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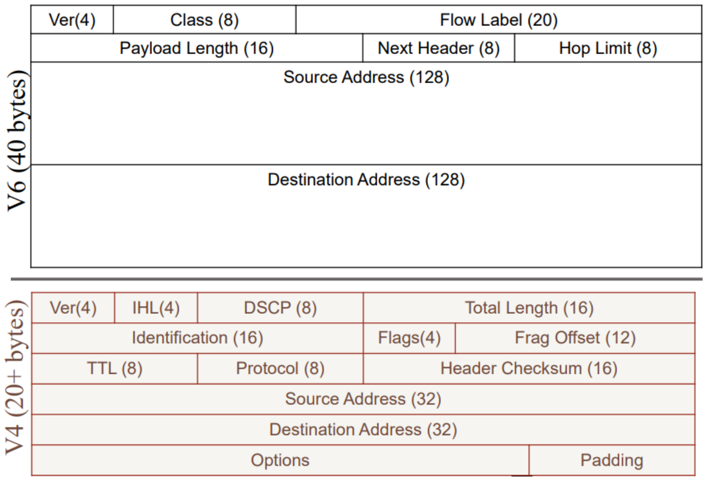
IPV6

Why IPv6?

- Address Exhaustion: IPv4 addresses are running out; NAT is a temporary solution
- Improve router performance: simplifies IP header, aligns to 64 bits, address hierarchy with more levels, and simplifies routing tables
- Improve Mobile IP support

Headers

- **Ver -** protocol version (=6)
- **Class -** similar to IPv4's ToS / DSCP
- **Flow Label -** flow identification;
  - Unique for each flow with the same (src,dst) pair
  - Zero means "no flow label"
- **Payload length -** data field size
  - Limited to 2^{16}-1 bytes, but there there's an option for Jumbograms up to 2^{32}-1 bytes
  - No need for total length since the header size is fixed
- **Next Header -** type of next header
- **Hop Limit -** IPv4's TTL (but done properly)
- No checksum, with error checking performed by lower layers



Addresses

- 128 bits represented in hexadecimal
- Leading zeroes may be omitted
- A sequence of zeroes may be abbreviated by ::
  - Only one :: in an address to avoid ambiguity
- Mask (prefix length) similar to IPv4 CIDR
- IPv4 can be embedded in IPv6 addresses

Unicast

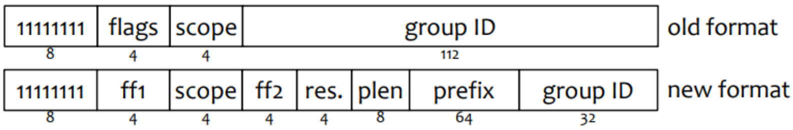
- Loopback ::1 (/128)

- Link-local:
    - Only used on the local link (not routed)
        - FE80::/64 (last 64 bits are device identifier)
- Site-local (deprecated):
    - Used within the same site, and therefore only valid therein
        - FEC0:0000:0000:<Subnet(16)>:<Interface(64)>
- Global address:
    - Internet routable address
        - 2000::/3
        - But there can be routable IPv6 addresses outside this range

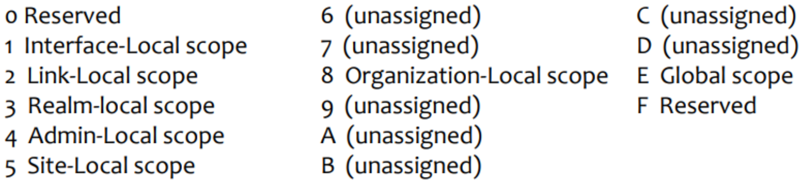
Multicast

- Multicast:

    - With different scopes



- 4-bit multicast scope field used to limit the scope of the multicast group



0	Reserved
1	Interface-Local scope
2	Link-Local scope
3	Realm-local scope
4	Admin-Local scope
5	Site-Local scope
6	(unassigned)
7	(unassigned)
8	Organization-Local scope
9	(unassigned)
A	(unassigned)
B	(unassigned)
C	(unassigned)
D	(unassigned)
E	Global scope
F	Reserved

