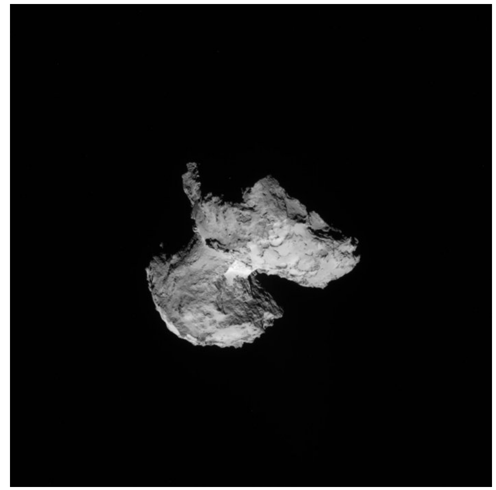
What's so special about the number 512?

Geoff Huston
Chief Scientist, APNIC Labs
1 September 2014

12 August 2014

World Elephant Day



Rosetta closes in on comet 67P/Churyumov-Gerasimenko

Newborn Panda Triplets in China

Violence continues in the Gaza Strip

The Telegraph

Is the Internet full? Major sites brought problems

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

The Switch

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

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By Andrea Peterson August 13 Follow @kansasalps

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.

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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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By DREW FITZGERALD CONNECT
Updated Aug. 13, 2014 7:38 p.m. ET

Network engineers are buzzing that 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
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LATEST IN ONLINE
Internet service dead as a dodo
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Piracy coming apart at the streams
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

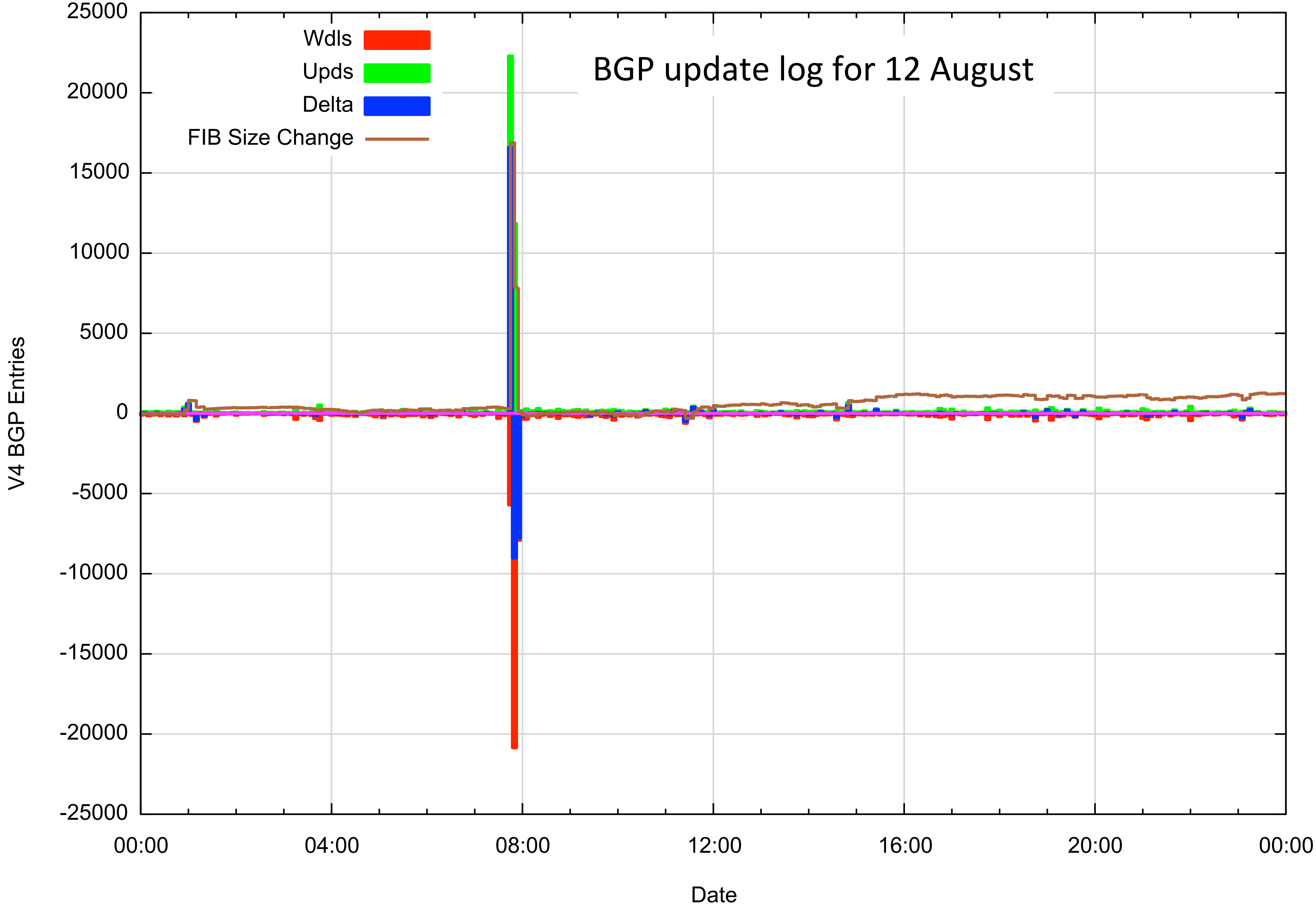
Video Image

STORY BY
Network Writer
News Corp Australia

What happened?

Did we all sneeze at once and cause the routing system to fail?

12 August 2014



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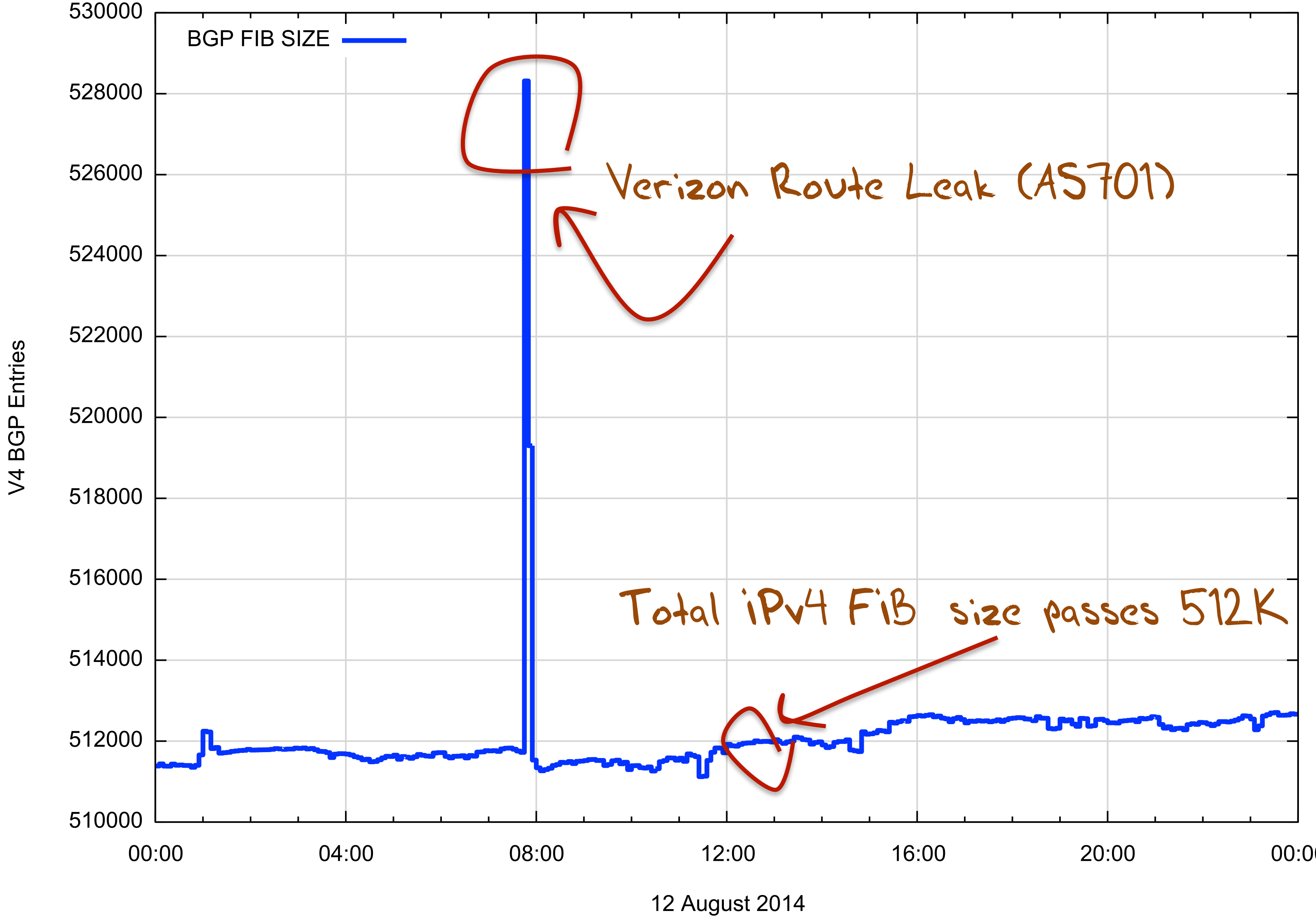

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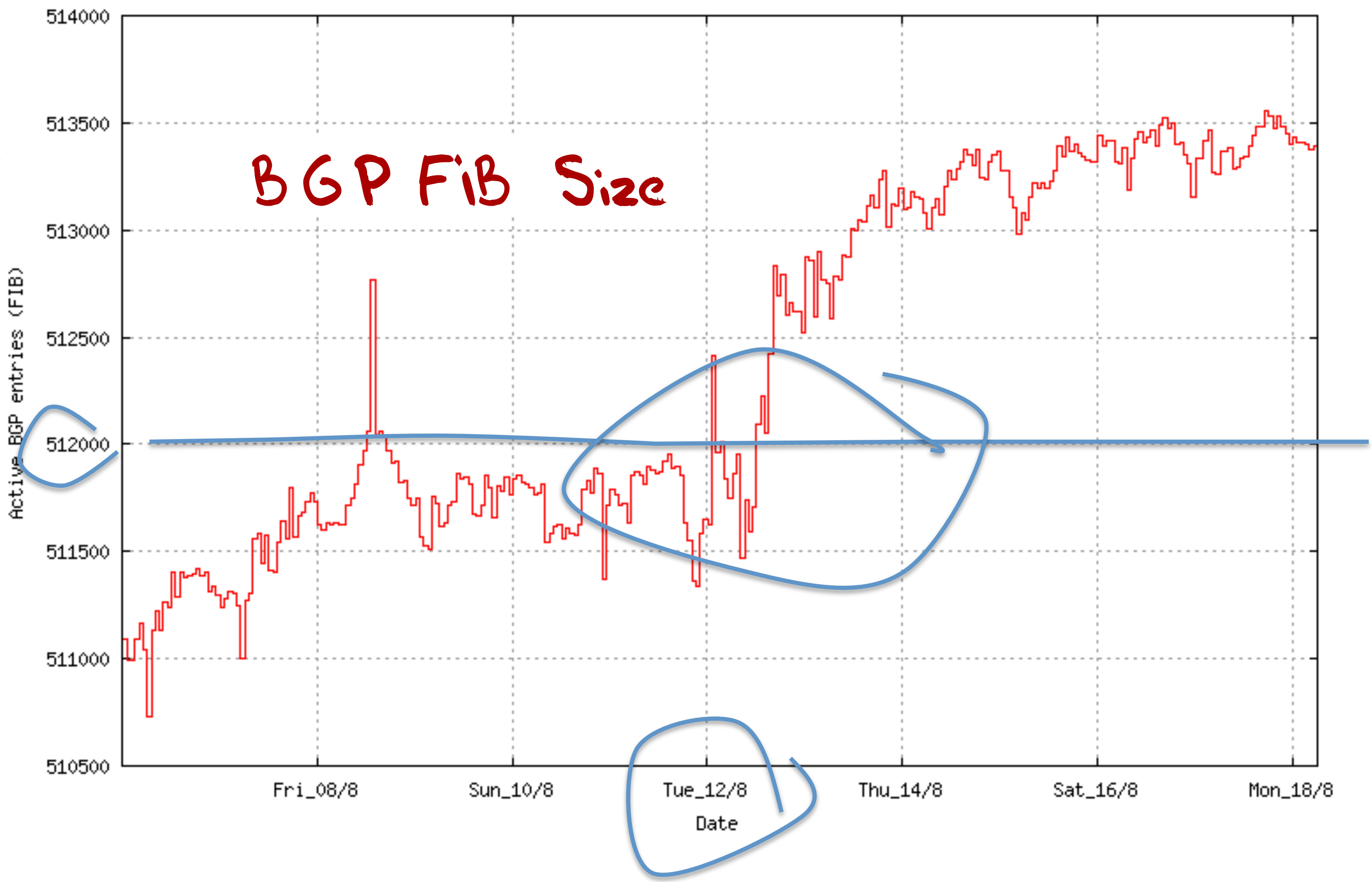

512K is a default constant in some Cisco and Brocade products

http://www.cisco.com/c/en/us/support/docs/switches/catalyst-6500-series-switches/116132-problem-catalyst6500-00.html

Cisco Catalyst 6500 Series Switches

Catalyst 6500 Switches Ternary Content Addressable Memory Customization

Contents

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 millon (1M) IPv4 routes and 512,000 (512k) IPv6 routes. However, default outputs look different:

```
6500#show mls cef 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 cef 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.

TAC

Document ID: 116132
Updated: Jun 04, 2013

Contributed by Shashank Singh, Cisco TAC Engineer.

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- Cisco Catalyst 6500 Borderless Services Node - Cisco
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- Cisco Express Forwarding (CEF)
- Cisco Catalyst 6500 Series Switches

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 cef 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.

Cisco Cat 6500

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

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.

