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Kommunikationsnetze 2
2 – IPv6

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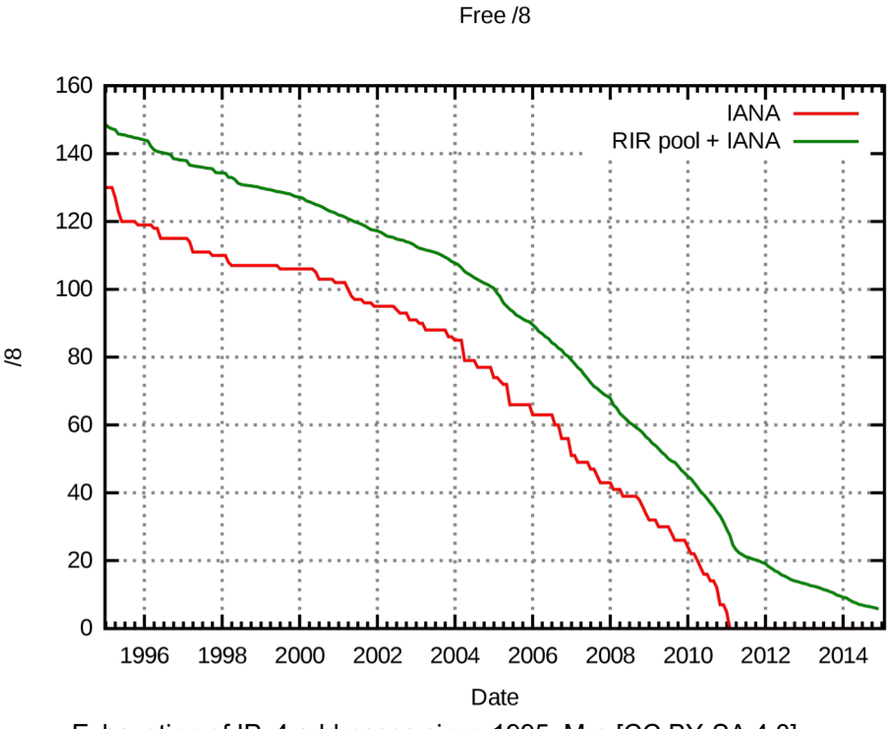
IPv6: Motivation

- Initial motivation
  - Too few addresses
  - Too large routing tables
- Additional motivation (opportunity)
  - Header format helps speeding up processing/forwarding
  - Header changes to facilitate QoS
- Why is NAT not sufficient?
  - Many applications and services need unique addresses
  - Affect performance, robustness, security and manageability



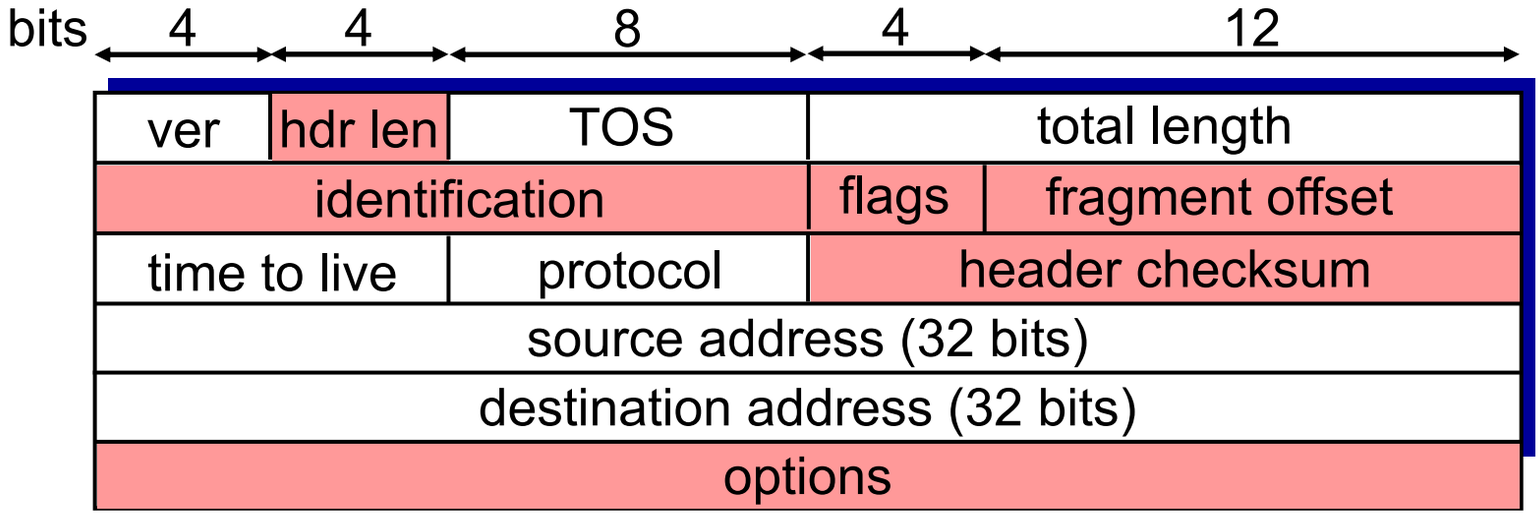
Exhaustion of IPv4 addresses since 1995. Mro [CC BY-SA 4.0]
https://upload.wikimedia.org/wikipedia/commons/c/cf/Ipv4-exhaust.svg