Other

- Anycast address
    - Defined on more than one interface, but delivered only to one
- Unspecified address
    - Denoted by :: and used only during configuration

Required addresses

- Node:
    - Loopback
    - Link-local for each interface
    - Configured unicast (or anycast)
    - All-nodes multicast
    - Solicited-node multicast address for each of its unicast and anycast addresses
    - Multicast groups that the node belongs to
- Router: all the above plus
    - Subnet-Router Anycast (equal to the subnet prefix)
    - All-Routers multicast

ICMPv6 (Internet control message protocol for IPv6)

- **Type** defines the type, **code** a subtype (similar to ICMP (v4))
- Example:
  - Type = 1 (Error code for destination unreachable)
  - Code = 0 (no route to destination)
- Errors have type with high-order bit = 0 (0-126)
  - Informational are 128-254

Neighbour Discovery

- Replaces IPv4 ARP
- Adds auto-configuration helper functions
- Extensible: messages may have options for added information
- IP Hop limit: set to 255

Neighbour solicitation

- Sent by hosts or routers, for address resolution, neighbour unreachability detection (NUD), and duplicate address detection (DAD)
- Type = 135, code = 0
- **Target address**
  - IP address of the solicitation target
- **IP destination address**
  - solicited-node multicast address corresponding to the target address, or the target address itself
- **IP source address**
  - address of the interface where the packet is sent, or unspecified address for DAD

Neighbour advertisement

- Sent by hosts or routers, in response to solicitations or unsolicited
- Type = 136, code = 0
- **Target address**
  - For solicited: same as in solicitation
  - For unsolicited: IP address that changed link-layer address
- Option: source link-layer address of sender

Solicited-Node MC Address

- Multicast address formed using ff02:0:0:0:0:1:ff00::/104 prefix and low-order 24 bits of an address (unicast or anycast)
  - Example:
    - Unicast address: 4037::01:800:20**0e:8c6c**
    - Solicited Address: ff02:0:0:0:0:1:ff**0e:8c6c**
- Most probably, no two nodes in the same network map to the same multicast address ➔ much more efficient than the local broadcast used by ARP!

Router Discovery

- For discovering routers on the link and, possibly, address information

- **Router solicitations** (Type = 133, code = 0)
    - Sent by hosts to the link-local all-routers multicast address
- **Router advertisements** (Type = 134, code = 0)
    - Sent by routers
    - In response to solicitations - to unicast address of requester
    - Unsolicited - to all-nodes multicast address with link-local scope
    - Advertise: net prefix, default router(s), MTU

Auto Configuration - SLAAC

- **StateLess** Address AutoConfiguration
    1. Generating link-local address
    2. Generating global address(es)
    3. Performing duplicate address detection (DAD)
- Based on Router Advertisements
- Uses advertised prefix and MAC address of interface
- Valid only for /64 networks

What about DNS servers?

- IPv6 Router Advertisement Options for DNS Configuration
- Type: 25
- Length: indicates the length of the option
    - Implicitly the number of advertised DNS servers

