IPv6

Tecnologie e Servizi di Rete

Computer Network Technologies and Services

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IPv6

Motivation and History

Motivation

- Why a new version of the IP protocol?
- Only one true answer:

"A larger address space"

32bit di IPV4 non bastano

Motivation

- Additional answers:
  - More efficient on LANs
  - Multicast and Anycast
  - Security comunicazione crittografata e autenticata a Livello 3
  - Policy routing
  - Plug and Play semplice x utenti
  - Traffic Differentiation
  - Mobility
  - Quality of Service support

Ported to IPv4

The long way to IPv6 adoption

NON CAMBIATO IL PROTOCOLLO MA
LA VERSIONE DEL PROTOCOLLO

- Long time for defining IPv6 and migrating to it
- Problems needed an interim solution in IPv4
  - Port IPv6 solutions to IPv4
  - Find workaround (e.g., NAT)
- When IPv6 reached "production" stage, many IPv4 solutions were acceptable

↳ CHE HANNO RESO IPV4 INGRADO DI SUPERARE
TUTTE LE LIMITAZIONI INCLUSA LA
DIMENSIONI DI INDIRIZZI GRAZIE A:

- INDIRIZZI PRIVATI
- NAT

Why are IPv4 addresses scarce?

OFF-TOPIC SU IPV6
CLASSE D → MULTICAST
CLASSE E → INUTILIZZATI

- 32-bit long addresses → about 4 billion addresses!
- However:
  - Only part of the addresses are assigned to stations
    - Divided into Class A, B and C
    - Addresses beginning by bx111 → CLASSE D are used for multicast and otherwise
    - Hence, "just" 3.5 billion addresses can be used!
  - They are used hierarchically
    - The prefix used in a physical network cannot be used in a different one
    - → Lots of unused addresses

→ HA RIDOTTO NOTEVOLMENTE IL NR DI INDIRIZZI UTILIZZABILI
≠
NR DI RETI CHE POSSO AVERE NEL MONDO

- Who needs them?
  - Roughly half the world populations has home access (4 billion)
  - 5.5 billion mobile phones in the world require Internet connectivity;
  - Internet of Things (IoT) will add about another 50 billion devices in this decade.

ABOUT IPV6

Interim solutions to the saturation of address space

- Introduction of network with "taylored" size
  - Netmask
- Private addresses
  - Intranet, RFC 1918
  - Not enough to solve the problem
    - It should be used in conjunction with NAT or ALG
- Network Address Translator (NAT)
  - Extremely popular but…
    - it breaks end-to-end reachability, increases processing load at gateways, adds complexity
  - Proposal for RSIP (Realm Specific IP)
- ALG (Application Layer Gateway)

Has all this been effective?

Who assigns IP addresses?

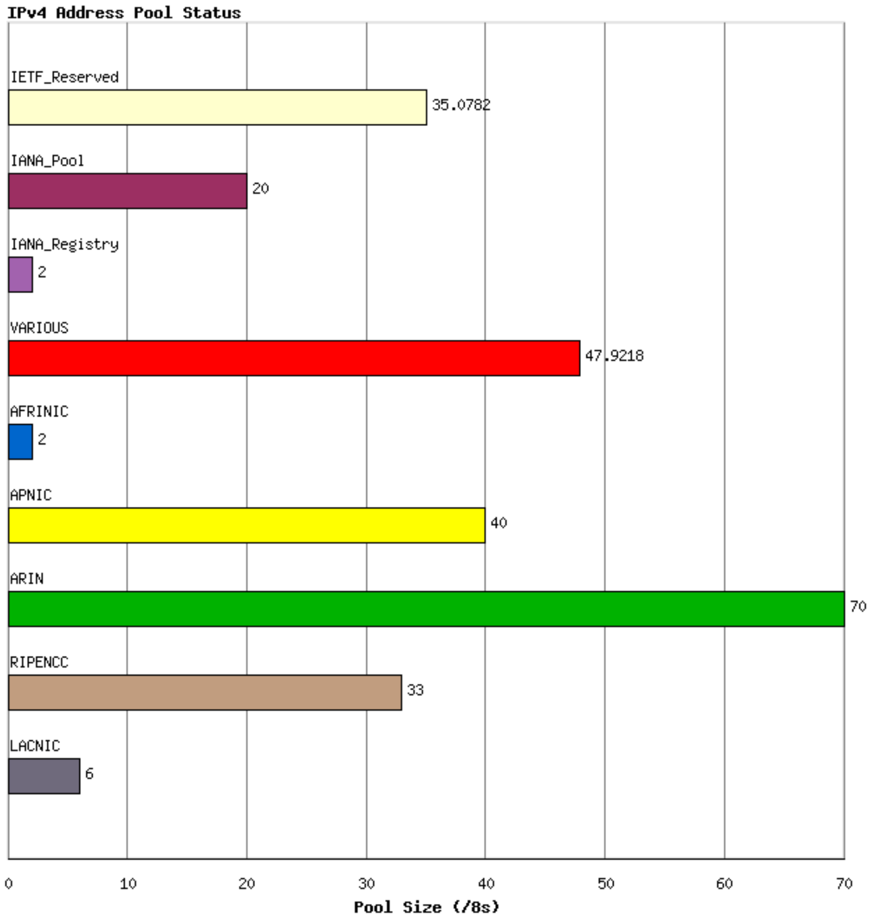
- IANA assigns blocks of /8 IP addresses to each Regional Internet Registry (RIR)
  - AFRINIC – Africa
  - APNIC – East Asia, Australia and Oceania
  - ARIN – USA, Canada and some Caribbean islands
  - LACNIC – South America, Mexico and some Caribbean islands
  - RIPE NCC – Europe, Middle East and Central Asia

