Internet Protocol version 6

Computer Networks

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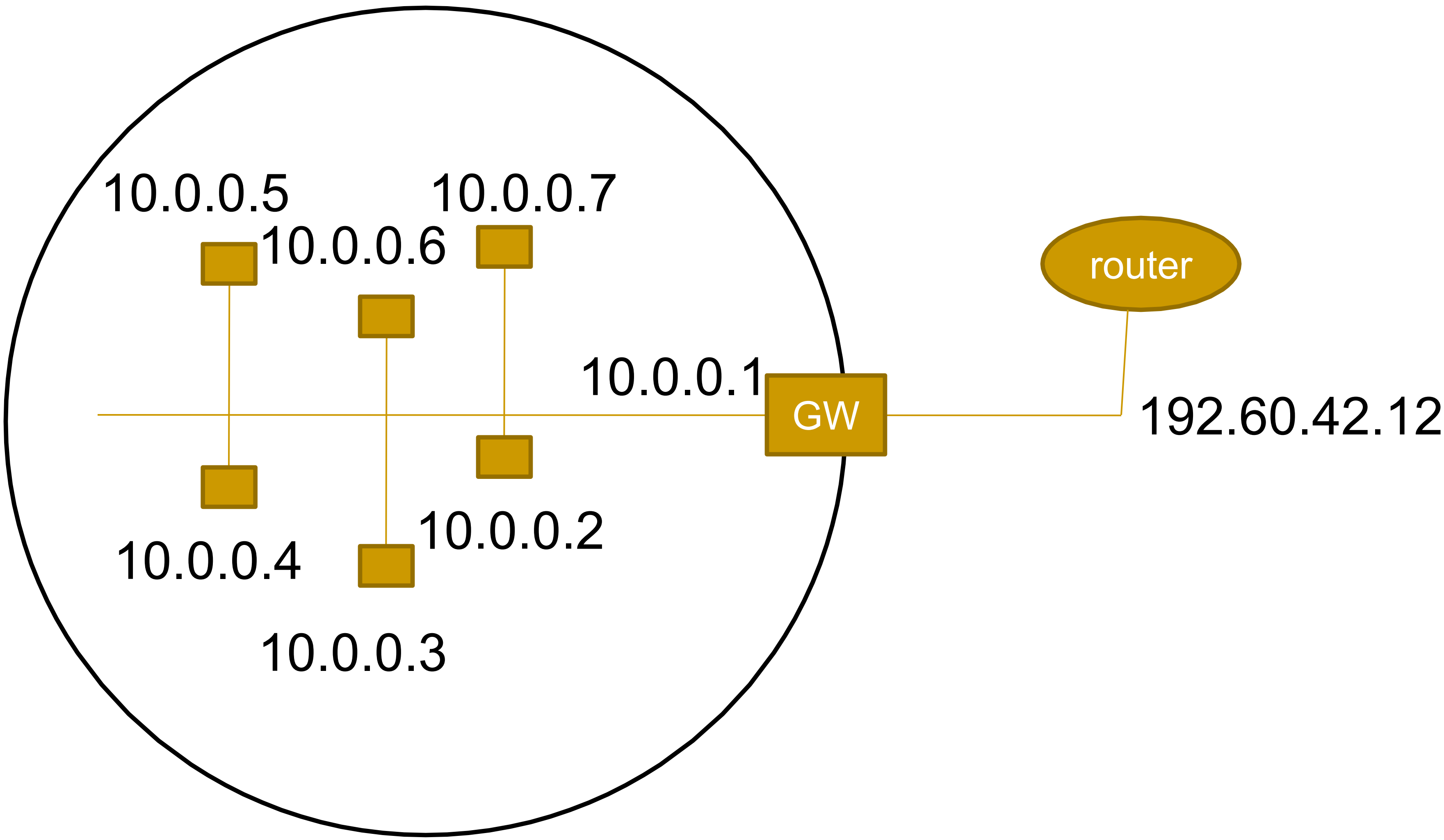
Why IPv6?

- Problems with IPv4
  - "Address is running out!"
- Routing table explosion **(as of 2010 over 320k route prefixes to be exchanged between backbone routers)**
- Temporary solutions
  - NAT
  - CIDR
- Best solution: IPv6

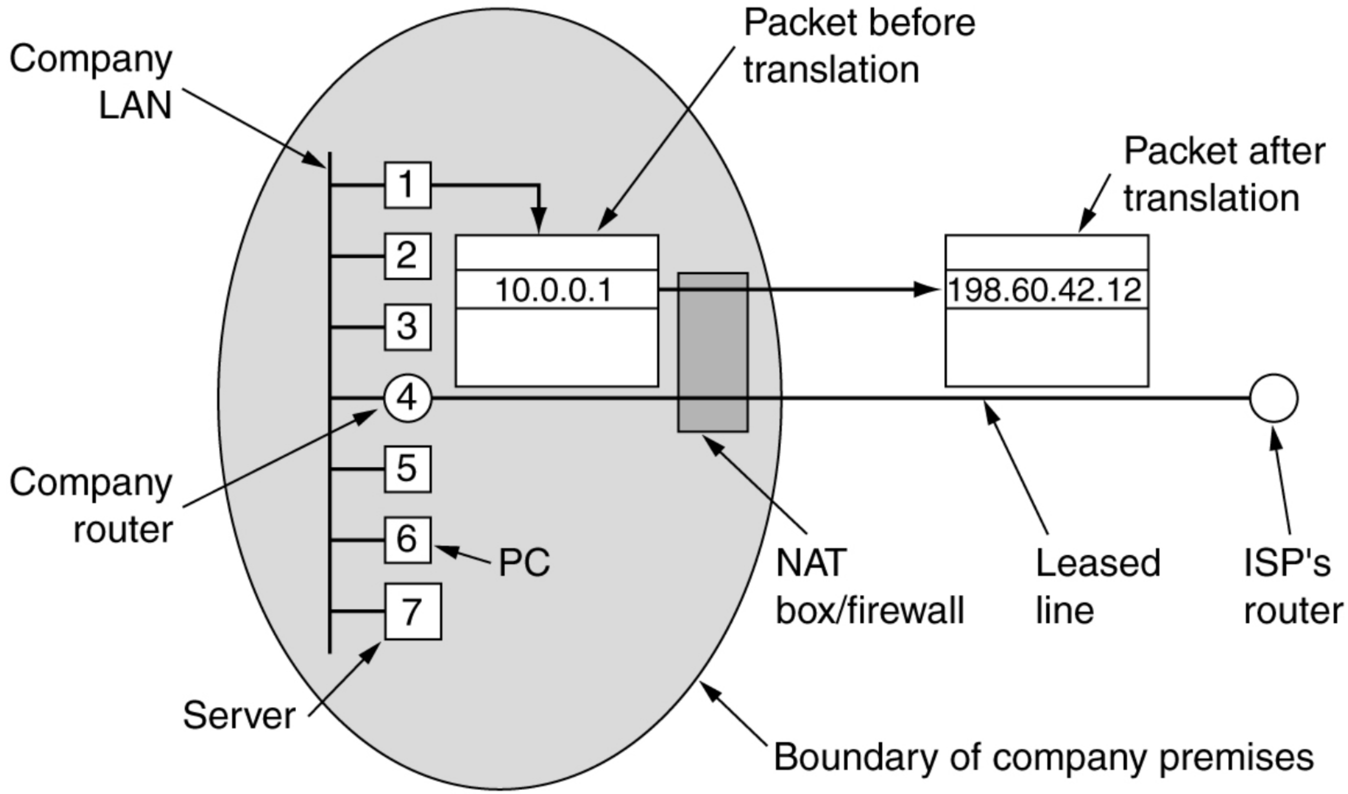
NAT – Network Address Translation

- Reserve a single IP address for local networks that operate behind a special router (which can also operate as a firewall), and allow only **outgoing** connections
  - To make this scheme possible, 3 ranges of IP addresses have been declared **private**
    - 10.0.0.0 – 10.255.255.255/8 (16,777,216 hosts)
    - 172.16.0.0 – 172.31.255.255/12 (1,048,576 hosts)
    - 192.168.0.0 – 192.168.255.255/16 (65,536 hosts)


10.0.0.5
10.0.0.7
10.0.0.6
router
10.0.0.1
GW
192.60.42.12
10.0.0.2
10.0.0.4
10.0.0.3

NAT – Network Address Translation

Placement and operation of a NAT box.



