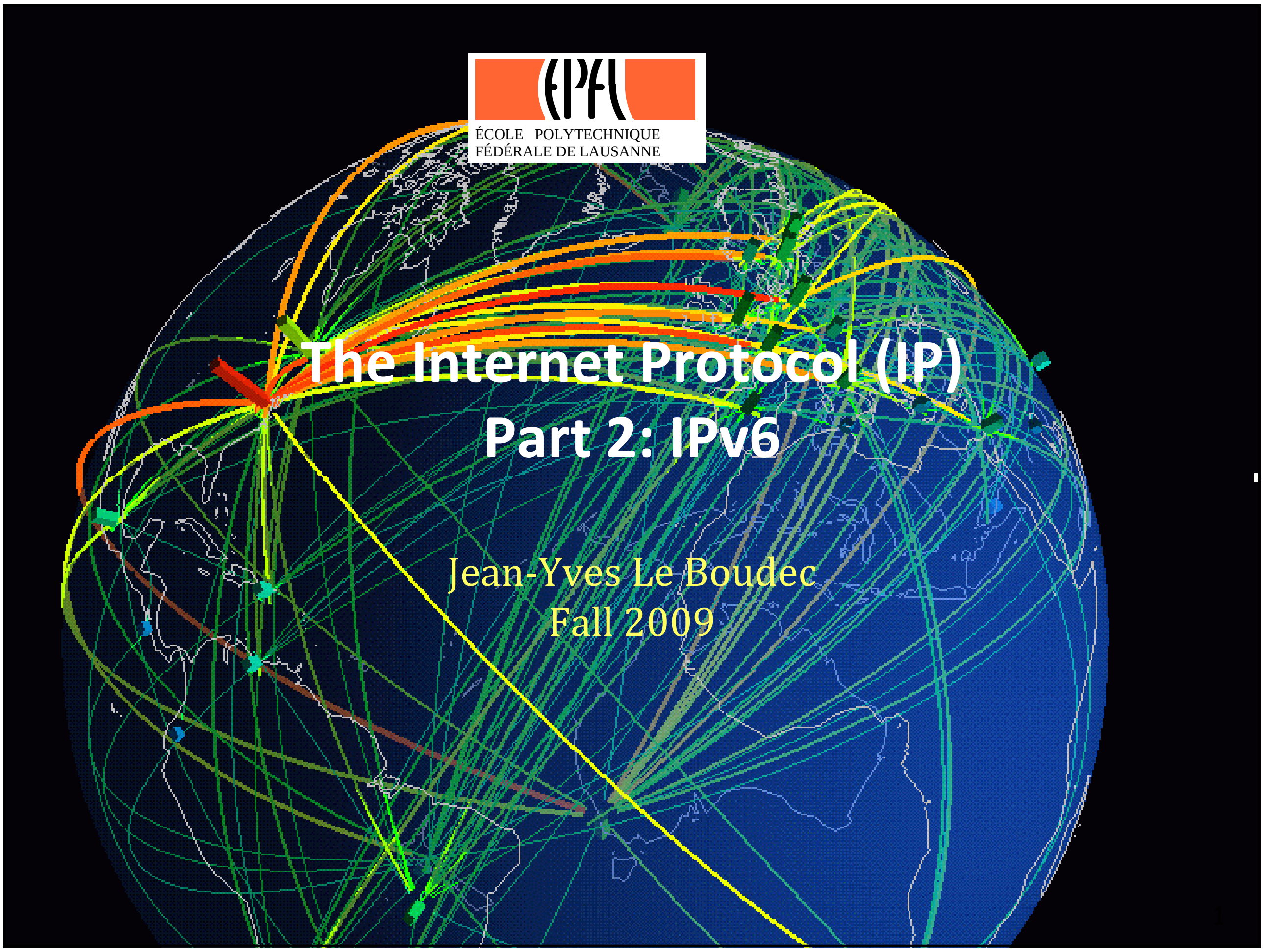
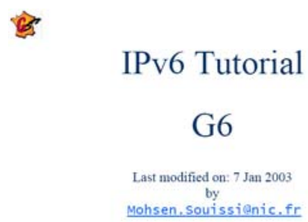

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE
The Internet Protocol (IP)
Part 2: IPv6
Jean-Yves Le Boudec
Fall 2009

Contents

1. IPv6
2. NATs
3. Interworking IPv4 / IPv6
4. Routing Implications
5. Recap



Some slides come from:
ipv6-g6-tutorial.pdf
by Mohsen.Souissi@nic.fr

Some slides come from:
RIPE 40 Meeting
by Florent.Parent@viagenie.qc.ca

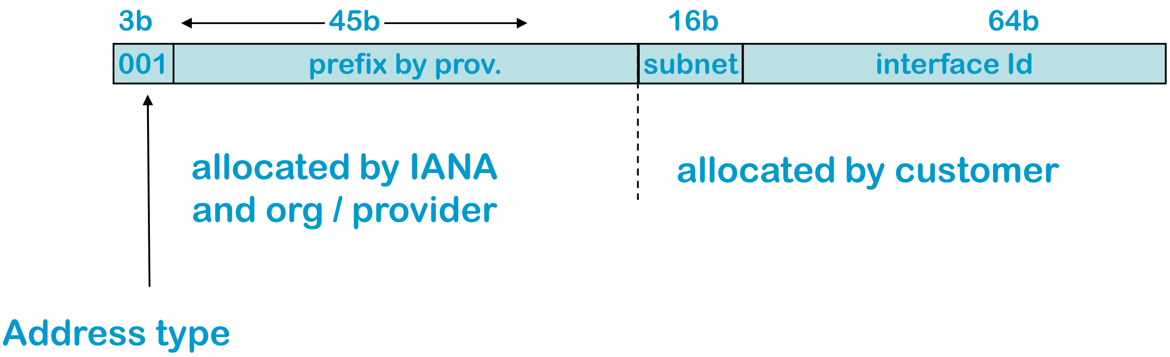
2

1. IPv6

- The current IP is IPv4. IPv6 is the next version of IP
- *Why* a new version ?
  - IPv4 address space is too small (32 bits). It will be exhausted some day.
    - IP over cellular, UMTS
- *What* does IPv6 do ?
  - Redefine packet format with a larger address: 128 bits
  - Otherwise essentially the same as IPv4, but with minor improvements on header format
    - Facilitate hardware implementation – not seen in this module
- We now review *how* the IPv6 addresses are made and what new facilities this allows

Why IPv6 and not IPv5 ? Because the version number 5 is already used by an experimental Protocol called ST2, used to provide quality of service for example in military networks.

IPv6 Addresses



IPv6 Addresses: Notation

- IPv6 address is 16B = 128 bits
- Notations: 1 *piece* = 16 bits = [0-4]hexa digits; pieces separated by ":"
  :: replaces any number of 0s; appears only once in address
- Examples
  2001:80b2:9c26:0:800:2078:30f9
  permanent IPv6 address (allocated 2001 and later)
  2002:80b2:9c26:0:800:2078:30f9
  6to4 IPv6 address of dual stack host with IPv4 address 128.178.156.38 and MAC address 08:00:20:78:30:f9
  0:0:0:0:0:FFFF:128.178.156.38
  IPv4 mapped address (IPv4 only host)
  ::FFFF:80b2:9c26
  same as previous
  FF02::43
  all NTP servers on this LAN
  0:0:0:0:0:0:0:0 = :: = unspecified address (absence of address)
- hosts may have several addresses
- addresses are: unicast, anycast or multicast
- url with IPv6 address: use square brackets
  http://[2001:80b2:9c26:0:800:2078:30f9]/index.html

5

From RFC4291, Feb 2006

Address type	Binary prefix	IPv6 notation
Unspecified	00...0 (128 bits)	::/128
Loopback	00...1 (128 bits)	::1/128
Multicast	11111111	FF00::/8
Link-Local unicast	1111111010	FE80::/10
Global Unicast	(everything else)	

INTERNET PROTOCOL VERSION 6 ADDRESS SPACE (IANA)

[last updated 27 February 2006]

IPv6 Prefix	Allocation	Reference	Note
0000::/8	Reserved by IETF	[RFC3513]	[1] [5]
0100::/8	Reserved by IETF	[RFC3513]	
0200::/7	Reserved by IETF	[RFC4048]	[2]
0400::/6	Reserved by IETF	[RFC3513]	
0800::/5	Reserved by IETF	[RFC3513]	
1000::/4	Reserved by IETF	[RFC3513]	
2000::/3	Global Unicast	[RFC3513]	[3]
4000::/3	Reserved by IETF	[RFC3513]	
6000::/3	Reserved by IETF	[RFC3513]	
8000::/3	Reserved by IETF	[RFC3513]	
A000::/3	Reserved by IETF	[RFC3513]	
C000::/3	Reserved by IETF	[RFC3513]	
E000::/4	Reserved by IETF	[RFC3513]	
F000::/5	Reserved by IETF	[RFC3513]	
F800::/6	Reserved by IETF	[RFC3513]	
FC00::/7	Unique Local Unicast	[RFC4193]	
FE00::/9	Reserved by IETF	[RFC3513]	
FE80::/10	Link Local Unicast	[RFC3513]	
FEC0::/10	Reserved by IETF	[RFC3879]	[4]
FF00::/8	Multicast	[RFC3513]	

[0] The IPv6 address management function was formally delegated to IANA in December 1995 [RFC1881].

