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Outline

→ A new version of IP: why?
→ Addresses
→ Modified protocols
→ Socket programming interface
→ Packet header format
→ Neighbor discovery
→ Transition to IPv6(?)
A NEW VERSION OF IP: WHY?
Why a new IP?

Only one true answer

A larger address space
Other answers

- More efficient on LANs
- Multicast and anycast
- Security
- Policy routing
- Plug and play
- Traffic differentiation
- Mobility
- Quality of service support

Ported to IPv4
A long way to IPv6 adoption

- Long time for defining IPv6 and migrating to it
- Problems needed an interim solution in IPv4
- When IPv6 reached "production" stage, many IPv4 solutions were acceptable
Why are IPv4 addresses scarce?

32 bit long

About 4 billion addresses!!!

however ...
Only part of the addresses are assigned to stations

- Class A, B and C
- Addresses beginning by bx111 are used for multicast and else

Hence, “just” 3.5 billion addresses can be used!!!
They are used hierarchically

- The prefix used in a physical network cannot be used in a different one
- Lots of unused addresses
Interim (IPv4) solutions to the saturation of address space

- Introduction of network with "tailored" size
  - Netmask
- Private addresses
  - Intranet, RFC 1918
  - Not enough to solve the problem
    - It should be used in conjunction with NAT or ALG
- Network Address Translator (NAT)
  - Extremely popular
- Proposal for RSIP (Realm Specific IP)
- ALG (Application Level Gateway)
Has all of this been effective?
Agencies assigning addresses

IANA distributes (better: distributed) /8 IPv4 network prefixes to regional registries
Situation (2010)

IPv4 Address Pool Status

- IETF_Reserved: 35,078
- IANA_Pool: 20
- IANA_Registry: 2
- VARIOUS: 47,921
- AFRINIC: 2
- APNIC: 40
- ARIN: 70
- RIFENCC: 33
- LACNIC: 6
Situation (2011)

IPv4 Address Pool Status

- IETF_Reserved: 35,0782
- AFRINIC: 12,9961
- APNIC: 55
- ARIN: 83,9257
- RIPENCC: 49
- LACNIC: 20

Pool Size (/8s)
Routing scalability issues

- Routing table size
  - Internet size
  - Each subnetwork must be advertised

- Problems
  - Router resource limitations
    - Too much information to manage
  - Routing protocol limitations
    - High probability of route changes
  - Mainly affecting backbone routers
Routing scalability issues

http://bgp.potaroo.net/
Isn’t there a solution with IPv4?

→ Aggregate multiple routes in one
→ Shorter prefix including others
→ 1.2.1.0/24, 1.2.2.0/24 ...
→ 1.2.0.0/16

→ CIDR (Classless Inter-Domain Routing)
→ Limited by non-rational assignment of IP prefixes
Interim (IPv4) solutions to routing scalability

- CIDR
  - Classless Inter-Domain Routing
  - Limiting the assignment of IP addresses
  - Regional Internet Registry: assign address blocks only to big players
  - E.g., minimum /20 (4096 addresses) network

- Scalability of routing protocols
  - With no solution, at present
  - Problem not completely solved
  - It is the major problem that IPv6 wanted to solve that it is still open
Birth of IPv6

- IETF Boston Meeting (1992), “Call for proposals”

- Appointment of dedicated Working Groups

- Several proposals

- TUBA: adopting OSI CLNP as new IP

- CATNIP: integration of different network (IP, CLNP, IPX) and transport (TP4, SPX, TCP, UDP) protocols

- SIPP: incremental over IPv4

  - Fix some drawbacks

  - Simple: increasing the address field and eliminating unused ones

- Winning proposal: SIPP with 128 bit addresses
ADDRESSES
So, how many addresses should IPv6 have?