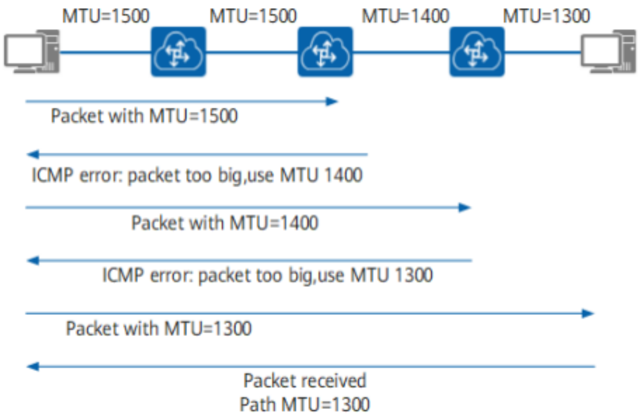
Duplicate Address Detection

- Used after address auto-configuration to check uniqueness of address
    - Not performed for anycast addresses (configured)
- Node sends neighbour solicitation with:
    - **Src address:** unspecified
    - **Dst address:** solicited-node multicast address of the tentative address
    - **Target address:** the tentative address
- Receiving Neighbour Solicitation
    - Target address is the tentative address
        - If src address is unicast (not DAD): ignore packet
        - If src address is unspecified: other node wants to use same address (DAD)
            - No node will use the target address (as extra precaution)
- Receiving Neighbour Advertisement
    - Target address is the tentative address
    - Address is not unique (cannot be used)

Path MTU Discovery

- IPv6 does not support fragmentation in routers
- Senders need to transmit packets ≤ smallest MTU along the path (i.e., Path MTU)
- Procedure for discovering the Path MTU
    - Source node assumes path MTU = 1st hop link MTU

    - If this is too large for a link
        - router drops the packet
        - returns an ICMPv6 Packet Too Big (type = 2, code = 0)
    - Source reduces MTU to the indicated size
    - When the MTU used by the source ≤ Path MTU, packets reach the destination



Other Layers

DHCPv6

- Stateful configuration
- Uses UDP (like DHCPv4)
- DHCP clients use the link-local address
- Uses two multicast groups
- Requires DAD to ensure address uniqueness
- Possible to obtain partial information via Information-Request message
- DHCP Unique Identifier (DUID) for client-server identification
    - Not all messages require this ID
- Optional authentication and encryption
- Information carried in options

Messages

DHCPv6 Message Type	DHCPv4 Message Type
Solicit (1)	DHCPDISCOVER
Advertise (2)	DHCPOFFER
Request (3), Renew (5), Rebind (6)	DHCPREQUEST
Reply (7)	DHCPACK / DHCPNAK
Release (8)	DHCPRELEASE
Information-Request (11)	DHCPINFORM
Decline (9)	DHCPDECLINE
Confirm (4)	none
Reconfigure (10)	DHCPFORCERENEW
Relay-Forw (12), Relay-Reply (13)	none

Recursive DNS server configuration

- Approaches for DNS configuration in clients
    - Router Advertisements, DHCPv6, or well-known anycast address

DNS - changes for IPv6

- AAAA new record type
    - IPv6 address
- AAAA queries returns all IPv6 addresses associated with domain name

- IP6.ARPA domain for reverse (PTR) queries (similar to IPv4's in-addr.arpa)
- Existing query types
  - NS, SRV, MX: re-defined to also return AAAA entries

DNS in IPv4 and IPv6

- Maintain IPv4 and IPv6 accessible DNS recursive server
  - IPv4 only or dual stack
  - At least one IPv4 reachable server per DNS zone

Transition and Interoperation Mechanisms

IPv6 in an IPv4 world

Problem

- Incompatibility arises due to differences in header formats, Sockets API, and applications

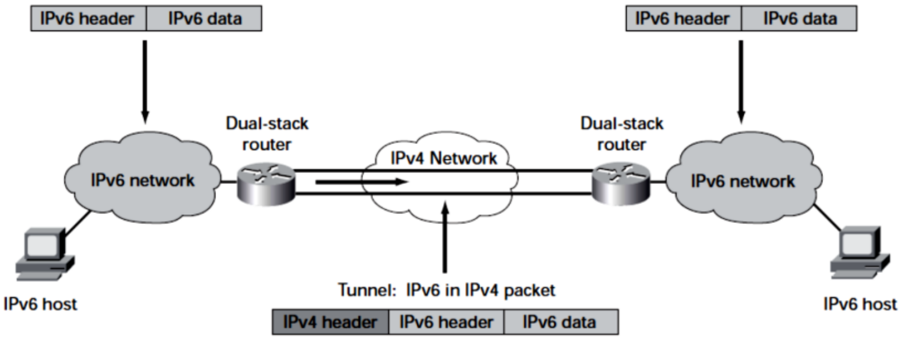
Solutions

Dual stack nodes

- Support both IPv4 and IPv6
- Routers must maintain both routing tables, protocols, etc.

