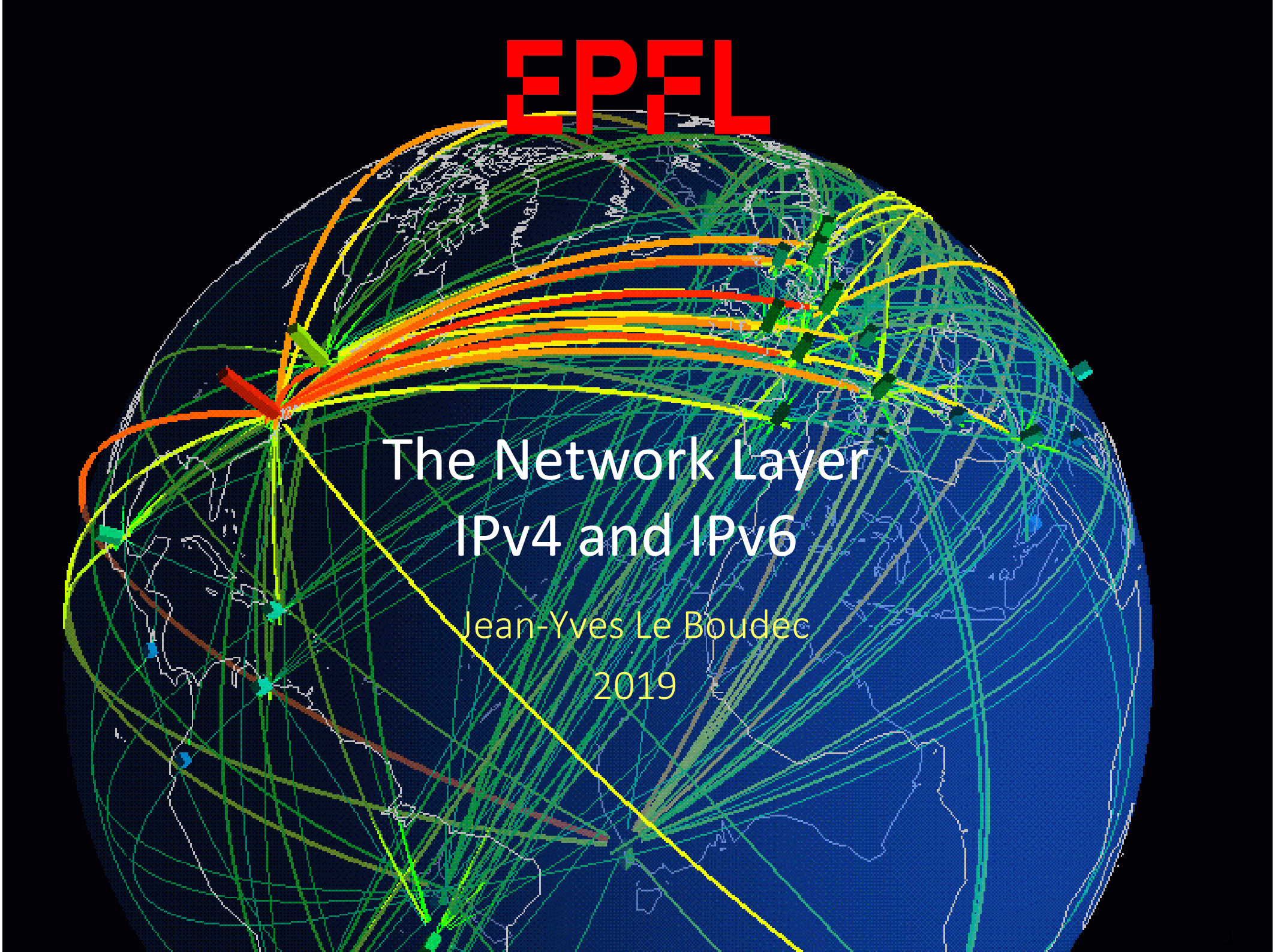


The Network Layer
IPv4 and IPv6

Jean-Yves Le Boudec

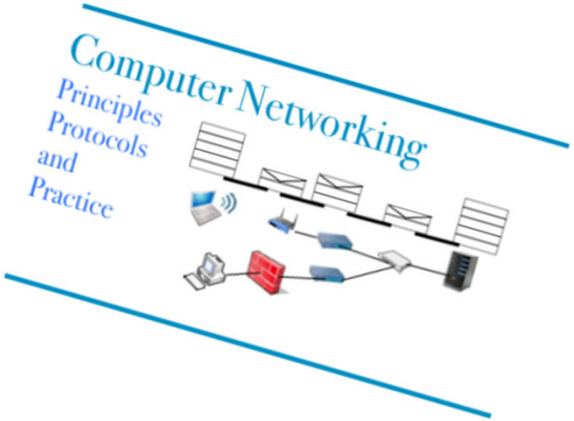
2019

Contents

1. The Two Principles of IP Unicast
2. IPv4 addresses
3. IPv6 addresses
4. NATs
5. Subnets and Masks
6. ARP
7. Host configuration
8. IP packet format, HL and TTL

Textbook

Chapter 5: The Network Layer

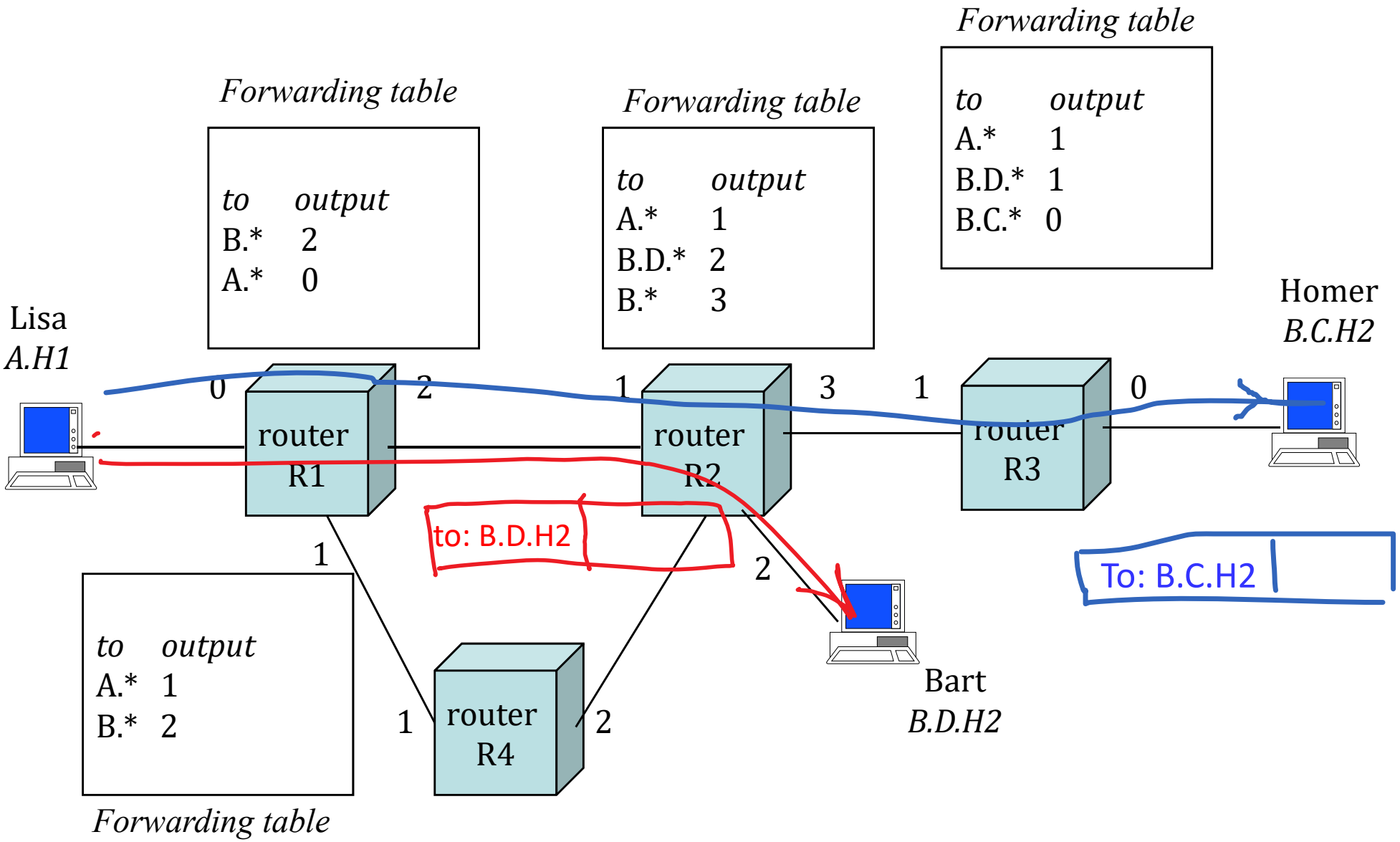


IP Principle #1 = Structured addresses + Longest prefix match

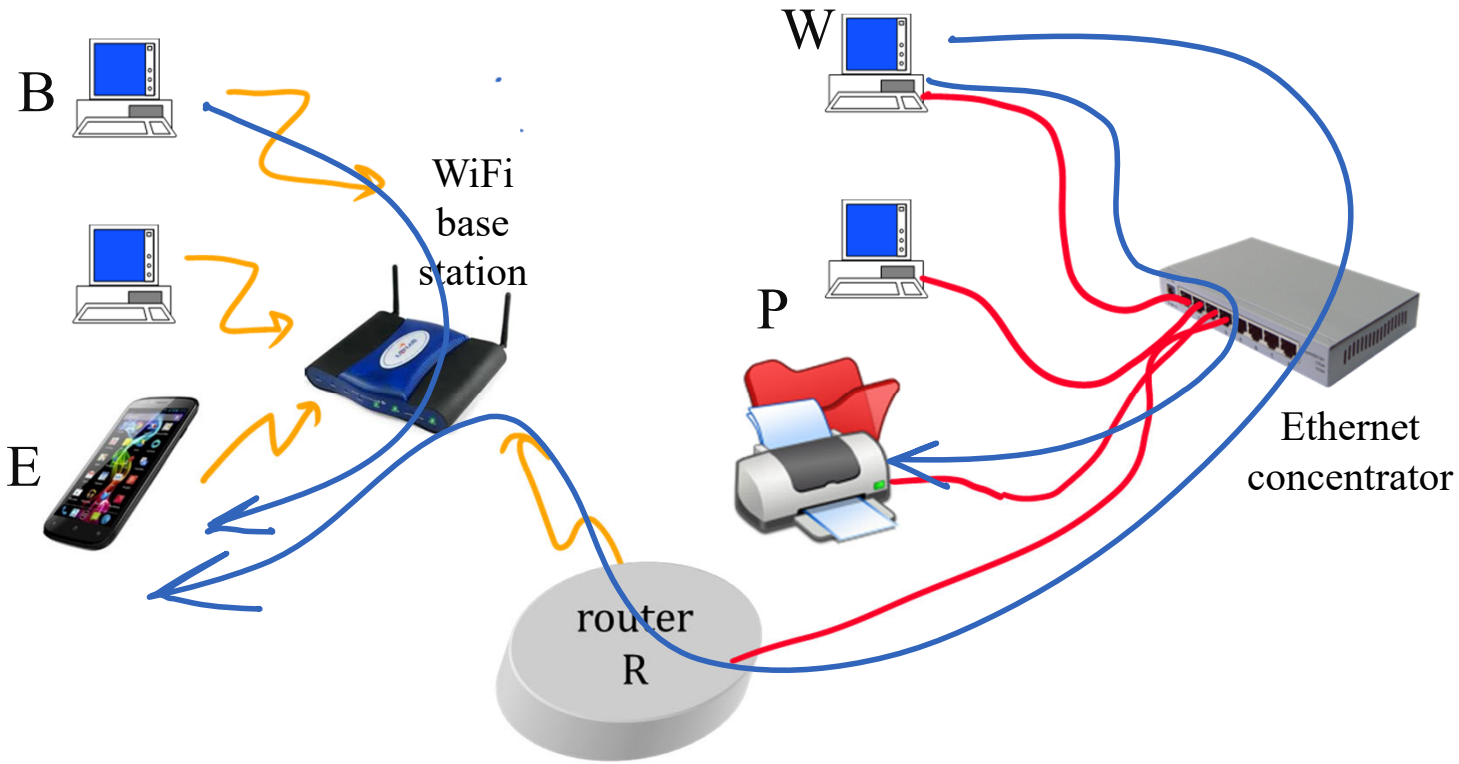
Recall goal of Internet Protocol (IP) = interconnect all systems in the world

Principle #1:

- every interface has an IP address
- IP address is structured to reflect where the system is in the world
- every packet contains IP address of destination
- every system has a forwarding table (= routing table) and performs longest prefix match on destination address


Forwarding table
to output
A.* 1
B.D.* 1
B.C.* 0
Forwarding table
to output
A.* 1
B.D.* 2
B.* 3
Forwarding table
to output
B.* 2
A.* 0
Lisa
A.H1
Homer
B.C.H2
router R1
router R2
router R3
router R4
0
2
1
3
1
0
1
2
1
2
to: B.D.H2
To: B.C.H2
Bart
B.D.H2
Forwarding table
to output
A.* 1
B.* 2

IP Principle #2 = Don’t use routers inside a LAN



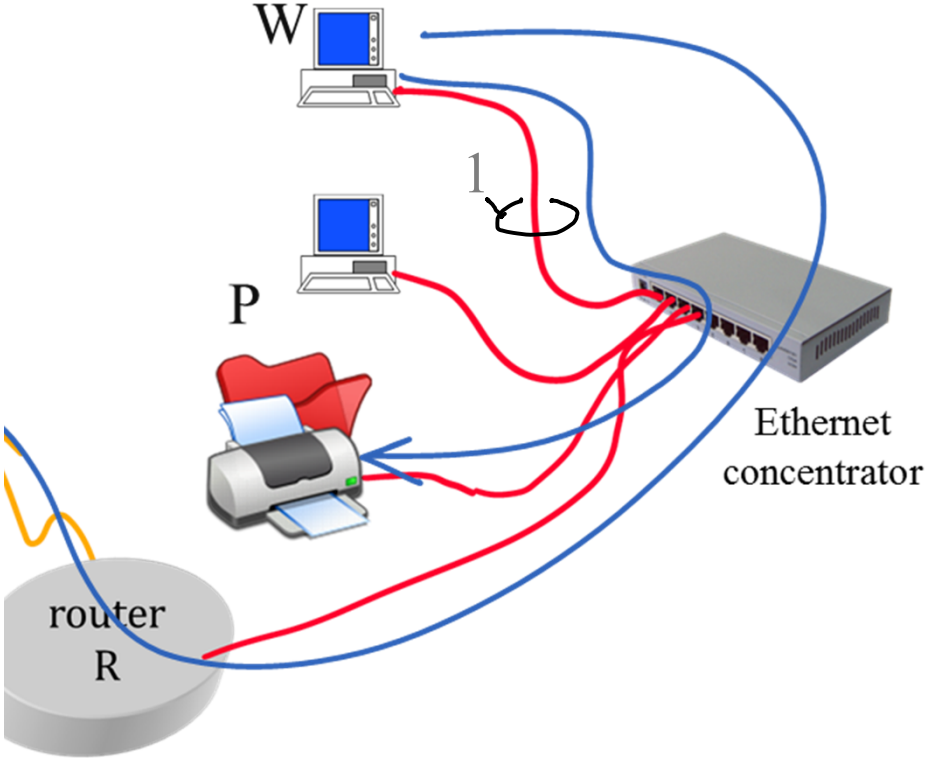
B ↔ E and W↔P should not go through router

W ↔ E goes through router

Terminology: LAN = *subnet*

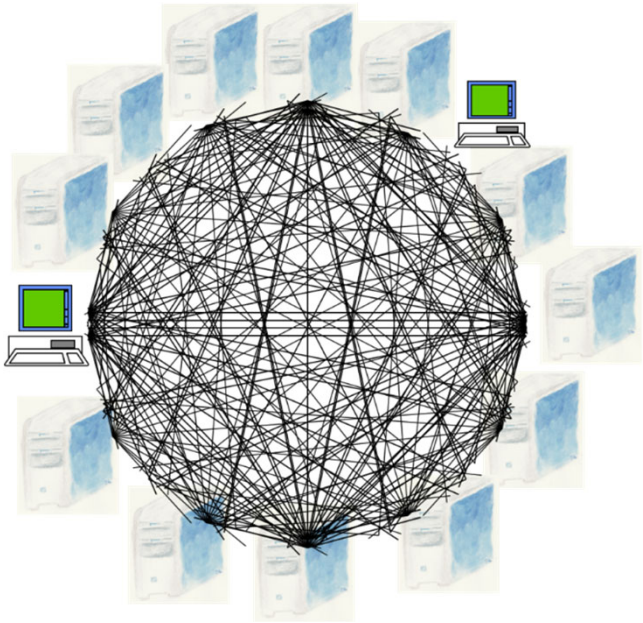
IP principle 2 says: between subnets use routers, inside subnet don’t

We observe a packet from W to P at 1. Which IP destination address do we see ?