↳ ENTITÀ CHE A LORO VOLTA RIASSEGNANO AI VARI PROVIDER CHE NE FANNO RICHIESTA

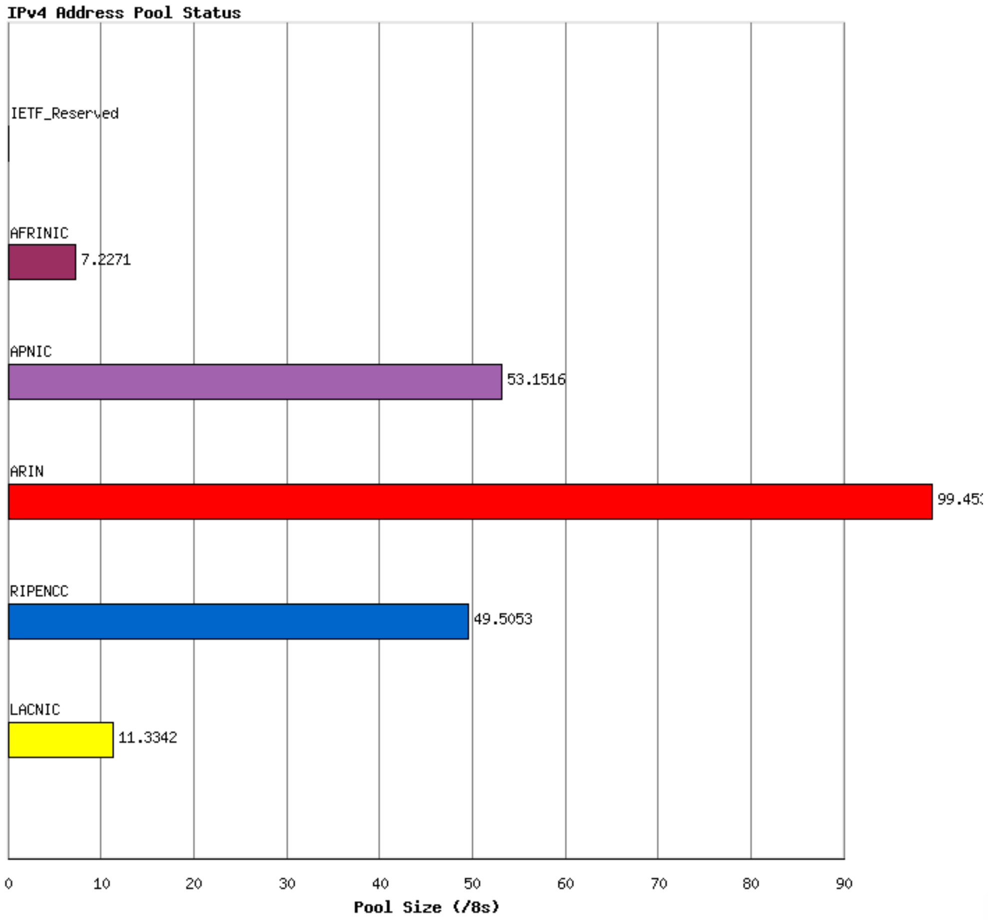
- Subsequently, RIRs split the blocks into smaller blocks and assign them to respective National Internet Registries (NIRs) and Local Internet Registries (LIRs)

