IPv4 Address Allocation and Evolution of BGP Routing Tables

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Overview

- Regional Internet Registries (RIRs) allocate and assign IP address blocks
- Do prefixes show up in the routing as allocated?
- The evolution of the routing table over the last 4 years
- What can we conclude from this info?
IPv4 Address Allocation

- In hierarchy fashion
  - Four regional Internet Registries (RIR)
  - ISP, Large enterprises
  - End-Users

- Policy changes
  - Classless Inter-domain Routing (CIDR)
  - Default allocation size from /19 to /20 (2000)
Migration of Address Allocation Policy

How has IPv4 address allocation/assignment been performed?
- Block Sizes and bit alignment

What is distribution of prefix lengths over time?
Distribution of Address Allocation (before and after CIDR deployed)

- **1993**
  - Total number of allocated addresses: 92562272 (21.55%)
  - Total number of allocations: 26333
  - Average length of allocations: 21.69

- **1996**
  - Total number of allocated addresses: 95359246 (02.22%)
  - Total number of allocations: 1573
  - Average length of allocations: 19.27
Distribution of Address Allocation (before and after “/19 to /20”)

1999

Total number of allocated addresses: 446,141,444 (0.04%)
Total number of allocations: 1,764
Average length of allocations: 18.76

2001

Total number of allocated addresses: 1,642,705,92 (0.82%)
Total number of allocations: 3,347
Average length of allocations: 18.99
Allocated Blocks Over Time

Graph showing the number of allocated address blocks over time from 1993 to 2002. The x-axis represents allocation time, and the y-axis represents the number of allocated address blocks. The graph includes data for all allocated address blocks and non-aligned allocated address blocks.
Small Allocated Blocks (01/01/1998-04/30/2002)
Non-Aligned Prefixes?

- Arin|US|ipv4|209.243.9.128|27|199807 17|assigned
  - This can be broken into 4 prefixes
  - Another allocation was a /16 assigned all except last /24.
  - Some just look non-aligned because of database representation
Appearance in Routing Table

- Do allocated/assigned blocks always appear?
- How long after they are allocated do they appear?
- How do they appear? Aggregated? Fragmented?
- Our study period: 1/1/98 -- 4/30/02
  - total allocated prefixes: 9,554
Do All the Allocated Prefixes Appear?
First-Advertised-Delay

The interval between allocation time and the first time the block appears in the routing table.
<table>
<thead>
<tr>
<th>Block</th>
<th>date</th>
<th>RIR</th>
<th>F.A.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>/20</td>
<td>2001-11-14</td>
<td>ARIN</td>
<td>-143</td>
</tr>
<tr>
<td>/20</td>
<td>2001-09-25</td>
<td>ARIN</td>
<td>-19</td>
</tr>
<tr>
<td>/16</td>
<td>1998-05-15</td>
<td>RIPE</td>
<td>-188</td>
</tr>
<tr>
<td>/24</td>
<td>1997-11-08</td>
<td>ARIN</td>
<td>-1</td>
</tr>
<tr>
<td>/19</td>
<td>2001-07-13</td>
<td>ARIN</td>
<td>-1343</td>
</tr>
<tr>
<td>/19</td>
<td>2002-02-06</td>
<td>ARIN</td>
<td>-1551</td>
</tr>
<tr>
<td>/20</td>
<td>2001-08-20</td>
<td>ARIN</td>
<td>-270</td>
</tr>
<tr>
<td>/13</td>
<td>2001-11-15</td>
<td>APNIC</td>
<td>-1205</td>
</tr>
<tr>
<td>/10</td>
<td>2001-10-31</td>
<td>APNIC</td>
<td>-680</td>
</tr>
</tbody>
</table>
Advertisement modes

- Allocated prefixes announced in routing tables in different ways:
  - Identical
  - Fragmented
  - Aggregated (encouraged by CIDR)
  - Identical + Fragmented
  - Identical + Aggregated
  - Fragmented + Aggregated
  - Identical + Fragmented + Aggregated
Example

