Where did all those IPv6 addresses go?

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APNIC
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It seems rather odd…

• To be considering address capacity issues in a technology that is really only ramping up.
• 128 bits allows an awesomely large pool of unique values
  “If the earth were made entirely out of 1 cubic millimetre grains of sand, then you could give a unique address to each grain in 300 million planets the size of the earth” -- Wikipedia

• This is a highly speculative exercise....
IETF IPv6 Address Structure

- Interface ID: 64 bits
- Subnet ID: n bits (64 - n bits)
- Global ID: /64

RIR IPv6 Address Structure

- Interface ID: 64 bits
- Subnet ID: 16 bits
- Global ID: 48 bits
Current Address Allocation Policies

• RIR to ISP(LIR):
  • Initial allocation: /32 (minimum)
  • Subsequent allocation: /32 (minimum)
• ISP(LIR) to customer:
  • Only 1 interface ever: /128
  • Only 1 subnet ever: /64
  • Everything else: /48 (minimum)
• ISP(LIR) to each POP:
  • /48
## Address Efficiency – HD=0.8

<table>
<thead>
<tr>
<th>Prefix</th>
<th>/48 count</th>
<th>end-site count</th>
</tr>
</thead>
<tbody>
<tr>
<td>/32</td>
<td>65,536</td>
<td>7,132</td>
</tr>
<tr>
<td>/31</td>
<td>131,072</td>
<td>12,417</td>
</tr>
<tr>
<td>/30</td>
<td>262,144</td>
<td>21,619</td>
</tr>
<tr>
<td>/29</td>
<td>524,288</td>
<td>37,641</td>
</tr>
<tr>
<td>/28</td>
<td>1,048,576</td>
<td>65,536</td>
</tr>
<tr>
<td>/27</td>
<td>2,097,152</td>
<td>114,105</td>
</tr>
<tr>
<td>/26</td>
<td>4,194,304</td>
<td>198,668</td>
</tr>
<tr>
<td>/25</td>
<td>8,388,608</td>
<td>345,901</td>
</tr>
<tr>
<td>/24</td>
<td>16,777,216</td>
<td>602,249</td>
</tr>
<tr>
<td>/23</td>
<td>33,554,432</td>
<td>1,048,576</td>
</tr>
<tr>
<td>/22</td>
<td>67,108,864</td>
<td>1,825,677</td>
</tr>
<tr>
<td>/21</td>
<td>134,217,728</td>
<td>3,178,688</td>
</tr>
<tr>
<td>/20</td>
<td>268,435,456</td>
<td>5,534,417</td>
</tr>
<tr>
<td>/19</td>
<td>536,870,912</td>
<td>9,635,980</td>
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<tr>
<td>/18</td>
<td>1,073,741,824</td>
<td>16,777,216</td>
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Google ("subscribers millions")

• Broadband
  • 150 million total globally
    • 85 million DSL Globally
      • 12 million in US today
      • 58 million in US in 2008

• Cellular
  • Cingular: 50 million
  • Verizon: 43 million
  • Korea: 37 million
  • Russia: 20 million
  • Asia: 560 million
    • China: 580 million subscribers by 2009
Squeezing in Bigger Numbers for Longer Timeframes

• The demand - global populations:
  • Households, Workplaces, Devices, Manufacturers, Public agencies
  • Thousands of service enterprises serving millions of end sites in commodity communications services
  • Addressing technology to last for decades
  • Total end-site populations of tens of billions of end sites
    i.e. the total is order \(10^{11}\) ?

• The supply – inter-domain routing
  • We really may be stuck with BGP
  • Approx 200,000 routing (RIB) entries today
  • A billion routing (RIB) entries looks a little too optimistic
    i.e. a total entry count is order\(10^7\)

• The shoe horn
  • Aggregation and hierarchies in the address plan
Putting it together

- Aggregation and hierarchies are not highly efficient addressing structures
- The addressing plan needs to accommodate both large and small
- The addressing plan needs to be simple

16 bit subnets + HD = 0.8 + global populations + 60 years =?
# HD Ratio for Bigger Networks

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<td>16,777,216</td>
</tr>
<tr>
<td>/17</td>
<td>2,147,483,648</td>
<td>29,210,830</td>
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<tr>
<td>/16</td>
<td>4,294,967,296</td>
<td>50,859,008</td>
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<tr>
<td>/15</td>
<td>8,589,934,592</td>
<td>88,550,677</td>
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<tr>
<td>/14</td>
<td>17,179,869,184</td>
<td>154,175,683</td>
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<tr>
<td>/13</td>
<td>34,359,738,368</td>
<td>268,435,456</td>
</tr>
<tr>
<td>/12</td>
<td>68,719,476,736</td>
<td>467,373,275</td>
</tr>
<tr>
<td>/11</td>
<td>137,438,953,472</td>
<td>813,744,135</td>
</tr>
<tr>
<td>/10</td>
<td>274,877,906,944</td>
<td>1,416,810,831</td>
</tr>
<tr>
<td>/9</td>
<td>549,755,813,888</td>
<td>2,466,810,934</td>
</tr>
<tr>
<td>/8</td>
<td>1,099,511,627,776</td>
<td>4,294,967,296</td>
</tr>
<tr>
<td>/7</td>
<td>2,199,023,255,552</td>
<td>7,477,972,398</td>
</tr>
<tr>
<td>/6</td>
<td>4,398,046,511,104</td>
<td>13,019,906,166</td>
</tr>
<tr>
<td>/5</td>
<td>8,796,093,022,208</td>
<td>22,668,973,294</td>
</tr>
<tr>
<td>/4</td>
<td>17,592,186,044,416</td>
<td>39,468,974,941</td>
</tr>
<tr>
<td>/3</td>
<td>35,184,372,088,832</td>
<td>68,719,476,736</td>
</tr>
<tr>
<td>/2</td>
<td>70,368,744,177,664</td>
<td>119,647,558,364</td>
</tr>
<tr>
<td>/1</td>
<td>140,737,488,355,328</td>
<td>208,318,498,661</td>
</tr>
</tbody>
</table>
Multiplying it out