A. The IP address of P
B. The IP address of an Ethernet interface of the Ethernet concentrator
C. There is no destination IP address in the packet since communication is inside the subnet and does not go through a router
D. I don't know

The Internet Protocol (IP)



Communication between IP hosts requires knowledge of IP addresses

An IP address is unique across the whole network (= the world in general)

An IP address is the address of an interface

There are two versions:

IPv4 (old version) and IPv6 (current version)

Terminology:

packet = IP data unit

intermediate system = system that forwards data units to another system; an IP intermediate system is called a "router"

an IP system that does not forward is called a "host"

2. IPv4 addresses

IPv4 address

Uniquely identifies one interface in the world (in principle)

An IPv4 address is 32 bits, usually noted in dotted decimal notation

dotted decimal: 4 integers (one integer = 8 bits)

example 1: `128.191.151.1`

example 2: `129.192.152.2`

hexadecimal: 8 hexa digits (one hexa digit = 4 bits)

example 1: `x80 bf 97 01`

example 2: `x81 c0 98 02`

binary: 32 bits

example 1: `b1000 0000 1011 1111 1001 0111 0000 0001`

example 2: `b1000 0001 1100 0000 1001 1000 0000 0010`

Binary, Decimal and Hexadecimal

Given an integer B “the basis”: any integer can be represented in “base B” by means of an alphabet of B symbols

Usual cases are

decimal: 234

binary: 1110 1010

hexadecimal: ea

Mapping binary <-> hexa is simple: one hexa digit is 4 binary digits

$e_{hex} = 1110_{bin}$ $a_{hex} = 1010_{bin}$ ea_{hex} = b1110 1010_{bin}

Mapping binary <-> decimal is best done by a calculator

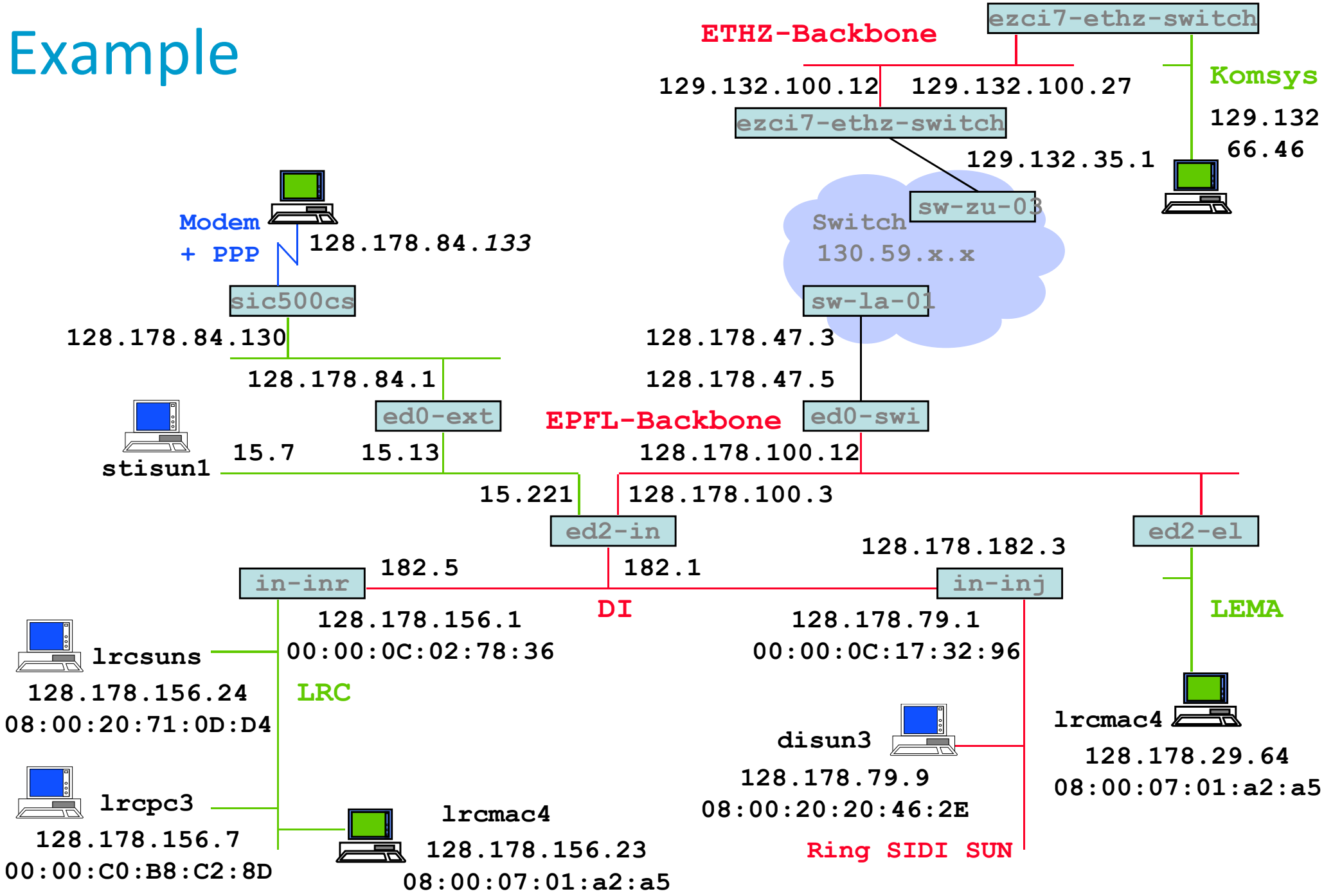
1110 1010_{bin} = 128 + 64 + 32 + 8 + 2 = 234

Special Cases to remember

$f_{hex} = 1111_{bin} = 15$

$ff_{hex} = 11111111_{bin} = 255$

Example

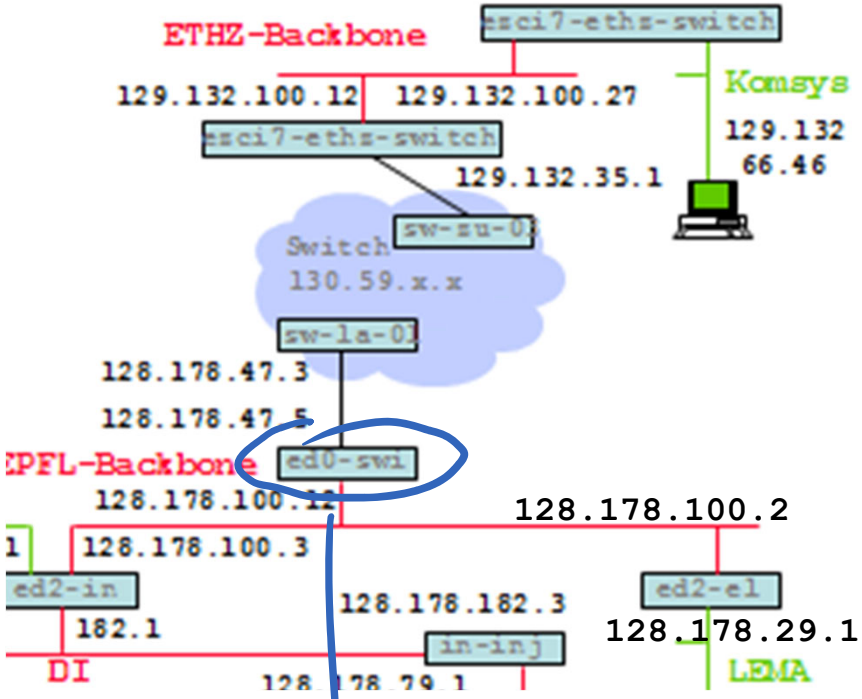

ezci7-ethz-switch
ETHZ-Backbone
129.132.100.12
129.132.100.27
Komsys
129.132
66.46
ezci7-ethz-switch
129.132.35.1
sw-zu-03
Switch
130.59.x.x
Modem
+ PPP
128.178.84.133
sic500cs
128.178.84.130
128.178.84.1
sw-la-01
128.178.47.3
128.178.47.5
ed0-ext
ed0-swi
EPFL-Backbone
stisun1
15.7
15.13
128.178.100.12
15.221
128.178.100.3
ed2-in
ed2-el
128.178.182.3
182.5
182.1
in-inr
in-inj
DI
LEMA
128.178.156.1
00:00:0C:02:78:36
128.178.79.1
00:00:0C:17:32:96
lrcsuns
128.178.156.24
08:00:20:71:0D:D4
LRC
lrcmac4
128.178.29.64
08:00:07:01:a2:a5
disun3
128.178.79.9
08:00:20:20:46:2E
lrcpc3
128.178.156.7
00:00:C0:B8:C2:8D
lrcmac4
128.178.156.23
08:00:07:01:a2:a5
Ring SIDI SUN

Network Prefix

Network prefixes are used in routing tables

/24 is the prefix length in bits

0/0 means the default route



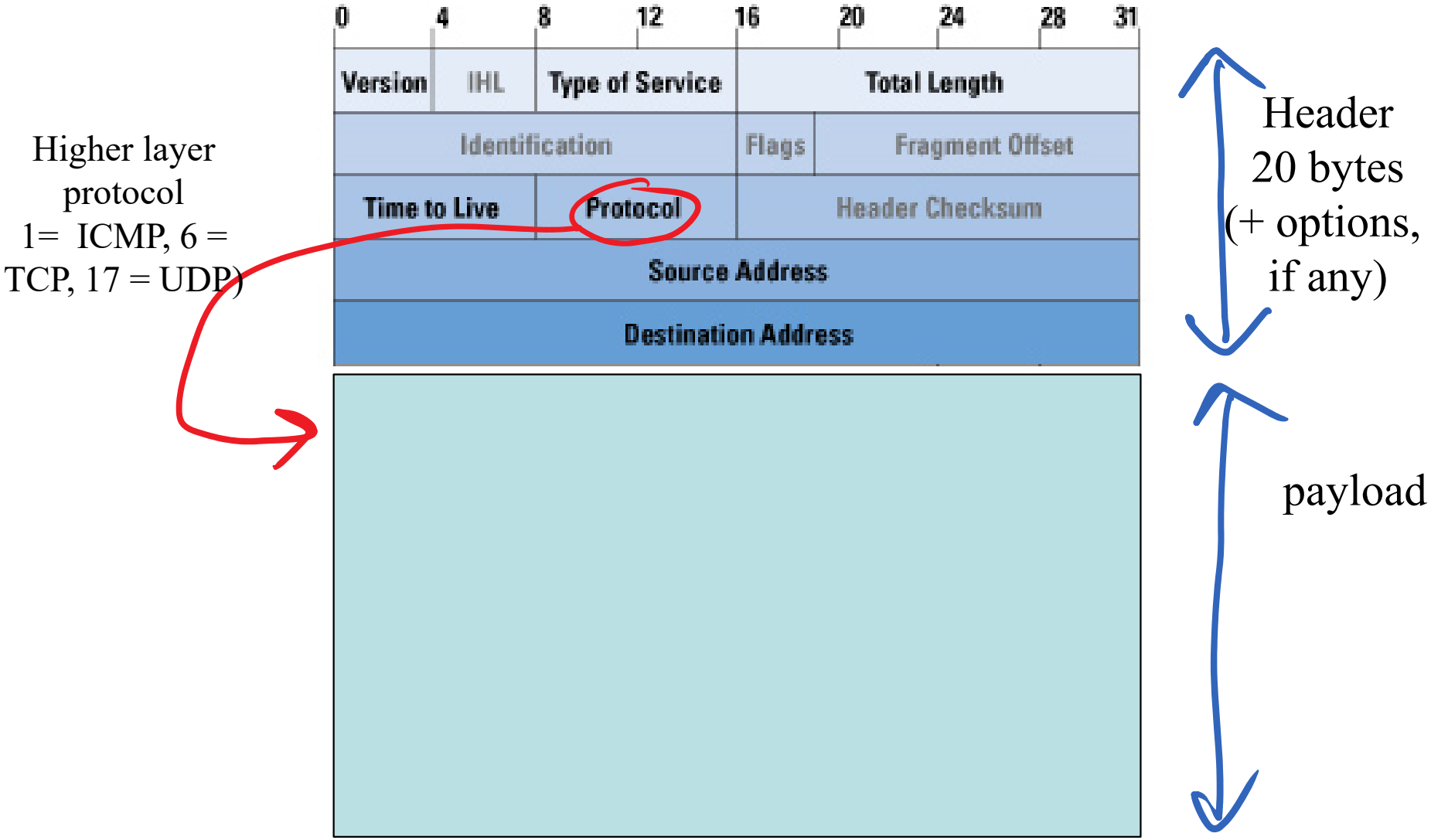
Extract from routing table at ed0-swi

Destination	Next hop
128.178.29/24	128.178.100.2
128.178/16	128.178.100.3
0/0	128.178.47.3

Special Addresses

0.0.0.0	absence of address
127.0.0/24 for example 127.0.0.1	this host (loopback address)
10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16	private networks (e.g in IEW) cannot be used on the public Internet
169.254.0.0/16	link local address (can be used only between systems on same LAN)
224/4	multicast
240/5	reserved
255.255.255.255/32	link local broadcast

IPv4 Packet Format



3. IPv6 Addresses

The old version of IP is IPv4. IPv6 is the current (and final) version of IP

Why a new version ?

IPv4 address space is too small (32 bits $\rightarrow \approx 4 \cdot 10^9$ addresses)

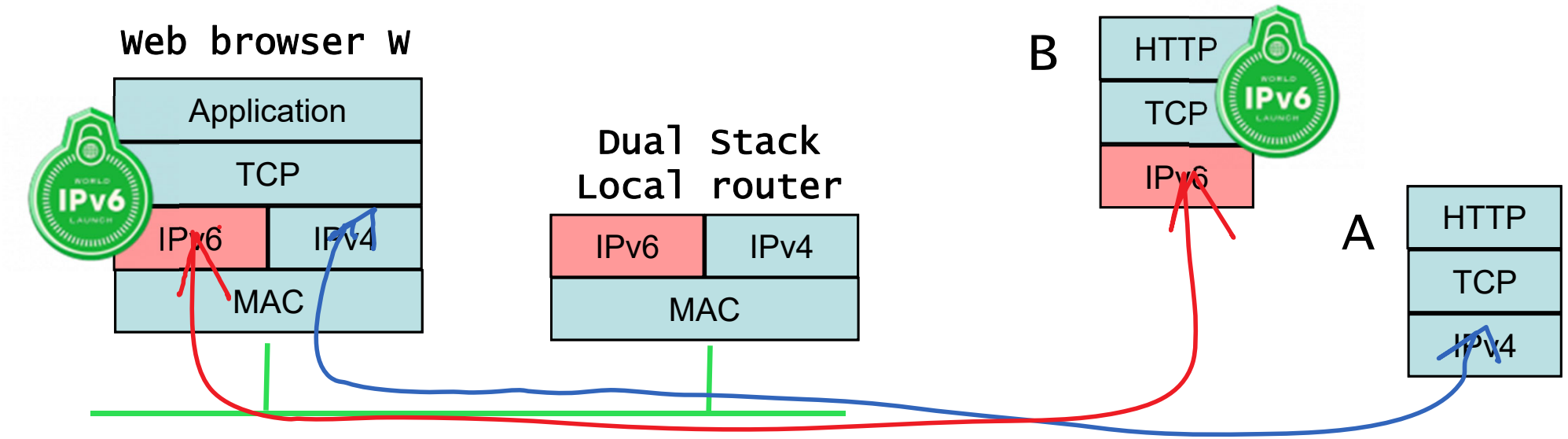
What does IPv6 do ?

