IPv6 Basics

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Jordi Palet
(jordi.palet@consulintel.es)

Why a New IP?

Only *compelling* reason: more addresses!

- for billions of new devices,
  e.g., cell phones, PDAs, appliances, cars, etc.
- for billions of new users,
  e.g., in China, India, etc.
- for "always-on" access technologies,
  e.g., xDSL, cable, ethernet-to-the-home, etc.

But Isn't There Still Lots of IPv4 Address Space Left?

- ~ Half the IPv4 space is unallocated
  - if size of Internet is doubling each year, does this mean only one year's worth?!
- No, because today we deny unique IPv4 addresses to most new hosts
  - we make them use methods like NAT, PPP, etc. to share addresses
- But new types of applications and new types of access need unique addresses!

Why Are NAT's Not Adequate?

- They won't work for large numbers of "servers", i.e., devices that are "called" by others (e.g., IP phones)
- They inhibit deployment of new applications and services
- They compromise the performance, robustness, security, and manageability of the Internet

Incidental Benefits of Bigger Addresses

- Easy address auto-configuration
- Easier address management/delegation
- Room for more levels of hierarchy, for route aggregation
- Ability to do end-to-end IPsec (because NATs not needed)

Incidental Benefits of New Deployment

- Chance to eliminate some complexity, e.g., in IP header
- Chance to upgrade functionality, e.g., multicast, QoS, mobility
- Chance to include new enabling features, e.g., binding updates

Summary of Main IPv6 Benefits

- Expanded addressing capabilities
- Server-less autoconfiguration ("plug-n-play") and reconfiguration
- More efficient and robust mobility mechanisms
- Built-in, strong IP-layer encryption and authentication
- Streamlined header format and flow identification
- Improved support for options / extensions

Why Was 128 Bits Chosen as the IPv6 Address Size?

- Some wanted fixed-length, 64-bit addresses
  - easily good for 10^{12} sites, 10^{15} nodes, at .0001 allocation efficiency (3 orders of mag. more than IPng requirement)
  - minimizes growth of per-packet header overhead
  - efficient for software processing
- Some wanted variable-length, up to 160 bits
  - compatible with OSI NSAP addressing plans
  - big enough for autoconfiguration using IEEE 802 addresses
  - could start with addresses shorter than 64 bits & grow later
- Settled on fixed-length, 128-bit addresses
  - (340,282,366,920,938,463,463,374,607,431,768,211,456 in all!)

What Ever Happened to IPv5?

0–3		unassigned
4	IPv4	(today's widespread version of IP)
5	ST	(Stream Protocol, not a new IP)
6	IPv6	(formerly SIP, SIPP)
7	CATNIP	(formerly IPv7, TP/IX; deprecated)
8	PIP	(deprecated)
9	TUBA	(deprecated)
10-15		unassigned

IPv6 Tutorial

Header Formats

RFC2460

- Internet Protocol, Version 6: Specification
- Changes from IPv4 to IPv6:
  - Expanded Addressing Capabilities
  - Header Format Simplification
  - Improved Support for Extensions and Options
  - Flow Labeling Capability
  - Authentication and Privacy Capabilities

IPv4 Header Format

- 20 Bytes + Options

bits: 4	8	16	20	32
Version	H. Length	TOS	Total Length	
Identification			Flags	Fragment Offset
Time To Live		Protocol	Header Checksum	
32 bits Source Address				
32 bits Destination Address				
Options				

Modified Field
Deleted Field

IPv6 Header Format

- From 12 to 8 Fields (40 bytes)

bits: 4	12	16	24	32
Version	Class of Traffic	Flow Label		
Payload Length			Next Header	Hop Limit
128 bits Source Address				
128 bits Destination Address				

  - Avoid checksum redundancy
  - Fragmentation end to end

Summary of Header Changes

- 40 bytes
- Address increased from 32 to 128 bits
- Fragmentation and options fields removed from base header
- Header checksum removed
- Header length is only payload (because fixed length header)
- New Flow Label field
- TOS -> Traffic Class
- Protocol -> Next Header (extension headers)
- Time To Live -> Hop Limit
- Alignment changed to 64 bits

