

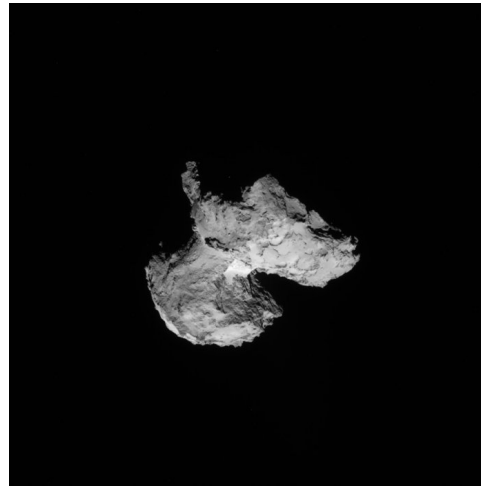
That 512K Route Thing

Geoff Huston
APNIC

12 August 2014



World Elephant Day



Rosetta closes in on
comet 67P/
Churyumov-
Gerasimenko



Newborn Panda Triplets in China

The internet apparently has a bad hair day

The Telegraph

HOME > TECHNOLOGY > INTERNET

Is the Internet full? Major sites brought problems

Likely repeat of this week's technical problems affecting eBay, millions as the Internet runs out of space, experts fear

The Switch

Here's why your Internet might have been slow on Tuesday



By Andrea Peterson August 13 Follow @kansalsps

Some users were frustrated to find some of their favorite Web sites were unresponsive or otherwise inaccessible Tuesday. But it wasn't a data center outage or a squirrel chewing through a cable line causing the disruption. Instead, structural problems with one of the core technologies that keeps the Internet working were to blame, researchers say.

THE WALL STREET JOURNAL. | TECH

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Echoes of Y2K: Engineers Buzz That Internet Is Outgrowing Its Gear

Routers That Send Data Online Could Become Overloaded as Number of Internet Routes Hits '512K'

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A A

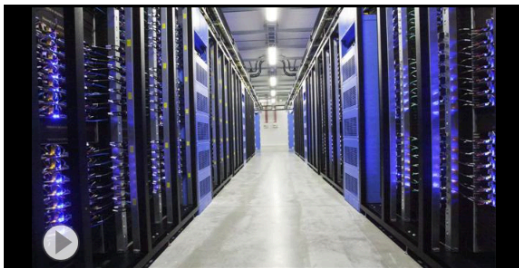
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By DREW FITZGERALD CONNECT

Updated Aug. 13, 2014 7:38 p.m. ET



Network engineers are buzzing that the internet is outgrowing some of its gear. WSJ's Drew Fitzgerald discusses what that means on Lunch Break with Sara Murray. Photo: Getty

Network engineers are buzzing this week as the Internet outgrows some of its gear.

MarketWatch
MARKETS NEWS

10:26 pm / Nov 6, 2013

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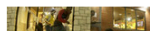
What's This?

ARTICLES

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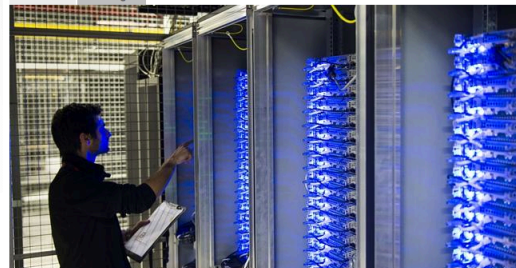
LATEST IN ONLINE

These people will help you change your life

The internet broke yesterday and it was all because of the number 512

This story was published: 4 DAYS AGO | AUGUST 14, 2014 2:15PM

Video Image



NOCTION NETWORK INTELLIGENCE

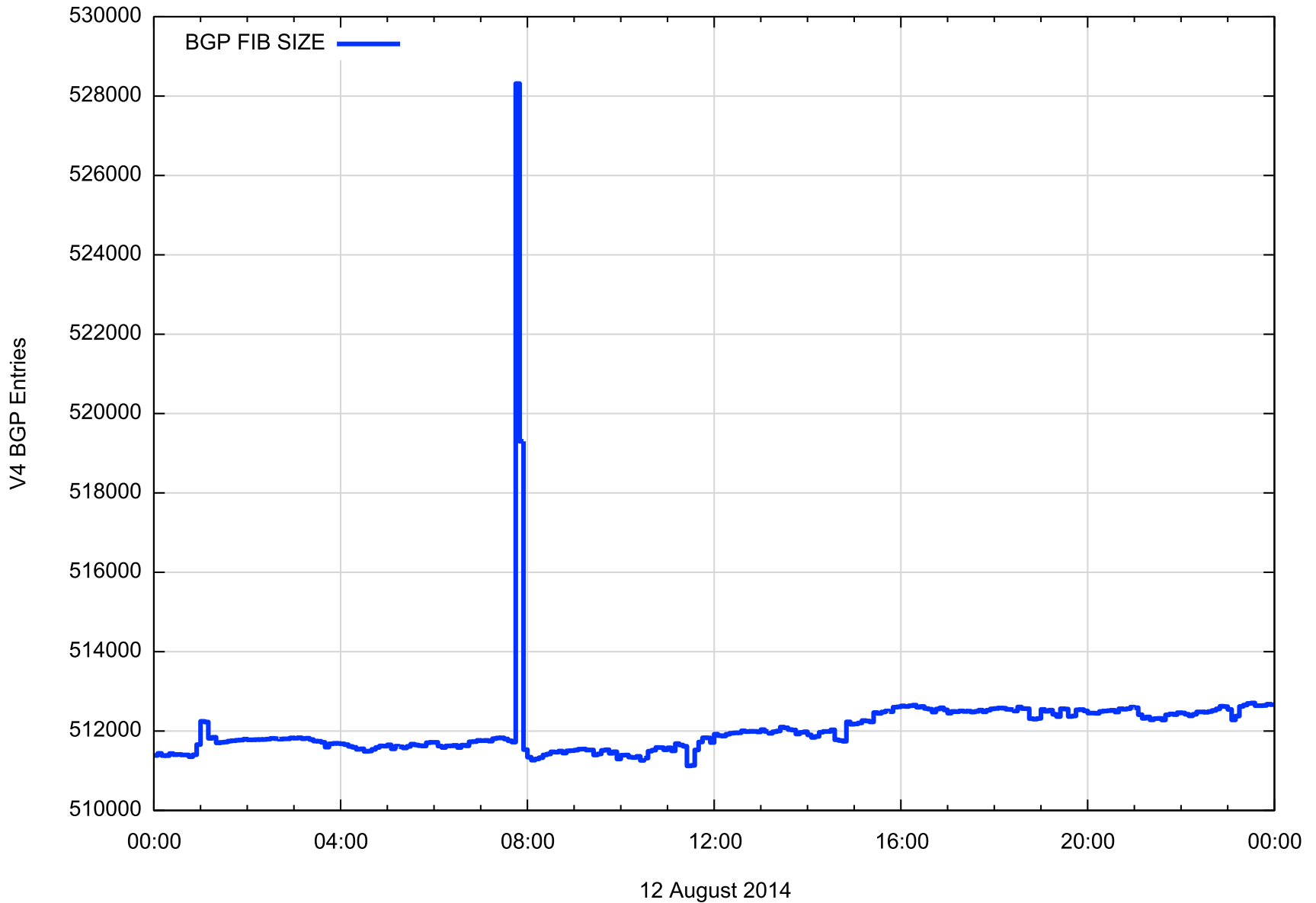
NEW INTELLIGENT ROUTING PLATFORM Version 2.5 Free Trial

STORY BY

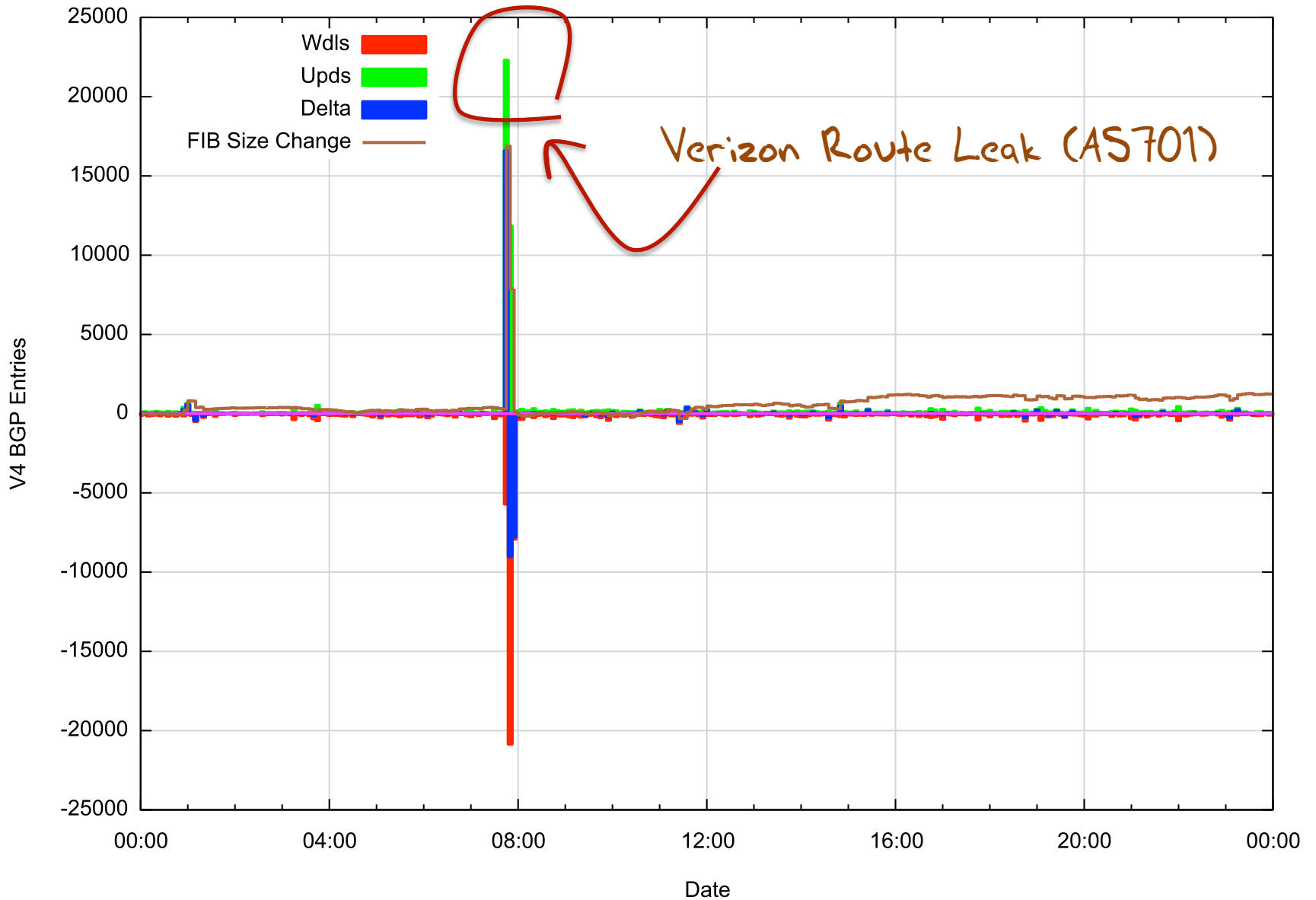
Network Writer
News Corp Australia

What happened?

Someone sneezed all over BGP!



Who was that?



But route leaks happen all
the time

Why was this one so different from the rest?

But route leaks happen all the time

Firstly, its because the leaker was AS 701

- AS701 is a tier 1 ISP
- So very few networks (noone?) filters what they hear from AS701
- Which means that when AS701 leaks all non-default AS's (and a few more besides) are likely to see the route leak

So **everybody** saw this route leak!

But route leaks happen all the time

- Secondly because it caused the routing table to exceed 512K entries for many networks
 - It leaked 27,000 more specifics
 - And most non-default BGP speakers were carrying between 490,000 and 510,000 entries in this table
 - So many BGP environments exceeded 512K IPv4 entries for the first time
 - And for some routers 512K is a magic number!

Cisco Catalyst 6500 Series Switches

Catalyst 6500 Switches Ternary Content Addressable Memory Customization

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Catalyst 6500 Switches Ternary Content Addressable Memory Customization

Contents

- Introduction
- Requirements
- Components Used
- Problem
- Solution
- Related Information
- Related Cisco Support Community Discussions

Introduction

This document describes how to customize the forwarding information base (FIB) ternary content addressable memory (TCAM) on Catalyst 6500 switches that run the Supervisor Engine 720.

Prerequisites

Requirements

There are no specific requirements for this document.

Components Used

The information in this document is based on a Cisco Catalyst 6500 switch that runs on a Supervisor Engine 720 with PFC3BXL/PFC3CXL.

The information in this document was created from the devices in a specific lab environment. All of the devices used in this document started with a cleared (default) configuration. If your network is live, make sure that you understand the potential impact of any command.

Problem

As outlined in the datasheet, PFC3BXL and PFC3CXL support one million (1M) IPv4 routes and 512,000 (512k) IPv6 routes. However, default outputs look different:

```

6500#show mls of maximum-routes
FIB TCAM maximum routes :
*****
Current :
*****
IPv4 + MPLS      - 512k (default)
IPv6 + IP Multicast - 256k (default)
    
```

Solution

The default numbers for PFC3BXL/PFC3CXL are 512k IPv4 routes and 256k IPv6 routes. These numbers can be increased to 1M IPv4 OR 512k IPv6 routes if you enter `mls of maximum-routes ip|ipv6 []` and reload. But, you cannot achieve both 1M IPv4 AND 512k IPv6 routes at the same time. If you increase the IPv4 TCAM size above the default value, it automatically takes up the IPv6 space and vice versa.

512K is a default constant in some of the more mature Cisco and Brocade products

Brocade NetIron XMR

http://www.brocade.com/downloads/documents/html_product_manuals/NI_05600_ADMIN/wwhelp/wwhimpl/common/html/wwhelp.htm#context=Admin_Guide&file=CAM_part.11.2.html



Multi-Service Ironware Administration Guide
R05.6.00
Part Number: 53-1003028-02
documentation@brocade.com

Foundry Direct Routing and CAM Partition Profiles for the NetIron XMR and the Brocade MLX Series - CAM partition profiles

CAM partition profiles

CAM is partitioned on the device by a variety of profiles that you can select depending on your application. The available profiles are described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series. To implement a CAM partition profile, enter the following command.

Syntax: cam-partition profile [ipv4 | ipv4-ipv6 | ipv4-ipv6-2 | ipv4-vpls | ipv4-vpn | ipv6 | l2-metro | l2-metro-2 | mpls-3vpn | mpls-3vpn-2 | mpls-vpls | mpls-vpls-2 | mpls-vpn-vpls | multi-service | multi-service-2 | multi-service-3 | multi-service-4]

- The **ipv4** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for IPv4 applications.
- The **ipv4-ipv6** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for IPv4 and IPv6 dual stack applications.
- The **ipv4-ipv6-2** parameter that was introduced in version 03.7.00, adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for increased IPv4 routes with room for IPv6.
- The **ipv4-vpls** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for IPv4 and MPLS VPLS applications.
- The **ipv4-vpn** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for IPv4 and MPLS Layer-3 VPN applications.
- The **ipv6** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for IPv6 applications.
- The **l2-metro** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series, to optimize the device for Layer 2 Metro applications.
- The **l2-metro-2** parameter provides another alternative to **l2-metro** to optimize the device for Layer 2 Metro applications. It adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers.
- The **mpls-3vpn** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers, to optimize the device for Layer 3, BGP or MPLS VPN applications.
- The **mpls-3vpn-2** parameter provides another alternative to **mpls-3vpn** to optimize the device for Layer 3, BGP or MPLS VPN applications. It adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers.
- The **mpls-vpls** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers, to optimize the device for MPLS VPLS applications.
- The **mpls-vpls-2** parameter provides another alternative to **mpls-vpls** to optimize the device for MPLS VPLS applications. It adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers.
- The **mpls-vpn-vpls** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers, to optimize the device for MPLS Layer-3 and Layer-2 VPN applications.
- The **multi-service** parameter adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers, to optimize the device for Multi-Service applications.
- The **multi-service-2** parameter provides another alternative to **multi-service** to optimize the device for Multi-Service applications. It adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers.
- NOTE:** You must reload your device for this command to take effect.
- The **multi-service-3** parameter provides another alternative to **multi-service** to optimize the device for Multi-Service applications to support IPv6 VRF. It adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers.
- The **multi-service-4** parameter provides another alternative to **multi-service** to optimize the device for Multi-Service applications to support IPv6 VRF. It adjusts the CAM partitions, as described in Table 47 for Brocade NetIron XMR and Table 48 for Brocade MLX series routers.
- There are fourteen CAM partitioning profiles for Brocade NetIron XMR and Table 48 for Brocade MLX series routers. The profiles for Brocade XMR routers are described in Table 47 and the profiles for Brocade MLX routers are described in Table 48.

TABLE 47 CAM partitioning profiles available for Brocade NetIron XMR routers

Profile	IPv4	IPv6	MAC or VPLS MAC	IPv4 or VPN	IPv6 Inbound ACL	IPv6 Outbound ACL	IPv4 or L2 Inbound ACL	IPv6 Outbound ACL
---------	------	------	-----------------	-------------	------------------	-------------------	------------------------	-------------------

TABLE 47 CAM partitioning profiles available for Brocade NetIron XMR routers

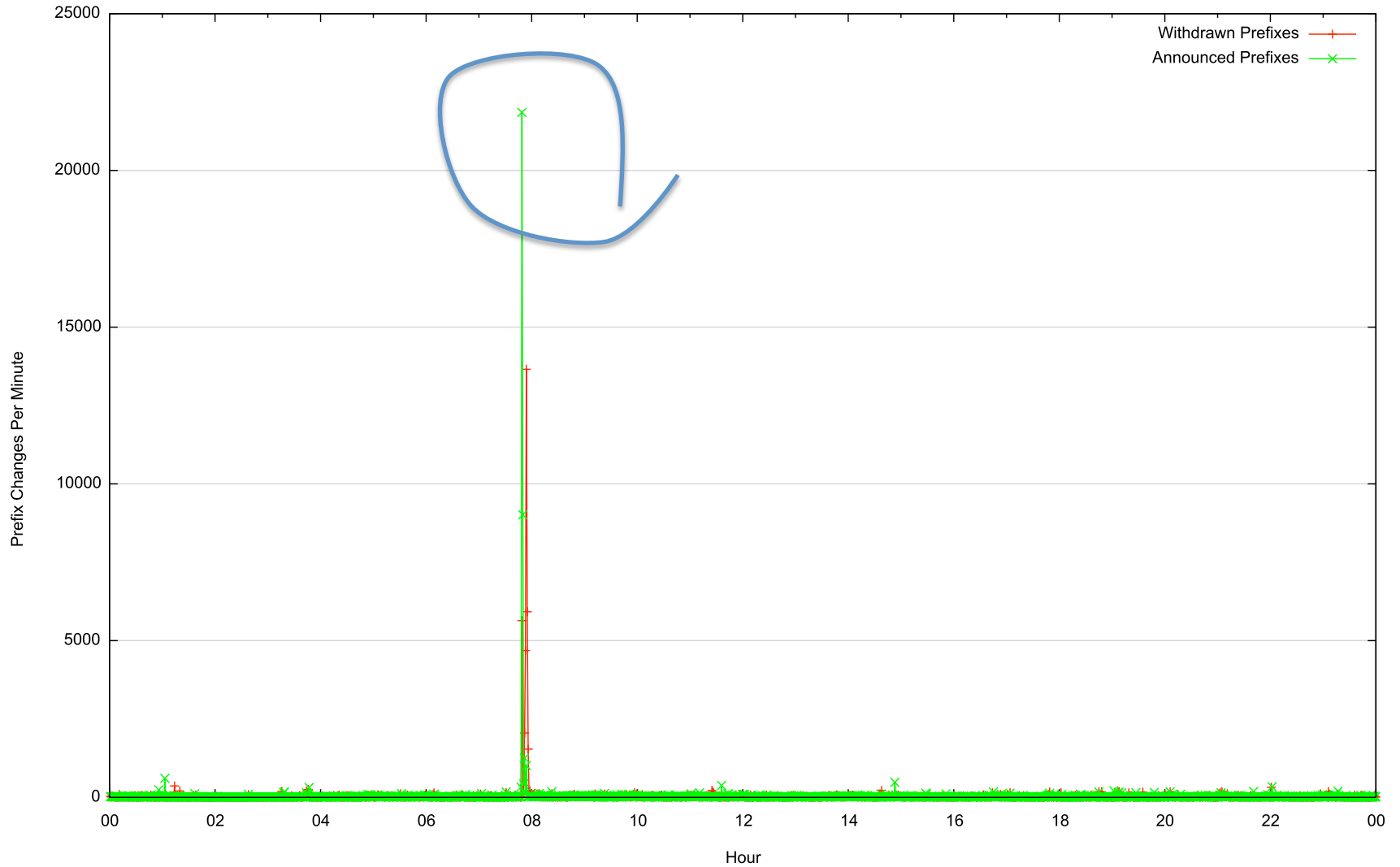
Profile	IPv4	IPv6	MAC or VPLS MAC	IPv4 VPN	IPv6 VPN	IPv4 or L2 Inbound ACL	IPv6 Inbound ACL	IPv4 or L2 Outbound ACL	IPv6 Outbound ACL
Default Profile	Logical size: 512K	Logical size: 64K	Logical size: 128K	Logical size: 128K	0	Logical size: 48K	Logical size: 4K	Logical size: 48K	Logical size: 4K
ipv4 Profile	Logical size: 1M	0	Logical size: 32K	0	0	Logical size: 112K	0	Logical size: 64K	0

Cisco Cat 6500

The default numbers for PFC3BXL/PFC3CXL are 512k IPv4 routes and 256k IPv6 routes. These numbers can be increased to 1M IPv4 OR 512k IPv6 routes if you enter `mls of maximum-routes ip|ipv6 []` and reload. But, you cannot achieve both 1M IPv4 AND 512k IPv6 routes at the same time. If you increase the IPv4 TCAM size above the default value, it automatically takes up the IPv6 space and vice versa.

