Routing 2016

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There are very few ways to assemble a single view of the entire Internet

The lens of routing is one of the ways in which information relating to the entire reachable Internet is bought together

Even so, its not a perfect lens…
23 Years of Routing the Internet

1994: Introduction of CIDR

2001: The Great Internet Boom and Bust

2005: Broadband to the Masses

2009: The GFC hits the Internet

2011: Address Exhaustion

This is a view pulled together from each of the routing peers of Route-Views.
23 Years of Routing the Internet

1994: Introduction of CIDR
2001: The Great Internet Boom and Bust
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2011: Address Exhaustion

This is a view pulled together from each of the routing peers of Route-Views.
2015-2016 in detail
2015-2016 in detail

- Route Views Peers
- RIS Peers
- Average growth trend
October 24, 0800 UTC

Active BGP entries (FIB)

4,500 new RIB entries in 2 hours!

Plot Range: 24-Oct-2016 0024 to 25-Oct-2016 0025

<table>
<thead>
<tr>
<th>AS</th>
<th>net</th>
<th>+</th>
<th>- AS-Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS6327</td>
<td>744</td>
<td>744</td>
<td>0 SHAW - Shaw Communications Inc., CA</td>
</tr>
<tr>
<td>AS9829</td>
<td>211</td>
<td>221</td>
<td>10 BSNL-NIB National Internet Backbone, IN</td>
</tr>
<tr>
<td>AS18881</td>
<td>92</td>
<td>92</td>
<td>0 TELEFONICA BRASIL S.A, BR</td>
</tr>
<tr>
<td>AS43754</td>
<td>80</td>
<td>89</td>
<td>9 ASIATECH, IR</td>
</tr>
<tr>
<td>AS18566</td>
<td>80</td>
<td>80</td>
<td>0 MEGAPATH5-US - MegaPath Corporation, US</td>
</tr>
<tr>
<td>AS9116</td>
<td>78</td>
<td>79</td>
<td>1 GOLDENLINES-ASN 012 Smile Communications Main Autonomous System, IL</td>
</tr>
<tr>
<td>AS4800</td>
<td>76</td>
<td>1036</td>
<td>960 LINTASARTA-AS-AP Network Access Provider and Internet Service Provider, ID</td>
</tr>
<tr>
<td>AS38264</td>
<td>70</td>
<td>70</td>
<td>0 WATEEN-IMS-PK-AS-AP National WiMAX/IMS environment, PK</td>
</tr>
<tr>
<td>AS40676</td>
<td>61</td>
<td>85</td>
<td>24 AS40676 - Psychz Networks, US</td>
</tr>
<tr>
<td>AS16322</td>
<td>60</td>
<td>61</td>
<td>1 PARSONLINE Tehran - IR, IR</td>
</tr>
</tbody>
</table>
Routing Indicators for IPv4

Routing prefixes - growing by some 54,000 prefixes per year

AS Numbers - growing by some 3,450 prefixes per year
Routing Indicators for IPv4

More Specifically are still taking up one half of the routing table.

But the average size of a routing advertisement is getting smaller.
Routing Indicators for IPv4

Address Exhaustion is now visible in the extent of advertised address space.

The “shape” of inter-AS interconnection appears to be relatively steady, as the Average AS Path length has been steady through the year.
AS Adjacencies (Route-Views)

19,700 out of 57,064 ASNs have 1 or 2 AS Adjacencies (72%)

3,062 ASNs have 10 or more adjacencies

22 ASNs have >1,000 adjacencies

6,202 AS6939  HURRICANE - Hurricane Electric, Inc., US
5,069 AS174   COGENT-174 - Cogent Communications, US
4,767 AS3356  LEVEL3 - Level 3 Communications, Inc., US
2,632 AS3549  LVLT-3549 - Level 3 Communications, Inc., US
2,397 AS7018  ATT-INTERNET4 - AT&T Services, Inc., US
1,959 AS209   CENTURYLINK-US-LEGACY-QWEST - Qwest, l
1,953 AS57463  NETIX , BG
1,691 AS37100  SEACOM-AS, MU
1,620 AS34224  NETERRA-AS, BG
What happened in 2016 in V4?

Routing Business as usual – despite IPv4 address exhaustion!