- Identical
  - Allocated blocks: 1.1.0.0/16
  - Routing prefix: 1.1.0.0/16

- Fragmented
  - Allocated blocks: 1.1.0.0/16 → 1.1.1.0/24
  - Allocated blocks: 1.1.0.0/16 → 1.1.2.0/24

- Aggregated
  - Allocated blocks: 1.0.0.0/16
  - Allocated blocks: 1.1.0.0/16
  - Routing prefix: 1.2.0.0/15
Advertisement Mode for Allocated Prefixes (all)
Advertisement Mode for Allocated Prefixes (/16)
Advertisement Mode for Allocated Prefixes (/19)
Advertisement Mode for Allocated Prefixes (/20)
How many routing prefixes are fragmented from the allocated prefixes?
Announced Allocations that are Aggregated into Shorter Prefixes
Allocation Contribution to Routing Table

- Allocations: 30,704 in total
- Routing prefixes: 117,060 in total
/24s Advertised as Allocated

![Graph showing the number of /24s advertised as allocated over time, with peaks in 1993 and 1996.](graph.png)
/24s Fragments of Larger Allocations

![Bar chart showing number of /24 fragments from larger-sized allocation blocks over time (years 1993 to 2002)]
/24 Fragments

![Bar chart showing the number of /24 fragmented from larger-sized allocation blocks.](chart.png)
### Average Number of Fragments Per Allocation

<table>
<thead>
<tr>
<th></th>
<th>Allocated Prefixes</th>
<th>Allocated addresses</th>
<th>Average number of routing entries fragmented (aggregated) from single allocated block</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>3,194</td>
<td>214,809,088</td>
<td>6.8 (0.3)</td>
</tr>
<tr>
<td>Canada</td>
<td>293</td>
<td>7,461,632</td>
<td>2.4 (0.4)</td>
</tr>
<tr>
<td>China</td>
<td>165</td>
<td>21,010,432</td>
<td>6.7 (0.5)</td>
</tr>
<tr>
<td>Japan</td>
<td>105</td>
<td>25,952,512</td>
<td>6.2 (0.3)</td>
</tr>
</tbody>
</table>
Changes in the Global Routing Table

  - How many new prefixes added?
  - How many prefixes disappeared?
- Changes in consumed address space
  - An IP address is “consumed” if it is contained in existing routing prefixes
Routing Table Size vs. Address Consumption
Overall Change (Jan. 98 – Jan.02)

- Routing table size: 53,929 to 114,324
  - Growth: 112%
  - 87,941 prefixes added
  - 34,012 prefixes removed

- Address Consumption: 921,694,960 to 1,163,961,392
  - Growth: 26.3%
  - 35416 new prefixes (40.6% of 87,941) cover existing consumed address space
  - 311 new prefixes originally existed as longer prefixes
Where do the new advertisements come from?

- Total number: 87,941
- Relationship with allocations
  - Fragments of larger allocations (88.4%)
  - Allocations of equal size (10.0%)
  - Aggregation of multiple smaller allocations (0.7%)
  - Others. (No matched allocation records)
Where do the new advertisements come from? (cont.)

- **Allocation Time**

<table>
<thead>
<tr>
<th>Allocation Time</th>
<th>before 93</th>
<th>94</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers</td>
<td>10117</td>
<td>7405</td>
<td>7290</td>
<td>8139</td>
<td>4109</td>
<td>5316</td>
</tr>
<tr>
<td>Allocation Time</td>
<td>99</td>
<td>00</td>
<td>01</td>
<td>02</td>
<td>No Time Info</td>
<td></td>
</tr>
<tr>
<td>Numbers</td>
<td>10670</td>
<td>14257</td>
<td>10363</td>
<td>3248</td>
<td>5659</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.** Distribution of newly-appeared prefixes in terms of the time when the matched allocations are made

- **Geographic location**

<table>
<thead>
<tr>
<th>Allocation Country</th>
<th>US</th>
<th>AU</th>
<th>FR</th>
<th>CA</th>
<th>DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers</td>
<td>49446</td>
<td>3913</td>
<td>3907</td>
<td>3264</td>
<td>1937</td>
</tr>
</tbody>
</table>

**Table 4.** Distribution of newly-appeared prefixes in terms of the country to which the matched allocations are made
Where do the advertisements go?