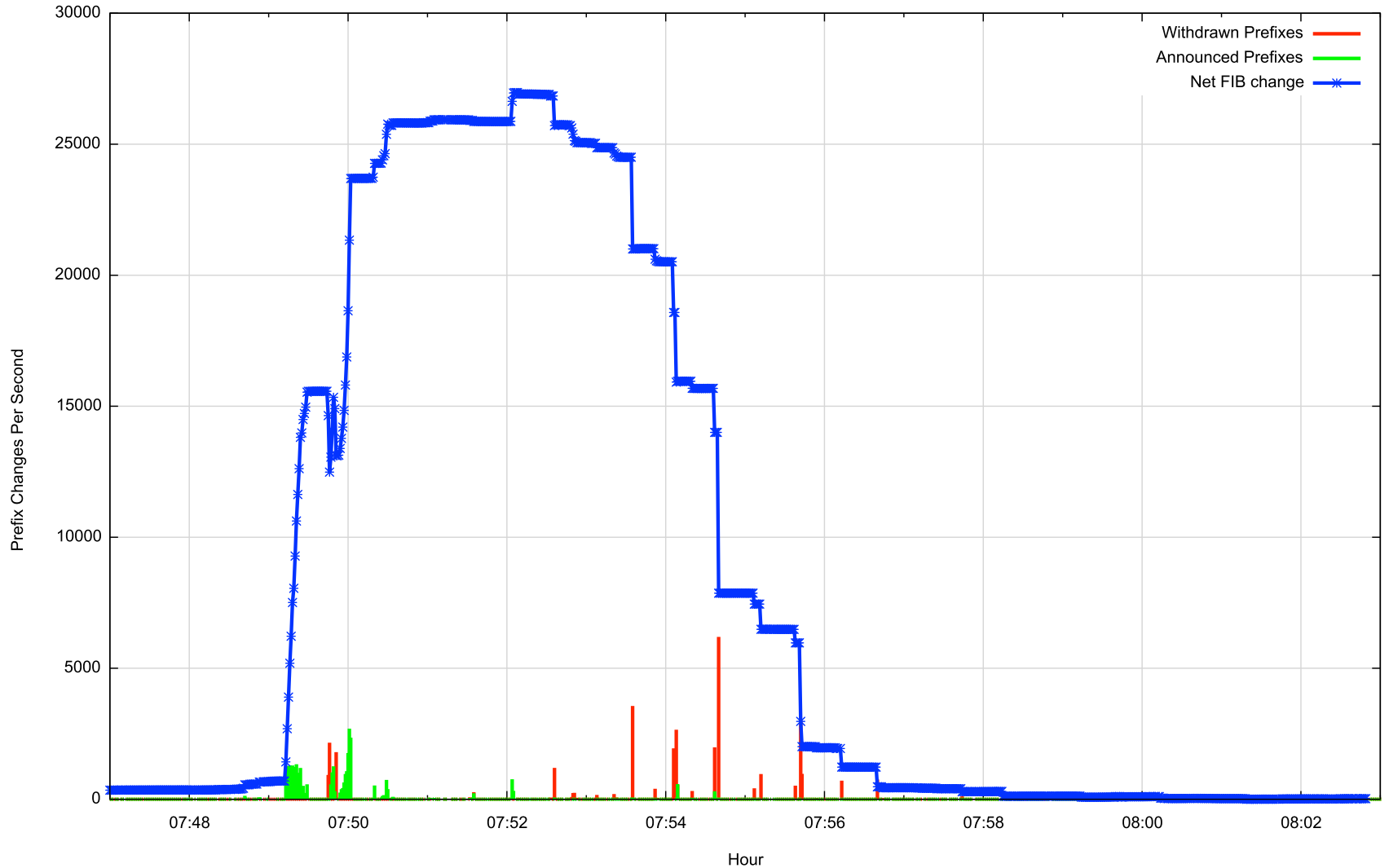
Minute by Minute ANNces & WDLs

BGP Update Profile for 12 August 2014



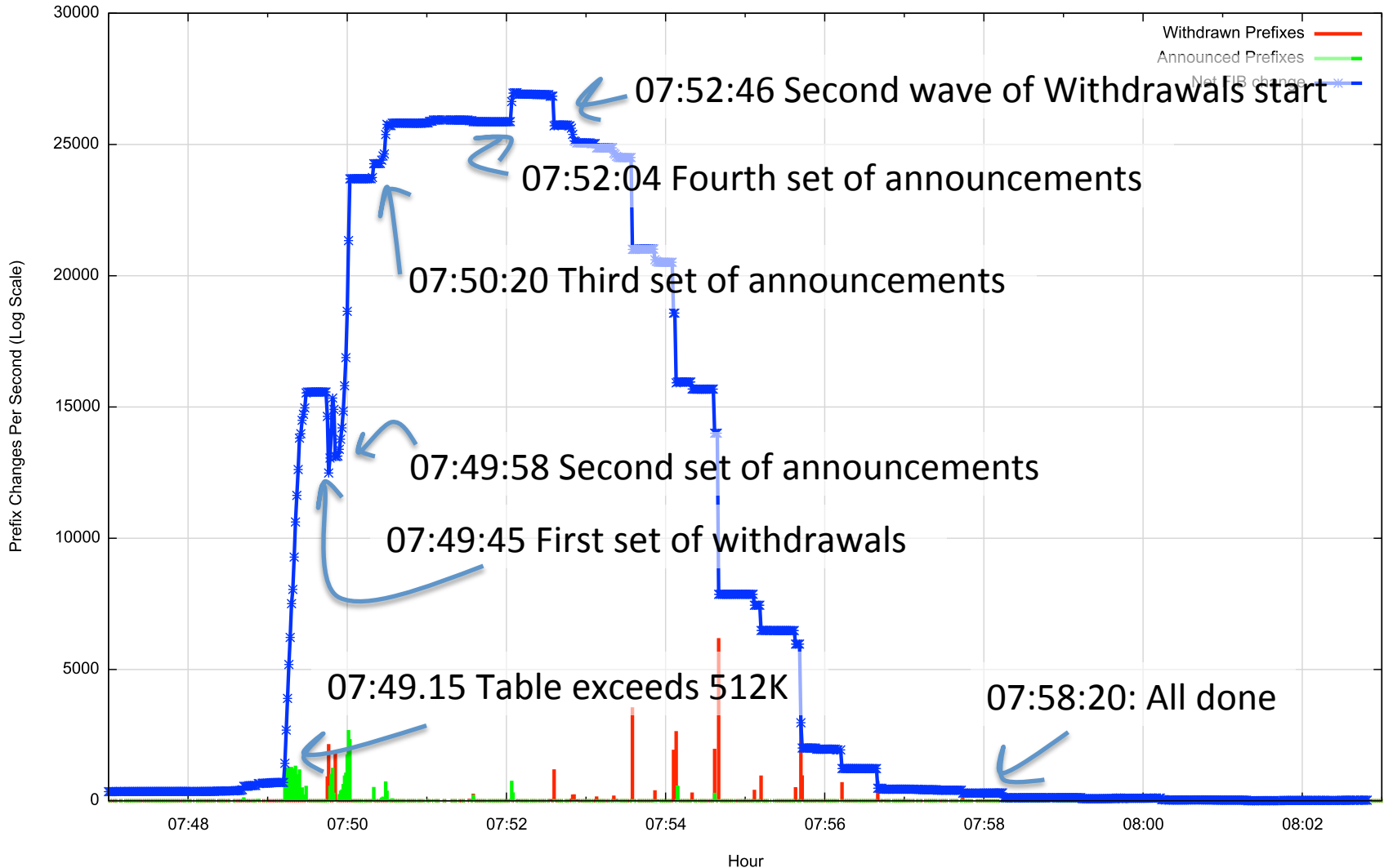
Second by Second

BGP Update Profile for 12 August 2014 (07:47-08:03 UTC)



Second by Second

BGP Update Profile for 12 August 2014 (07:47-08:03 UTC)



What happens then?

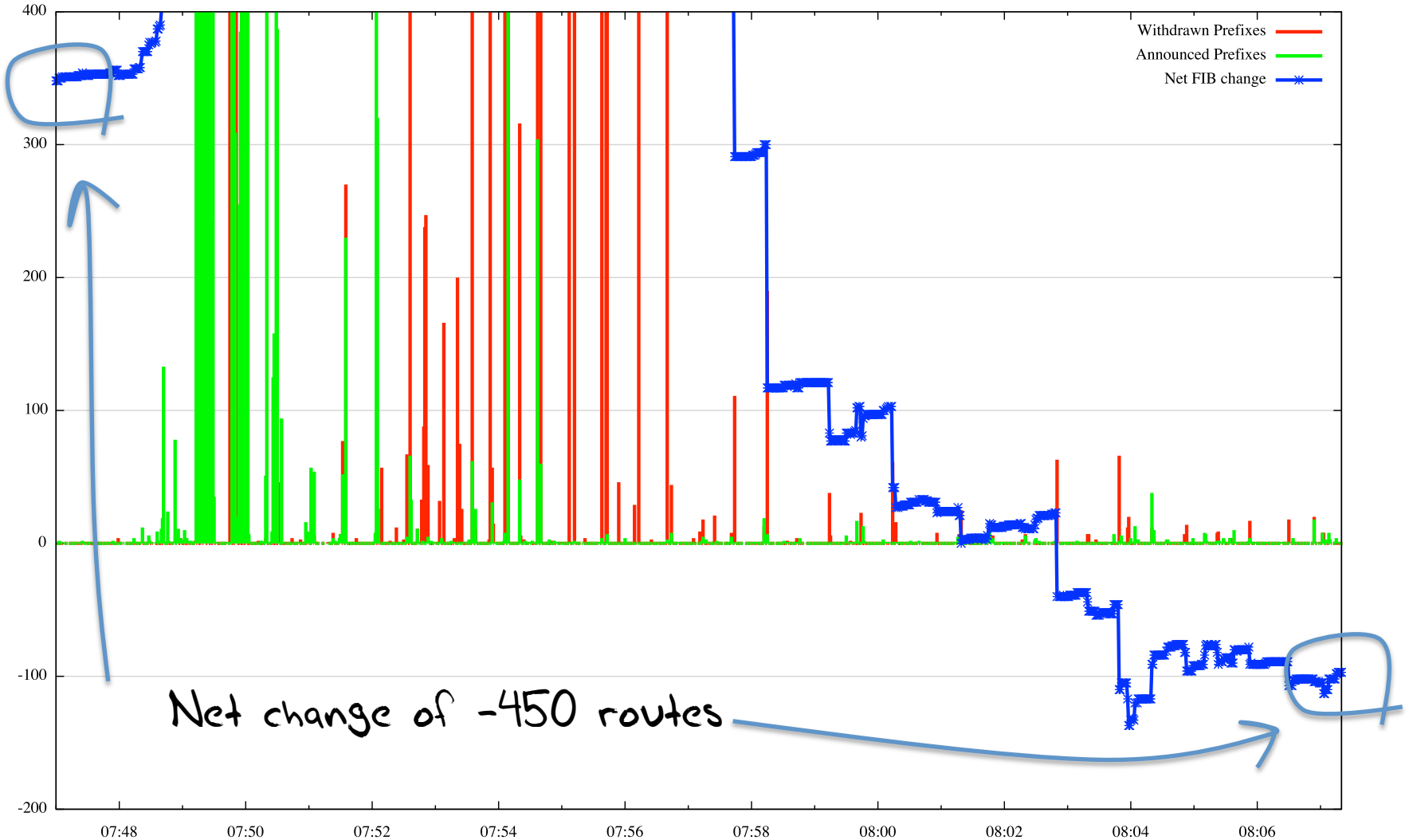
- Crash and reboot?
- Crash and die?
- Push excess routes to slow path?
- Discard excess routes

Did anyone crash and die?

Was there any evidence of dropped routes?

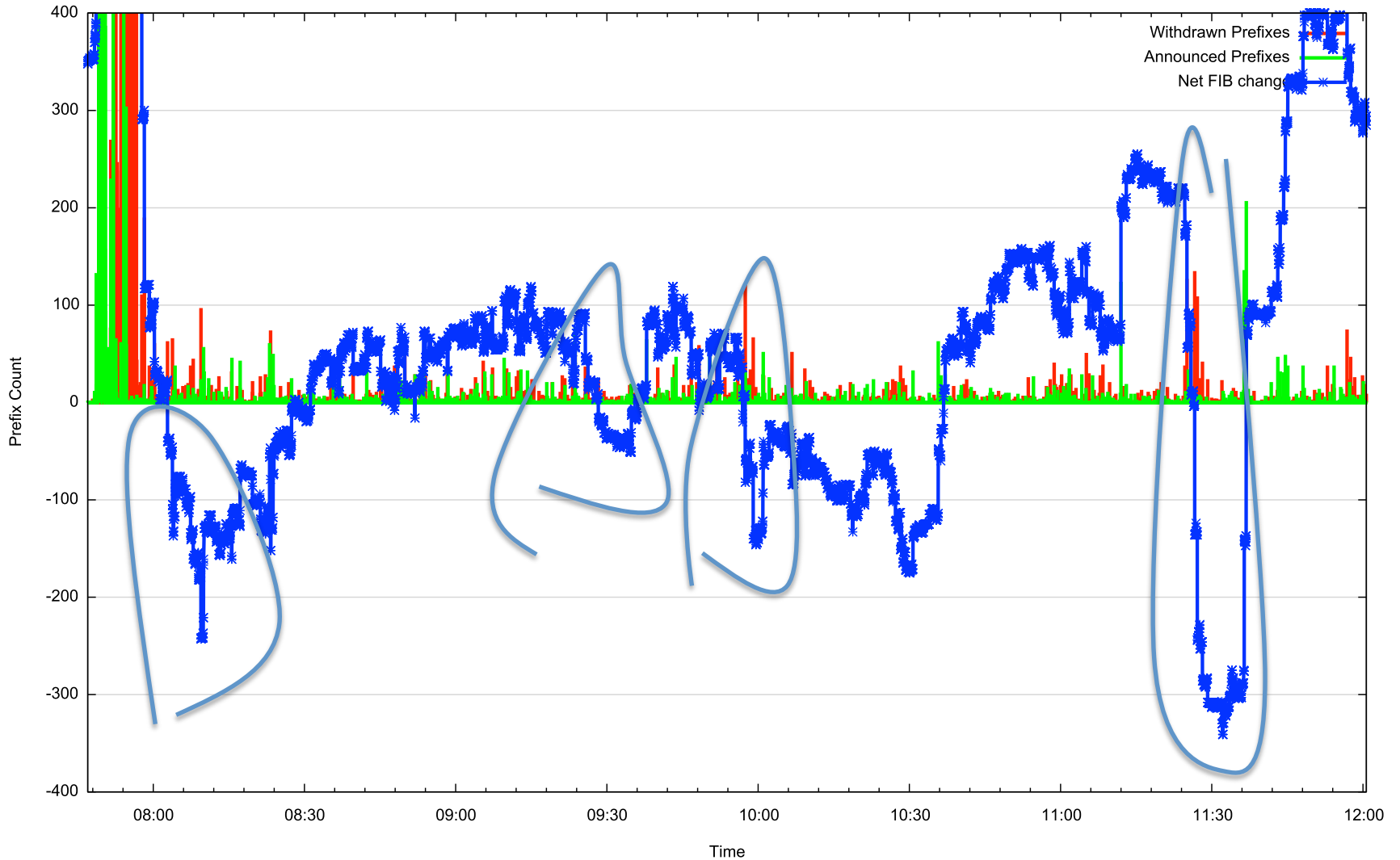
Dropped Routes?

BGP Update Profile for 12 August 2014 (07:47-08:07 UTC)



Maybe there's more...

BGP Update Profile for 12 August 2014 (07:47-12:00 UTC)



Collateral Damage

Outside of AS701, a further ~**4,424** routes were withdrawn for some period of between 07:47 and 12:00

Some of these were probably part of the route leak as they appeared to be part of the Verizon enterprise structure.

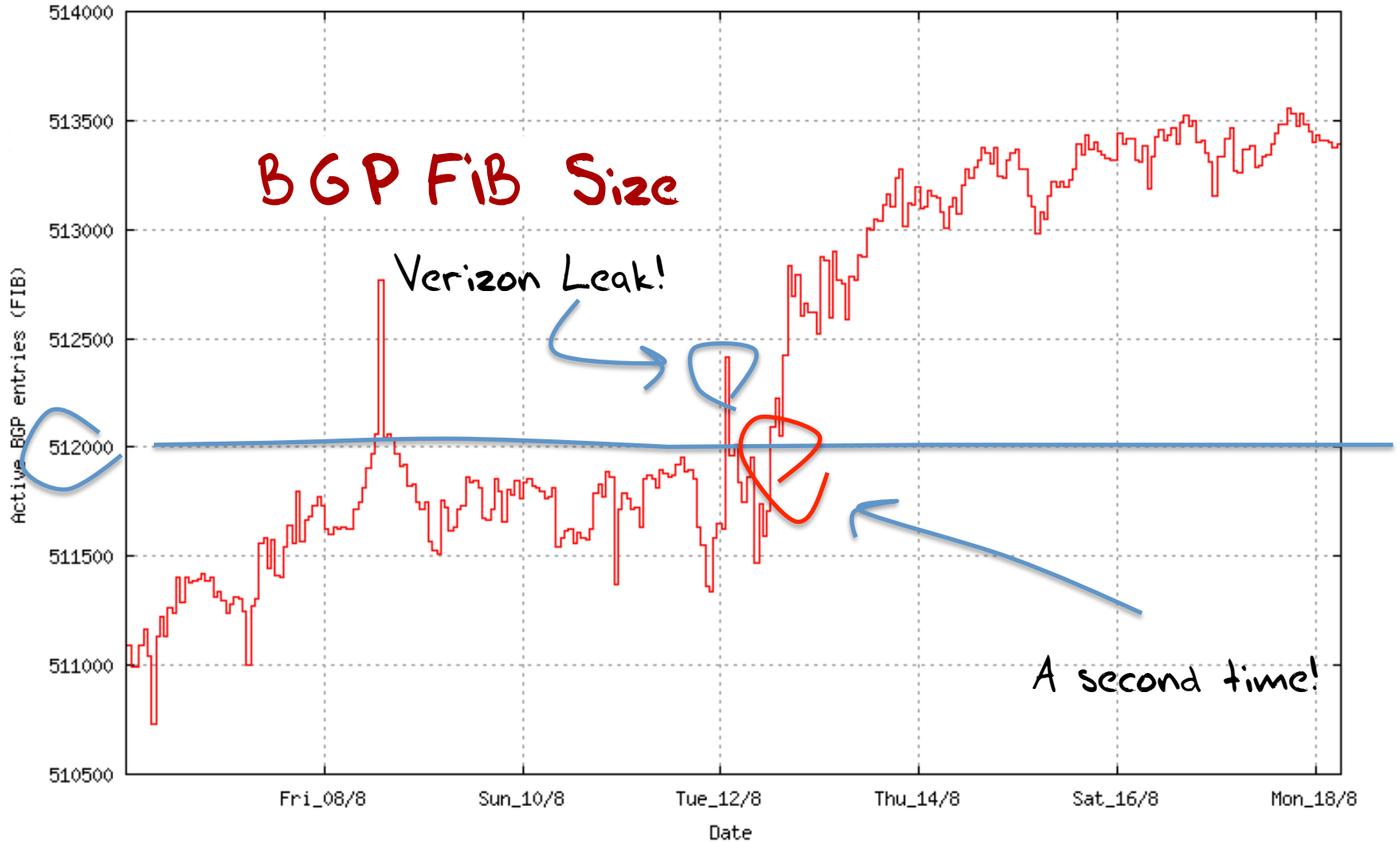
But there were others who were clearly unrelated to Verizon...

Collateral Damage

Up to 896 Origin ASes were possibly affected

AS Pfxs	AS Name
9658 435	ETPI-IDS-AS-AP Eastern Telecoms Phils., Inc.,PH
7046 1 77	RFC2270-UUNET-CUSTOMER - MCI Communications Services, Inc. d/b/a Verizon Business,US
6648 132	BAYAN-TELECOMMUNICATIONS Bayan Telecommunications, Inc.,PH
23498 77	CDSI - COGECODATA,CA
21332 61	NTC-AS OJSC "Vimpelcom",RU
27882 60	Telefonica Celular de Bolivia S.A.,BO
131222 59	MTS-INDIA-IN 334,Udyog Vihar,IN
8402 56	CORBINA-AS OJSC "Vimpelcom",RU
30036 55	MEDIACOM-ENTERPRISE-BUSINESS - Mediacom Communications Corp,US
46805 54	CACHED - CachedNet LLC,US
6459 49	TRANSBEAM - I-2000, Inc.,US
18025 45	ACE-1-WIFI-AS-AP Ace-1 Wifi Network,PH
45664 42	LBNI Liberty Broadcasting Network Inc,PH
55465 41	TTT-AS-AP TT&T Co., Ltd., Bangkok.,TH
15085 38	IMMEDION - Immedion, LLC,US
16058 37	Gabon-Telecom,GA
27229 35	WEBHOST-ASN1 - Webhosting.Net, Inc.,US
21284 33	VIVODI-AS ON S.A.,GR
13188 33	BANKINFORM-AS CONTENT DELIVERY NETWORK LTD,UA
23606 33	BELLTELECOM-PH-AS-PH Bell Telecommunication Philippines,PH
35017 32	SWIFTWAY-AS Swiftway Sp. z o.o.,GB
7018 31	ATT-INTERNET4 - AT&T Services, Inc.,US
15467 31	ENTERNET-LIBERCOM-AS Enternet 2001 Ltd., Hungary,HU
50576 30	KRASNET-UA-AS Krasnet Ltd.,UA

But then it happened again!