→ A scientific approach
→ Addressing efficiency

\[ H = \frac{\log_{10} \text{(number of addresses)}}{\text{number of bits}} \]
Addressing Efficiency

→ In existing networks
  → H varies between 0.22 and 0.26
→ Assuming one million billion networked stations
  → 68 bits in the minimum efficiency case
Melius abundare quam deficere

128 bits
(16 bytes)

655.570.793.348.866.943.898.599 IPv6 addresses per sqm of Hearth surface
Notation

8 hexadecimal numbers separated by 

Groups of 2 bytes

FEDC:BA98:0876:45FA:0562:CDAF:3DAF:BB01
1080:0000:0000:0007:0200:A00C:3423:A089
Shortcuts

Leading Os in each digit group can be omitted


Groups of Os can be substituted by “::”

→ 1O80::7:20O:AOOC:3423

→ Not more than once
Addressing Space Organization

→ Multicast
→ 1111 1111
→ FF00::/8
→ FFxx:xx…
HOST ADDRESSES
Routing and Addressing Principles
Same routing principles as IPv4
Address Structure

Prefix: $n$ bit

Interface Identifier: 128 - $n$ bit

$n = 64$
Same Address Assignment Principles as IPv4
(different terminology)

→ Sub network: set of hosts with same prefix

→ Link: physical network

Subnetwork ≡ link
→ On-link hosts have same prefix
  → Communicate directly

→ Off-link stations have different prefix
  → Communicate through a router
Prefix

Address/netmask pair is substituted by a “Prefix”
Address/N, where N is the prefix length [bit]

→ FEDC:0123:8700::/36
→ 1111111011011100
  0000000100100011100

No address classes
→ Link local/site local
→ 1111 1110 1
→ Link local
→ 1111 1110 10
→ FE80::/64
→ Site local (deprecated)
→ 1111 1110 11
→ FEC0::/10
→ FE[C-F]…
→ Equivalent to IPv4 private addresses
Why Deprecated?

- Overlapping private address spaces
- Not a problem in principle, but in practice
- Extranets
- Mergers and acquisitions
Private Addresses

→ Unique Local Addresses (ULA)
  → FC00::/7
  → 1111 110
→ FC00::/8 for future use

→ Private addresses
  → 1111 1101
→ FD00::/8
Local Unicast Addresses

<table>
<thead>
<tr>
<th>Type</th>
<th>Prefix</th>
<th>Flags</th>
<th>Subnet ID</th>
<th>Interface ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private</td>
<td>1111-1101</td>
<td>randomly generated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Local</td>
<td>1111-1110-11</td>
<td>any</td>
<td></td>
<td>Interface ID</td>
</tr>
<tr>
<td>Link Local</td>
<td>1111-1110-10</td>
<td>0</td>
<td></td>
<td>Interface ID</td>
</tr>
</tbody>
</table>
Remaining addresses

Global Unicast
Global Unicast Addressing Space Organization

→ IPv4 interoperability
→ 0...0 (80 bit) → 0::/80
→ To be used during transition phase
→ IPv4-mapped addresses
→ 16 bits set to 1
→ 0:0:0:0:0:FFFF::/96
→ IPv4-compatible

→ Another 16 bits to 0 → 0::/96
  E.g. 0:0:0:0:0:0:A00:1

→ Compact notation

→ ::A00:1

→ Special notation

→ ::10.0.0.1
Aggregatable Global Unicast

→ Begin with bxOO1
→ [2-3]...
→ Topology-based assignment
→ Service provider hierarchy
→ Effective aggregation
Different assignment criterion for other addresses
Address Assignment

IPv6 - 45

Prefix 64bit
Interface Identifier 64bit
00 01
TLA ID NLA ID SLA ID

Address Assignment

Ethernet Address (EUI 64)

Top level authority
Next level authority
Subnet level authority
Large ISP
Organization

Automatic renumbering
More Flexibility

2001::/21 – 2001::/23 delegated to registries
Plug and Play

Scenarios

- Dentist Office
- Thousand computers on the dock

Solution: autoconfiguration

- Stateless: no server needed
- Statefull: DHCP server
Special Addresses

- Loopback address ::1
- All nodes (multicast) address FF02::1
- All routers (multicast) address FF02::2
- Unspecified address ::
MODIFIED PROTOCOLS
What changes in the protocol architecture?