IPv4 Address Pool status

2010



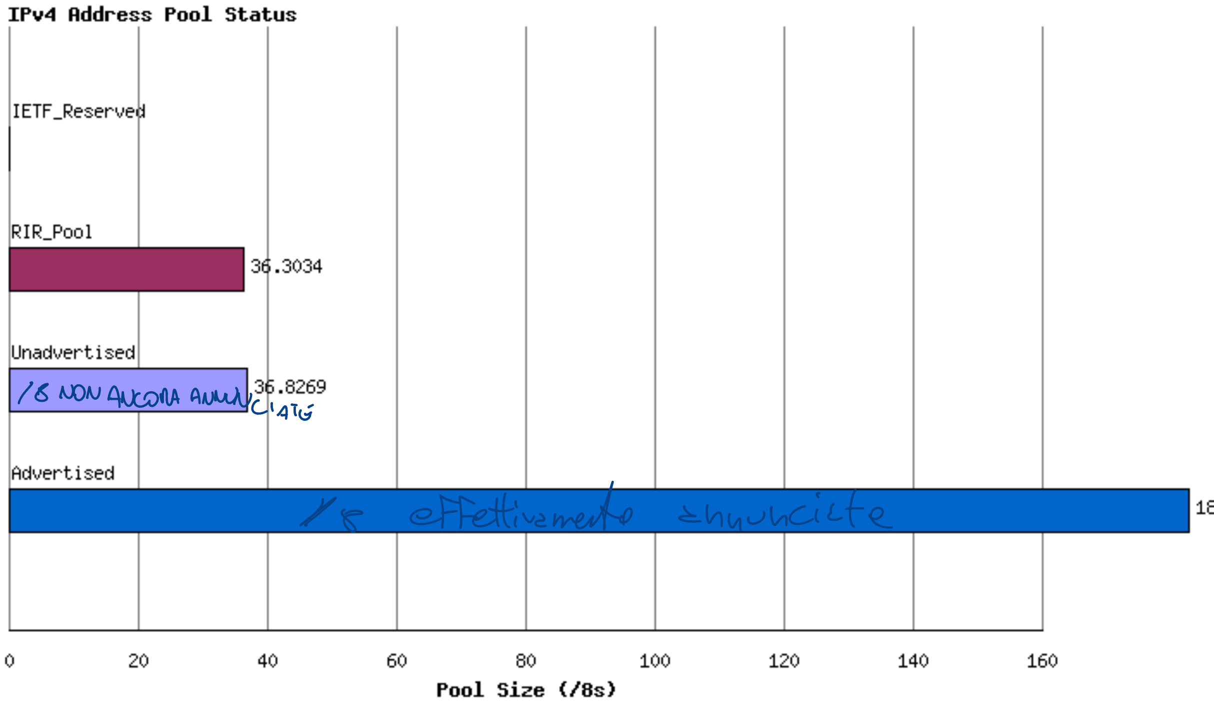
Today



IPv4 Address Pool status

BGP: protocollo di routing che tiene insieme le varie reti IP ⇒ FA SI CHE I PROVIDER POSSANO SCAMBIARSI TRA LORO

- Any individual IPv4 address can be in any one of five states:
  - reserved for special use, or
  - part of the IANA unallocated address pool,
  - part of the unassigned pool held by an RIR,
  - assigned to an end user entity but unadvertised by BGP, or
  - assigned and advertised in BGP



IPv4 Address Pool status

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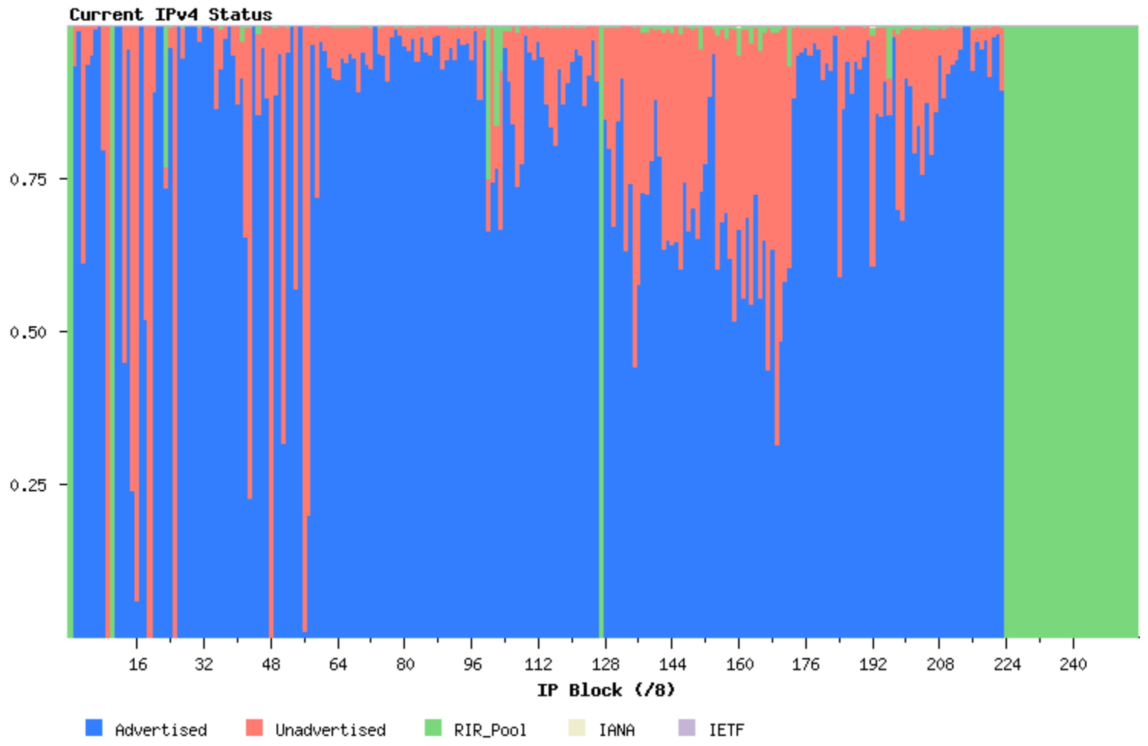
  - reserved for special use, or
  - part of the IANA unallocated address pool,
  - part of the unassigned pool held by an RIR,
  - assigned to an end user entity but not advertised in the routing system, or
  - assigned and advertised in BGP.