THE IPv6 PORTAL

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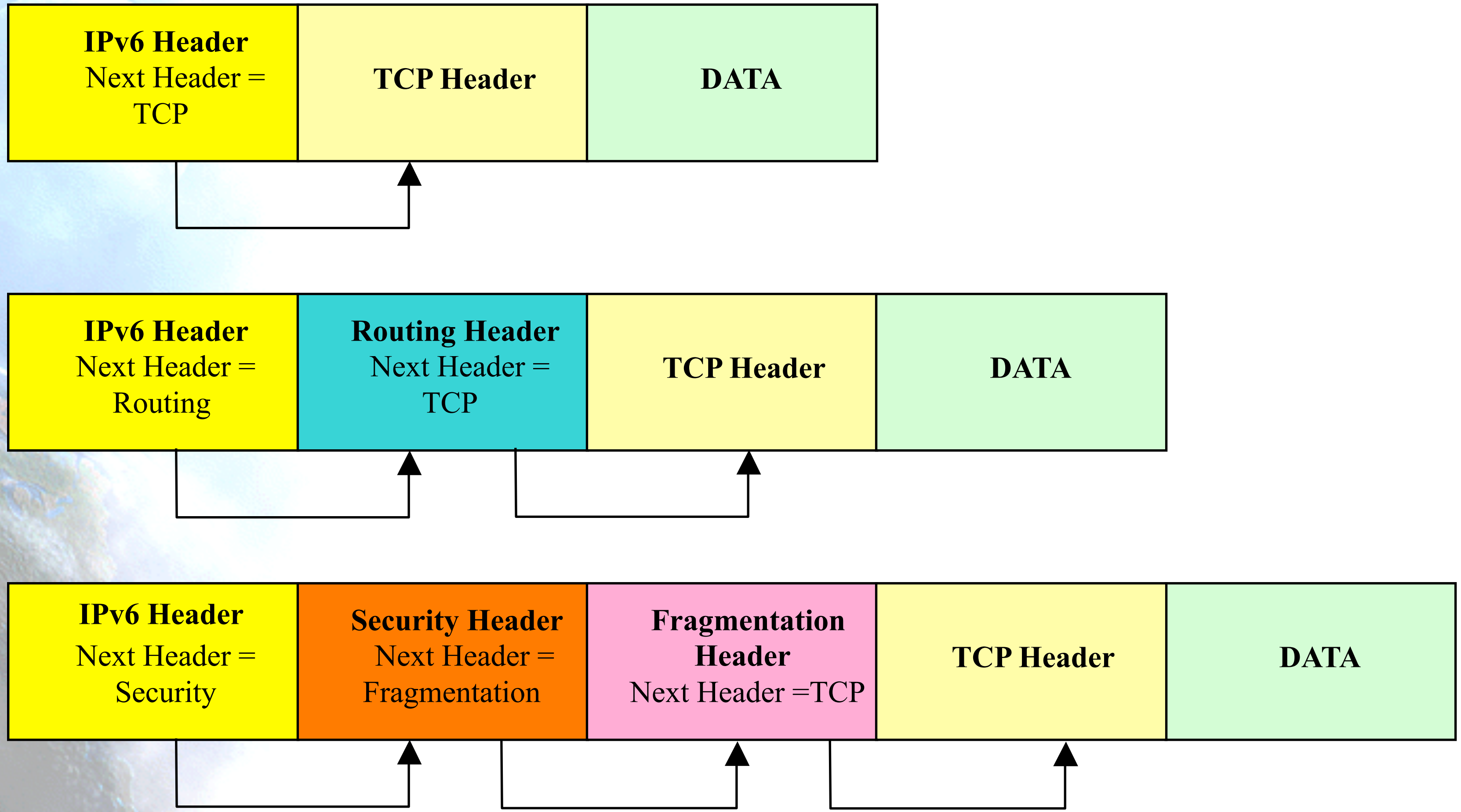
Extension Headers