[1] The "unspecified address", the "loopback address", and the IPv6 Addresses with Embedded IPv4 Addresses are assigned out of the 0000::/8 address block.

[2] 0200::/7 was previously defined as an OSI NSAP-mapped prefix set [RFC-gray-rfc1888bis-03.txt]. This definition has been deprecated as of December 2004 [RFC4048].

[3] The IPv6 Unicast space encompasses the entire IPv6 address range with the exception of FF00::/8. [RFC3513] IANA unicast address assignments are currently limited to the IPv6 unicast address range of 2000::/3. IANA assignments from this block are registered in the IANA registry: iana-ipv6-unicast-address-assignments.

[4] FEC0::/10 was previously defined as a Site-Local scoped address prefix. This definition has been deprecated as of September 2004 [RFC3879].

[5] 0000::/96 was previously defined as the "IPv4-compatible IPv6 address" prefix. This definition has been deprecated by [RFC4291].

IPv6 Multicast Addresses

```
   8b      4b   4b                112 bits
 11111111 flgs scpe               group Id
```

flgs: *(flags)*=000T   T=0: well-known   T=1: transient
scpe: *(scope)*
      0: reserved 1: node local 2:link local 5: site local
      8: org local E: global   F: reserved
       examples: FF01::43 = all NTP servers on this node
                  FF02::43 = all NTP servers on this link
                  FF05::43 = all NTP servers on this site
                  FF0E::43 = all NTP servers in the Internet

reserved addresses:
- FF0x::1   all nodes in the scope (x=1, 2)
- FF0x::2   all routers in the scope (x=1, 2)
- FF02::1:0 all DHCP servers/relay on this link

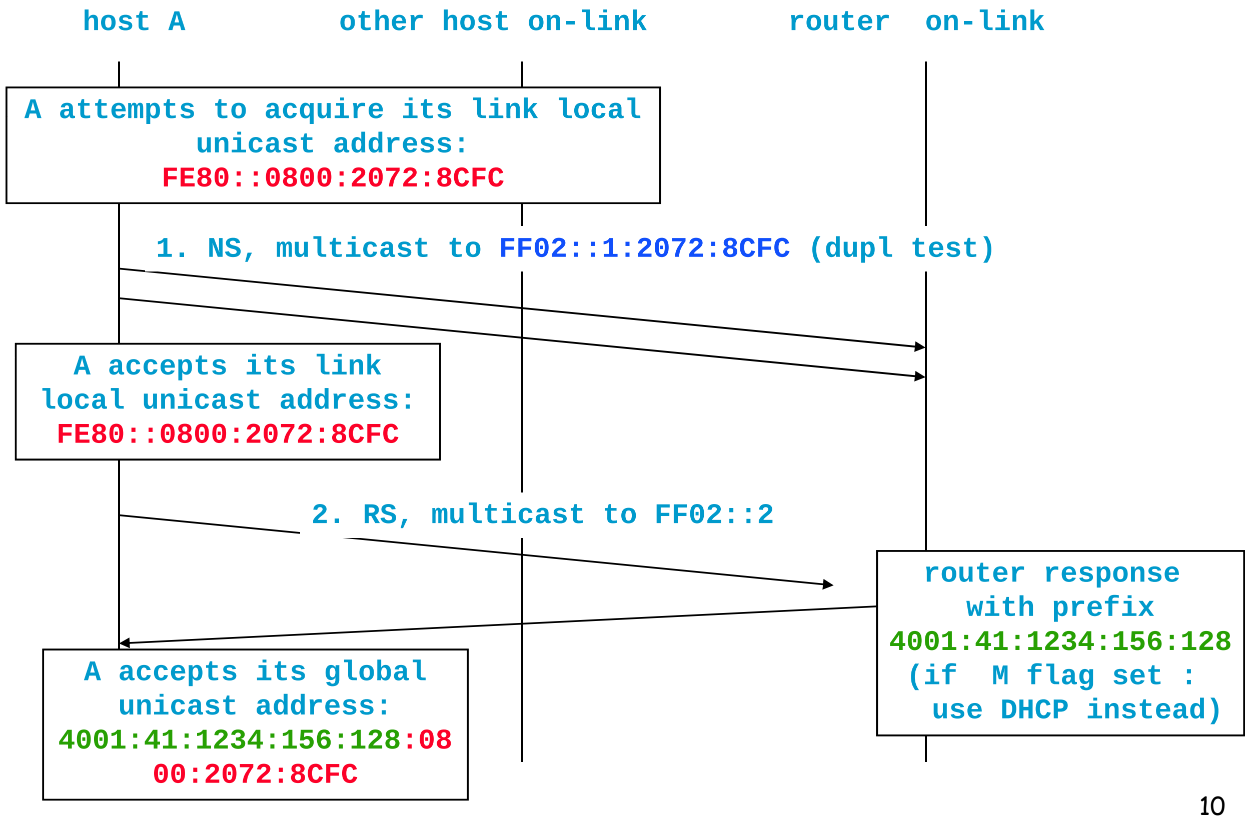
solicited node multicast:
- FF02::1:XXXX:XXXX
- where XXXX:XXXX= lowest order 32 bits of unicast addr.

8

The New Address Format Allows Plug and Play

- Automatic assignment of addresses in hosts is possible, using MAC address
  - This is called "stateless" autoconfiguration
- The next slide shows how it works:
  1. Host creates a *link local unicast address* from its MAC address (cannot be used outside a LAN, but can be used to reach a router). Validity of address is verified by sending a packet to a special multicast address that only nodes with the same MAC address can have.
  2. Host asks for a router present and gets a prefix.

Stateless Autoconfiguration Overview



10

IPv6 Host Configuration Example

- Output of "netstat -q" at lrcsun12;

```
Interface     Destination/Mask            Phys Addr          Ref        State
---------     -------------------        ----------        -------   ---------------
le0#v6        ff02::2/128                33:33:00:00:00:02    1         REACHABLE
le0#v6        ff02::1:80b2:9c26/128      33:33:80:b2:9c:26    1         REACHABLE
le0#v6        fe80::1:0:800:2078:30f9/128 08:00:20:78:30:f9   1         REACHABLE
le0#v6        ff02::1:2078:30f9/128      33:33:20:78:30:f9    1         REACHABLE
```

```
Q. analyze the addresses on the four lines;
           given that lrcsun13's IPv4 address is 128.178.156.38
           and lrcsun13's MAC address is 08-00-20-78-30-F9
```

solution

11

IPv6 Host Configuration Example

- Output of "netstat -q" at lrcsun12;

```
Interface     Destination/Mask             Phys Addr           Ref         State
---------     -------------------          ----------         -------    ---------------
le0#v6        ff02::2/128                  33:33:00:00:00:02     1          REACHABLE
le0#v6        ff02::1:80b2:9c26/128        33:33:80:b2:9c:26     1          REACHABLE
le0#v6        fe80::1:0:800:2078:30f9/128 08:00:20:78:30:f9      1          REACHABLE
le0#v6        ff02::1:2078:30f9/128        33:33:20:78:30:f9     1          REACHABLE
```

```
Q. analyze the addresses on the four lines;
           given that lrcsun13's IPv4 address is 128.178.156.38
           and lrcsun13's MAC address is 08-00-20-78-30-F9
A.
ff02::2/128                  33:33:00:00:00:02     all routers on link
ff02::1:80b2:9c26/128        33:33:80:b2:9c:26     snmc addr of ::128.178.156.38 (special
   multicast address)
fe80::1:0:800:2078:30f9/128 08:00:20:78:30:f9      link local of lrcsun13
ff02::1:2078:30f9/128        33:33:20:78:30:f9     snmc addr of above

Comment: could have been present:
4800::1:0:800:2078:30f9/128 08:00:20:78:30:f9      configured addr of lrcsun13
```

back

12

Issues with use of MAC address inside IPv6 Address

Interface Identifier (3)

(Privacy issues)

- IEEE 24 bit OUI can be used to identify HW:
  - http://standards.ieee.org/regauth/oui/oui.txt
- Interface Identifier can be used to trace a user:
  - The prefix changes, but the interface ID remains the same,
  - Psychological issue.
- Possibility to change Interface ID (RFC 3041 PS):
  - If local storage, use MD5 algorithm
  - Otherwise draw a random number

G6 Tutorial *35*

Source: ipv6-g6-tutorial.pdf by Mohsen.Souissi@nic.fr

13

DHCP

- Why invented ?
  - Allocation of IP addresses is painful and error prone – wrong address = system does not work
  - Renumbering is difficult, but once in while is needed
- What does it do ?
  - Dynamic Host Configuration Protocol = DHCP: Allocate an IP address and network mask to host when it boots (or on user's demand)
- How does it do its job ?
  - DHCP servers maintain lists of addresses and prefixes that are available for allocation
  - MAC address used to identify a host to DHCP server
  - DHCP was initially developed for IPv6, so we show it in this context. Now it also applies to IPv4.