Redefine packet format with a larger address: 128 bits ($\approx 3 \cdot 10^{38}$ addresses)

Otherwise essentially the same as IPv4

IPv6 is incompatible with IPv4; routers and hosts must handle both separately

A can talk to W, B can talk to W, A and B cannot communicate at the network layer



v6 Routing Tables at ed0-swi

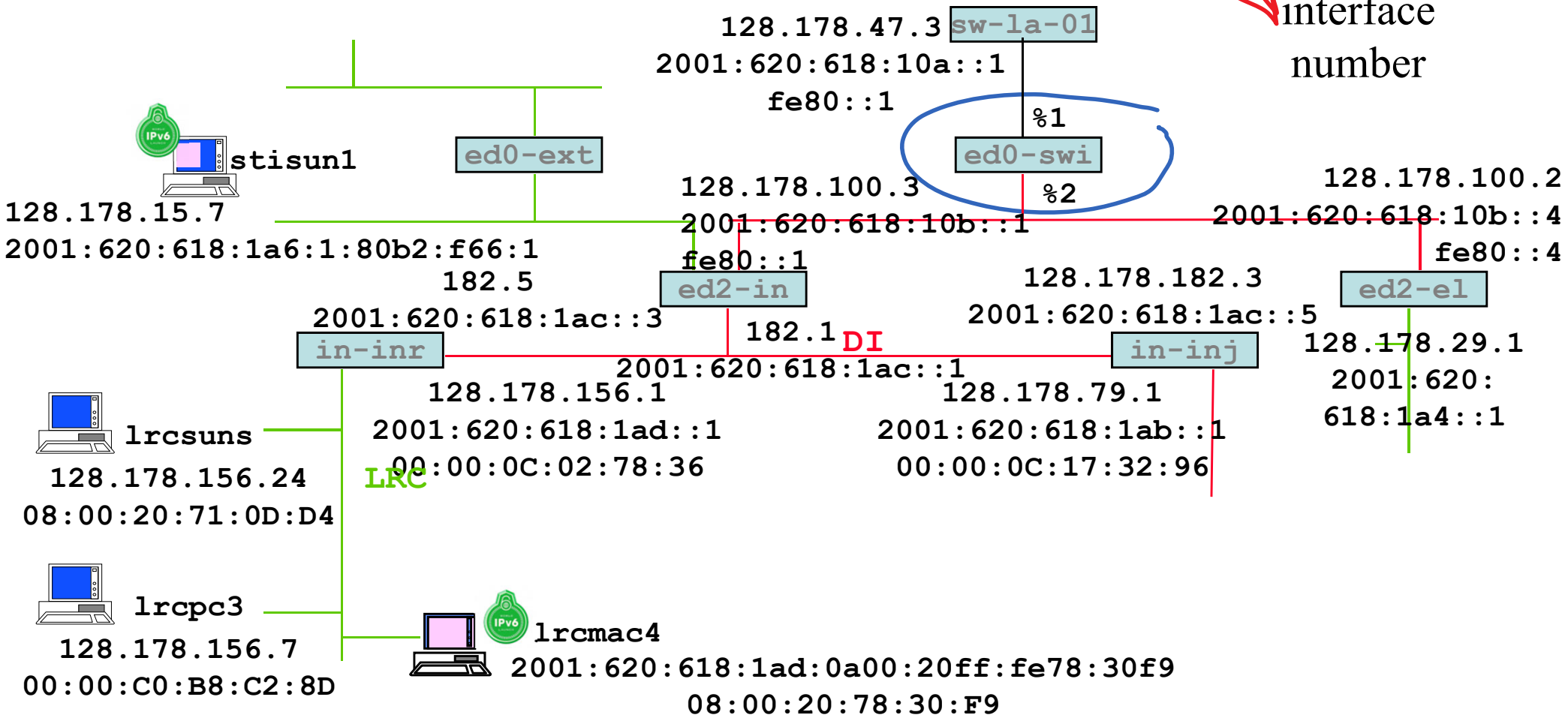
Destination	Next hop
2001:620:618:1a4/64	fe80::1%2
2001:620:618/48	fe80::4%2
::/0	fe80::1%1

IP address of next hop

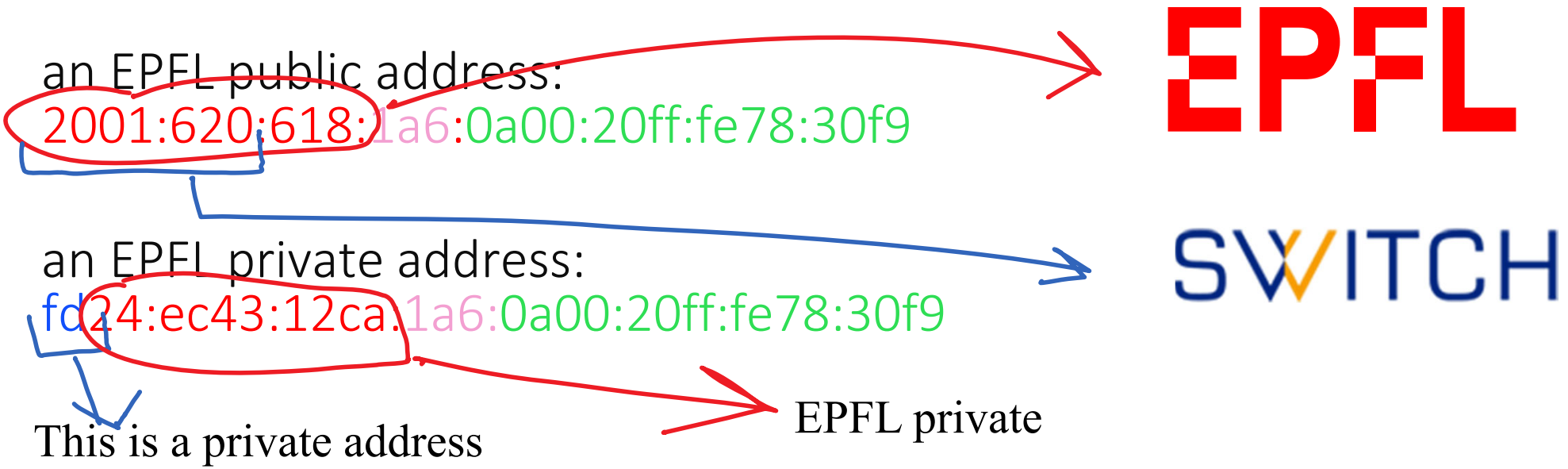
Routing tables at ed0-swi

Destination	Next hop
128.178.29/24	128.178.100.2
128.178/16	128.178.100.3
0/0	128.178.47.3

interface number



IPv6 addresses are 128 bit long and are written using hexadecimal digits



Compression Rules for IPv6 Addresses

1 *piece* = 16 bits = [0-4]hexa digits; leading zeroes in one piece are omitted ;

prefer lower case

pieces separated by “:” (colon)

one IPv6 address uncompressed = 8 pieces

:: replaces any number of 0s in more than one piece; appears only once in address

uncompressed	*compressed*
2002:0000:0000:0000:0000:ffff:80b2:0c26	2002::ffff:80b2:c26
2001:0620:0618:01a6:0000:20ff:fe78:30f9	2001:620:618:1a6:0:20ff:fe78:30f9

A Few IPv6 Global Unicast Addresses

The block 2000/3 (i.e. 2xxx and 3xxx) is allocated for global unicast addresses

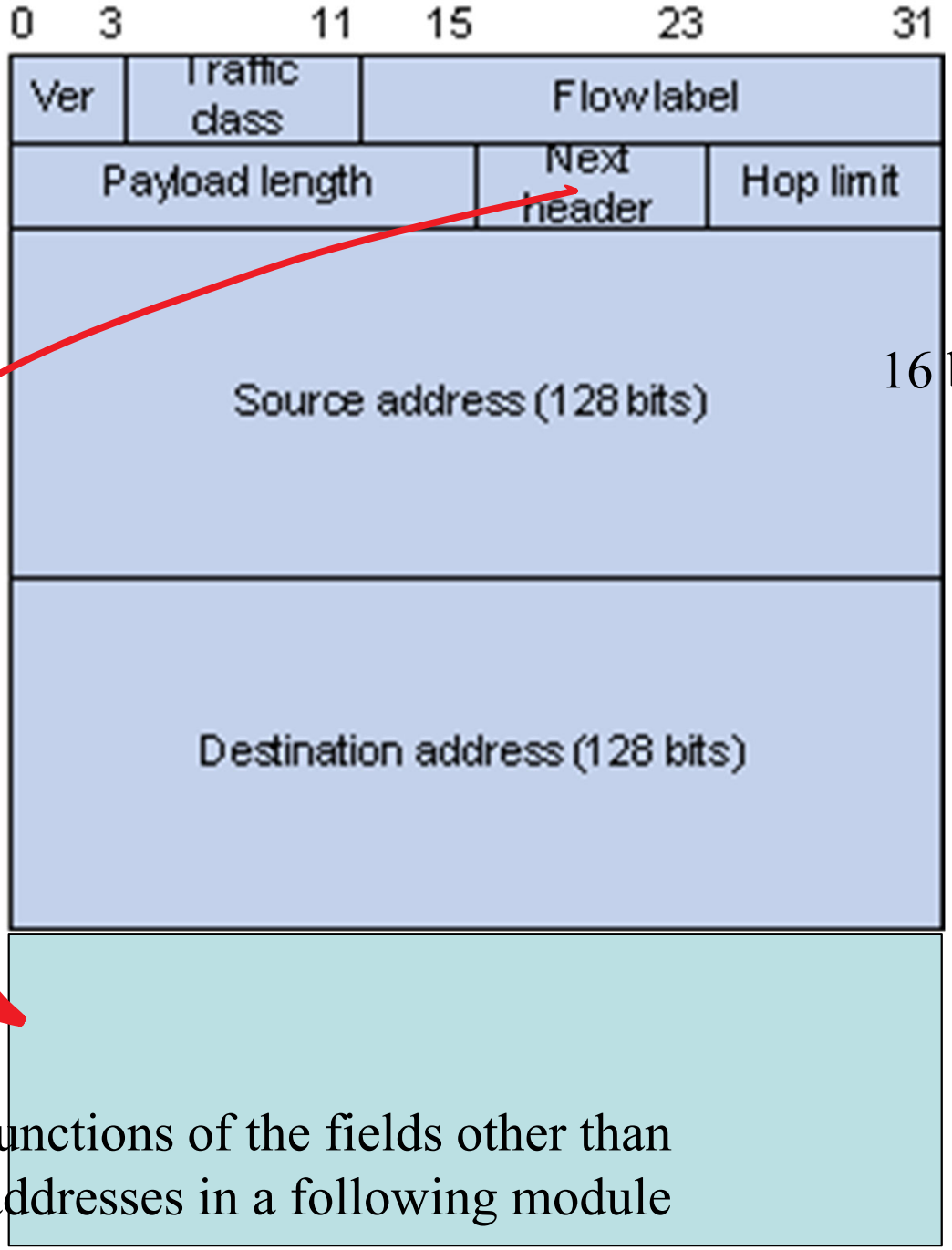
2001:620::/32	Switch
2001:620:618::/48	EPFL
2001:620:8::/48	ETHZ
2a02:1200::/27	Swisscom
2001:678::/29	provider independent address
2001::/32	Teredo
2002::/16	6to4

Examples of Special Addresses

::/128	absence of address
::1/128	this host (loopback address)
fc00::/7 (i.e. fcxx: and fdxx:) For example fd24:ec43:12ca:1a6:a00: 20ff:fe78:30f9	Unique local addresses = private networks (e.g in IEW) cannot be used on the public Internet
fe80::/10	link local address (can be used only between systems on same LAN)
ff00::/8	multicast
ff02::1:ff00:0/104	Solicited node multicast
ff02::1/128 ff02::2/128	link local broadcast all link local routers

EPFL Private

IPv6 Packet Format



e.g.
Higher layer protocol
1= ICMP, 6 = TCP, 17 = UDP)

16 bytes

Header
40 bytes
(+ options, if any)

payload

We will see the functions of the fields other than the addresses in a following module

The dotted decimal notation for $0102{:}\,ffff$ is …

A. 1.2.255.255
B. 16.32.255.255
C. 228.393.255.255
D. I don’t know

In full, the hexadecimal notation «2001::bad:babe» means…

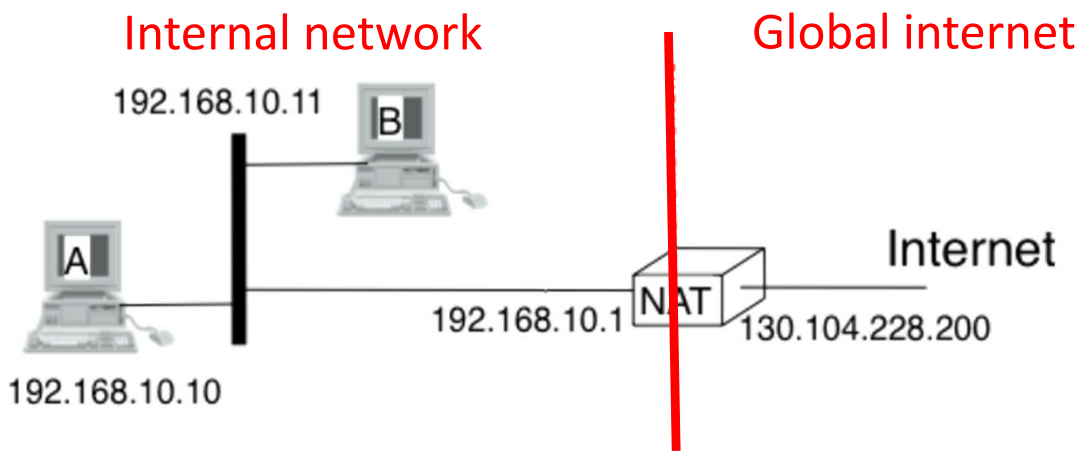
A. 2001:0bad:babe
B. 2001:0000:0000:0000:0000:0000:0bad:babe
C. 2001:0000:0bad:babe
D. 2001:0000:bad:babe
E. None of the above
F. I don’t know

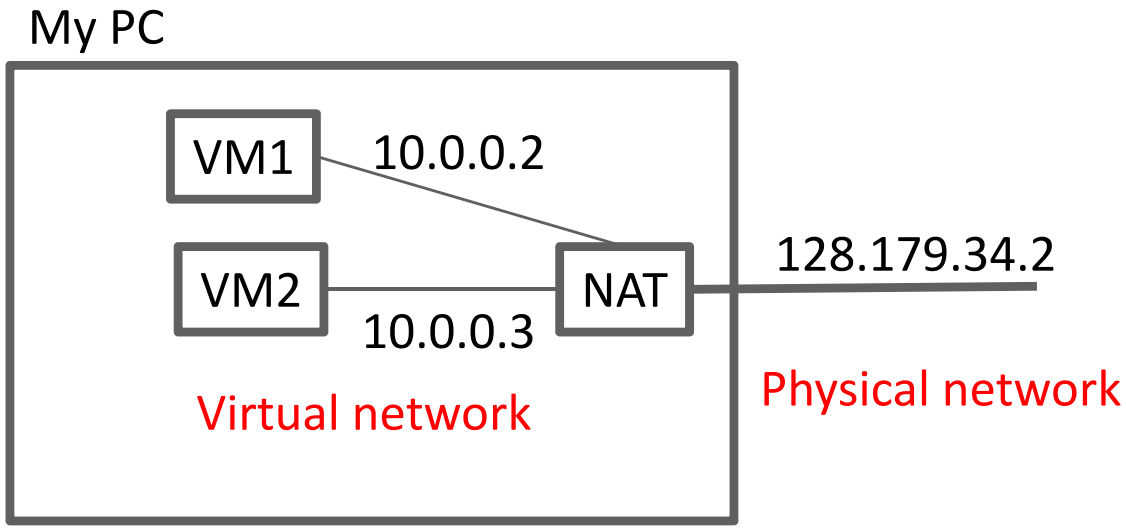
4. NATs: Why invented ? (Network Address Translation boxes)

Goal: re-use same IP address for several devices / use private addresses

This is our first example of «middle box», that deviates from the TCP/IP architecture

Used in residential networks («ADSL Modem») / in smartphones / in companies to save IP addresses / in Virtual Machines





What does Network Address Translation do ?