- From the look of the growth plots, its business as usual, despite the increasing pressures on IPv4 address availability
- The number of entries in the IPv4 default-free zone is now heading to 700,000 by the end of 2017
- The pace of growth of the routing table is still relatively constant at ~54,000 new entries and 3,400 new AS’s per year
  - IPv4 address exhaustion is not changing this!
  - Instead, we are advertising shorter prefixes into the routing system
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.

Some of these addresses are transferred in ways that are recorded in the registry system, while others are being "leased" without any clear registration entry that describes the lessee.
IPv4 in 2016 – Growth is Steady

• Overall IPv4 Internet growth in terms of BGP is at a rate of some ~54,000 entries p.a.

• But we’ve run out of the unallocated address pools everywhere except Afrinic

• So what’s driving this post-exhaustion growth?
  – Transfers?
  – Last /8 policies in RIPE and APNIC?
  – Leasing and address recovery?
80% of all new addresses announced in 2010 were allocated or assigned within the past 12 months.

2% of all new addresses announced in 2010 were >= 20 years ‘old’ (legacy).
IPv4 Advertised Address "Age"

2016

39 % of all new addresses announced in 2016 were >= 20 years ‘old’ (legacy)

24 % of all new addresses announced in 2016 were allocated or assigned within the past 12 months
IPv4: Advertised vs Unadvertised Addresses
IPv4: Unadvertised Addresses
IPv4: Assigned vs Recovered

Growth in Advertised Addresses

RIR Allocations

"draw down"

"recovery"

Change in the Unadvertised Address Pool
IPv4 in 2016

The equivalent of 1.8 /8s was added to the routing table across 2016

• Approximately 1.3 /8s were assigned by RIRs in 2015
  – 0.7 /8’s assigned by Afrinic
  – 0.2 /8s were assigned by APNIC, RIPE NCC (Last /8 allocations)
  – 0.1 /8s were assigned by ARIN, LACNIC

• And a net of 0.5 /8’s were recovered from the Unadvertised Pool
The Route-Views view of IPv6
2015-2016 in detail
Routing Indicators for IPv6

Routing prefixes - growing by some 6,000 prefixes per year

AS Numbers - growing by some 1,700 prefixes per year (which is half the V4 growth)
Routing Indicators for IPv6

More Specifics now take up more than one third of the routing table.

The average size of a routing advertisement is getting smaller.
Routing Indicators for IPv6

The "shape" of inter-AS interconnection in IPv6 appears to be steady, as the Average AS Path length has been held steady through the year.

Advertised Address span is growing at a linear rate.
AS Adjacencies (Route Views)

9,105 out of 13,197 ASNs have 1 or 2 AS Adjacencies (69%)
917 ASNs have 10 or more adjacencies
4 ASNs have >1,000 adjacencies

3,276 AS6939  HURRICANE - Hurricane Electric, Inc., US
1,607 AS174  COGENT-174 - Cogent Communications, US
1,310 AS3356  LEVEL3 - Level 3 Communications, Inc., US
1,112 AS37100  SEACOM-AS, MU
IPv6 in 2015

• Overall IPv6 Internet growth in terms of BGP is steady at some 6,000 route entries p.a.

This is growth of BGP route objects is 1/9 of the growth rate of the IPv4 network – as compared to the AS growth rate which is 1/2 of the IPv4 AS number growth rate
What to expect
BGP Size Projections

For the Internet this is a time of extreme uncertainty

- Registry IPv4 address run out
- Uncertainty over the impacts of market-mediated movements of IPv4 on the routing table
- Uncertainty over the timing of IPv6 takeup leads to a mixed response to IPv6 so far, and no clear indicator of trigger points for change for those remaining IPv4-only networks
V4 - Daily Growth Rates
V4 - Daily Growth Rates
V4 - Relative Daily Growth Rates
Growth in the V4 network appears to be constant at a long term average of 120 additional routes per day, or some 45,000 additional routes per year.

Given that the V4 address supply has run out this implies further reductions in address size in routes, which in turn implies ever greater reliance on NATs.

It’s hard to see how and why this situation will persist at its current levels over the coming 5-year horizon.
Growth in the V4 network appears to be constant at a long term average of 150 additional routes per day, or some 54,000 additional routes per year.

Given that the V4 address supply has run out this implies further reductions in address size in routes, which in turn implies ever greater reliance on NATs.