- IP
- ICMP
- ARP
- Integrated in ICMP
- IGMP
- Integrated in ICMP
What about layer independence?

- DNS (type AAAA record)
- RIP and OSPF
- BGP and IDRP
- TCP and UDP
- Socket interface
What is it?

→ Programming interface for TCP/IP services
→ Used in application implementation
→ UDP messages
→ Bytes on TCP connections
Underlying Principles

- Originated in Unix Environment
- I/O as file access
- Socket descriptor equivalent to a file descriptor for network use
Socket

⇒ Point of access to network services

⇒ Associated to TCP connection or UDP session
Socket Operations

→ Wait for connection requests on a port
   → Server
   → `listen()`

→ Accept requests (server)
→ Connect to a port of a remote server

→ Client

→ Requires specifying address and port

→ Send and receive data
PACKET HEADER FORMAT
Do You Remember the IPv4 Header?

- Version (VER)
- Header Length (HLEN)
- Type of Service (ToS)
- Total Length
- Identifier
- Flag
- Fragment Offset
- Time to Live (TTL)
- Protocol
- Checksum
- Source Address
- Destination Address
- Options
- Padding (PAD)
Here is the IPv6 One

VER | Priority | Flow label
---|---|---
Payload length | Next header | Hop limit

Source Address

Destination Address

Simple and constant length
Field Removal

- Not very useful
- Checksum
- Not used in each packet
- Fragmentation
- No longer needed
- Header length
Extension Headers

→ Added when useful
→ Not needlessly processed in each packet
Extension Headers

- Hop By Hop Option
- Routing
- Fragment
- Authentication
- Encrypted Security Payload
- Destination Option
Extension Header Format

Next Header  Length  Extension data

More extension data

More extension data
Header Chaining

IPv6 Header
N.H.=TCP

TCP Segment

IPv6 Header
N.H.=Routing

Routing header
N.H.=TCP

TCP Segment

IPv6 Header
N.H.=Routing

Routing header
N.H.=Fragm.

Fragm. header
N.H.=TCP

TCP Segment
Options

➔ To be used in Hop-by-hop and Destination Option Extension Headers

➔ TLV format

➔ Type - Length – Value
Sample Option Usage

- **Next Header**: 
  - **Length**: 
  - **Type 1**: 4
  - **Value**: 
- **Type 2**: 6
  - **Value**: 
  - **Value**
Sample Option: Jumbo Payload

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>194</td>
<td>4</td>
<td>Jumbo Payload Length</td>
</tr>
<tr>
<td>Jumbo Payload Length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Padding Options

- Extension Headers must be 64 bit aligned

- PadN Option

- Pad1 Option
### Type Field: first three bits

<table>
<thead>
<tr>
<th>First 2 bits: action in case the option is not recognized</th>
<th>Code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>00</td>
<td>The current option can ignored. It is possible to proceed with the next one</td>
</tr>
<tr>
<td>01</td>
<td>01</td>
<td>The packet must be discarded</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>The packet must be discarded and an ICMPv6 Parameter Problem message generated</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>The packet must be discarded and an ICMPv6 Parameter Problem must be generated, unless the destination address is a multicast one</td>
</tr>
</tbody>
</table>

### Third bit: indicates if the option can be modified on-the-fly

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>The option cannot be changed on-the-fly</td>
</tr>
<tr>
<td>1</td>
<td>The option can be changed on-the-fly</td>
</tr>
</tbody>
</table>
Routing Header

- Used by an IPv6 source to list nodes to traverse on the path to the destination.
- It can be a loose route.
- Segment Left Field shows the number of the remaining path segments.
- Points to the next router to reach.
Routing Header: example