Configured Tunneling (Aka 6in4)

- Tunnel endpoints encapsulate the original IPv6 in an IPv4 packet
- Tunnel endpoints (routes) are manually configured
- Does not scale well
  - Requires a different tunnel for each pair of routers ➔ O(n^2)

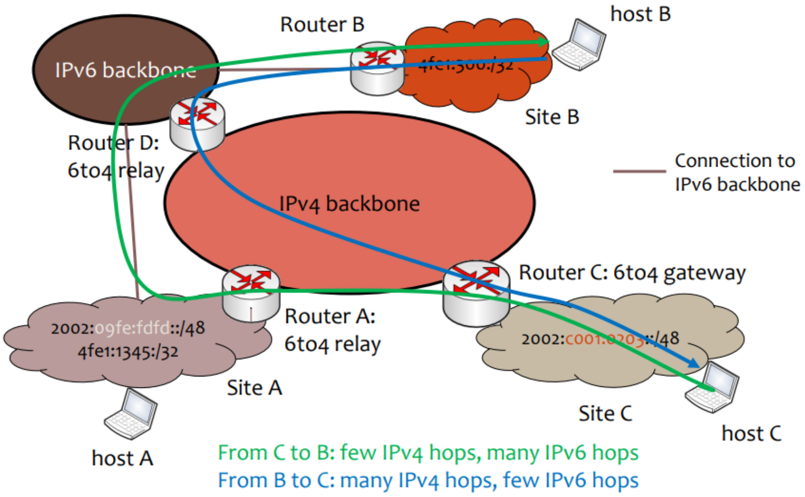


6to4

- 6to4 Tunnel (without explicit setup)
- Use of 2002:V4ADDR::/48 networks
- Sites use 6to4 relay to communicate through the tunnels
  - These relay routers can have an IPv4 anycast address of 192.88.99.1
  - Sites may also have connection to IPv6-only networks
- **Components:**

Router B	**6to4 Router C**	**6to4 relay Router A**
• Connects to the IPv6 backbone • Has a native IPv6 address (not 2002::/16) • Does not handle IPv4	• Connects to the IPv4 backbone • Does not relay packets to the IPv6 backbone • 6to4 IPv6 address and a native IPv4 address	• Connects to the IPv4 and IPv6 backbone • Has a 6to4 and a native (not 2002::/16) IPv6 address • Has a native IPv4 address

- **Issues:** 6to4 causes asymmetric routing and relays may receive traffic from anywhere. 6rd is a slight modification that solves this issue

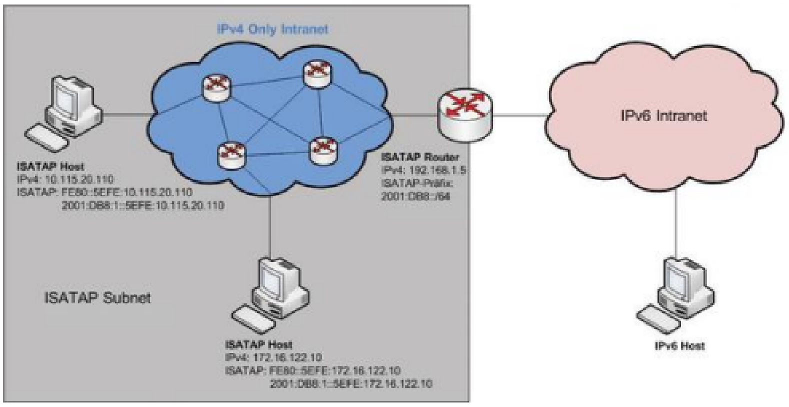


From C to B: few IPv4 hops, many IPv6 hops
From B to C: many IPv4 hops, few IPv6 hops

