Running Out of Integers
The Impending Scarcity of IP Addresses and What To Do About It

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Plan

• What IPs are and how they’re used
• Scarcity
• Possible alternatives
  – Adding digits
  – Sharing addresses
• Market for transferring IPs
  – Objectives
  – Basic approach
  – Restrictions
Checking Your IP Address

IP Address: 199.94.11.10
Subnet Mask: 255.255.252.0
Manually Configured
Domain Name – www.hbs.edu

IP Address - 199.94.20.117
Looking Up An IP Address

OrgName: Harvard University
OrgID: HARVAR
Address: UIS Network Operations Center
Address: Jay Tumas - Network Operations Manager
Address: 60 Oxford Street
Address: Suite 132
City: Cambridge
StateProv: MA
PostalCode: 02138
Country: US

NetRange: 140.247.0.0 - 140.247.255.255
CIDR: 140.247.0.0/16
NetName: HARVARD-COLL
NetHandle: NET-140-247-0-0-1
Parent: NET-140-0-0-0-0
NetType: Direct Assignment
NameServer: CNRDN31.FAS.HARVARD.EDU
NameServer: CNRDN32.FAS.HARVARD.EDU
Comment:
RegDate: 1992-09-18
Updated: 2006-08-21

RAbuseHandle: FN01-ARIN
RAbuseName: FAS Network Operations
RAbusePhone: +1-617-495-1262
RAbuseEmail: netmanager@fas.harvard.edu
## Widener Call Number Locations

<table>
<thead>
<tr>
<th>Code</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>WID-LC D</td>
<td>4 West</td>
</tr>
<tr>
<td>WID-LC E</td>
<td>1 East</td>
</tr>
<tr>
<td>WID-LC F</td>
<td>1 East</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>WID-LC G*–GV</td>
<td>Pusey 3</td>
</tr>
<tr>
<td>WID-LC H*, HA</td>
<td>Pusey 3</td>
</tr>
<tr>
<td>WID-LC HB*–HX</td>
<td>Pusey 2</td>
</tr>
<tr>
<td>WID-LC J–JZ</td>
<td>D East</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Address Assignment Structure

- ICANN / IANA
- ARIN
- APNIC
- RIPE
- LACNIC
- AfriNIC
- DoC
## ARIN Fees

<table>
<thead>
<tr>
<th>Size</th>
<th>Fee</th>
<th>Total Allocation Block Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-small</td>
<td>$1,250/year</td>
<td>blocks smaller than a /20 (&lt;2^{12} addresses)</td>
</tr>
<tr>
<td>Small</td>
<td>$2,250/year</td>
<td>blocks from a /20 to a /19 in size</td>
</tr>
<tr>
<td>Medium</td>
<td>$4,500/year</td>
<td>blocks larger than a /19, up to and including a /16</td>
</tr>
<tr>
<td>Large</td>
<td>$9,000/year</td>
<td>blocks larger than a /16, up to and including a /14</td>
</tr>
<tr>
<td>X-large</td>
<td>$18,000/year</td>
<td>blocks larger than a /14 (&gt;2^{18} addresses)</td>
</tr>
</tbody>
</table>
The Structure of IPv4 Addresses

199.94.20.117

11000111 01011110 00010100 01110101

\[ \begin{array}{cccc}
8 & 8 & 8 & 8 \\
01011110 & 00010100 & 01110101 &
\end{array} \]

\[ \rightarrow 2^{32} \text{ possible addresses} \]
“Add another digit”

- License plates
- Phone numbers
IPv6

\[ 2^{128} \approx 3.4 \times 10^{38} \]
v4-v6 Translation

- Forwards DNS Query: www.google.com
- DNS Reply: 3ff3:501:41c:c1ad::d8ef:3b68
- Destination: 3ff3:501:41c:c1ad::d8ef:3b68
- NAT-PT Server

Adapted from Vasaka Tisottiviseth
Costs to IPv6 Transition

- Forwards compatibility
- Backwards compatibility
- Renumbering
  - Hard-coded IPs
- Software upgrades
  - Commercial
  - Internal
- Hardware upgrades
  - Printers, firewalls, routers
- Training

DoC estimates $25 billion over 25 years
IPv6 Detriments

• IPv4 works
• IPv4 addresses are still easy & cheap to get
• Everyone else runs IPv4
• IPv6 transition is expensive and complicated
Sharing IPv4 Addresses

Network Address Translation

The Public Internet

NAT

PC 1

PC 2

PC 3

web server

but...
NAT Complexity
Inhibiting IPv4 Transfers

“Number resources are non-transferable and are not assignable to any other organization ...”

“[N]umber resources are assigned to an organization for its exclusive use for the purpose stated in the request, provided the terms of the Registration Services Agreement continue to be met and the stated purpose for the number resources remains the same. …

“ARIN will consider requests for the transfer of number resources only upon receipt of evidence that the new entity has acquired the assets which had, as of the date of the acquisition ..., justified the current entity's use of the number resource.”

-ARIN Number Resource Policy Manual Section 8.1-2
Sources of IPv4 Addresses

- Legacy operators
- Bankrupt / defunct networks
- Networks substituting out of IPv4
IPv4 Usage

Source:
The Measurement Factory
IPv4 Market Design Questions

- Allow paid transfers at all?
- Block size?
- Speculators?
  - “Need” requirement?
  - Minimum holding period?
- Inter-region transfers?
- Effect on IPv6 transition?
- Likely prices?
Subdivision and Full-Fill

• Subdivision by transferors
  – Could prohibit, limit, or allow

• Full-fill rule for transferees

→ Which side to regulate? Or both?
Full-Fill plus Unlimited Subdivision

• Suppose prices are concave.
• Prices are weakly convex.
• Resulting incentives for transferors? For transferees?
Political Economy of IPv4 Markets

• Tech-savvy network engineers
• Multiple regions with independent RIRs
• Networks vary dramatically
  – size, wealth, purpose
Alternatives

- Unrestricted markets
- RIR as warehouse, sole buyer, sole seller
  - At what price?
Research questions

- In a v4 market, what rules are appropriate?
- Likely prices in a v4 market? As a function of market rules?
- Effect of v4 market on v6 transition?
- Unpriced resources more generally
  - Addresses
  - Routing slots
  - Email, web browsing, end-user bandwidth, etc.