NAT + CIDR (IPv4)

- IPv4 addresses are non-hierarchical
  - V4 addresses are non-hierarchical and assigned irrespective of geographical topology.
  - This leads to fragmentation and thus big routing tables (as of 2010 over 320k route prefixes to be exchanged between backbone routers).
  - See http://bgp.potaroo.net/ or http://www.cidr-report.org/.
- Best solution: IPv6

IPv6 – the advantages

IPv6 solves the address scarcity problem (for now).

IPv6 should solve the route table size problem in backbone routers. IPv6 comes with

improved QoS support for real-time applications.

IPv6 will be one of the drivers of mobility (always-on mobile devices).

Security was an integral part of IPv6 from its inception (IPSec).

IPv6 has a simplified header thus greatly reducing routing processing load.

IPv6 is designed to scale almost indefinitely (to very large networks); the protocol should support routing speeds for OC-12+ (622Mbps) lines and beyond.

IPv6 is plug-and-play: automatic IP address assigment (no DHCP), router solicitation for getting the network prefix and router advertisment for making own IP address known to neighbors.

IPv6 is not something revolutionary new. It is designed to be as transparent to applications as possible while solving the biggest problems and deficiencies of IPv4.

Relevant IPv6 RFCs

RFC2460 „Internet Protocol, Version 6 (IPv6) Specification" RFC4291 „IP Version 6 Addressing Architecture"
RFC3587 „IPv6 Global Unicast Address Format"
RFC4213 „Transition Mechanisms for IPv6 Hosts and Routers„
RFC3056 „Connection of IPv6 Domains via IPv4 Clouds„
RFC2529 „Transmission of IPv6 over IPv4 Domains without Explicit Tunnels„ („6over4") RFC4862 „IPv6 Stateless Address Autoconfiguration"
RFC6177 „IAB/IESG Recommendations on IPv6 Addresses"
RFC3484 „Default Address Selection for Internet Protocol version 6 (IPv6)"
RFC6145 „IP/ICMP Translation Algorithm" RFC4861 „Neighbor discovery protocol" RFC3879 "Deprecating Site Local Addresses" RFC4147 "IANA IPv6 Registry"
RFC3849 "IPv6 Address Prefix Reserved for Documentation"
Various RFCs devoted to the different migration scenarios.

Obsoleted IPV6 concepts:
Some concepts in IPv6 have already been obsoleted (e.g. site-local unicast addresses).

These are left in this document for documentary purposes but are marked in light grey text.

IPv6 Addressing

IPv4 32-bits

IPv6 128-bits

2^{32} = 4,294,967,296

2^{128} = 340,282,366,920,938,463,463,374,607,431,768,211,456

$2^{128} = 2^{32} * 2^{96}$

2^{96} = 79,228,162,514,264,337,593,543,950,336 times the number of possible IPv4 Addresses (79 trillion trillion)

IPv6 Addressing

World's population is approximately 6.5 billion

$$\frac{2^{128}}{6.5 \text{ Billion}}$$ = 52 Trillion Trillion IPv6 addresses per person

Typical brain has ~100 billion brain cells (your count may vary)

$$\frac{\text{52 Trillion Trillion}}{\text{100 Billion}}$$ = 523 Quadrillion (523 thousand trillion) IPv6 addresses for every human brain cell on the planet!

Addressing Format

Representation

- 16-bit hexadecimal numbers

  colon hexadecimal format instead of *dotted decimal*

  8000:0000:0000:0000:0123:2345:34DA:DCBA

  8000::123:2345:34DA:DCBA

  ::192.168.100.1

- Numbers are separated by (:)
- Hex numbers are not case sensitive
- Abbreviations are possible

Leading zeros in contiguous block could be represented by (::)

Example:

2001:0db8:0000:130F:0000:0000:087C:140B

2001:0db8:0:130F::87C:140B

Double colon only appears once in the address

Hexa numbers

- Hexa numbers: 0123456789ABCDEF
- F = 15 = 1111 C = 12 = 1100
- E = 14 = 1110 B = 11 = 1011
- D= 13 = 1101 A = 10 = 1010
- 1 = 0001
- F50A = ???
- $DCBA_{(16)} = 1101\ 1100\ 1011\ 1010_{(2)}$

  $= 10.1 + 11*16 + 12*16^2 + 13*16^3\ _{(10)}$

????

Addressing

Prefix Representation

- Representation of prefix is just like CIDR
- In this representation you attach the prefix length
- Like v4 address:

198.10.0.0/16

- V6 address is represented the same way:

2001:DB8:12::/48

- Only leading zeros are omitted. Trailing zeros are not omitted.

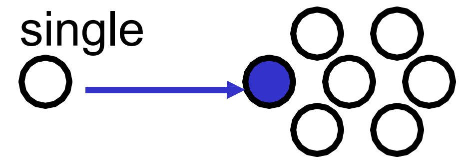
2001:0DB8:0012::/48 = 2001:DB8:12::/48

2001:DB8:**1200**::/48 ≠ 2001:DB8:12::/48

Types of IPv6 Addresses

- Unicast

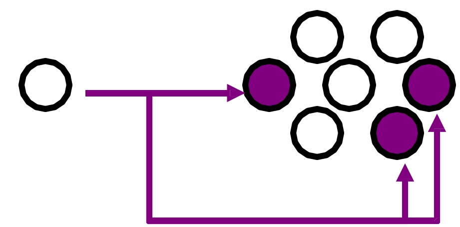
Address of a single interface. One-to-one delivery to single interface. **Same as IPv4 unicast address.**



- Multicast

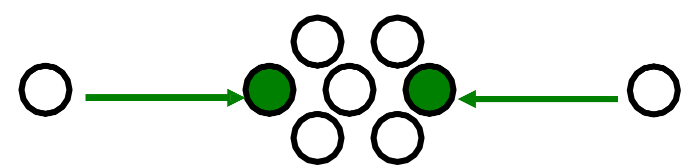
Address of a set of interfaces. One-to-many delivery to all interfaces in the set.

FF0x::<group ID>



- Anycast

Address of a set of interfaces. One-to-one-of-many delivery to a single interface in the set that is closest.
Anycast addresses are new in IPv6.
Anycast packets are routed to the nearest host.



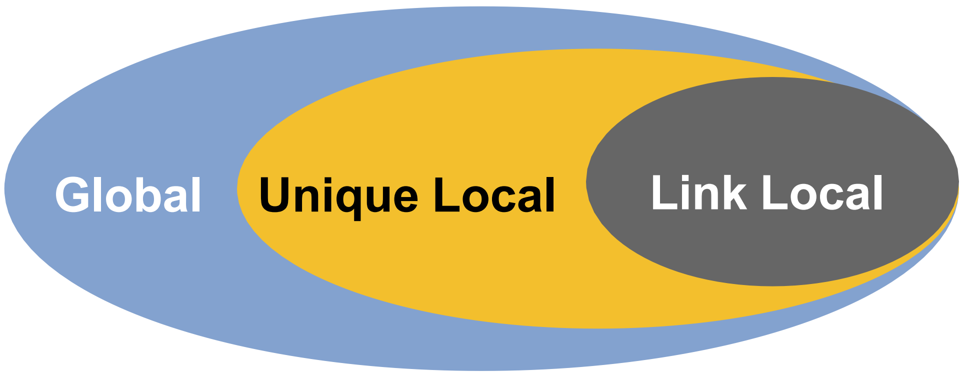
- No more broadcast addresses

IPv6—Addressing Model

- Addresses are assigned to interfaces

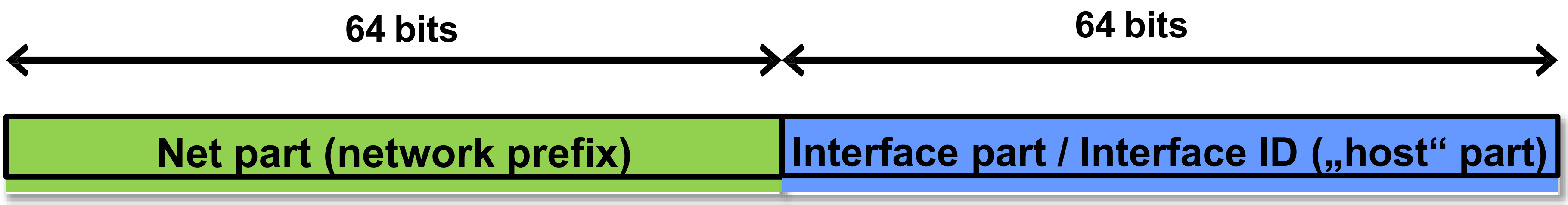
Change from IPv4 mode

- Interface "expected" to have multiple addresses
- Addresses have scope
  1. Global
  2. Unique local
  3. Link local



- Addresses have lifetime
  - Valid and preferred lifetime

General structure of IPv6 address (as proposed by RFC6177):



Network prefix: „Where are you connected to“.
Interface ID: „Who are you“. Created from MAC address or from IPv4 address (IPv6 compatible addresses). See RFC4291 2.5.