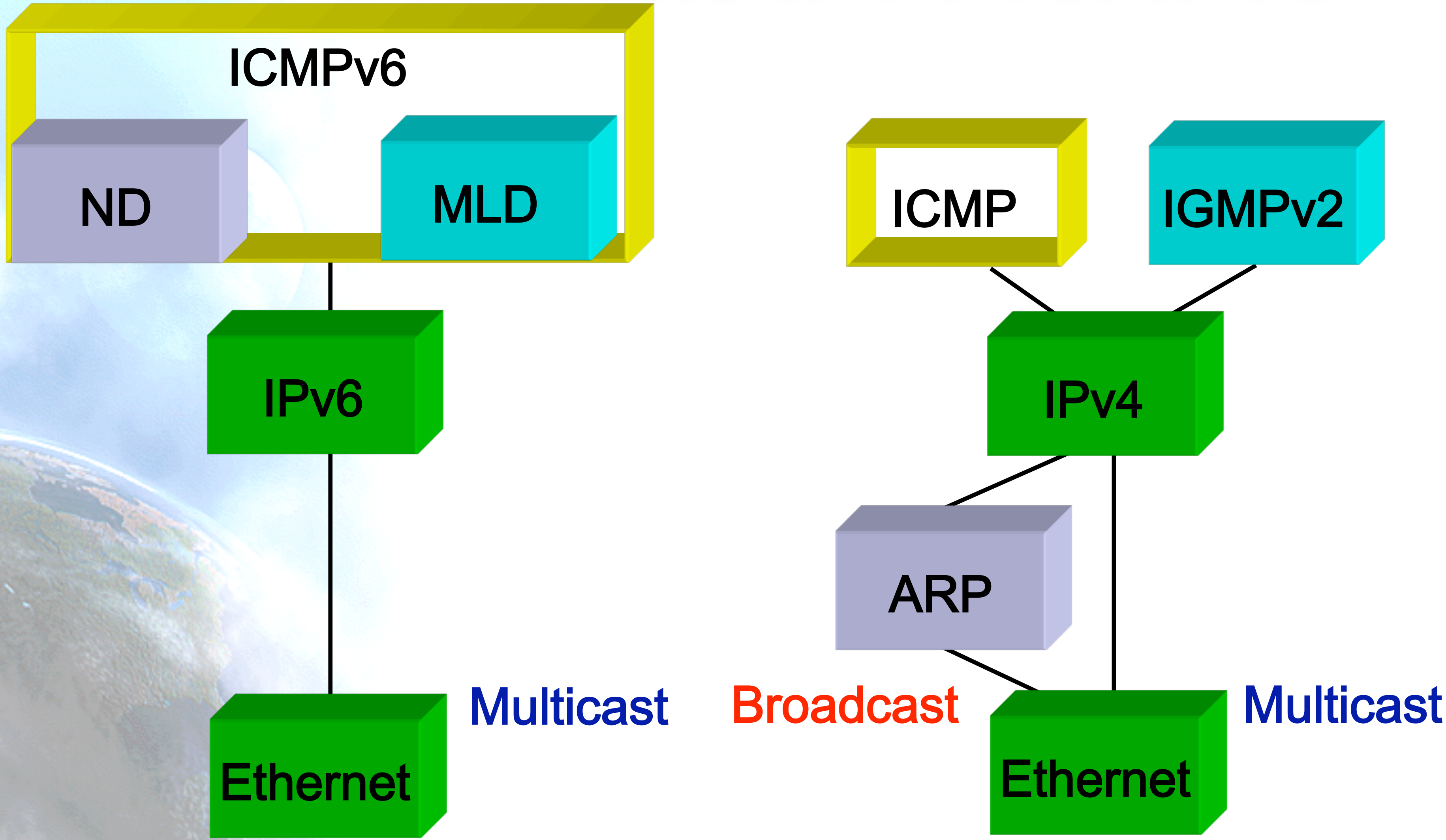
- "Next Header" Field



Extension Headers Goodies

- Processed Only by Destination Node
  - Exception: Hop-by-Hop Options Header
- No more "40 byte limit" on options (IPv4)
- Extension Headers defined currently (to be used in the following order):
  - Hop-by-Hop Options (0)
  - Destination Options (60) / Routing (43)
  - Fragment (44)
  - Authentication (RFC4302, next header = 51)
  - Encapsulating Security Payload (RFC4303, next header = 50)
  - Destination Options (60)
  - Mobility Header (135)
  - No next header (59)
    - TCP (6), UDP (17), ICMPv6 (58)

Control Plane IPv4 vs. IPv6



IPv6 Tutorial

Addressing and Routing

Text Representation of Addresses

"Preferred" form:	2001:DB8:FF:0:8:7:200C:417A
Compressed form:	FF01:0:0:0:0:0:0:43
	becomes FF01::43
IPv4-compatible:	::13.1.68.3 (deprecated)
IPv4-mapped:	::FFFF:13.1.68.3
URL:	http://[FF01::43]:80/index.html

Address Types

Unicast (one-to-one)
- global
- link-local
- site-local (deprecated)
- Unique Local (ULA)
- IPv4-compatible (deprecated)
- IPv6-mapped

Multicast (one-to-many)

Anycast (one-to-nearest)

Reserved

Address Type Prefixes

Address Type	Binary Prefix	IPv6 Notation
Unspecified	00…0 (128 bits)	::/128
Loopback	00…1 (128 bits)	::1/128
Multicast	1111 1111	FF00::/8
Link-Local Unicast	1111 1110 10	FE80::/10
ULA	1111 110	FC00::/7
Global Unicast	(everything else)	
IPv4-mapped	00…0:1111 1111:IPv4	::FFFF:IPv4/128
Site-Local Unicast (deprecated)	1111 1110 11	FEF0::/10
IPv4-compatible (deprecated)	00…0 (96 bits)	::/96