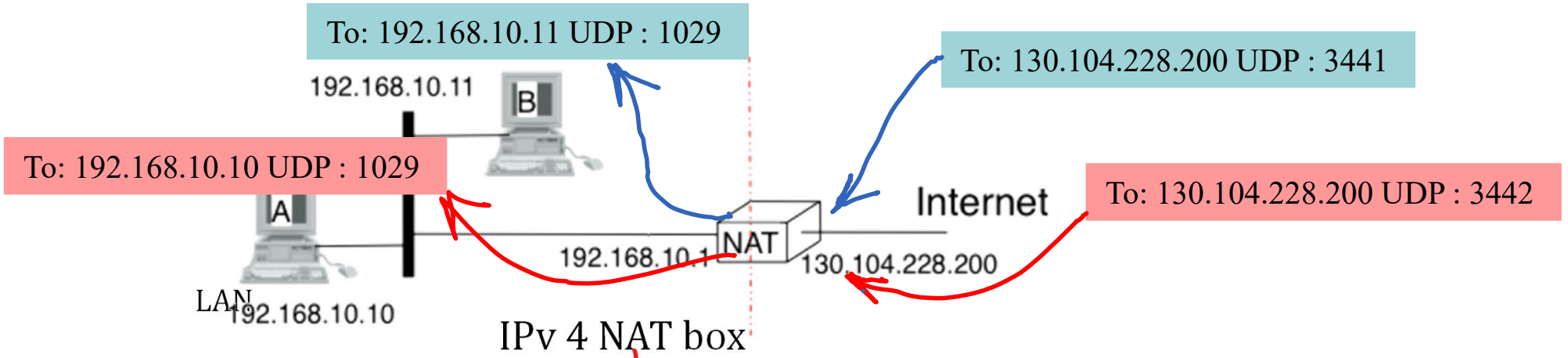
NAT translates LAN IP address to (typically) its WAN address

Collisions inside LAN are avoided by having NAT modify IP address *and* port number

(strictly speaking this should be called Network Address and Port Translation, NAPT)

Forwarding at NAT is by exact matching from NAT Table

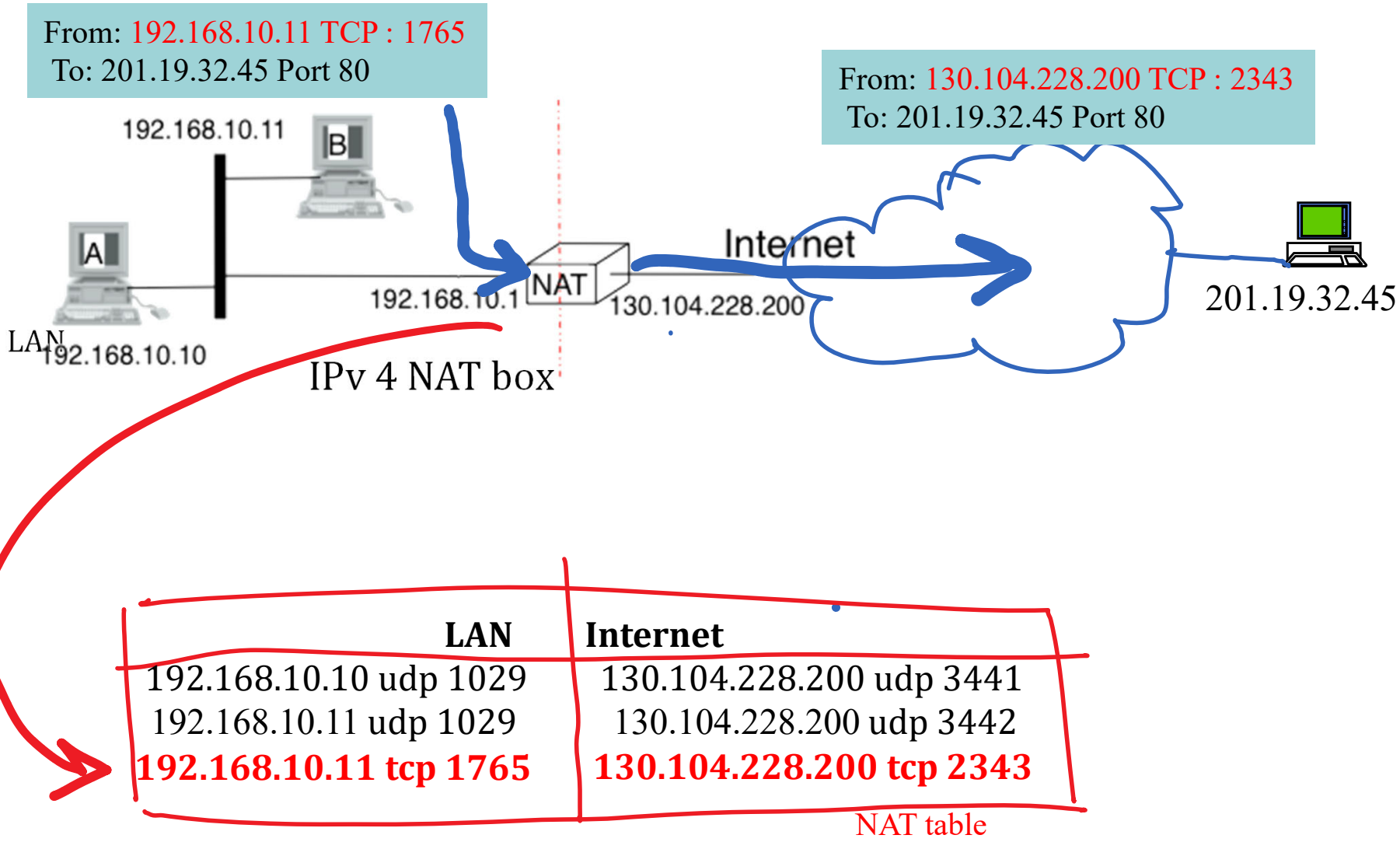
Implemented by iptables on Linux -- iptables modifies the TCP and IP headers before forwarding ("prerouting") or after ("postrouting")



LAN	Internet
192.168.10.10 udp 1029	130.104.228.200 udp 3441
192.168.10.11 udp 1029	130.104.228.200 udp 3442

NAT table

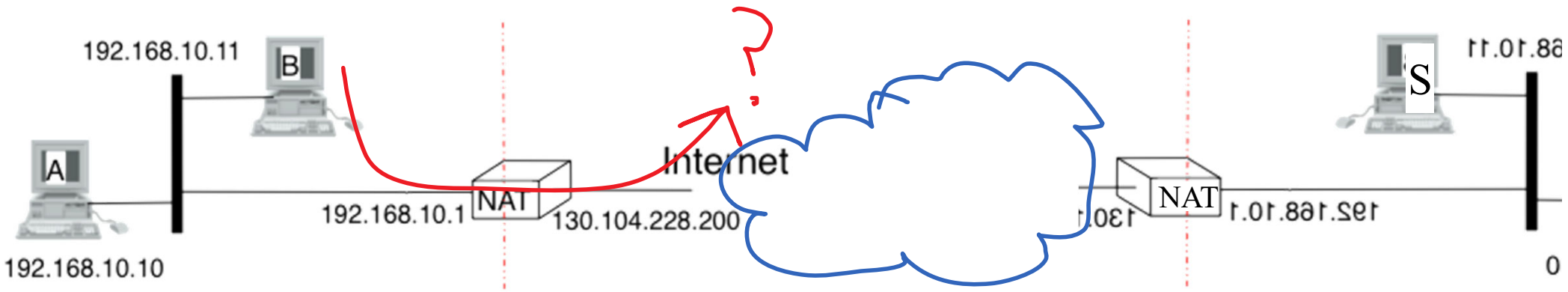
Creating a NAT table entry: on the fly



Mapping (iAddr, iPort) to (eAddr, ePort) can be done automatically, as shown; but also statically (e.g. to support a web server in LAN)

There are many variants on how mapping is done and how it is used on the return direction (Internet → LAN): full cone, restricted cone, symmetric etc … see Wikipedia page on NATs

Why some applications don’t work with NATs



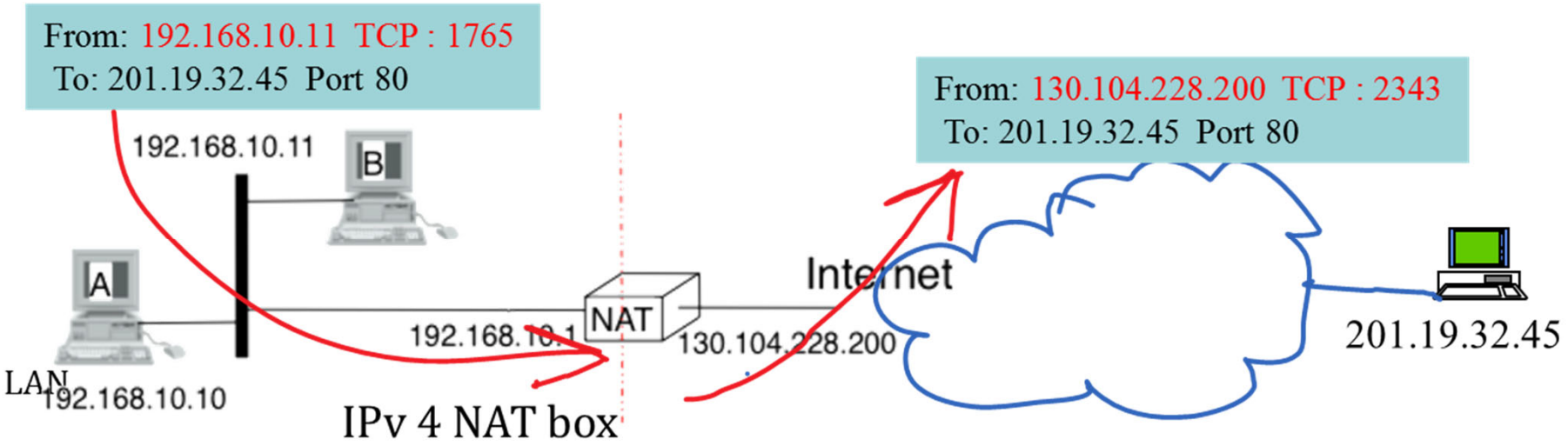
Assume A behind a NAT and S in the internet

Communication between A and S must be initiated by A

If A and S are both behind a NAT (e.g. with voice over IP), we have a bootstrap problem

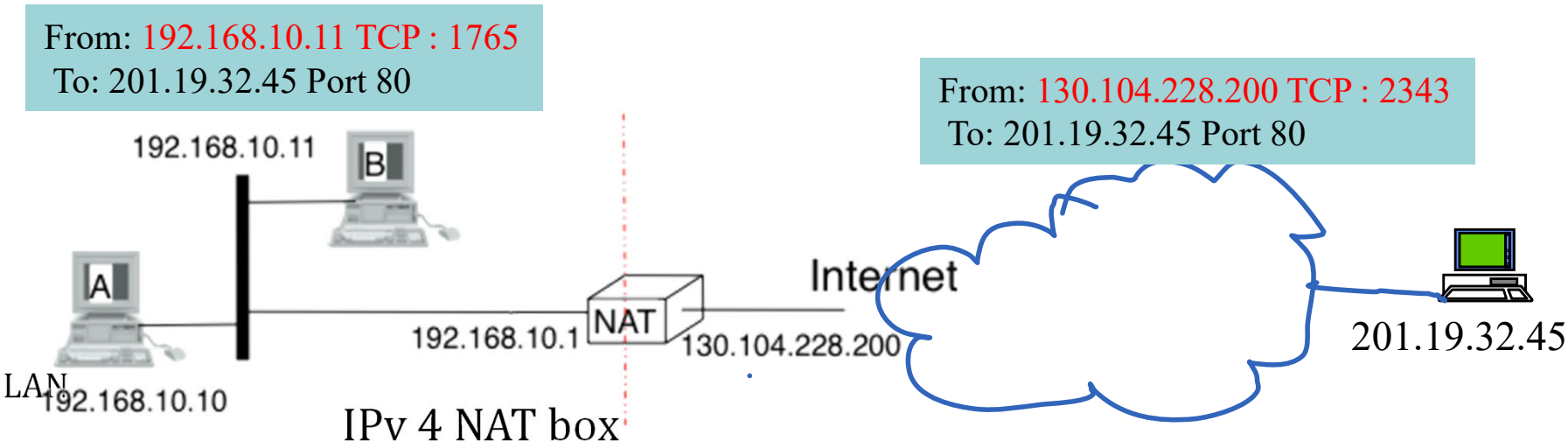
- A does not know its IP address as seen by S
- Solving this can be automatic with a third party – this is what made Skype’s fortune or can use static configuration of NATs – this is what made Messenger fail. Protocols such as TURN and STUN are used

When a NAT has a packet to forward and an association exists in the NAT table…



A. The NAT looks for a longest prefix match
B. The NAT looks for an exact match
C. None of the above
D. I don't know

From WAN to LAN, the NAT may modify…



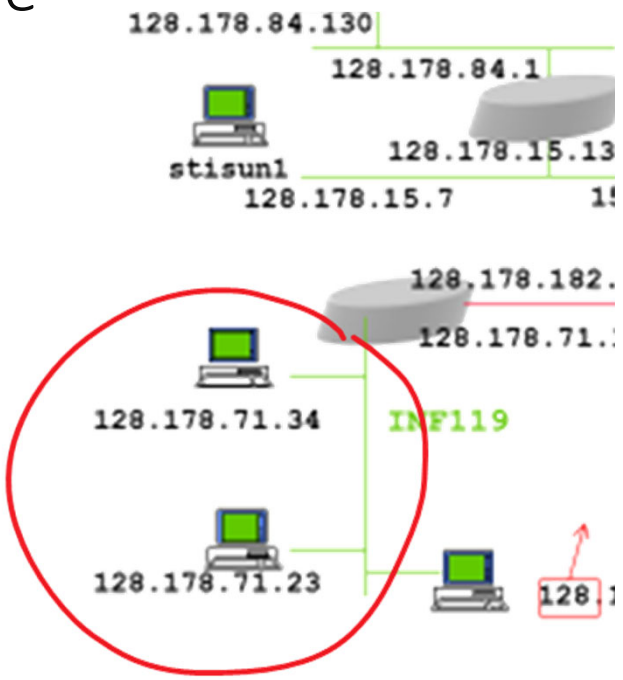
A. The source port
B. The destination port
C. None of the above
D. I don’t know

5. Network Masks

Machines in same subnetwork must have same "subnet prefix" (= "network part")

Size (in bits) of subnet prefix must be specified in the machine together with the address;

At EPFL-IPv4, it is 24 bits; at ETHZ-IPv4 it is 26 bits.
For IPv6 it is often 64 bits (but not always).