14

DHCPv6

- For IPv6, this is an alternative to stateless address allocation
  - Provides more control about who is allowed to insert itself in the network

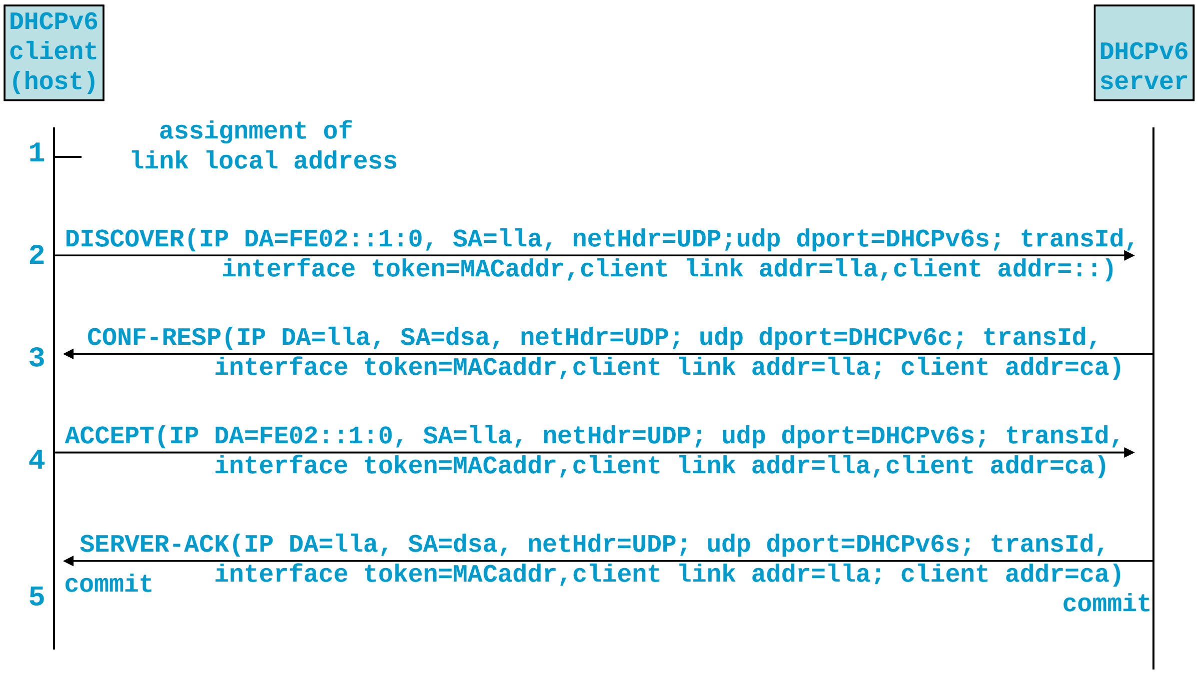
The next slides show how DHCPv6 (i.e. DHCP for IPv6) works

2: sent to IPv6 multicast address: well known, link scope address transId = set by client; token = depends on type of network (MAC@ on Ethernet)UDP destination port shown

4: sent to multicast address to inform other servers

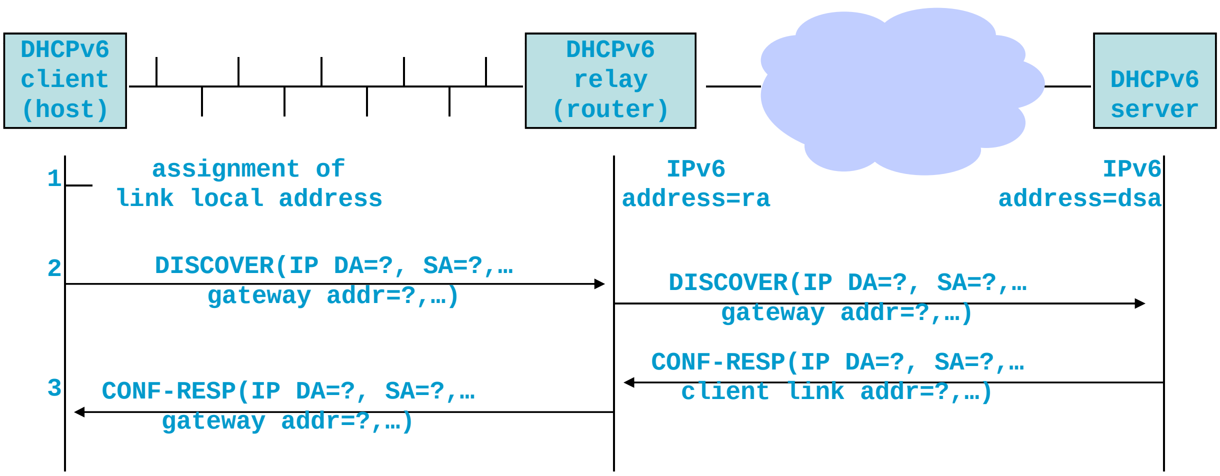
5 is the commit flow; commitment done by server when sending message; done by client on reception option field contains: printer addr, DNS server address, name of a file to retrieve from server with for example config info (such as name)

DHCPv6 Address Acquisition



16

DHCP with Remote DHCP Server



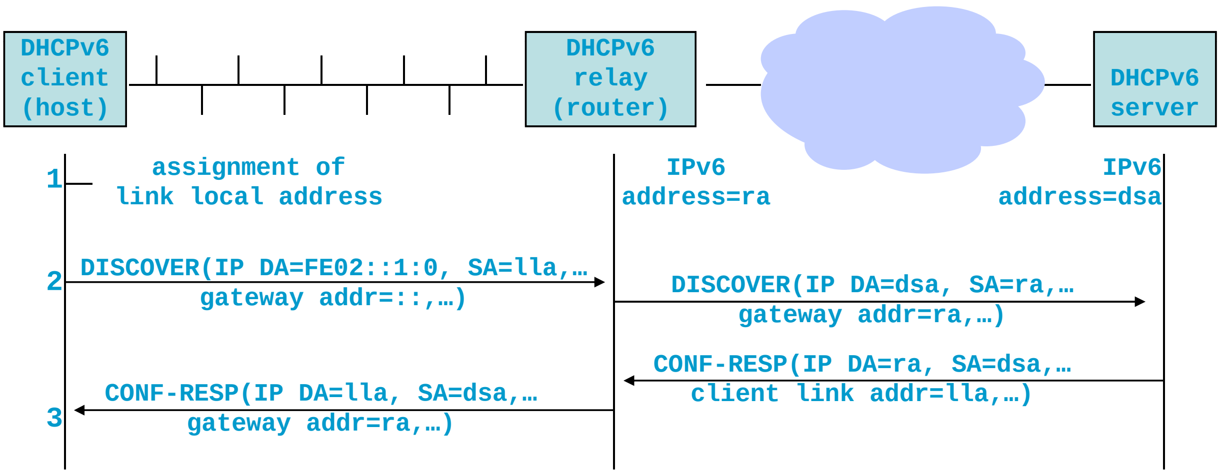
Q1. replace '?' by plausible values

Q2. does DHCP relay keep state information ?