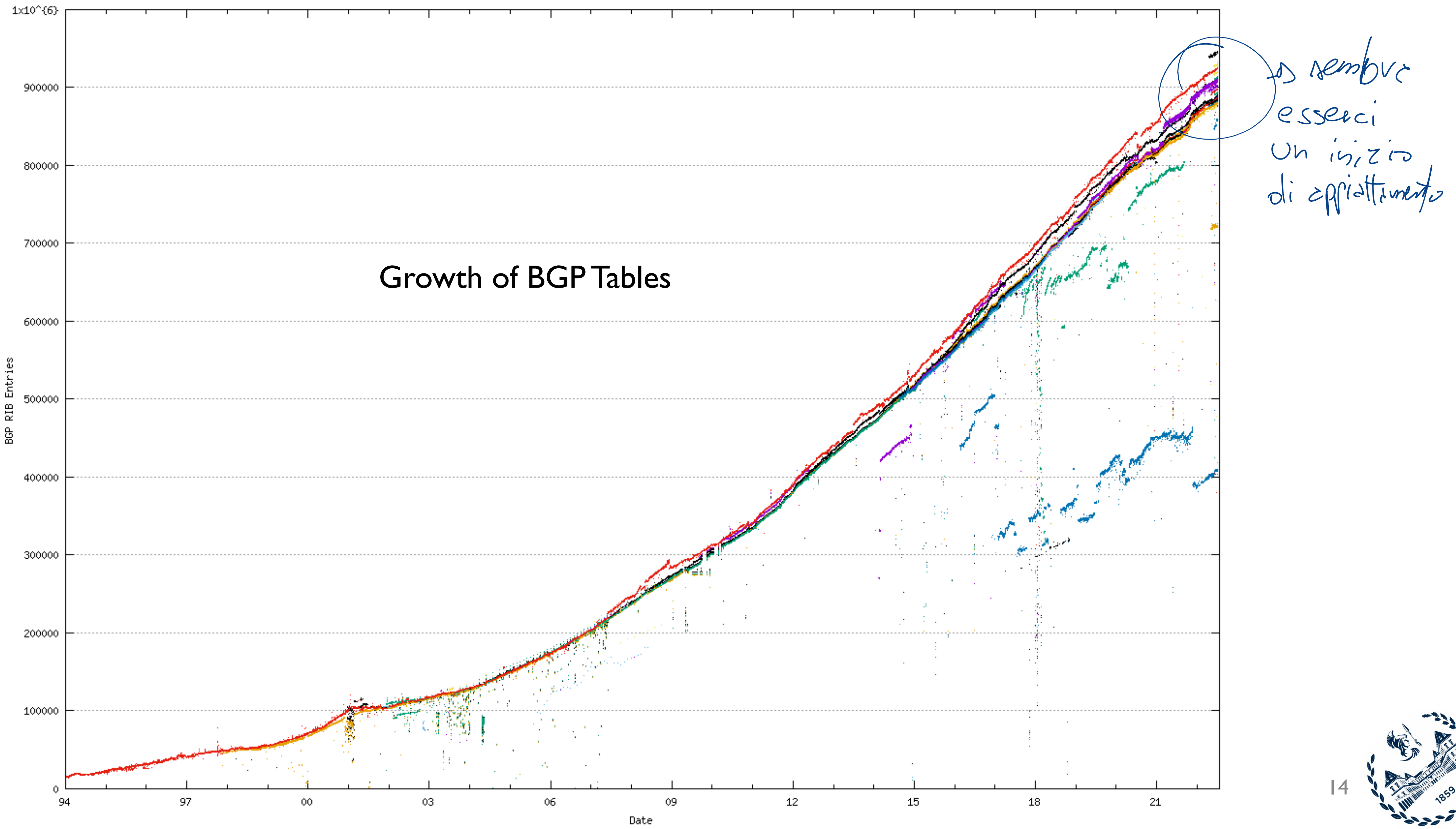


Routing Scalability Issues

- Routing table size
  - Internet size
  - Each subnetwork must be advertised → ANNUNCIATA
- Problems
  - Router resource limitations
    - Too much information to manage
- Routing protocol limitations
  - High probability of route changes
- Mainly affecting backbone routers

Routing Scalability Issues

PROBLEMA:
- DIVERSE RETI IPV4 SONO STATE ASSEGNATE IN MANIERA NON GERARCHICA MA CLASSFULL → non riesco ad aggregare tutti
- CAMBIO DI PROVIDER MANTENENDO STESSO INDIRIZZO IP → DEVO RIORGANIZZARE TABELLE
- ACCORDI TRA VARI PROVIDER PER SCAMBIARE TRAFFICO DIRETTO



Possible solution with IPv4

- Aggregate multiple routes in one
  - Shorter prefix including others
  - 1.2.1.0/24, 1.2.2.0/24 …
  - 1.2.0.0/16

- CIDR (Classless Inter-Domain Routing)

- Limited by non-rational assignment of IP prefixes

Interim (IPv4) solutions to routing scalability

- CIDR
  - Classless Inter-Domain Routing
- Limiting the assignment of IP addresses
  - Regional Internet Registry: assign address blocks only to big players
  - E.g., maximum /20 (4096 addresses) network
- Scalability of routing protocols
  - No solution, at present
- Problem not completely solved
  - It is the major problem that IPv6 wanted to solve that it is still open

→ HA UNA MODALITÀ DI AUTO CONFIGURAZIONE CHE DOVREBBE LIMITARE LA POSSIBILITÀ DI CAMBIARE PROVIDER SENZA CAMBIARE IP

→ QUANDO MI SPOSTO I ROUTER POSSONO AUTO-CONFIGURARE TUTTA LA RETE CON IL NUOVO IP

Birth of IPv6

- IETF Boston Meeting (1992), "Call for proposals for IPng"
  - Appointment of dedicated Working Groups

    → COMITATO CHE HA REALIZZATO LA NUOVA CONFIGURAZIONE DI IP
- Several proposals
  - TUBA (TCP and UDP with Bigger Addresses): adopting OSI CLNP as new IP
  - CATNIP: integration of different network (IP, CLNP, IPX) and transport (TP4, SPX, TCP, UDP) protocols
  - SIPP: incremental over IPv4 → PIÙ CONSEQUATIVA
    - Fix some drawbacks
    - Minimal protocol changes: increasing the address field and eliminating unused ones
- Winning proposal: SIPP with 128-bit addresses

IPv6

Addresses

How many addresses for IPv6?