But was this just me or
everyone?

Was this general background level of routes
passing 512 something that every BG{ speaker
observed on the 12th August?

Or was this something unique to me (AS131072)?

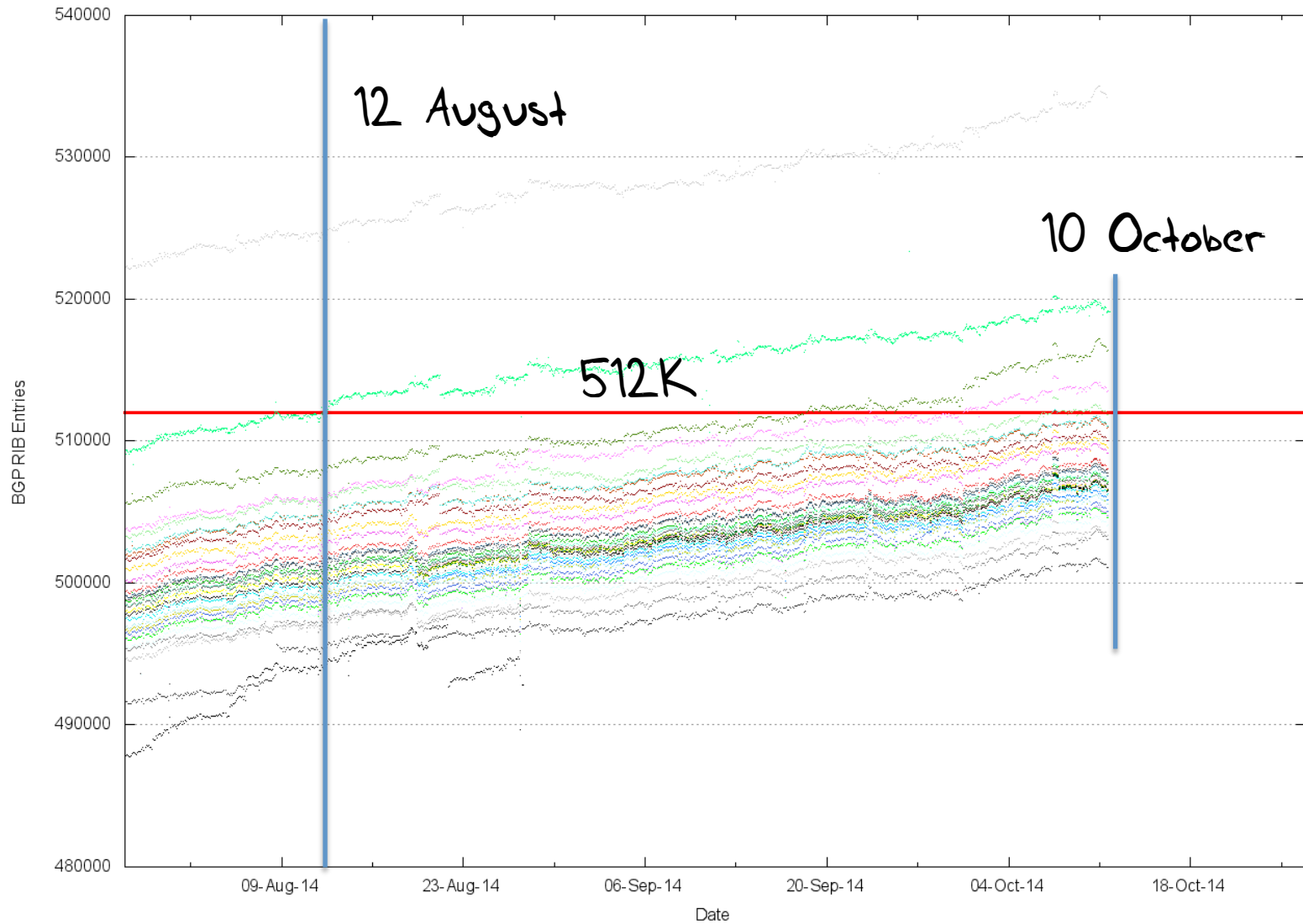
There is no Routing God!

There is no single objective “out of the system” view of the Internet’s Routing environment.

BGP distributes a routing view that is modified as it is distributed, so every eBGP speaker will see a slightly different set of prefixes, and each view is relative to a given location

When we look at some of the route collector sites we see a variance of ~20,000 routes across the routing peer set

Route Views Peers



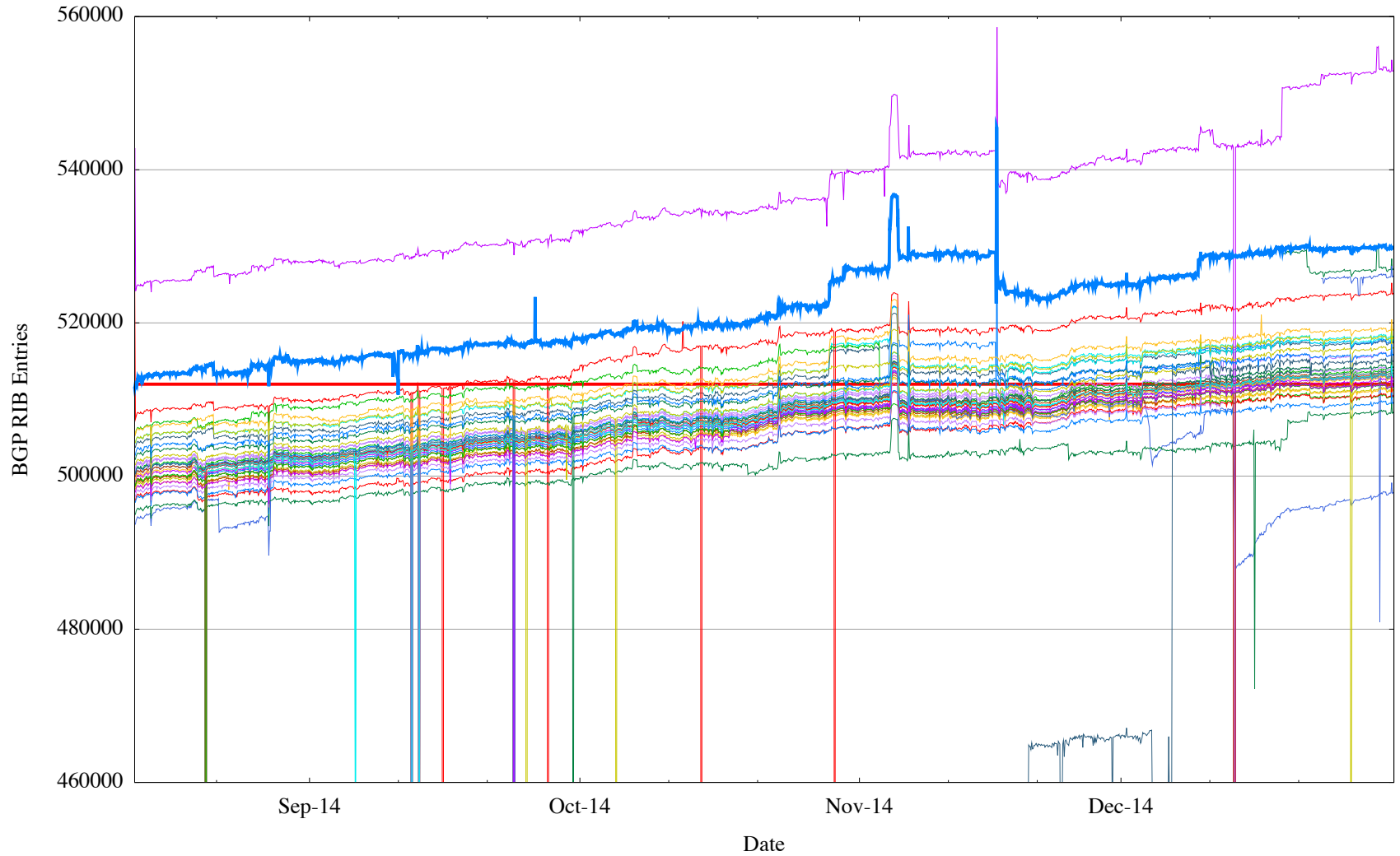
For most networks...

(probably including yours) the 12th August route leak pushed the network route count over 512K for a brief period

within an hour it all went back under again

But later on the IPv4 BGP table would pass over this threshold and not go back under again

Passing 512K

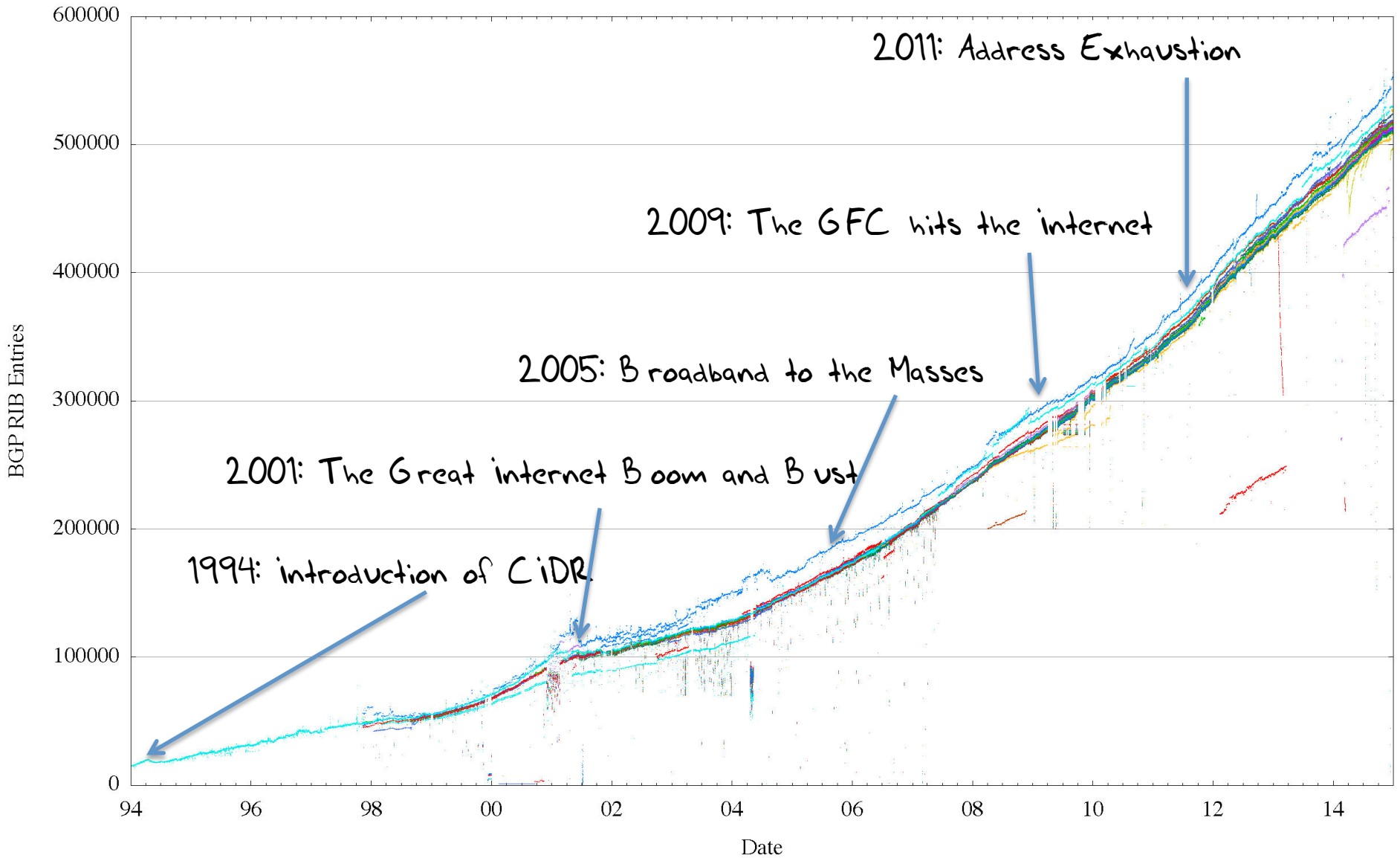


For most networks...

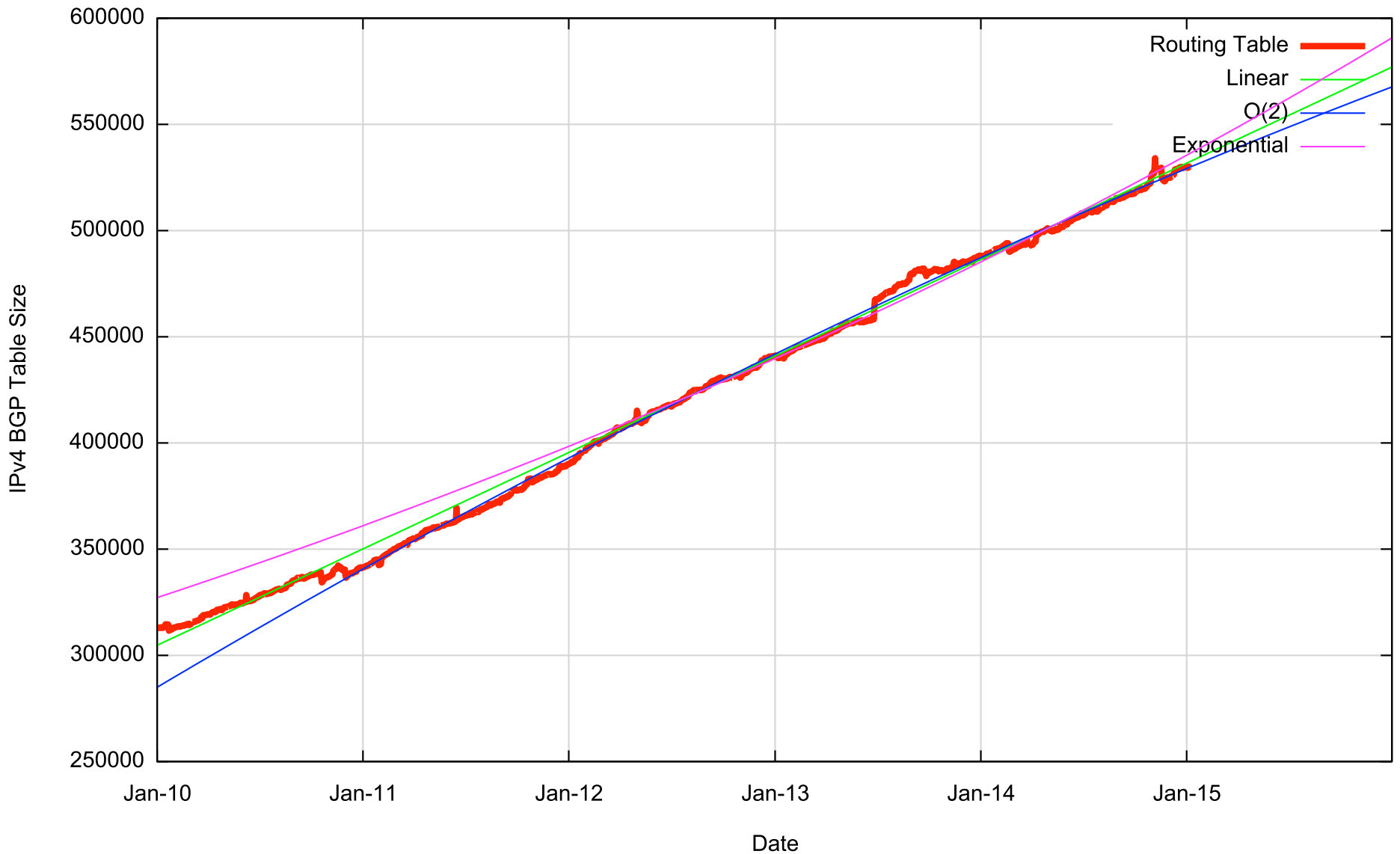
And what's next?

How quickly is the routing table growing?

20 years of Routing the Internet



IPv4 BGP Prefix Count 2010 - 2014

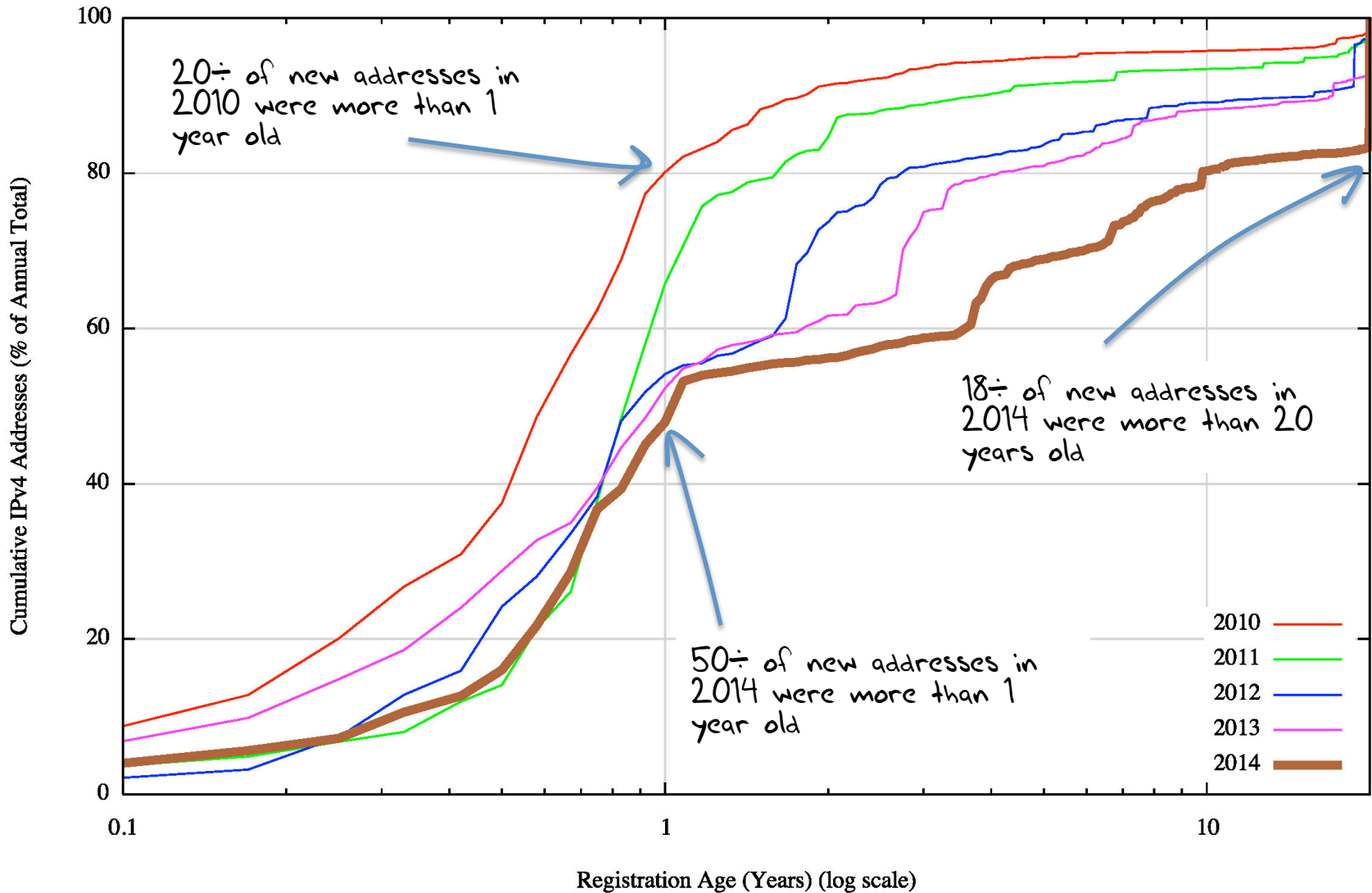


How can the IPv4 network
continue to grow when we
are running out of IPv4
addresses?