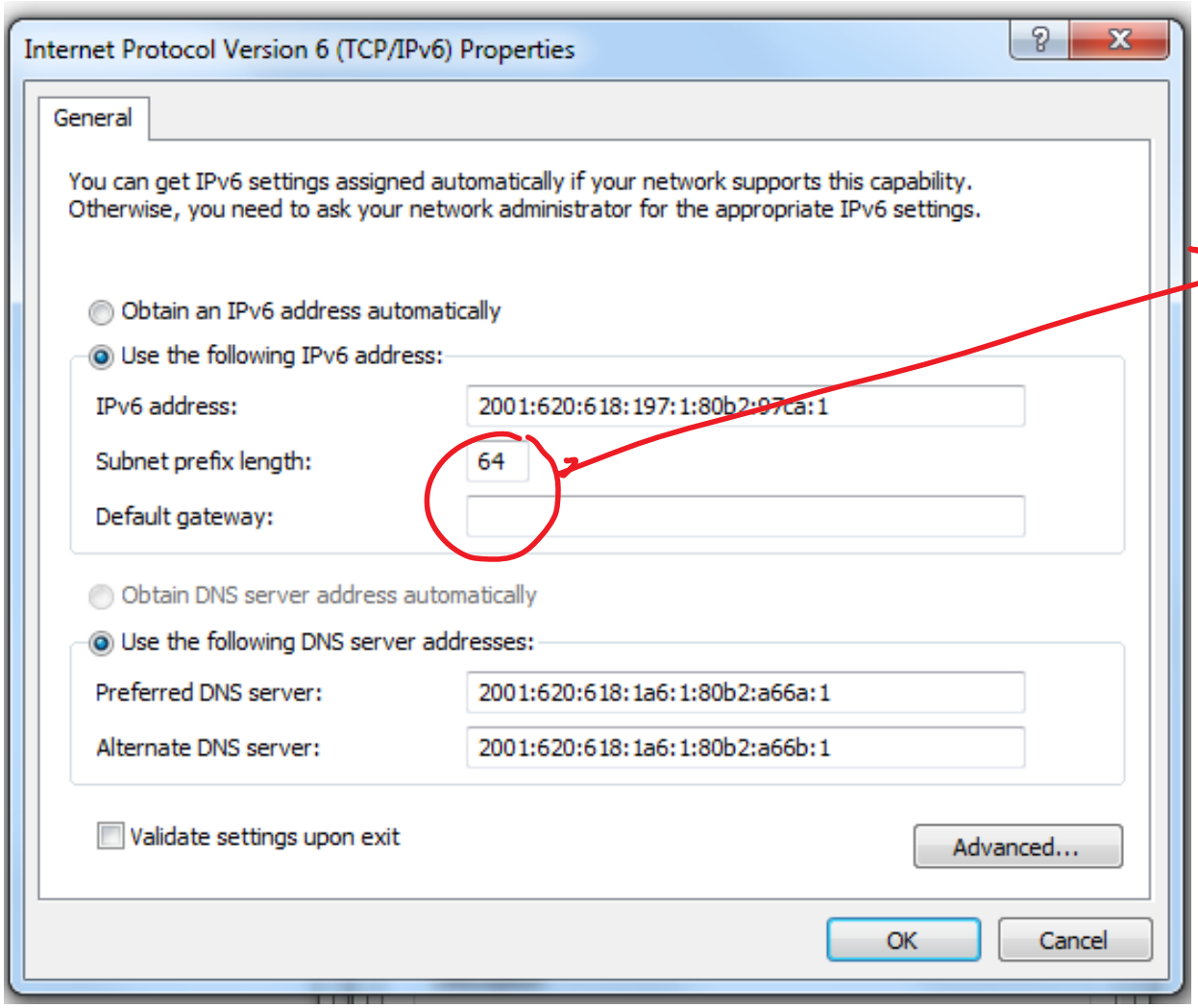
Size of the subnet prefix is often specified using a network mask = sequence of bits where 1s indicate the position of the prefix.

At EPFL-IPv4, network mask is 255.255.255.0;
At ETHZ-IPv4, network mask is 255.255.255.192

in binary 11111111 11111111 11111111 11000000
in dotted decimal 255.255.255.192

Example: address =128.178.71.34, mask =255.255.255.0

Example with IPv6



Same as saying
Mask = ffff:ffff:ffff:ffff::

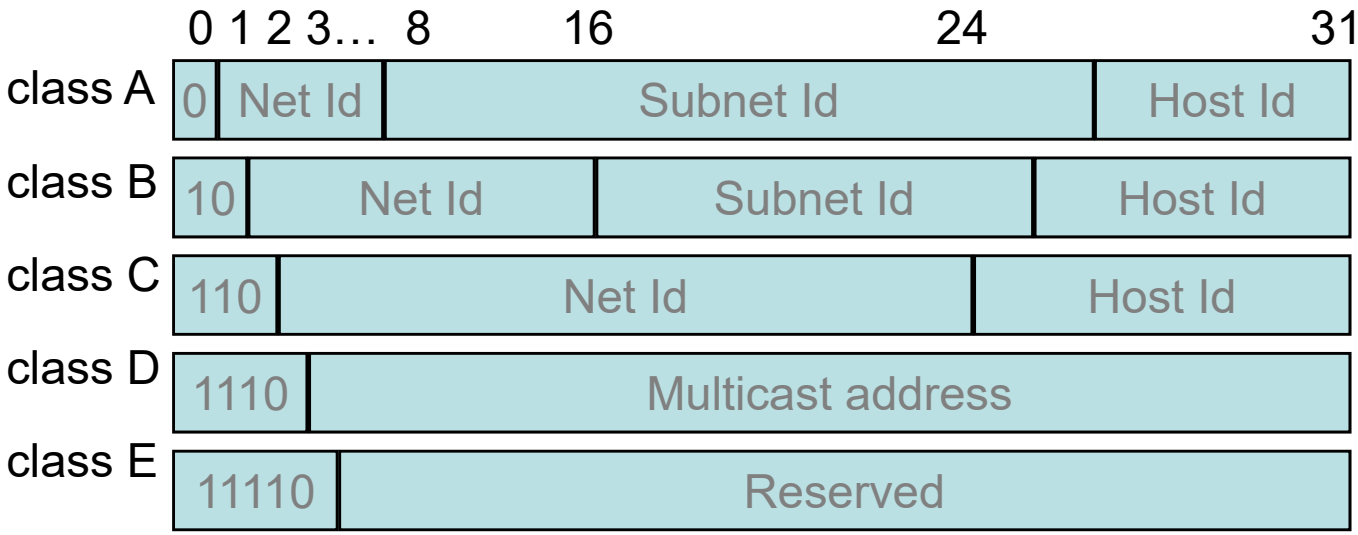
IPv4 address classes

Long ago, IPv4 addresses had a class

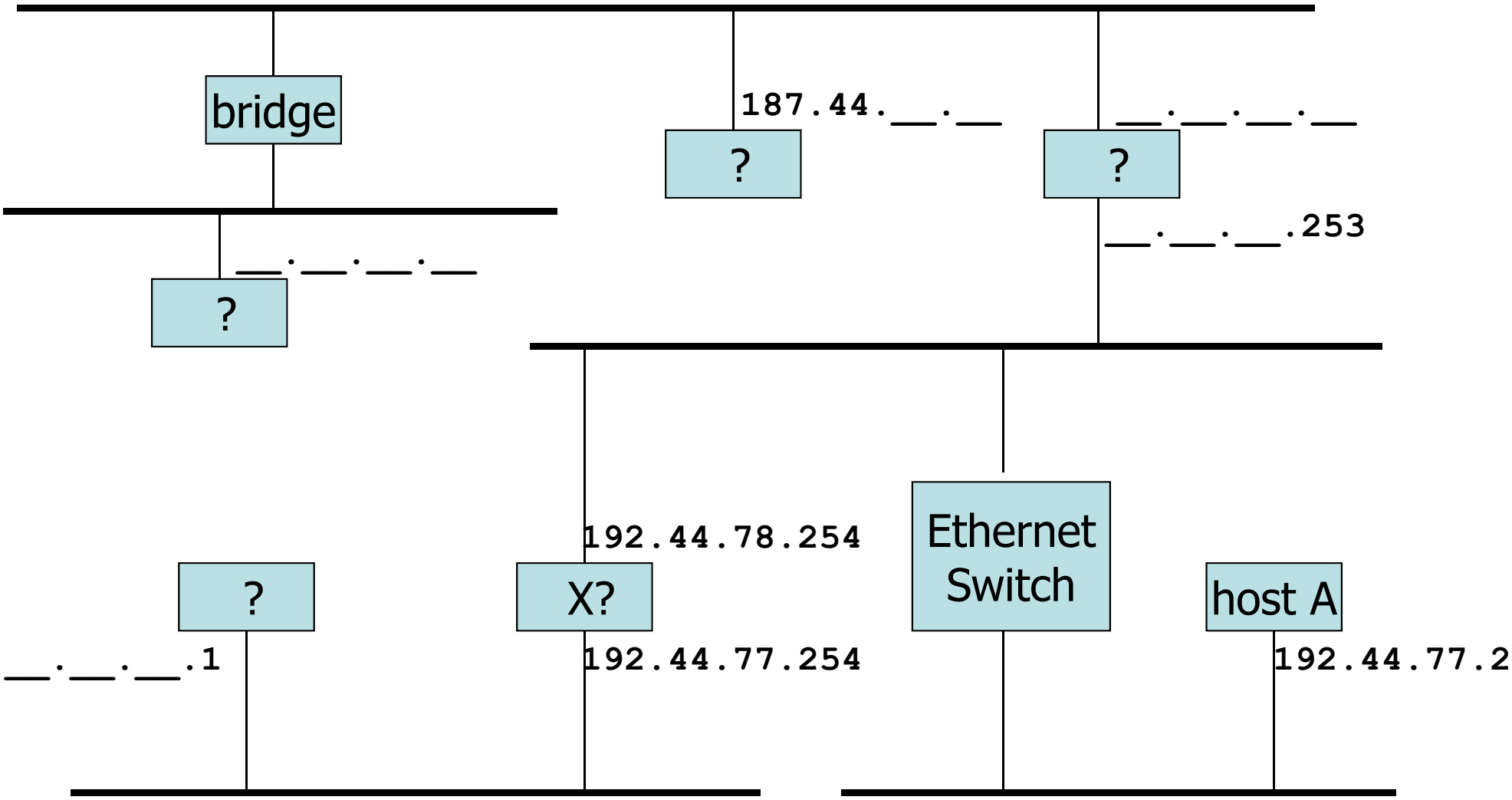
subnet mask was not necessary

This is now obsolete…

… but some people continue to use it.



Class	Range
A	0.0.0.0 to 127.255.255.255
B	128.0.0.0 to 191.255.255.255
C	192.0.0.0 to 223.255.255.255
D	224.0.0.0 to 239.255.255.255
E	240.0.0.0 to 247.255.255.255



Can Host A have this address ?
Masks are all 255.255.255.0

A. Yes

B. No

C. I don't know

What is the subnet broadcast address for subnet 129.132.100.0/26 ?

A. 129.132.100.0
B. 129.132.100.15
C. 129.132.100.63
D. 129.132.100.192
E. 129.132.100.255
F. I don’t know

6. MAC Address Resolution

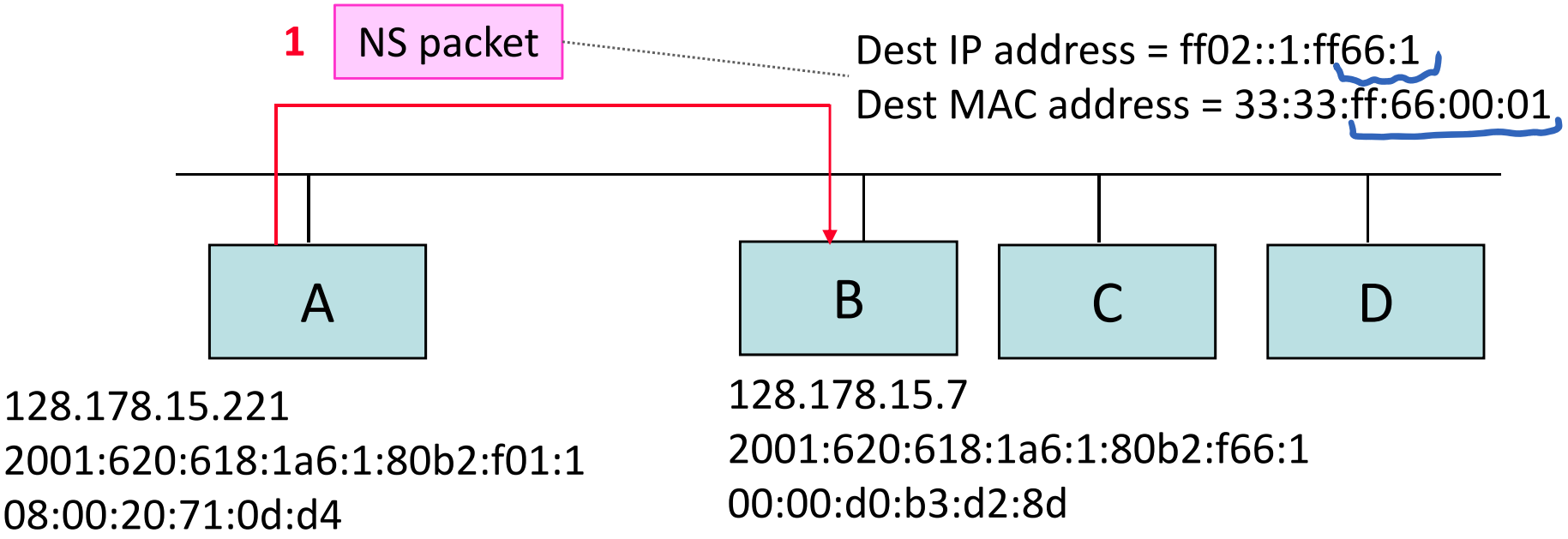
Why ?

An IP machine A has a packet to send to a next-hop B. A knows B's IP address (from routing table); A must find B's MAC address.

How ?

On Ethernet, A sends an address resolution packet on the LAN. All hosts that have the IP address of B (in principle only B) respond with their MAC address.

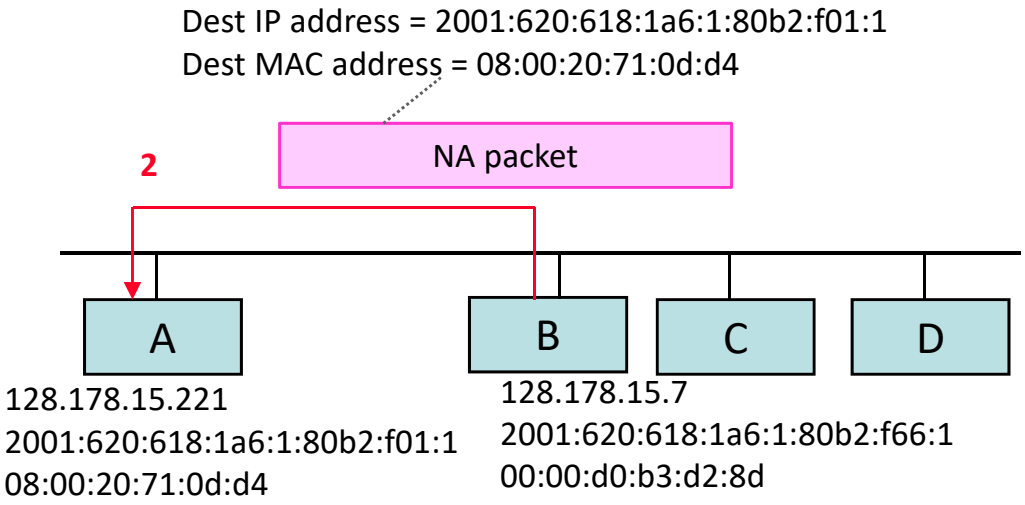
MAC Address Resolution with IPv6 (NDP)

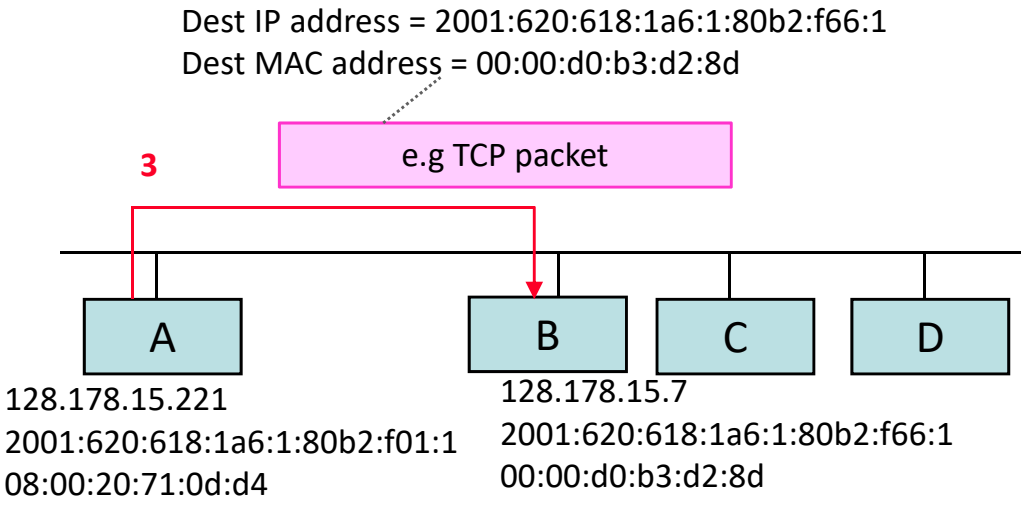


A has a packet to send to B = 2001:620:618:1a6:1:80b2:f66:1

This address is on the same subnet therefore A sends directly to B and looks for B's MAC address

1. A sends a Neighbour Solicitation (NS) packet using the Neighbour Discovery Protocol (NDP) containing the question: "who has IP address B ?". The IP destination address of this packet is a special multicast address (Solicited Node Multicast Address). The MAC address is derived from the multicast IP address. The NS packet is received by all hosts whose IP address has the same 24 bits as B (see next slide).