Unlike IPv4, IPv6 addresses are hierarchical to allow route aggregation (prefix). The prefix boundary can fall anywhere whithin the address („classlessness“).

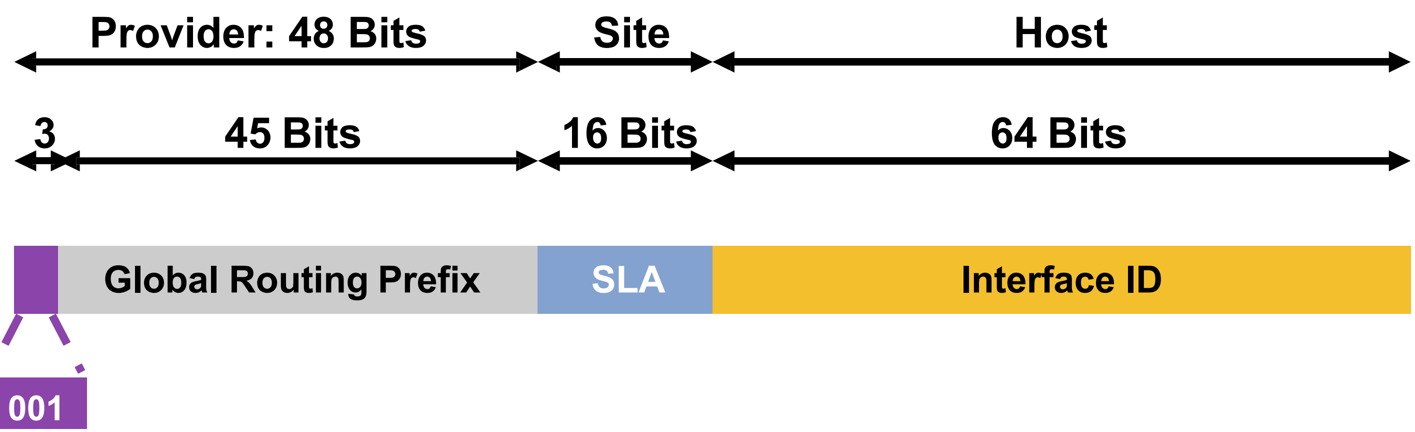
N.B.: In IPv6, there are no hosts anymore. Every address specifies an interface and not a host.
A host is expected to have multiple interfaces.

Addressing

Some Special Addresses

Type	Binary	Hex
Aggregatable Global Unicast Address	001	2 or 3
Unique Local Unicast Address	1111 1100 1111 1101	FC00::/7 FC00::/8(Registry) FD00::/8 (No Registry)
Link-Local Unicast Address	1111 1110 10	FE80::/10
Multicast Address	1111 1111	FF00::/8

1. Aggregatable Global Unicast Addresses
- main address type in IPv6 (see RFC3587)

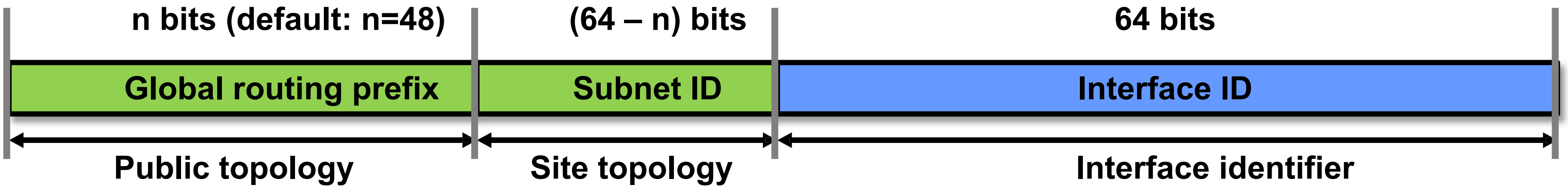


Aggregatable Global Unicast Addresses Are:

- Addresses for generic use of IPv6
- Structured as a hierarchy to keep the aggregation
- Globally valid

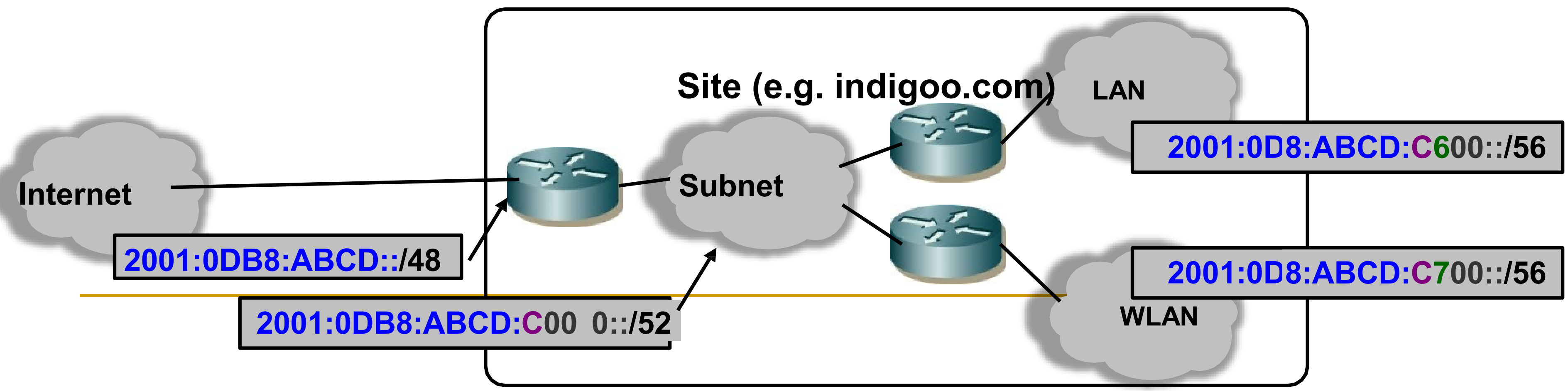
"IPv6 global unicast address" = main address type in IPv6 (see RFC3587)

Aggregation is used for of reducing routing tables (one of the main goals of IPv6). Format (see RFC3587):



The global routing prefix, usually 48 bits, identifies a site (organization, company), i.e. a cluster of subnets / links. In special cases, ISPs may use smaller prefixes (for very large organizations) or 64 bit prefixes (customer only needs exactly 1 address).

The subnet ID identifies a subnet within a site.

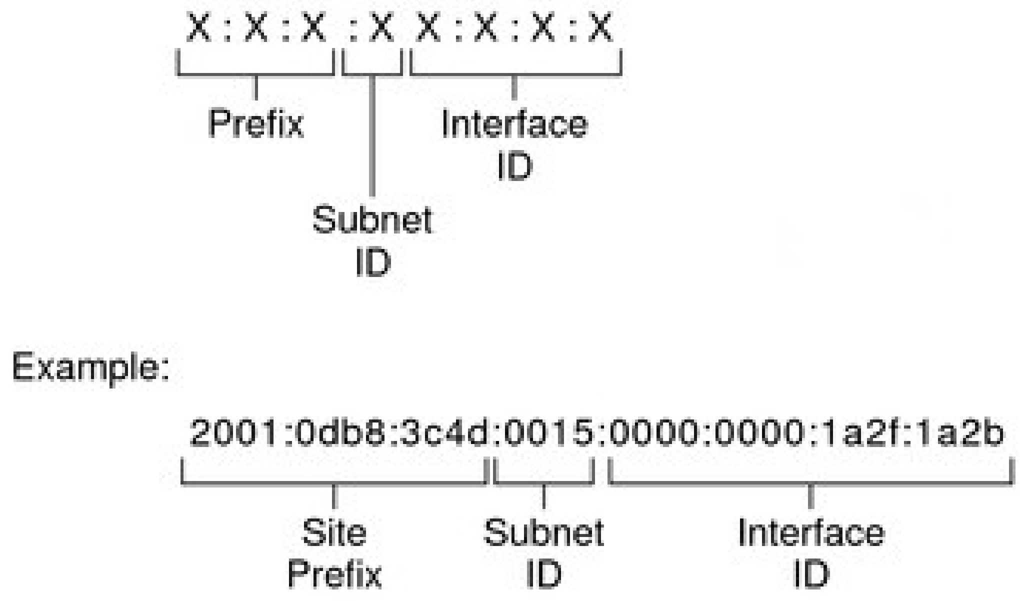


"IPv6 global unicast address" = main address type in IPv6 (see RFC3587)