- Scientific approach followed
- Addressing efficiency (RFC 1715)

effettivamente usati nel '92

Efficienza di indirizzamento $H = \dfrac{\log_{10}(\text{number of addresses})}{\text{number of bits}}$

- In existing non-IP networks, H varies between 0.14 (pessimistic) and 0.26 (optimistic)

→ NON MOLTO ELEVATA

	Pessimistic (0.14)	Optimistic (0.26)
32 bits	3 E+4	2 E+8
64 bits	9 E+8	4 E+16
80 bits	1.6 E+11	2.6 E+27
128 bits	8 E+17	2 E+33

Final decision: 128 bits

• 107 bit e H=0,14 → POSSO AVERE UN MILIONE DI MILIARDO DI RETI

- Assuming one million billion networked stations
  - 107 bits in the minimum efficiency case
- To put it in perspective… 655.570.793.348.866.943.898.599 IPv6 addresses per m^2 of Earth surface

IPv4
4.29 Billion

IPv6
340 Undecillion

Number Name	Scientific Notation	Number of Zeros
1 Thousand	10^3	1,000
1 Million	10^6	1,000,000
1 Billion	10^9	1,000,000,000
1 Trillion	10^{12}	1,000,000,000,000
1 Quadrillion	10^{15}	1,000,000,000,000,000
1 Quintillion	10^{18}	1,000,000,000,000,000,000
1 Sextillion	10^{21}	1,000,000,000,000,000,000,000
1 Septillion	10^{24}	1,000,000,000,000,000,000,000,000
1 Octillion	10^{27}	1,000,000,000,000,000,000,000,000,000
1 Nonillion	10^{30}	1,000,000,000,000,000,000,000,000,000,000
1 Decillion	10^{33}	1,000,000,000,000,000,000,000,000,000,000,000
1 Undecillion	10^{36}	1,000,000,000,000,000,000,000,000,000,000,000,000
340,282,366,920,938,463,463,374,607,431,768,211,456		

Notation

- 8 hexadecimal numbers separated by “:” **x:x:x:x:x:x:x:x**
  - Groups of 2 bytes → OGNI ESADECIMALE RAPPRESENTA 2 BYTE

- Examples:
  - FEDC:0000:0876:45FA:0562:0000:3DAF:BB01
  - 1080:0000:0000:0007:0200:A00C:3423:A089

- Shortcut rule #1: Leading 0s in each digit group can be omitted
  - 1080:0:0:7:200:A00C:3423:A089
- Shortcut rule #2: All-0s Hextets can be substituted by “::” (only once)
  - 1080::7:200:A00C:3423:A089
  - FEDC:0000:0876:45FA:0562:0000:3DAF:BB01 → FEDC::0876:45FA:0562::3DAF:BB01