```
Brocade(config) cam-partition profile ipv4
```

Syntax: cam-partition profile [ipv4 | ipv4-ipv6| ipv4-ipv6-2 | ipv4-vpls | ipv4-vpn | ipv6 | l2-metro | l2-metro-2 | mpls-l3vpn | mpls-l3vpn-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 or 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 routers, 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-l3vpn** 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-l3vpn-2** parameter provides another alternative to **mpls-l3vpn** 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 VPN | IPv6 VPN | IPv4 or L2 Inbound ACL | IPv6 Inbound ACL | IPv4 or L2 Outbound 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

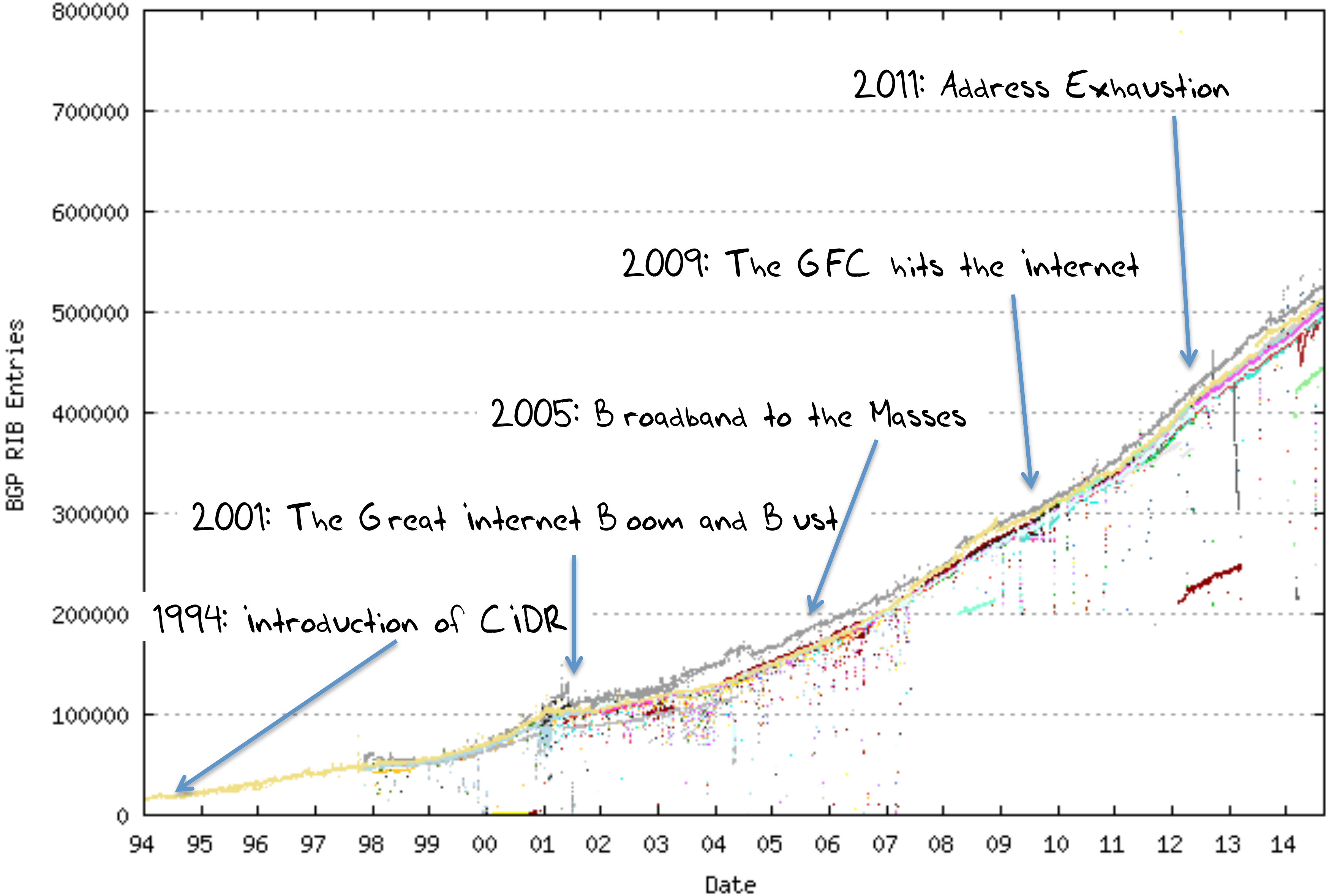
Routing Behaviour

Was the AS701 Route Leak the problem?

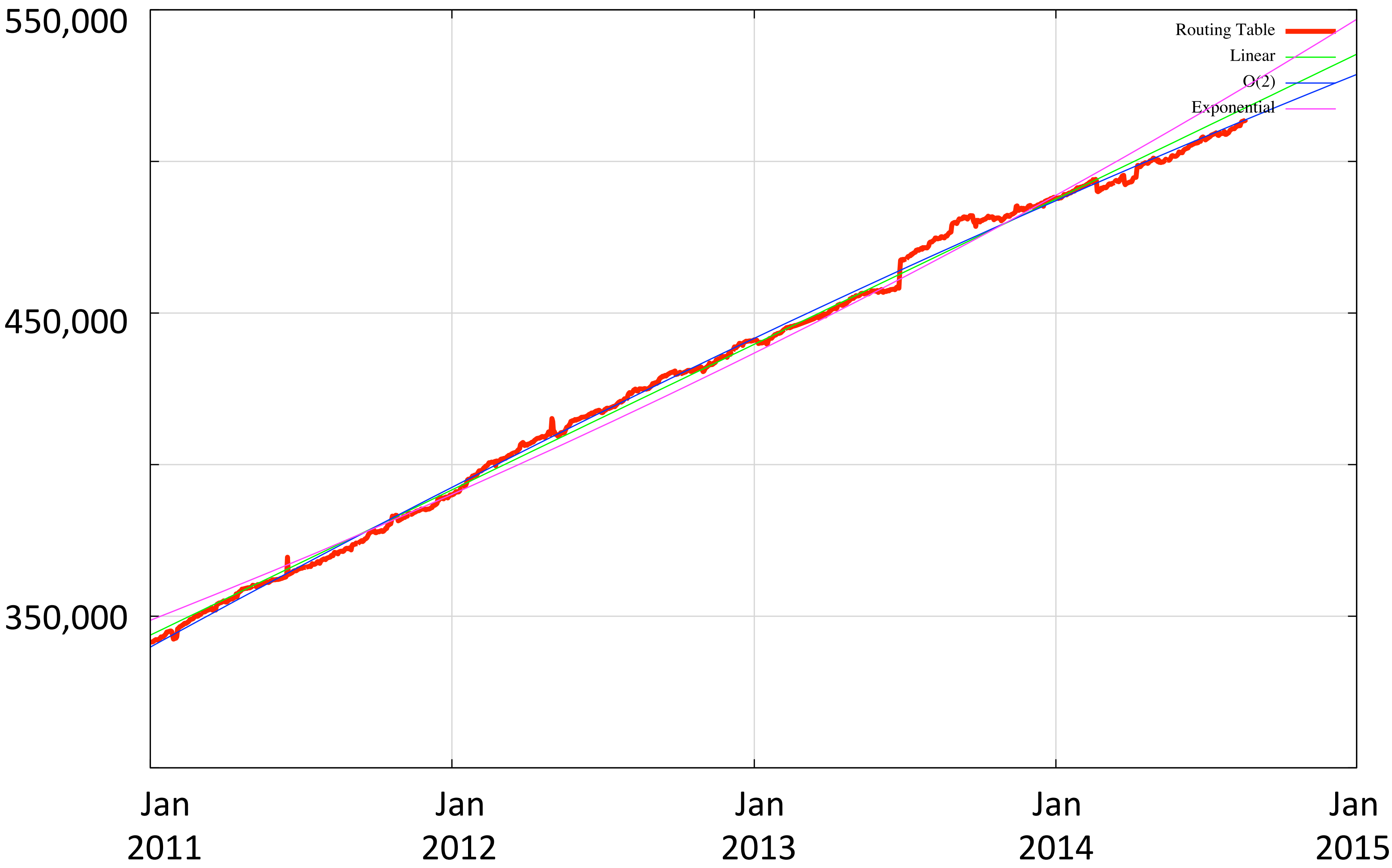
Or was the FIB growth passing 512K entries the problem?

What does routing growth look like anyway?

20 years of routing the Internet



IPv4 BGP Prefix Count 2011 - 2014



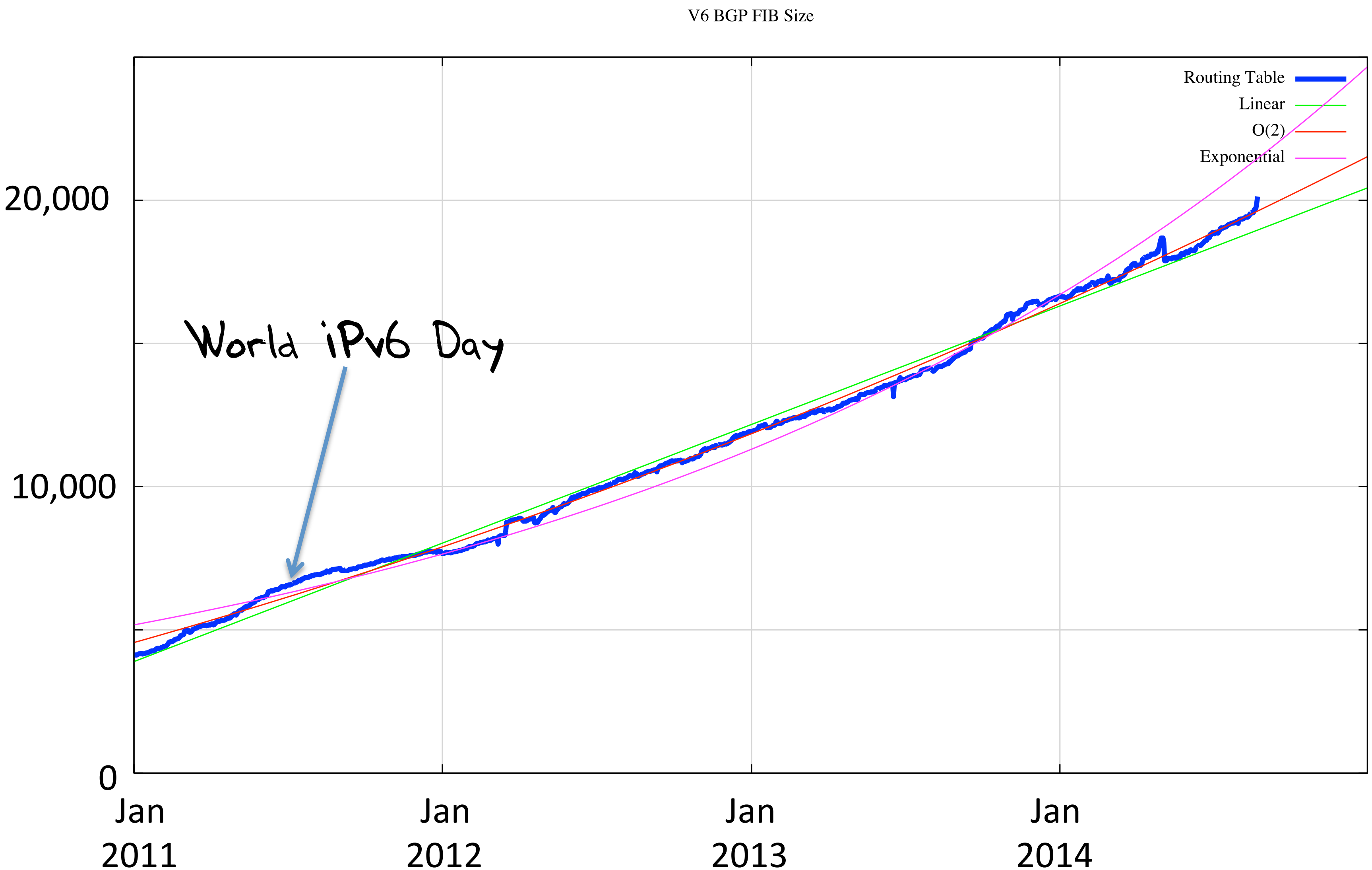
IPv4 2013- 2014 BGP Vital Statistics

	Jan-13	Aug-14	
Prefix Count	440,000	512,000	+ 11% p.a.
Roots	216,000	249,000	+ 9%