A possible consumption total:

- a simple address plan (/48s)
- x aggregation factor (HD = 0.8)
- x global populations (10**11)
- x 60 years time frame

= 50 billion – 200 billion
= /1 -- /4 range

RFC 3177 (Sept 2001) estimated 178 billion global IDs with a higher HD ratio. The total “comfortable” address capacity was a /3.
Is this enough of a margin?

/4 consumption
  • A total of 1/16 of the available IPv6 address space

/1 consumption
  • A total of 1/2 of the available IPv6 address space

Factors / Uncertainties:
  • Time period estimates (decades vs centuries)
  • Consumption models (recyclable vs one-time manufacture)
  • Network models (single domain vs overlays)
  • Network Service models (value-add-service vs commodity distribution)
  • Device service models (discrete devices vs ubiquitous embedding)
  • Population counts (human populations vs device populations)
  • Address Distribution models (cohesive uniform policies vs diverse supply streams)
  • Overall utilization efficiency models (aggregated commodity supply chains vs specialized markets)
If this is looking slightly uncomfortable…
then we need to re-look at the basic assumptions to see where there may be some room to shift the allocation and/or architectural parameters to obtain some additional expansion space.
Where’s the Wriggle Room?

- IPv6 Allocation Policies
  - The HD-Ratio target for address utilization
  - The subnet field size used for end-site allocation
- IPv6 Address Architecture
  - 64 bit Interface ID
1. Varying the HD Ratio

\[
\frac{\log(\text{utilized})}{\log(\text{total})} = \text{HD}
\]
Comparison of prefix size distributions from V6 registry simulations

Comparison of Prefix Distributions

HD = 0.8
HD = 0.87
HD = 0.94
Observations

• 80% of all allocations are /31, /32 for HD ratio of 0.8 or higher
  • Changing the HD ratio will not impact most allocations in a steady state registry function

• Only 2% of all allocations are larger than a /27
  • For these larger allocations the target efficiency is lifted from 4% to 25% by changing the HD Ratio from 0.8 to 0.94

• Total 3 year address consumption is reduced by a factor of 10 in changing the HD ratio from 0.8 to 0.94
What is a “good” HD Ratio to use?

• Consider **what is common practice** in today’s network in terms of internal architecture
  • APNIC is conducting a survey of ISPs in the region on network structure and internal levels of address hierarchy and will present the findings at APNIC 20

• Define a **common ‘baseline’ efficiency level** rather than an average attainable level
  • What value would be readily achievable by large and small networks without resorting to renumbering or unacceptable internal route fragmentation?

• Consider overall **longer term objectives**
  • Anticipated address pool lifetime
  • Anticipated impact on the routing space
2. The Subnet Identifier field

- **RFC 3177: The subnet field**
  
  Recommendation
  
  - /48 in the general case, except for very large subscribers
  - /64 when it is known that one and only one subnet is needed by design
  - /128 when it is absolutely known that one and only one device is connecting

  **Motivation**
  
  - reduce evaluation and record-keeping workload in the address distribution function
  - ease of renumbering the provider prefix
  - ease of multi-homing
  - end-site growth
  - allows end-sites to maintain a single reverse mapping domain
  - Allows sites to maintain a common reverse mapping zone for multiple prefixes
  - Conformity with site-local structure (now unique locals)
Alternatives for subnetting

- Consider /56 SOHO default size
  - Maintain /128 and /64 allocation points, and /48 for compound enterprise end-sites
  - Processing and record-keeping overheads are a consideration here
  - End-site growth models for SOHO are not looking at extensive subnetting of a single provider realm
  - Renumbering workload is unaltered
  - Multi-homing is not looking at prefix rewriting
  - Fixed points maintains reverse mapping zone functions

- Allow for overall 6 – 7 bits of reduced total address consumption
Alternatives for subnetting

- Consider variable length subnetting
  - Allows for greater end-site address utilization efficiencies
  - Implies higher cost for evaluation and record keeping functions
  - Implies tradeoff between utilization efficiency and growth overheads
  - Likely strong pressure to simplify the process by adopting the maximal value of the range
3. The Interface Identifier

- This identifier is now well embedded in the address architecture for V6
- Considerations for change here have extensive implications in terms of overlayed services of auto-configuration and discovery functions
Where’s the Wriggle Room?

The HD ratio
- If using HD = 0.8 consumes 1 block of address space
- Using HD = 0.87 consumes 1/2 as much space
- Using HD = 0.94 consumes 1/10 as much space
- i.e. moving to a higher HD ratio will recover 3 bits here

The subnet field
- /56 SOHO default subnet size may alter cumulative total by 6 - 7 bits

/10 -- /17 range total

Is this sufficient margin for error / uncertainty in the initial assumptions about the deployment lifetime for IPv6?