IPv6, MPLS.

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SS 2020/21, Lecture 4

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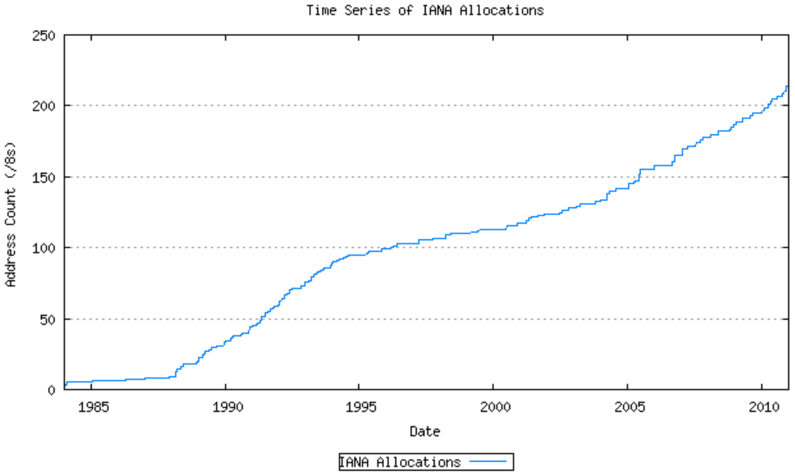
IPv4 address allocation



Source: https://ipv4.potaroo.net/

IPv4 – what next?

- classful design (1980s) was very inefficient
  - 127 Class A occupied half the address space
- 1990s: classless design (CIDR)
  - it has been found that CIDR does not solve the problem of lack of IP addresses
- exhaustion of address space
  - February 3, 2011 - IANA has split the last blocks of IPv4 addresses
  - May 2011 - exhaustion of regional administrators
  - part of the address space is not actually used

New requirements for IP

- Larger address space
- Automatic configuration without external server (DHCP)
- QoS support
- Extended security
- Mobility

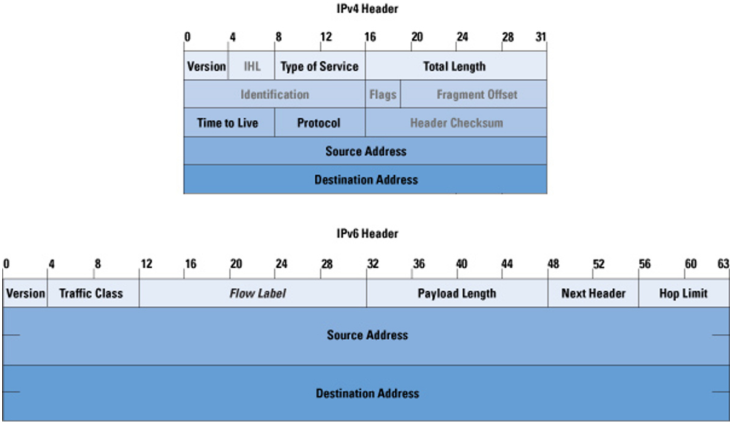
IPv6 milestones

- 1993 – creating of IPng working group (IP next generation)
- 1995 – RFC1550 first specification of IPv6
- 1998 RFC2460 Internet Protocol Version 6 Specification
- 2004 RFC3775 Mobility Support in IPv6

6bone – experimental IPv6 network (1996 – 2006)
Support in root DNS servers - 2003
Operating systems:

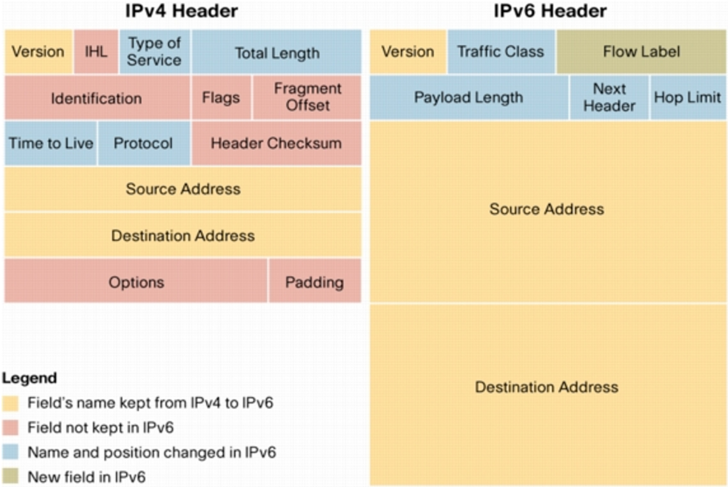
- 1996 Linux (2.1.8)
- 1997 IBM AIX 4.3
- 2000 Sun Solaris v.8, FreeBSD, OpenBSD, NetBSD,
- 2002 WindowsXP (SP1), Windows Server 2003

IPv4 and IPv6 headers comparison I



Source: https://www.cisco.com/

IPv4 and IPv6 headers comparison II



Source: https://www.cisco.com/

IPv6 header

- Version (4b) – value 6
- Source & destination address (128b)
  - $4\times$ longer address
  - $2^{96}\times$ larger address space
- Payload length (16b)
  - is calculated from the end of the main header
  - includes extension headers
- Next header (8b) – type of the following header or data
- Hop limit (8b) – maximum number of “hops”
  - similar to TTL in IPv4
  - protection from loops
  - each router reduces the value by 1
  - after reaching zero value the packet is discarded and an ICMP message is sent
- Traffic class (8b)
  - differentiated services, diffserv (6b)
  - explicit congestion notification (2b)

IPv6 header: changes

Some fields from IPv4 are omitted in IPv6:

- fragmentation, options: replaced by extension headers
- header length: is fixed now
- checksum: get rid of recalculation on each router

New field:

- Flow label (20b) – identification of data flow to make routing easier

Extension headers (EH)

- extension header(s) may be placed after the main IPv6 header
- the only must requirement: Hop-by-Hop EH has to be the first one
- last EH contains type of data in payload (upper layer)

Order	Header type	Next header code
1	Basic IPv6 Header	–
2	Hop-by-Hop Options	0
3	Destination Options (with Routing Options)	60
4	Routing Header	43
5	Fragment Header	44
6	Authentication Header	51
7	Encapsulation Security Payload Header	50
8	Destination Options	60
9	Mobility Header	135
	No next header	59
Upper layer	TCP	6
Upper layer	UDP	17
Upper layer	ICMPv6	58

Jumbogram

- maximal payload length is 65535 ($2^{16} - 1$)
- IPv6 allows larger packet – jumbogram – up to 4 GB
  - make sense for MTU $>$ 64 kB
  - "Payload length" is set to 0
  - length(32b) value is in EH type Hop-by-Hop Options

Fragmentation

- minimal MTU for IPv6 is 1280 bytes
- path MTU discovery
- fragmentation is performed by sender, not by routers
- if packet is larger:
    - router will drop it
    - send ICMP message with MTU information to the sender
    - effort to avoid fragmentation
    - set datagram size to MTU

IPv6 address notation

8 groups of 4 hex numbers (16 bytes, 128 bits)

- delimiter ":"
- continuous group/groups of 0s is substituted by "::"
- last 4 bytes could be written in decimal form, delimiter is "."
  - compatibility with IPv4
  - implementation is not mandatory

Example (the same address):

- 2001:0db8:0000:0000:0000:0000:1428:57ab
- 2001:0db8:0000:0000:0000::1428:57ab
- 2001:0db8:0:0:0:0:1428:57ab
- 2001:0db8::1428:57ab
- 2001:0db8::20.40.87.171