More Specifics	224,000	264,000	+ 11%
Address Span	156/8s	162/8s	+ 2%
AS Count	43,000	48,000	+ 7%
Transit	6,100	7,000	+ 9%
Stub	36,900	41,000	+ 7%

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?

IPv6 BGP Prefix Count



IPv6 2013-2014 BGP Vital Statistics

	Jan-13	Aug-14	p.a. rate
Prefix Count	11,500	19,036	+ 39%
Roots	8,451	12,998	+ 32%
More Specifics	3,049	6,038	+ 59%
Address Span (/32s)	65,127	73,153	+ 7%
AS Count	6,560	8,684	+ 19%
Transit	1,260	1,676	+ 20%
Stub	5,300	7,008	+ 19%

IPv6 in 2013

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

(Looking at the AS count, if these relative growth rates persist then the IPv6 network would span the same network domain as IPv4 in ~16 years time -- 2030!)

IPv6 in 2013 - Growth is Slowing?

- Overall Internet growth in terms of BGP is at a rate of some **~20-40% p.a.**
- AS growth sub-linear
- The rate of growth of the IPv6 Internet is also slowing down
  - Lack of critical momentum behind IPv6?
  - Saturation of critical market sectors by IPv4?
  - *<some other factor>*?

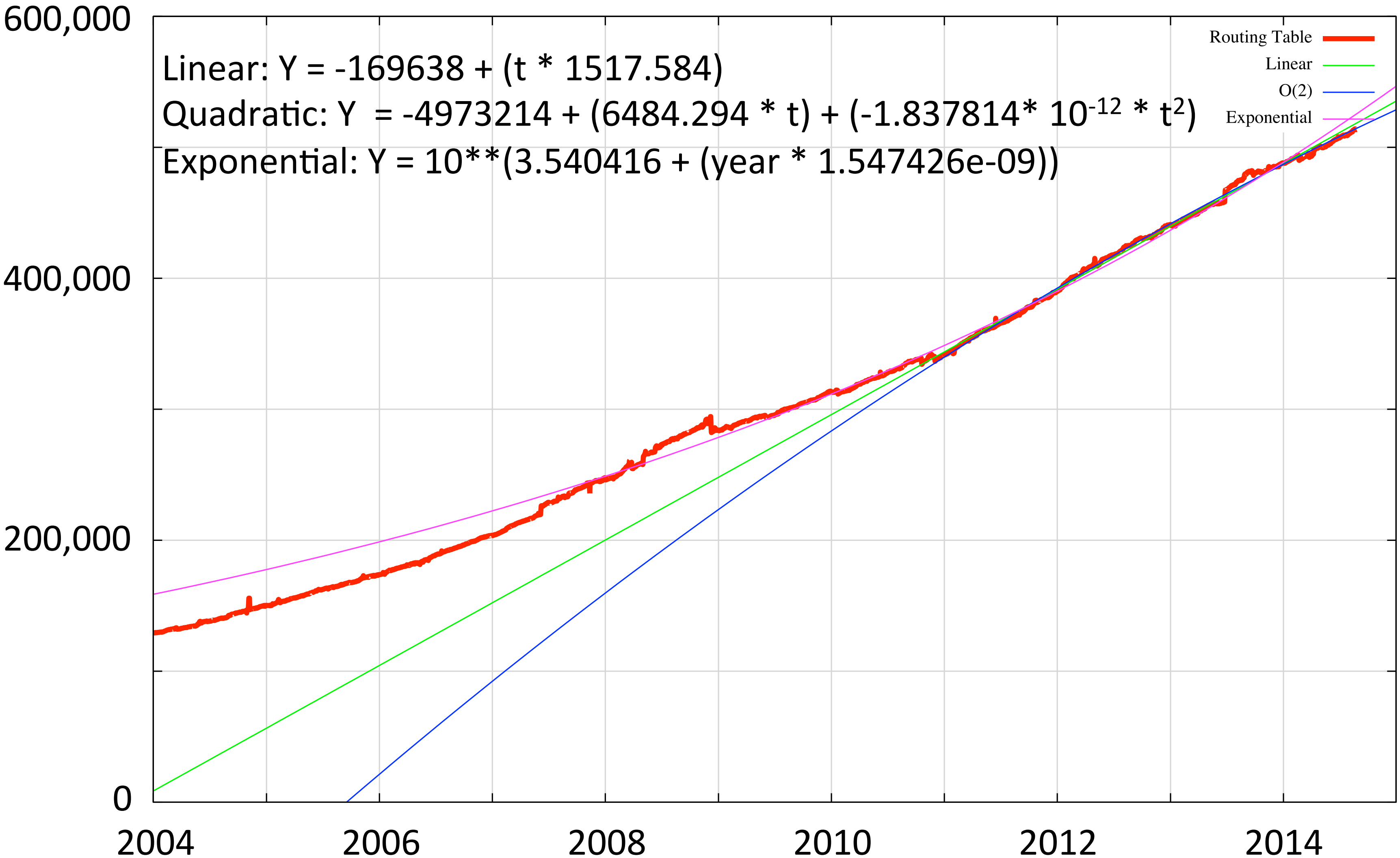
What to expect

BGP Size Projections

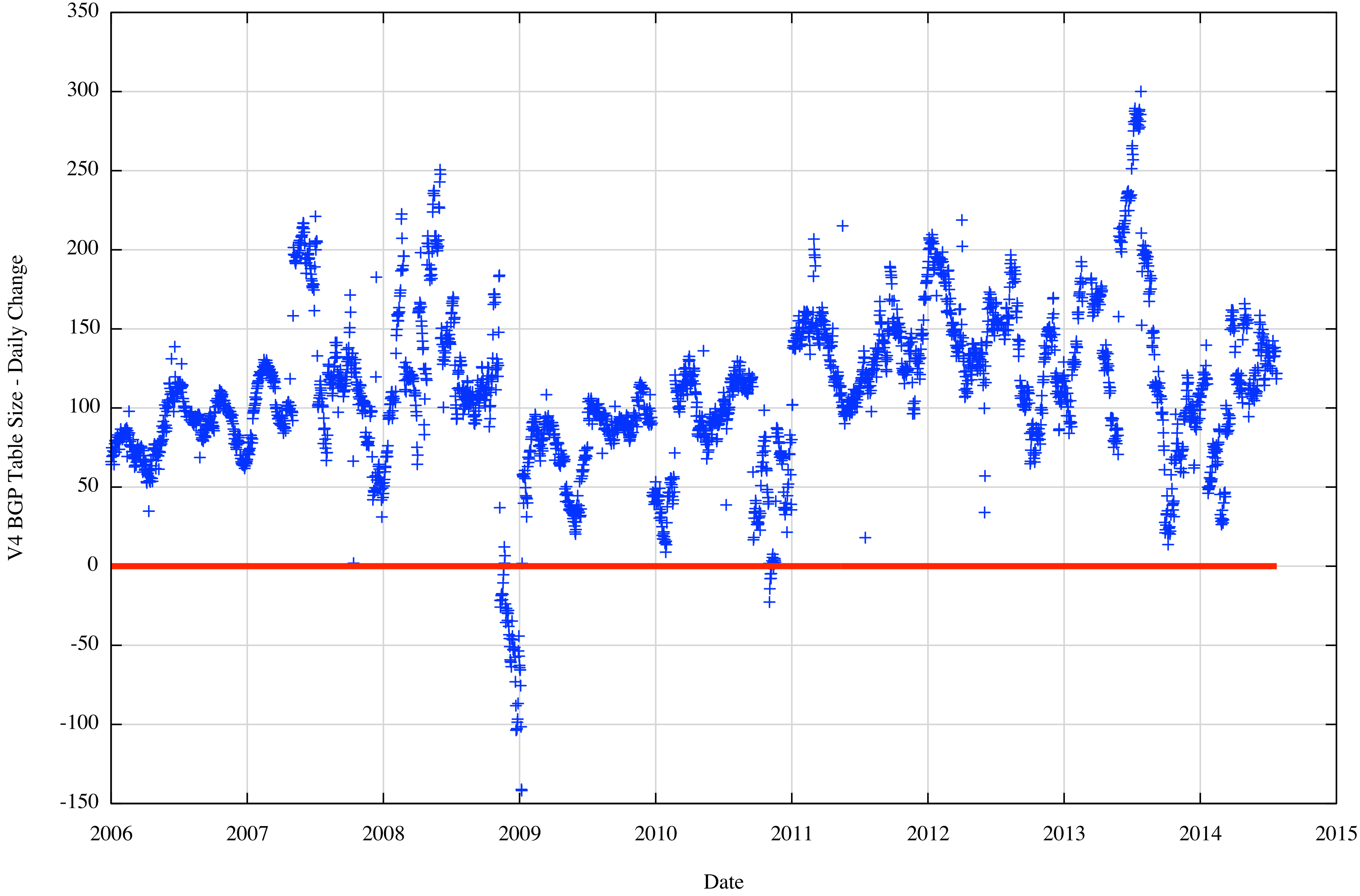