Example:

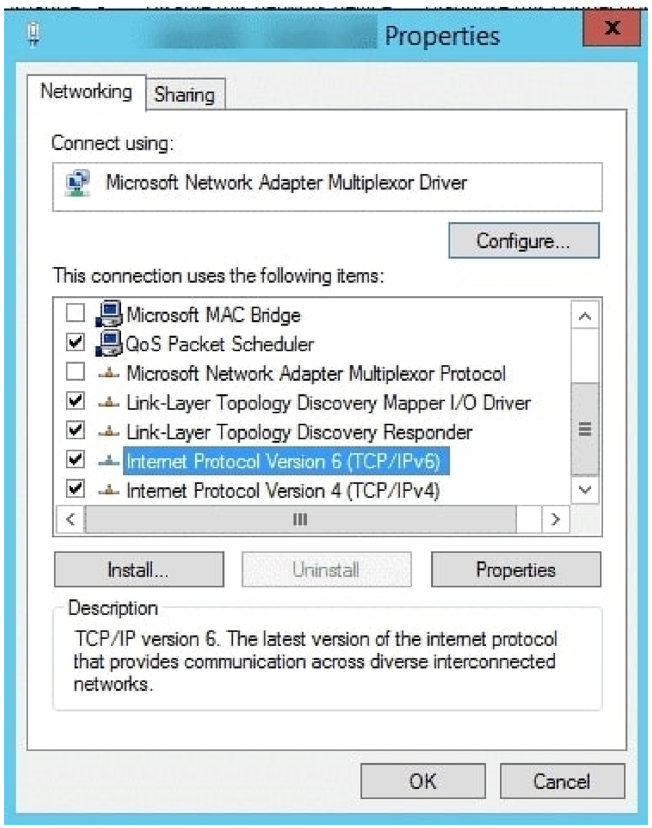
2001:0f68:0000:0000:0000:0000:1986:69af

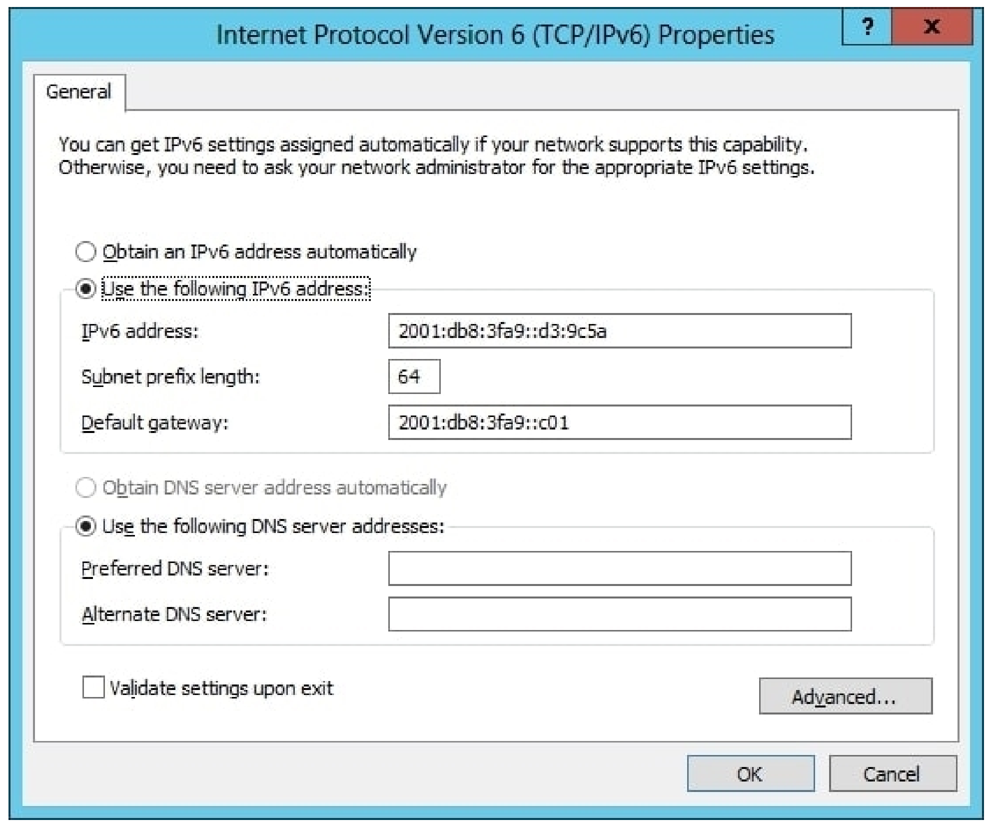
- **Site prefix: 2001:0f68:0000**
- **Subnet ID: 0000**
- **Interface ID: 0000:0000:1986:69af**



How to configure IPv6 address in Windows OS

Manual : Internet Protocol Version 6 (TCP/IPv6) or Windows PowerShell
Automatic: DHCPv6





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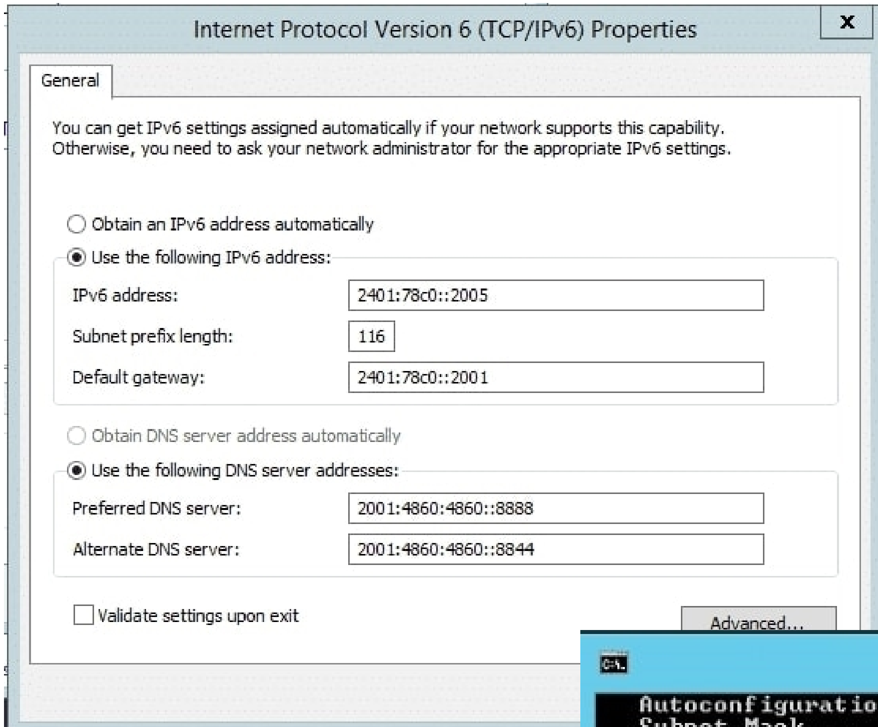
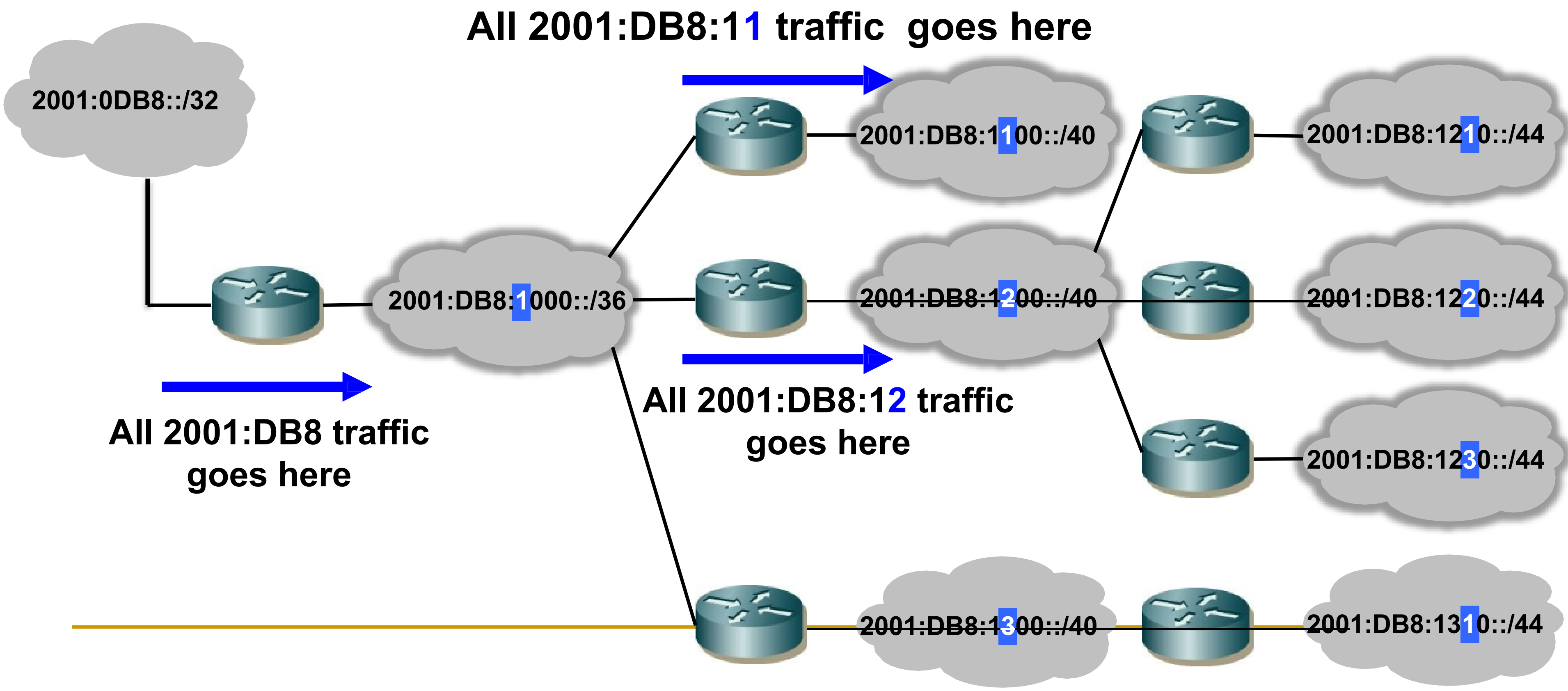