Solutions

17

DHCP with Remote DHCP Server



Q2. no; DHCP relay puts all needed info in request and so does the DHCPv6 server

back

18

DHCP for IPv4

- Originally, DHCP was intended for IPv6
- Q: How would one map the concepts of DHCP used with IPv6 to IPv4 ?
- Q: is DHCP relay a router function ?
- Q: should the DHCP server be colocated on router or not ?

solution

DHCP for IPv4

- Originally, DHCP was intended for IPv6
- Q: How would one map the concepts of DHCP used with IPv6 to IPv4 ?
- A: one needs to replace the IPv6 multicast address and the link local address;
  - client sends DHCPDISCOVER to broadcast IP address; source IP address =0; UDP is used (ports 67 on server, 68 on client); message contains the MAC address of client
  - DHCP server or relay (colocated in router) receives it and answers; sends it to the MAC address of client, to IP address = broadcast or the address allocated to client
- Q: is DHCP relay a router function ?
  - no, it can be colocated in a router but is not a layer-3 IS function
- Q: should the DHCP server be colocated on router or not ?
  - DHCP server requires permanent storage (disk) usually better placed on a server than on a router.
    back

Functions Developped for IPv6 Retrofitted to IPv4

- Example: DHCP
- Other functions such as quality of service, mobility, security are now supported equally well by IPv6 and IPv4.
- Example: can you do stateless address allocation in IPv4 as in IPv6 ?
  Q. Explain how you would do it using private IP addresses instead of link local unicast address.

solution

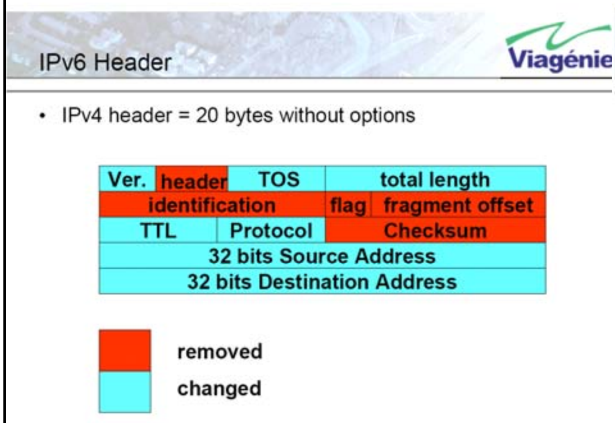
Functions Developed for IPv6 Can Often be Retrofitted to IPv4

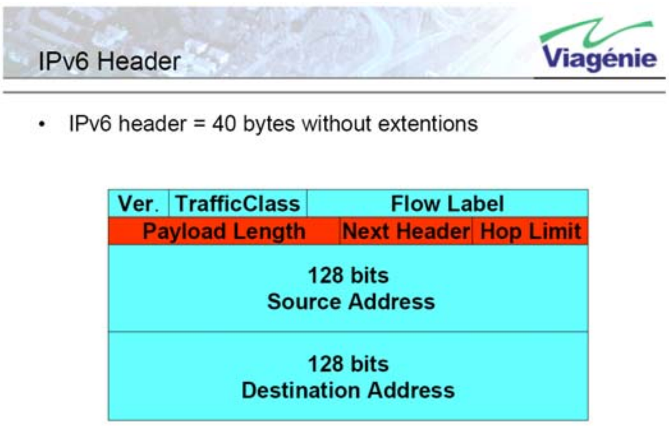
- Example: DHCP
- Other functions such as quality of service, mobility, security are now supported equally well by IPv6 and IPv4.
- Example: can you do stateless address allocation in IPv4 as in IPv6 ?
  Q. Explain how you would do it using private IP addresses instead of link local unicast address.
  A. 1. when booting, host uses 192.168.x.y where x and y are drawn at random. An ARP packet is broadcast to resolve this address to check if it is use. If not, host keeps this address.

  However, this works only for hosts on the same LAN, and the address obtained in this way is private, so we need for example a Network Address Translator between this host and the rest of the internet. So we have an example where IPv6 brings more (the IPv6 address allocated in this way is globally unique and is valid worldwide).

back

IPv6 Packet Format





23

Next Header Field

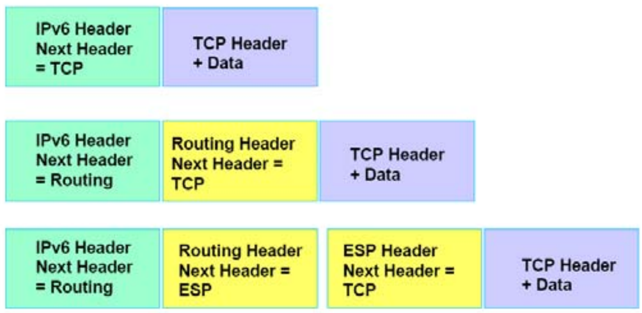
Viagénie

- Next Header (8 bits)
  - ~= Protocol field in IPv4
  - Used to identify the encapsulated protocol
    - TCP, UDP
    - ESP, AH (confidentiality and authentication in IPsec)
    - ICMPv6
    - Other extensions

Extension Headers

Viagénie

- New way of doing options
- Added after the basic IPv6 header
- Daisy chained



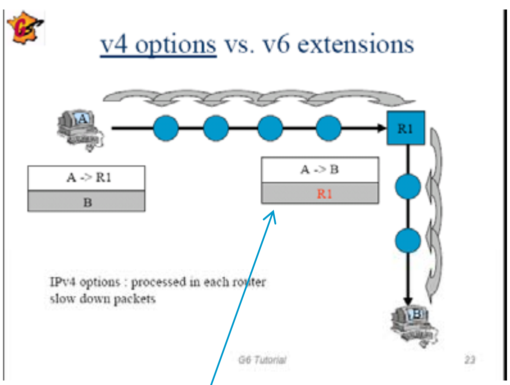
24

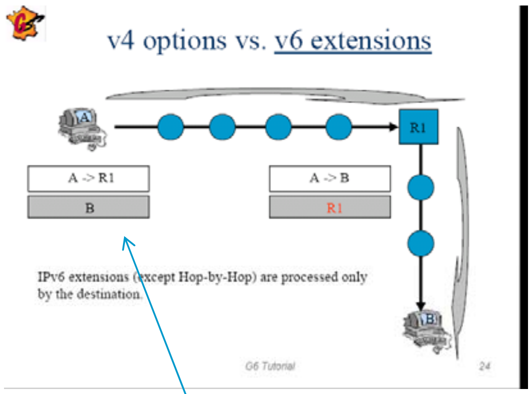
Routing Header

- Source Routing
  - Go through this list of routers: A, B, C, D
  - List is included in the routing header
  - Destination address is always the next router in the list, up to the last one where the destination address is the destination node
  - Destination address is changed on every router in the list
- Simpler use:
  - MobileIPv6: Care-of-Address is the "next router" and Home-Address is the final destination

25

IPv6 Extensions Avoid Unnecessary Router Processing





The IPv4 way

The IPv6 way

26

Is There a TCPv6 ?

- No, TCP remains unchanged
  - But TCP code must be modified
  - A program that uses TCP or UDP socket must be modified
    - the IP address format is different
- Is there Ethernetv6 or WiFiv6 ?
  - No, Ethernet and IEEE 802.11 (and all layer 2 protocols) remain unaffected
  - Bridges need not be aware of IPv6
- ICMP, DNS must be modified
  - ICMPv6 is the version of ICMP that handles IPv6 error messages
  - DNS remains the same but handles new record formats
    - An « A » record maps a name to an IPv4 address
    - A « AAAA » maps a name to an IPv6 address

What are the Main Expected Benefits of IPv6 ?

- Larger address space means
  - growth of number of Internet hosts
  - 2^{128} = ca. 3.4 10^{38} addresses
  - There are ca. 10^{30} addresses per person on the planet
- Address aggregation becomes possible
  - Stop the explosion of routing table sizes in the backbone of the Internet and in BGP
- Permanent addresses for mobile nodes and for objects become possible

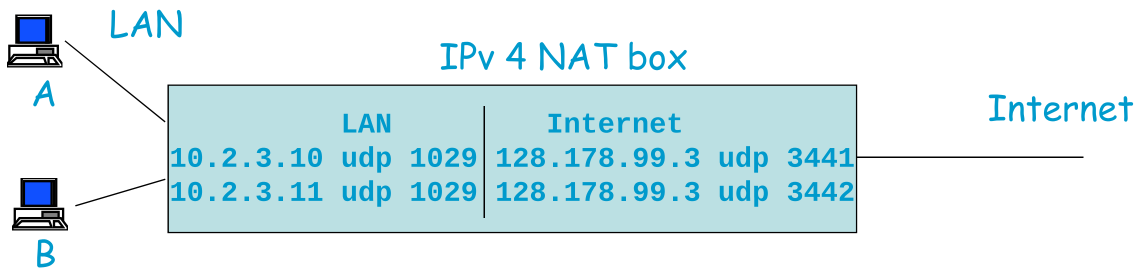
28

IPv6, Section 2

NATS

Network Address Translation

- Network Address Translation
  - an Internet standard that enables a local-area network (LAN) to use one set of IP addresses for internal traffic and a second set of addresses for external traffic.
  - A *NAT box* located where the LAN meets the Internet makes all necessary IP address translations.
- NAT box: a « router » that modifies the IP address
- Looks at UDP and TCP ports for packet forwarding
- There are many variants for how to do this in practice



30

NAT

- Q1: what fields are modified by a NAT in a packet (a) coming from the LAN side ? (b) from the WAN side ?

- Q2: compare the lookup function that a NAT performs with that of a standard router

solution

31

NAT

- Q1: what fields are modified by a NAT in a packet (a) coming from the LAN side ? (b) from the WAN side ?