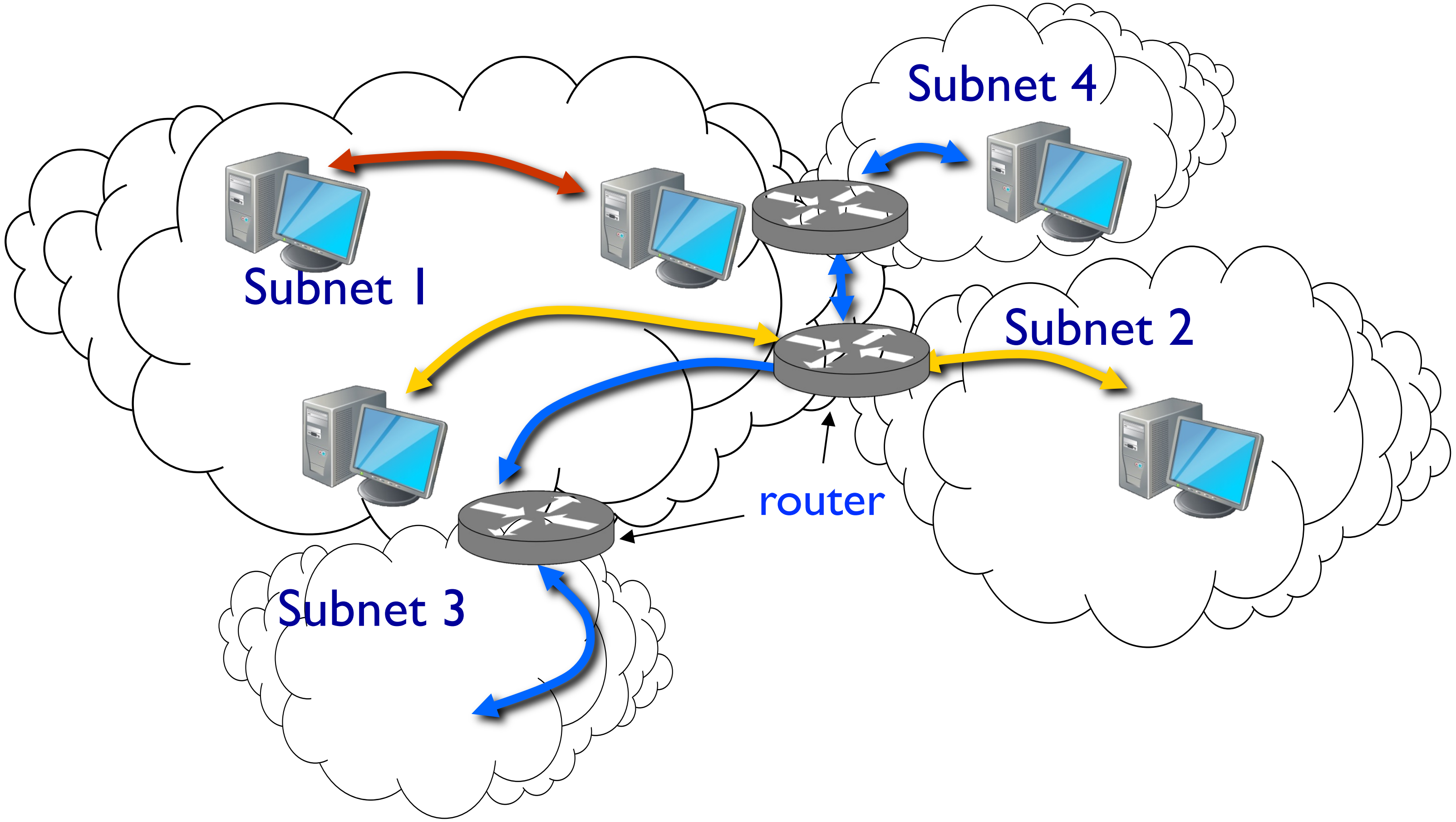
IPv6

Routing and Addressing Principles

Host Addresses

Same routing principles as IPv4

SOBNET INTERCONNESSE DA ROUTER



Address Structure

Prefix (n bits)	Interface ID (128-n bits)

n=64

→ al momento fissato a 64 → tutte le reti IPv6 fisiche
DELLA STESSA DIMENSIONE /64

Prefix

- Address/netmask pair is substituted by a “Prefix”
- Address/N, where N is the prefix length [bit]
- Examples:
  - FEDC:0123:8700::100/40 → DOPO 40 BIT MI FINISCE IL PREFISSO
  - Prefix: 1111111011011100000000010010001110000000
  - Interface ID: 0000000000000000000000000000000000000000000000000000000000000000
    000000000000000100000000

- No address classes!

Address assignment principles

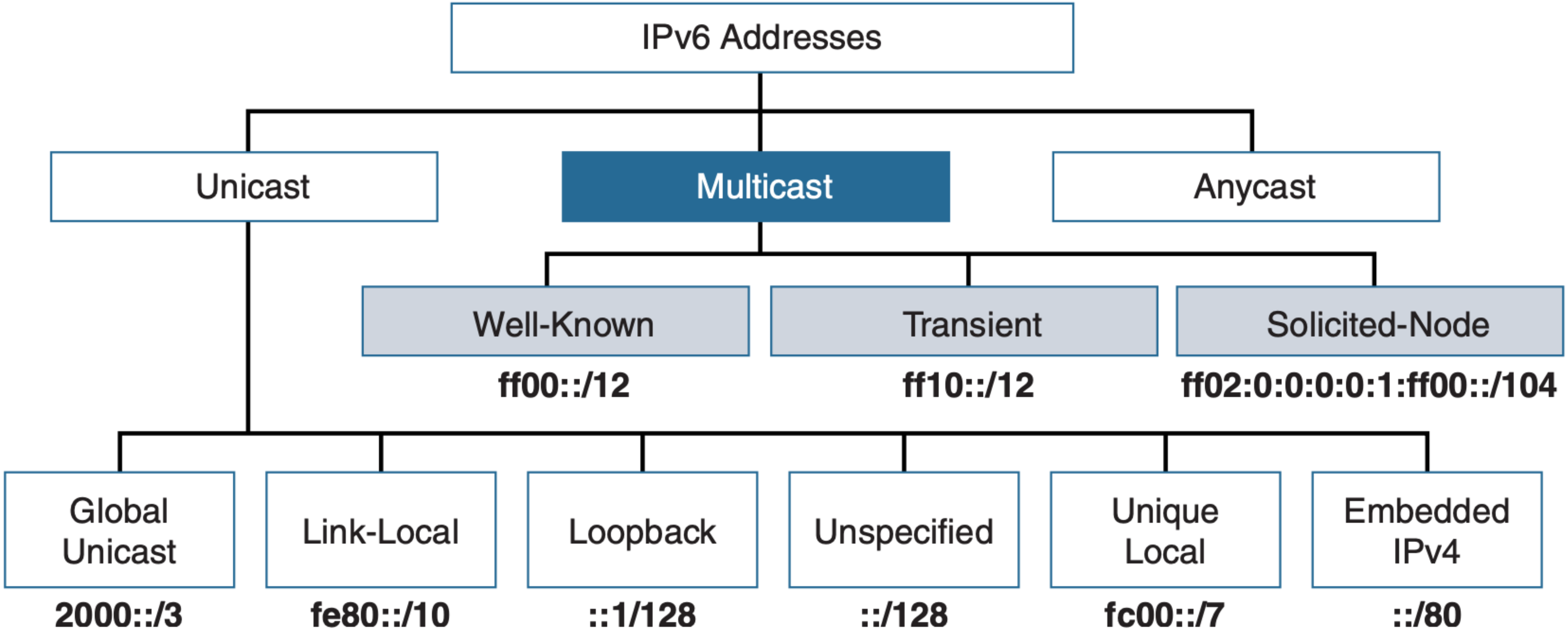
- Same as IPv4 (different terminology)
- Subnetwork: set of hosts with same prefix
- Link: physical network
- Subnetwork = Link!