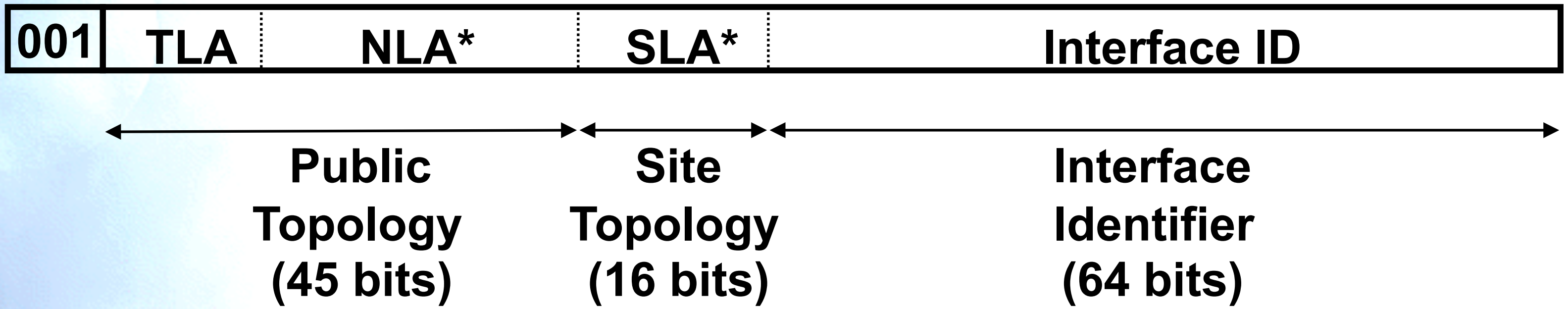
- **Anycast** addresses allocated from unicast prefixes

Global Unicast Prefixes

Address Type	Binary Prefix
IPv4-compatible	0000...0 (96 zero bits) (deprecated)
IPv4-mapped	00…0FFFF (80 zero+ 16 one bits)
Global unicast	001
ULA	1111 110x (1= Locally assigned) (0=Centrally assigned)

- **2000::/3** prefix is being allocated for Global Unicast, all other prefixes reserved (approx. 7/8ths of total)

Aggregatable Global Unicast Addresses (RFC2374) (Deprecated)



- TLA = Top-Level Aggregator
  NLA* = Next-Level Aggregator(s)
  SLA* = Site-Level Aggregator(s)
- TLAs may be assigned to ISPs and IX

Global Unicast Addresses (RFC3587)

001	Glob. Rout. prefix	subnet ID	Interface ID
	Global Routing Prefix (45 bits)	Sub-network ID (16 bits)	Interface ID (64 bits)

- The global routing prefix is a value assigned to a zone (site, a set of subnetworks/links)
  - It has been designed as an hierarchical structure from the Global Routing perspective
- The subnetwork ID, identifies a subnetwork within a site
  - Has been designed to be an hierarchical structure from the site administrator perspective
- The Interface ID is build following the EUI-64 format

Global Unicast Addresses in Production Networks

001	Glob. Rout. prefix	subnet ID	Interface ID
	Global Routing Prefix (45 bits)	Sub-network ID (16 bits)	Interface ID (64 bits)

- LIRs receive by default /32
  - Production addresses today are from prefixes 2001, 2003, 2400, 2800, etc.
  - Can request for more if justified
- /48 used only within the LIR network, with some exceptions for critical infrastructures
- /48 to /128 is delegated to end users
  - Recommendations following RFC3177 and current policies
    - /48 general case, /47 if justified for bigger networks
    - /64 if only and only one network is required
    - /128 if it is sure that only and only one device is going to be connected

Global Unicast Addresses for the 6Bone

Until 06/06/06 !

001	TLA	pTLA	NLA*	SLA*	interface ID
	13	12	20	16	64 bits

- 6Bone: experimental IPv6 network used for testing only
- TLA 1FFE (hex) assigned to the 6Bone
  - thus, 6Bone addresses start with 3FFE:
  - (binary 001 + 1 1111 1111 1110)
- Next 12 bits hold a “pseudo-TLA” (pTLA)
  - thus, each 6Bone pseudo-ISP gets a /28 prefix
- Not to be used for production IPv6 service

Link-Local & Site-Local Unicast Addresses

Link-local addresses for use during auto -configuration and when no routers are present:

1111111010	0	interface ID

Site-local addresses for independence from changes of TLA / NLA* (deprecated !):

1111111011	0	SLA*	interface ID

Unique Local IPv6 Unicast Addresses
IPv6 ULA (RFC4193)

- Globally unique prefix with high probability of uniqueness
- Intended for local communications, usually inside a site
- They are not expected to be routable on the Global Internet
- They are routable inside of a more limited area such as a site
- They may also be routed between a limited set of sites
- Locally-Assigned Local addresses
  – vs Centrally-Assigned Local addresses

