IP Version 6 (IPv6)
Past, Present, and Future

Bob Hinden / Check Point Fellow
IPv6 Background

- In the early 1990s it was not clear that TCP/IP was going to be successful
- There were many competitors
  - OSI CLNP, ATM, AT&T Business, etc.
- Predictions of Internet melt downs
- The IETF was not considered to be an official standards organization
- Not having a plan for what follows IPv4 was a real issue
Some Old Slides from ~1995

INTERNET GROWTH

time
FACTORS CAUSING GROWTH

- More of what we have Today
  - All Computers on Internet
  - Real Commerce / Advertising
- New Users
  - Large Countries (China, India, ...)
  - New Industries (cable, mobile, ...)
- Networked Everything
  - All Information Devices (FAX, Printers, ...)
  - Energy Management (meters, controllers, switches....)
IETF IPng Time Line

• ~1990
  – Internet growing exponentially and started looking like running out of IP addresses
  – Projected exhaustion of Class B Address space

• 1991
  – Routing and Addressing (ROAD) group formed
    – Recommended implementing CIDR and develop IP Next Generation (IPng)

• 1992
  – IAB issues “IP Version 7”
    – This came to be known as the “Kobe Incident”

• 1992 (cont)
  – IETF issues call for IPng proposals

• 1993
  – IESG took on IPng responsibility
  – IPng Area formed
    – Scott Bradner & Allison Mankin area directors
    – RFC1550 Call for IPng Solicitation published

• 1994
  – IPng Recommendation
IPng Candidates

IPv7 (Ullman) → TP/IX → CATNIP

TUBA (Callon)

ENCAPS (Hinden) → IPAЕ

SIP (Deering) → SIPP → IPv6

PIP (Francis)

<table>
<thead>
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<th></th>
<th>Jan 92</th>
<th>July 9</th>
<th>Jan 93</th>
<th>July 93</th>
<th>Jan 94</th>
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# IP Version Numbers

<table>
<thead>
<tr>
<th>Version</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>Unassigned</td>
</tr>
<tr>
<td>4</td>
<td>Internet Protocol (current IPv4)</td>
</tr>
<tr>
<td>5</td>
<td>Stream Protocol (ST) (not an IPng)</td>
</tr>
<tr>
<td>6</td>
<td>SIP – SIPP – IPv6</td>
</tr>
<tr>
<td>7</td>
<td>IPv7 – TP/IX – CATNIP</td>
</tr>
<tr>
<td>8</td>
<td>Pip</td>
</tr>
<tr>
<td>9</td>
<td>TUBA</td>
</tr>
<tr>
<td>10-15</td>
<td>unassigned</td>
</tr>
</tbody>
</table>
Classless Inter-Domain Routing (CIDR)

- Relaxed fixed boundaries in IP address allocation
  - Original IP allocation strategy was “flat”

- Allocate blocks of IP addresses to Providers
  - Now called prefixes
  - Routing protocols changed to aggregate all routes to a single provider

- CIDR made address utilization more efficient and greatly improved core routing scaling
CATNIP

• Common Architecture for Next-generation Internet Protocol (CATNIP)
  – Chair: Vladimir Sukonnik
  – Documented in RFC1707

• Based on work of TP/IX working group
  – Goal was to find common ground between OSI and Novell protocols, and to increase the scale and performance

• Not well specified, interesting ideas, but not a complete proposal
TUBA

- TCP/UDP Over Bigger Addresses
  - Chairs: Peter Ford & Mark Knopper
  - Documented in RFC1347

- Approach was to run TCP/UDP over the ISO Connection-Less Network Protocol (CLNP)
  - Leveraged the ISO work

- Strength was CLNP, weakness was CLNP
SIP - Simple IP

- Simple IP
- Proposal from Steve Deering
- Technical
  - 64-bit addresses (twice the number of bits of IPv4)
  - Headers size kept at 20 bytes (same size as IPv4 header)
    - Simplified header, removed fragmentation and options
- Simple and clean design
- Questions about address size, in hindsight would have been the easiest transition
SIPP

- Simple Internet Protocol Plus (SIPP)
  - Chairs: Steve Deering, Paul Francis, Bob Hinden
  - Documented in RFC1710

- Based on merger of ENCAPS into IPAE, merged with SIP, and with PIP
  - New version of IP designed to be an evolutionary step from IPv4. Designed to work over a range of speeds and network types.

