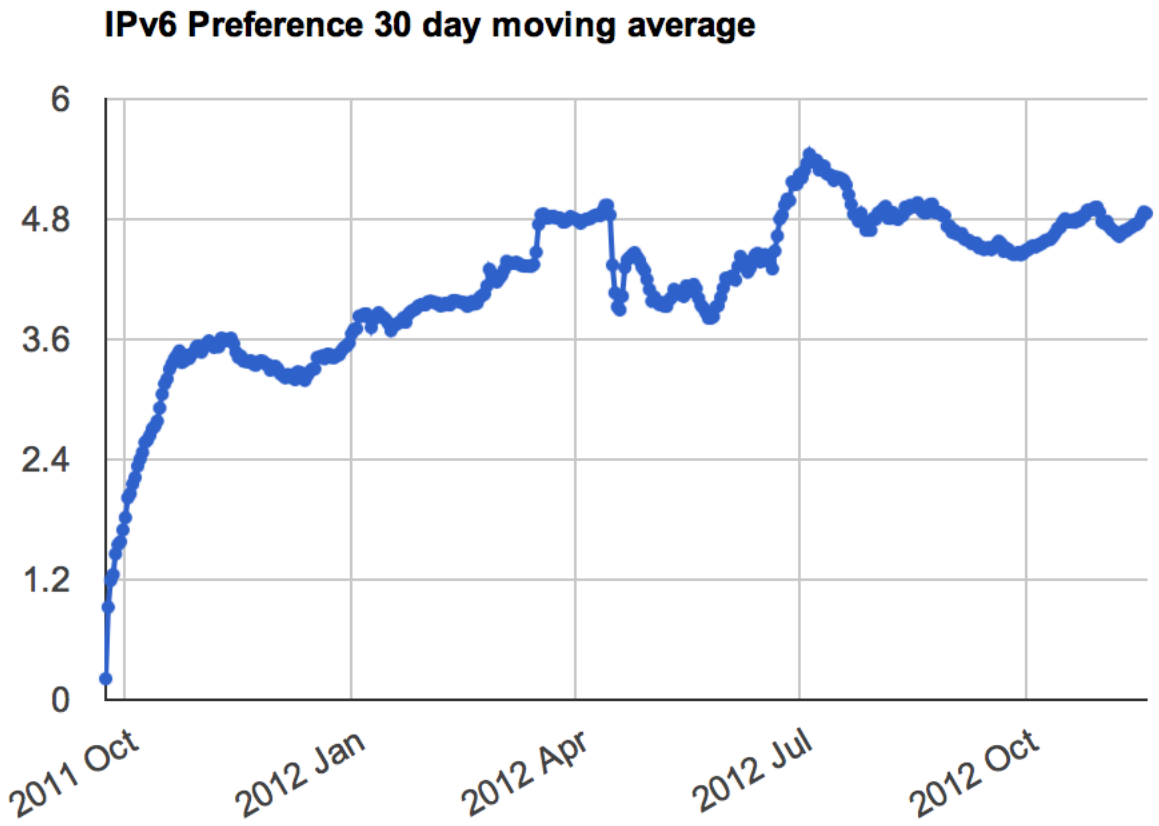
Date: 20 Nov 2012

Index	ISO-3166 Code	Internet Users	V6 Use ratio	V6 Users (Est) ▲	Population	Country
6	US	248541508	1.62%	4026372	317422106	United States of America
11	CN	516753534	0.70%	3617274	1345712330	China
2	FR	50078779	4.86%	2433828	64868886	France
4	JP	100861900	2.25%	2269392	126077375	Japan
1	RO	8661828	9.55%	827204	22096500	Romania
12	DE	67950489	0.65%	441678	82165042	Germany
22	RU	61056502	0.27%	164852	137825063	Russian Federation
24	GB	51885292	0.27%	140090	61694759	United Kingdom of Great Britain and Northern Ireland
10	NL	15160820	0.79%	119770	16939464	Netherlands
28	NG	42236048	0.23%	97142	159381315	Nigeria
15	TW	16198330	0.49%	79371	23140472	Taiwan
7	CZ	7214001	1.05%	75747	10174897	Czech Republic
25	CA	28074454	0.26%	72993	34404969	Canada
21	AU	19861207	0.28%	55611	22117158	Australia
9	CH	6452672	0.86%	55492	7663506	Switzerland
14	NO	4581203	0.63%	28861	4713172	Norway
13	SK	4345937	0.64%	27813	5487295	Slovakia
16	PT	5474241	0.47%	25728	10797321	Portugal
18	ZA	6818011	0.37%	25226	49050445	South Africa
65	IN	123601962	0.02%	24720	1211783943	India
32	UA	15167842	0.16%	24268	44742898	Ukraine
26	SE	8462019	0.25%	21155	9108740	Sweden
66	BR	87237749	0.02%	17447	206724526	Brazil
58	ID	55855165	0.03%	16756	249353417	Indonesia
42	PL	23819000	0.07%	16673	38417743	Poland
27	HU	6411603	0.25%	16029	9818689	Hungary