From IPv4 to IPv6

- Main changes
  - 128 bit addresses
  - Address hierarchy
  - Simplified header and flow identification
  - Simpler and better support for options
  - Support for server-less autoconfiguration
  - QoS
  - Host mobility
  - Security
  - No fragmentation in routers
  - No header checksum

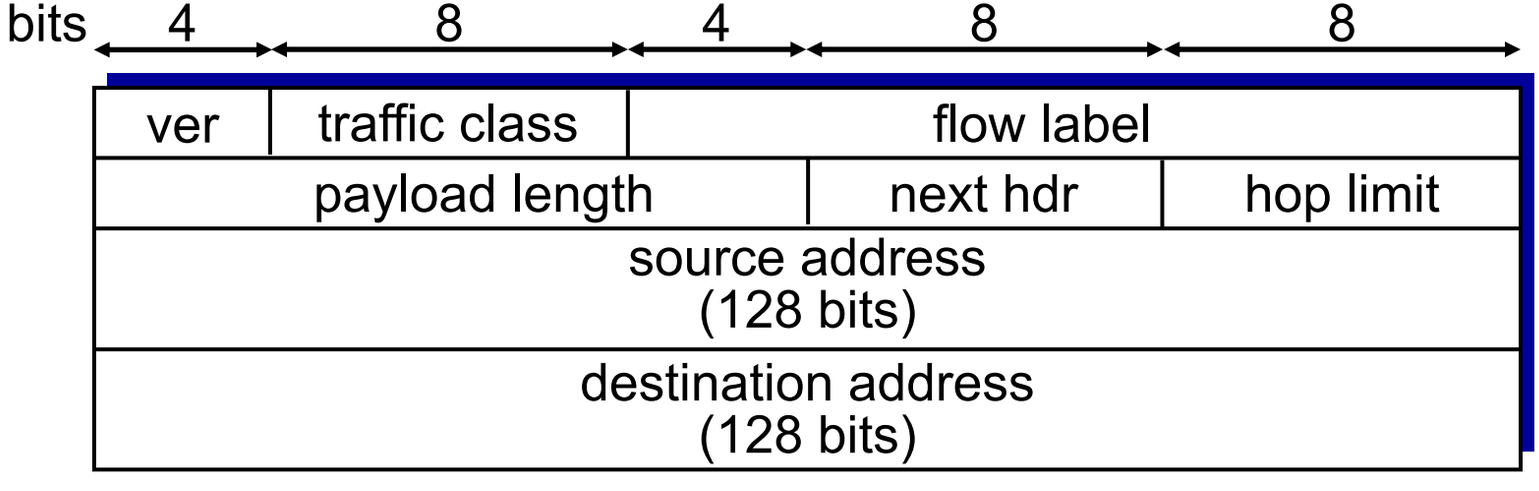
IPv6 Header

IPv4 header



deleted in IPv6

IPv6 header



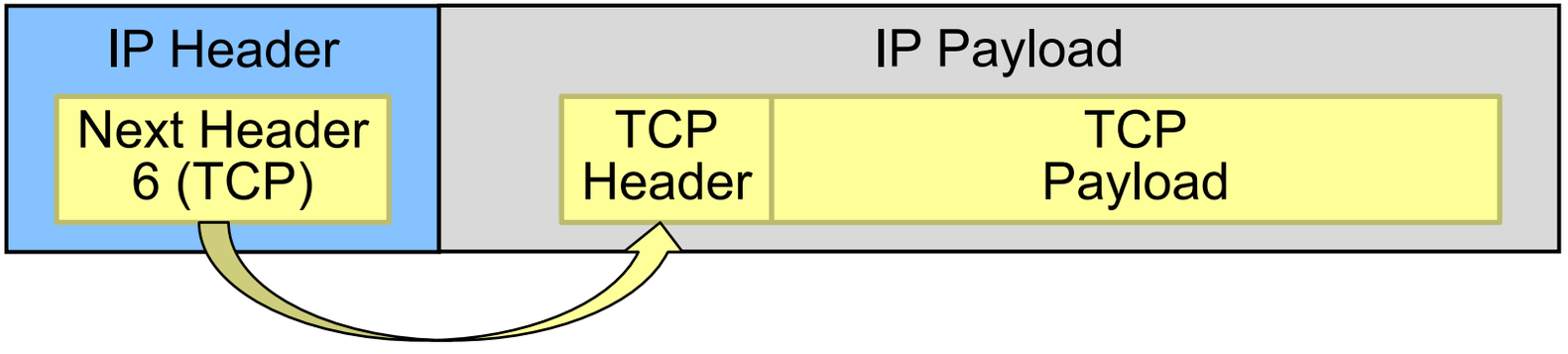
IPv6 Fields

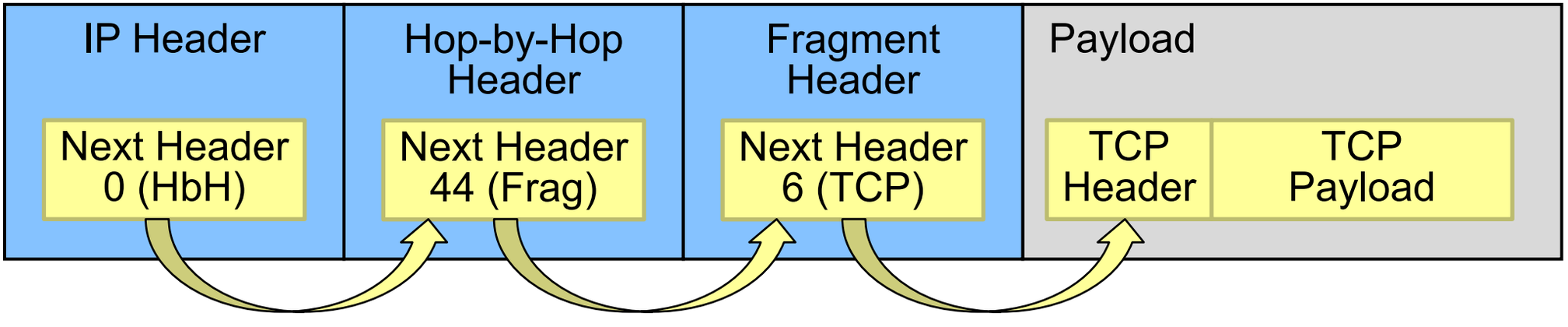
- Version: identical to IPv4, only the code is 6
- Traffic class: priority among datagrams to facilitate handling, e.g., real-time traffic
- Flow label: identifies packets with the same requirements
- Payload length: length of data following the header
  - fixed header length of 40 bytes in IPv6
- Next header: to support extension headers
- Hop limit: replaces time to live