IPv6 ULA Characteristics

- Well-known prefix to allow for easy filtering at site boundaries
- ISP independent and can be used for communications inside of a site without having any permanent or intermittent Internet connectivity
- If accidentally leaked outside of a site via routing or DNS, there is no conflict with any other addresses
- In practice, applications may treat these addresses like global scoped addresses

IPv6 ULA Format

- Format:

Prefix	L	global ID	subnet ID	interface ID
7 bits	1	40 bits	16 bits	64 bits

- FC00::/7 Prefix identifies the Local IPv6 unicast addresses
- L = 1 if the prefix is locally assigned
- L = 0 may be defined in the future
- ULA are created using a pseudo-randomly allocated global ID
  - This ensures that there is not any relationship between allocations and clarifies that these prefixes are not intended to be routed globally

Centrally Assigned Unique Local IPv6 Unicast Addresses (1)

- Centrally-Assigned Local addresses
  - vs Locally-Assigned Local addresses
- Latest Draft:
  - draft-ietf-ipv6-ula-central-01.txt
  - February 2005
  - No longer active
  - It defines the characteristics and requirements for Centrally assigned Local IPv6 addresses in the framework defined in IPv6 ULA – RFC4193

Centrally Assigned Unique Local IPv6 Unicast Addresses (2)

- The major difference between both assignments:
  - the Centrally-Assigned is uniquely assigned and the assignments can be escrowed to resolve any disputes regarding duplicate assignments
- It is recommended that sites planning to use Local IPv6 addresses use a centrally assigned prefix as there is no possibility of assignment conflicts. Sites are free to choose either approach
- The allocation procedure for creating global-IDs for centrally assigned local IPv6 addresses is setting L=0. Remember that the allocation procedure for locally assigned local IPv6 addresses is thru L=1, as is defined in RFC4193

Interface IDs

The lowest-order 64-bit field of unicast addresses may be assigned in several different ways:

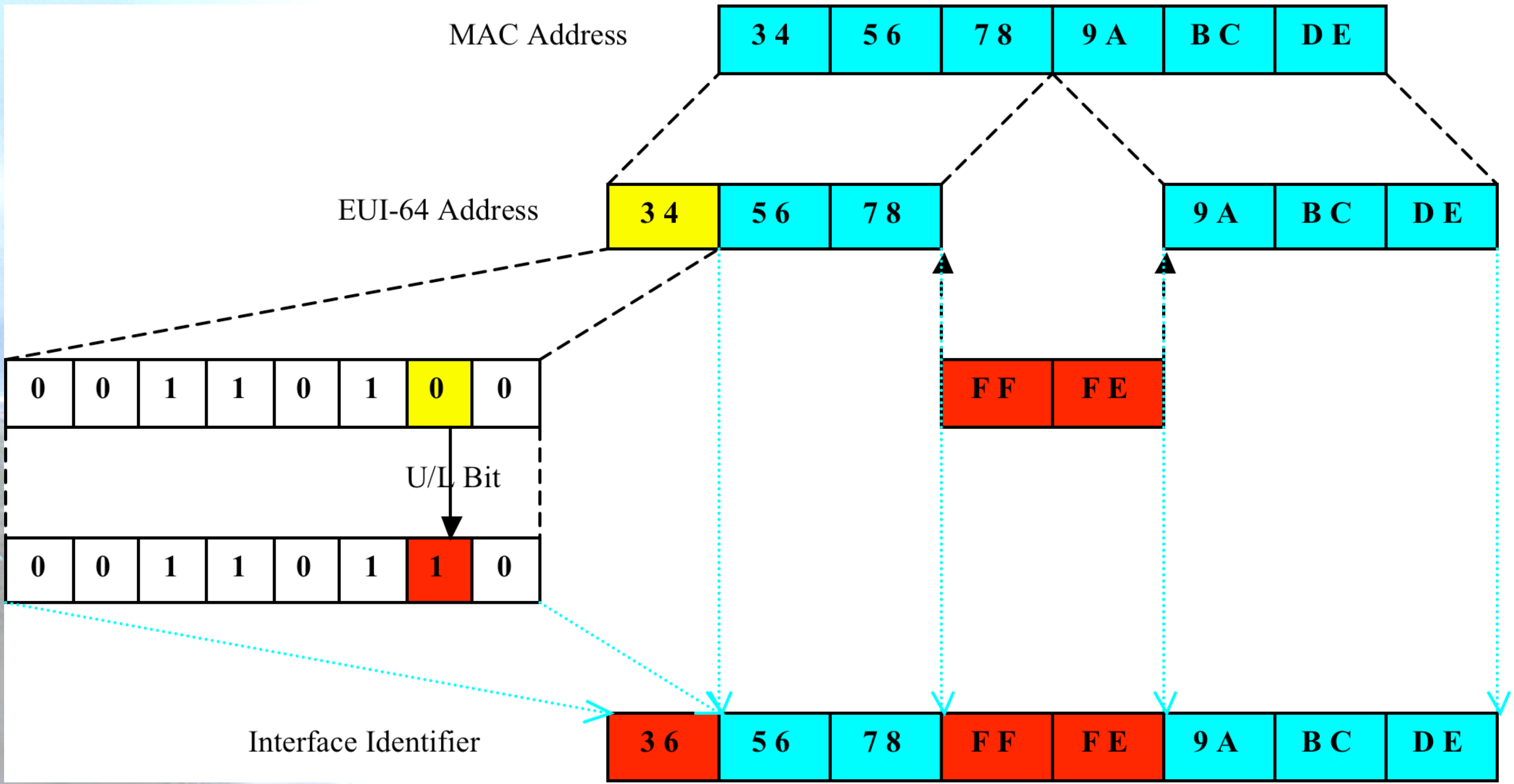
- auto-configured from a 48-bit MAC address (e.g., Ethernet address), expanded into a 64-bit EUI-64
- assigned via DHCP
- manually configured
- auto-generated pseudo-random number (to counter some privacy concerns)
- possibly other methods in the future