2. B responds with a Neighbour Advertisement (NA) packet, giving its MAC address. This NA packet is sent by B to A.

3. A reads NA, stores MAC address in its neighbour cache (also called ARP table) and can now send the data to B. The cache is refreshed whenever A receives a packet from B; it may expire after some timeout (e.g. 20 mn of inactivity).

NA, NS packets are carried as ICMPv6 packets, next-header =58 (0x3a), inside IPv6 packets.

The Solicited Node Multicast Address

SLAAC (and other protocols) use this multicast address - obtained by adding last 24 bits of target IP address to ff02::1:ff00:0/104

A packet with such a destination address is forwarded by layer 2 to all nodes that listen to this multicast address

Only for IPv6 – IPv4 uses broadcast instead

Target address	Compressed	2001:620:618:1a6:001:80b2:f66:1
	Uncompressed	2001:0620:0618:01a6:0001:80b2:0f66:0001
Solicited Node multicast address	Uncompressed	ff02:0000:0000:0000:0000:0001:ff66:0001
	Compressed	ff02::1:ff66:1

Look Inside an NDP Neighbour Solicitation Packet

```
ETHER:  Packet size =  86 bytes
ETHER:  Destination = 33:33:ff:01:00:01
ETHER:  Source = 3c:07:54:3e:ab:f2
ETHER:  Ethertype = 0x86dd
ETHER:
IP:   ----- IP Header -----
IP:
IP:   Version = 6
IP:   Traffic class =0x00000000
IP:      ....  0000 00.. .... .... .... .... .... = Default Differentiated Service Field
IP:      ....    ....     ..0.  .... .... .... .... .... = No ECN-Capable Transport (ECT)
IP:      ....    ....     ...0  .... .... .... .... ....  = No ECN-CE
IP:   .... .... ....  0000 0000 0000  0000 0000 =  Flowlabel: 0x00000000
IP:   Payload length = 32
IP:   NextHeader= 58
IP:   Hop limit= 255
IP:   Source address = 2001:620:618:197:1:80b2:97c0:1
IP:   Destination address = ff02::1:ff01:1
IP:
ICMPv6:     ----- ICMPv6 Header -----
ICMPv6:
ICMPv6:  Type = 135
ICMPv6:  Code=0
ICMPv6:  Checksum = 0xb199 [correct]
ICMPv6:  Reserved = 00000000
ICMPv6:  Target Address=2001:620:618:197:1:80b2:9701:1
ICMPv6:
```

Solicited Node Multicast Address corresponding to this IPv6 target address

Neighbor Solicitation (=ARP Request)

MAC Address Resolution with IPv4

Similar, except

the protocol is called ARP (Address Resolution Protocol)
ARP packets are not IP packets but directly in Ethernet frame
with Ethertype =ARP (86dd)

NDP NS /NA are called ARP Request /ARP replies

ARP request is broadcast to all nodes in LAN

Look inside an ARP packet

Ethernet II

Destination: ff:ff:ff:ff:ff:ff (ff:ff:ff:ff:ff:ff)

Source: 00:03:93:a3:83:3a (Apple_a3:83:3a)

Type: ARP (0x0806)

Trailer: 000000000000000000000000000000...

Address Resolution Protocol (request)

Hardware type: Ethernet (0x0001)

Protocol type: IP (0x0800)

Hardware size: 6

Protocol size: 4

Opcode: request (0x0001)

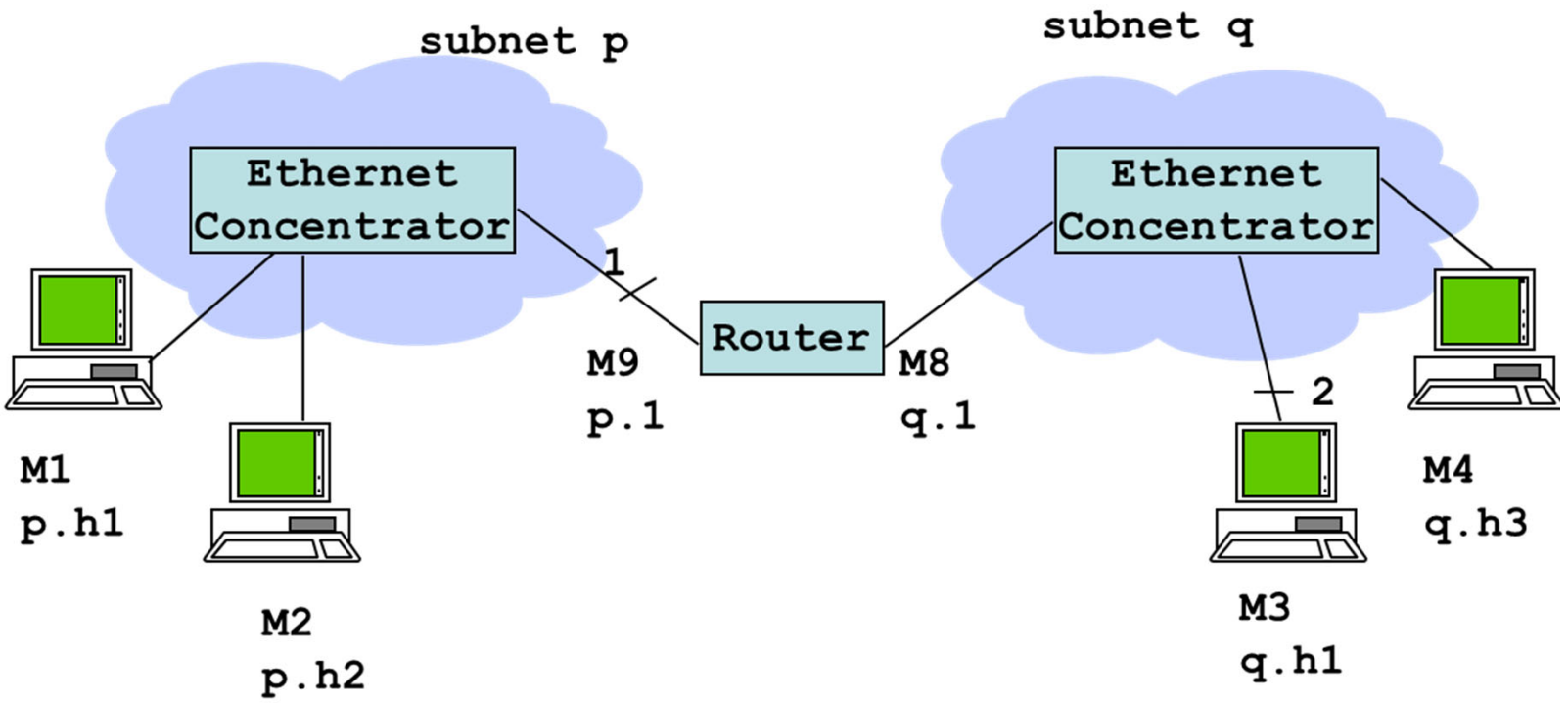
Sender MAC address: 00:03:93:a3:83:3a (Apple_a3:83:3a)

Sender IP address: 129.88.38.135 (129.88.38.135)

Target MAC address: 00:00:00:00:00:00 (00:00:00_00:00:00)

Target IP address: 129.88.38.254 (129.88.38.254)

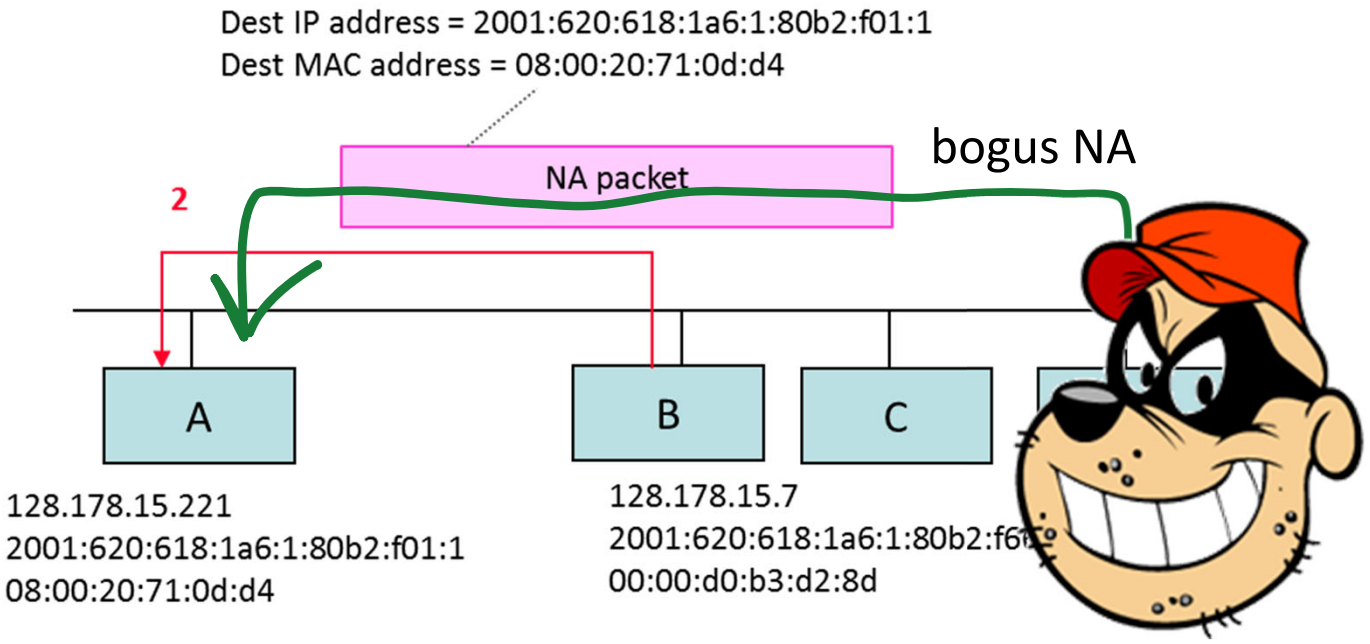
M1 sends a packet to M3 for the first time since last reboot.



A. M1 sends an NS /ARP packet for q.h1
B. M1 sends an NS / ARP packet for p.1
C. None of the above
D. I don't know

Security Issues with ARP/ NDP

ARP requests / replies may be falsified (ARP spoofing). Attacker will capture all packets intended to B (e.g. man in the middle attack)



DHCP Snooping and Dynamic ARP Inspection can prevent ARP spoofing in LANs

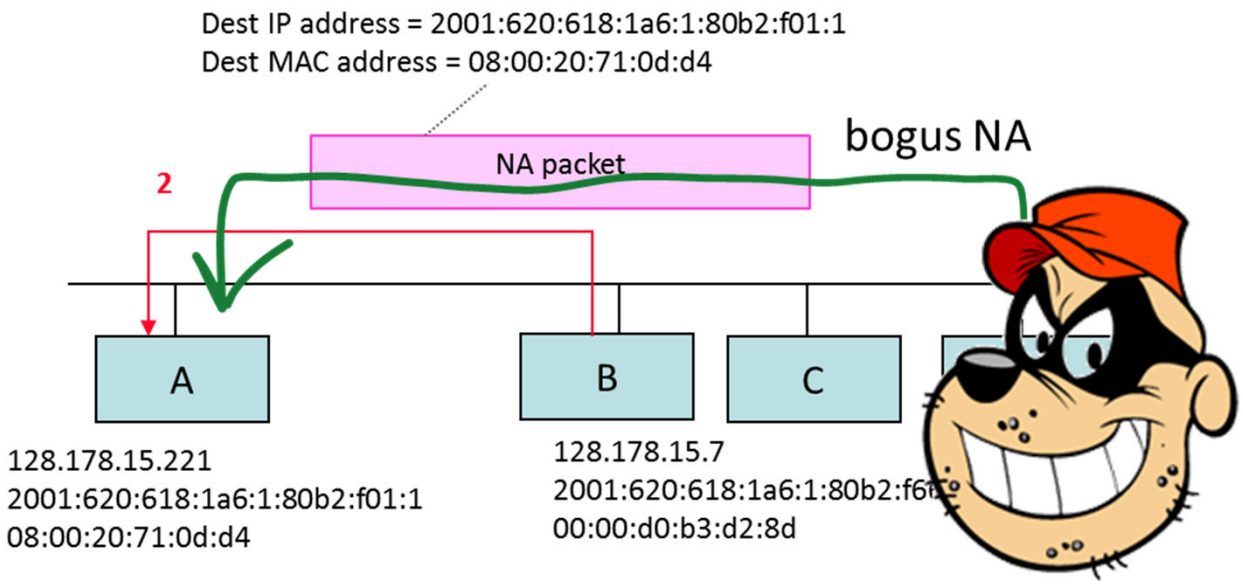
DHCP snooping = switch/Ethernet concentrator/WiFi base station observes all DHCP traffic and remembers mappings IP addr ↔ MAC addresses

(DHCP is used to automatically configure the IP address at system startup)

Dynamic ARP inspection: switch filters all ARP (or NDP) traffic and allows only valid answers – removes broadcasts (IPv4) and multicasts (IPv6)

Such solutions are deployed in enterprise networks, rarely in homes or WiFi access points

Secure NDP (SEND)



What ?

Make NDP spoofing impossible by cryptographic means

How ?

Host B has public/private key pair.

EUI of B is a CGA (cryptographically assigned address) = hash of B's public key and IPv6 address prefix (and other fields such as counters). This binds B's address and its public key.

NA message sent in response to A contains a signature (RSA) computed with B's private key. This proves that the message is sent by a system that has the private key that corresponds to the address, i.e. B (if the private key is kept secret).

Not widespread yet – requires a strong hash function. Problem is the need to change the crypto function by patching.

A private/public key system such as RSA has two keys : one public and one private (secret). With RSA, a clear text message can be encrypted with the private key and decrypted with the public key (or vice versa).

Let P be the public key that was used to generate B's address (using a hash function), and let p be the corresponding private key.

Here, A can verify the NA by applying RSA decryption with the public key P. This proves that the NA was originated by a system that knows the private key p. A can also verify that B's EUI is derived from the public key P, since the hash algorithm is known and public. This proves to A that the NA was originated by a system that owns B's EUI.

7. Host Configuration

An IP host needs to be configured on each interface with

- IP address of this interface
- Mask of this interface
- IP address of default router
- IP address of DNS server

Can be done manually, or automatically with

- IPv4 → DHCP (Dynamic Host Configuration Protocol)
- IPv6 → DHCP stateful, SLAAC (stateless), DHCP stateless

Same applies to routers connected to a provider

- IPv4 → PPP
- IPv6 → PPP, DHCP with Prefix Delegation

DHCP with IPv4

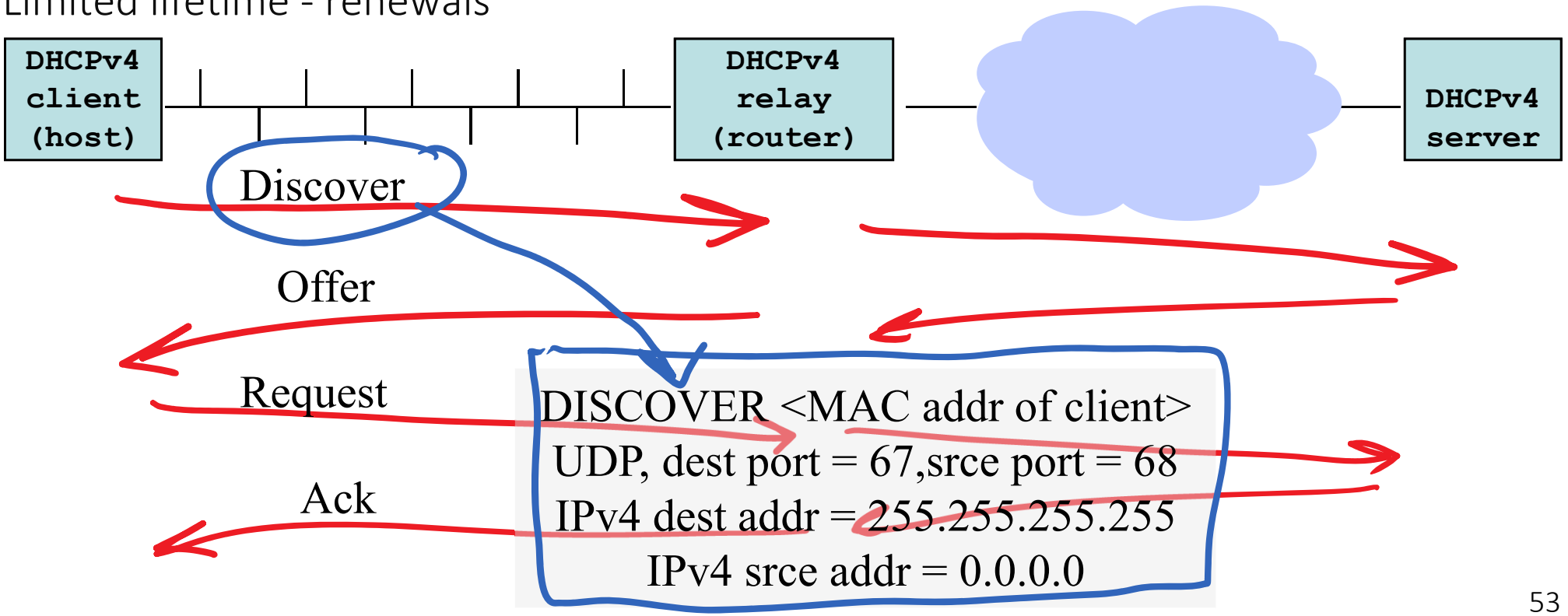
Configuration info is kept in central DHCP server, contacted by host when it needs an IP address; is commonly used with IPv4. Also works with IPv6 (with modifs – called DHCP stateful).