- Generate a projection of the IPv4 routing table using a quadratic (O(2) polynomial) over the historic data
  - For IPv4 this is a time of **extreme uncertainty**
    - Registry IPv4 address run out
    - Uncertainty over the impacts of any after-market in IPv4 on the routing table

    which makes this projection even more speculative than normal!

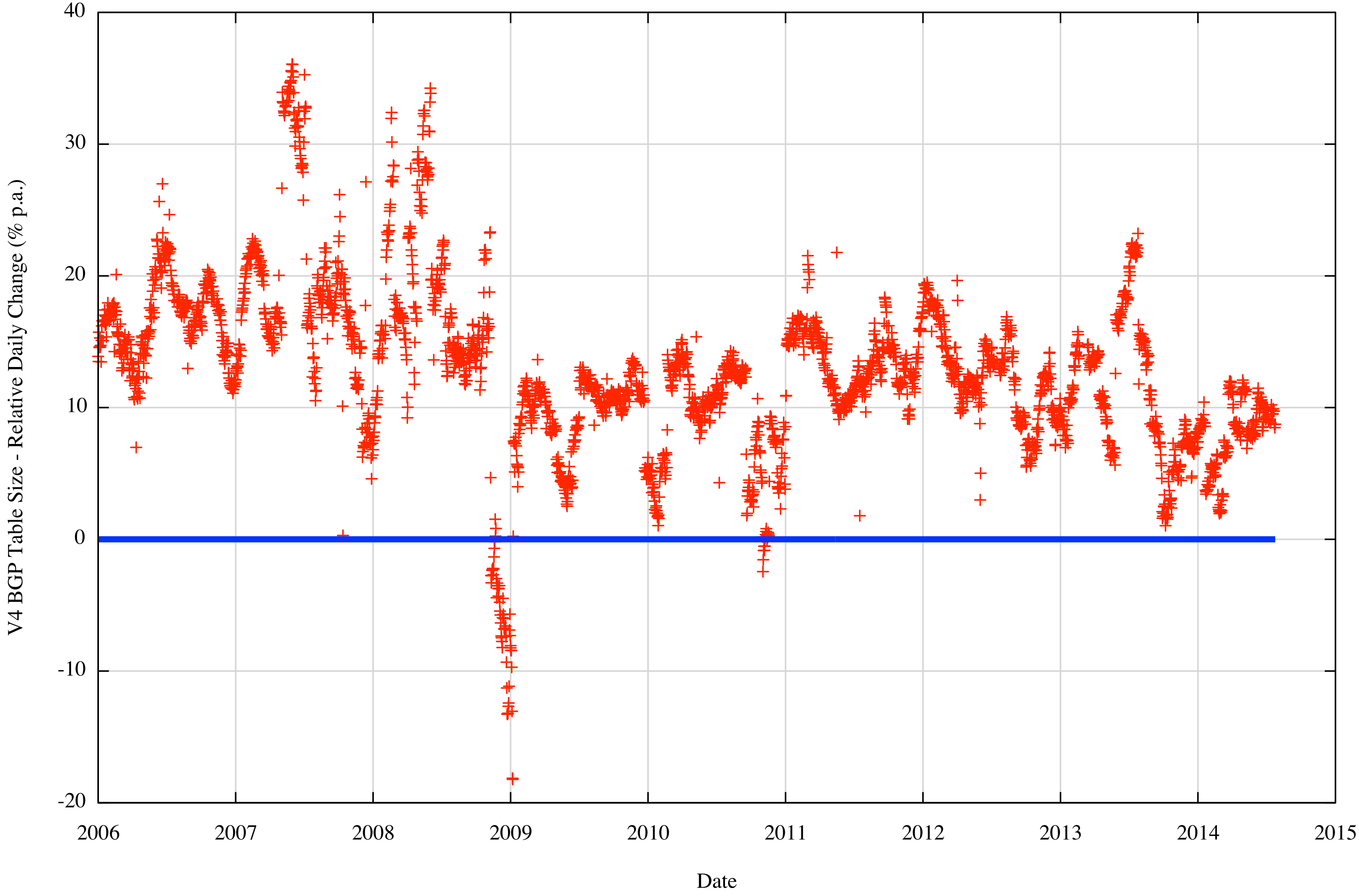
IPv4 Table Size



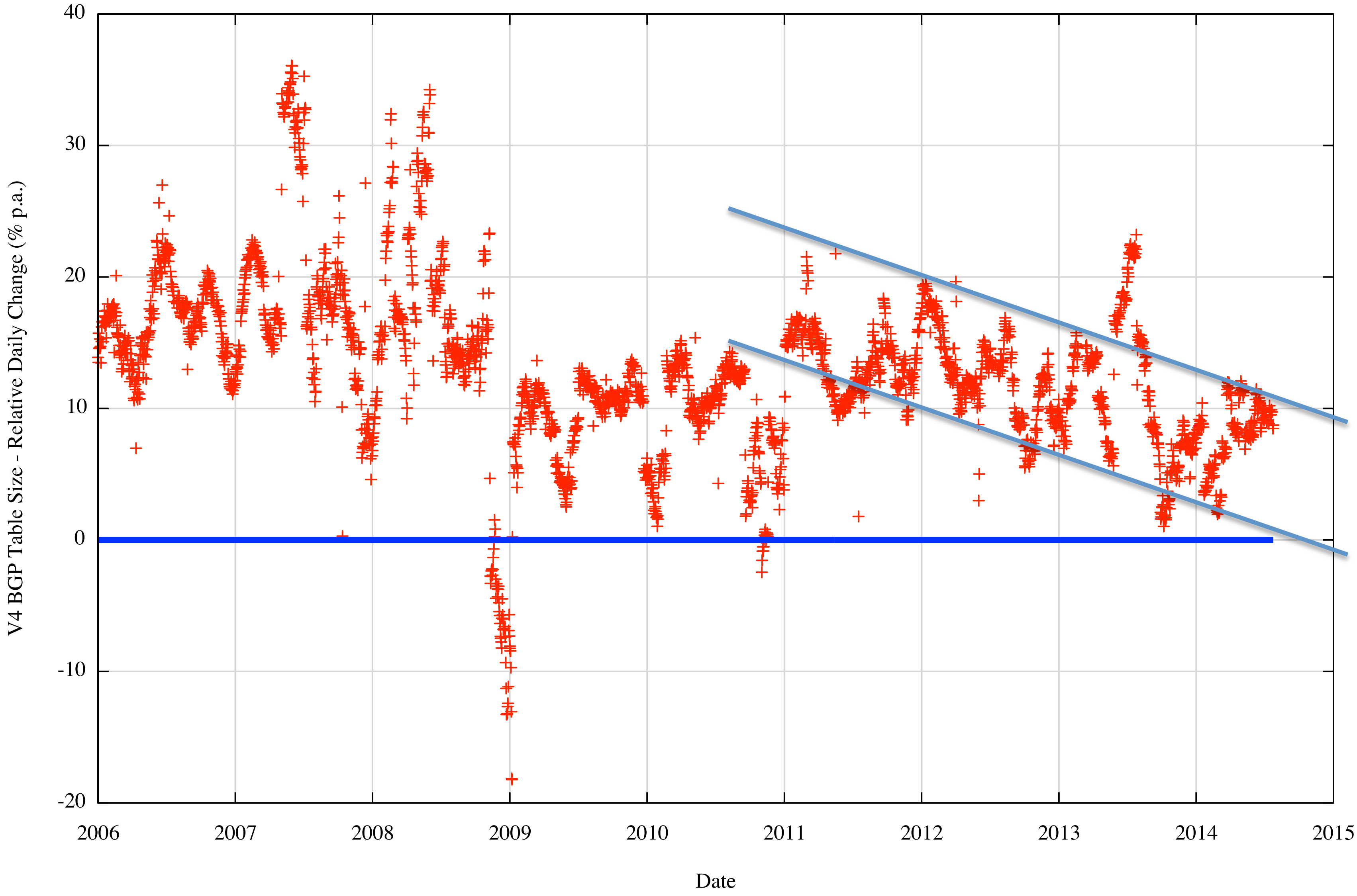
V4 - Daily Growth Rates



V4 - Relative Daily Growth Rates



V4 - Relative Daily Growth Rates

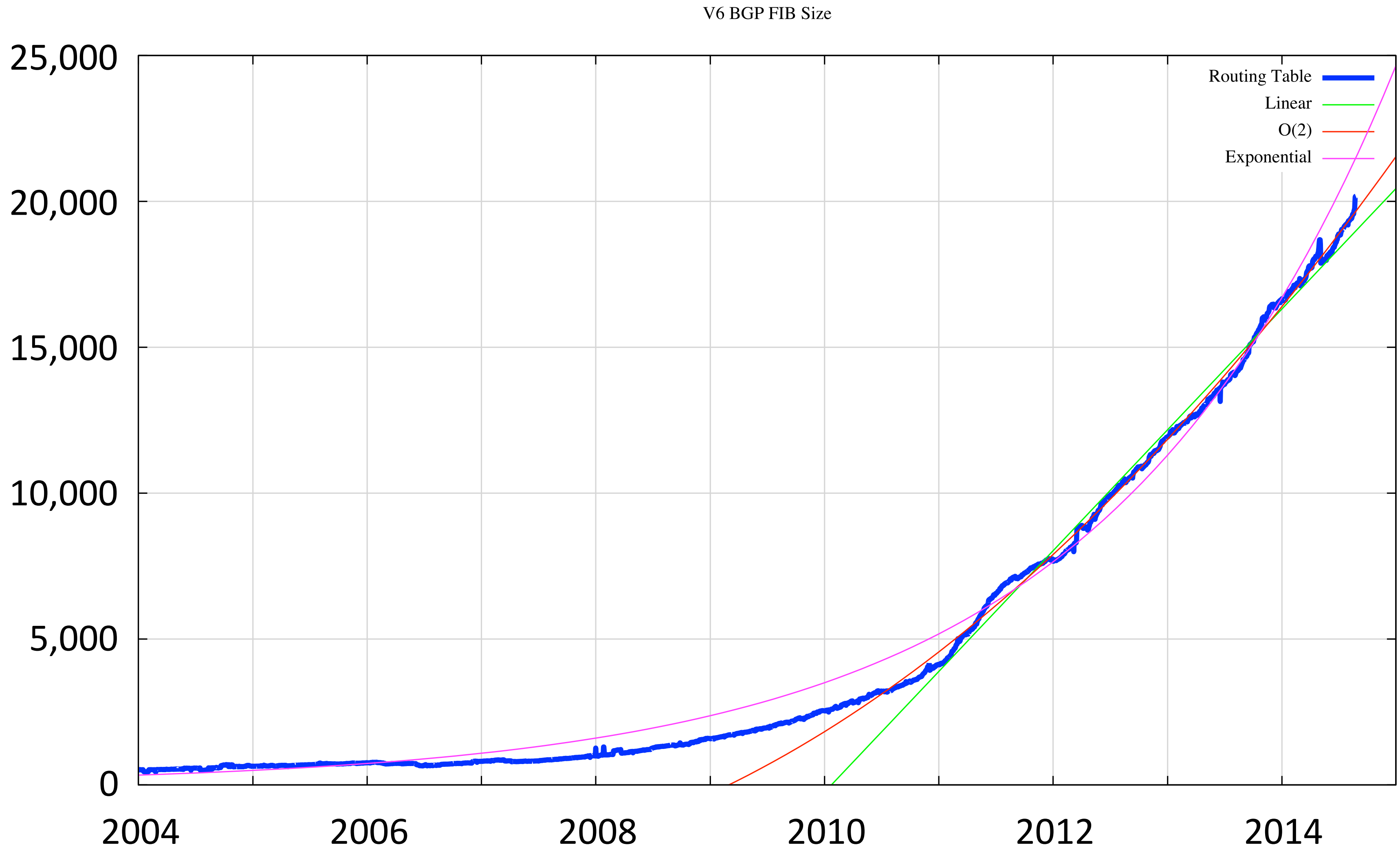


IPv4 BGP Table Size predictions

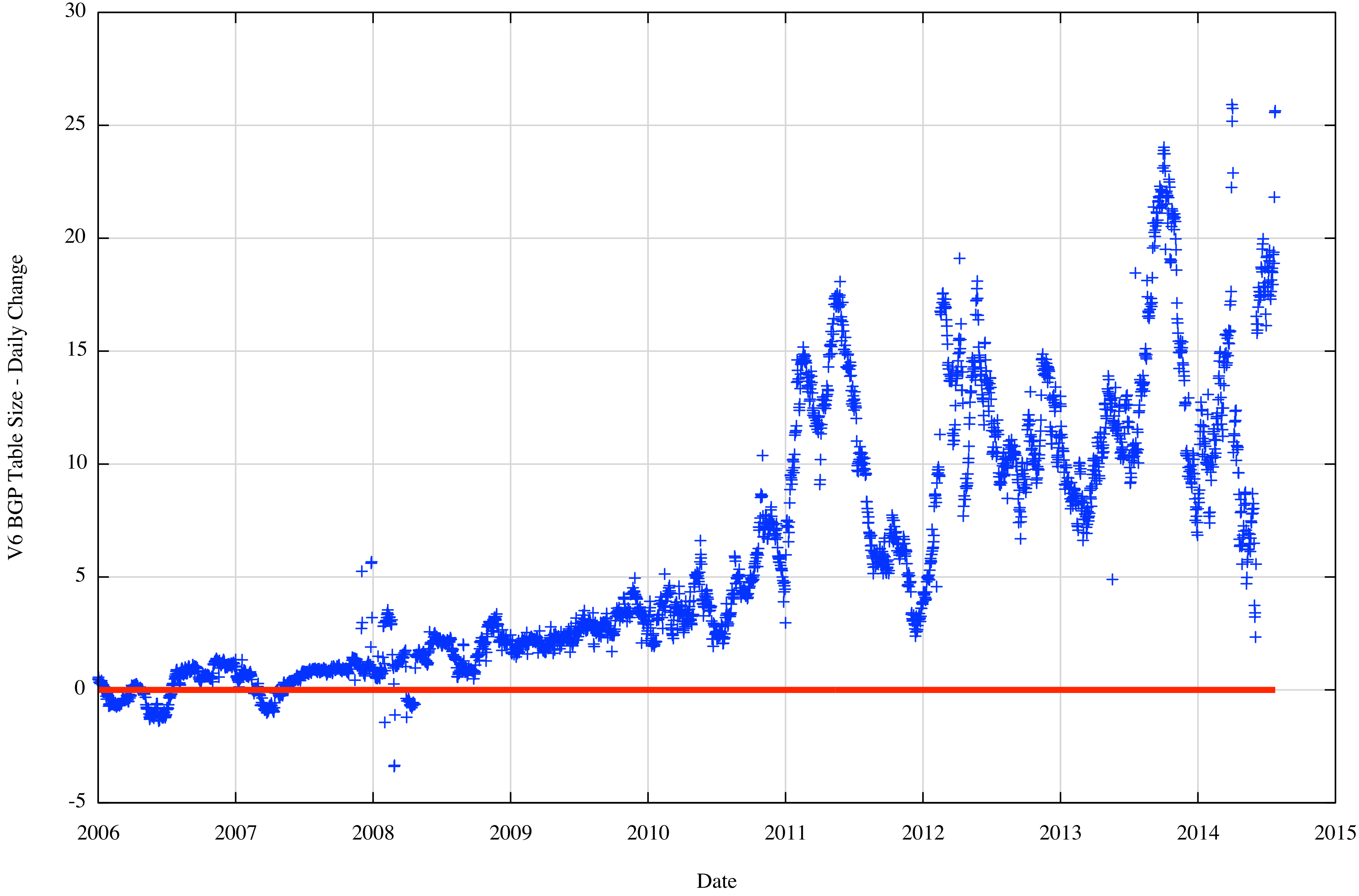
	Linear Model	Exponential Model
Jan 2013	441,172 entries	
2014	488,011 entries	
2015	*540,000 entries*	*559,000*
2016	*590,000 entries*	*630,000*
2017	*640,000 entries*	*710,000*
2018	*690,000 entries*	*801,000*
2019	*740,000 entries*	*902,000*

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

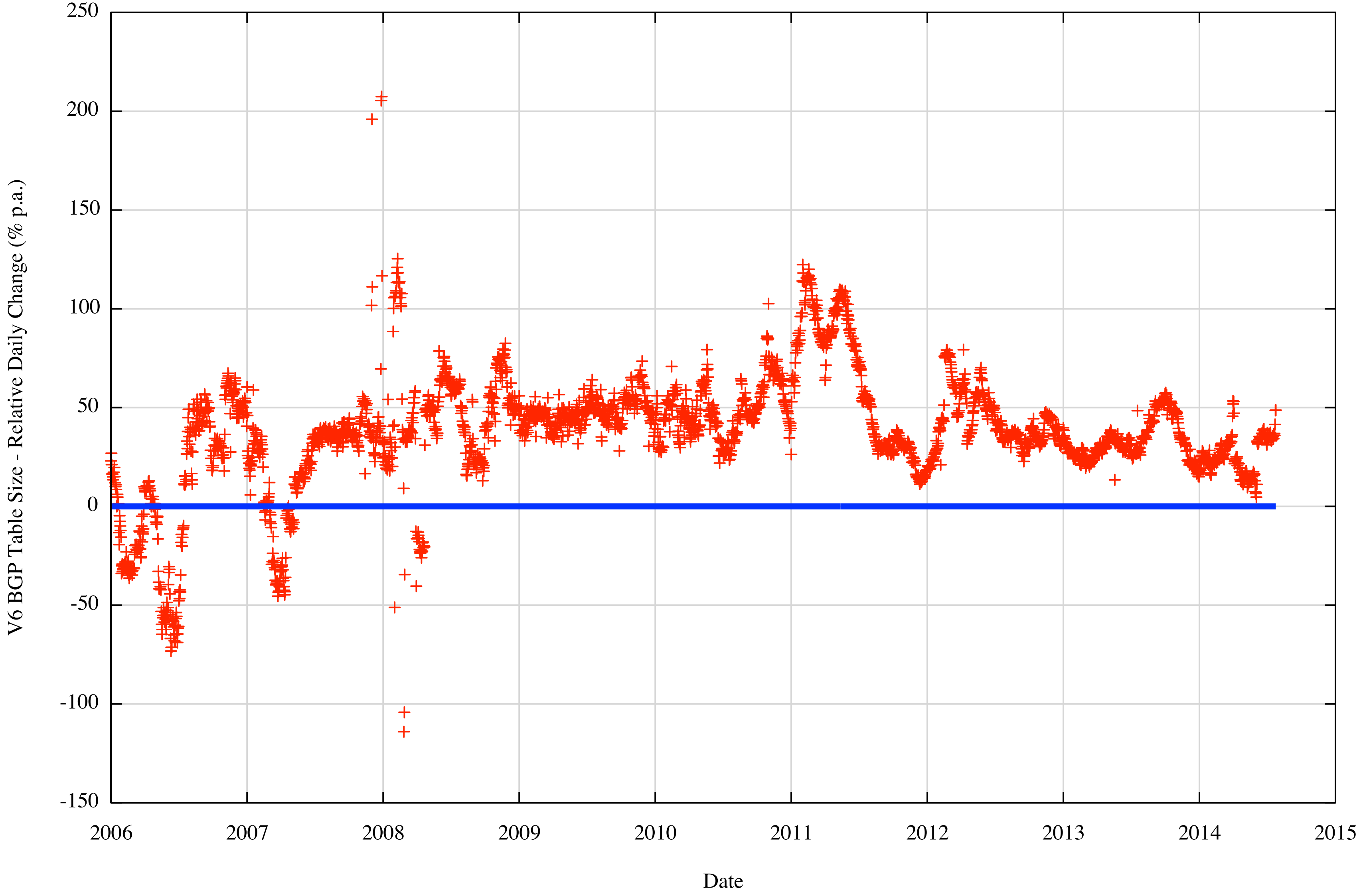
IPv6 Table Size



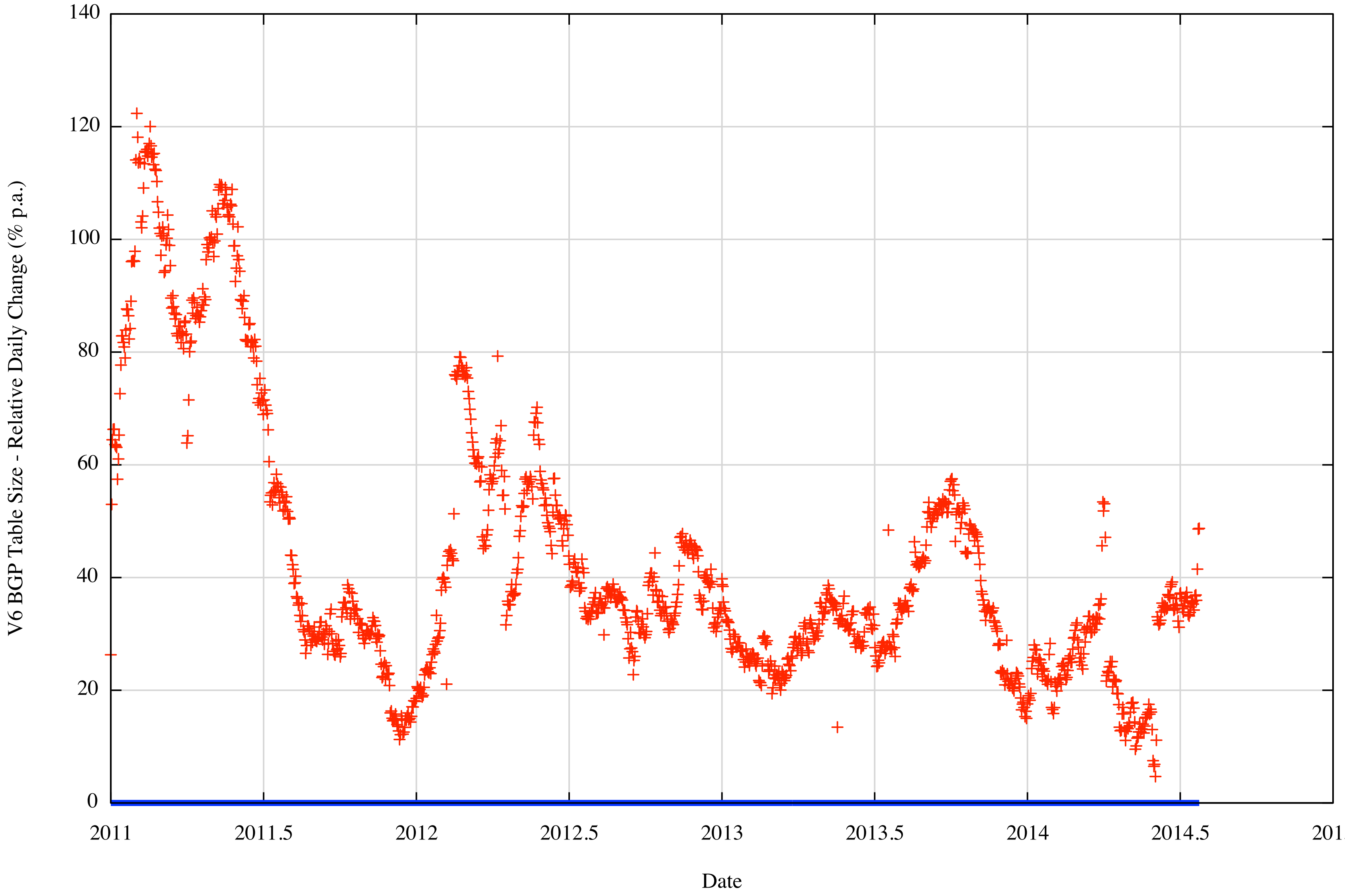
V6 - Daily Growth Rates



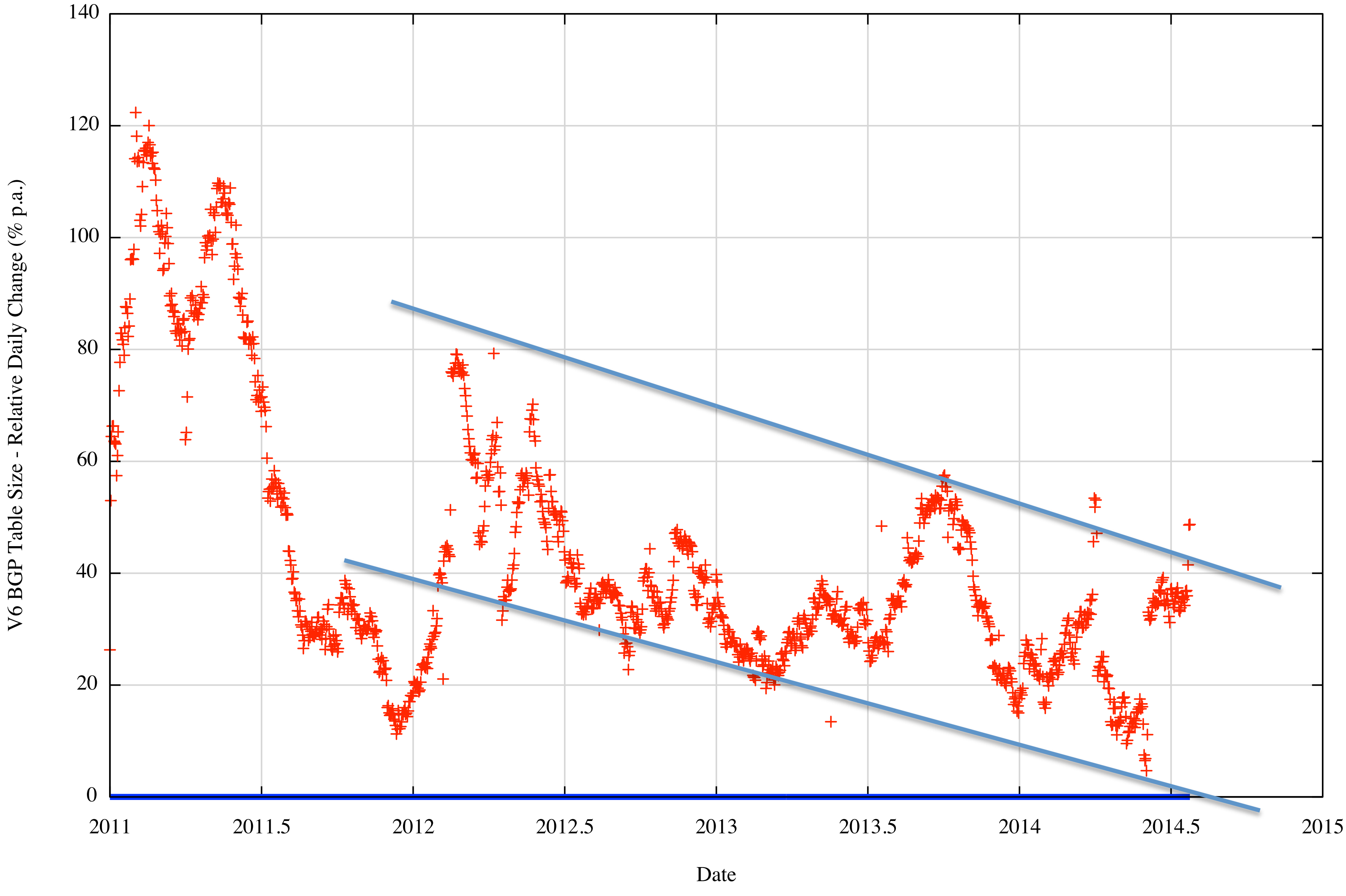
V6 - Relative Growth Rates



V6 - Relative Growth Rates