Extension Headers

- Basic header simplified to make it easier to process
- Additional information carried in extension headers
  - Hop-by-hop options (0)
  - Routing (43)
  - Fragment (44)
  - Authentication (51)
  - Encapsulating security payload (50)
  - Destination option (60)
  - Mobility (135)
  - Upper layer: TCP (6), UDP (17), ICMPv6 (58)
- Next header field indicates the type of header that follows
- Processed only by destination node
  - Only exception: Hop-by-Hop options

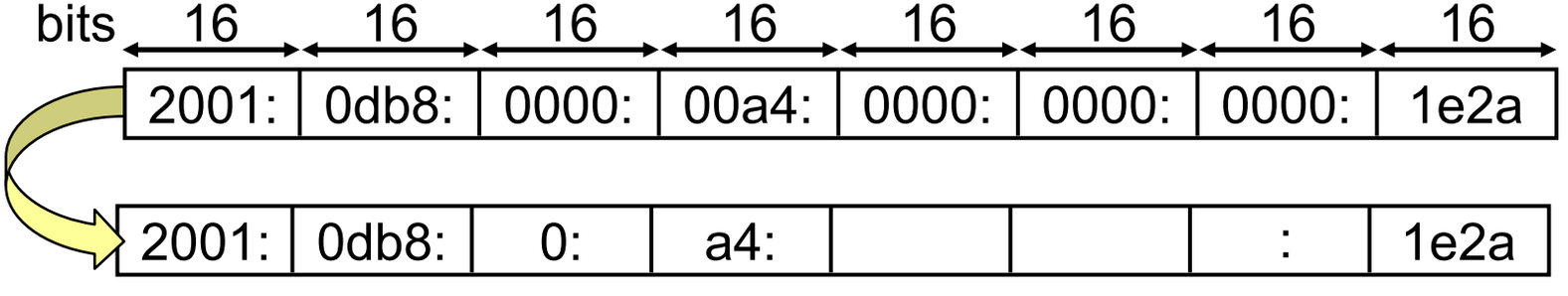
Extension Headers: Examples





Addressing

- 128 bits address space
  - 340 x 10^{36} (undecillion) IP addresses
  - 32 hex characters in 8 groups separated by :
  - 4 groups for network, 4 groups for host id
- Shortening
  - Heading 0s in each group can be omitted
  - One series of :0: can be replaced by :: (only once, why?)