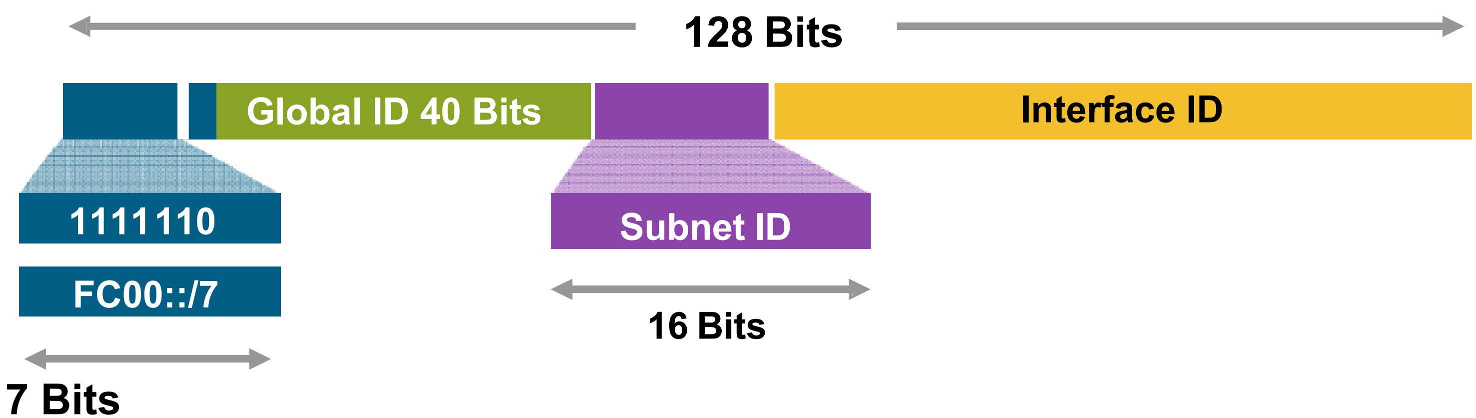
"IPv6 global unicast address" = main address type in IPv6 (see RFC3587)

➔ Hierarchical addresses allow assigning addresses according to geographical topology thus reducing routing tables (prefixes can be aggregated).

➔ The proposed aggregatable unicast address format is a tradeoff between minimizing routing tables and flexibility in IP address allocation.



2. Unique-Local Address (ULA)

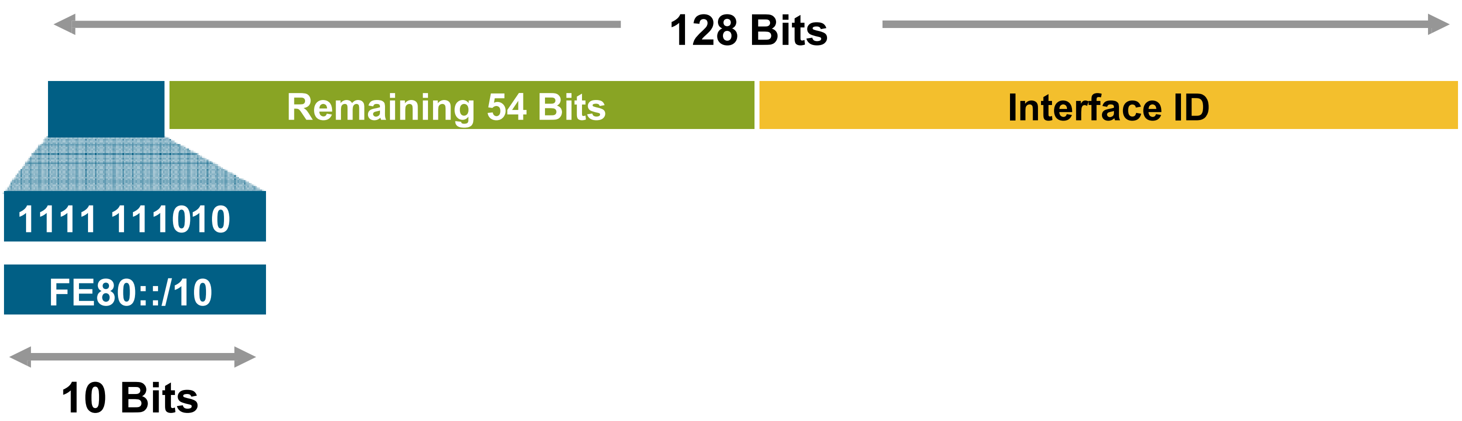


RFC4193 defines unique local addresses analogous to IPv4 private addresses (10.0.0.0/8, 172.16.0.0/12 and 192.168.0.0/16, see RFC1918).

Unique-Local Addresses Used for:

- Local communications
- Inter-site VPNs
- Not routable on the Internet

3. Link-Local



Link-Local Addresses Used for:

- Mandatory address for communication between two IPv6 device (like ARP but at layer 3)
- Automatically assigned by router as soon as IPv6 is enabled
- Also used for next-hop calculation in routing protocols
- Only link-specific scope (Only valid on link to which interface is attached)
- Remaining 54 bits could be zero or any manual configured value

Special IPv6 addresses

- **1. Loopback address representation**
  0000:0000:0000:0000:0000:0000:0000:0001 = ::1/128

  Same as 127.0.0.1 in IPv4 Identifies self

- **2. Unspecified address representation**
  0000:0000:0000:0000:0000:0000:0000:0000 = ::/128
  Meaning: Absence of address or invalid address.