- On-link hosts have the same prefix
  - Direct communication

- Off-link hosts have different prefix
  - Communication through a router

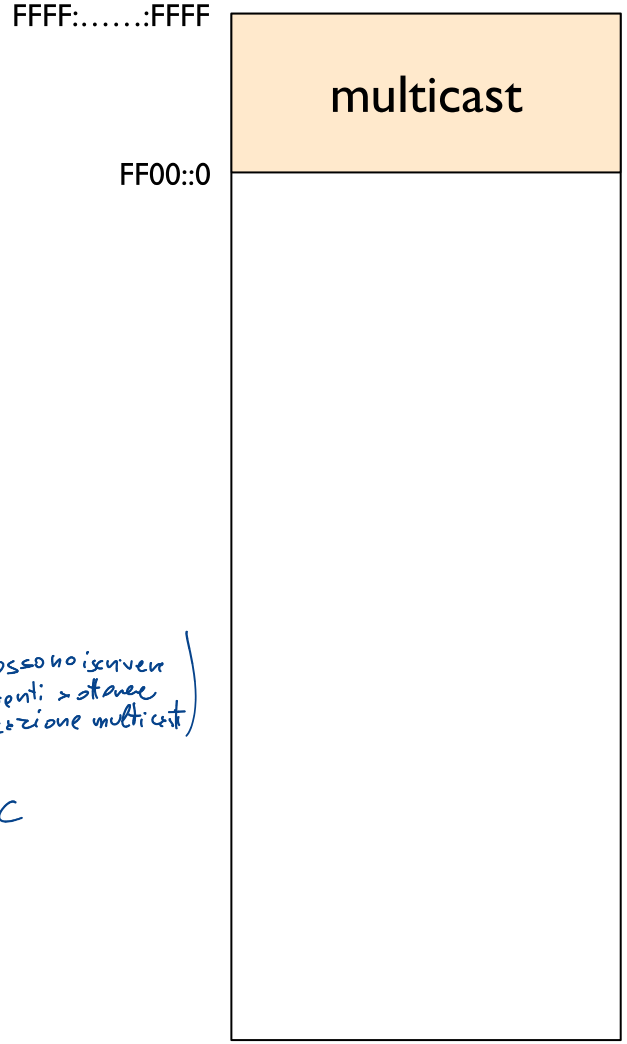
IPv6 Address Space - Multicast

BROADCAST e DIRECTED BROADCAST NON ESISTONO



Multicast addresses

- Multicast
  - 1111 1111 ….
  - FF00::/8 → FFxx:xxx….
- equivalent to the IPv4 multicast address 224.0.0.0/4
- Further divided into:
  - *Well-known Multicast* (FF00::/12): predefined or reserved multicast addresses for assigned groups of devices (e.g., routers)
  - *Transient* (FF10::/12): dynamically assigned by multicast apps (dove si possono iscrivere i vari utenti x ottenere comunicazione multicast)
  - *Solicited-node Multicast* (FF02:0:0:0:0:1:FF00::/104): similar to IP broadcast address in ARP (see later) → per risoluzione di indirizzi da IPv6 a MAC tramite IGMP