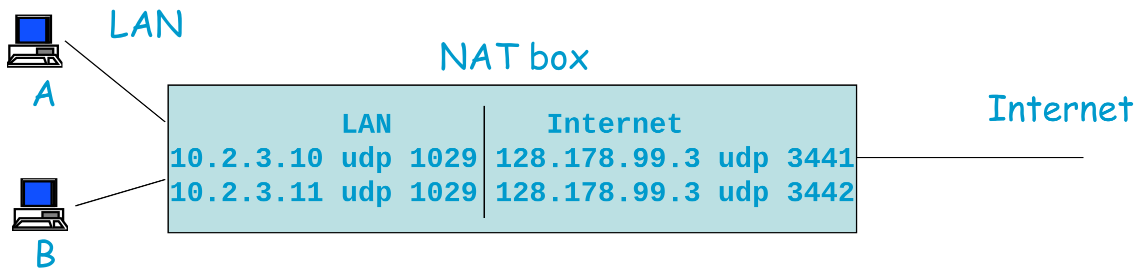
  A: (a) IP source address; source port number
  (b) IP destination address; dest port number

- Q2: compare the lookup function that a NAT performs with that of a standard router
  A: the NAT looks for an exact match for the field that it modifies and changes the value in the packet (this is also called “label swapping”). A router looks for longest prefix match and does not change the value in the packet.

back

Network Address Translation

- May change UDP, TCP ports and IP addresses
- Must translate ICMP messages ; must recompute UDP checksums
- Server ports on LAN side must be configured explicitly in NAT – this is why netmeeting does not work
- Is not fully transparent – it is a hack
- Used for
  - Using several IP addresses on one machine (ADSL box is a NAT box)
  - Control access to network (EPFL)
  - Extend IPv4 when there is not enough IP addresses for everyone
  - When end to end connectivity does not work natively at the network layer
    - Private addresses on LAN side
    - IPv6 versus IPv4



33

Limitations of NATs

- Needs to look inside the packets
  - ICMP, DNS must also be translated
- Not fully transparent
  - Cannot install server port behind NAT
  - This is why netmeeting does not work well
  - This is what made Skype sucessful
- Does not scale to very large networks
  - Exact match instead of longest prefix match
- Does not work in multi-homed networks

34

IPv6, Section 3

INTERWORKING IPV4/IPV6

A. What is the problem ?
B. Ingredients
C. Solutions for like to like
D. Solutions for interworking

Quiz

- Q. What is the greatest challenge (in communication systems) to come during B. Obama's term as President of the United States ?
- A. Migration to IPv6

36

A. Compatibility of IPv4 and IPv6

- IPv6 is *incompatible* with IPv6
  - Packet format is different – address size does not fit
  - Software is different – socket programs are different
    TCP code for IPv6 need to be different, DNS code etc. because they all contain data structures for IP addresses that are fixed size

    Q. How does a host know, when receiving a packet from Ethernet, whether it is an IPv4 or IPv6 packet ?
    solution

37

Compatibility of IPv4 and IPv6

- IPv6 is *incompatible* with IPv6
  - Packet format is different – address size does not fit
  - Software is different – socket programs are different

    TCP code for IPv6 need to be different, DNS code etc. because they all contain data structures for IP addresses that are fixed size

    Q. How does a host know, when receiving a packet from Ethernet, whether it is an IPv4 or IPv6 packet ?

    A. The protocol type in the Ethernet header is different

back

Deployment of IPv6

- IPv6 is implemented in Unix, Windows, Cisco but… is not deployed. Why ?
  Q. Give possible explanations.

solution

39

Deployment of IPv6

- IPv6 is implemented in Unix, Windows, Cisco but… is not deployed. Why ?
  Q. Give possible explanations.
  A.
  1. IPv6 is incompatible, so a smooth deployment is not easy. If I install IPv6 in my PC and remove IPv4, I cannot access the existing base of IPv4 services.
  2. Address space exhaustion is not critical in the US, which is the main source of product development. This is because many networks use network address translation or HTTP proxies that allow one to use private addresses for hosts.
  3. The benefit of introducing IPv6 is for others (those who do not have enough addresses). There is no incentive for a company to move to IPv6 (but there are many associated costs).

  So the move to IPv6 is likely to occur under pressure of serious problems – it is like moving to green power sources…

back

What is the problem ?

- IPv6 is a new, incompatible version of IPv4
- Transition to IPv6 will occur
  - A complex and painful process
- An experimental IPv6 Internet existed parallel to the commercial Internet; called the "6bone"
  - Used addresses 3FFE/16
  - Now extinct
- The IPv6 Internet uses addresses 2001/16
  - Assumed to be globally fully connected
  - Exists parallel to, and connected to, IPv4 internet,
- We will review the main mechanisms
  - The scenarios are multiple, there are several solutions to the same problem

41

What Needs to Be Solved

- **like to like access**
  - 6 to 6 over IPv4 infrastructure
    - IPv6 host at EPFL connects to IPv6 server on US DoD
  - 4 to 4 over IPv6
- **interworking:** allow IPv6 only hosts and IPv4 only hosts to communicate
  - example: IPv6 PC connects to an IPv4 web server

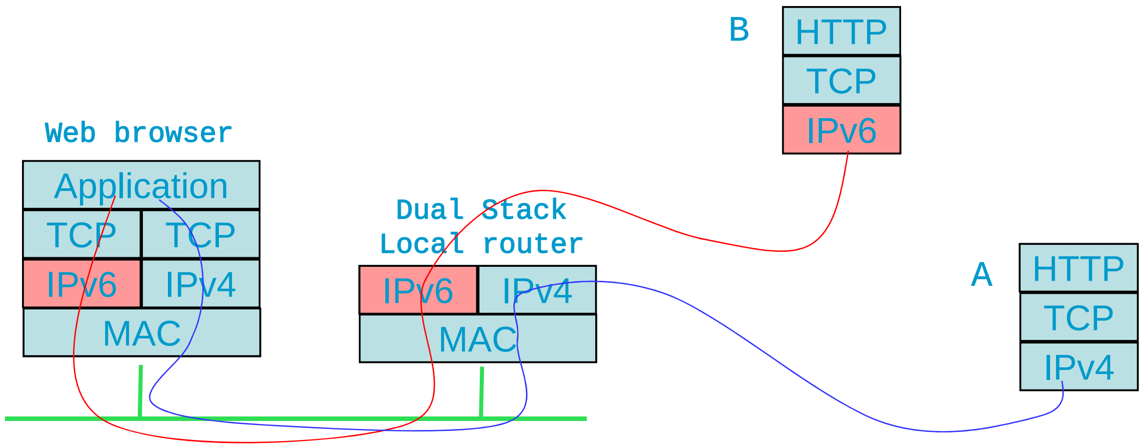
B. Ingredients for Transition

- Dual Stack
  - hosts
  - application layer gateways
  - routers
- Tunneling
  - Configured
- 6to4 addresses
- 6to4 relay routers
- NAT Boxes

43

Dual Stack Host

- A dual stack host implement both IPv4 and IPv6; it is configured with both an IPv4 address and an IPv6 address

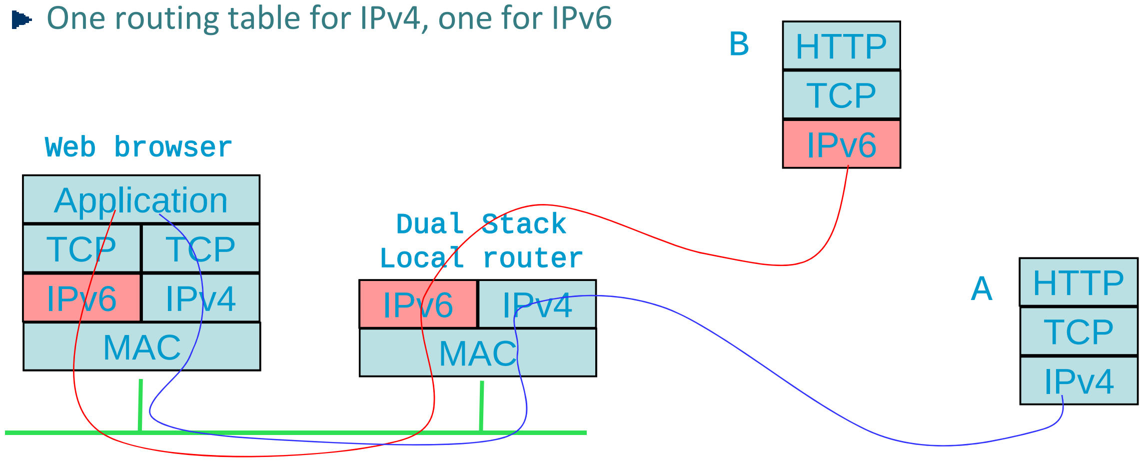


- Uses DNS to know whether to use IPv4 or IPv6 send packets
  - **hostname2addr(AF_INET6,** *hostName***)** returns IPv6 address (read from AAAA record) if available, else IPv4 *mapped* address read from A record