global ID	subnet ID	Interface ID
48 bits	16 bits	64 bits

IPv6 in Ethernet

48 bits	48 bits	16 bits	
Ethernet Destination Address	Ethernet Source Address	1000011011011101 (86DD)	IPv6 Header and Data

EUI-64



MAC Address
3 4
5 6
7 8
9 A
B C
D E
EUI-64 Address
3 4
5 6
7 8
9 A
B C
D E
0 0 1 1 0 1 0 0
F F
F E
U/L Bit
0 0 1 1 0 1 1 0
Interface Identifier
3 6
5 6
7 8
F F
F E
9 A
B C
D E

Some Special-Purpose Unicast Addresses

- The unspecified address, used as a placeholder when no address is available:

  0:0:0:0:0:0:0:0

- The loopback address, for sending packets to self:

  0:0:0:0:0:0:0:1

Multicast Addresses

11111111	flags	scope	group ID
8	4	4	112 bits

- Low-order flag indicates permanent/transient group; three other flags reserved
- Scope field:
  1 - node local
  2 - link-local
  5 - site-local
  8 - organization-local
  B - community-local
  E - global
  (all other values reserved)

Routing

- Uses same "longest-prefix match" routing as IPv4 CIDR
- Straightforward changes to existing IPv4 routing protocols to handle bigger addresses
  - –unicast: OSPF, RIP-II, IS-IS, BGP4+, …
  - –multicast: MOSPF, PIM, …
- Can use Routing header with anycast addresses to route packets through particular regions
  - –e.g., for provider selection, policy, performance, etc.