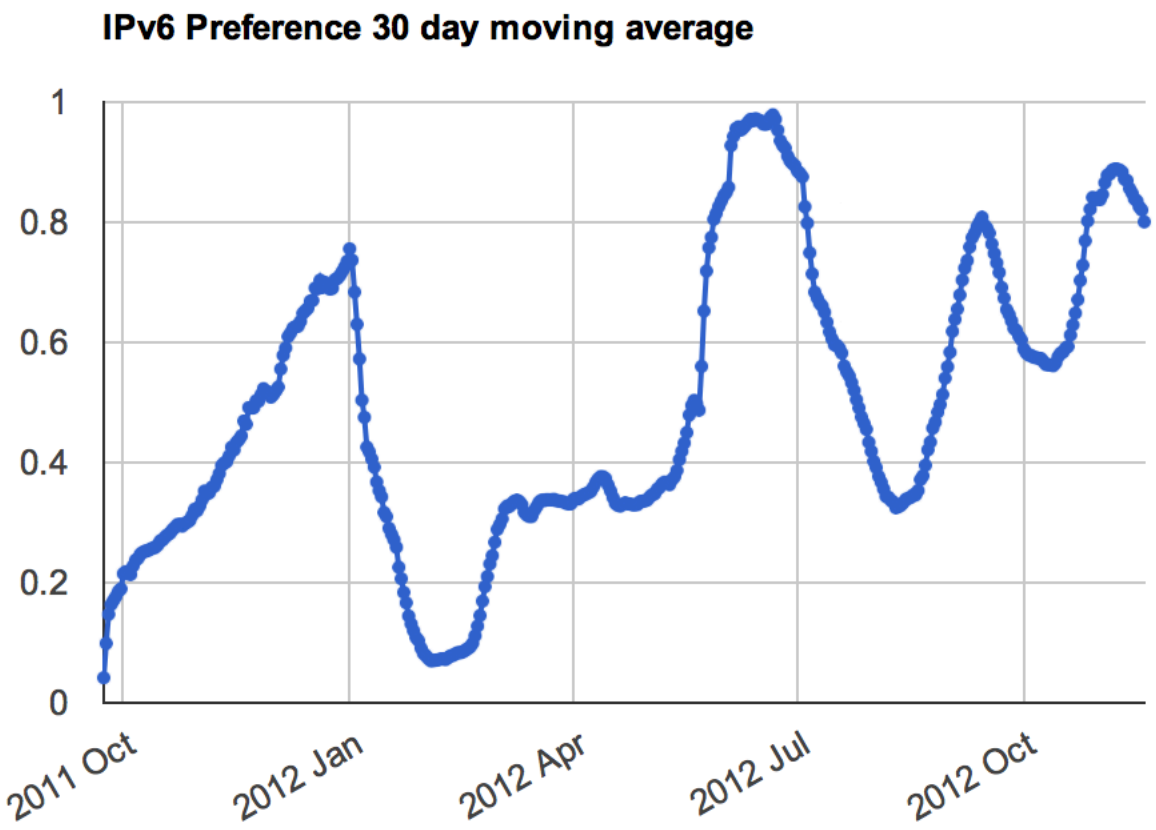
United States



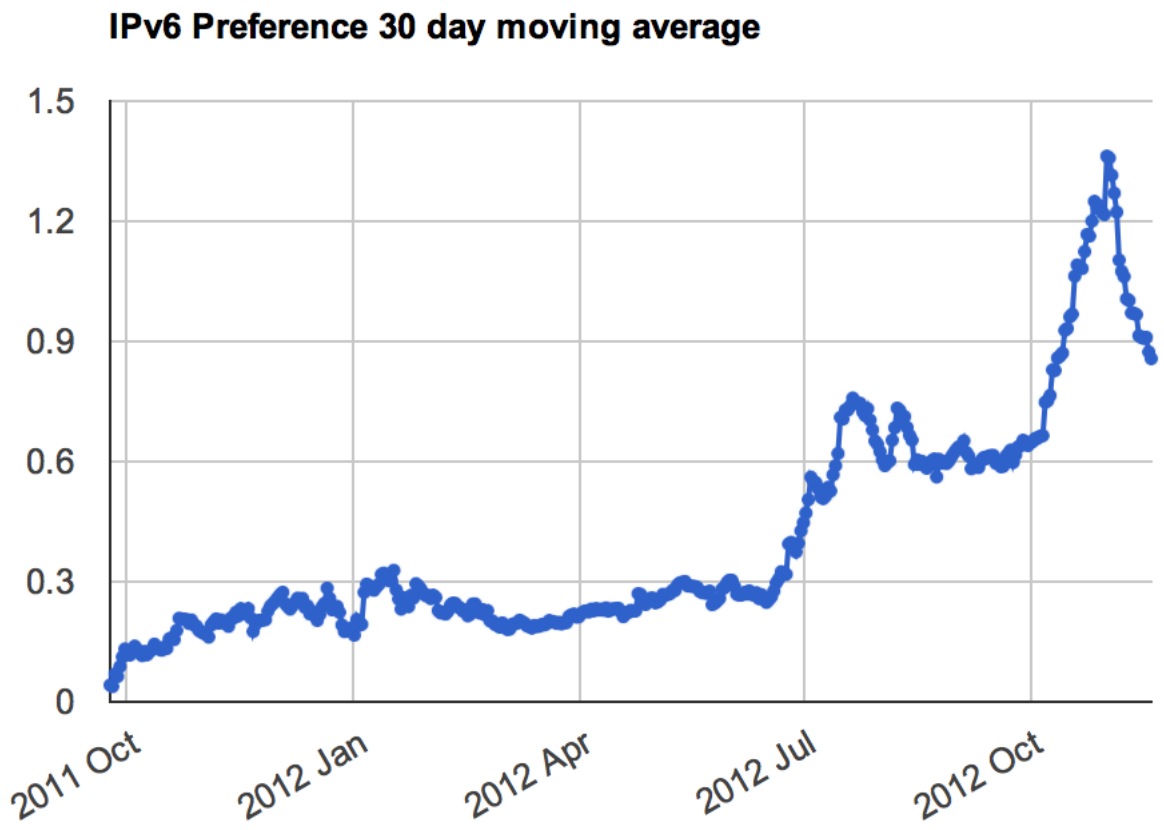
France


IPv6 Preference 30 day moving average
6
4.8
3.6
2.4
1.2
0
2011 Oct
2012 Jan
2012 Apr
2012 Jul
2012 Oct

China


IPv6 Preference 30 day moving average
1
0.8
0.6
0.4
0.2
0
2011 Oct
2012 Jan
2012 Apr
2012 Jul
2012 Oct

Netherlands



Counting IPv6...