IPv6 Address Types

- Unicast
  - Communication with 1 specific host
- Multicast
  - Communication with a group of hosts
- Anycast
  - Communication with any host inside a group
  - From the unicast address space
- No broadcast address
  - “All nodes” multicast instead
- Network prefix represented by /length at address end

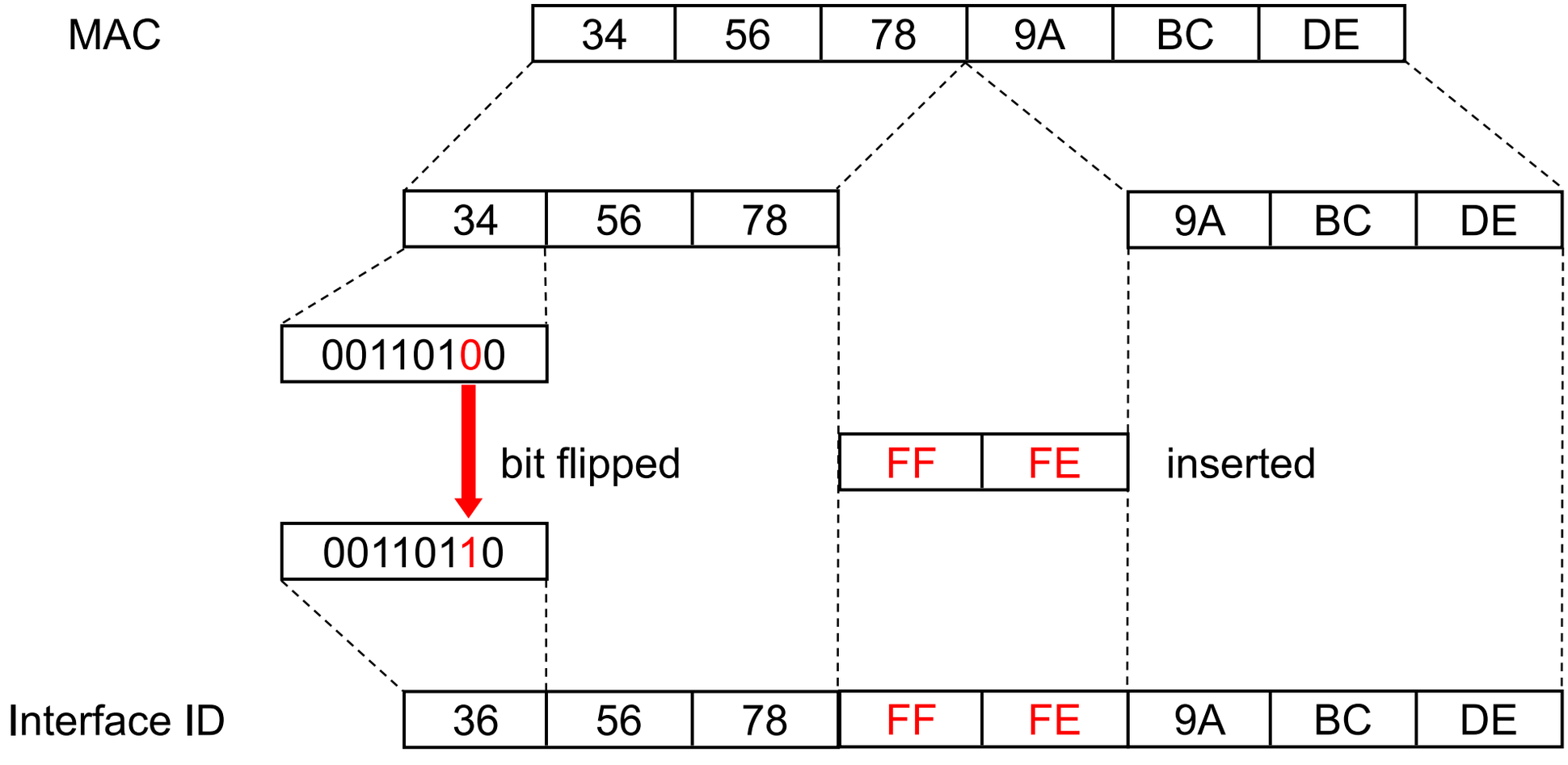
IPv6 Unicast Addresses

- Global addresses
  - Unique globally, routed globally. Just like IPv4
  - 2xxx::/4 or 3xxx:: /4
- Unique Local Addresses (ULAs)
  - Used within a site, not routed globally, but globally valid
  - Reserved prefix fc00::/7 (fd00::/8 for locally assigned)
- Link-local addresses
  - Unique on a subnetwork and never routed
  - Reserved prefix fe80::/10
- Loopback ::1/128
- In IPv6, hosts usually have multiple addresses