  Used as a placeholder when no address available

  (Initial DHCP request, Duplicate Address Detection, DAD)

Special IPv6 addresses

- **3. IPv6 Address Prefix for Documentation:**
  2001:0DB8::/32

  In order to avoid confusion, IETF set aside a special range of IPv6 addresses to be used in documentation (and not to be used in real deployments). See RFC3849

- **4. IPv4-mapped address:**
  0:0:0:0:0:FFFF:w.x.y.z or ::FFFF:w.x.y.z,

  It is used only for internal representation. The IPv4-mapped address is never used as a source or destination address of an IPv6 packet. The IPv4-mapped address is used by some IPv6 implementations when acting as a translator between IPv4-only and IPv6-only nodes (e.g. used by RFC2765 SIIT = stateless IPv4 to IPv6 address translation)

Special IPv6 addresses

- **5. IPv4-translated address (used by RFC2765 SIIT stateless IPv4 to IPv6 address translation):**

  0::FFFF:0:a.b.c.d

  Used to represent an IPv6-enabled node.

- **6. 6to4 addresses:**
  2002::WWXX:YYZZ::[subnet-ID]:[InterfaceID]/48
  (colon-hexadecimal notation)

  Used by RFC3056 6to4 tunneling

Special IPv6 addresses

- **7. 6over4 addresses:**

  FE80::*WWXX*:*YYZZ* (colon-hexadecimal notation)

Example: IPv4 = 131.107.4.92

=1000 0011.0110 1011.0000 0100.0101 1100=83.6B.04.5C)

➔ 6over4 IPv6 address FE80::836B:45C

- **8. ISATAP addresses:**

Valid 64-bit unicast prefix and interface identifier

0:5EFE:*w.x.y.z*

Example: FE80::5EFE:131.107.4.92 (link local)

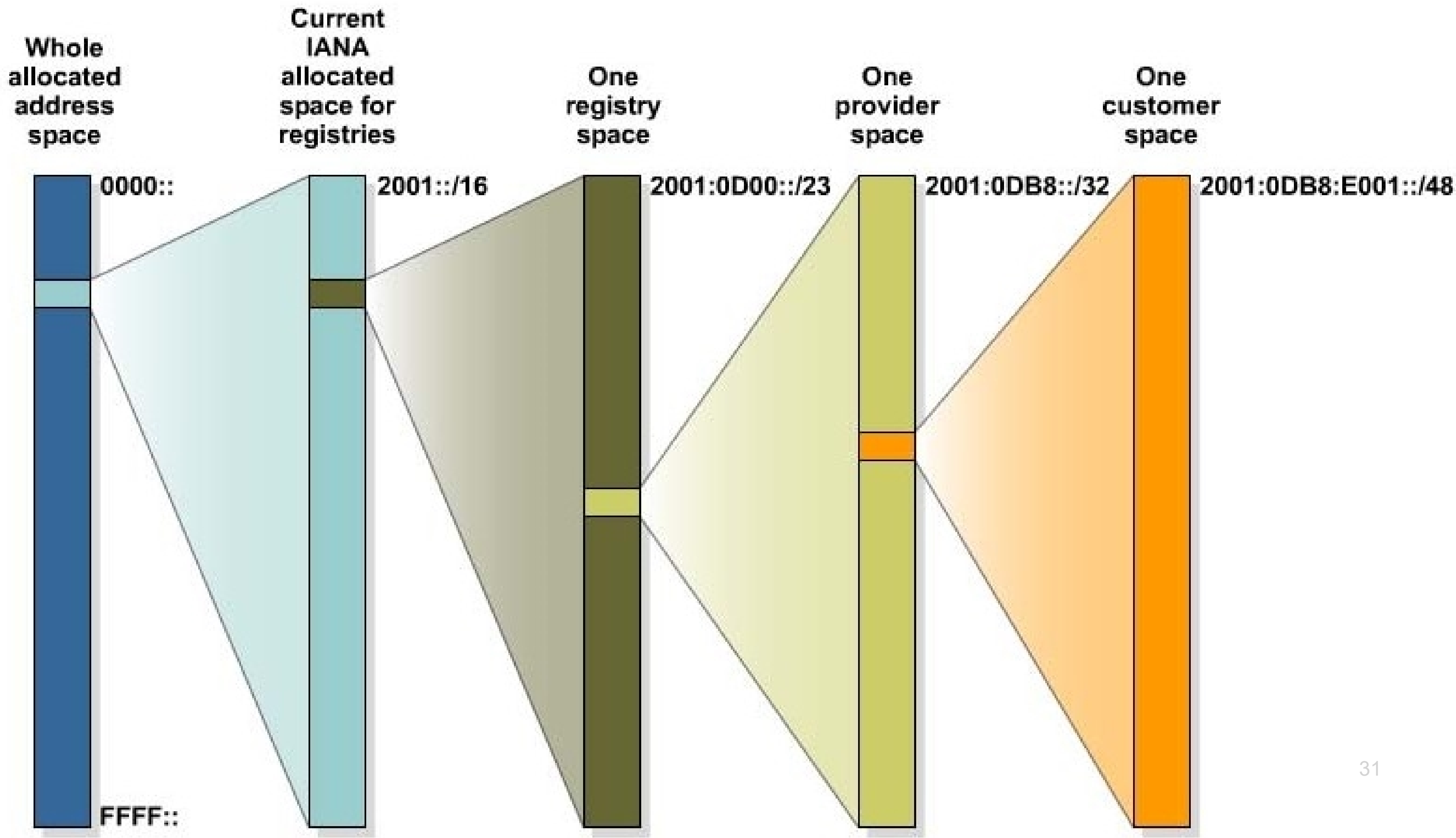
Special IPv6 addresses

9. Teredo addresses (NAPT traversal):
Use of prefix 3FFE:831F::/32
Example:
3FFE:831F:CE49:7601:8000:EFFF:62C3:FFFE

10. IPv4-translatable addresses (defined in RFC6052, used by RFC6145 and RFC6146):
IPv4 address embedded in IPv6 address starting at bit positions 32, 40, 48, 56, 72 or 96.
Ex: IPv4 address = 198.51.100.2 = 1100 0110.0011 0011.0110 0100.0000 0010 = C6.33.64.02
Example 1: 2001::0DB8:1C6:3364:02::
Example 2: 2001::0DB8:1000:C633:0064:02::

IPv6 Address Allocation Process

Partition of Allocated IPv6 Address Space



IPv6 Address Allocation Process

Partition of Allocated IPv6 Address Space (Cont.)

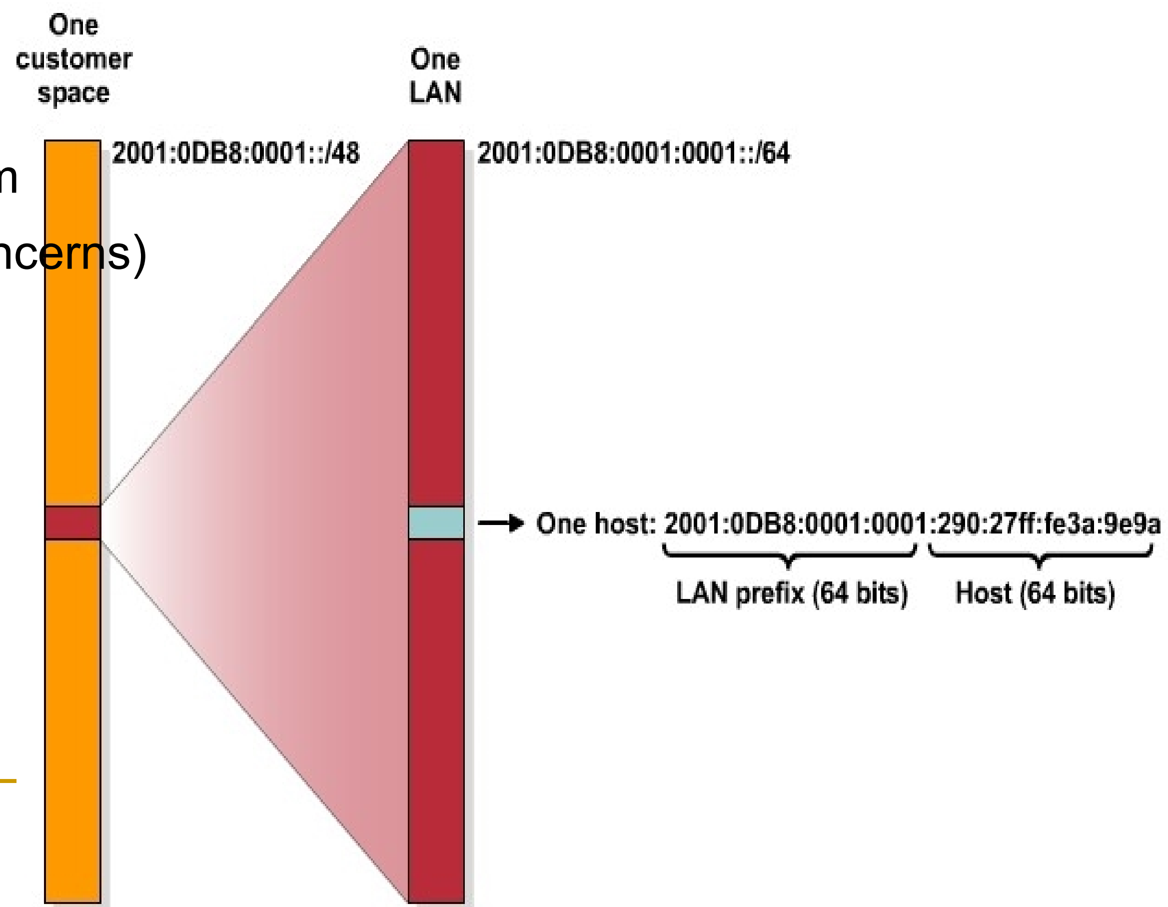
- Lowest-order 64-bit field of unicast address may be assigned in several different ways:

–Auto-configured from a 64- bit EUI-64, or expanded from a 48-bit MAC address (e.g., Ethernet address)

–Autogenerated pseudo-random number (to address privacy concerns)

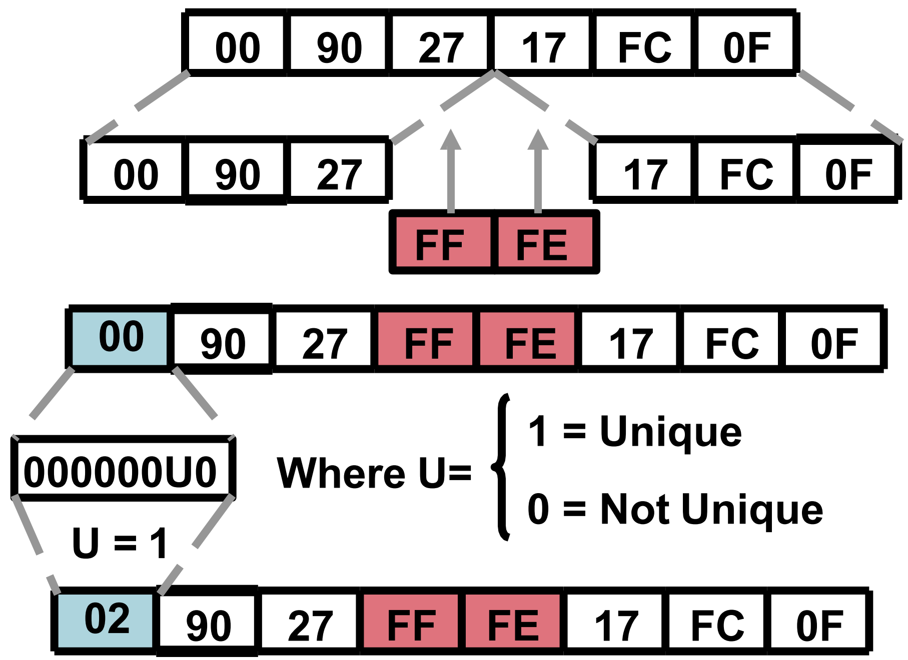
–Assigned via DHCP

–Manually configured

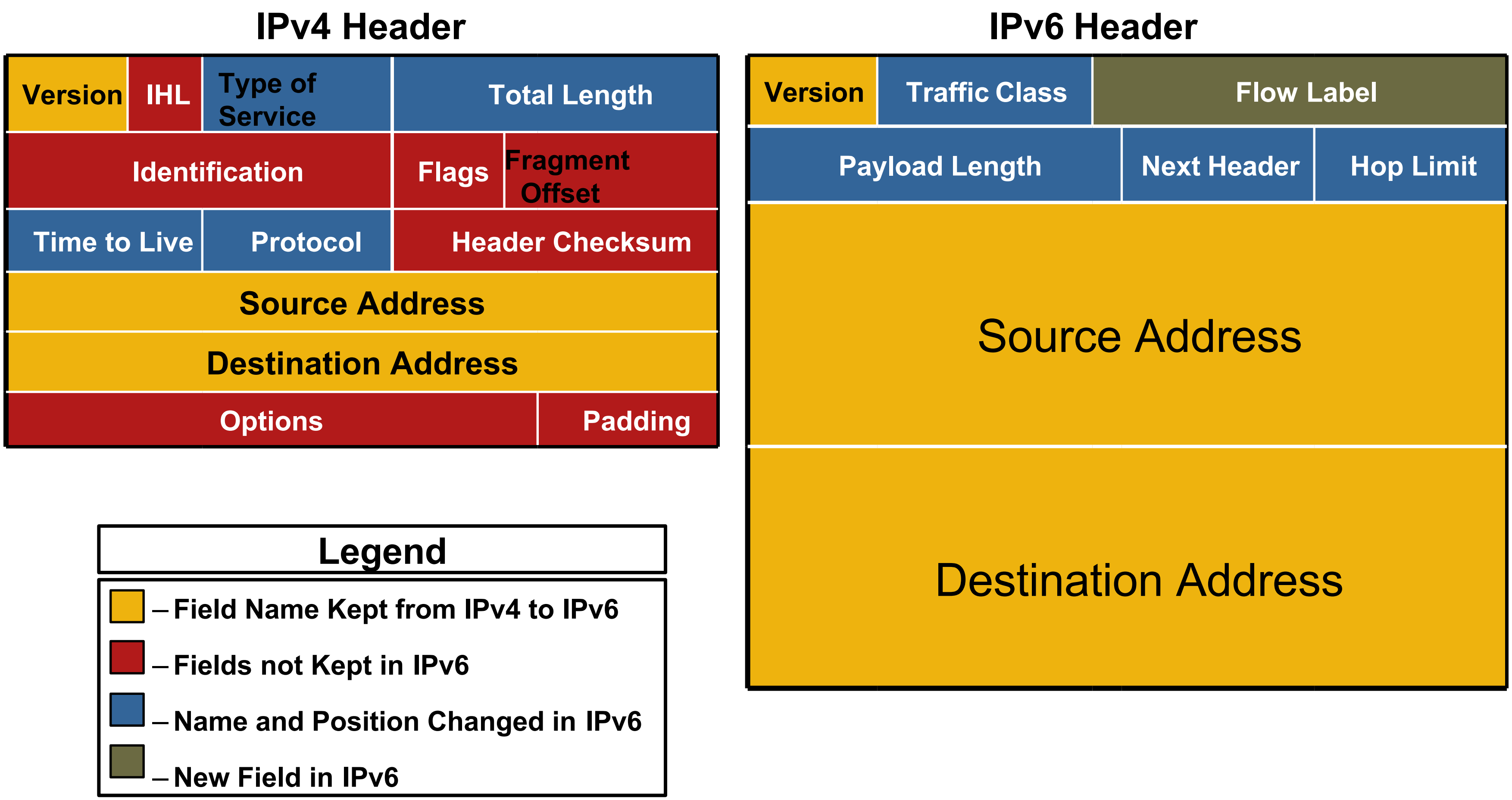


IPv6 Interface Identifier

- Cisco uses the EUI-64 format to do stateless auto-configuration
- This format expands the 48-bit MAC address to 64 bits by inserting FFFE into the middle 16 bits
- To make sure that the chosen address is from a unique Ethernet MAC address, the universal/ local (“u” bit) is set to 1 for global scope and 0 for local scope



IPv4 and IPv6 Header Comparison



Basic Specification

- Version (4 bits)
  - 6 for IPv6
- Traffic Class (8 bits)
  - ~ TOS in IPv4
  - identify classes and priorities (diffserv)
- Flow Label (20 bits)
- Payload Length (16 bits)
  - ~ Total Length in IPv4