- "Aggregated": disappeared prefixes that are aggregated into shorter prefixes.
- "Fragmented": disappeared prefixes that are fragmented into longer prefixes.
- "Discarded": disappeared prefixes whose address space entirely goes out of use.
### Distribution of New Announced Prefixes (total: 87,941)

<table>
<thead>
<tr>
<th>Prefix Len</th>
<th>/8</th>
<th>/9</th>
<th>/10</th>
<th>/11</th>
<th>/12</th>
<th>/13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>23</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefix Len</td>
<td>/14</td>
<td>/15</td>
<td>/16</td>
<td>/17</td>
<td>/18</td>
<td>/19</td>
</tr>
<tr>
<td>Number</td>
<td>128</td>
<td>249</td>
<td>1959</td>
<td>1107</td>
<td>1942</td>
<td>5694</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefix Len</td>
<td>/20</td>
<td>/21</td>
<td>/22</td>
<td>/23</td>
<td>/24</td>
<td>/25</td>
</tr>
<tr>
<td>Number</td>
<td>5461</td>
<td>3816</td>
<td>6106</td>
<td>7635</td>
<td>50917</td>
<td>582</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefix Len</td>
<td>/26</td>
<td>/27</td>
<td>/28</td>
<td>/29</td>
<td>/30</td>
<td>/32</td>
</tr>
<tr>
<td>Number</td>
<td>784</td>
<td>335</td>
<td>279</td>
<td>229</td>
<td>436</td>
<td>155</td>
</tr>
</tbody>
</table>
### Distribution of Disappeared Prefixes (total: 34,012)

<table>
<thead>
<tr>
<th>Prefix Len</th>
<th>/8</th>
<th>/9</th>
<th>/10</th>
<th>/11</th>
<th>/12</th>
<th>/13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Prefix Len</td>
<td>/14</td>
<td>/15</td>
<td>/16</td>
<td>/17</td>
<td>/18</td>
<td>/19</td>
</tr>
<tr>
<td>Number</td>
<td>34</td>
<td>55</td>
<td>1095</td>
<td>117</td>
<td>279</td>
<td>704</td>
</tr>
<tr>
<td>Prefix Len</td>
<td>/20</td>
<td>/21</td>
<td>/22</td>
<td>/23</td>
<td>/24</td>
<td>/25</td>
</tr>
<tr>
<td>Number</td>
<td>753</td>
<td>1050</td>
<td>1668</td>
<td>2635</td>
<td>22166</td>
<td>53</td>
</tr>
<tr>
<td>Prefix Len</td>
<td>/26</td>
<td>/27</td>
<td>/28</td>
<td>/29</td>
<td>/30</td>
<td>/32</td>
</tr>
<tr>
<td>Number</td>
<td>67</td>
<td>89</td>
<td>66</td>
<td>17</td>
<td>2832</td>
<td>304</td>
</tr>
</tbody>
</table>
Impact on Address Consumption

- 37%: Address space represented by the “Aggregated” prefixes.
- 22%: Address space represented by the “Fragmented” prefixes and is still in use.
- 23%: Address space represented by the “Fragmented” prefixes and goes out of use.
- 18%: Address space represented by the “Discarded” prefixes.
Observations

- New allocations play a dominant role in the global routing table
- Did the /19 to /20 change have an impact?
- There is no requirement that allocations have to be advertised as allocated
What Next?

- What other questions should we be answering?
- Comments? Questions?
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