Problem: host cannot contact DHCP server since it is still does not have an IP address;

Solution: router implement a "DHCP Relay" function.

Two phase commit to avoid inconsistent reservations.

Limited lifetime - renewals



The Point to Point Protocol (PPP)

Why ?

allocate address automatically over telecom lines (modem, ADSL)

link is point to point, no MAC address, DHCP not suitable

How ? Similar to (simpler than) DHCP

PPPv4 for IPv4

PPPv6 for IPv6

Stateless Address Autoconfiguration (SLAAC) = Plug and Play --- IPv6 only

Why invented: avoid configuring DHCP servers
Fully automatic

How it works :

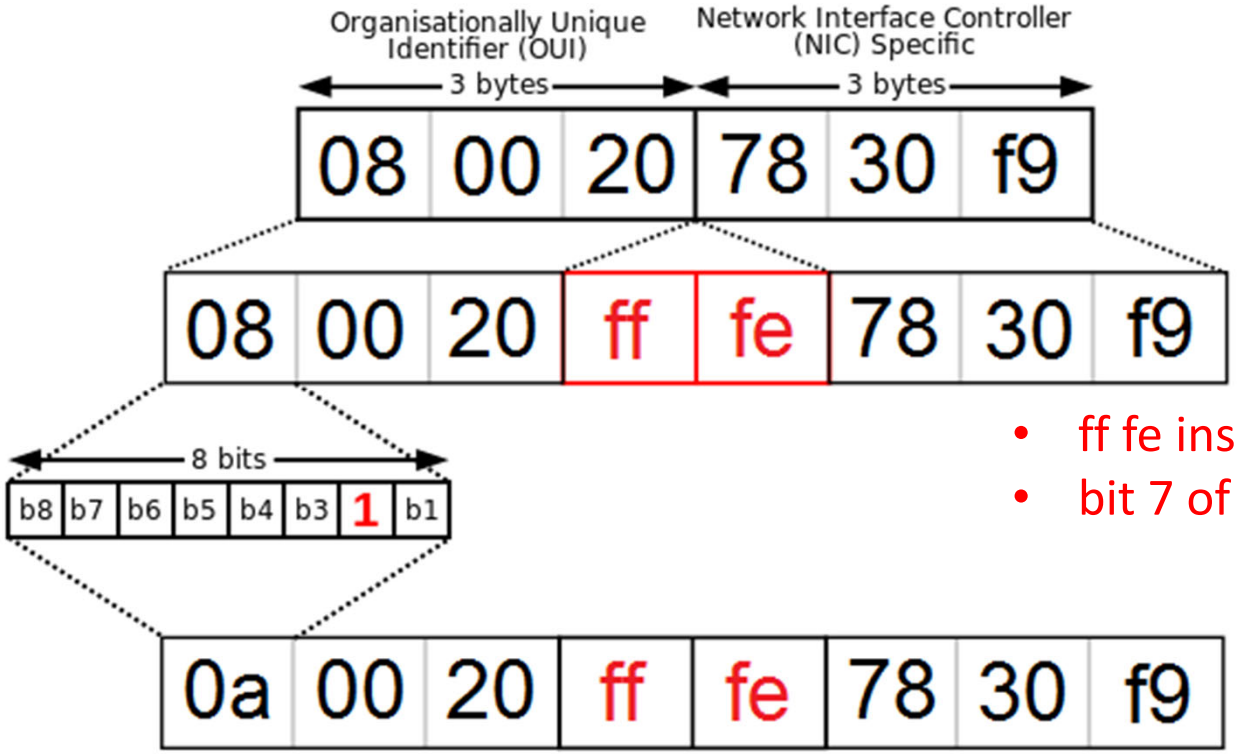
1. host auto-configures a link local address; 64 bit host part obtained by one of these methods:

   manually assigned e.g. ::1;
   derived from MAC address (modified EUI - next slide)
   randomly assigned
   cryptographically generated address (CGA) – by hashing the public key of the host

2. host performs address duplication test by sending a multicast packet (to solicited node multicast address)

3. host tries to add globally valid addresses by obtaining network prefix from routers if any present;

Host Part derived from MAC address: MAC@ → EUI (Extended Unique Identifier)



MAC @
48 bits

- ff fe inserted in the middle
- bit 7 of MAC address is flipped

modified EUI format
64 bits

Q: Why is bit 7 flipped ? A: Bit 7 is the "g" bit -- an EUI is defined by IEEE; a locally assigned EUI (i.e not derived from MAC address) has g bit equal to 1; this is inconvenient for IPv6 addresses. IPv6 uses the reverse convention: bit 7 of modified EUI is 1 for EUI derived from globally assigned MAC addresses, and 0 for manually assigned addresses (e.g. 2001:620:618:100::1).

Randomly Assigned Host Part

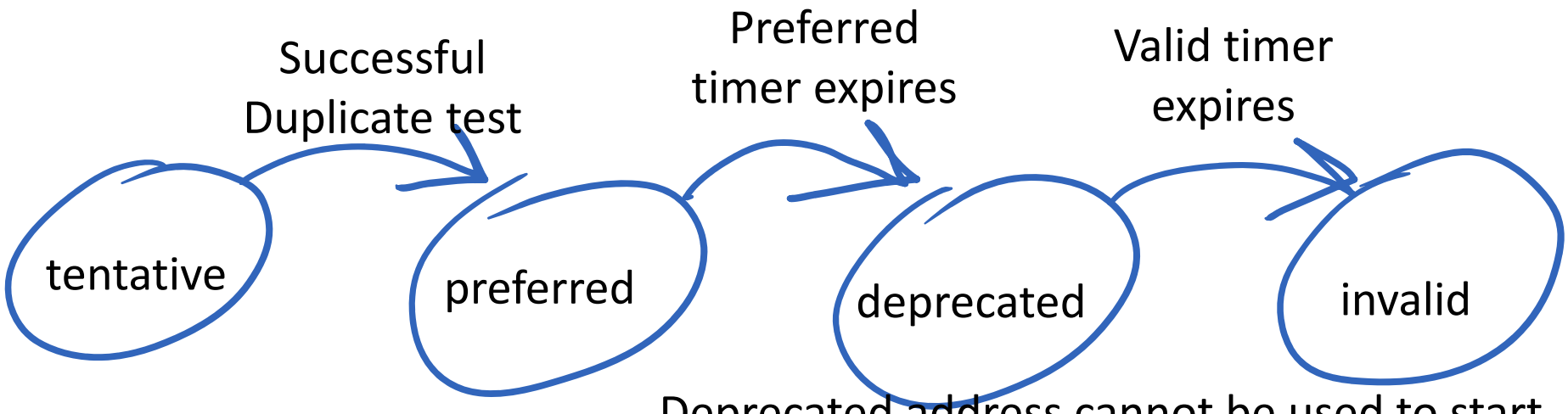
Privacy concern: MAC address allows tracking a mobile node

Randomly assigned Host Part can be used as alternative

- 7th bit of address must be 0

Host randomly computes one tentative host part

- Duplicate test is used to avoid (unlikely) collisions
- Has a limited lifetime
- Limited lifetime, renewed before expiration



- Deprecated address cannot be used to start new TCP connections
- Host should obtain a new address

Stateless DHCPv6

Why invented: solve problem left by stateless auto-configuration

DNS server address is not provided to host by stateless auto-configuration

How:

Stateless auto-configuration is performed first

Router response contains a flag = USE STATELESS DHCP

Host sends a query to DHCP server to obtain missing info, such as DNS server address

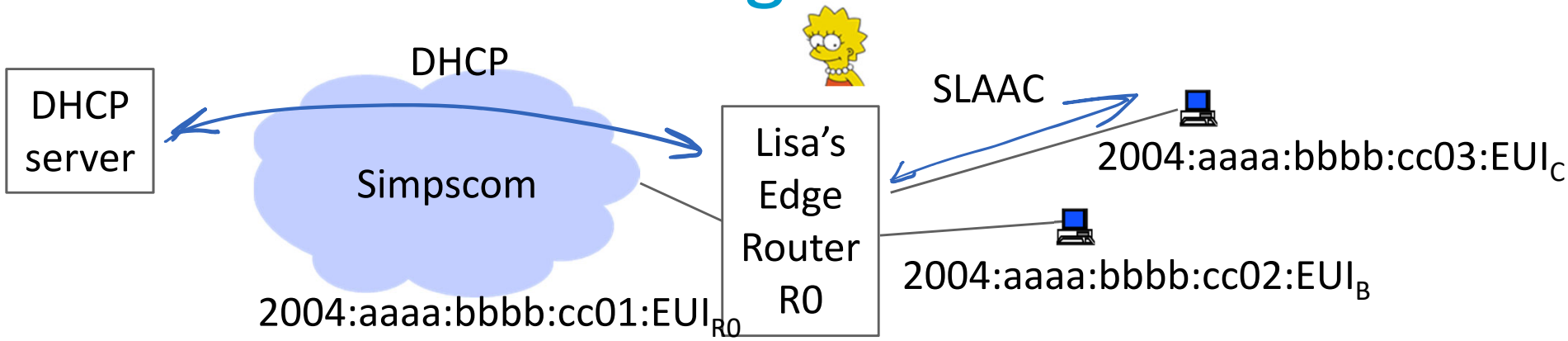
Why called stateless ?

A: DHCP servers does not keep state information

A better solution ?

Router Advertisements indicate address of DNS server in an optional RA extension (RFC 6106)

DHCP with Prefix Delegation



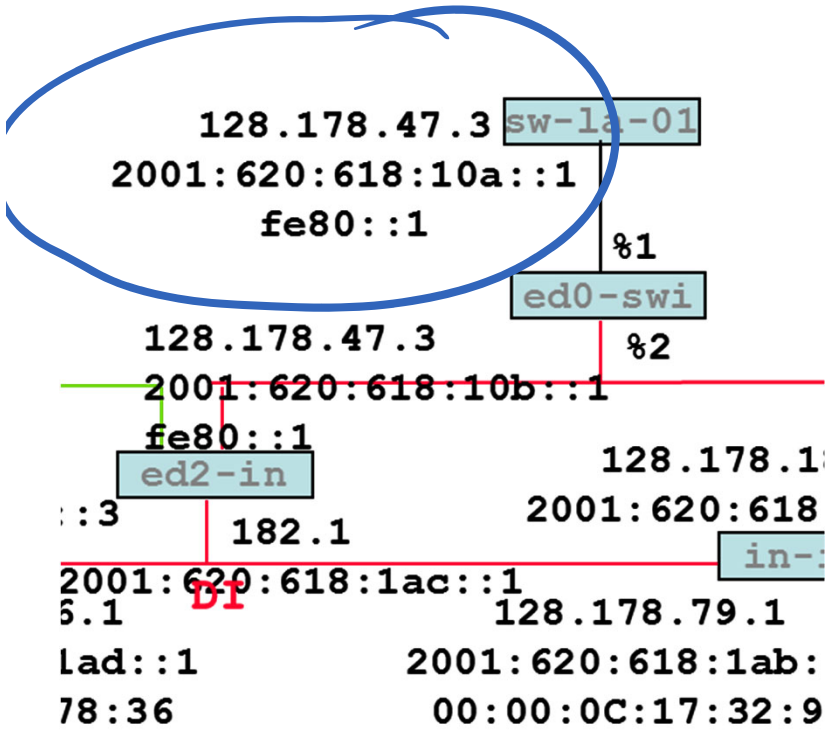
Why ? A home (or enterprise) IPv6 router R0 is configured by ISP using DHCP. Local devices are autoconfigured from home router using e.g. SLAAC. Home router needs an IPv6 prefix for the entire home network.

How ? ISP DHCP server (delegating router) provides to home router not just its IPv6 address but also the network prefix that this router can delegate to its devices. This is called prefix delegation. This prefix may include the prefix of the link from ISP to R0 (RFC 6603).

Compare to IPv4 !

Simpscom delegates 2004:aaaa:bbbb:cc00/56 to Lisa
Lisa can create many subnets; e.g. 2004:aaaa:bbbb:cc02/64 and 2004:aaaa:bbbb:cc03/64
the subnet 2004:aaaa:bbbb:cc01/64 is excluded from the delegation
For ISP, all of Lisa is one prefix: 2004:aaaa:bbbb:cc00/56

Multiple Addresses per Interface are the Rule with IPv6



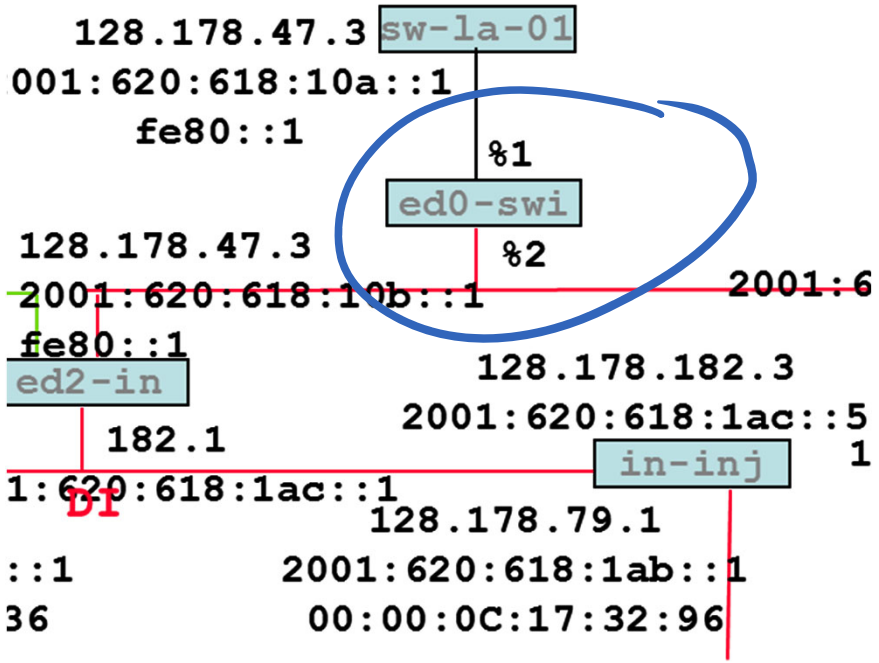
A host interface typically has

- One or several link local addresses
- Plus one or several global unicast addresses

The preference selection algorithm, configured by OS, says which address should be used as source address – see RFC 3484

In contrast, there is usually only one *IPv4* address per interface

Zone Index



Identifies an interface inside one machine that has several interfaces – typically visible in Windows machines

Never inside an IP packet

E.g. `fe80::1%2` means: the destination IPv6 address `fe80::1` on interface %2

618:1ad:0a00:20ff:fe78:30f9
08:00:20:78:30:F9

Ipconfig example

Wireless LAN adapter Wireless Network Connection:

Physical Address. . . . . : 10-0B-A9-A3-91-08
DHCP Enabled. . . . . : Yes
Autoconfiguration Enabled . . . . : Yes
Link-local IPv6 Address . . . . . : fe80::945c:d22c:b0e2:a885%16(Preferred)
IPv4 Address. . . . . : 123.255.96.194(Preferred)
Subnet Mask . . . . . : 255.255.252.0
Lease Obtained. . . . . : mercredi 25 juillet 2012 09:05:03
Lease Expires . . . . . : mercredi 25 juillet 2012 09:35:02
Default Gateway . . . . . : 123.255.99.254
DHCP Server . . . . . : 10.3.1.12
DHCPv6 IAID . . . . . : 386927529
DHCPv6 Client DUID. . . . . : 00-01-00-01-16-E8-19-59-F0-DE-F1-BE-ED-EB
DNS Servers . . . . . : 202.45.188.37
137.189.192.3
137.189.196.3
NetBIOS over Tcpip. . . . . : Enabled

IAID = logical number of this interface, assigned by client

Ethernet MAC address
Identifies this host in the DHCP database

IPv4 Link Local Addresses

Some form of autoconfiguration also exists with IPv4

- When host boots, if no DHCP and no configuration info available, it picks an IPv4 link local address at random in the 169.254/16 block
- Address duplicate test is performed by broadcast
- Allows to operate in routerless network («Dentist's Office», à la AppleTalk) but not in a general setting
- Implemented in Windows, not supported by the Linux version we use in the lab

a) When an IPv4 host uses DHCP, which of the following information does it acquire:

A. its IP address;

B. its subnet mask

C. its default gateway address

D. its DNS server address

A. A

B. A, B

C. A, B, C

D. A, B, C, D

E. None of the above

F. I don’t know

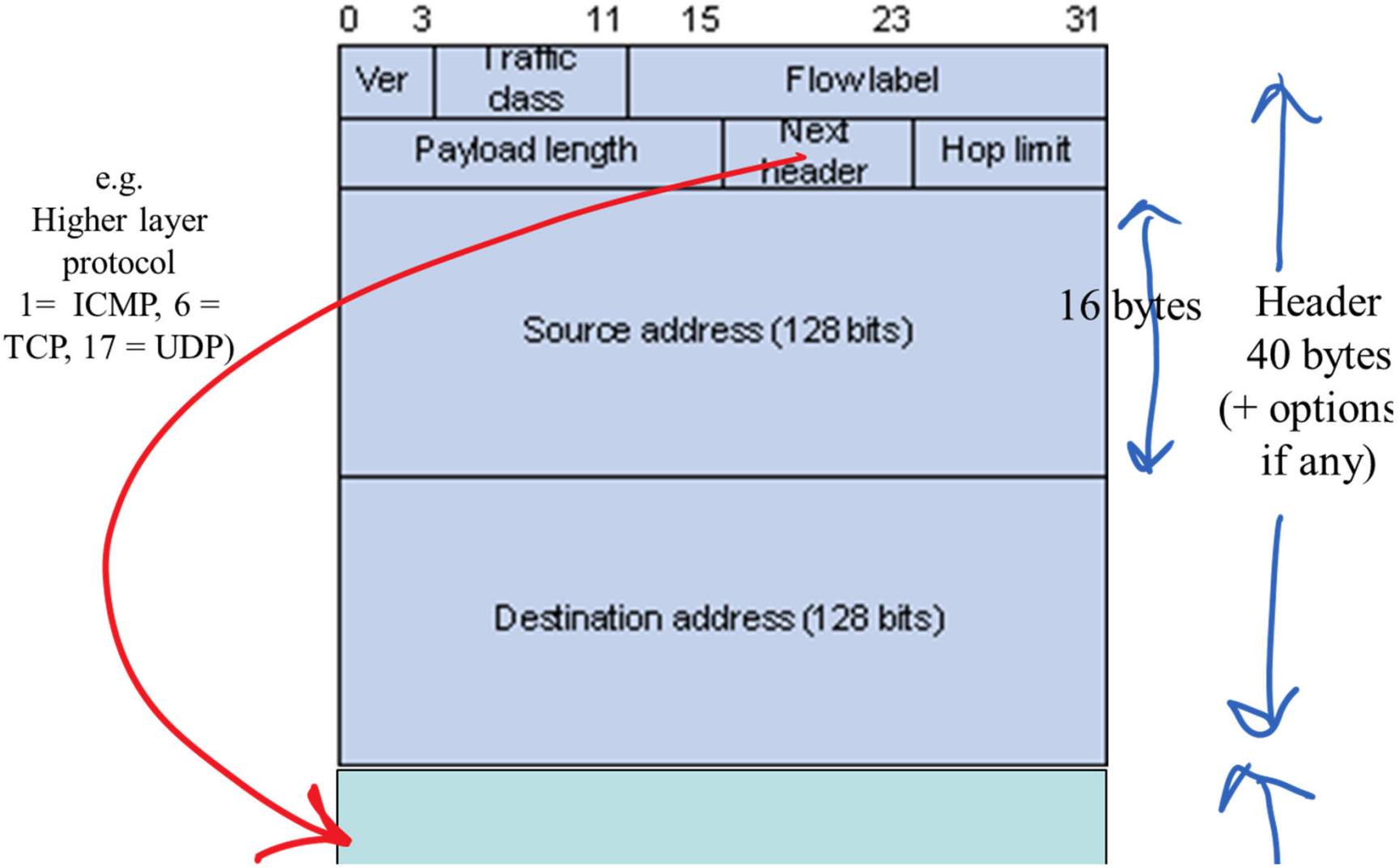
b) When an IPv6 host uses SLAAC, the host part is…

A. Mapped from MAC address
B. Randomly chosen
C. Both of the above are possible
D. None of the above are possible
E. I don’t know

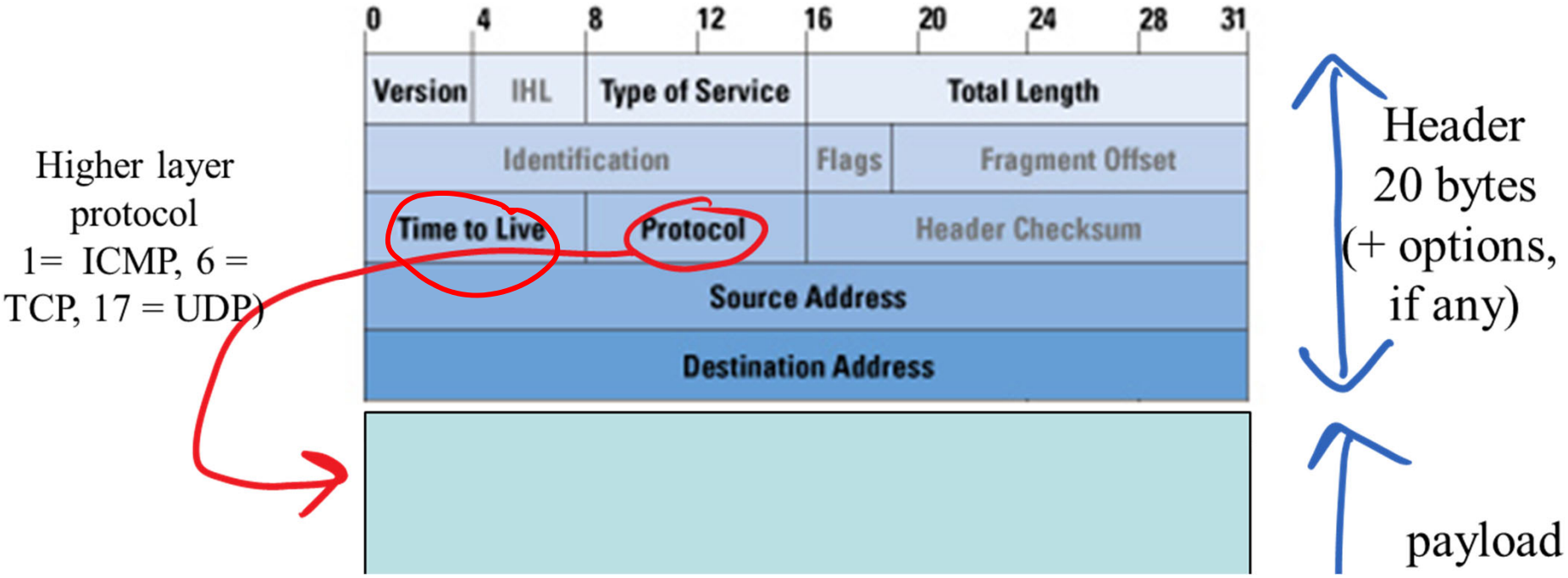
c) With SLAAC an IPv6 host has…

A. A link local address and, if a router is present in the subnet, also a global unicast address
B. If a router is present in the subnet a global unicast address and no link-local address
C. None of the above
D. I don’t know

8. IPv6 Header



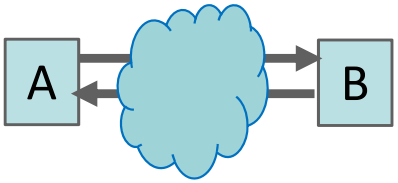
IPv4 Packet Format

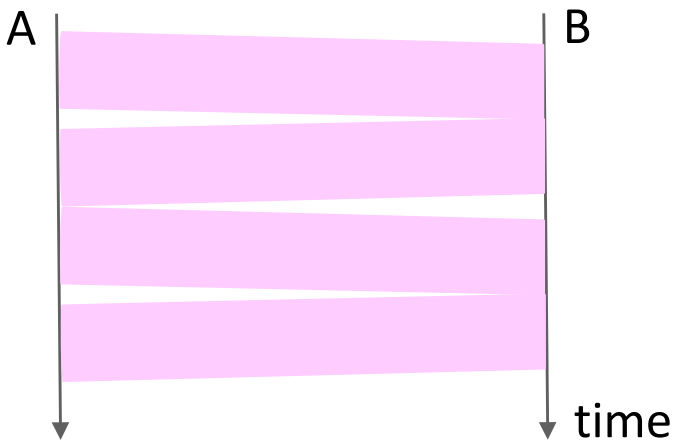


Hop Limit is called TTL (Time-to-live) in IPv4; however it is not a time but a hop count

Hop Limit (HL) / Time to Live (TTL)

Why ? Avoid looping packets in transient loops. If propagation time is small compared to transmission time, a single packet caught in a loop can congest the line.





Transient loops may exist due to non instantaneous changes to routing tables.

How ? Every IP packet has a field on 8 bits (from 0 to 255) (called HL for IPv6 / TTL for IPv4) that is decremented at every hop. When it reaches 0, packet is discarded. At source, value is 64 by default.

Traceroute

Sends a series of packets (using UDP) with TTL = 1, 2, 3, …

tracert (windows) similar but uses ICMP

Routers on the path discard packets and send ICMP error message back to source

source learns address of router on the path by looking at source address of error message

Tracing route to www.google.com [2a00:1450:4008:800::1012]
over a maximum of 30 hops:

1	1 ms	<1 ms	<1 ms	cv-ic-dit-v151-ro.epfl.ch [2001:620:618:197:1:80b2:9701:1]
2	<1 ms	<1 ms	<1 ms	cv-gigado-v100.epfl.ch [2001:620:618:164:1:80b2:6412:1]
3	<1 ms	<1 ms	<1 ms	c6-ext-v200.epfl.ch [2001:620:618:1c8:1:80b2:c801:1]
4	1 ms	<1 ms	<1 ms	swiEL2-10GE-3-2.switch.ch [2001:620:0:ffdc::1]
5	<1 ms	<1 ms	<1 ms	swiLS2-10GE-1-2.switch.ch [2001:620:0:c00c::2]
6	7 ms	7 ms	7 ms	swiEZ1-10GE-2-7.switch.ch [2001:620:0:c03c::2]
7	8 ms	8 ms	7 ms	swiEZ2-P2.switch.ch [2001:620:0:c0c3::2]
8	8 ms	8 ms	8 ms	swiIX2-P1.switch.ch [2001:620:0:c00a::2]
9	8 ms	8 ms	8 ms	swissix.google.com [2001:7f8:24::4a]
10	38 ms	34 ms	15 ms	2001:4860::1:0:4ca2
11	14 ms	14 ms	17 ms	2001:4860::8:0:5038
12	17 ms	50 ms	17 ms	2001:4860::8:0:8f8e
13	24 ms	24 ms	24 ms	2001:4860::8:0:6400
14	25 ms	25 ms	25 ms	2001:4860::1:0:6e0f
15	25 ms	24 ms	25 ms	2001:4860:0:1::4b
16	25 ms	25 ms	25 ms	ber01s08-in-x12.1e100.net [2a00:1450:4008:800::1012]

Other fields

Type of service / Traffic Class

- Differentiated Services (6bits) – sort of priority eg voice over IP
  Used only in corporate networks
- Explicit Congestion Notification (2bits) see congestion control

Total length / Payload length

- in bytes including header

≤ 64 Kbytes; limited in practice by link-level MTU (Maximum Transmission Unit)

- every subnet should forward packets of 576 = 512 + 64 bytes

Protocol / Next Header = identifier of protocol

- 6 = TCP, 17 = UDP
- 1 = ICMP for IPv4, 58 = ICMP for IPv6
- 4 = IPv4; 41 = IPv6 (encapsulation = tunnels)
- 50 = ESP (encrypted payload)
  51 = AH (authentication header)

Checksum

- IPv4 only, protects header against bit errors
- Absent in IPv6 ⇒ layer 2 and router hardware assumed to have efficient error detection

ICMP is used to carry error messages

Look inside an IPv4 packet

```
Ethernet II
    Destination: 00:03:93:a3:83:3a (Apple_a3:83:3a)
    Source: 00:10:83:35:34:04 (HEWLETT-_35:34:04)
    Type: IP (0x0800)
Internet Protocol, Src Addr: 129.88.38.94 (129.88.38.94), Dst Addr:
129.88.38.241 (129.88.38.241)
    Version: 4
    Header length: 20 bytes
    Differentiated Services Field: 0x00 (DSCP 0x00: Default; ECN: 0x00)
    Total Length: 1500
    Identification: 0x624d
    Flags: 0x04
    Fragment offset: 0
    Time to live: 64
    Protocol: TCP (0x06)
    Header checksum: 0x82cf (correct)
    Source: 129.88.38.94 (129.88.38.94)
    Destination: 129.88.38.241 (129.88.38.241)
```

Look inside an IPv6 packet

```
ETHER:  ----- Ether Header -----
ETHER:
ETHER:  Packet 1 arrived at 11:55:22.298
ETHER:  Packet size =  86 bytes
ETHER:  Destination = 33:33:ff:01:00:01
ETHER:  Source = 3c:07:54:3e:ab:f2
ETHER:  Ethertype = 0x86dd
ETHER:
IP:   ----- IP Header -----
IP:
IP:   Version = 6
IP:   Traffic class =0x00000000
IP:      ....  0000 00.. .... .... .... .... .... = Default Differentiated Service Field
IP:      ....    ....     ..0.  .... .... .... .... .... = No ECN-Capable Transport (ECT)
IP:      ....    ....     ...0  .... .... .... .... ....  = No ECN-CE
IP:   .... .... ....  0000 0000 0000  0000 0000 =  Flowlabel: 0x00000000
IP:   Payload length = 32
IP:   NextHeader= 58
IP:   Hop limit= 255
IP:   Source address = 2001:620:618:197:1:80b2:97c0:1
IP:   Destination address = ff02::1:ff01:1
IP:
```

IPv6

ICMP for IPv6 (this is an NDP packet used for address resolution)

solicited node multicast address

A host generates a packet with Hop Limit = 1

A. This packet is invalid
B. This packet will never be forwarded by a bridge nor by a router
C. This packet will never be forwarded by a bridge but may be forwarded by a router
D. This packet will never be forwarded by a router but may be forwarded by a bridge
E. None of the above is true
F. I don’t know

Conclusion

IP is built on two principles:

- one IP address per interface and longest prefix match; this allows to compress routing tables by aggregation
- inside subnet, don't use routers

IPv4 and IPv6 are not compatible – interworking requires tricks

NATs came as an after-thought and are widely deployed

ARP/NDP finds the MAC address corresponding to an IP address

DHCP is used allocates IP address, network mask and DNS server's IP address to a host

SLAAC automatically allocates IPv6 addresses without DHCP

TTL/HL limits the number of hops of an IP packet