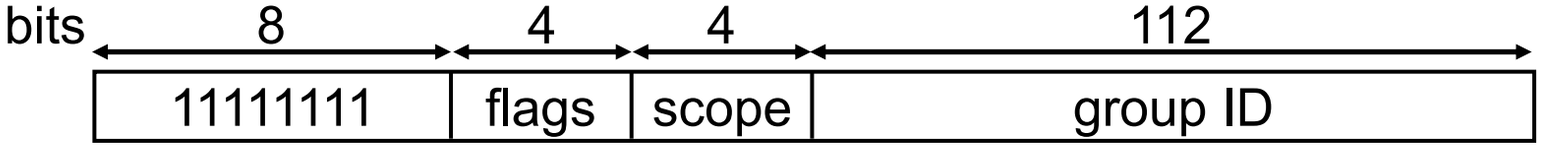
Interface IDs

- The host portion of the address (lowest-order 64 bits) is called interface ID
  - Uniquely identifies one interface on a link
- Assigned in different ways
  - Auto-configured from a 48-bit MAC address and expanded into a 64-bit EUI-64
  - DHCPv6
  - Manually configured

MAC-Derived Interface ID



Multicast Addresses



- Low-order flag for permanent or transient group
- Scope field
  - Node local (1)
  - Link local (2)
  - Site local (5)
  - Organization local (8)
  - Community local (B)
  - Global (E)

ICMPv6

- ICMPv4 modified to fit IPv6
  - Opportunity to clean up and consolidate
- Similar to ICMPv4 with two categories
  - Informational
    - To support diagnostic and further functionalities
  - Error
    - To notify errors encountered in forwarding or delivery
- Incorporates functionalities of ARP and IGMP from IPv4
  - Removed RARP (DHCP serves already the purpose)

ICMPv6 Messages

- Error messages
  - Destination unreachable
  - Packet too big (new in IPv6)
  - Time exceeded
  - Parameter problems
  - Redirection
- Information messages
  - Echo request and reply
  - Router solicitation and advertisement
  - Neighbour solicitation and advertisement (ARP in IPv4)
  - Group membership (IGMP in IPv4)

ICMPv6 Neighbour Discovery

- Router Advertisement messages from routers
  - Hosts know about properties of the links served
- Router Solicitation from hosts
  - Requesting any router to send a Router Advertisement
- Neighbour Solicitation and Neighbour Advertisement
  - Same purpose of IPv4 ARP
- Router Redirect
  - Used to notify a host about a better first-hop router to reach the destination

ICMPv6 MTU Discovery

- In IPv4, routers are responsible of fragmenting packets when the MTU of the outgoing link is smaller than the size of the packet
- IPv6 routers do NOT fragment packets
  - Any fragmentation needs to be handled by the source
- How to know the minimum link MTU on the path to the destination?
  - Trying!
  - Use ICMPv6 packet-too-big error messages (which provide information about the max MTU of the link)

IPv6 Configuration

- DHCPv6
  - Similar to DHCPv4
  - Stateful: the server holds lease information for each address used by a host
  - Stateless: for use with SLAAC to gather additional configuration information only
- StateLess Address AutoConfiguration (SLAAC)
  - Allows hosts to select their own interface ID
  - Host joins all-nodes multicast address (FF02::1)
  - Host communicates to routers using all-routers multicast address (FF02::2)
  - Host sends ICMPv6 router solicitation to request additional information
  - Router sends ICMPv6 router advertisement to inform about prefixes for local and global addresses

SLAAC and Privacy

- MAC-derived interface ID can ensure unique addresses
- However, it is possible to
  - Derive identity and vendor of the interface
  - Exploit bugs corresponding to the used equipment
  - Track a device through different visited networks
- IPv6 privacy addressing
  - Pseudo-randomly assign interface ID when attaching to a network
  - Change it periodically even within the same subnetwork
- Both SLAAC and randomly/changing addresses complicate network management
  - Which addresses belong to which hosts?

Multi-Homing

- Multihoming: multiple access interfaces or providers
  - Redundant links to achieve external connectivity
- Reasons
  - Redundancy and availability
  - Performance, e.g., higher throughput, load-balancing
  - Cost policies
- Problem: growth of routing tables
- One approach: SHIM6, a host centric solution
  - Sits between IP and Transport layers to switch between IPs transparently
  - A obtains a subset of B's addresses
  - A chooses one address to contact B and negotiates alternative addresses
  - REAchability Protocol (REAP): Keepalive packets used to check availability
  - Probe packets to explore alternative addresses in case of failures

Routing

- Static routing unchanged from IPv4
- Dynamic routing has corresponding versions of the IPv4 routing protocols
  - Straightforward changes to support longer addresses
  - IGP (Interior Gateway Protocol)
    - RIPng
    - OSPFv3
  - EGP (Exterior Gateway Protocol)
    - BGP4