Some 50% of the Internet's transit ISPs support IPv6 transit

Some 50% of the Internet's host devices have an active IPv6 stack

and the rest run Windows XP!

But only 1% of the Internet actually uses IPv6!

and the problem appears to lie in the last mile access infrastructure!

What's gone wrong?

It seems that we've managed to achieve only 2 out of 3 necessary prerequisites for IPv6 deployment

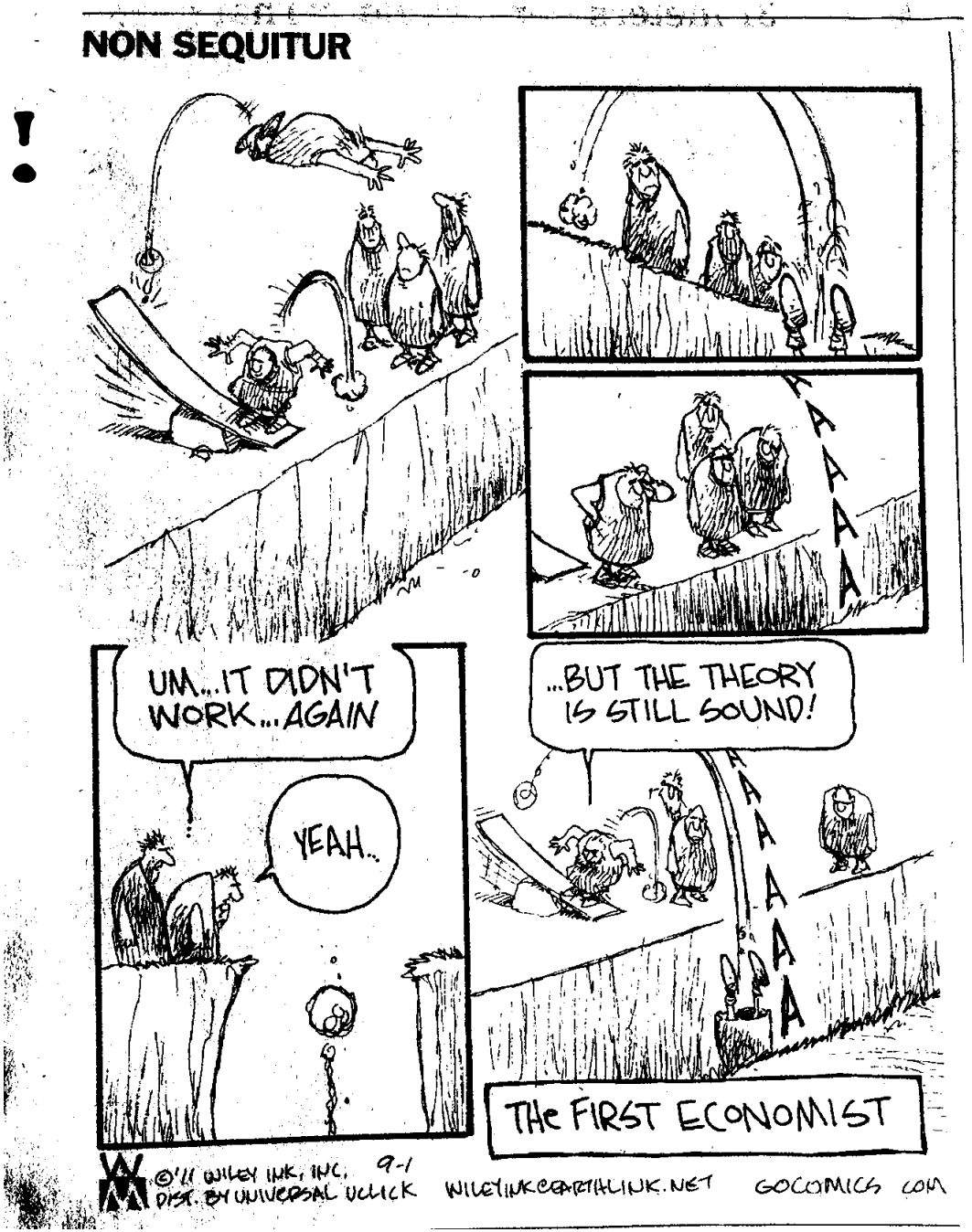
To support further growth the access industry has to secure more IPv4 addresses, deploy (and fund) IPv4 address extension mechanisms, in addition to funding an IPv6 deployment program

What's gone wrong?