V6 - Relative Growth Rates



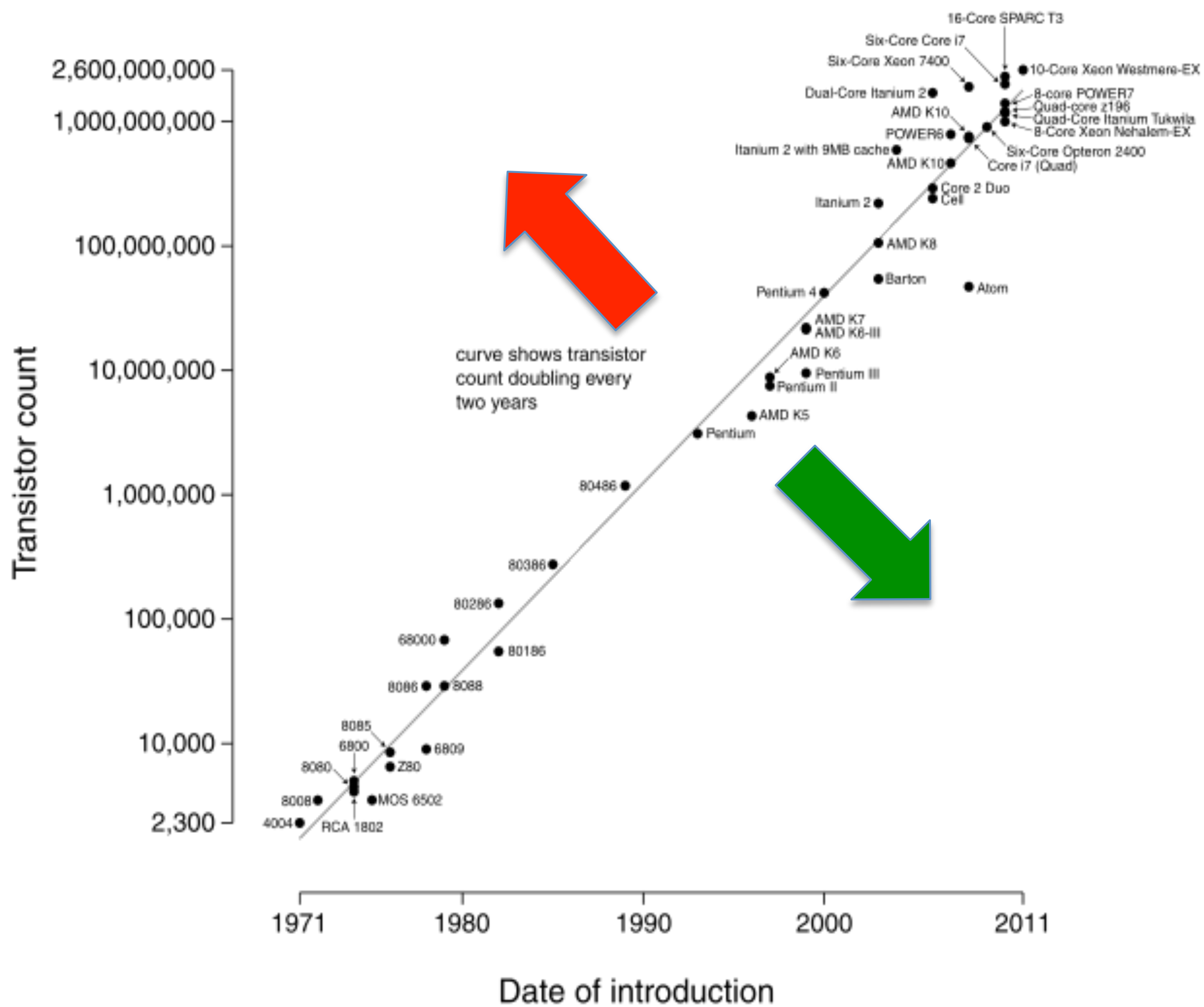
IPv6 BGP Table Size predictions

	Exponential Model	LinearModel
Jan 2013	11,600 entries	
2014	16,200 entries	
2015	*24,600 entries*	*19,000*
2016	*36,400 entries*	*23,000*
2017	*54,000 entries*	*27,000*
2018	*80,000 entries*	*30,000*
2019	*119,000 entries*	*35,000*

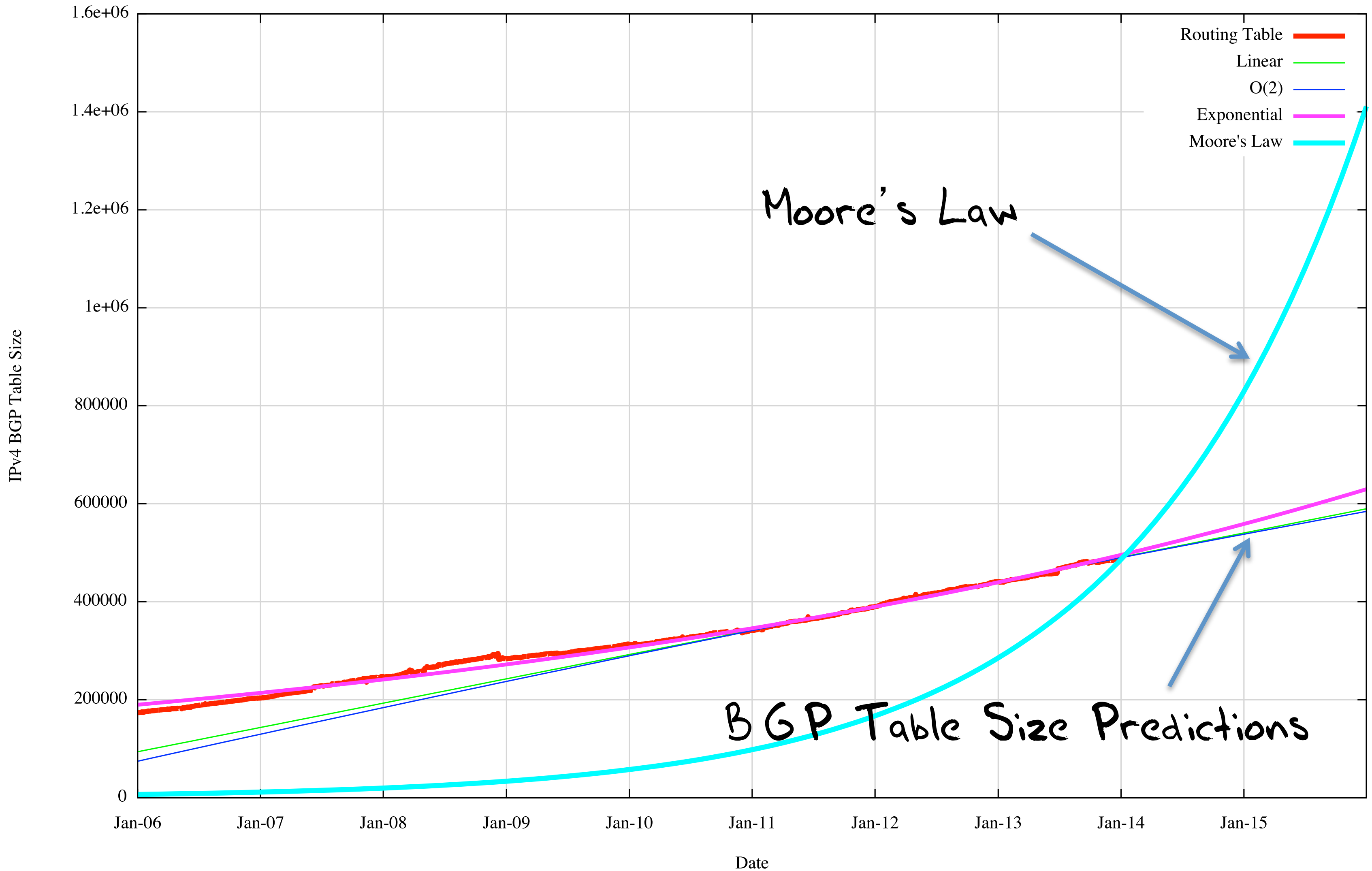
Up and to the Right

- Most Internet curves are “up and to the right”
- But what makes this curve painful?
  - The pain threshold is approximated by Moore’s Law

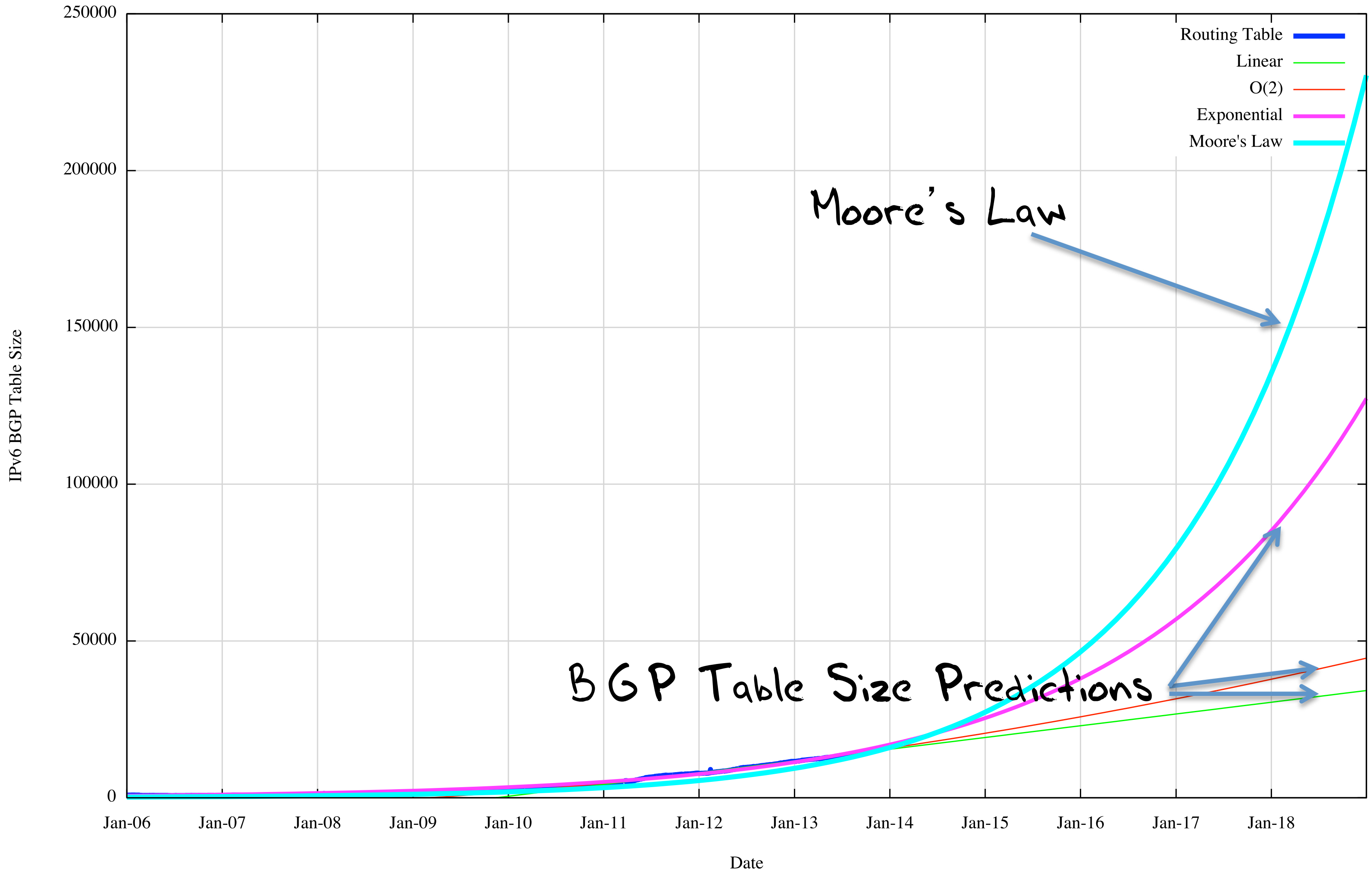
Microprocessor Transistor Counts 1971-2011 & Moore's Law



IPv4 BGP Table size and Moore's Law



IPv6 Projections and Moore's Law



BGP Table Growth

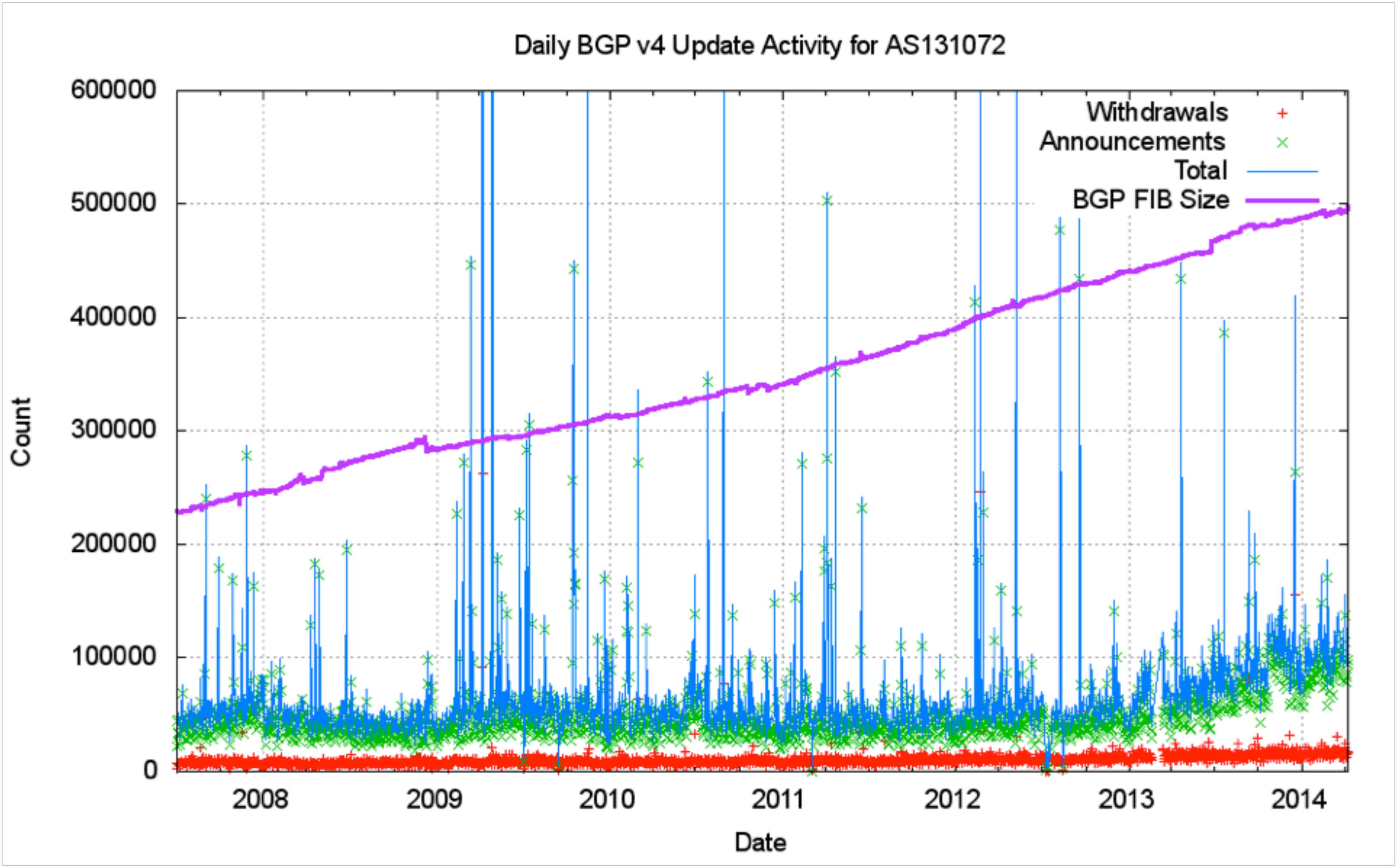
- Nothing in these figures suggests that there is cause for urgent alarm -- at present
- The overall eBGP growth rates for IPv4 are holding at a modest level, and the IPv6 table, although it is growing rapidly, is still relatively small in size in absolute terms
- As long as we are prepared to live within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

Table Size vs Updates