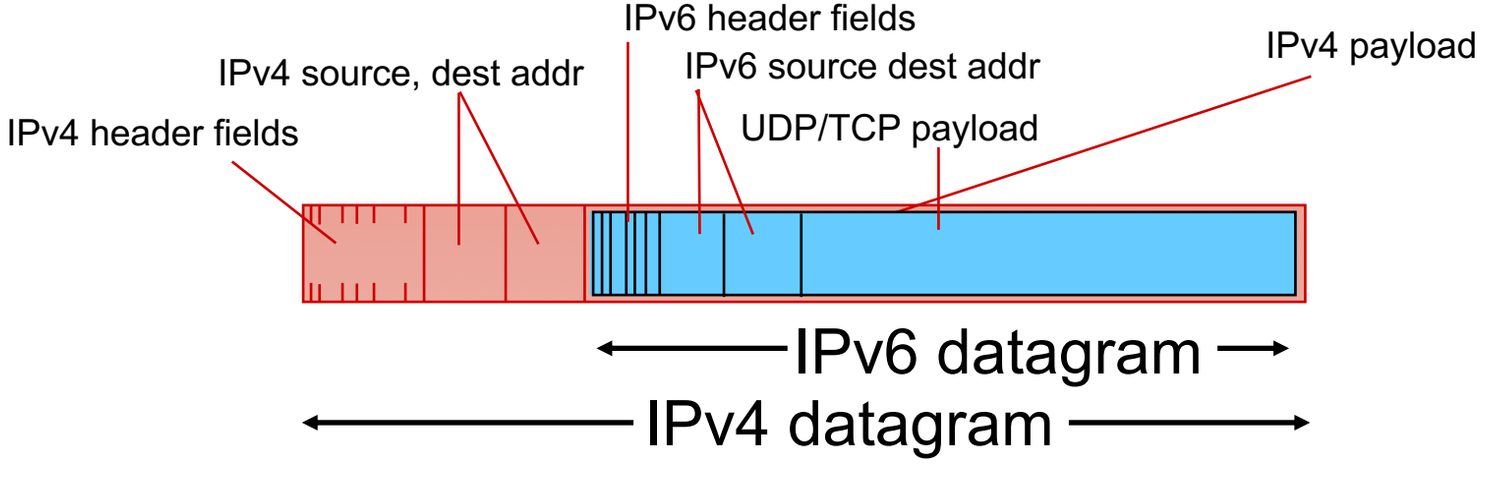
To be continued…

Transition from IPv4 to IPv6

- Not all routers can be upgraded simultaneously
- Many scenarios where IPv4 and IPv6 need to coexist
  - Users on IPv4-only ISP that want to access remote IPv6 services
  - IPv6 networks with only IPv4 connectivity in between
  - IPv6 host that needs to talk to an IPv4 “legacy” host
- Approaches
  - Tunnels/encapsulation
  - Dual-stack
  - Translation

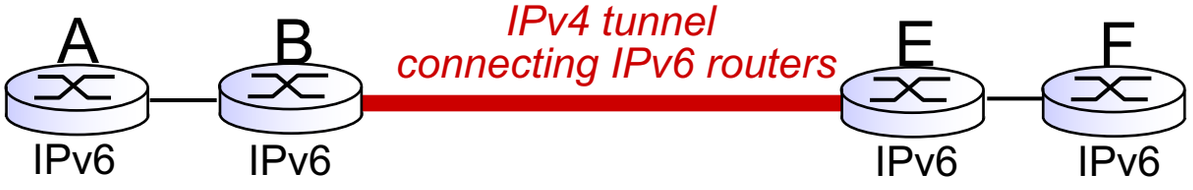
Tunnelling IPv6 over IPv4

- IPv6 Datagrams carried as payload in IPv4 datagram among IPv4 routers
- Different approaches
  - Manual configuration
  - Tunnel brokers (via web services)