Types of IPv6 addresses

- individual: unicast
- group: multicast
- selective: anycast

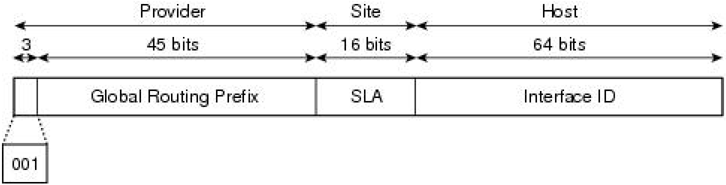
IPv6 network ranges

- ::1/128 - loopback
- fc00::/7 - unigue local addresses (local network range)
- fe80::/10 - link local range
- ff00::/8 - multicast
- 2000::/3 - global addresses
- 2001:db8::/32 - used for documentation and illustration purposes

Global IPv6 address

- prefix 2000::/3 (binary 001) is specified for now

Structure:



Interface ID is to be constructed in IEEE EUI-64 format. Example:
MAC: 00:40:D0:7D:6A:86
Interface ID: 0240:D0FF:FE7D:6A86

Addresses of the network interface

The network interface has multiple IPv6 addresses:

- loopback
- local link
- unicast and anycast
- multicast for all nodes
- multicast for groups of which it is a member
- solicited-node multicast (neighbor discovery)

The router has additional addresses:

- multicast for all routers
- subnet-router anycast
- all assigned anycast addresses

Neighbor Discovery Protocol

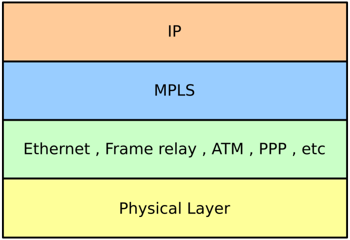
- extended replacement for ARP
- uses ICMPv6
  - Router Solicitation
  - Router Advertisement
  - Neighbor Solicitation
  - Neighbor Advertisement
  - Redirect

Allows:

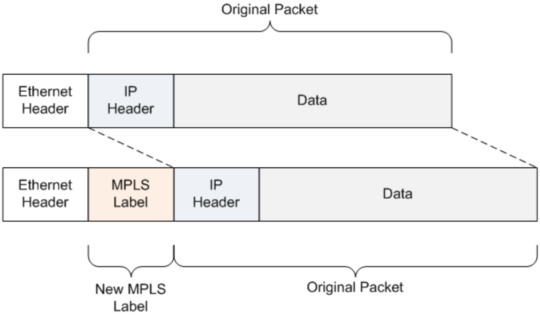
- find out link addresses in the local network
- quick update of changes and invalid entries
- routers discovery
- redirection
- detection of duplicate addresses
- verification of neighbors' accessibility
- discovering information for automatic configuration

MultiProtocol Label Switching (MPLS)

- in OSI model is between 2nd and 3rd layers: “layer 2.5 protocol”
- adds label to layer 3 packets
- packets are then switched according the label
- implements end-to-end connection independent of link layer



Source: Wikipedia



Source: https://www.packetflow.co.uk/

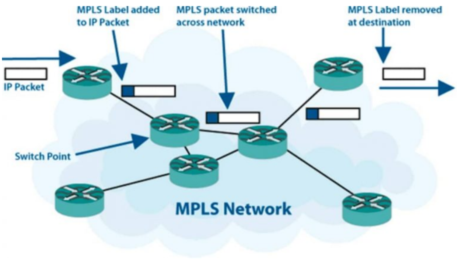
MPLS header

Source: cisco

- total length – 32 bits
- label – 20 bits, used by label switch router (LSR)
- traffic class – experimental – 3 bits
- bottom of label stack flag – 1 bit
- time to live – 8 bits, decremented by each LSR

MPLS network

- Label Edge Router(LER) attaches label to packet when it enters MPLS network
- inside the MPLS network, packets are forwarded according labels by Label Switch Routers(LSRs)
- when packet exits the MPLS network, the edge router removes the label



Source: https://www.mushroomnetworks.com/