It's hard to see how and why this situation can persist at its current levels over the coming 5 year horizon.
# IPv4 BGP Table Size Predictions

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan 2017 Prediction</th>
<th>Jan 2016 Prediction</th>
<th>Jan 2015 Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>441,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>488,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>530,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>586,000</td>
<td></td>
<td>580,000</td>
</tr>
<tr>
<td>2017</td>
<td><strong>646,000</strong></td>
<td>628,000</td>
<td>620,000</td>
</tr>
<tr>
<td>2018</td>
<td>700,000</td>
<td>675,000</td>
<td>670,000</td>
</tr>
<tr>
<td>2019</td>
<td>754,000</td>
<td>722,000</td>
<td>710,000</td>
</tr>
<tr>
<td>2020</td>
<td>808,000</td>
<td>768,000</td>
<td>760,000</td>
</tr>
<tr>
<td>2021</td>
<td>862,000</td>
<td>815,000</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>916,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These numbers are dubious due to uncertainties introduced by IPv4 address exhaustion pressures.
V6 - Daily Growth Rates
V6 - Relative Growth Rates

IPv6 Relative Daily RIB Change (in %)

Date:
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017

Graph showing the relative growth rates of IPv6 RIB change over time.
Growth in the V6 network appears to be increasing, but in relative terms this is slowing down.

Early adopters, who have tended to be the V4 transit providers, have already received IPv6 allocation and are routing them. The trailing edge of IPv6 adoption are generally composed of stub edge networks in IPv4. Many of these networks appear not to have made any visible moves in IPv6 as yet.

If we see a change in this picture the growth trend will likely be exponential. But its not clear when such a tipping point will occur.
# IPv6 BGP Table Size predictions

<table>
<thead>
<tr>
<th>Year</th>
<th>Exponential Model</th>
<th>Linear Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>16,100</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>21,200</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>27,000</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>35,000</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>50,000</td>
<td>43,000</td>
</tr>
<tr>
<td>2019</td>
<td>65,000</td>
<td>51,000</td>
</tr>
<tr>
<td>2020</td>
<td>86,000</td>
<td>59,000</td>
</tr>
<tr>
<td>2021</td>
<td>113,000</td>
<td>67,000</td>
</tr>
<tr>
<td>2022</td>
<td>150,000</td>
<td>75,000</td>
</tr>
</tbody>
</table>

Range of potential outcomes
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 at a faster relative rate, is still small in size in absolute terms

- As long as we are prepared to live within the technical constraints of the current routing paradigm, the Internet's use of BGP will continue to be viable for some time yet

- Nothing is melting in terms of the size of the routing table as 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
IPv4 Announcements and Withdrawals

Daily BGP v4 Update Activity for AS131072

Count

Date

IPv4 Announcements and Withdrawals

Daily BGP v4 Update Activity for AS131072

Count

Withdrawals
Announcements
Total
BGP FIB Size

Date

IPv4 Convergence Performance

Average Convergence Time per day (AS 131072)
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 relatively constant, which for a distance vector routing protocol is weird, and completely unanticipated. Distance Vector routing protocols should get noisier as the population of protocol speakers increases, and the increase should be multiplicative.

– But this is not happening in the Internet

– Which is good, but why is this not happening?

Likely contributors to this outcome are the damping effect of widespread use of the MRAI interval by eBGP speakers, and the topology factor, as seen in the relatively constant V4 AS Path Length
V6 Convergence Performance

Average Convergence Time per day (AS 131072)

High noise components in IPv6
V6 Updated prefixes per day
V6 Updates per event

Average Convergence Update Count per day (AS 131072)
Updates in IPv6

BGP Route Updates are very unequally distributed across the prefix set – they appear to affect a very small number of prefixes which stand out well above the average.
# Updates in IPv6

The busiest 50 IPv6 prefixes accounted for 1/2 of all BGP IPv6 prefix updates.