We are now recycling old addresses back into
the routing system

IPv4 Address Reuse

Relative Age of New Reachable IPv4 Addresses per Year

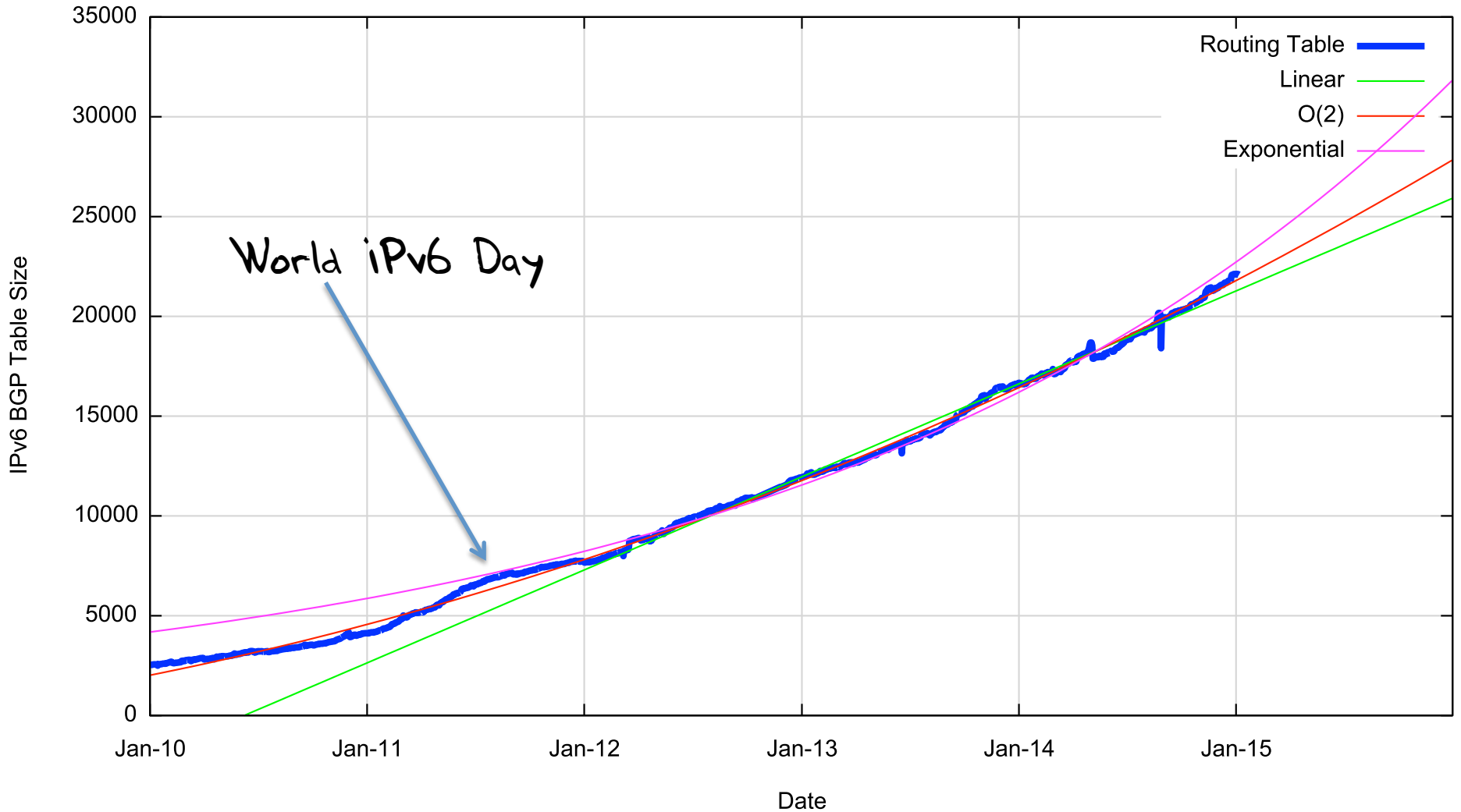


IPv4 in 2014 - Growth is Slowing (slightly)

- Overall IPv4 Internet growth in terms of BGP is at a rate of some **~9%-10% p.a.**
- Address span growing far more slowly than the table size (although the LACNIC runout in May caused a visible blip in the address rate)
- The rate of growth of the IPv4 Internet is slowing down (slightly)
 - Address shortages
 - Masking by NAT deployments
 - Saturation of critical market sectors
 - Transition uncertainty

IPv6 BGP Prefix Count

V6 BGP FIB Size



IPv6 in 2013

- Overall IPv6 Internet growth in terms of BGP is **20% - 40 % p.a.**
 - 2012 growth rate was ~ 90%.

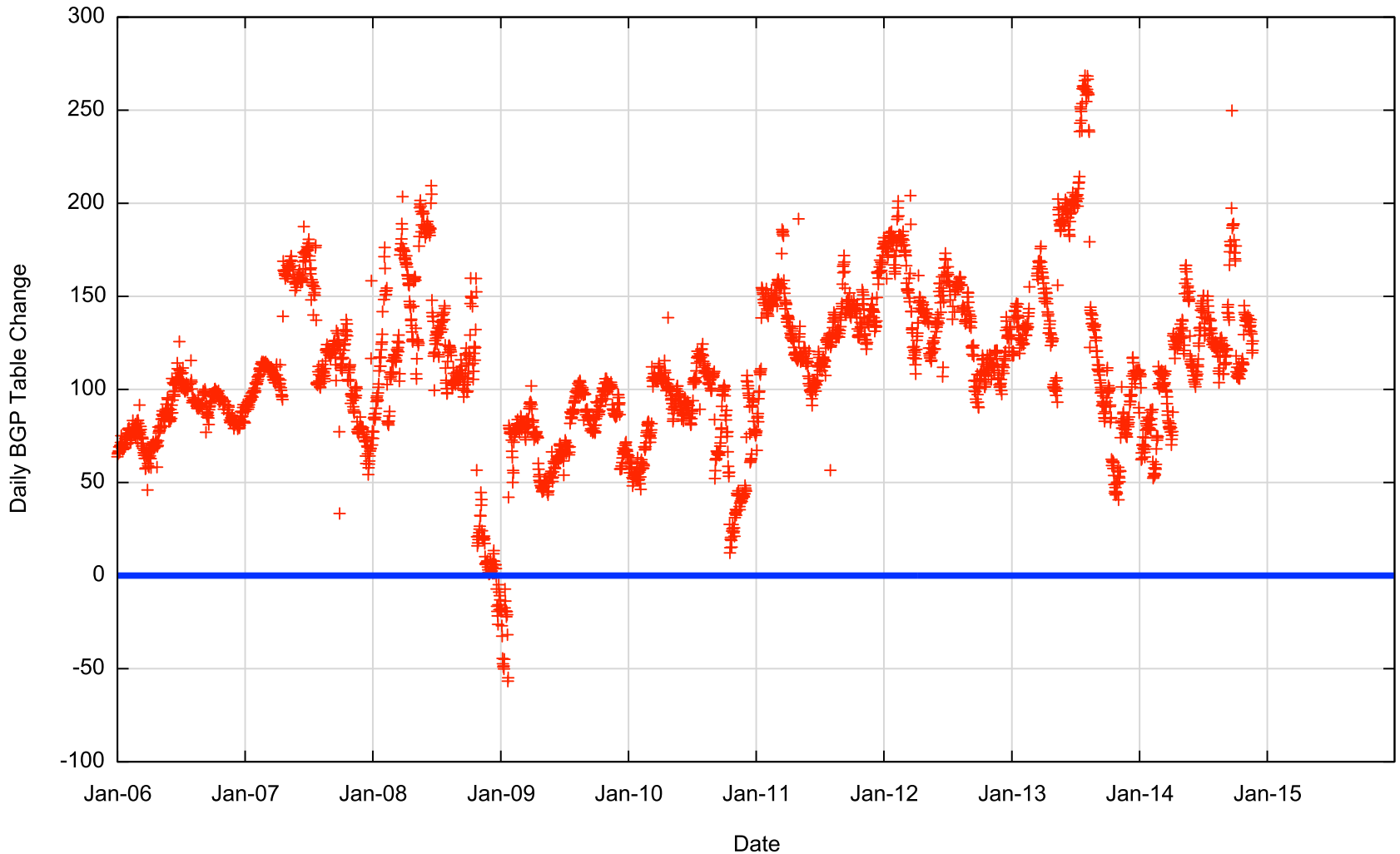
If these relative growth rates persist then the IPv6 network would span the same network domain as IPv4 in ~16 years time

What to expect

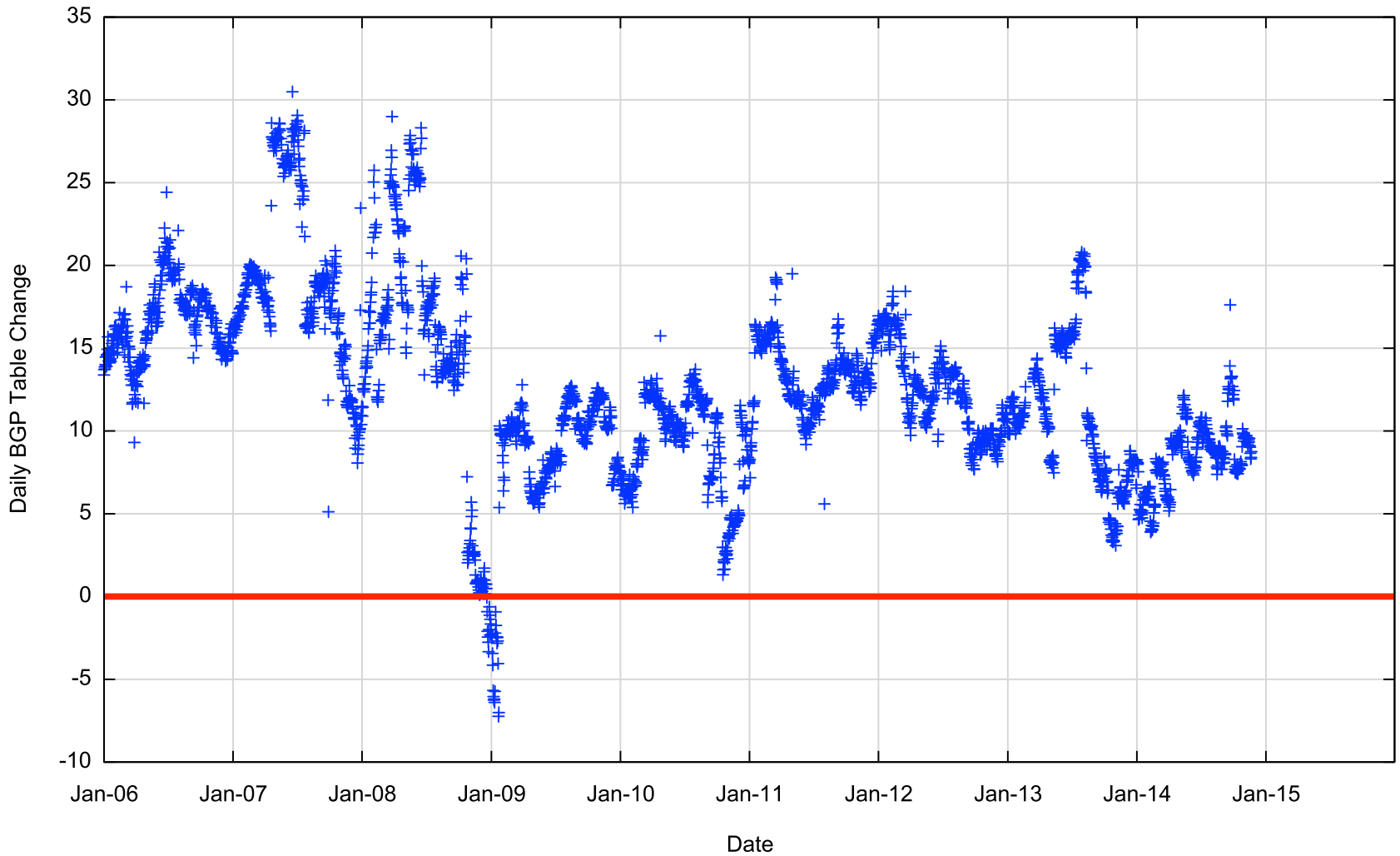
BGP Size Projections

- For IPv4 this is a time of **extreme uncertainty**
 - Registry IPv4 address run out
 - Uncertainty over the impacts of any after-market in IPv4 on the routing table
- which makes this projection even more speculative than normal!

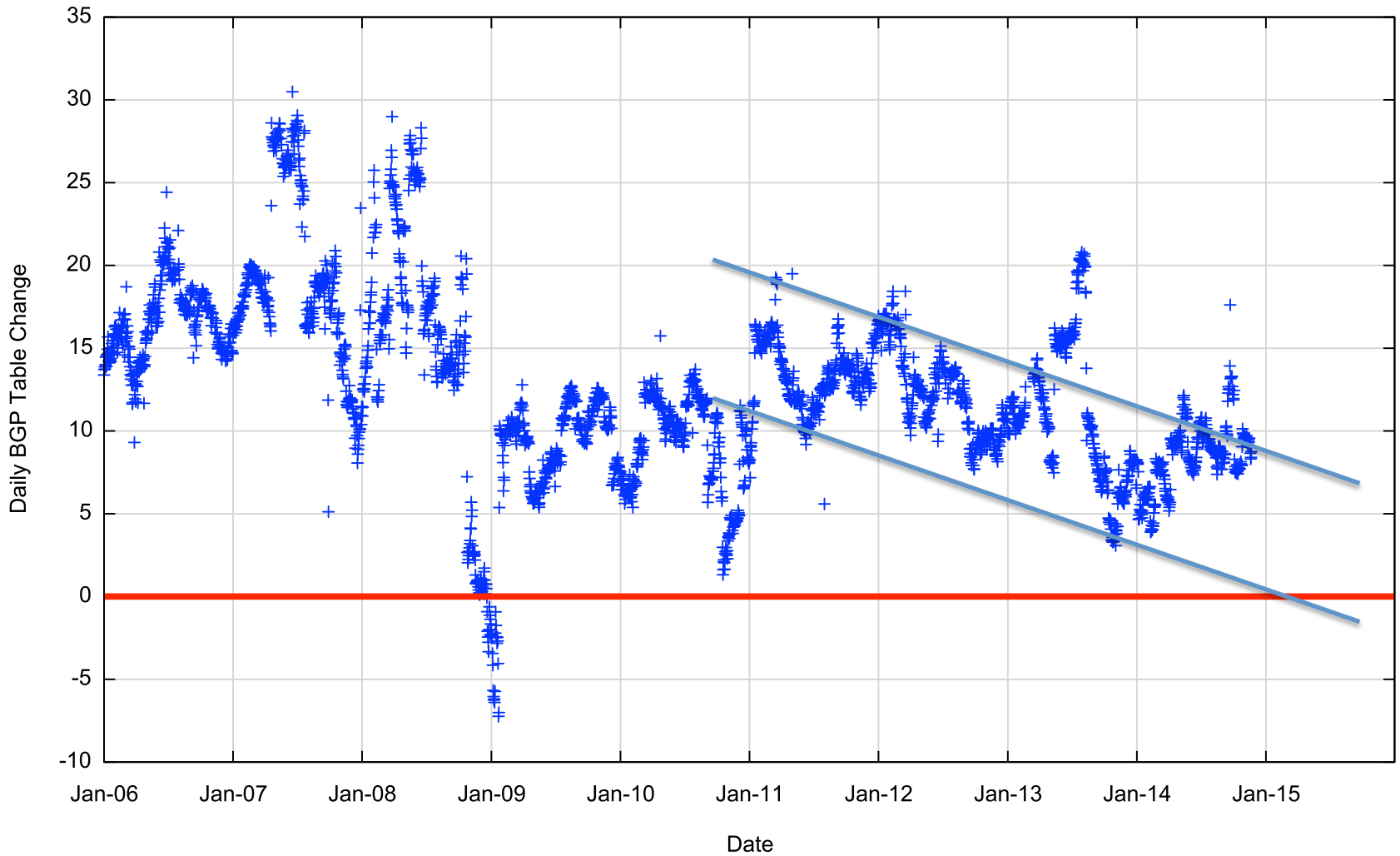
V4 - Daily Growth Rates



V4 - Relative Daily Growth Rates



V4 - Relative Daily Growth Rates

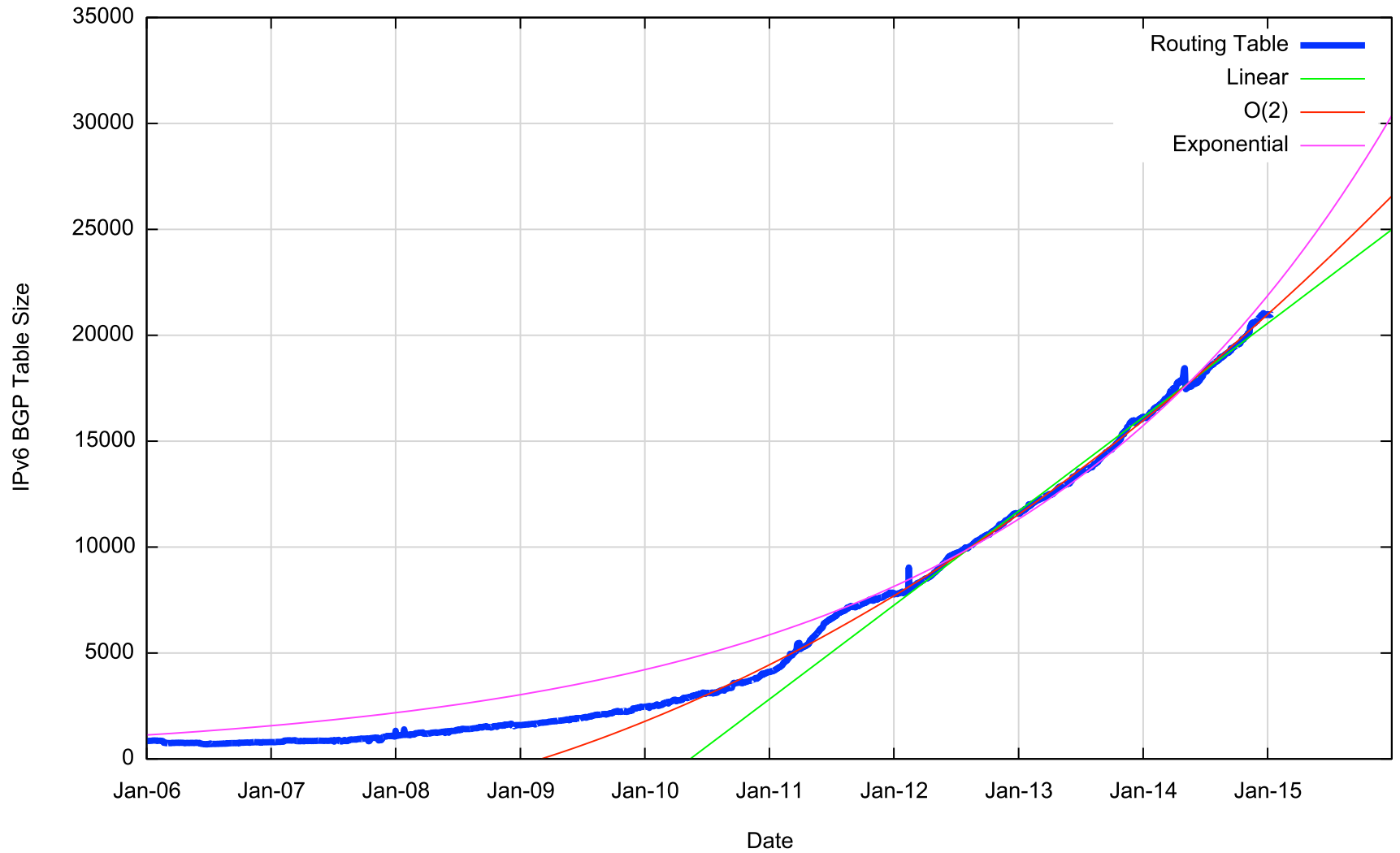


IPv4 BGP Table Size predictions

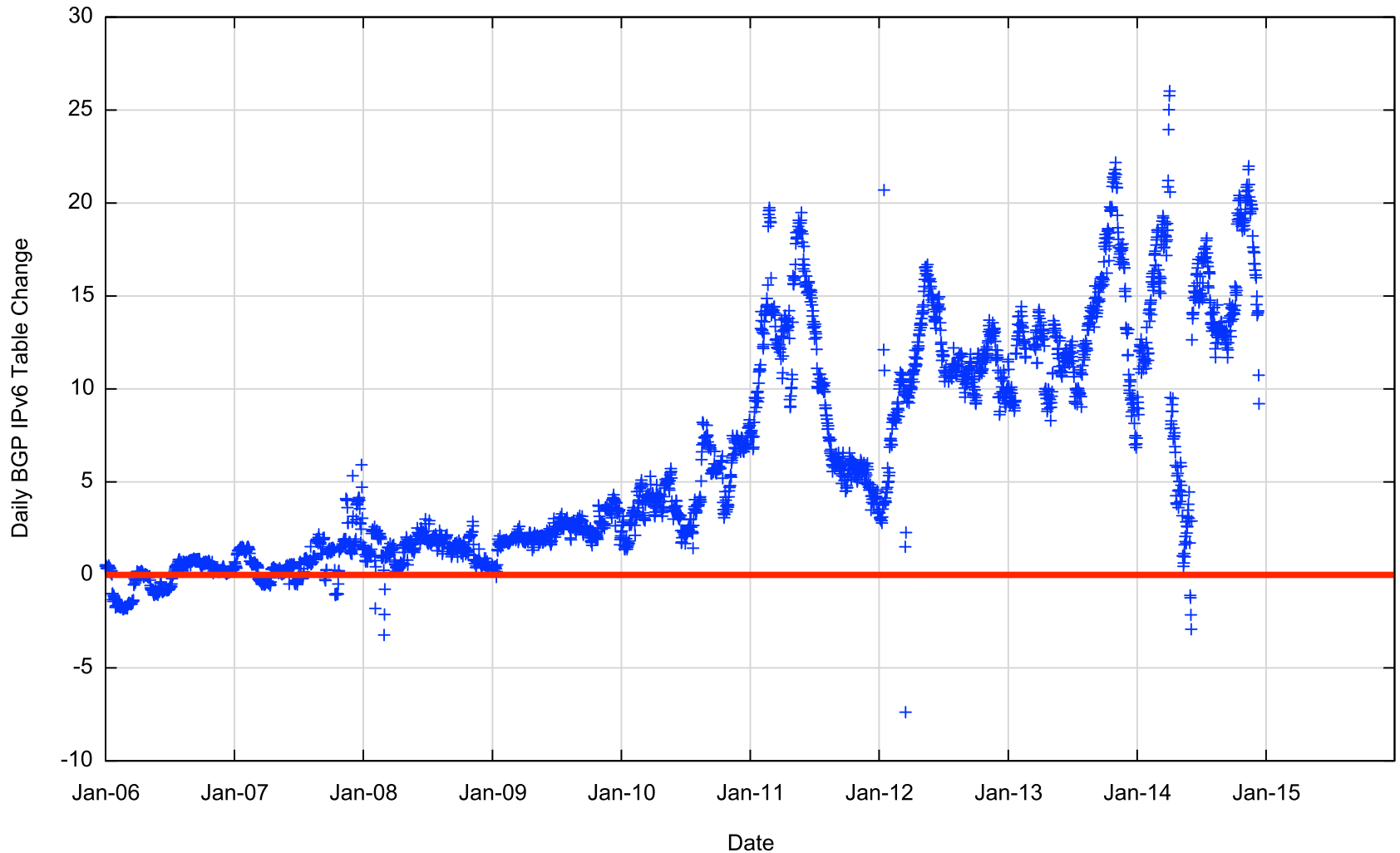
Jan 2013	441,172 entries
2014	488,011
2015	529,806
2016	580,000
2017	620,000
2018	670,000
2019	710,000
2020	760,000

These numbers are dubious due to uncertainties introduced by IPv4 address exhaustion pressures.