44

Dual Stack Router

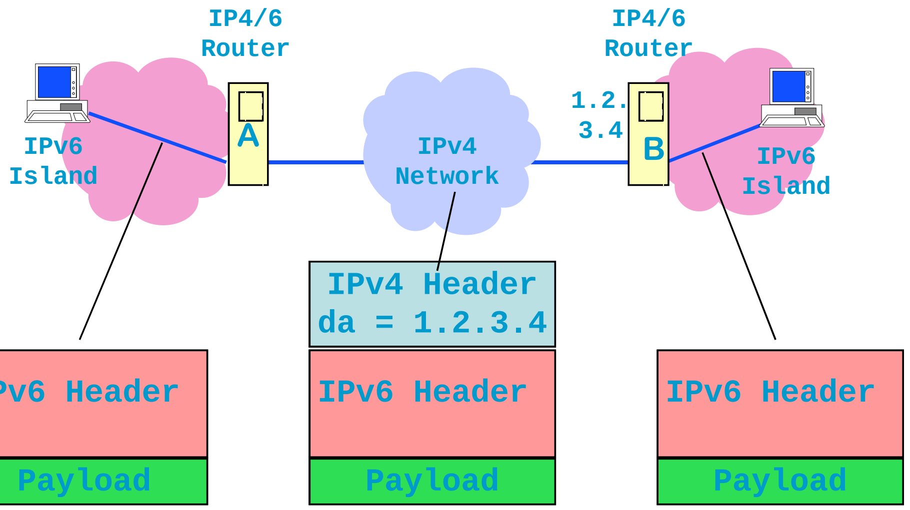
- A dual stack router implements both IPv4 and IPv6
- It becomes a "multiprotocol router"
  - One routing table for IPv4, one for IPv6



45

Tunneling

- Definition: carry an IP packet as payload inside an IP packet
  - IPv6 in IPv4 packets (and vice –versa)
  - In an IPV4 packet, Protocol = 41 means the payload is an IPv6 packet
- In principle, a tunnel needs to be *configured,*
  - the encapsulator must be configured with the IPv4 address of the decapsulator
  - Works only for isolated cases



46

6to4 Addresses

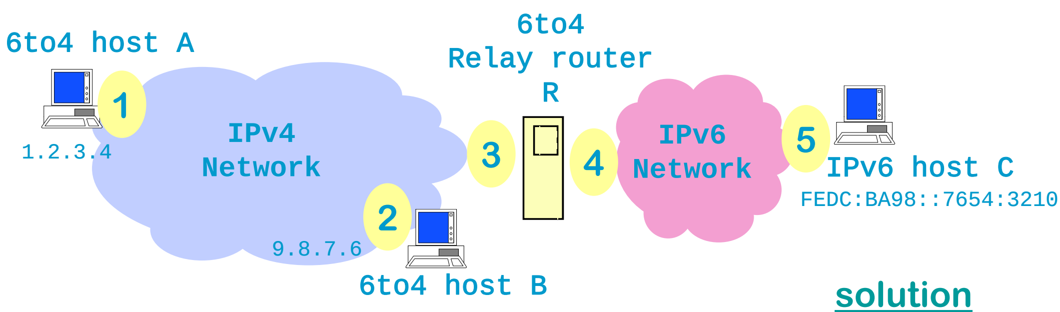
- Introduced to support *automatic* tunnels, i.e. without configuration of encapsulator/decapsulator pairs
- Definition: *6to4 address*
  - To any valid IPv4 address *n* we associate the IPv6 prefix
    2002:n / 48

    example: the 6to4 address prefix that corresponds to

    128.178.156.38
    is
    2002: 80b2:9c26

  - An IPv6 address that starts with 2002:... is called a 6to4 address
  - The bits 17 to 48 of a 6to4 address are the corresponding IPv4 address
  - 2002::/16 is the prefix reserved for 6to4 addresses
- A 6to4 host or router is one that is dual stack and uses 6to4 as IPv6 address
- In addition, the IPv4 address 192.88.99.1 is reserved for use in the context of 6to4 addresses (see next slides)

Example of Use: Isolated 6to4 Hosts



solution

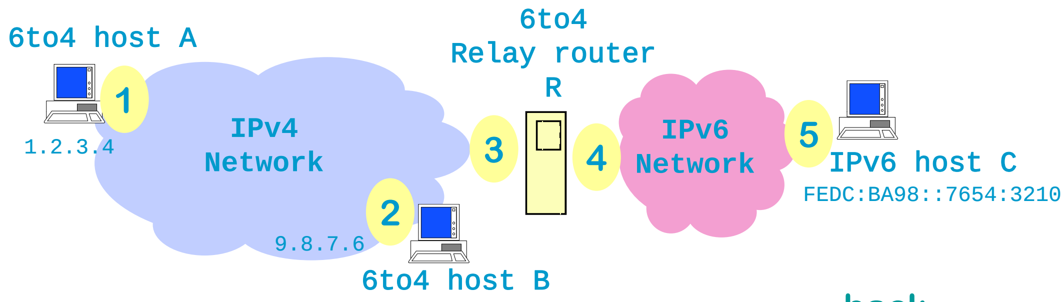
- A's IPv4 address is 1.2.3.4; its IPv6 address may be 2002:0102:0304:0:EUI_A where EUI is A's 64-bit MAC address
- B's IPv4 address is 9.8.7.6; its IPv6 address may be 2002:0908:0706:0:EUI_B where EUI is B's 64-bit MAC address

A sends packet to B's 6to4 address

- Dest addr is 6to4, therefore A encapsulates, with decapsulator's IPv4 address = that of B
- Packet sent at 1 has
  IPv4 source = ______; IPv4 dest = ______; protocol = ___
  IPv6 source = ______________ IPv6 dest =__________________

48

Example of Use: Isolated 6to4 Hosts



back

- A's IPv4 address is 1.2.3.4; its IPv6 address is 2002:0102:0304:0:EUI_A where EUI is A's 64-bit MAC address
- B's IPv4 address is 9.8.7.6; its IPv6 address is 2002:0908:0706:0:EUI_B where EUI is B's 64-bit MAC address

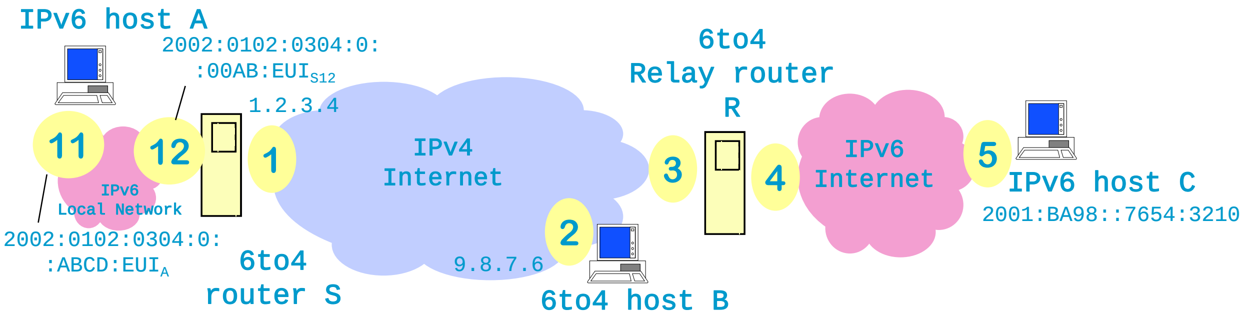
A sends packet to B's 6to4 address

- Dest addr is 6to4, therefore A encapsulates, with decapsulator's IPv4 address = that of B
- Packet sent at 1 has
  IPv4 source = 1.2.3.4; IPv4 dest = 9.8.7.6; protocol = IPv6
  IPv6 source = 2002:0102:0304:0:EUI_A IPv6 dest =2002:0908:0706:0:EUI_B