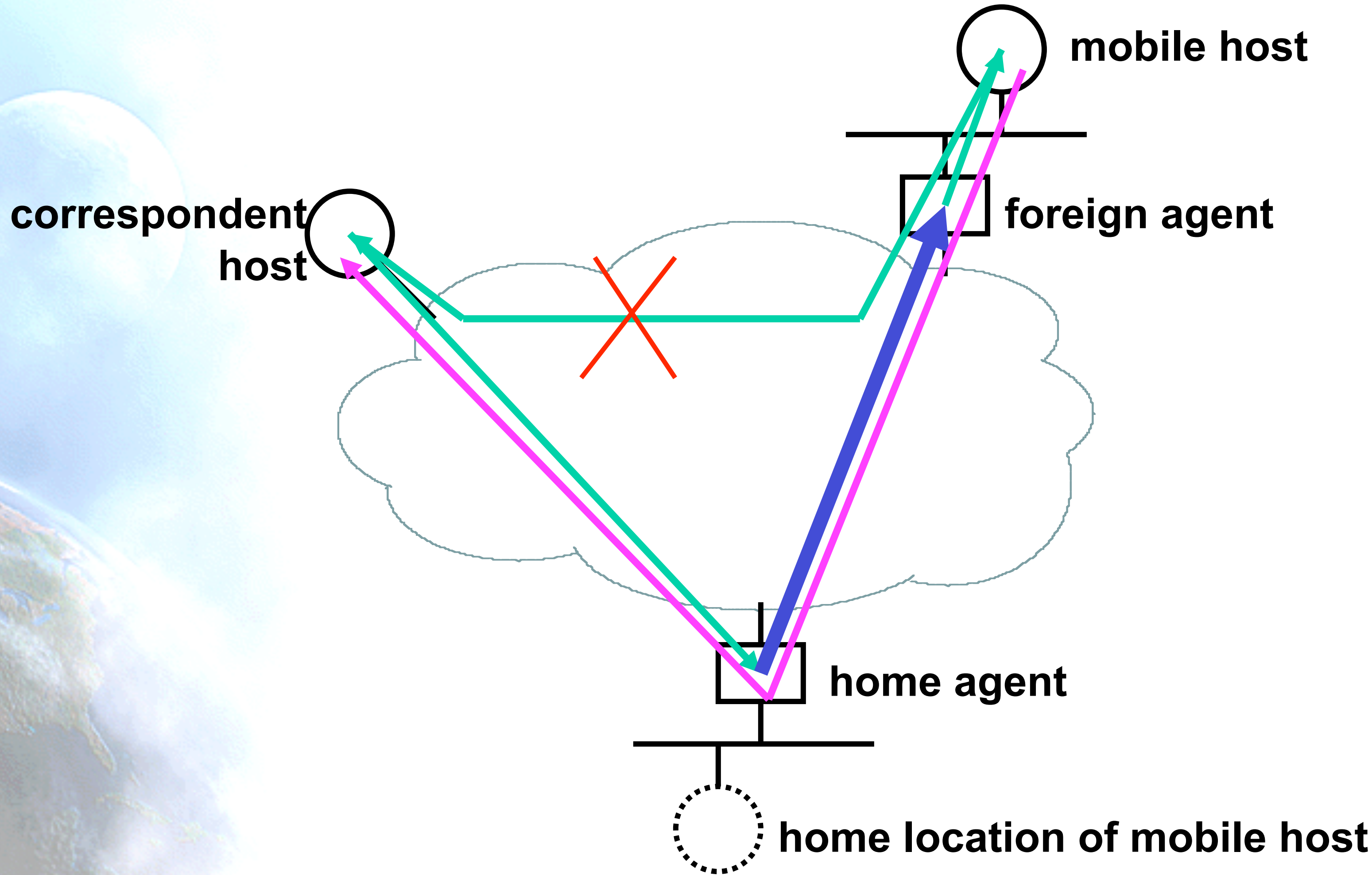
IPv6 Tutorial

Mobility

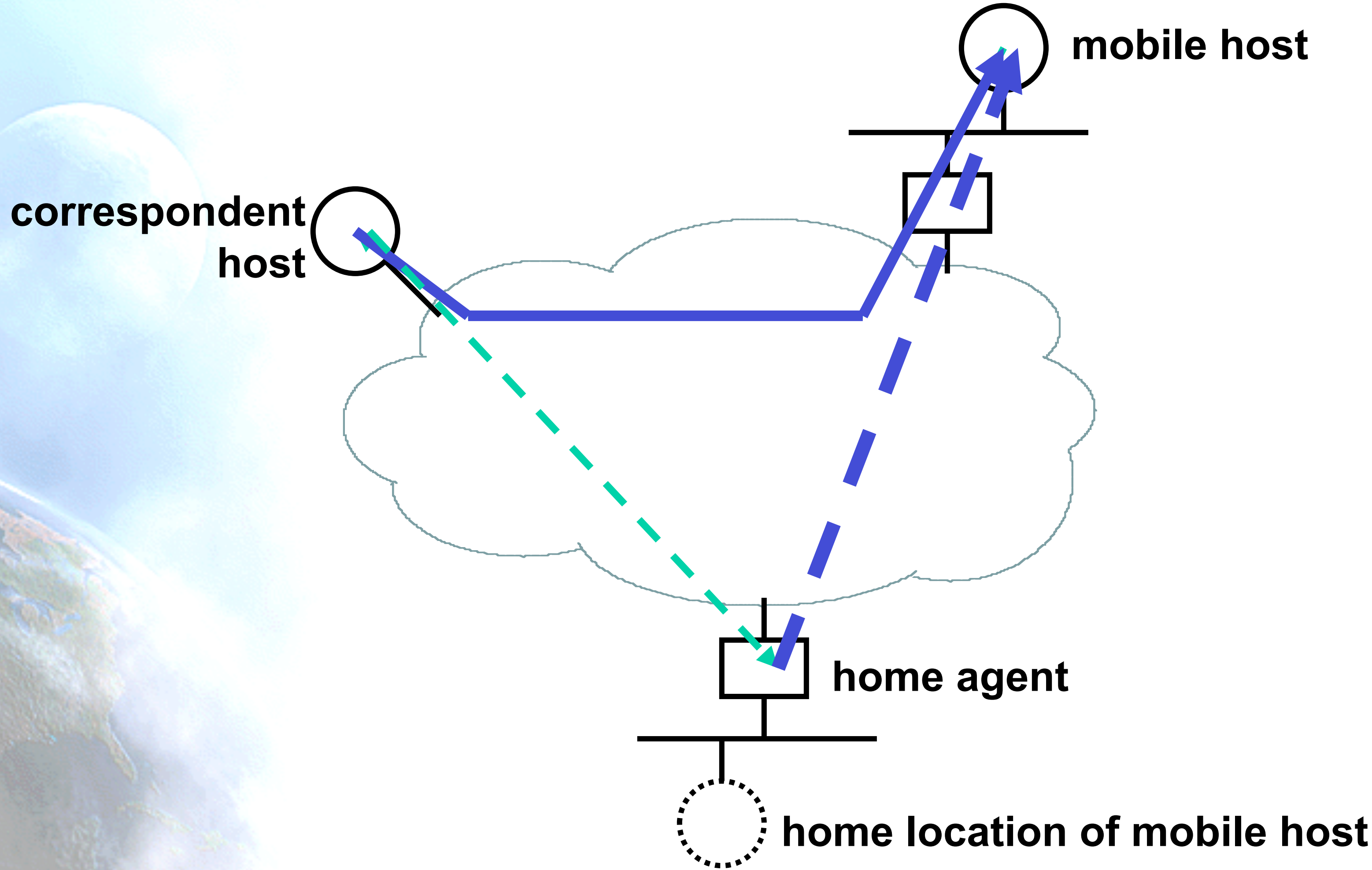
IPv6 Mobility

- A mobile host has one or more home address(es)
  - relatively stable; associated with host name in DNS
- When it discovers it is in a foreign subnet (i.e., not its home subnet), it acquires a foreign address
  - uses auto-configuration to get the address
  - registers the foreign address with a home agent, i.e, a router on its home subnet
- Packets sent to the mobile's home address(es) are intercepted by home agent and forwarded to the foreign address, using encapsulation

Mobile IPv4


mobile host
correspondent host
foreign agent
home agent
home location of mobile host

Mobile IPv6


mobile host
correspondent host
home agent
home location of mobile host

IPv6 Tutorial

IPv4-IPv6 Coexistence & Transition

Transition / Co-Existence Techniques

A wide range of techniques have been identified and implemented, basically falling into three categories:

(1) dual-stack techniques, to allow IPv4 and IPv6 to co-exist in the same devices and networks

(2) tunneling techniques, to avoid order dependencies when upgrading hosts, routers, or regions

(3) translation techniques, to allow IPv6-only devices to communicate with IPv4-only devices

Expect all of these to be used, in combination

Dual-Stack Approach

- When adding IPv6 to a system, do not delete IPv4
  - this multi-protocol approach is familiar and well-understood (e.g., for AppleTalk, IPX, etc.)
  - note: in most cases, IPv6 will be bundled with new OS releases, not an extra-cost add-on
- Applications (or libraries) choose IP version to use