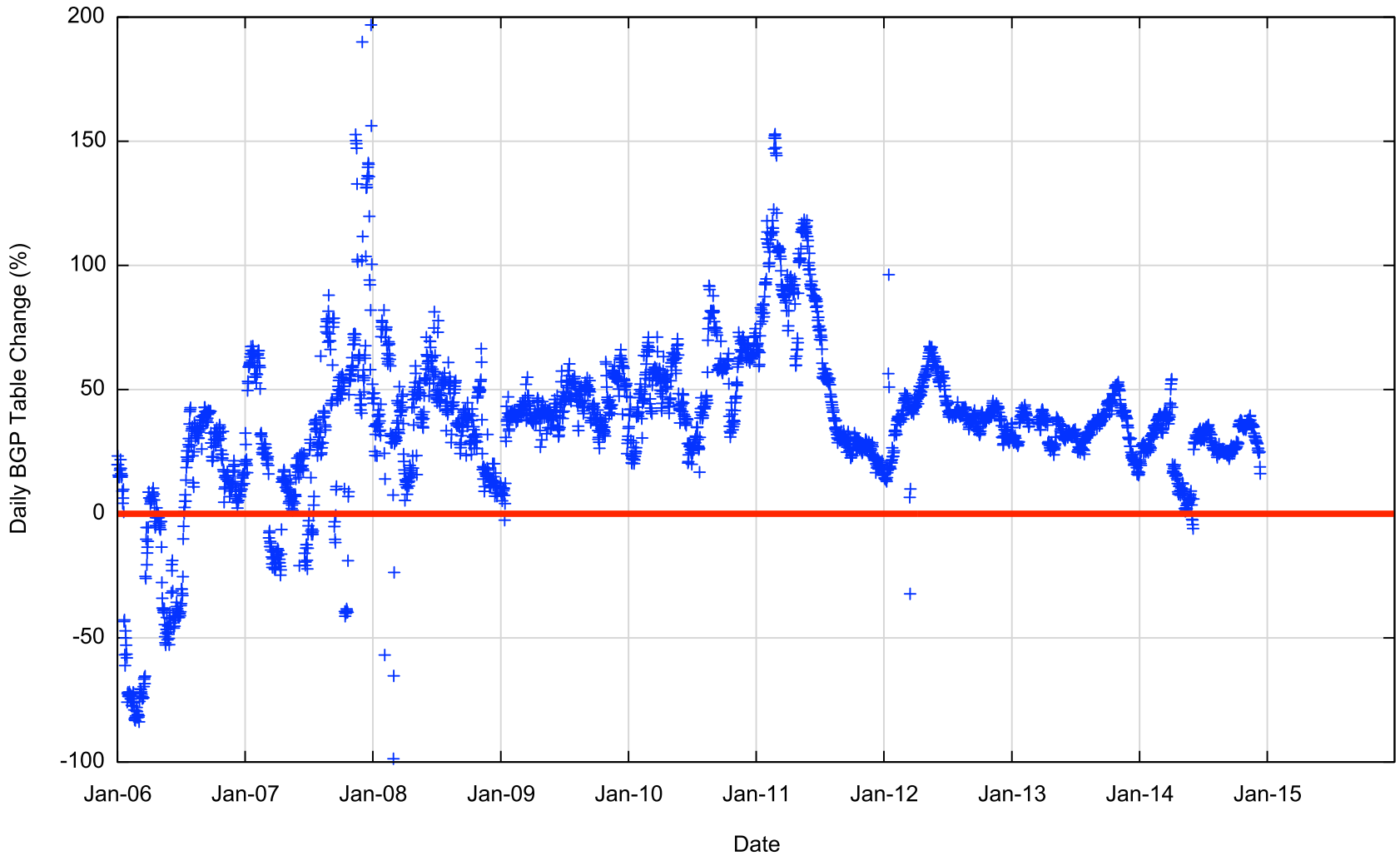
IPv6 Table Size



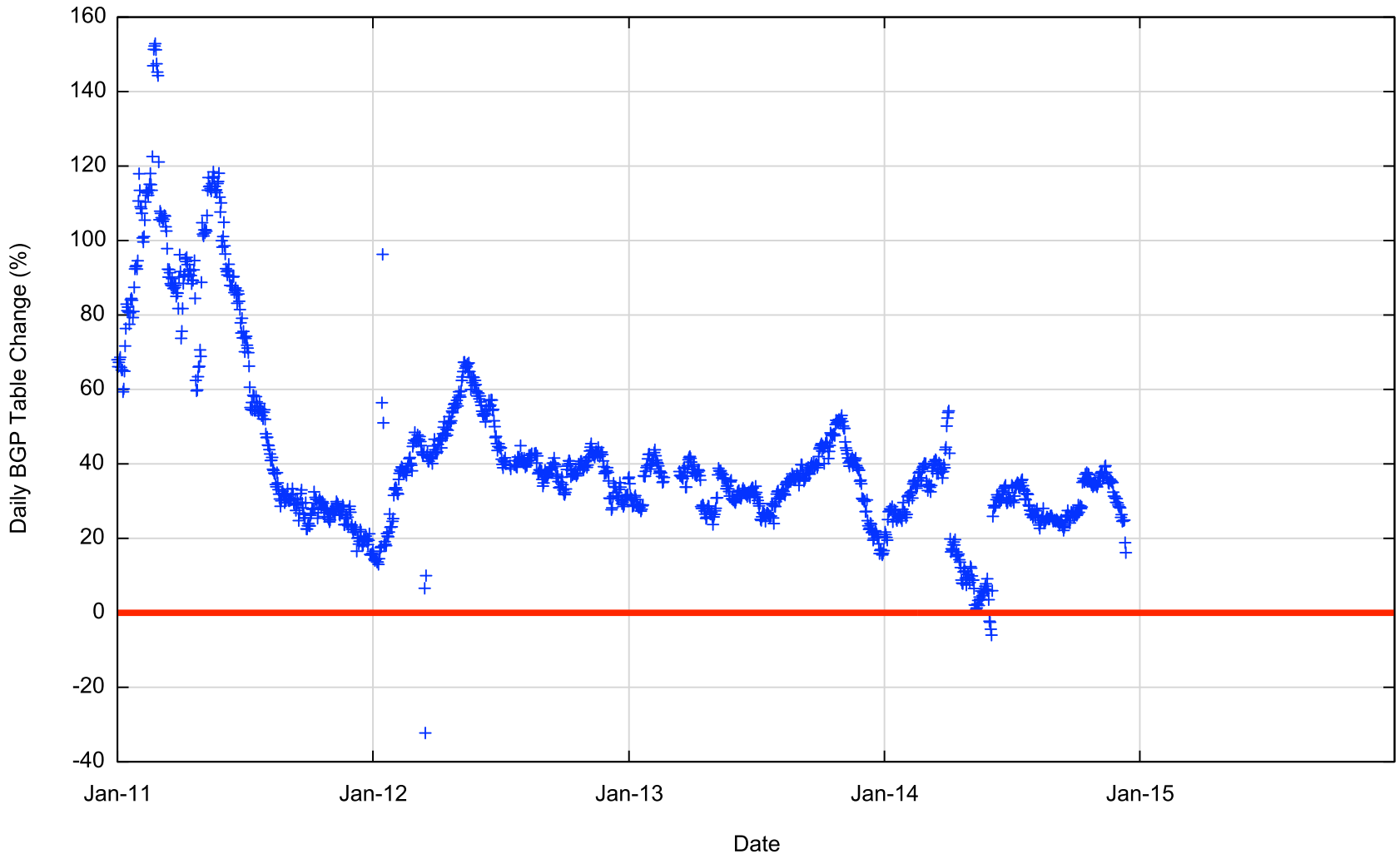
V6 - Daily Growth Rates



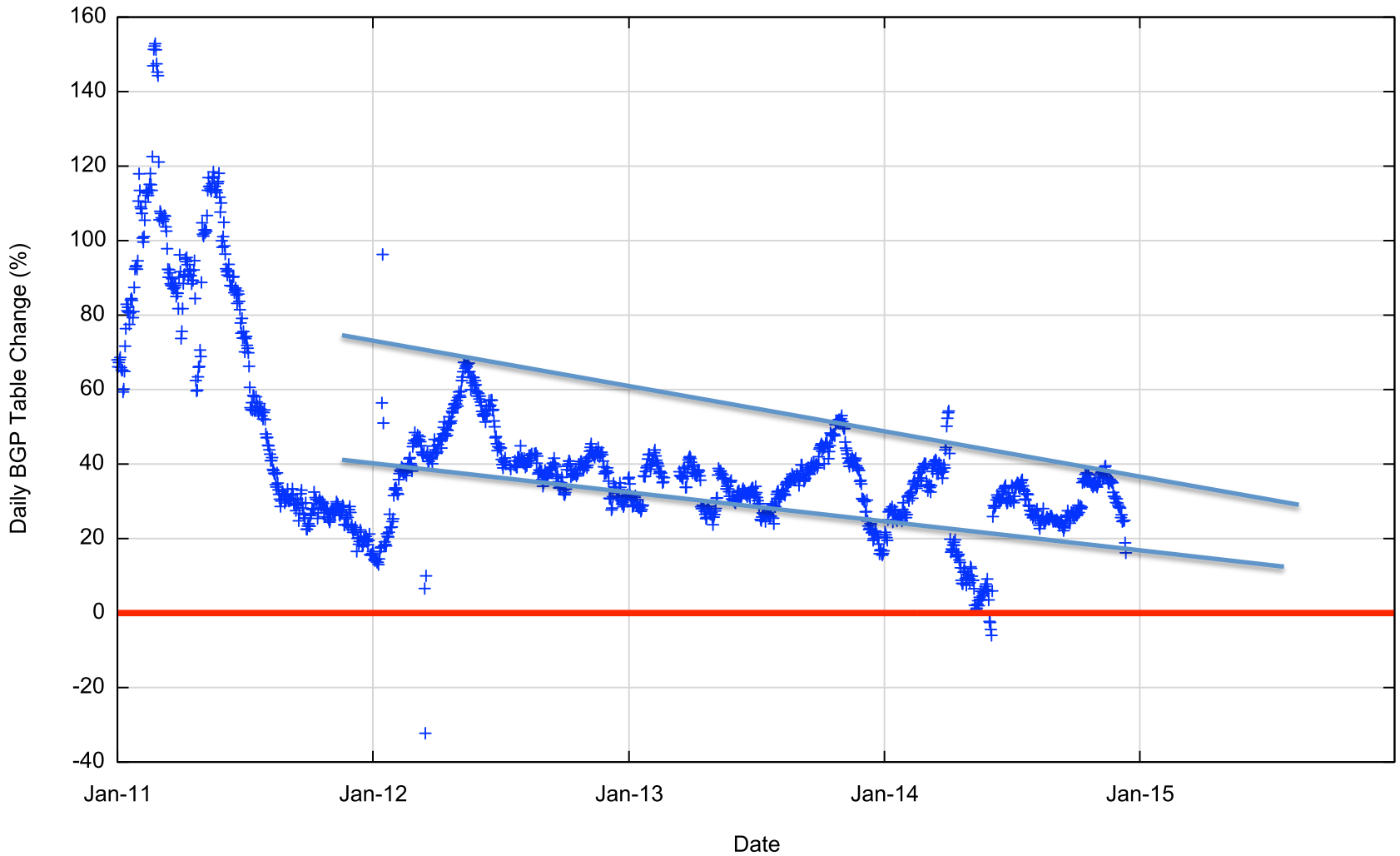
V6 - Relative Growth Rates



V6 - Relative Growth Rates



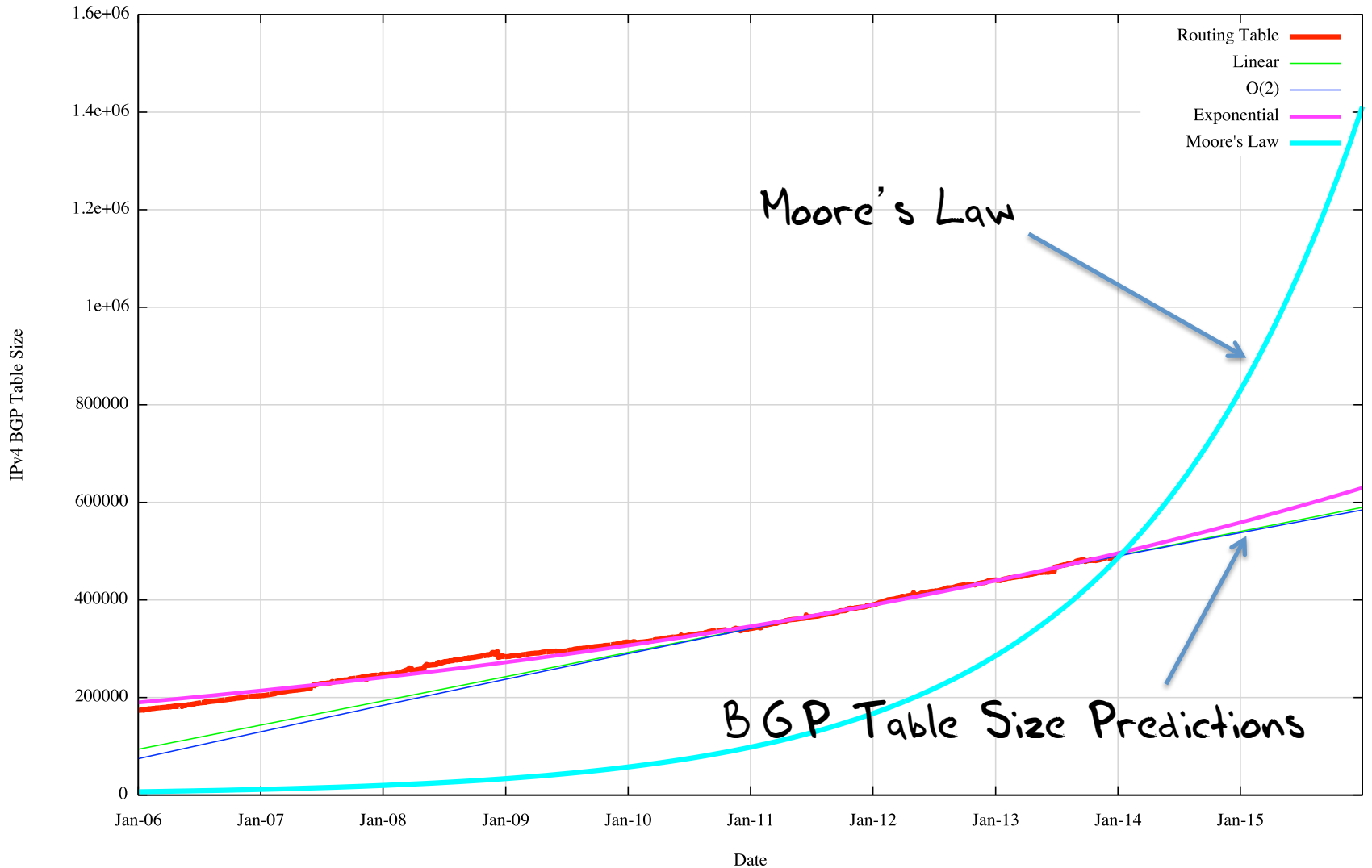
V6 - Relative Growth Rates



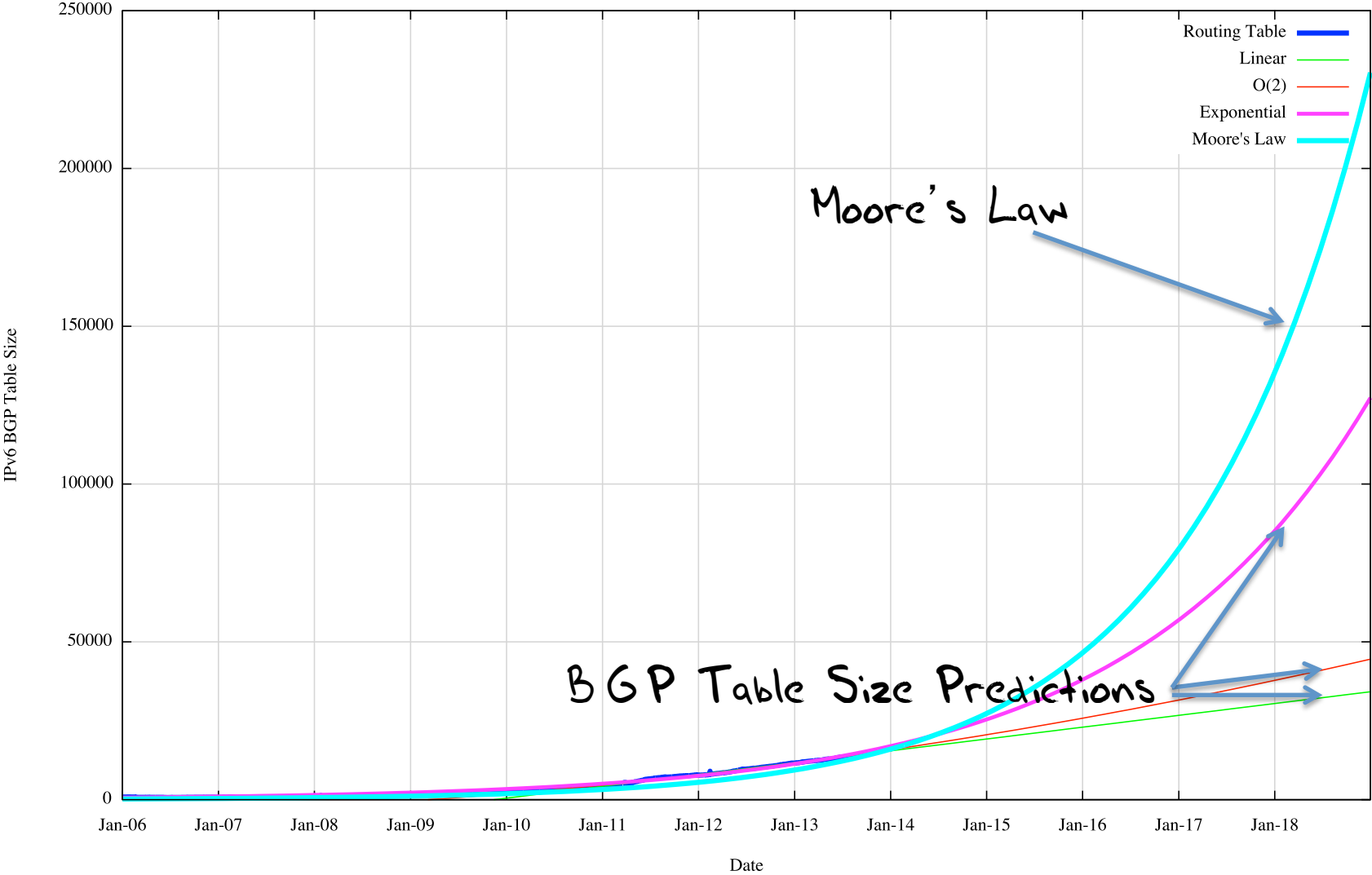
IPv6 BGP Table Size predictions

	Exponential Model	Linear Model
Jan 2013	11,600 entries	
2014	16,200 entries	
<i>2015</i>	<i>21,000 entries</i>	
<i>2016</i>	<i>30,000 entries</i>	<i>25,000</i>
<i>2017</i>	<i>42,000 entries</i>	<i>29,000</i>
<i>2018</i>	<i>58,000 entries</i>	<i>34,000</i>
<i>2019</i>	<i>82,000 entries</i>	<i>38,000</i>
<i>2019</i>	<i>113,000 entries</i>	<i>43,000</i>