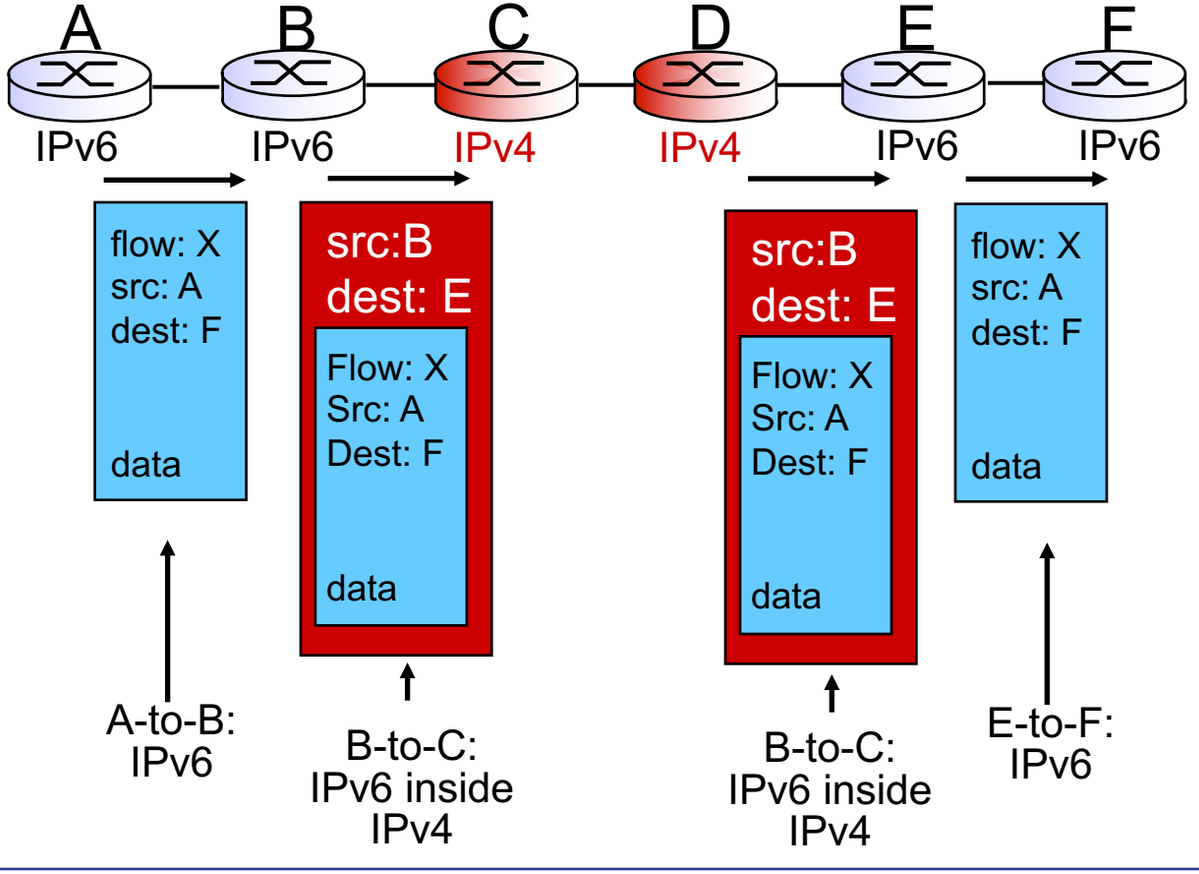


Tunnelling Example

logical view:



physical view:



Dual Stack IPv4/IPv6

- Run both protocols on hosts and routers
- Let applications/services decide which to use
  - Name lookup may return IPv4 (A) and/or IPv6 (AAAA) responses
  - Application may decide which one to favour
- If IPv6 preferred, performance issues might be encountered
  - Manifested as timeouts before falling back to IPv4
- This allows indefinite co-existence of IPv4 and IPv6 and gradual applications upgrades

Translation

- Allow IPv6-only devices to communicate with IPv4-only devices
- Basically an extension of NAT techniques
  - IPv6 nodes behind a translator talk with other IPv6 nodes anywhere without issues
  - Nodes are “downgraded” via normal NAT when talking to IPv4 devices
- When DNS is used, a client can made believe that it sends to an IPv6 destination by translating the IPv4 destination address
- Without DNS, 464XLAT allows clients to translate IPv4 to IPv6 addresses and vice versa