It seems that we've managed to achieve only 2 out of 3 necessary prerequisites for IPv6 deployment

Why didn't we do this a few years ago when it would've been far easier to undertake this transition?

Economics!


NON SEQUITUR
AAAAA
UM...IT DIDN'T WORK...AGAIN
YEAH..
...BUT THE THEORY IS STILL SOUND!
AAAAA
THE FIRST ECONOMIST
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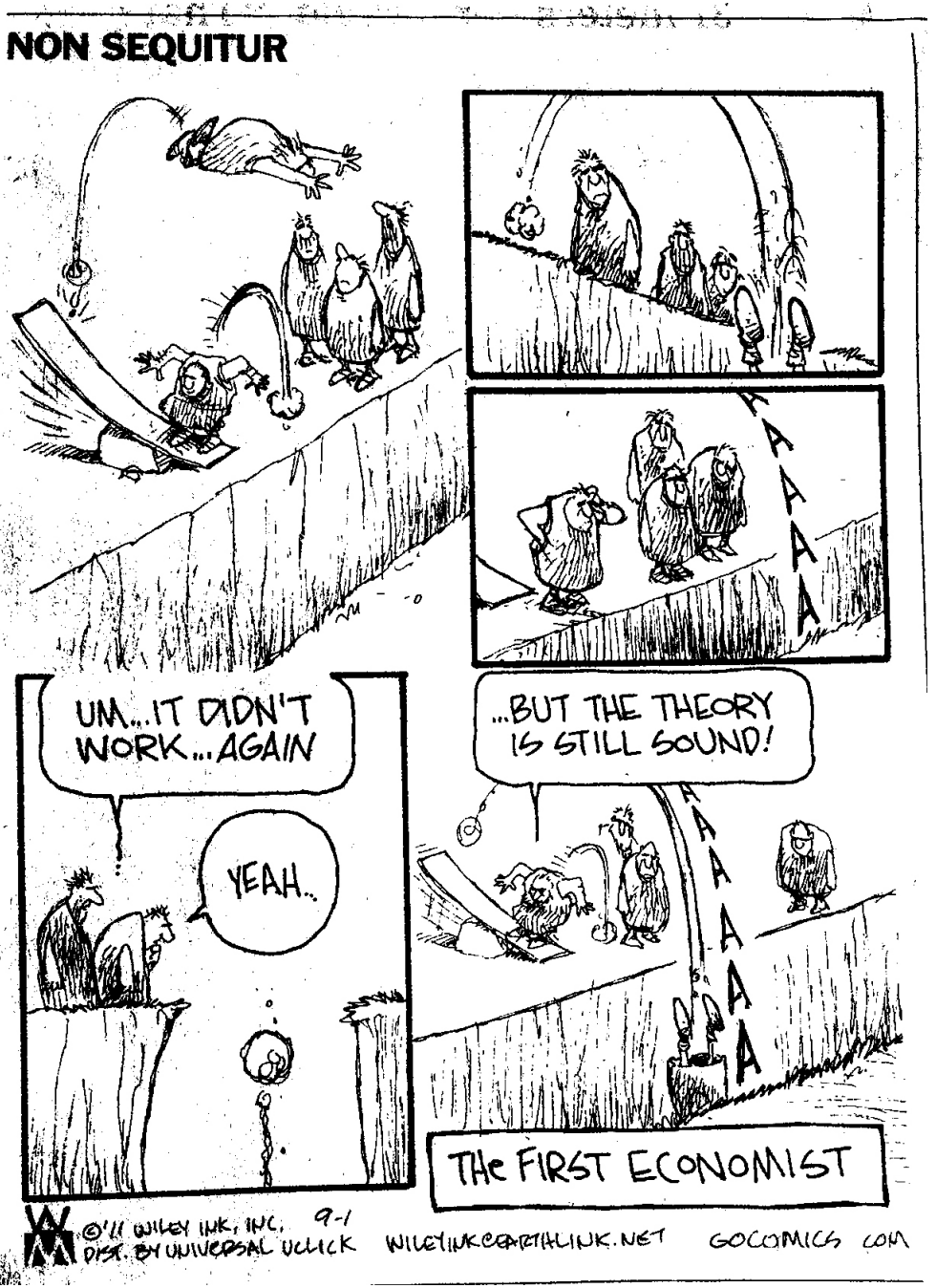
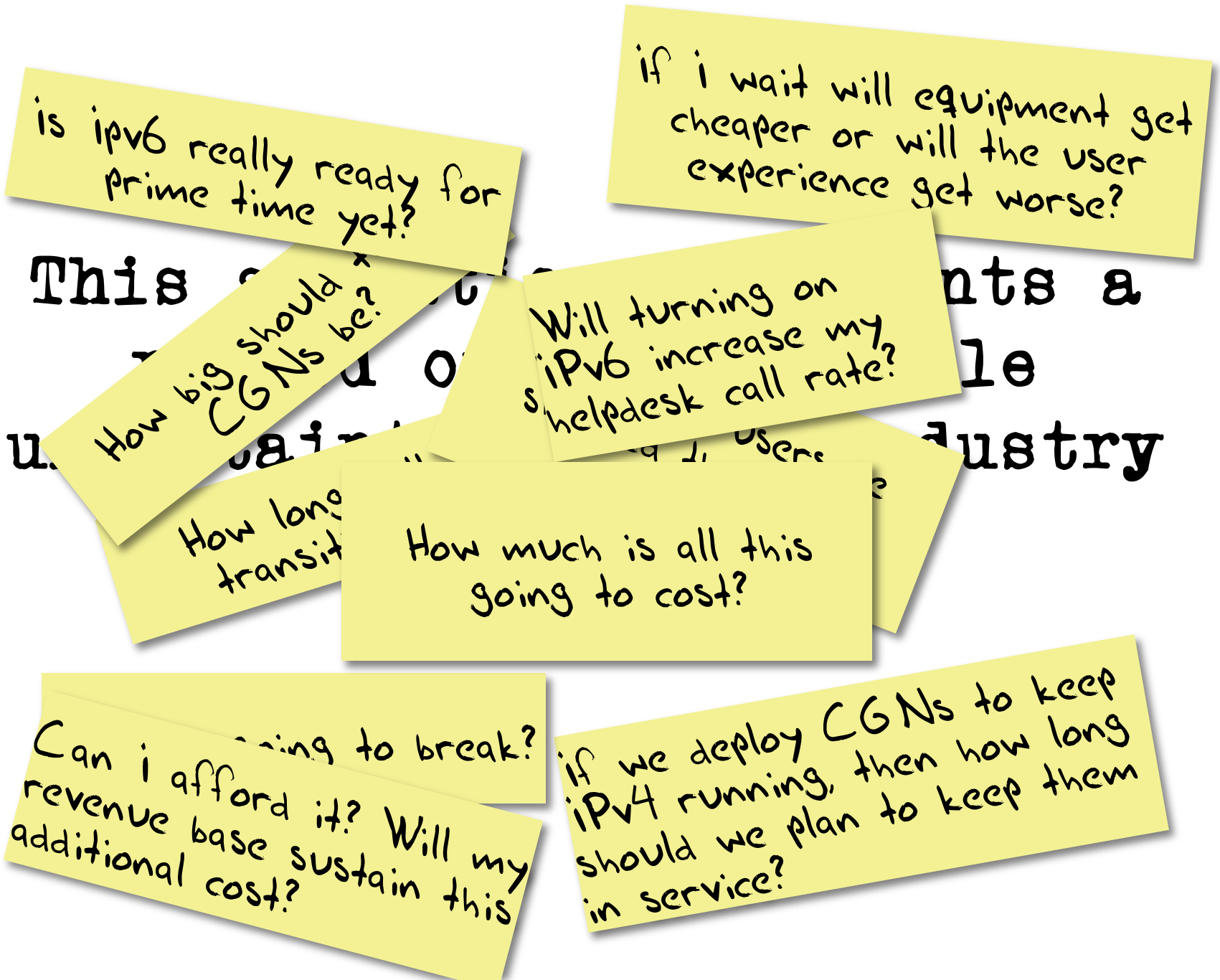
WILEYINK@EARTHLINK.NET
GOCOMICS.COM