IPv4 BGP Table size and Moore's Law



IPv6 Projections and Moore's Law



BGP Table Growth

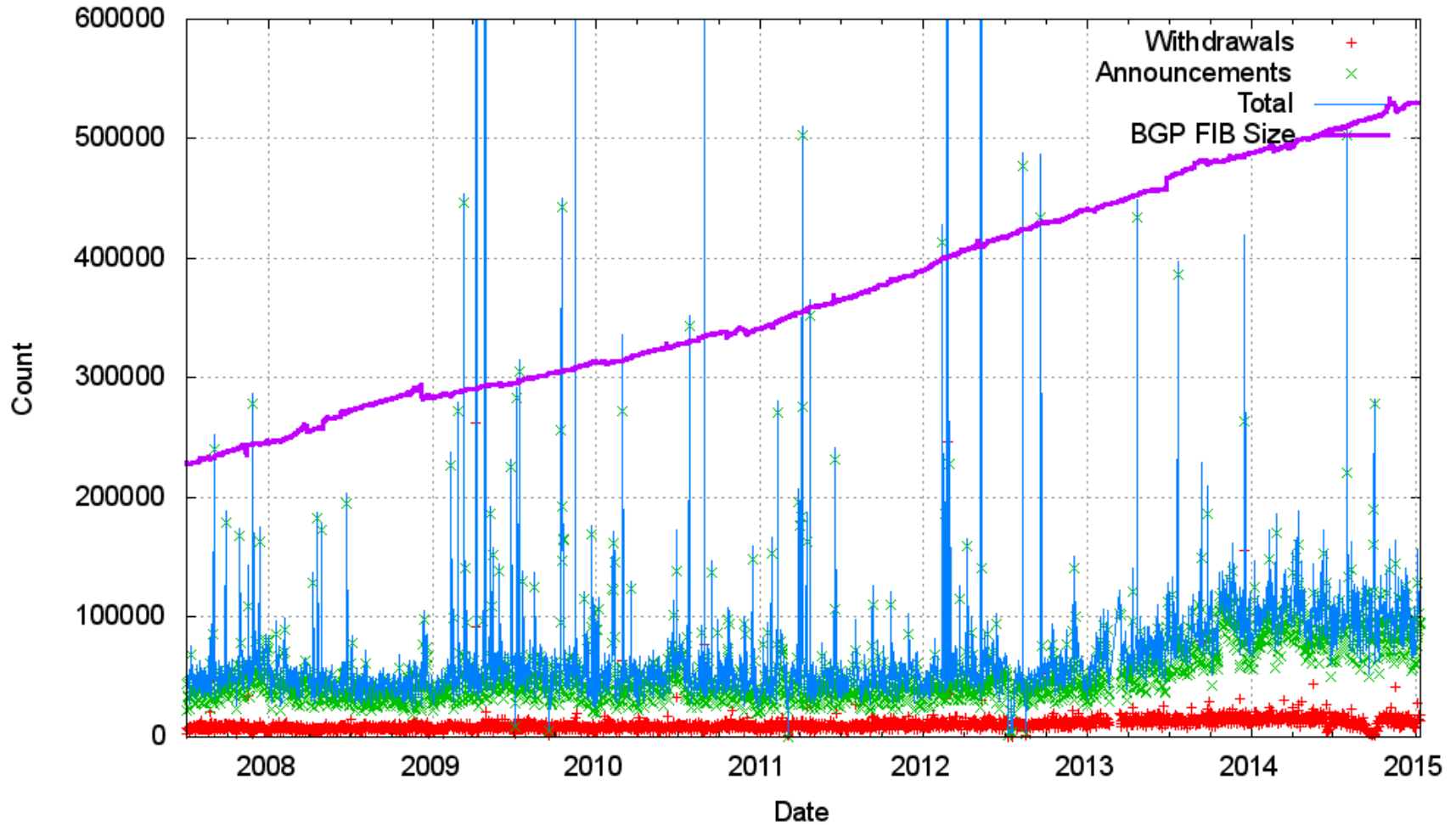
- Nothing in these figures suggests that there is cause for urgent alarm -- at present
- The overall eBGP growth rates for IPv4 are holding at a modest level, and the IPv6 table, although it is growing rapidly, is still relatively small in size in absolute terms
- As long as we are prepared to live within the technical constraints of the current routing paradigm it will continue to be viable for some time yet

BGP Updates

- What about the level of updates in BGP?
- Let's look at the update load from a single eBGP feed in a DFZ context

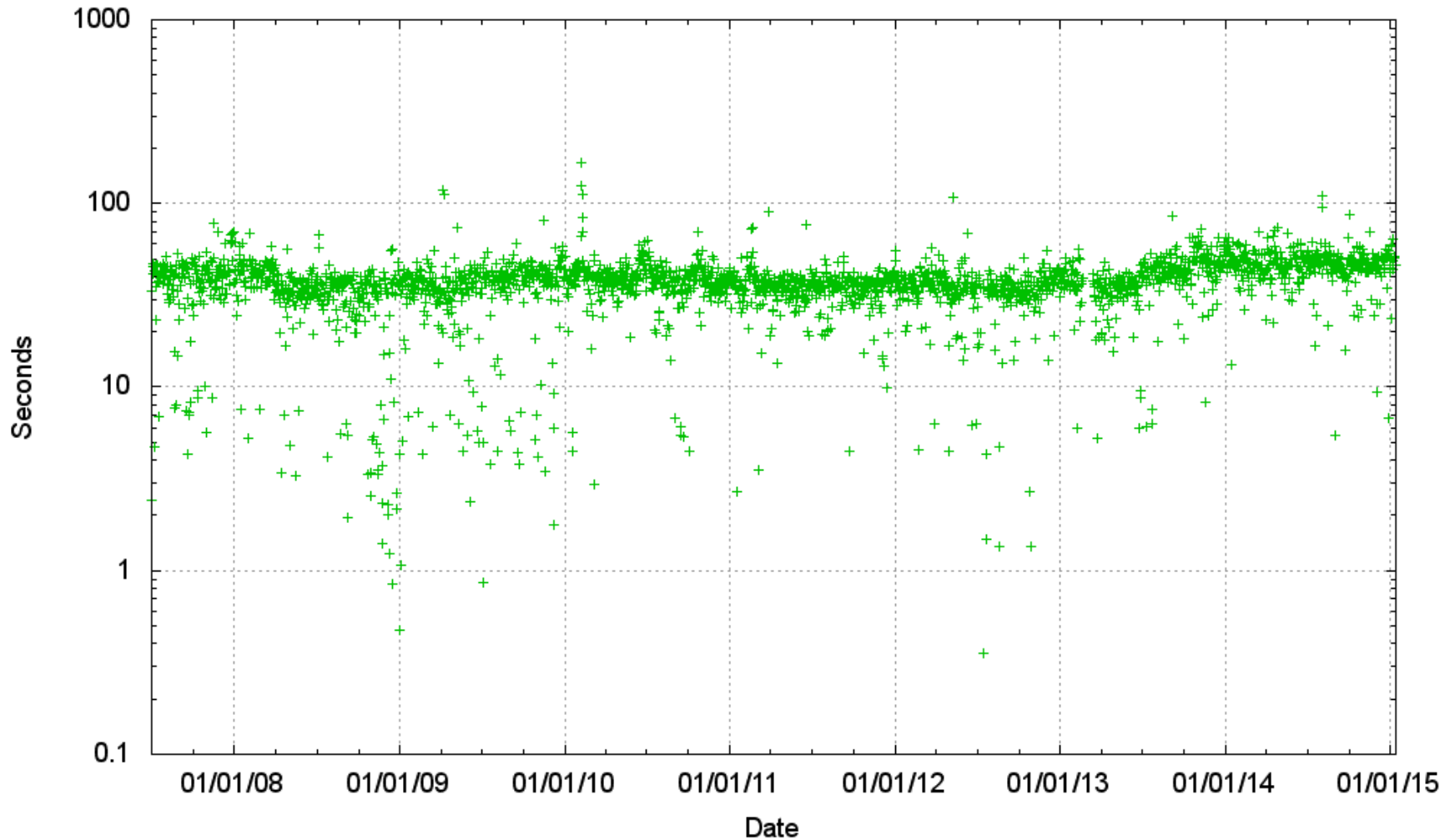
Announcements and Withdrawals

Daily BGP v4 Update Activity for AS131072

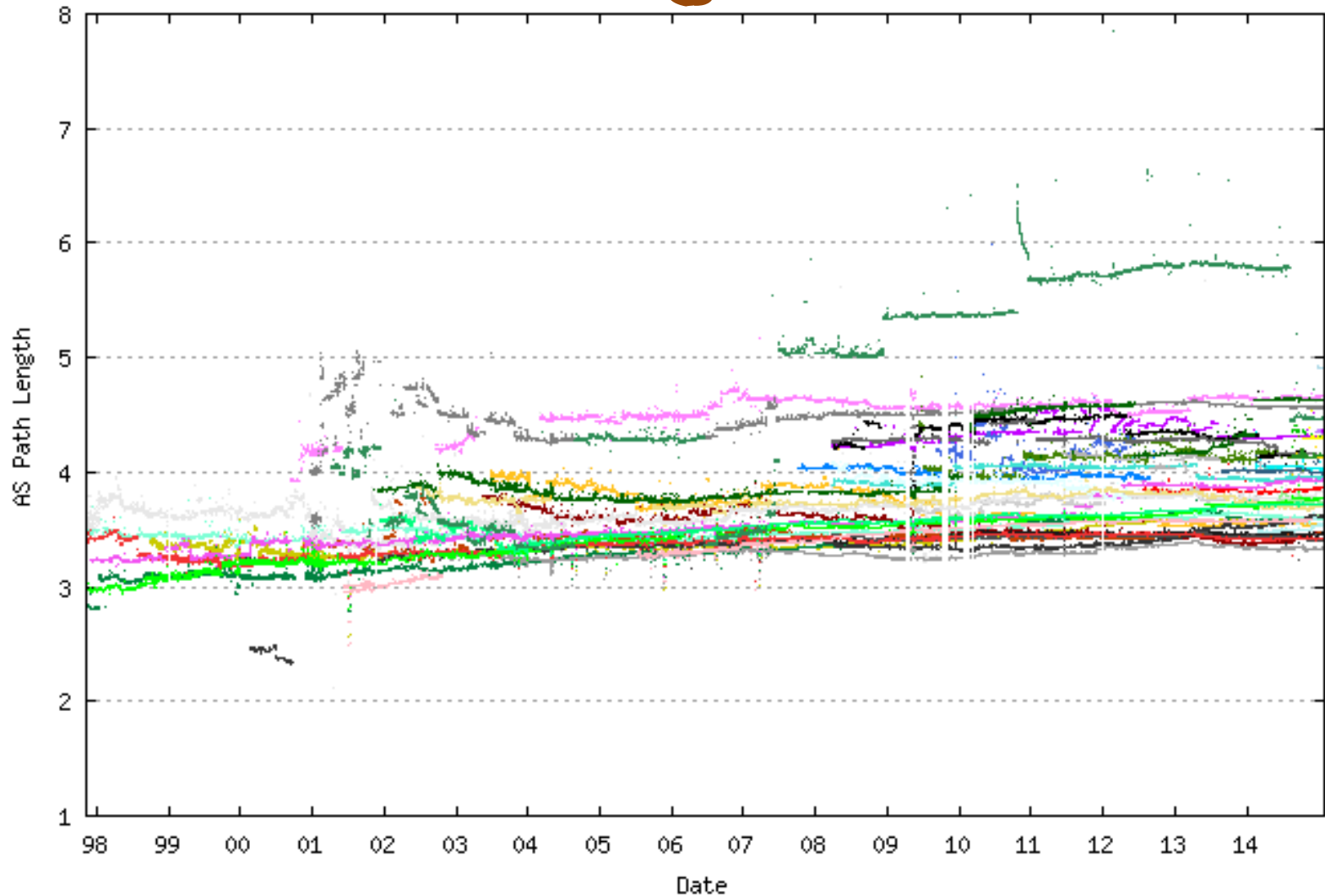


Convergence Performance

Average Convergence Time per day (AS 131072)



IPv4 Average AS Path Length



Data from Route Views

Updates in IPv4 BGP

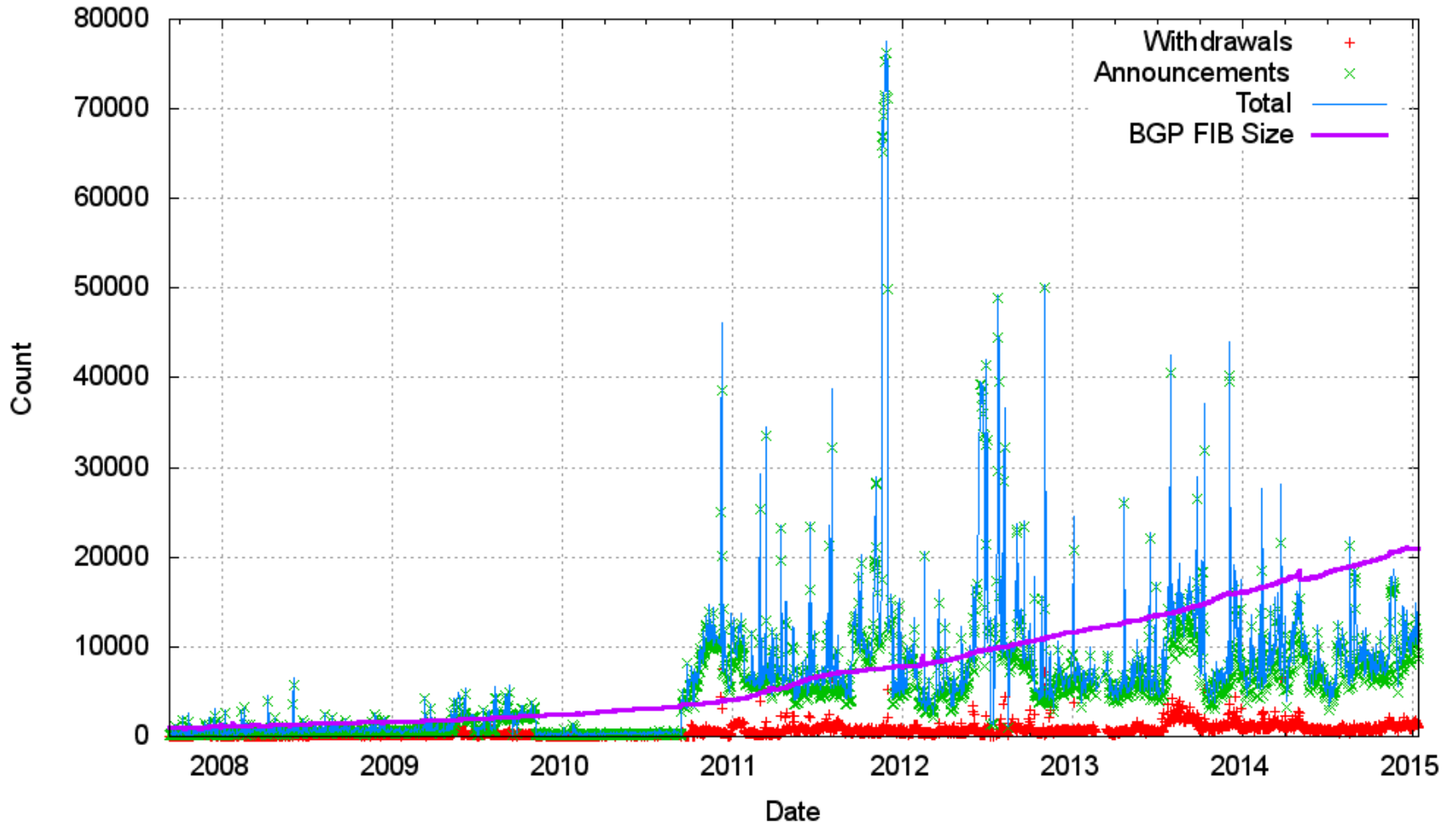
Nothing in these figures is cause for any great level of concern ...

- The number of updates per instability event has been constant, due to the damping effect of the MRAI interval, and the relatively constant AS Path length over this interval

What about IPv6?

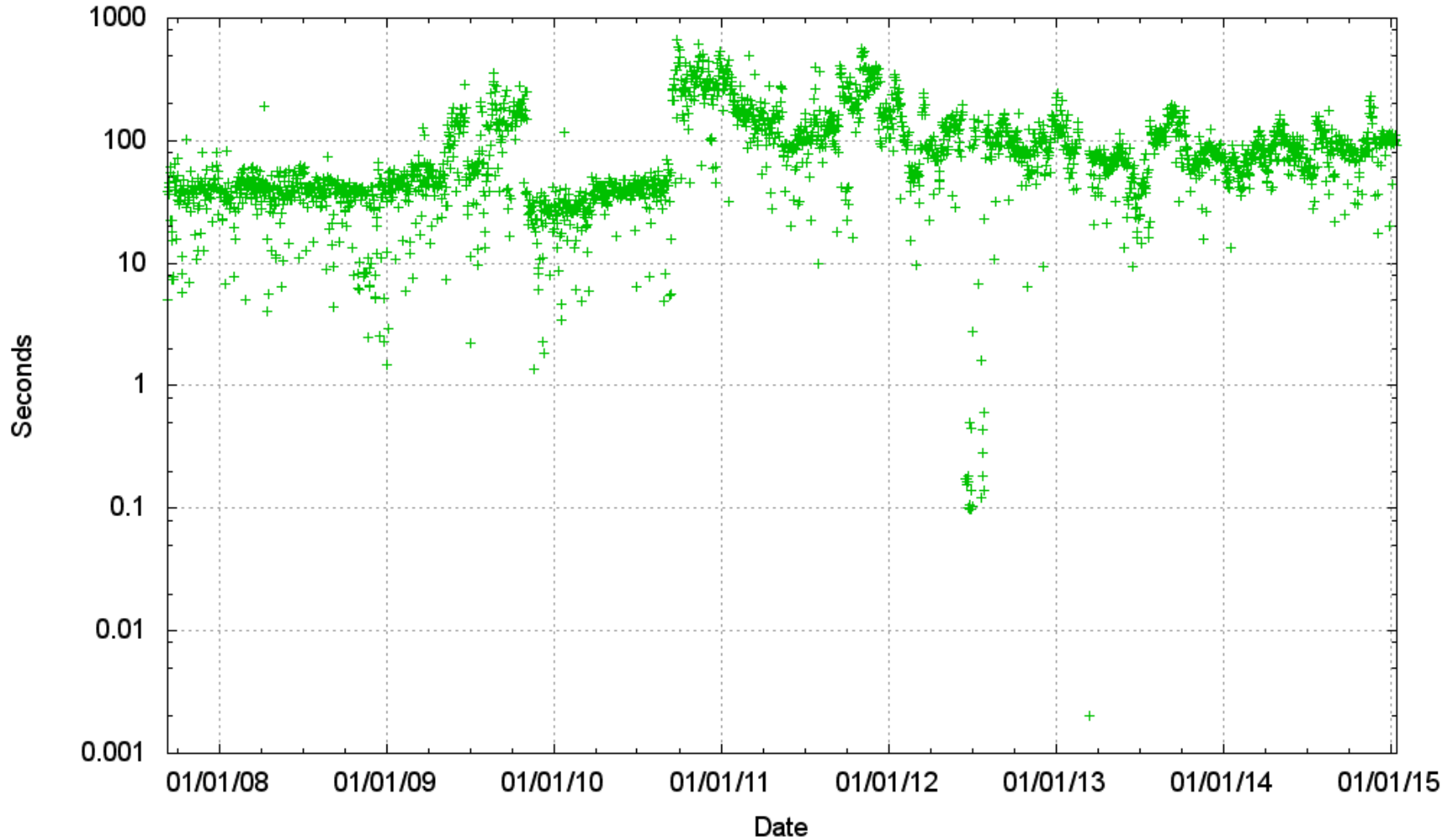
V6 Announcements and Withdrawals

Daily BGP v6 Update Activity for AS131072

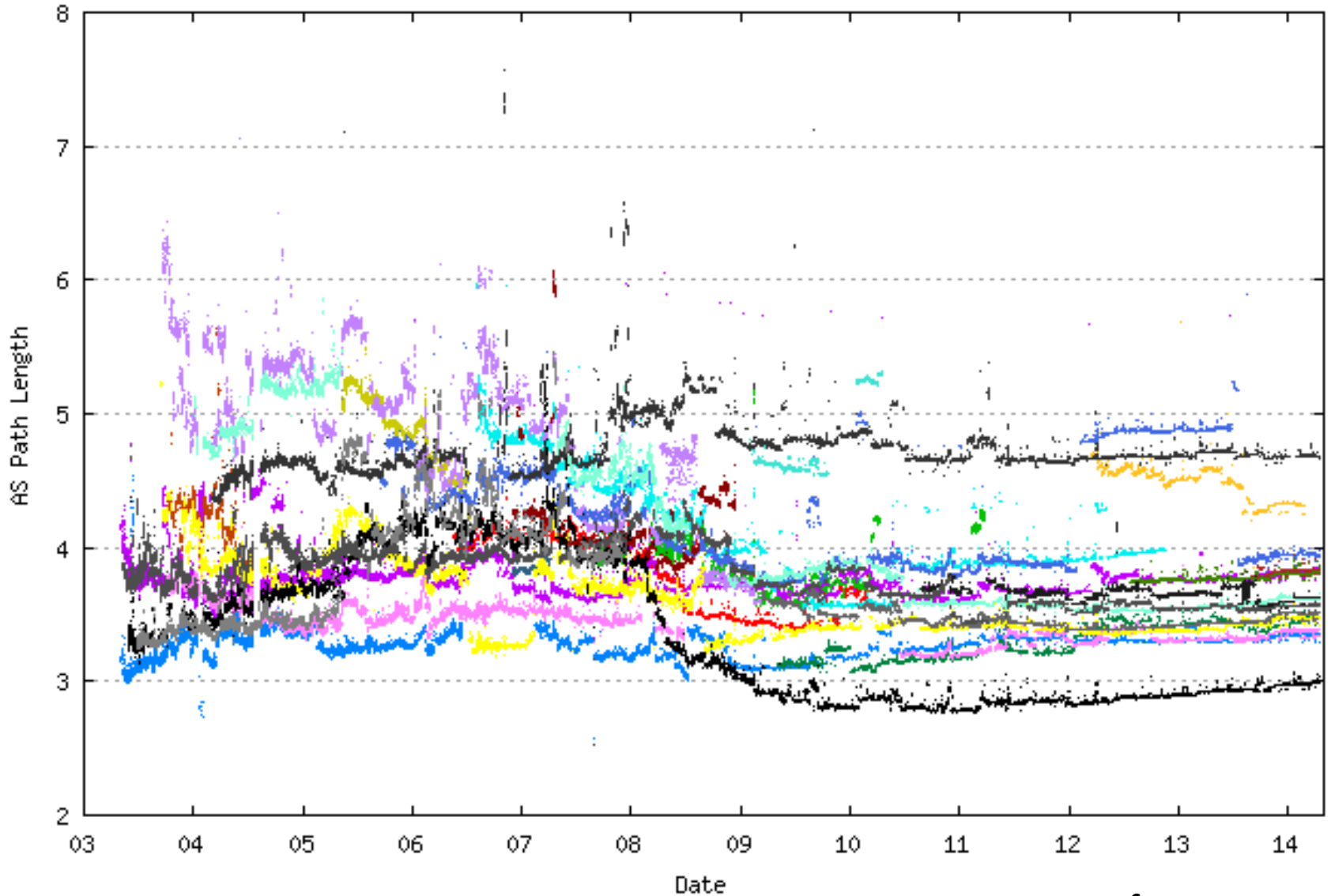


V6 Convergence Performance

Average Convergence Time per day (AS 131072)