6rd

- IPv**6** **R**apid **D**eployment on IPv4 Infrastructures
- Similar to 6to4 but using ISP-specific prefix instead of 2002::/16
  - Allows use of private IPv4 addresses
  - ISP-specific prefix length not fixed
- The ISP
  - Operates one or more gateways at the IPv4/IPv6 border
  - Deploys relays with specific anycast addresses (only for its customers)
  - Has more control over traffic flowing through its network

Intra-Site Automatic Tunnel Addressing Protocol (ISATAP)



- Connects dual-stack nodes over IPv4 networks
- Uses entire IPv4 network as a link layer (NBMA)
- Defines locators (mappings) on interfaces for routing packets
- Requires a Potential Router List (PRL) (obtained by doing a DNS lookup for

isatap.<domain>) for communication with the public IPv6 Internet

- ISATAP IPv6 addresses:
  - <prefix>:0000:5efe:<IPv4 addr>

Teredo

- Allows automatic IPv6 tunneling between hosts that are located across one or more IPv4 NATs
- Encapsulates IPv6 packets in UDP
  - More overhead than other techniques ➔ use only when they are infeasible
- Use of 2001:0000::/32 for Teredo clients
  - 2001:0000:<teredo server IP address>:<flags (16)>:<obscured UDP port>:<obscured public IPv4 address>
- Discovers and maintains NAT mappings to the client
- Components:
  - Client: has IPv4 connectivity, wants IPv6
  - Server: to discover external address and type of NAT
  - Relay: forwards traffic using the Teredo encapsulation on IPv4 and to the IPv6

IPv4 in an IPv6 world

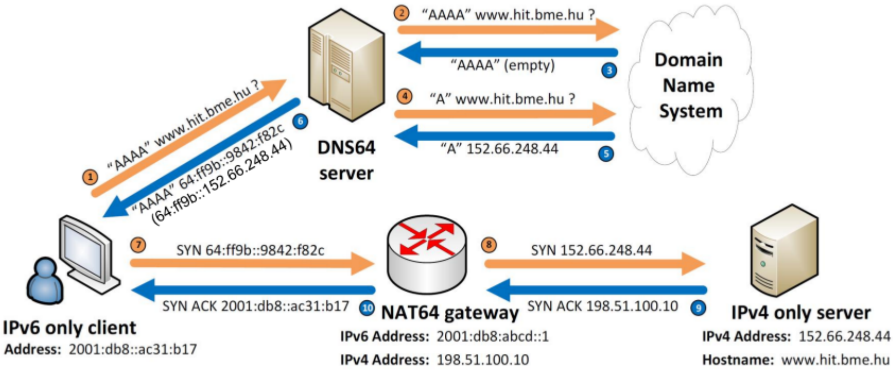
- Increasing deployment of IPv6 ➔ need for
  - Nodes in IPv6-only networks to reach IPv4-only services on the Internet
  - Traversal of IPv6-only operator networks to reach IPv4-only services on the Internet
- Larger IPv6 addresses make it easier to use translation/NAT instead of tunneling
  - IPv6 addresses can embed IPv4 addresses

NAT64/DNS64

- NAT64 facilitates access to IPv4-only services from IPv6-only networks by translating IPv6 to IPv4 addresses.

- DNS64 synthesizes AAAA records for services offering only A records, using the chosen prefix.

- Example:

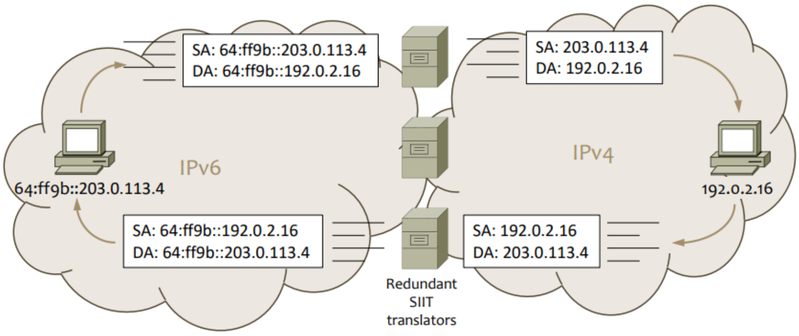


1 "AAAA" www.hit.bme.hu ?
2 "AAAA" www.hit.bme.hu ?
"AAAA" (empty) 3
4 "A" www.hit.bme.hu ?
"A" 152.66.248.44 5
Domain Name System
"AAAA" 64:ff9b::9842:f82c (64:ff9b::152.66.248.44) 6
DNS64 server
7 SYN 64:ff9b::9842:f82c
8 SYN 152.66.248.44
SYN ACK 198.51.100.10 9
SYN ACK 2001:db8::ac31:b17 10
IPv6 only client
Address: 2001:db8::ac31:b17
NAT64 gateway
IPv6 Address: 2001:db8:abcd::1
IPv4 Address: 198.51.100.10
IPv4 only server
IPv4 Address: 152.66.248.44
Hostname: www.hit.bme.hu

- Limitations include IPv4-only software, IPv4 literals (no DNS lookup is performed), and IPv4 networks behind IPv6-only ISP networks

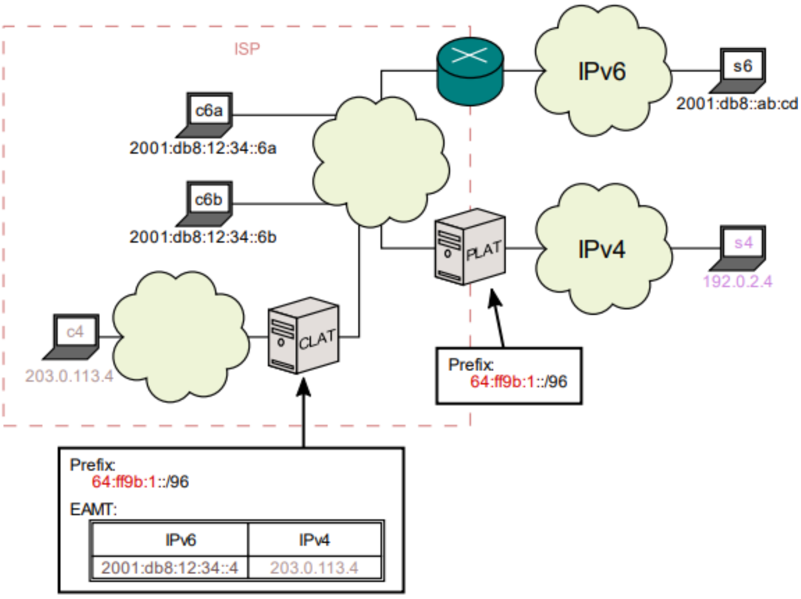
Stateless IP/ICMP Translation (SIIT)

- Translates headers of IP packets and IP packet fragments inside ICMP messages (for transparency)
- Comes in two flavors:
  - "Traditional" SIIT (entire IPv4 address embedded in an IPv6 address with given prefix)
  - SIIT with Explicit Address Mappings (EAM) (uses configured host-specific or block mappings)
- Advantages of stateless translation:
  - No need to maintain per-flow state
  - Easier load distribution - translator for outgoing and incoming packets needs not be the same
- Disadvantage: the 1:1 mapping between IPv4 and IPv6 addresses wastes scarce IPv4 addresses
- Example ("traditional" SIIT):



464XLAT

- 464XLAT is an architecture combining Stateful NAT64 with an additional, stateless translator (SIIT)
  - CLAT: Client-side transLATor (SIIT)
  - PLAT: Provider-side transLATor (Stateful NAT64)
- Addresses the use cases not covered by NAT64/DNS64


ISP
IPv6
s6
2001:db8::ab:cd
c6a
2001:db8:12:34::6a
c6b
2001:db8:12:34::6b
PLAT
IPv4
s4
192.0.2.4
c4
203.0.113.4
CLAT
Prefix:
64:ff9b:1::/96
Prefix:
64:ff9b:1::/96
EAMT:
IPv6
IPv4
2001:db8:12:34::4
203.0.113.4