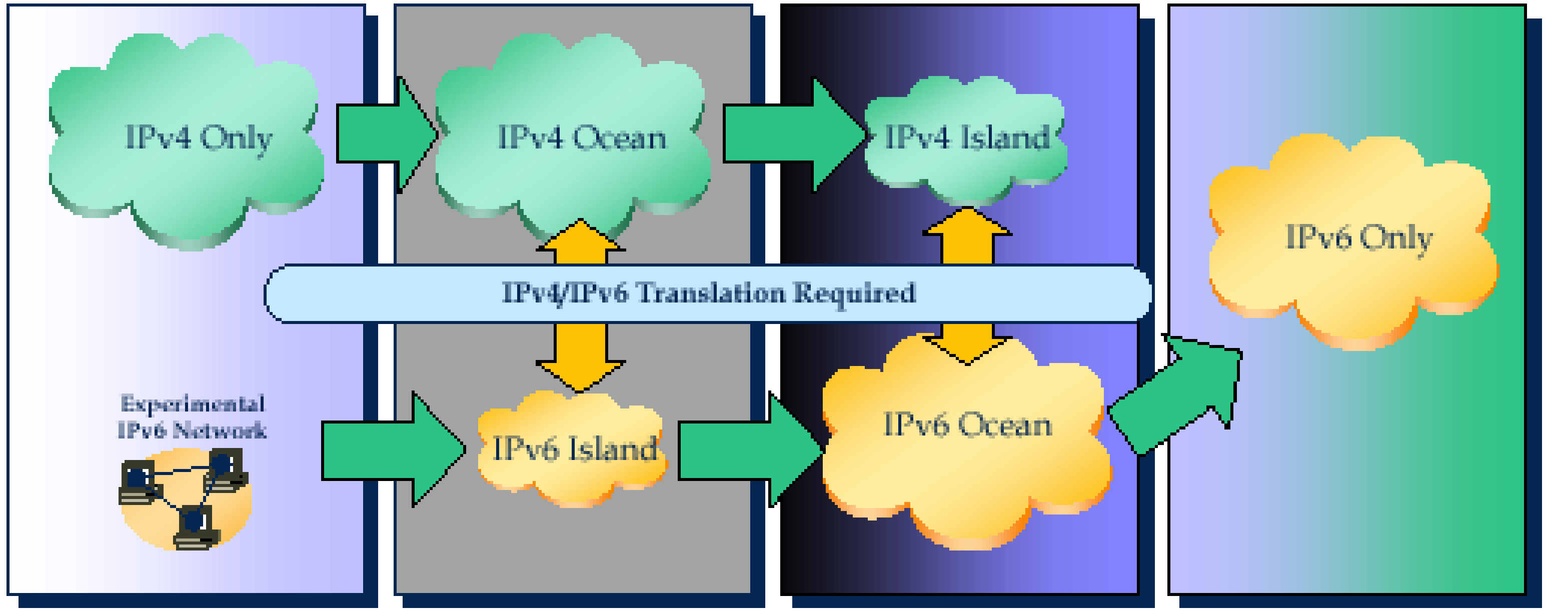
Basic Specification

- Next Header (8 bits)
  - Extensible header structure
- Hop Limit (8 bits)
  - ~ TTL in IPv4
- MTU
  - at least 1280 bytes
  - no fragment at transit nodes
- UDP checksum required

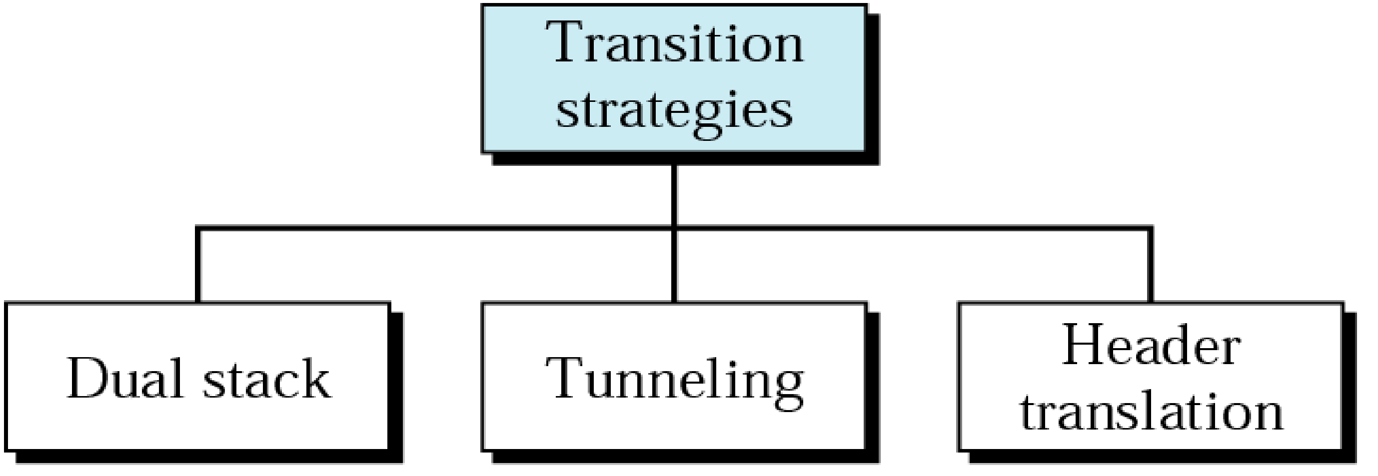
Migration steps for transition from IPv4 to IPv6

- IPv4 and IPv6 will coexist for a long time to come, possibly forever!
- There exist many different migration protocols for the different scenarios.

Phase 1 Phase 2 Phase 3 Phase 4

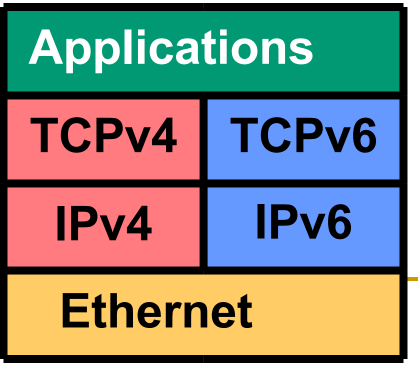


IPv4 and IPv6 – Living together



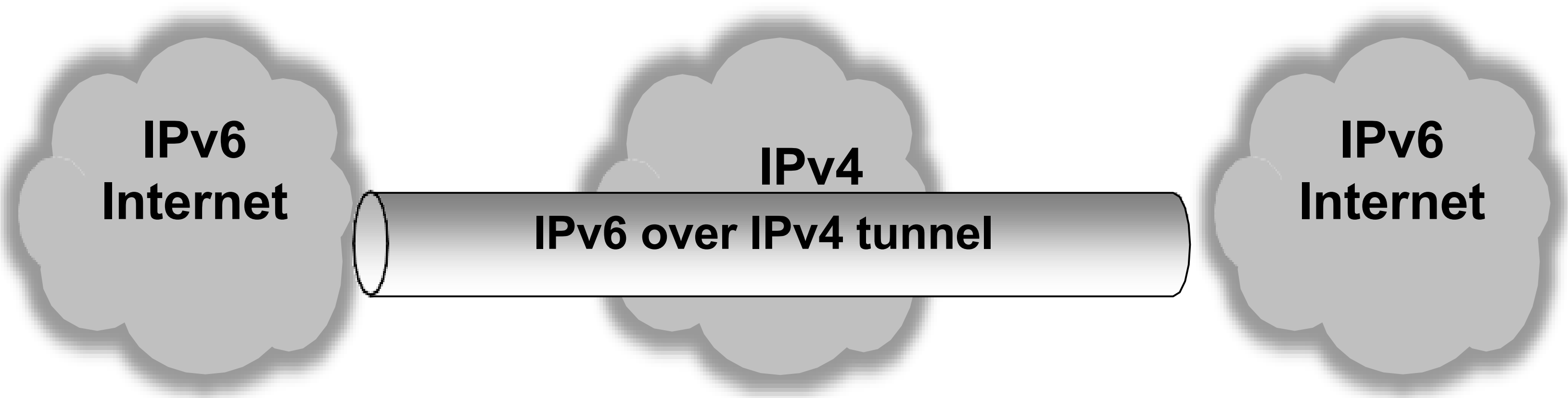
Transitioning the Internet

- Dual-stack strategy
  - A dual-stack node simply runs both an IPv4 and IPv6 stack. Depending on the application and DNS settings, such a node sends packets either over IPv4 or IPv6.
  - The handling of IPv6 within TCP and UDP
  - Modifications to the sockets libs



Transitioning the Internet

- Tunneling
  - Tunneling techniques connect IPv6 islands or hosts over IPv4 networks or vice versa.
  - IP packets (IPv4 or IPv6) are encapsulated in another IP packet (IPv6 or IPv4) for transport



Transitioning the Internet

- Translation
  - Translation technologies connect IPv6 hosts or islands to IPv4 hosts or islands through a translating device, either running the translation on application level or directly in the network stack