V6 Average AS Path Length



Data from Route Views

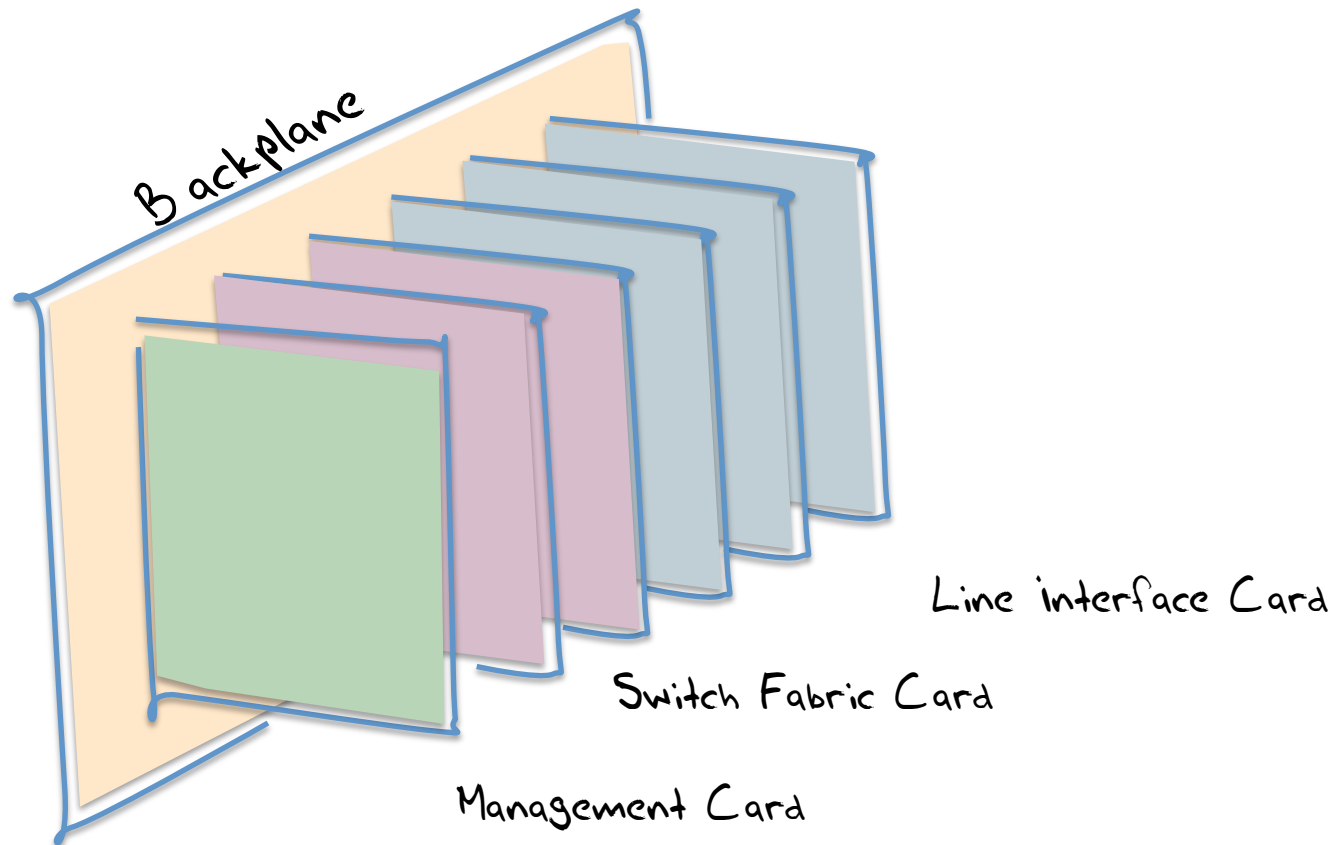
Problem? Not a Problem?

It's evident that the global BGP routing environment suffers from a certain amount of neglect and inattention

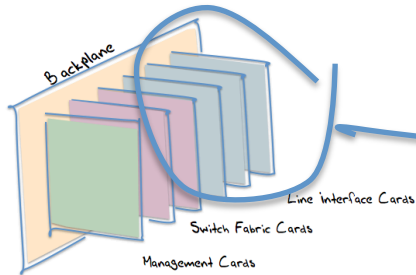
But whether this is a problem or not depends on the way in which routers handle the routing table.

So lets take a quick look at routers...

Inside a router

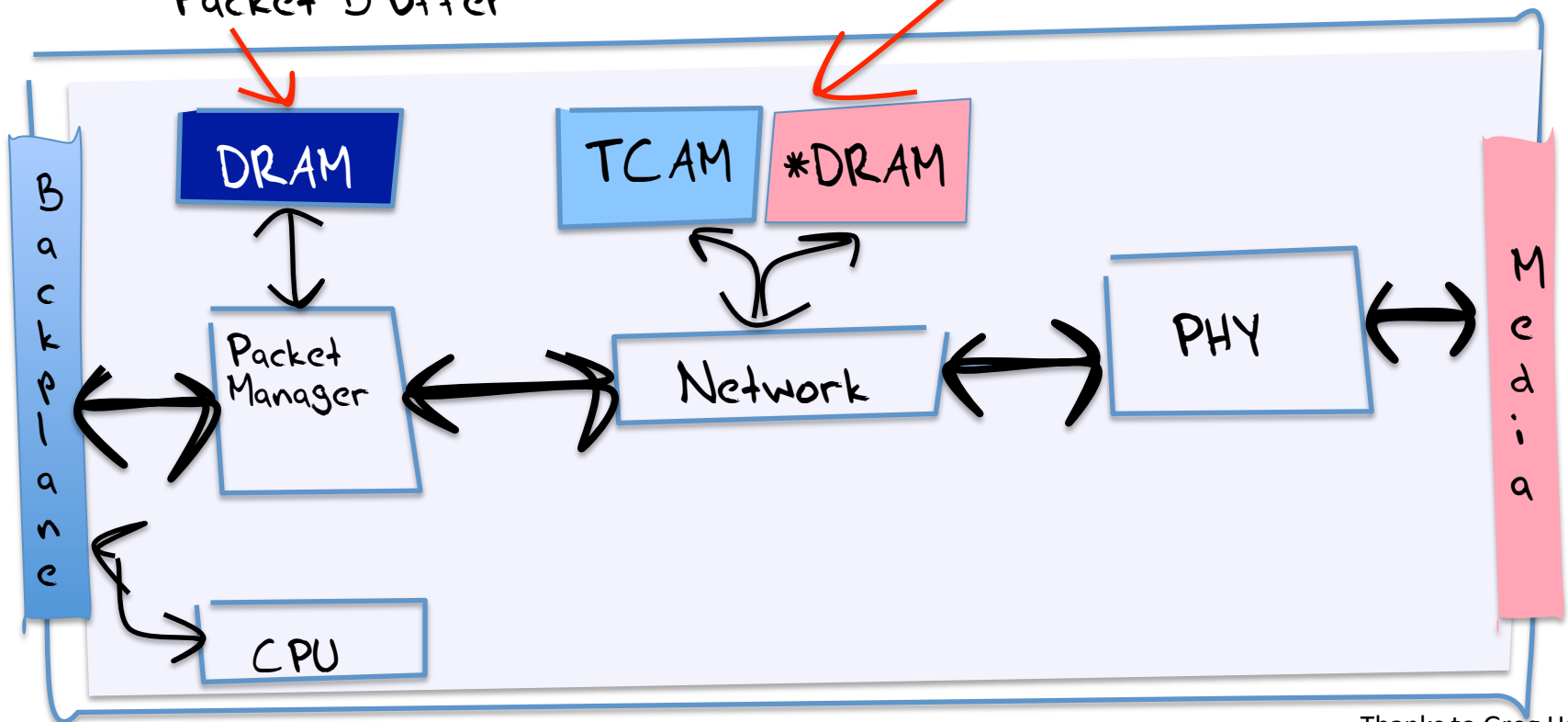


Inside a line card

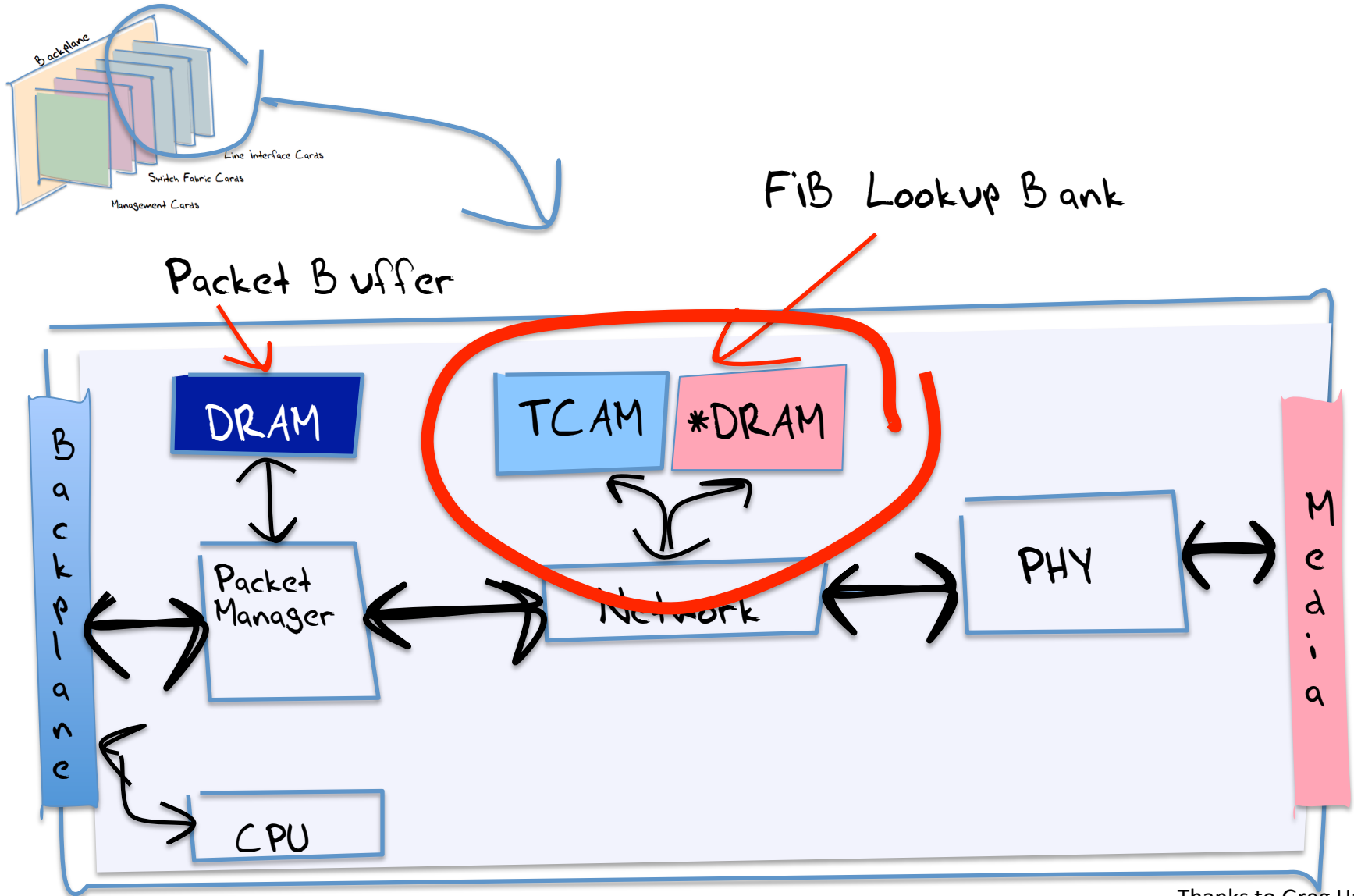


FIB Lookup Bank

Packet Buffer



Inside a line card



FIB Lookup Memory

The interface card's network processor passes the packet's destination address to the FIB module.

The FIB module returns with an outbound interface index

FIB Lookup

This can be achieved by:

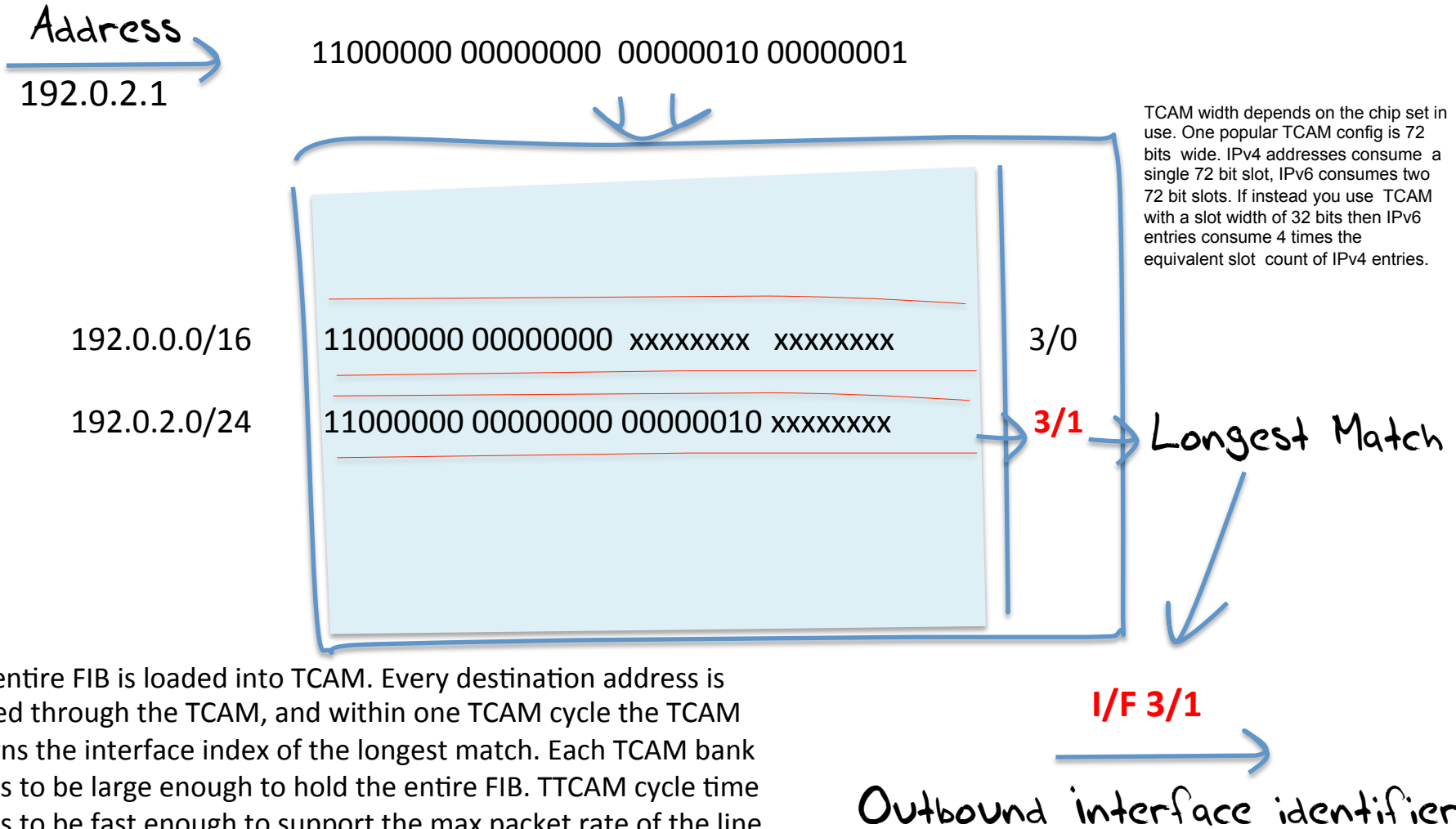
- Loading the entire routing table into a Ternary Content Addressable Memory bank (**TCAM**)

or

- Using an ASIC implementation of a TRIE representation of the routing table with **DRAM** memory to hold the routing table

Either way, this needs **fast** memory

TCAM Memory

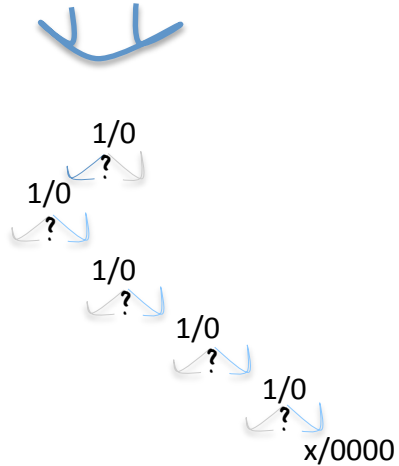
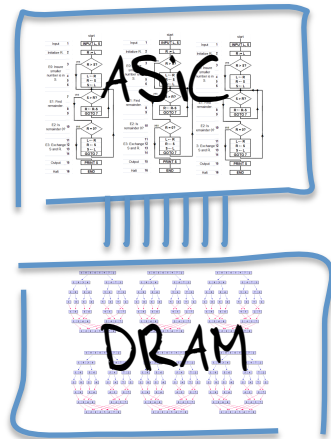


TCAM width depends on the chip set in use. One popular TCAM config is 72 bits wide. IPv4 addresses consume a single 72 bit slot, IPv6 consumes two 72 bit slots. If instead you use TCAM with a slot width of 32 bits then IPv6 entries consume 4 times the equivalent slot count of IPv4 entries.

The entire FIB is loaded into TCAM. Every destination address is passed through the TCAM, and within one TCAM cycle the TCAM returns the interface index of the longest match. Each TCAM bank needs to be large enough to hold the entire FIB. TTCAM cycle time needs to be fast enough to support the max packet rate of the line card.

TRIE Lookup

Address → 11000000 00000000 00000010 00000001
192.0.2.1



...

The entire FIB is converted into a serial decision tree. The size of decision tree depends on the distribution of prefix values in the FIB. The performance of the TRIE depends on the algorithm used in the ASIC and the number of serial decisions used to reach a decision



I/F 3/1



Outbound interface identifier

Memory Tradeoffs

	TCAM	ASIC + RLDRAM 3
Access Speed	Lower	Higher
\$ per bit	Higher	Lower
Power	Higher	Lower
Density	Higher	Lower
Physical Size	Larger	Smaller
Capacity	80Mbit	1G bit

Memory Tradeoffs

TCAMs are higher cost, but operate with a fixed search latency and a fixed add/delete time. TCAMs scale linearly with the size of the FIB

ASICs implement a TRIE in memory. The cost is lower, but the search and add/delete times are variable. The performance of the lookup depends on the chosen algorithm. The memory efficiency of the TRIE depends on the prefix distribution and the particular algorithm used to manage the data structure

Size

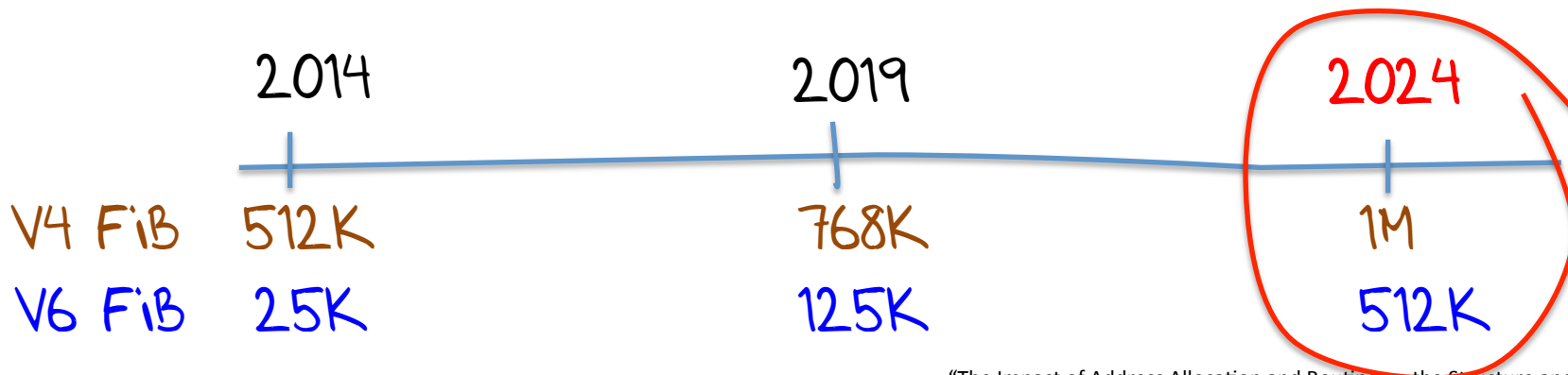
What memory size do we need for **10 years** of FIB growth from today?

TCAM

V4: 2M entries (1G+)
plus
V6: 1M entries (2G+)

Trie

V4: 100Mbit memory (500M+)
plus
V6: 200Mbit memory (1G+)



Scaling the FIB

BGP table growth is slow enough that we can continue to use simple FIB lookup in linecards without straining the state of the art in memory capacity

However, if it all turns horrible, there are alternatives to using a complete FIB in memory, which are at the moment variously robust and variously viable:

- FIB compression

- MPLS

- Locator/ID Separation (LISP)

- OpenFlow/Software Defined Networking (SDN)

But it's not just size

It's speed as well.