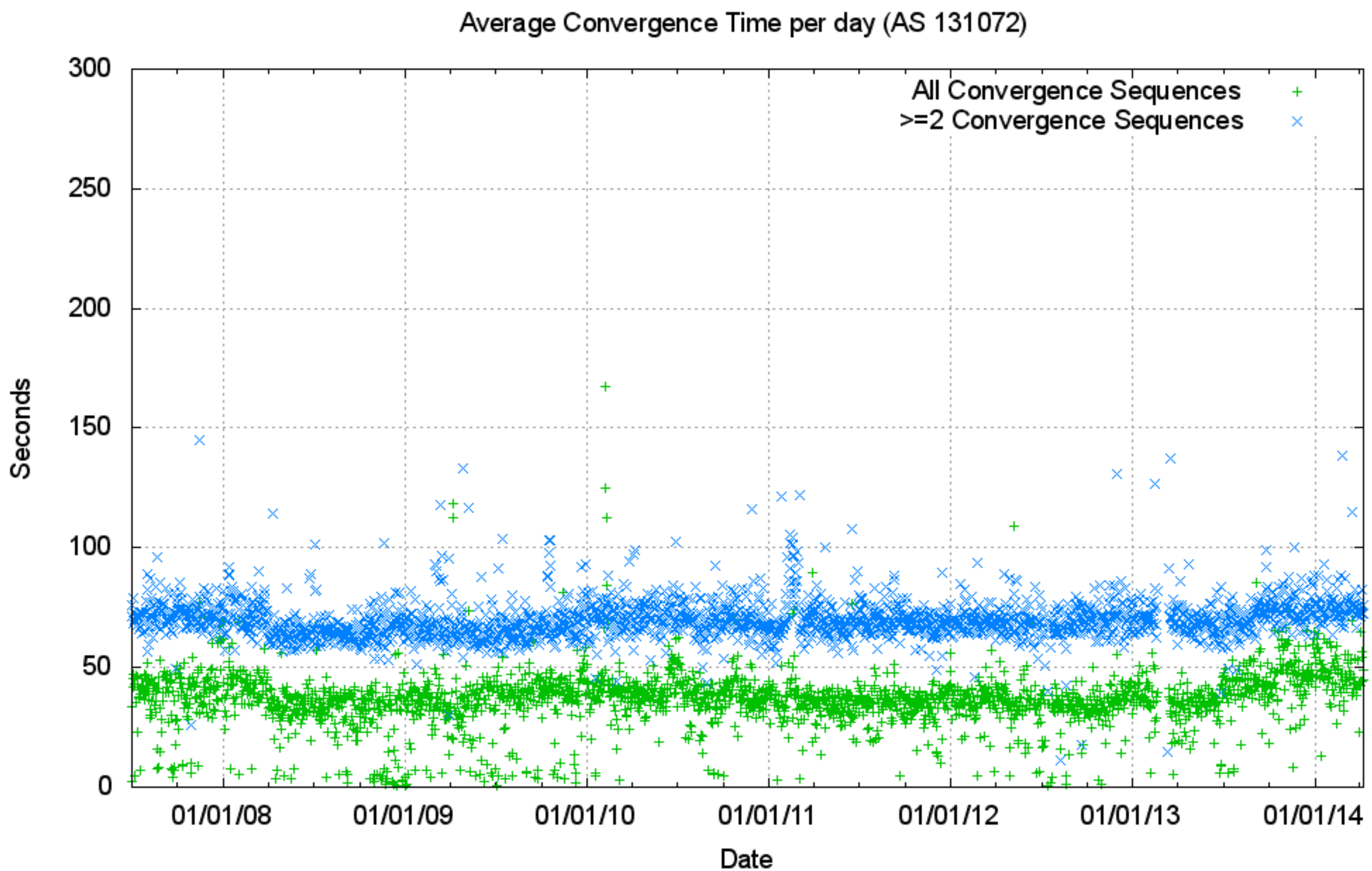
BGP Updates

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

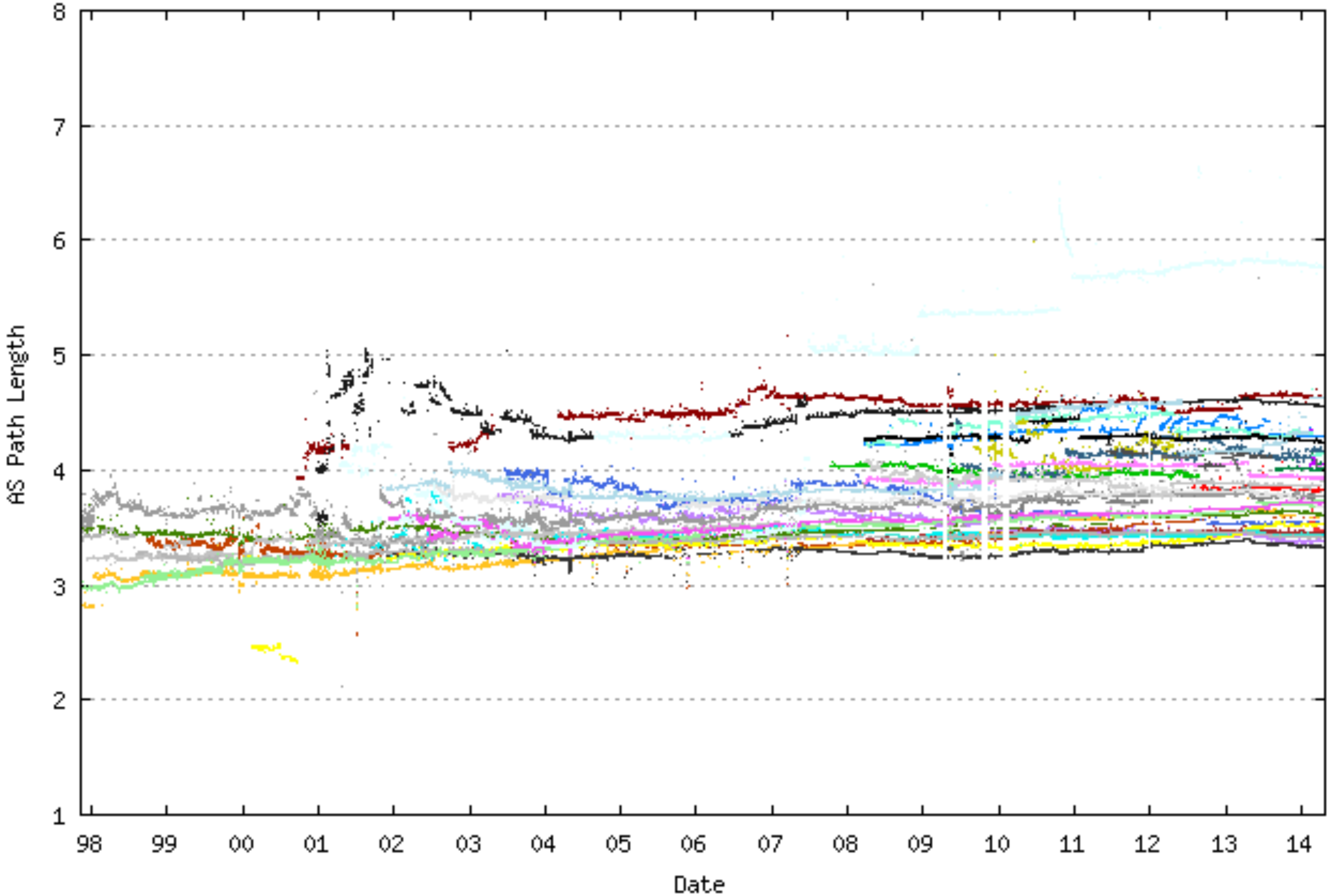
Announcements and Withdrawals



Convergence Performance



IPv4 Average AS Path Length



Data from Route Views

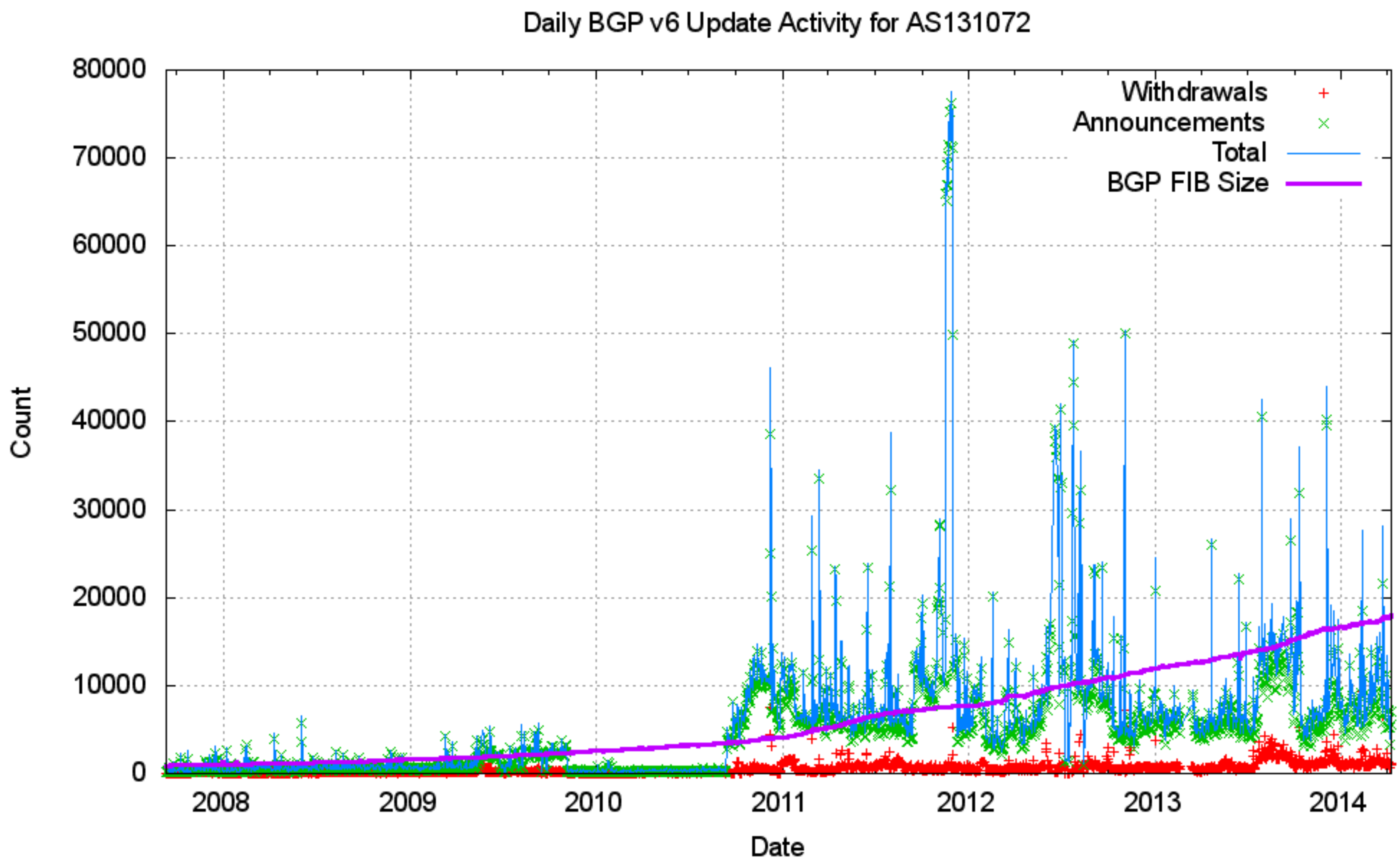
Updates in IPv4 BGP

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

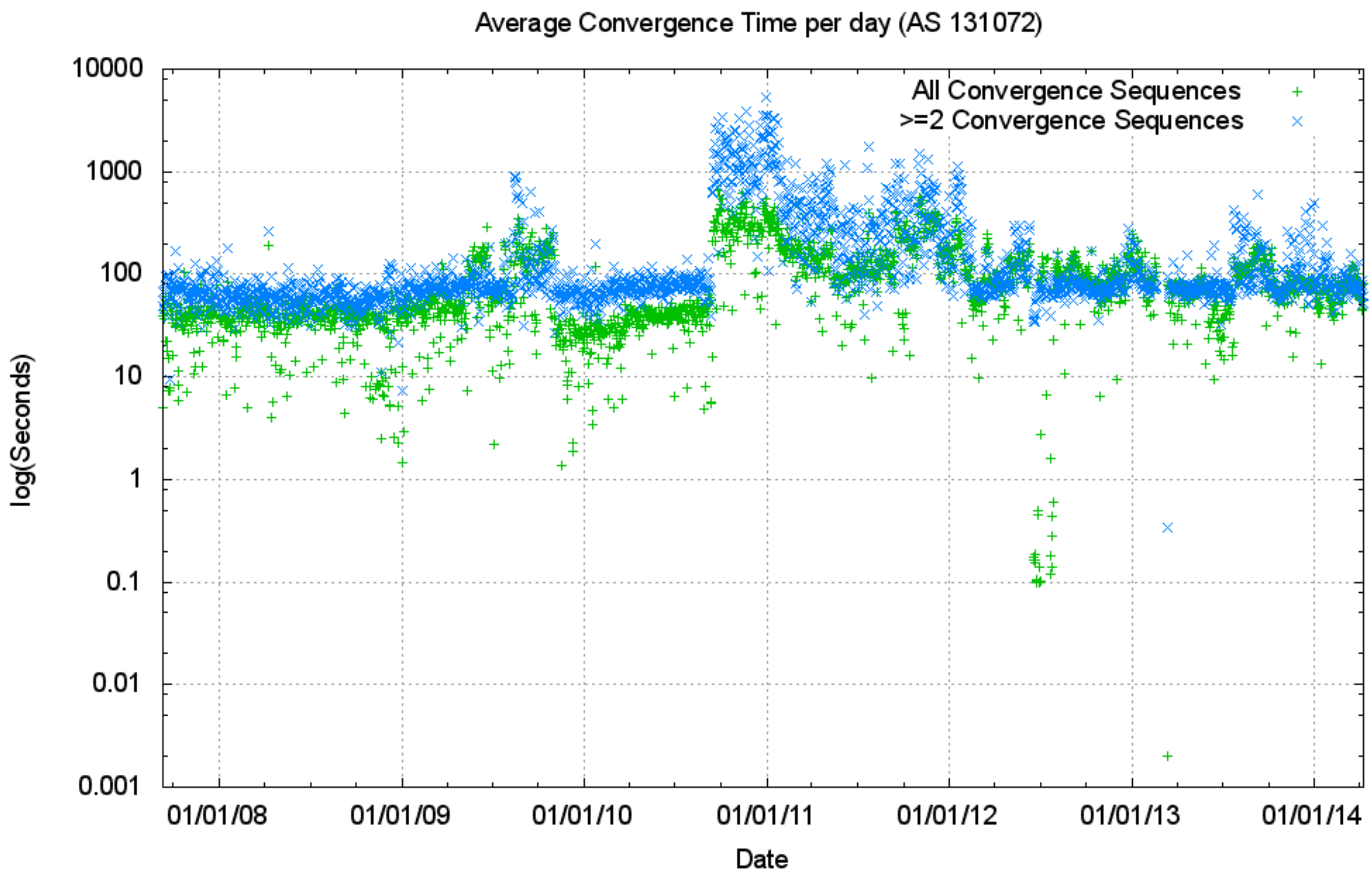
– The number of updates per instability event has been constant, due to the damping effect of the MRAI interval, and the relatively constant AS Path length over this interval

What about IPv6?

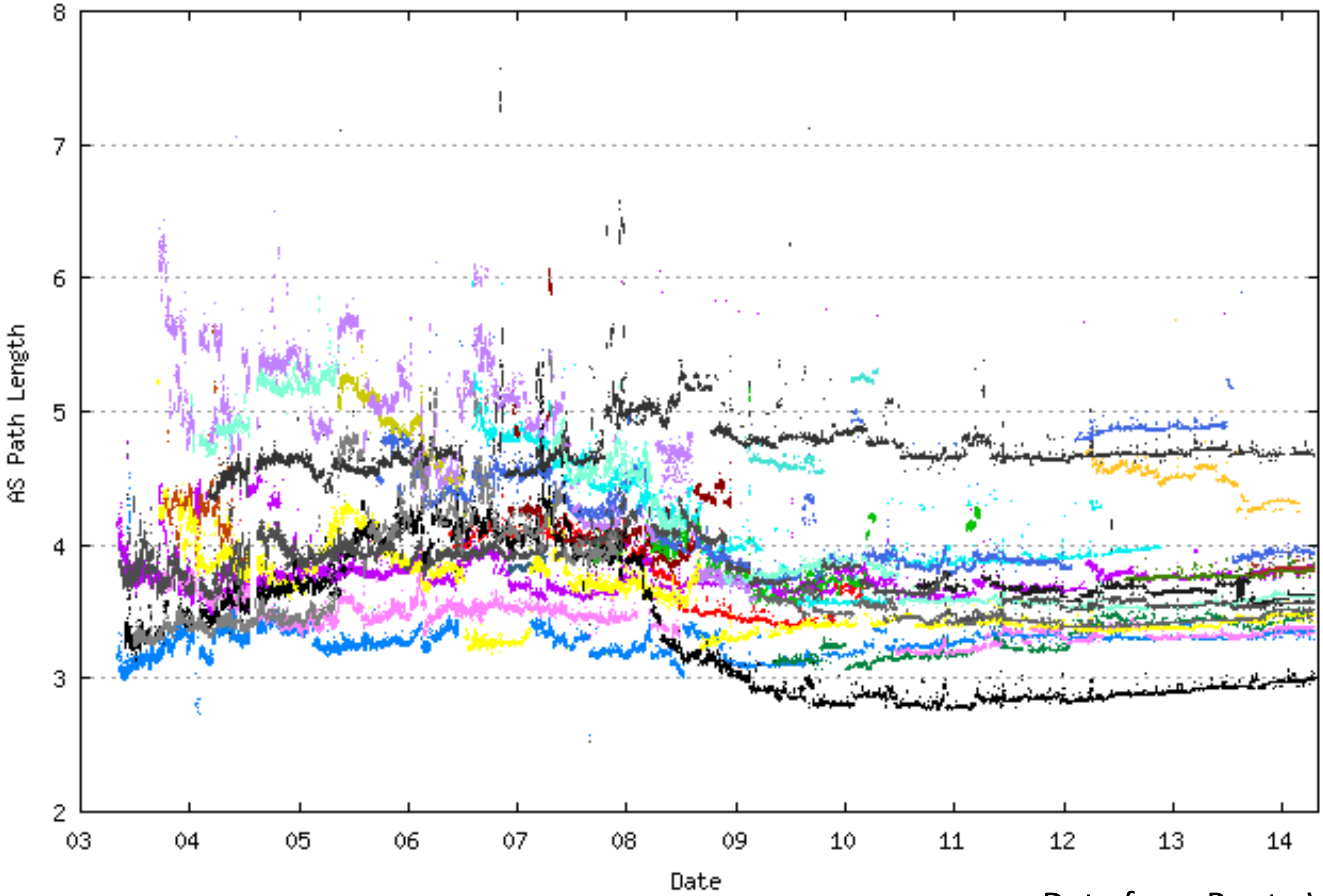
V6 Announcements and Withdrawals



V6 Convergence Performance



V6 Average AS Path Length



Data from Route Views

BGP Convergence

- The long term average convergence time for the IPv4 BGP network is some 70 seconds, or 2.3 updates given a 30 second MRAI timer
- The long term average convergence time for the IPv6 BGP network is some 80 seconds, or 2.6 updates

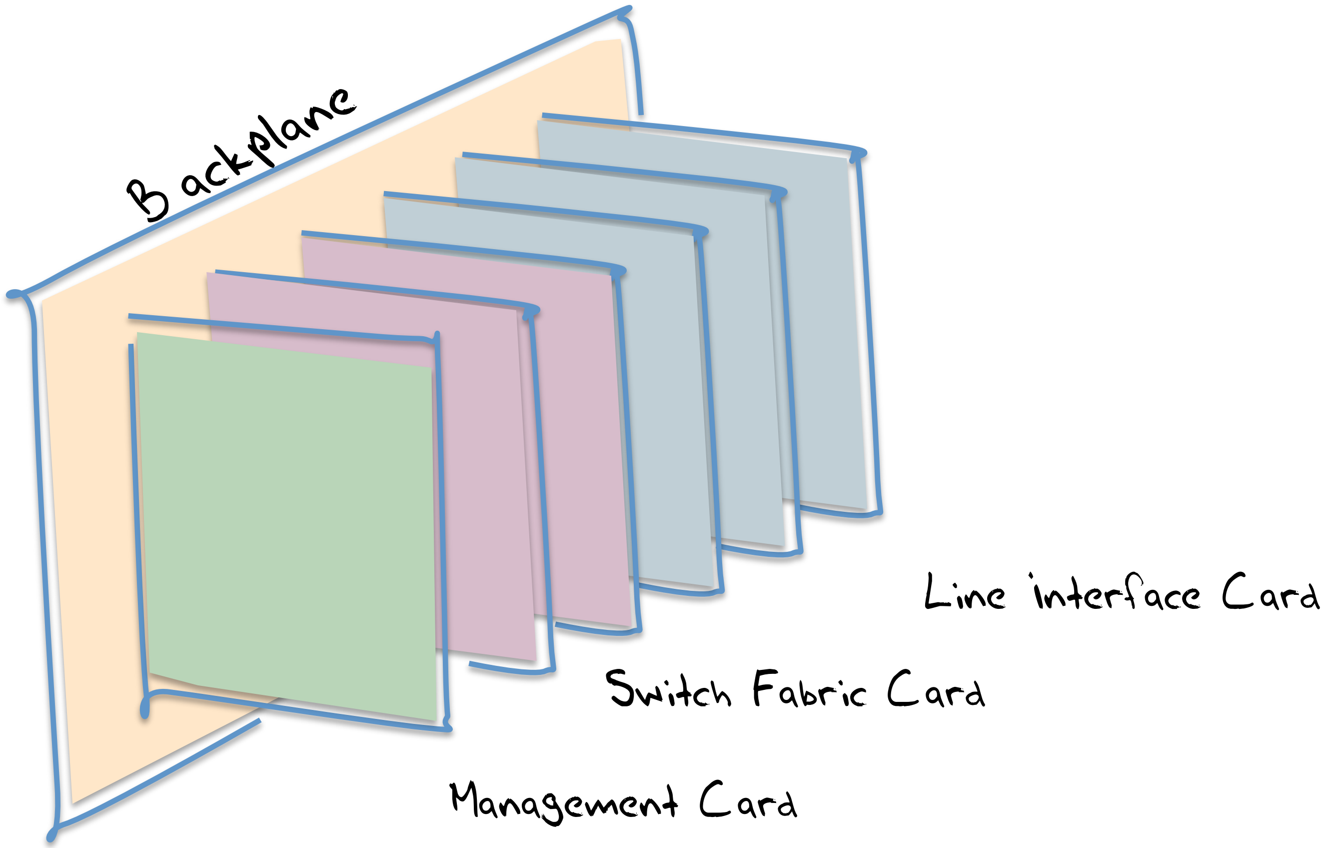
Problem? Not a Problem?

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.

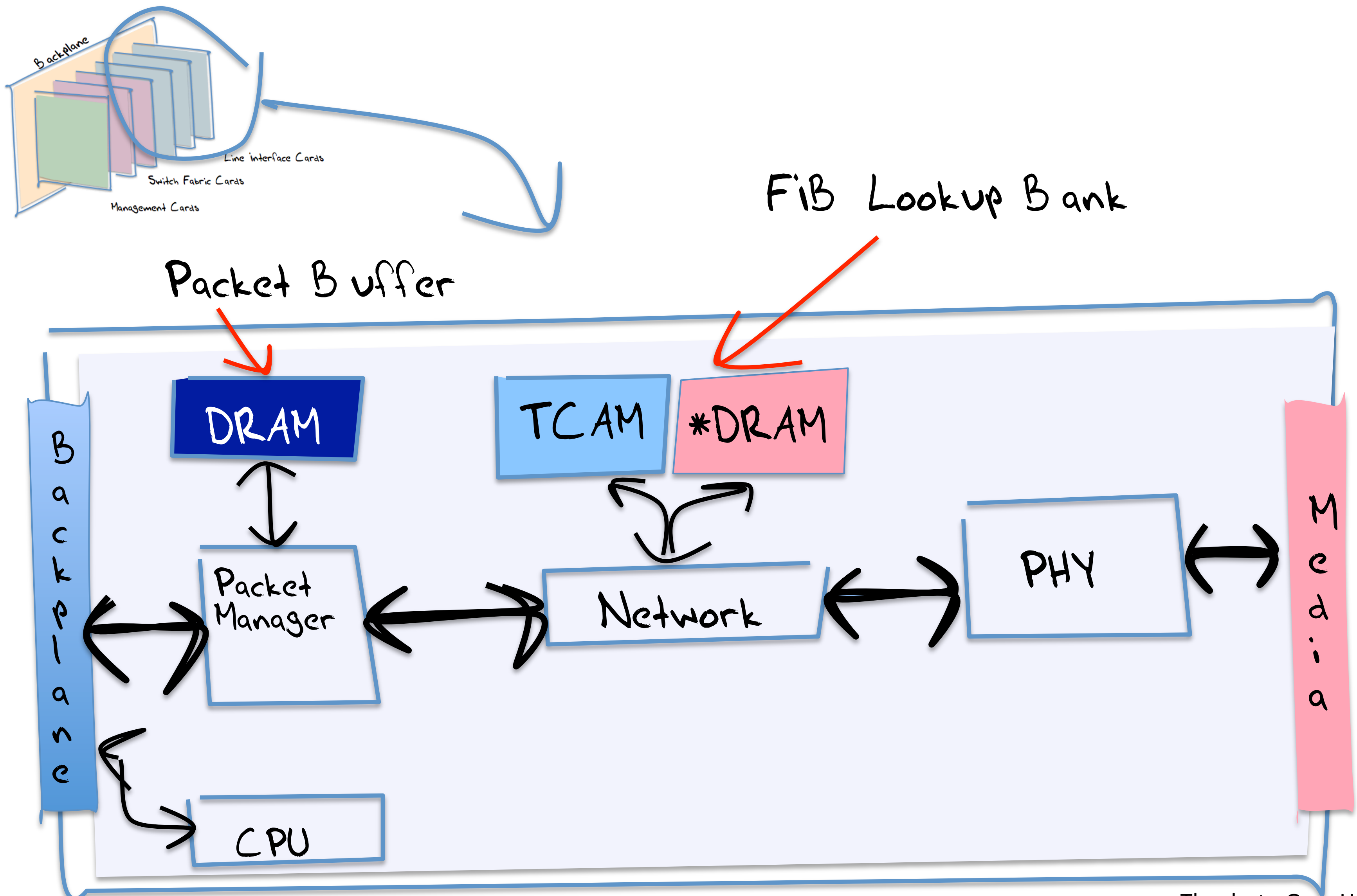