Economics!

The Internet's last mile access is mired in commodity utility economics. Relentless competition has resulted in a sector where margins are thin. A move to IPv6 represents expenditure without immediate revenue gain. This is classic case of economic dislocation in an unbundled industry, where expenditure in one sector: -carriage- yields benefits in another sector: -content-



This situation represents a period of considerable uncertainty for our industry


is ipv6 really ready for prime time yet?
if i wait will equipment get cheaper or will the user experience get worse?
How big should CGNs be?
Will turning on IPv6 increase my helpdesk call rate?
How much is all this going to cost?
Can i afford it? Will my revenue base sustain this additional cost?
if we deploy CGNs to keep IPv4 running, then how long should we plan to keep them in service?

Where is this heading?

In the next five years...

In the next five years...

So we need to chose carefully!

We need to think about how to build a post-PC world where content, computation, storage and communications are sustainable abundant and openly available commodities.

And its not yet clear which path the internet will take!

And its not yet clear which path ~~the internet~~ will take!

market forces

If IPv6 is what we are after as an open and accessible platform for further network growth and innovation then the public interest in a continuing open and accessible network needs to be expressed within the dynamics of market pressures.

Today's question is:

How can we do this?

How can we "manage" this transition?

To ensure that the industry maintains a collective focus on IPv6 as the objective of this exercise!

How can we "manage" this transition?

To ensure that the industry maintains a collective focus on IPv6 as the objective of this exercise!

And to ensure that we do not get distracted by attempting to optimize what were intended to be temporary measures

How can we help the Internet through this transition?

Or at least, how can we avoid making it any worse than it is now?

Yes, that was intentionally left blank!

I really don't know what will work.

And as far as I can see, nor does anyone else!

But even though I don't have an answer here, I have some thoughts to offer about this issue of pulling the Internet though this transition

Three thoughts...

Firstly

If we want one working Internet at the end of all this, then keep an eye on the larger picture

Think about what is our common interest here

and try to find ways for local interests to converge

with our common interest in a single cohesive network

that remains open, neutral, and accessible

Secondly

Addresses should be used in working networks, not hoarded

- Scarcity generates pain and uncertainty
- Hoarding exacerbates scarcity in both its intensity and duration
- Extended scarcity prolongs the pain and increases the unpredictability of the entire transition process
- Closed or opaque address markets create asymmetric information that encourages speculation and hoarding, further exacerbating the problem

Finally...

Bring it on! A rapid onset of exhaustion and a rapid transition represents the best chance of achieving an IPv6 network as an outcome

The more time we spend investing time, money and effort in deploying IPv4 address extension mechanisms, the greater the pain to our customers, and the higher the risk that we will lose track of the intended temporary nature of transition and the greater the chances that we will forget about IPv6 as the objective!

The risk here is no less than the future of open networking and open content – if we get this wrong we will recreate the old stifling vertically bundled carriage monopolies of the telephone era!

And at that point we've lost everything!

Thank You!