IPv6 Hdr
From: S
To: R1
NextHdr: Routing
Routing Hdr
Segment Left: 2
Hop 1: R2
Hop 2: D

IPv6 Hdr
From: S
To: R2
NextHdr: Routing
Routing Hdr
Segment Left: 1
Hop 1: R1
Hop 2: D

IPv6 Hdr
From: S
To: D
NextHdr: Routing
Routing Hdr
Segment Left: 0
Hop 1: R1
Hop 2: R2
INTERFACING WITH THE LOWER LAYER
Encapsulation

- Encapsulated in layer 2 frames
- EtherType: 86DD
- As a new protocol
  - Enables dual stack approach
  - Keep running IPv4 as-is
Address Mapping

What is the destination MAC address?

➔ IP unicast address
➔ Procedural (protocol-based) discovery
➔ Neighbor Discovery
➔ IP multicast address
➔ Algorithmic mapping
IPv6 Multicast Transmission

→ Based on MAC multicast
→ IPv6 multicast address mapped to MAC address
→ 33-33 | 4 least significant bytes of IPv6 address
Multicast Address Mapping Example

→ When sending a packet to the IP multicast address FFOC::89:AABB:CCDD

→ Encapsulate in MAC frame to 33:33:AA:BB:CC:DD
NEIGHBOR DISCOVERY
New Function in ICMP

- It substitutes ARP
- Based on multicast
- Most likely only one station gets involved
Solicited Node Multicast Address

→ Subscribed by all hosts
→ FFO2::1:FF/104 | 24 least significant bits of IP address
→ Likely 1 host per group
Address Resolution

⇒ ICMP Neighbor Solicitation
⇒ To Solicited Node
  Multicast Address
  of target IPv6 address
⇒ ICMP Neighbor Advertisement
⇒ To requester address
Resolution Example

→ To find the MAC address of host 2001::ABCD:EF98

→ ICMP Neigh Sol to Sol Node Mult Add: FFO2::1:FFCD:EF98

Host Cache

- Mapping between IPv6 and MAC address
- Equivalent to ARP cache
TRANSITION TO IPv6 (?)
IPv4 to IPv6 Transition

- Incremental
- Seamless
- Smooth
How can we enable this?

- Dual-stack approach
  - IPv6 as a new protocol
  - Generate/receive v6 or v4 packets as needed
- Address mapping
- Tunneling
- Translation mechanisms
Isolated IPv6 Networks

- Dual-stack Hosts
- IPv6 in IPv4 Tunnel
IPv6 Islands Grow

IPv6-only Hosts

IPv4

IPv6

Dual-stack Translating Devices

IPv6

IPv6

IPv6

IPv6
Native IPv6 Connectivity

- IPv6-only Hosts
- IPv4
- Dual-stack Translating Devices
- IPv6
- IPv6
- IPv6
- IPv6

All the Way to the Doomsday

IPv4 in IPv6 Tunnel
Are we ready?

→ All protocols specified

→ For a while: since 1996!!
→ Implemented on routers
→ Even if less stable than IPv4
→ Possibly not all functionalities
→ Some hardware implementations (Layer 3 switch)
→ Implemented in end systems
→ Windows since 2000 and XP
→ Unix, FreeBSD, Linux
→ Quite a few applications
→ Possibly with a few bugs
When will it happen?

- Large IPv4 install base
- Only one true motivation:

  Address space depletion
The issue has been mitigated

- Provident address assignment
- Extensive use of private addressing
- NAT and proxying
So, don’t we need IPv6?

→ NAT not suitable for all applications

→ Problematic with security mechanisms
→ User traceability

→ Not practical with servers
  → Not many → public addresses

Acceptable limitations so far
Just Plain Address Space Exhaustion

→ Especially in the Asia-Pacific region
→ IANA ran out of class A prefixes in Feb 2011
→ RIPE by end 2011

Possibly legislation
Current IPv6 web deployment

www.vyncke.org