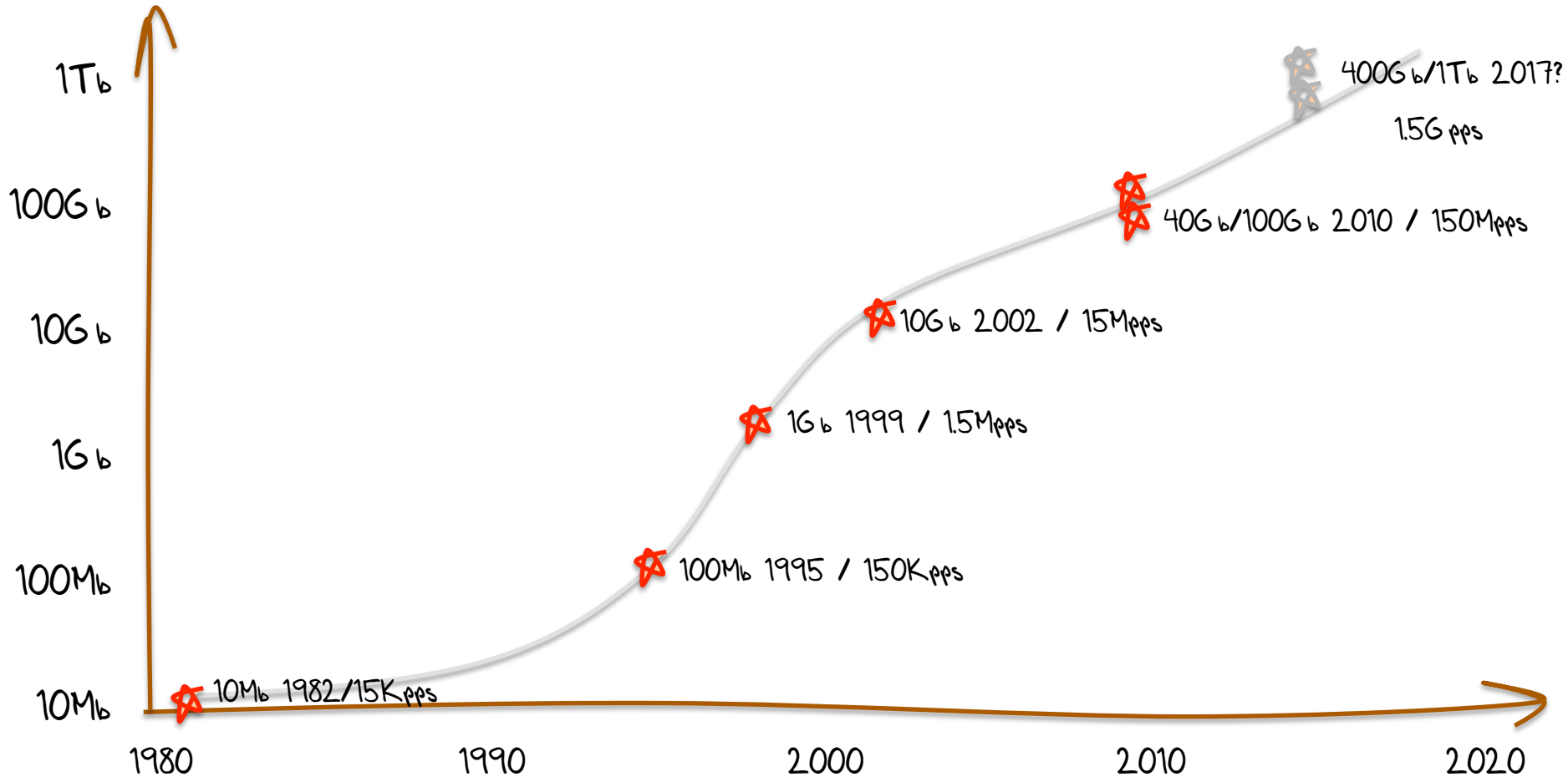
10Mb Ethernet had a 64 byte min packet size, plus preamble plus inter-packet spacing

=14,880 pps

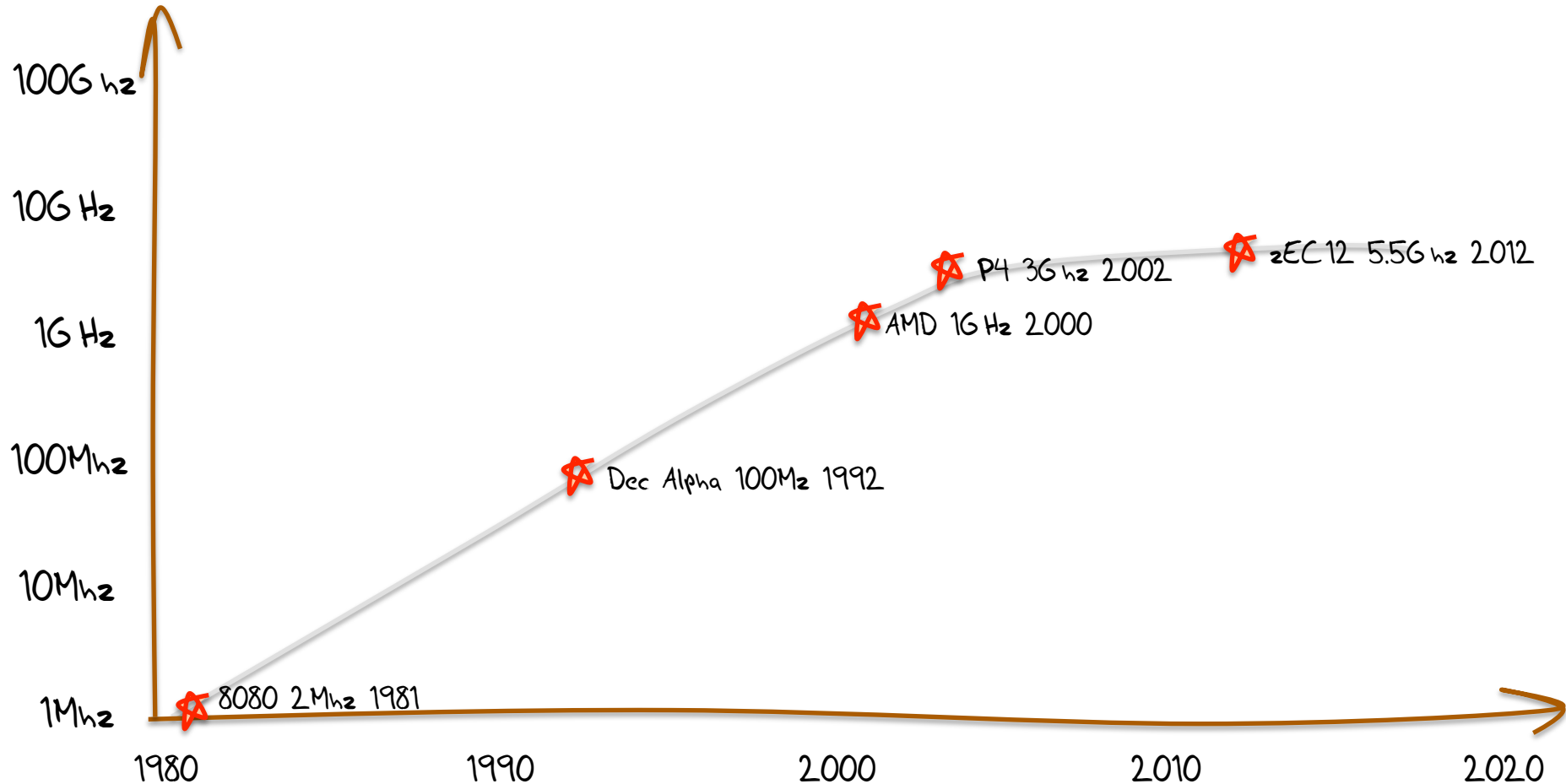
=1 packet every 67usec

We've increased speed of circuits, but left the Ethernet framing and packet size limits largely unaltered. What does this imply for router memory?

Wireline Speed - Ethernet

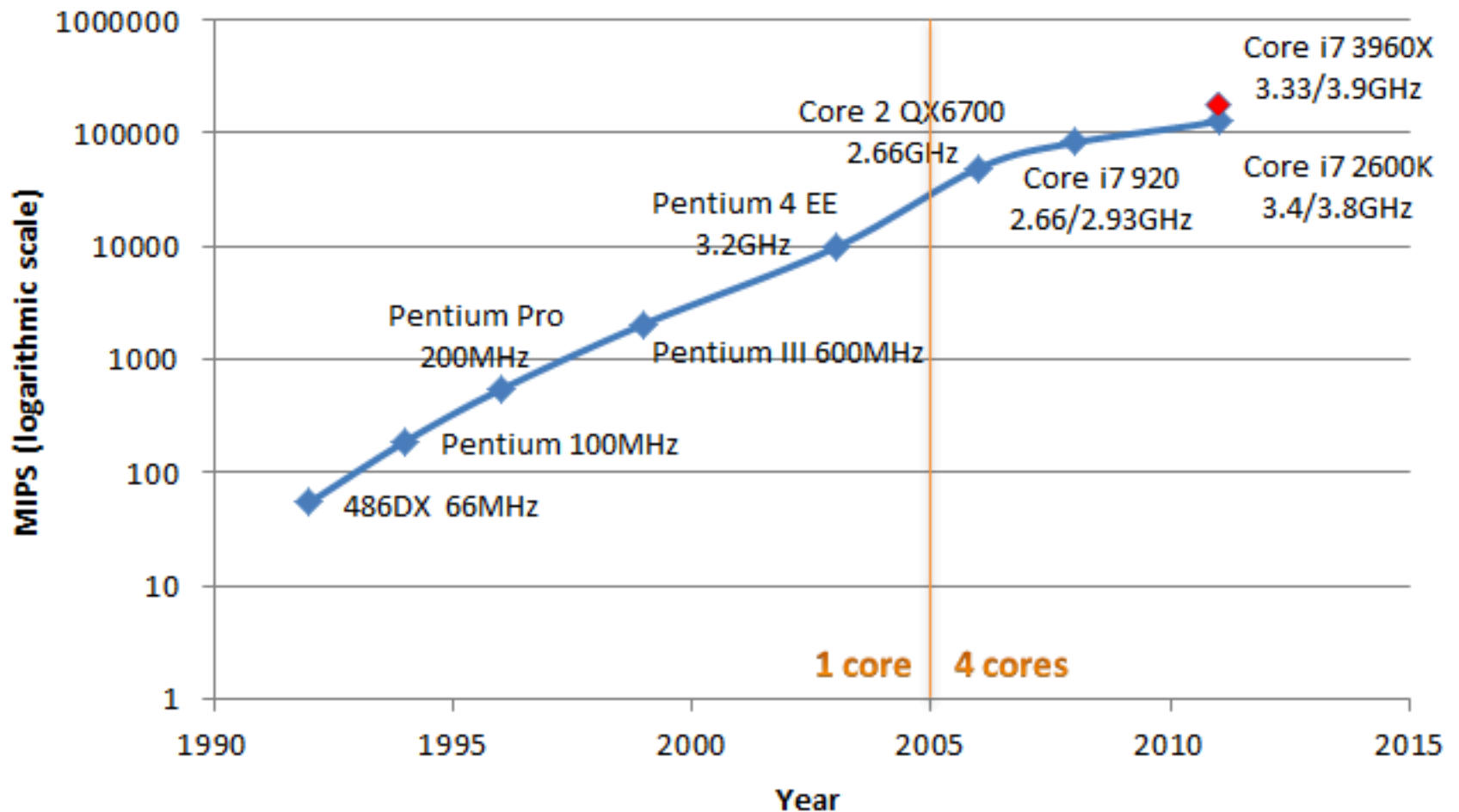


Clock Speed - Processors

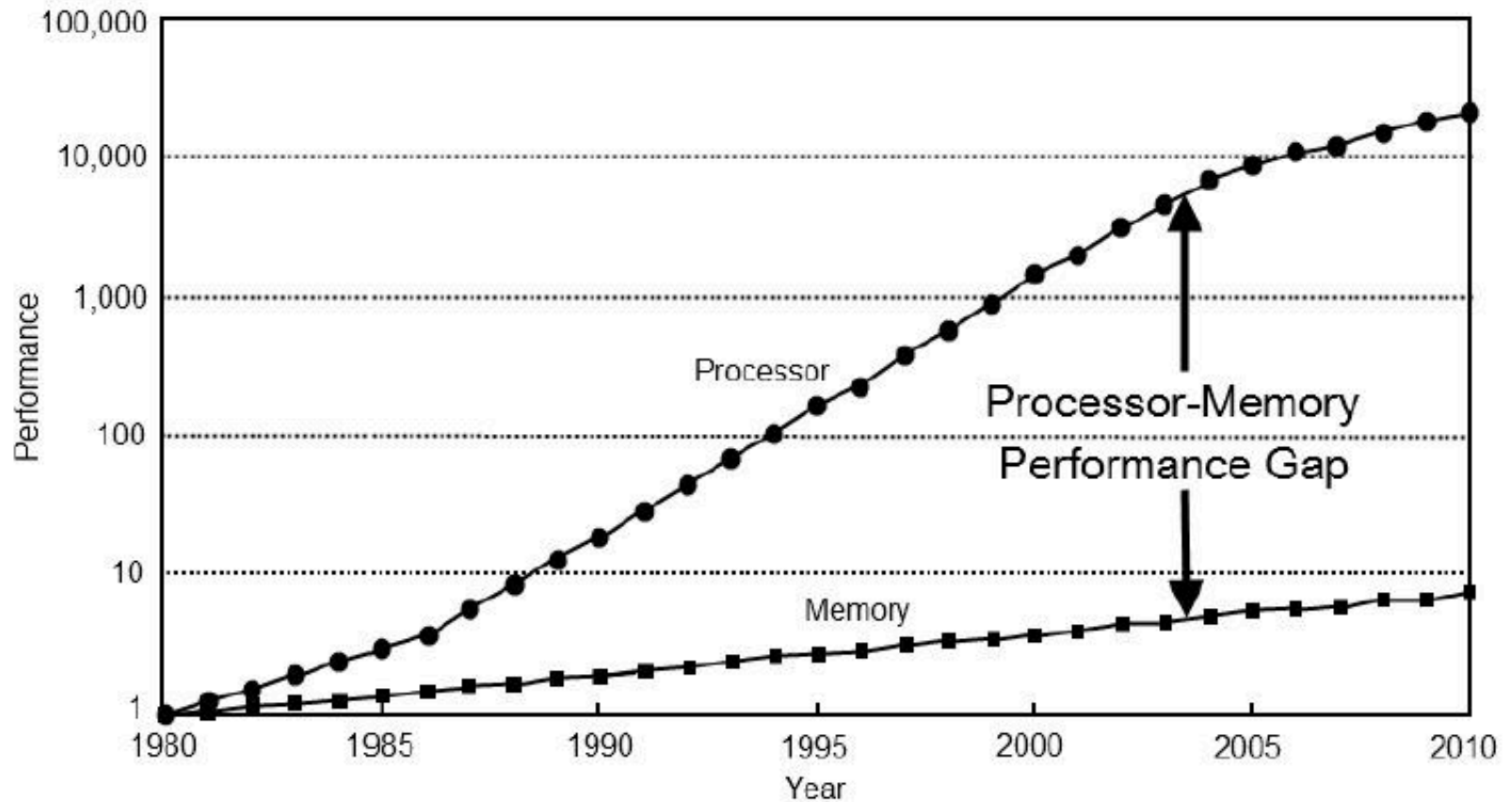


Clock Speed - Processors

Intel CPU Speeds Over Time



CPU vs Memory Speed



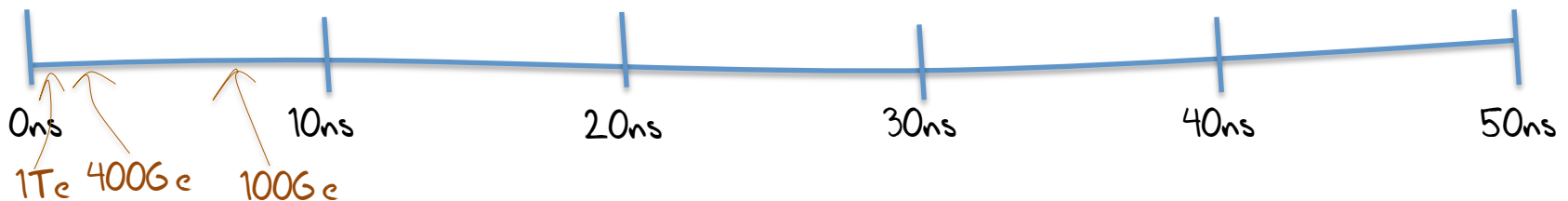
Speed, Speed, Speed

What memory speeds are necessary to sustain a maximal packet rate?

$$100G E \approx 150Mpps \approx 6.7ns \text{ per packet}$$

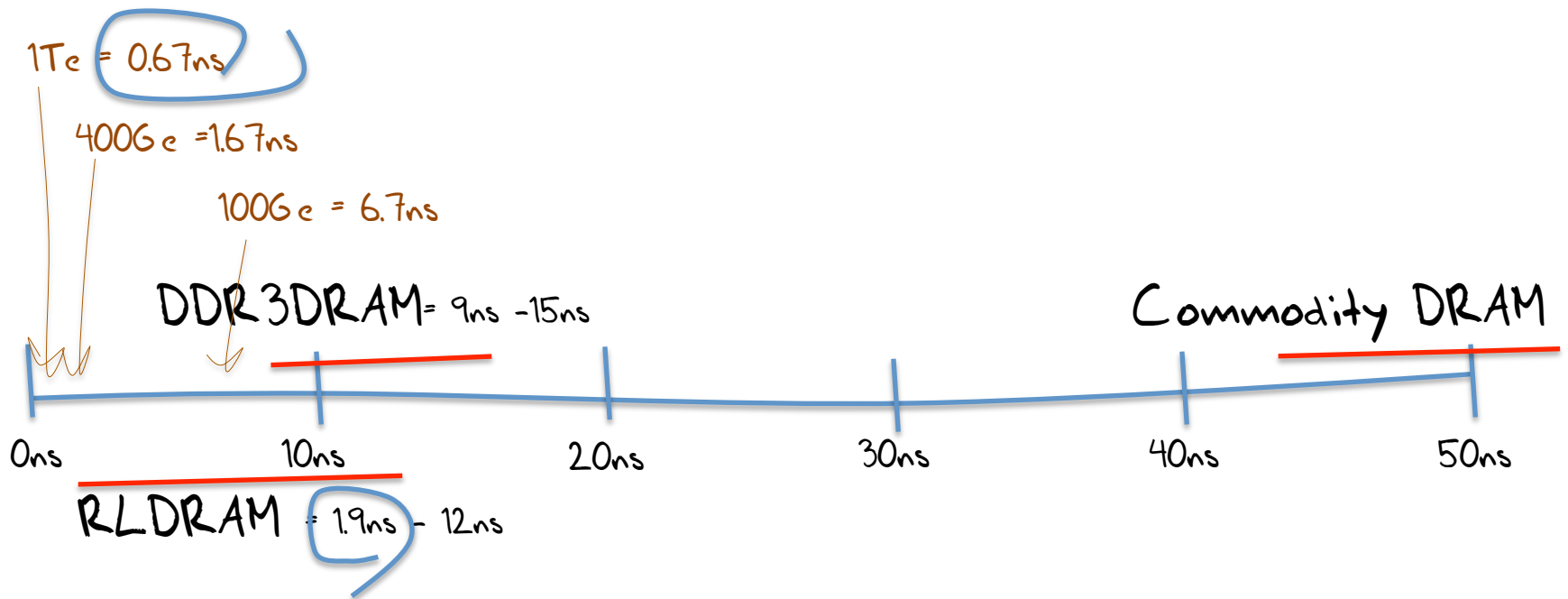
$$400G e \approx 600Mpps \approx 1.6ns \text{ per packet}$$

$$1Te \approx 1.5Gpps \approx 0.67ns \text{ per packet}$$



Speed, Speed, Speed

What memory speeds do we have today?



Scaling Speed

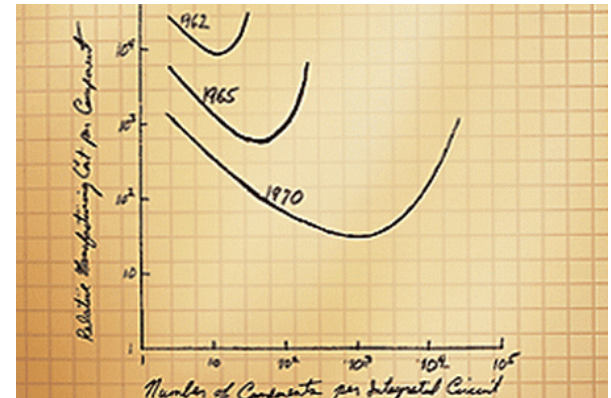
Scaling size is not a dramatic problem today
Scaling speed is going to be tougher over time

Moore's Law talks about the number of gates per circuit, but not circuit clocking speeds

Speed and capacity could be the major design challenge for network equipment in the coming years

If we can't route the max packet rate for a terrabit wire then:

- If we want to exploit parallelism as an alternative to wireline speed for terrabit networks, then is the use of best path routing protocols, coupled with destination-based hop-based forwarding going to scale?
- Or are we going to need to look at path-pinned routing architectures to provide stable flow-level parallelism within the network to limit aggregate flow volumes?
- Or should we reduce the max packet rate by moving away from a 64byte min packet size?



<http://www.startupinnovation.org/research/moores-law/>

Thank You

Questions?