So lets take a quick look at routers…

Inside a router



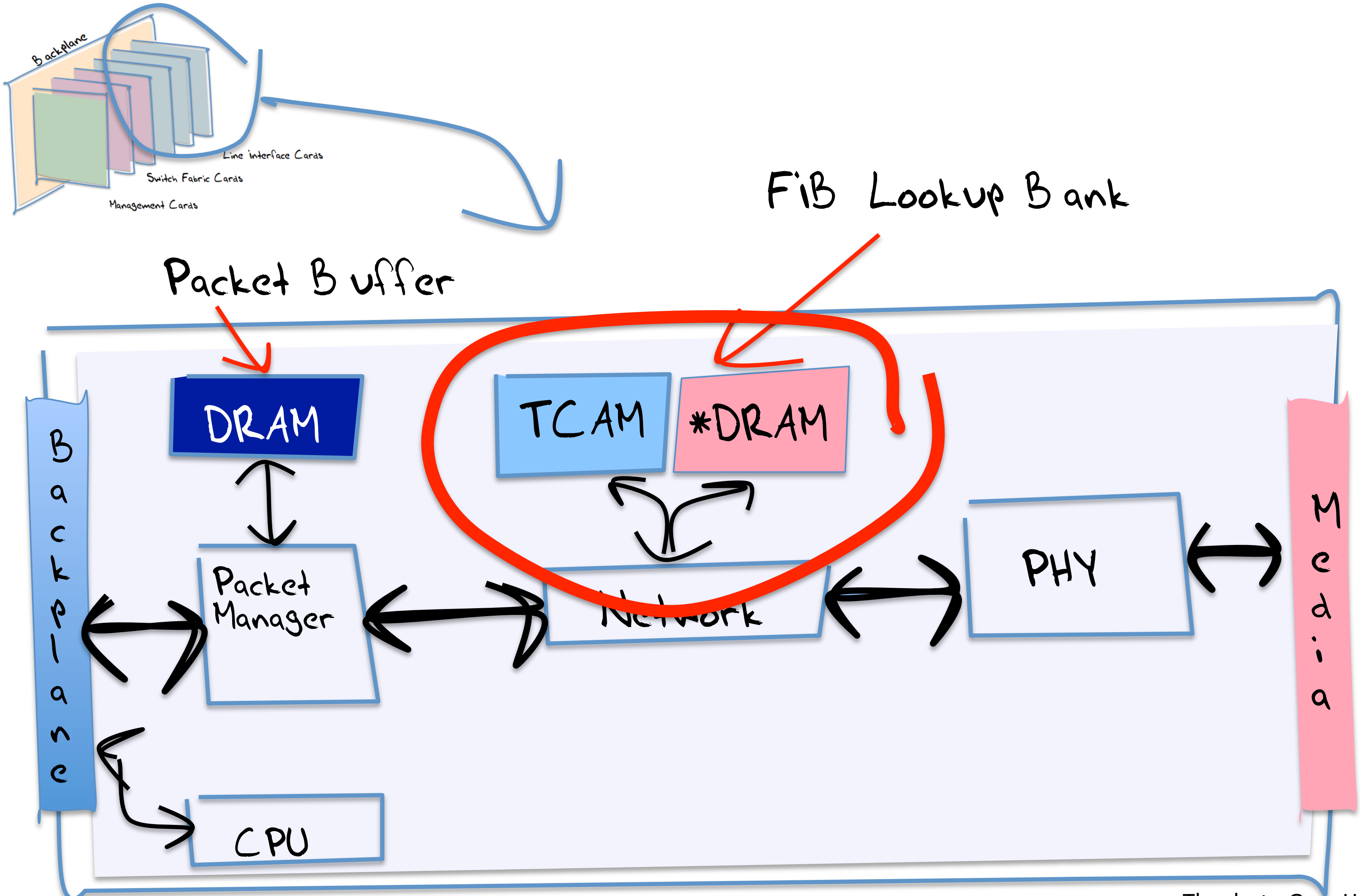
Thanks to Greg Hankins

Inside a line card



Thanks to Greg Hankins

Inside a line card



Thanks to Greg Hankins

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:

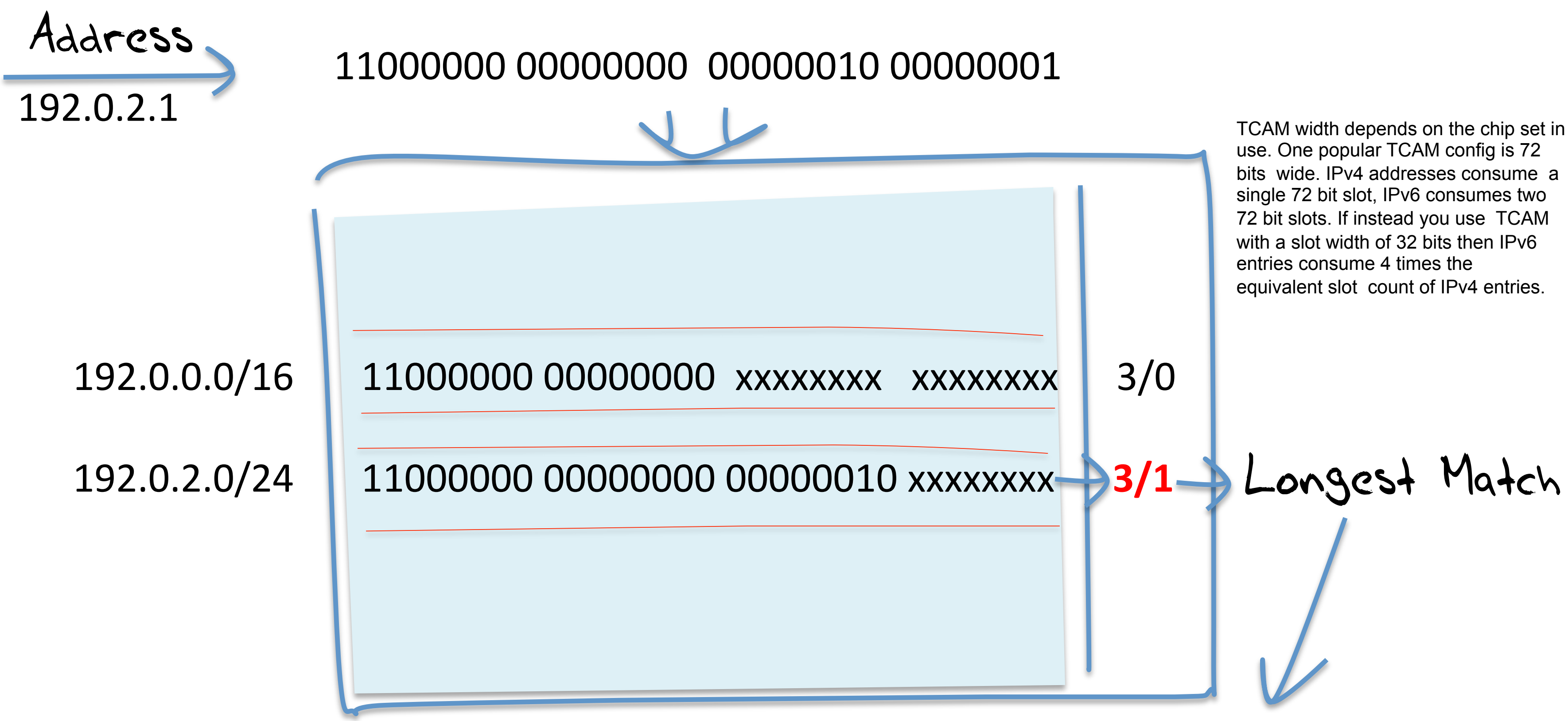
- Loading the entire routing table into a Ternary Content Addressable Memory bank (TCAM)

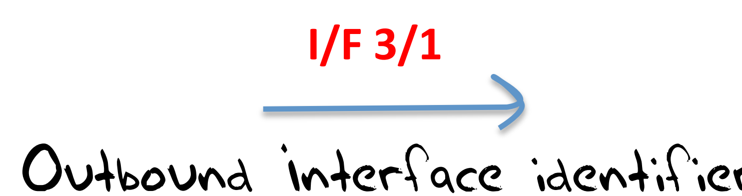
or

- 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





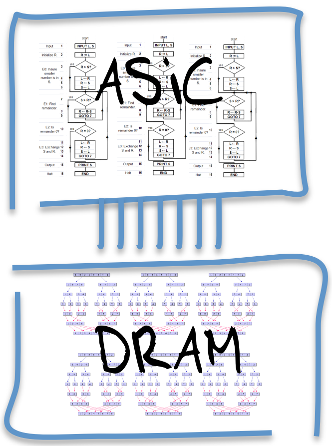
The entire FIB is loaded into TCAM. Every destination address is passed through the TCAM, and within one TCAM cycle the TCAM returns the interface index of the longest match. Each TCAM bank needs to be large enough to hold the entire FIB. TTCAM cycle time needs to be fast enough to support the max packet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

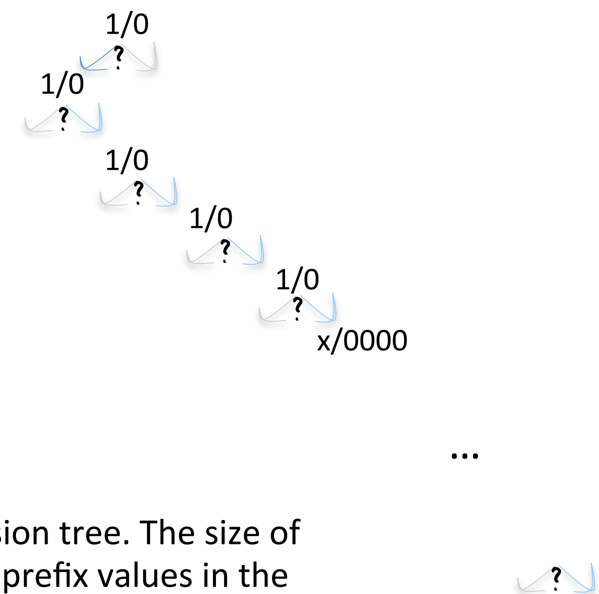
TRIE Lookup

Address

192.0.2.1

11000000 00000000 00000010 00000001





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

Thanks to Greg Hankins

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$)
plus