- Clean design from SIP, addresses too small, extended addresses too complex.
The Address Size Debate

- Fixed length 64-bit addresses (SIP)
  - Met requirements by 3 orders of magnitude, $10^{12}$ sites, $10^{15}$ nodes at .0001 allocation
  - Minimizes growth of packet
  - Efficient for software processing

- Variable length addresses, up to 160-bits (TUBA)
  - Compatible with OSI NSAP address plans
  - Large enough for auto-configuration using IEEE 802 addresses
  - Could start with short addresses and grow later

- Compromised on fixed length 128-bit addresses
IPng Recommendation

- IPng based on SIPP with 128-bit addresses

- IPng working group created to create specifications and standardize IPv6
  - Chairs: Steve Deering, Ross Callon
  - Document editor: Bob Hinden

- Goal to resolve remaining issues, complete unfinished work, move to Proposed Standard
  - IPv6 first published as RFC1883 December 1995
We did Run Out of IPv4 Addresses

(Last allocation to RIRs from the IANA free pool 31 Jan 2011)
~24% of User Access to Google is with IPv6

## ISP Status

<table>
<thead>
<tr>
<th>ISP</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Verizon Wireless</td>
<td>84%</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>51%</td>
</tr>
<tr>
<td>Comcast</td>
<td>54%</td>
</tr>
<tr>
<td>T-Mobile</td>
<td>87%</td>
</tr>
<tr>
<td>Reliance Jio</td>
<td>83%</td>
</tr>
<tr>
<td>Sprint</td>
<td>44%</td>
</tr>
<tr>
<td>Time Warner Cable</td>
<td>30%</td>
</tr>
<tr>
<td>Deutsche Telekom</td>
<td>44%</td>
</tr>
</tbody>
</table>

# Adoption by Country

<table>
<thead>
<tr>
<th>ISP</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>66%</td>
</tr>
<tr>
<td>USA</td>
<td>40%</td>
</tr>
<tr>
<td>India</td>
<td>37%</td>
</tr>
<tr>
<td>Greece</td>
<td>32%</td>
</tr>
<tr>
<td>Germany</td>
<td>26%</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>22%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>21%</td>
</tr>
<tr>
<td>Finland</td>
<td>21%</td>
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IPv6 is now an Internet Standard

- The IETF published the IPv6 as an Internet Standard in July 2017
  - Internet Standard is the last step in the IETF Standards Process

STD 86
RFC 8200
Title: Internet Protocol, Version 6 (IPv6) Specification
Author: S. Deering, R. Hinden
Status: Standards Track
Date: July 2017
Obsoletes: RFC 2460
IPv6 State Today

- Major platforms all support IPv6
  - MacOS, Windows 10, Linux, Android, iOS, …
  - Routers, Switches, Firewalls, …
- Major content providers support IPv6
  - Google, Netflix, Facebook, LinkedIn, YouTube, …
- Large ISPs support IPv6
- CDN provide IPv6 access to IPv4 only sites
- AWS now supports IPv6
- Some large Enterprise are starting IPv6 only
Challenges going Forward

- Mid size sites
  - Banks, Commerce, …
- Enterprises are mostly IPv4 today
- Smaller ISPs
- IoT Devices
- Some new networks products still come IPv4 only
  - IPv6 is on the roadmap, but…

We have come a long way, but more to do
IPv6 Conclusions

- We were right about running out of IPv4 addresses
  - But did not understand the impact of NAT

- We were not right about
  - How long it would take to develop IPv6
  - When IPv4 addresses would run out
  - How hard and long to deploy

- We made IPv6 happen by building a broad community of motivated and dedicated people around the world
Conclusions (2)

- We did not anticipate how Internet would change
  - No longer “build it and they will come”
  - Now there has to be a business case

- A lot of the industry was in denial for a long time

- No one has done this before
The Internet Today

- It’s very hard to deploy anything that requires global deployment before it becomes useful
  - Anything new needs immediate return
  - It has to solve a local problem, before it can solve a global problem

- The good news is that IPv6 deployment has become a local problem
THANK YOU

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