IPv6 Adoption

Google IPv6

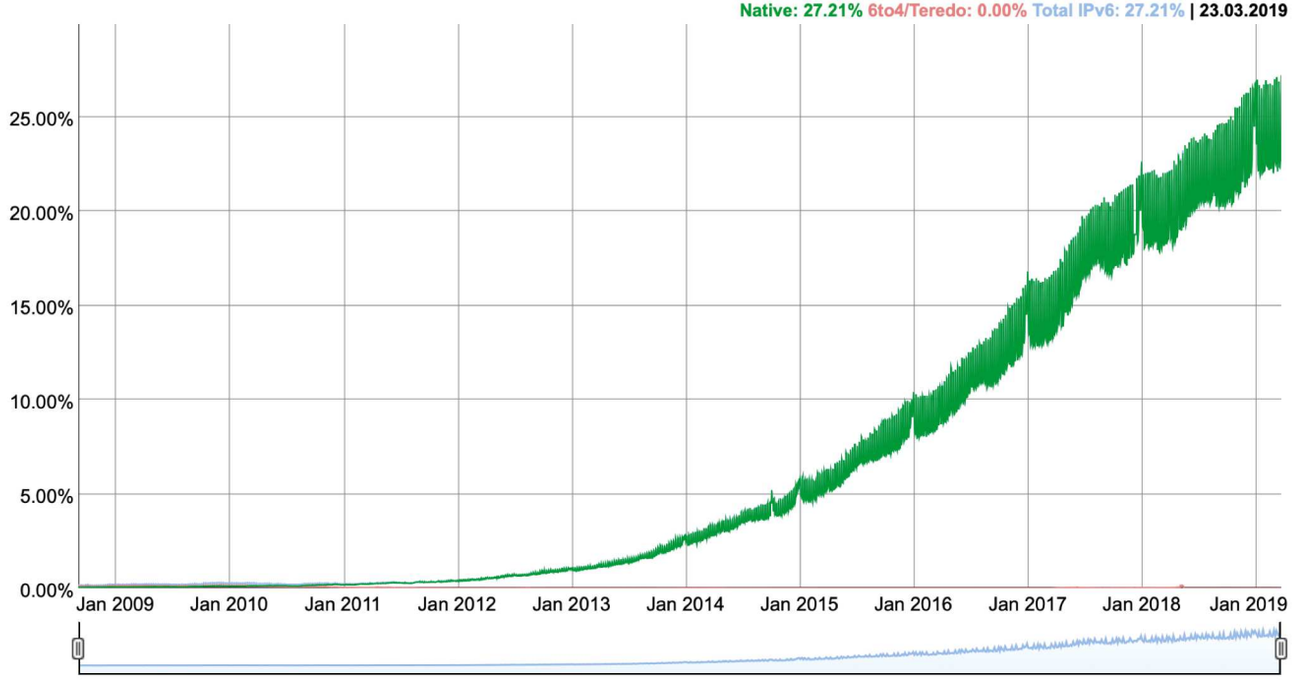
Statistics

Google collects statistics about IPv6 adoption in the Internet on an ongoing basis. We hope that publishing this information will help Internet providers, website owners, and policy makers as the industry rolls out IPv6.

IPv6 Adoption | Per-Country IPv6 adoption

IPv6 Adoption

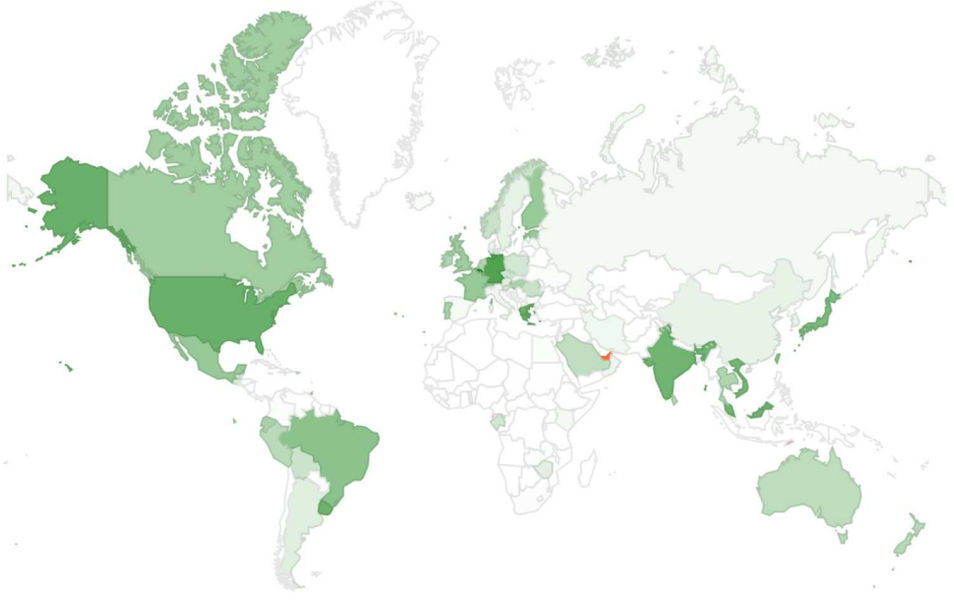
We are continuously measuring the availability of IPv6 connectivity among Google users. The graph shows the percentage of users that access Google over IPv6.



IPv6 Adoption

IPv6 Adoption | **Per-Country IPv6 adoption**

Per-Country IPv6 adoption



World | Africa | Asia | Europe | Oceania | North America | Central America | Caribbean | South America

The chart above shows the availability of IPv6 connectivity around the world.

- Regions where IPv6 is more widely deployed (the darker the green, the greater the deployment) and users experience infrequent issues connecting to IPv6-enabled websites.
- Regions where IPv6 is more widely deployed but users still experience significant reliability or latency issues connecting to IPv6-enabled websites.
- Regions where IPv6 is not widely deployed and users experience significant reliability or latency issues connecting to IPv6-enabled websites.