V6: 200Mbit memory (1G$)

	2014	2019	2024
V4 FIB	512K	768K	1M
V6 FIB	25K	125K	512K

"The Impact of Address Allocation and Routing on the Structure and Implementation of Routing Tables", Narayn, Govindan & Varghese, SIGCOMM '03

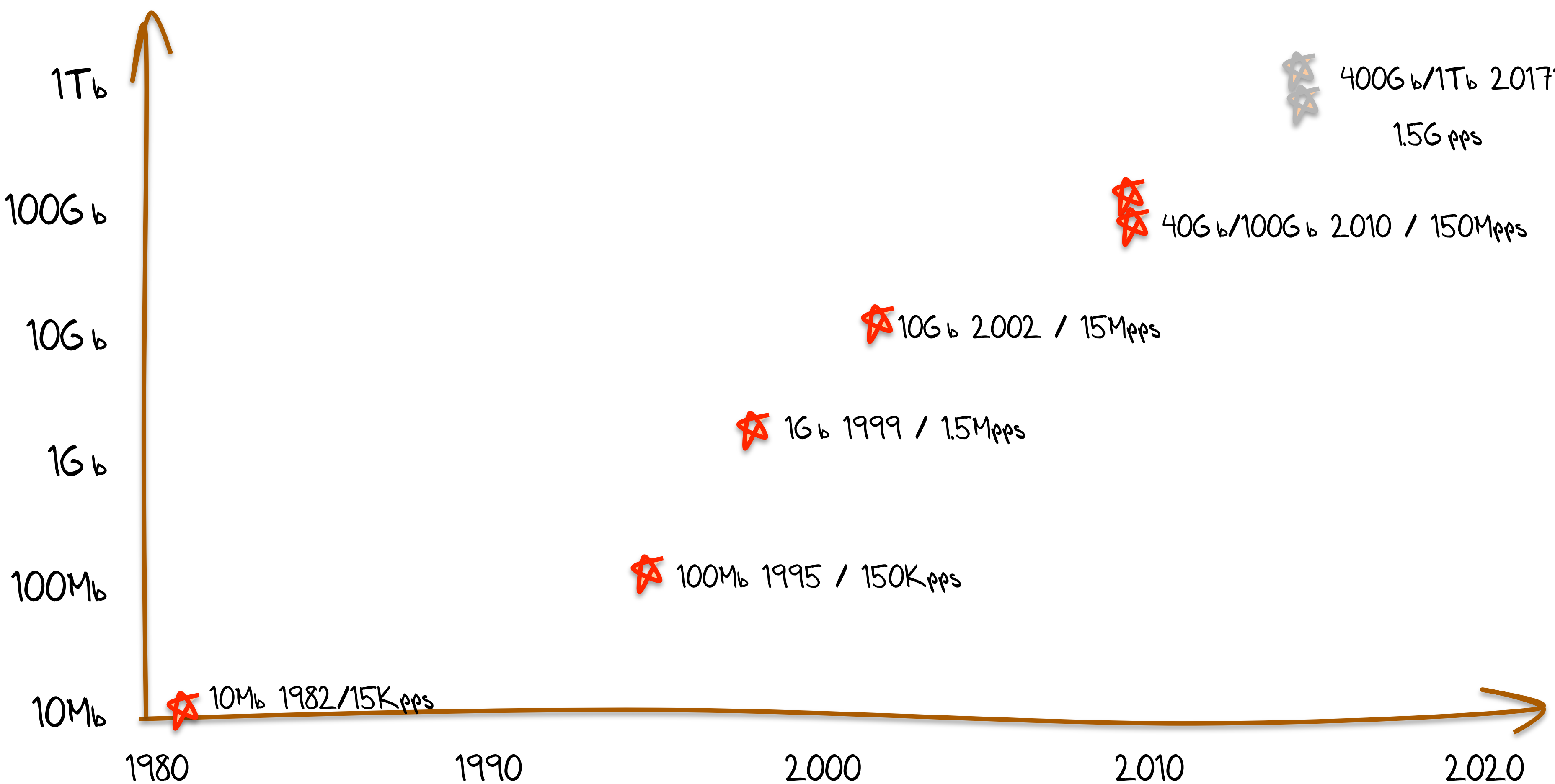
Scaling the FIB

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)

Speed


1Tb
100Gb
10Gb
1Gb
100Mb
10Mb
1980
1990
2000
2010
2020
10Mb 1982/15Kpps
100Mb 1995 / 150Kpps
1Gb 1999 / 1.5Mpps
10Gb 2002 / 15Mpps
40Gb/100Gb 2010 / 150Mpps
400Gb/1Tb 2017?
1.5G pps

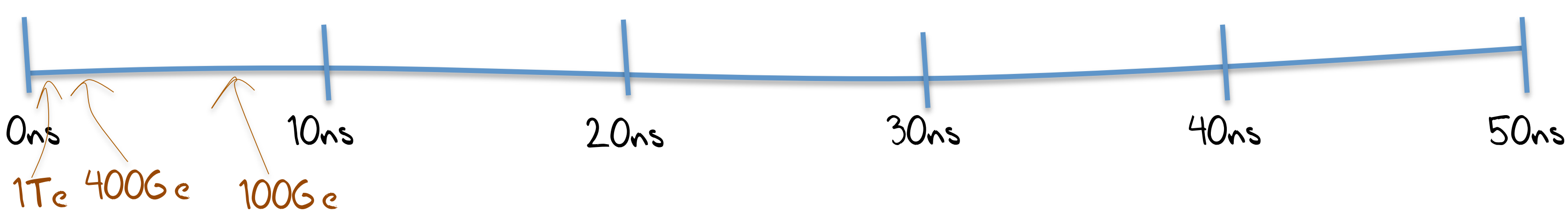
Speed, Speed, Speed

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

100GE ≈ 150Mpps ≈ 6.7ns per packet

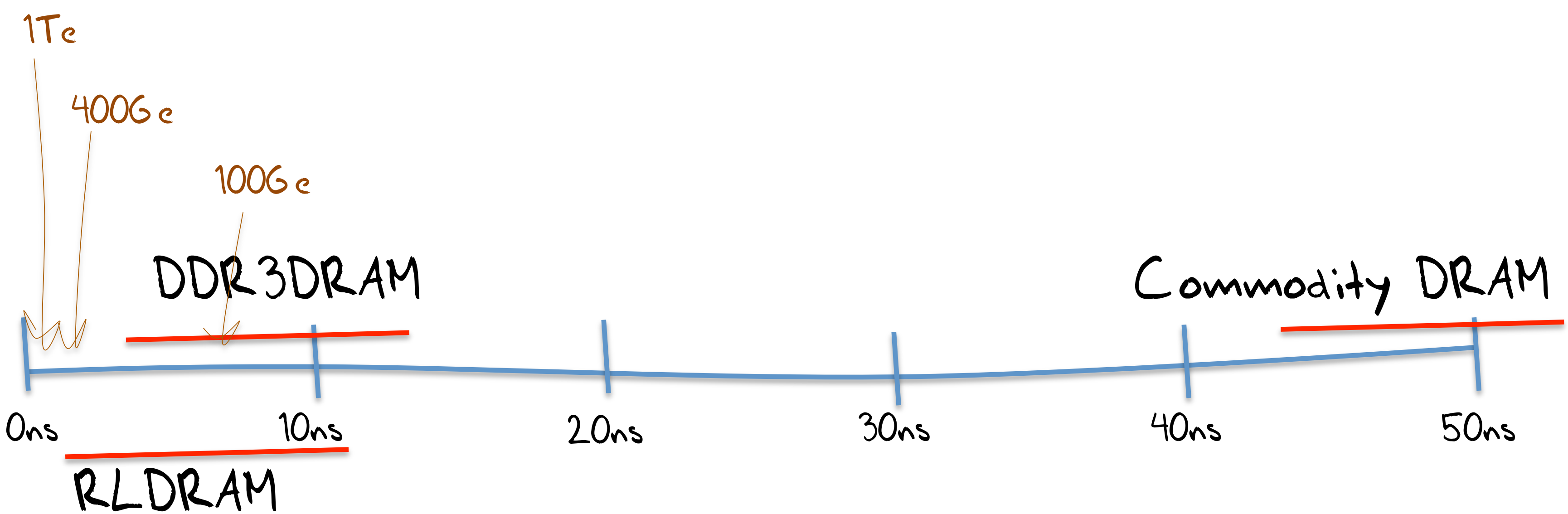
400Ge ≈ 600Mpps ≈ 1.6ns per packet

1Te ≈ 1.5G pps ≈ 0.67ns per packet



Speed, Speed, Speed

What memory speeds do we HAVE?



Thanks to Greg Hankins

Scaling Speed

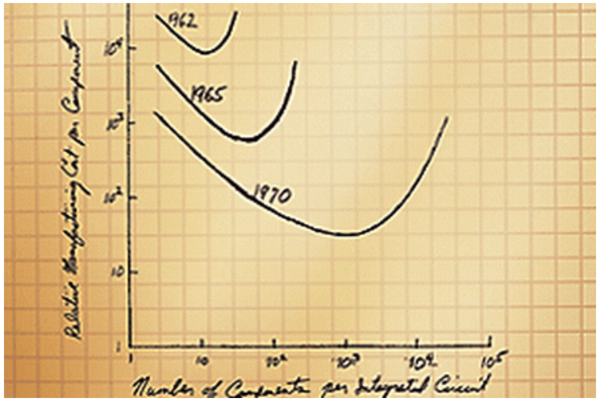
Scaling speed is going to be tougher over time

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 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?



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

Thank You

Questions?