49

6to4 Addresses Simplify IPv6 Address Allocation

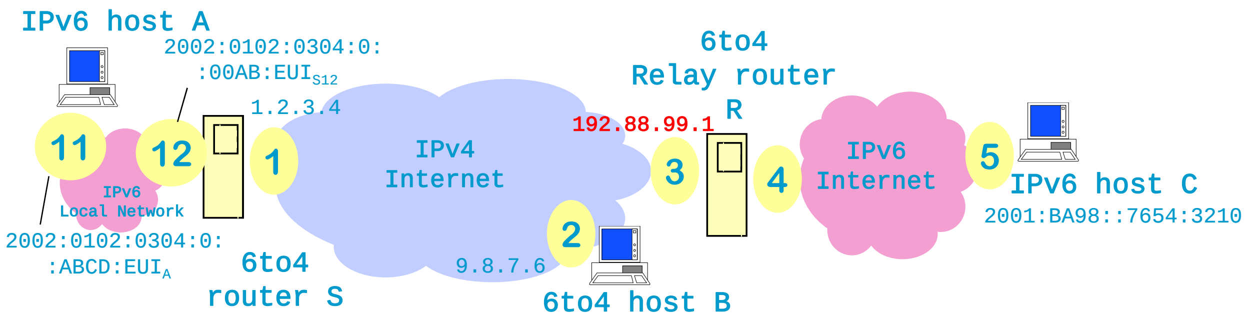
- Normally, an IPv6 address is
  - Provider allocated prefix + subnet + host part
- If your network is connected to the IPv6 Internet, you receive a provider allocated prefix
- Else, you use the 6to4 address of an IPv4 address given to you by your IPv4 provider



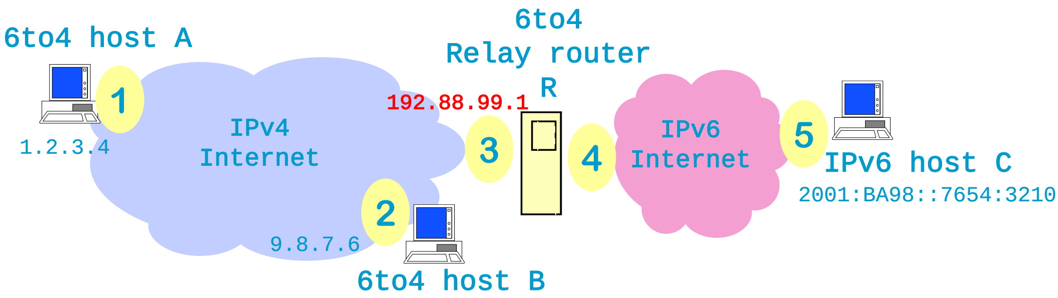
50

6to4 Relay Router and the 192.88.99.1 Anycast Address

- R is a "6to4 relay router": has 6to4 interfaces and is both on the IPv4 and IPv6 internets
- All of R's interfaces on the IPv4 internet have an IPv4 address plus the address 192.88.99.1
- This is a reserved *anycast* address.
  - It is a normal IPv4 address, but there can be several machines with this same address, as there are several relay routers on the Internet.
  - This does not matter: routing protocols continue to work even if we inject the same address at different points – it happens all the time with addresses learnt by BGP.



C. Like to Like Solutions

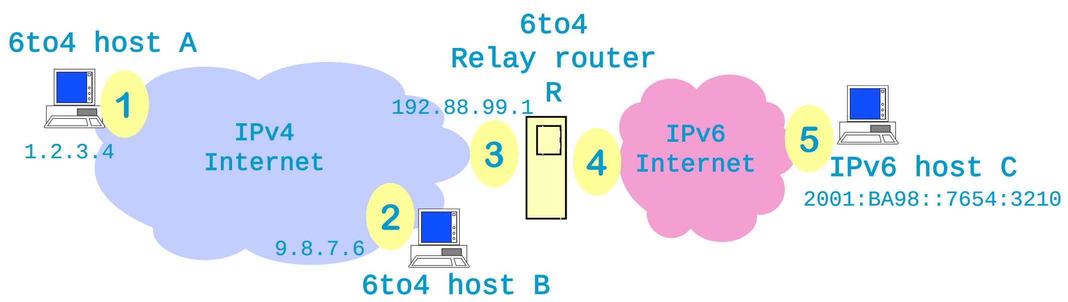


A sends IPv6 packet to C

- C's IPv6 address does not have same IPv6 prefix as A ("destination not on link"), so A sends to a router
- R is a "6to4" relay router
- A's default IPv6 router entry is R; more precisely, it is 2002:c058:6301::0, which is a 6to4 address corresponding to 192.88.99.1
- A builds an automatic tunnel with decapsulator = R

52

Like to Like Solutions: Packet Headers



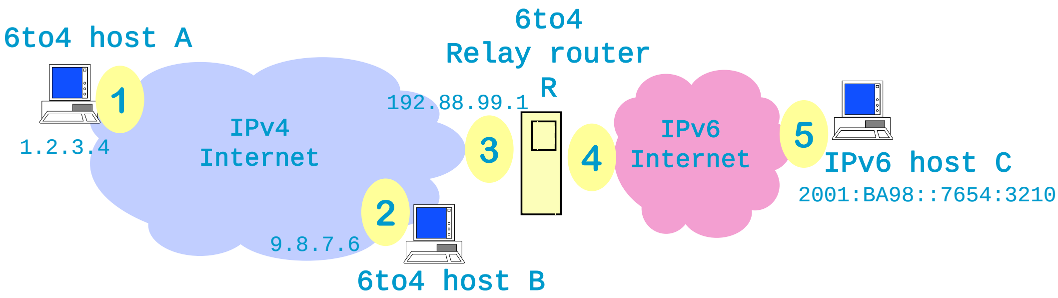
- At R, the packet is decapsulated and transported to 3 without encapsulation. At 3:

  IPv6 source addr = ?   IPv6 dest addr = ?

- Which prefix should R injects into the IPv6 internet?

53

Like to Like Solutions: Packet Headers



- At R, the packet is decapsulated and transported to 3 without encapsulation. At 3:

  IPv6 source = ?

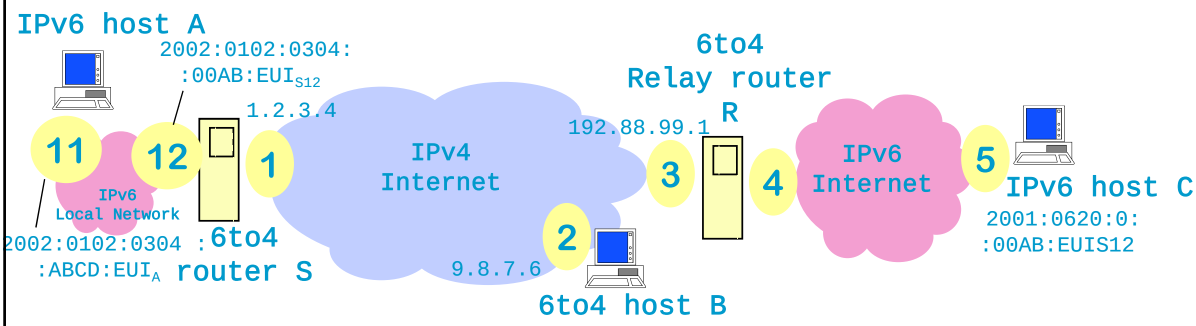
- IPv6 source = 2002:0102:0304:0:EUI$_A$
  IPv6 dest =2001:BA98::7654:3210

- Which prefix should R injects into the IPv6 internet?

  Sol: 2002/16

54

IPv6 Local Network



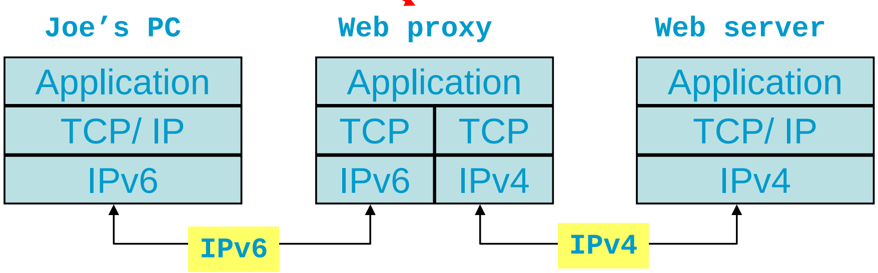
- A has packet to send to C
  - Destination not on link, send to router in local IPv6 router
  - Default IPv6 route inside local IPv6 network is 2002:0102:0304::, i.e. the 6to4 address of interface 1 of router S
  - S builds a tunnel with decapsulator = relay router R

  Rest as before, i.e.
  - S's default IPv6 router entry is R; more precisely, it is 2002:c058:6301::0, which is a 6to4 address corresponding to 192.88.99.1

55

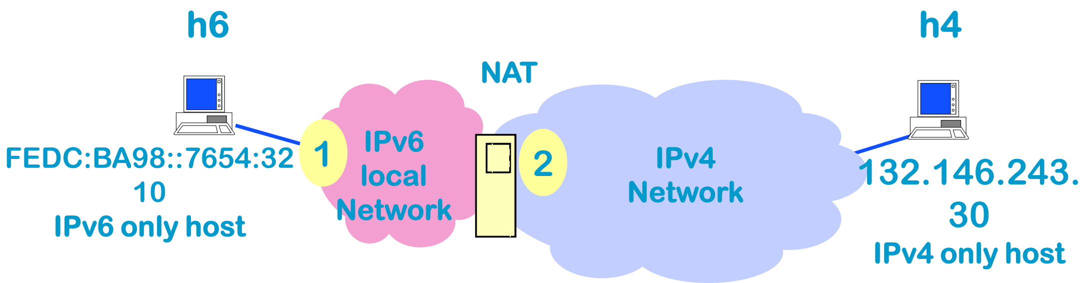
D. Interworking
Dual Stack Application Layer Gateway