  - when initiating, based on DNS response:
    - if (destination has AAAA record) use IPv6, else use IPv4
  - when responding, based on version of initiating packet
- This allows indefinite co-existence of IPv4 and IPv6, and gradual app-by-app upgrades to IPv6 usage
- A6 record as experimental

Tunnels to Get Through IPv6-Ignorant Routers

- Encapsulate IPv6 packets inside IPv4 packets (or MPLS frames)
- Many methods exist for establishing tunnels:
  – manual configuration
  – "tunnel brokers" (using web-based service to create a tunnel)
  – "6-over-4" (intra-domain, using IPv4 multicast as virtual LAN)
  – "6-to-4" (inter-domain, using IPv4 addr as IPv6 site prefix)
- Can view this as:
  – IPv6 using IPv4 as a virtual link-layer, or
  – an IPv6 VPN (virtual public network), over the IPv4 Internet (becoming "less virtual" over time, we hope)

Translation

- May prefer to use IPv6-IPv4 protocol translation for:
  - new kinds of Internet devices (e.g., cell phones, cars, appliances)
  - benefits of shedding IPv4 stack (e.g., serverless autoconfig)
- This is a simple extension to NAT techniques, to translate header format as well as addresses
  - IPv6 nodes behind a translator get full IPv6 functionality when talking to other IPv6 nodes located anywhere
  - they get the normal (i.e., degraded) NAT functionality when talking to IPv4 devices
  - methods used to improve NAT functionality (e.g, RSIP) can be used equally to improve IPv6-IPv4 functionality

Thanks !

Contact:

– Jordi Palet Martínez (Consulintel): jordi.palet@consulintel.es

The IPv6 Portal:

- http://www.ipv6tf.org