<table>
<thead>
<tr>
<th>RANK</th>
<th>PREFIX</th>
<th>UPDs</th>
<th>% Origin AS -- AS NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2001:0:0::/31</td>
<td>49904</td>
<td>2.95% INDOMATM2-ID INDOMATM2 ASIN, ID</td>
</tr>
<tr>
<td>2</td>
<td>2402:0:80::/48</td>
<td>49823</td>
<td>2.95% 38768 -- TELNET-AS-ID PT, TIME EXCELINDO, ID</td>
</tr>
<tr>
<td>3</td>
<td>2402:0:80:1::/48</td>
<td>49821</td>
<td>2.95% 38768 -- TELNET-AS-ID PT, TIME EXCELINDO, ID</td>
</tr>
<tr>
<td>4</td>
<td>2403:a00::/32</td>
<td>49810</td>
<td>2.95% 39150 -- TELNET-AS-ID PT, TIME EXCELINDO, ID</td>
</tr>
<tr>
<td>5</td>
<td>2400:8b00:a001::/48</td>
<td>40699</td>
<td>2.41% 45727 -- THREE-AS-ID Hutchison CP Telecommunications, PT, ID</td>
</tr>
<tr>
<td>6</td>
<td>2001:df5:b400::/48</td>
<td>38088</td>
<td>2.25% 131735 -- IDNIE-TNC-ID PT Telerama Network Cakrawala, ID</td>
</tr>
<tr>
<td>7</td>
<td>2403:8000::/32</td>
<td>36252</td>
<td>2.14% 4796 -- BANDUNG-INET-AS-AP Institute of Technology Bandung, ID</td>
</tr>
<tr>
<td>8</td>
<td>2804:1d:b2a2::/48</td>
<td>29735</td>
<td>1.76% 28573 -- CLARO S.A., BR</td>
</tr>
<tr>
<td>9</td>
<td>2a00:66c0:98::/48</td>
<td>27722</td>
<td>1.64% 2906 -- AS-SSI - Netflix Streaming Services Inc., US</td>
</tr>
<tr>
<td>10</td>
<td>2a00:66c0:99::/48</td>
<td>27614</td>
<td>1.63% 2906 -- AS-SSI - Netflix Streaming Services Inc., US</td>
</tr>
<tr>
<td>11</td>
<td>2402:ab00:140::/48</td>
<td>27160</td>
<td>1.61% 24208 -- CHANNEL11-AS-ID PT Cakra Lintas Nusantara, ID</td>
</tr>
<tr>
<td>12</td>
<td>2620:10c:7007::/48</td>
<td>26703</td>
<td>1.58% 2906 -- AS-SSI - Netflix Streaming Services Inc., US</td>
</tr>
<tr>
<td>13</td>
<td>2406:9800::/32</td>
<td>25991</td>
<td>1.54% 10208 -- THENET-AS-ID-AP PT, Millenium Internet, ID</td>
</tr>
<tr>
<td>14</td>
<td>2402:a600::/32</td>
<td>25392</td>
<td>1.50% 17996 -- UJINET-ID-AP PT Global Prima Utama, ID</td>
</tr>
<tr>
<td>15</td>
<td>2a00:66c0:29::/29</td>
<td>21149</td>
<td>1.25% 50107 -- AS_TCP_CLOUD , CZ</td>
</tr>
<tr>
<td>16</td>
<td>2804:1d:90af::/48</td>
<td>19537</td>
<td>1.16% 28573 -- CLARO S.A., BR</td>
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<tr>
<td>17</td>
<td>2804:1d:9081::/48</td>
<td>19536</td>
<td>1.16% 28573 -- CLARO S.A., BR</td>
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<td>18</td>
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<td>19501</td>
<td>1.15% 28573 -- CLARO S.A., BR</td>
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<td>19</td>
<td>2804:1d:90bd::/48</td>
<td>19134</td>
<td>1.13% 28573 -- CLARO S.A., BR</td>
</tr>
<tr>
<td>20</td>
<td>2804:1d:90ae6::/48</td>
<td>18939</td>
<td>1.12% 28573 -- CLARO S.A., BR</td>
</tr>
</tbody>
</table>
Compared to IPv4
Updates in IPv6 BGP

IPv6 routing behaviour is similar to IPv4 behaviour:

Most announced prefixes are stable all of the time

And as more prefixes are announced, most of these announced prefixes are highly stable.

But for a small number of prefixes we observe highly unstable behaviours that dominate IPv6 BGP updates which appear to be more unstable (relatively) than IPv4
The State of Routing

“Mostly Harmless”

The levels of growth of the tables, and the levels of growth of updates in BGP do not pose any immediate concerns.

The trends are predictable and steady, so network operators can plan well in advance for the capacity of routing equipment to meet their future needs.

But:

The advanced levels of instability by a small number of networks are always annoying! How can we prevent these highly unstable prefixes?
That’s it!

Questions?