- A dual stack Application Layer gateway implements both IPv4 and IPv6; it is configured with an IPv4 address and an IPv6 address



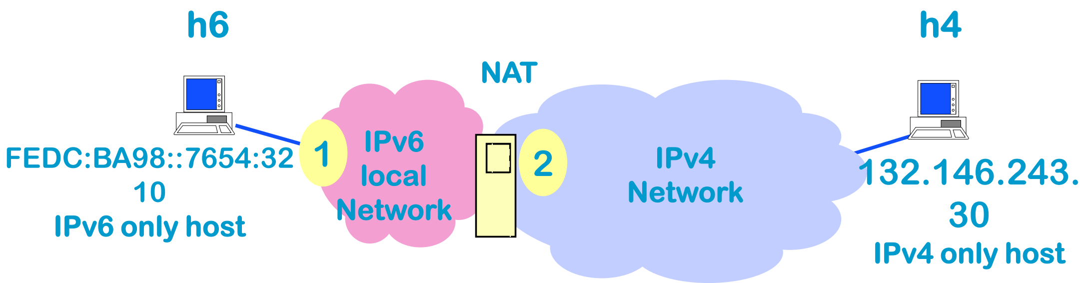
56

IPv6/IPv4 Interworking without Application Layer Gateway



- NAT *translates* an IPv4 packet into an IPv6 packet and vice-versa; no encapsulation
- Example
  - NAT owns address pool 120.130.26/24
  - NAT owns IPv6 prefix called PREFIX
  - h6 issues a packet to h4
    - IPv6 Addresses at 1 and 2 ?
- Q: what are the addresses at 1 and 2 for return packet from h4 to h6 ? Solution
- Port translation can be used also (as in any NAT) to save number of IPv4 addresses

NAT-PT for IPv6/IPv4 interworking



- h6 issues a packet to h4
  - At 1: SA=FEDC:BA98::7654:3210 DA=PREFIX::132.146.243.30
  - NAT translates IPv6 header to IPv4; allocates 120.130.26.10 to h6
    at 2: SA=120.130.26.10 DA=132.146.243.30
- Q: what are the addresses at 1 and 2 for return packet from h4 to h6 ?

A: at 1 SA=132.146.243.30 DA=120.130.26.10
at 2 SA=PREFIX:: 132.146.243.30 DA=FEDC:BA98::7654:3210

back

Limitations of NAT solutions

- Requires DNS interworking
  - NAT needs to intercept DNS queries
- Is not transparent to all applications
  - NAT must know where IP addresses are used by applications and modify them (as with ftp)

59

IPv6 Section 4

ROUTING IMPLICATIONS

60

Ships in the Night

- There is an IPv4 Internet and an IPv6 internet
- But…
  most routers will become dual stack IPv4/IPv6

  i.e. the IPv4 Internet and IPv6 Internet share much of the same infrastructure

- Common practice is to separate the routing processes ("ships in the night")
  - One routing protocol and routing process for IPv4 (e.g. OSPFv2) and one for IPv6 (e.g. OSPFv3)
  - An integrated protocol is possible (IS-IS) but is considerd risky

Avoid Injecting IPv4 Routes into IPv6

- Q: give an example where IPv4 addresses could be injected into the IPv6 internet.
  -
- Q: is this not the same as separating the routing processes ?
  -

62

Avoid Injecting IPv4 Routes into IPv6

- Q: give an example where IPv4 addresses could be injected into the IPv6 internet.
  - A: 6to4 addresses are valid IPv6 addresses derived from valid IPv4 addresses. A 6to4 relay router could either inject for example 2002: 80b2:9c26/48 or only 2002/16. In the former case, IPv4 addresses are injected into the IPv6 internet. This should be avoided.

- Q: is this not the same as separating the routing processes ?
  - A: no. Injection means that IPv6 routing tables contain information that comes from the IPv4 internet.

- Current practice is to avoid injecting IPv4 routes into IPv6 in order to keep the benefits of aggregation in IPv6 (keep IPv6 routing tables small)

IPv6 Section 5

RECAP

Recap 1

Problem	*Solution*
Like to like - IPv6 host to IPv6 host over IPv4 internet	- Tunnels - Automatic tunnels with 6to4 hosts / routers
Interworking - IPv6 host to IPv4 host	- Application layer gateway - NAT

65

Recap 2

Scenario

1. DoD runs only IPv6 servers; you need to upload a document from your PC
2. You are an ISP and provide IPv6 only addresses to some customers. They want access to the IPv4 internet

Possible Solution

1. Run IPv6 on your PC with 6to4 addresses
2. You must have access to both the IPv4 and IPv6 internets. Use NATs or application layer gateways at the boundary between your v4 and v6 networks

66

Explain the addresses here

```
C:\Users\leboudec\desktop> ipconfig
Windows IP Configuration
Ethernet adapter Local Area Connection:

   Connection-specific DNS Suffix  . : epfl.ch
   Link-local IPv6 Address . . . . . : fe80::c59e:2837:b9cc:6f7e%12
   IPv4 Address. . . . . . . . . . . : 128.178.151.101
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : 128.178.151.1

Tunnel adapter Local Area Connection* 11:

   Connection-specific DNS Suffix  . : epfl.ch
   IPv6 Address. . . . . . . . . . . : 2002:80b2:9765::80b2:9765
   Default Gateway . . . . . . . . . : 2002:c058:6301::c058:6301
```

Explain the addresses here

```
C:\Users\leboudec\desktop> ipconfig
Windows IP Configuration
Ethernet adapter Local Area Connection:

   Connection-specific DNS Suffix  . : epfl.ch
   Link-local IPv6 Address . . . . . : fe80::c59e:2837:b9cc:6f7e%12
   IPv4 Address. . . . . . . . . . . : 128.178.151.101
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : 128.178.151.1

Tunnel adapter Local Area Connection* 11:

   Connection-specific DNS Suffix  . : epfl.ch
   IPv6 Address. . . . . . . . . . . : 2002:80b2:9765::80b2:9765
   Default Gateway . . . . . . . . . : 2002:c058:6301::c058:6301
```

Link local address

6to4 address derived from IPv4 address 128.178.151.101

6to4 address derived from IPv4 address 192.88.99.1

Q: can this host connect to Internetv6 ?

68

Q: can this host connect to Internetv6 ?

A: yes.

```
C:\> tracert 192.88.99.1

Tracing route to 192.88.99.1 over a maximum of 30 hops
  1    <1 ms    <1 ms    <1 ms  cv-ic-dit-v151.epfl.ch [128.178.151.251]
  2    <1 ms    <1 ms    <1 ms  c6-gigado-1-v100.epfl.ch [128.178.100.18]
  3    <1 ms    <1 ms    <1 ms  c6-ext-v200.epfl.ch [128.178.200.1]
  4     1 ms    <1 ms    <1 ms  swiel2.epfl.ch [192.33.209.33]
  5    <1 ms    <1 ms    <1 ms  swils2-10ge-1-2.switch.ch [130.59.36.69]
  6     2 ms     2 ms     2 ms  swiBE1-10GE-1-1.switch.ch [130.59.37.130]
  7     2 ms     2 ms     2 ms  swibe2-10ge-1-4.switch.ch [130.59.36.198]
  8     2 ms     2 ms     2 ms  192.88.99.1
```

Problems solved by Interworking at Application Layer

- **Q.** Review the problems posed by the deployment of IPv6 and discuss whether this dual stack approach solves them.

Problems solved by Interworking at Application Layer

- **Q.** Review the problems posed by the deployment of IPv6 and discuss whether this dual stack approach solves them.

  A. 1. PCs deployed with only IPv6 addresses (IPv4 address exhaustion). They can access the IPv6 services directly. For services provided by IPv4 servers, they have no access, except if the server is dual stack. This is OK for email, as the PC connects to its local server, which we assume runs both IPv6 and IPv4. In contrast, web access requires something else: web proxies that run both IPv6 and IPv4.

  2. This solution does not solve the problem of interconnecting IPv6 devices over a network of IPv4 only routers, and vice-versa.

Conclusions

- IPv6 is IP with a larger address space
- Is incompatible with IPv6
- Co-existence with IPv4 will involve
  - Dual stack gateways or NATs for interworking
  - Tunnels, 6to4 addresses and 6to4 routers for like to like

72

To Know More

- IETF (www.ietf.org) working group “v6ops”
- http://www.6diss.org/