Considerations on IPv6 Scalability
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Why IPv6?

IPv4 addresses (4 Bio)
World population (7 Bio)
IoT population (50 Bio)

Scalability challenge

2020
Mathematical Representations

Number of IPv6 unique addresses:

\[ 2^{128} \]

\[ 3.4 \times 10^{38} \]

340 undecillions \((340 \times 10^{36})\)

\[ 2^{2^7} \]

Knuth’s up-arrow notation \(2 \uparrow\uparrow 128\).

Forth tetration of 2: \((2 \uparrow\uparrow\uparrow 4)^8\)

Maurer (or Rudy Rucker) presentation as \((^42)^8\)
How Big?
7.5 Billion Humans

7.5 \times 10^9 < P\text{v}6 (3.4 \times 10^{38})
50 Billion IoT Devices

$5 \times 10^{10} < P_{v6} (3.4 \times 10^{38})$
100 Billion Planets in our Galaxy

$1 \times 10^{11} < P_v6 (3.4 \times 10^{38})$
860 Billion Neurones in a Brain

$8.6 \times 10^{11} < \text{Pv6} (3.4 \times 10^{38})$
2 Trillion Galaxies in the Universe

\[ 2 \times 10^{12} < \text{Pv6} \ (3.4 \times 10^{38}) \]
1 Quadrillion Synapses in a Brain

$1 \times 10^{15} < P_{v6} (3.4 \times 10^{38})$
7.5 Quintillion Grains of Sand on Earth

\[ 7.5 \times 10^{18} < P_v6 \ (3.4 \times 10^{38}) \]
7 Octillion Atoms in a Human Body

7 \times 10^{27} < P_6 (3.4 \times 10^{38})
300 Sextillion Stars in the Universe

$3 \times 10^{23} < \text{Pv6} \ (3.4 \times 10^{38})$
51 Undecillion Atoms in Humanity

$5.1 \times 10^{37} < P_v6 (3.4 \times 10^{38})$
IPv6

340 Undecillions IPv6 Addresses

$3,4 \times 10^{38}$
Mass of the Universe

$10^{50} \text{ to } 10^{60} > \text{ Pm6 } (3.4 \times 10^{38})$
Moving Beyond

Googol: $10^{100}$
Googolplex: $10^{\text{Googol}}$ or $10^{10^{100}}$
$10 \uparrow \uparrow 10$ (Guillion)
$100 \uparrow \uparrow 100$ (Theillion)
$1000 \uparrow \uparrow 1000$ (Vintillion)
$10 \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow 10$ (Ziegion)

$F^{10}(10)$, $F(F(F(F(F(F(F(F(F(F(10))))))))))$, where $F(n) = n \uparrow n$. (Annilion)

Graham’s number

Mathematical Big Numbers
Human Limitations

Human capacity
1 IP address allocation per second
80 years (days and nights)
= 80 x 365 x 24 x 60 x 60
= 2'522'880'000 addresses
= ~2.5 x 10^9

1 IPv6 Subnet
= 2^{64} unique public IP addresses
= 1.8 x 10^{19}
= ~ Ten Billion larger (10^{10}) than human capacity
= ~ Humanity capacity
Conjectures

#1
IPv6 addressing capacity is sufficient to provide a unique 64 bits Host ID to each and every present and future IoT device on earth and in our solar system, as well as to each individual human and machine Internet user.

#2
Mankind will never be able to use and exhaust the complete potential of IPv6 addressing capacity, as long as the address block allocation is aligned with effective needs of end-users (i.e. limiting GRP allocation to /56 or /48).

#3
IPv6 addressing capacity is sufficient to provide a unique complete 128 bits address to each and every star in the universe, but would either require an extended Network GRP or a NAT architecture to address large deployments of IoT in each stellar system.
Conjectures

#4
IPv6 addressing capacity is sufficient to address effective mankind requirements, but can be theoretically superseded by identifiers allocation in mathematical models based on hyperoperations tending towards very large results domains, such Googols, Googolplex, Guilions, Vintillions, Zieglions, Anilions and Graham number.

#5
A single IPv6 Subnet addressing capacity is superior to the whole humanity capacity to manually allocate an configure IPv6 addresses.
**IPv6 Address Structure**

Two halves; three segments:

A. The Routing Address, which is split in two parts:
   I. The Global Routing Prefix (GRP)
   II. The Subnet Identifier (Subnet ID)

B. The Host ID
Galactic IPv6 Addressing Scheme

~ 100 Billion planets in our Galaxy (NASA)

- First block or 48 bits for a Global Routing Prefix for each planet
- Each planet can then allocate 16 bits for subnets
- 64 bits range for IPv6 Host ID fully available.

<table>
<thead>
<tr>
<th>48 bits</th>
<th>16 bits</th>
<th>64 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stellar Global Routing Prefix</td>
<td>Subnet ID</td>
<td>Interface ID</td>
</tr>
</tbody>
</table>
Intergalactic IPv6 Addressing Scheme

~2 x 10^{12} Galaxies in the universe (NASA)
~1.5 x 10^{11} stars per galaxy

- First segment of 48 bits for a galaxy routing prefix.
- Second segment of 48 bits for the star routing prefix.
- 32 bits for border routers identifiers (or single node identifiers).

This would enable to allocate to each star an addressing capacity equivalent to the current IPv4-based Internet.
THANK YOU!
IoT Requirements:

- **Scalability:**
  \[2^{128}\text{ IP addresses}\]
- **Self-configuration:**
  Stateless Address Auto-Configuration Mechanism (SLAAC)
- **Mobility**
- **Security:**
  IPSec, DTLS, etc.
- **Lightweight code:**
  6LoWPAN, CoAP, 6TiSCH, etc.
- **Global availability and interconnectivity:**
  Internet
Ideas of Scalability

~4.3 \times 10^9 \text{ IPv4 addresses } (2^{32})

~7.5 \times 10^9 \text{ Human beings on earth}

~5 \times 10^{10} \text{ IoT devices by 2020}

~1 \times 10^{11} \text{ Planets in our galaxy}

~8.6 \times 10^{11} \text{ Neurons in a brain}

~2 \times 10^{12} \text{ Galaxies in the universe}

~5.1 \times 10^{14} \text{ Square meters on the Earth surface}

~1 \times 10^{15} \text{ Synapses in a brain}

~7.5 \times 10^{18} \text{ Grains of sand on earth}

~5.1 \times 10^{20} \text{ Square millimetres on the Earth}

~3 \times 10^{23} \text{ Stars in the universe}

~7 \times 10^{27} \text{ Atoms in one human body}

~5.3 \times 10^{37} \text{ Atoms in all human bodies}

~3.4 \times 10^{38} \text{ IPv6 addresses } (2^{128})