Multicast addresses

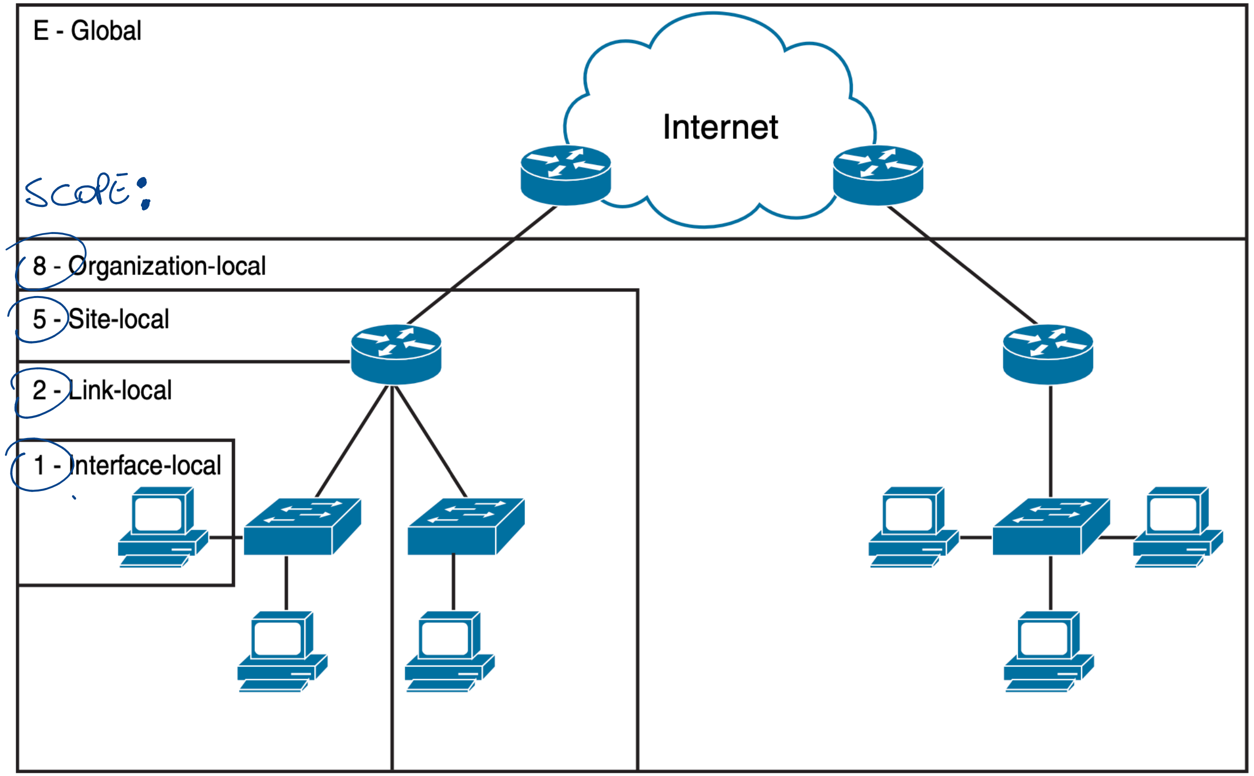
8 Bits	4 Bits	4 Bits	112 Bits
1111 1111 F F	Flag 0RPT	Scope	Group ID

FF00::/8

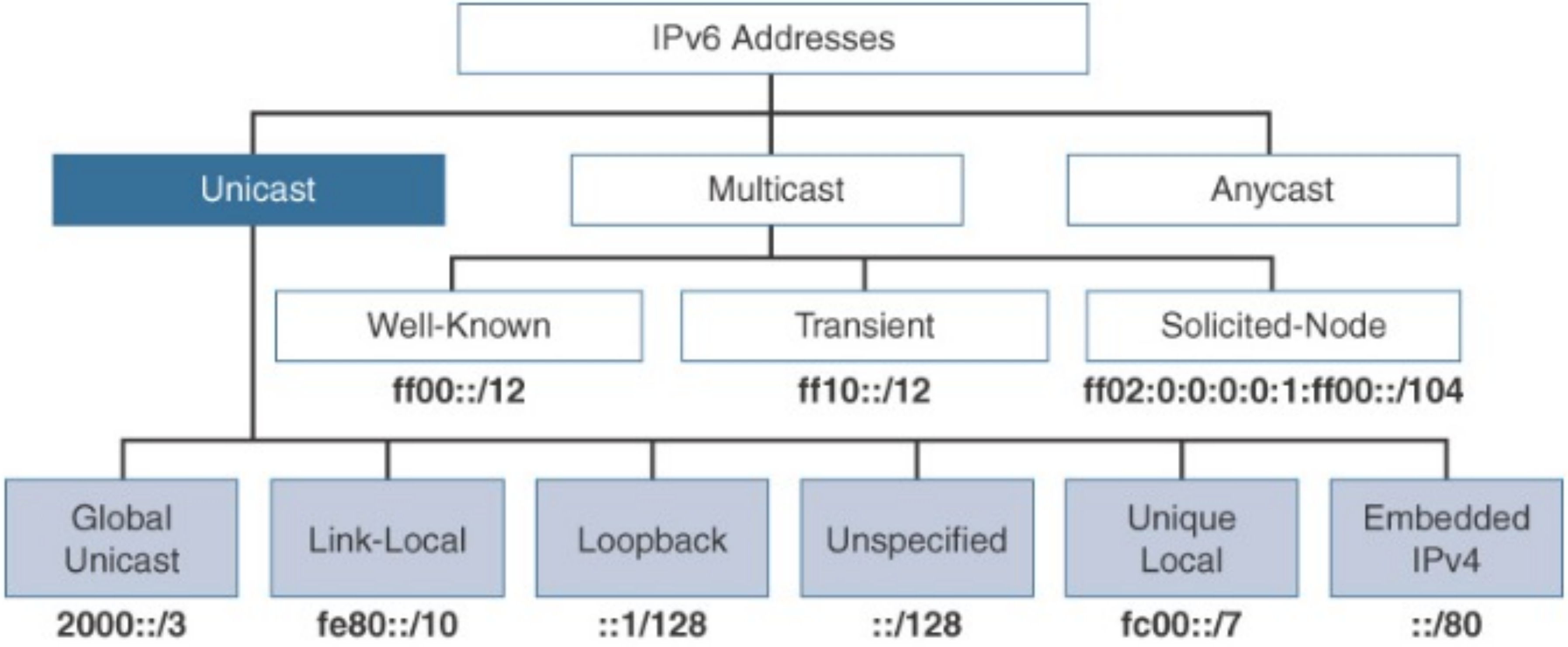
T Flag

0 Permanent, well-known multicast address assigned by IANA
1 Non-permanently-assigned ("transient" or "dynamically assigned") multicast address

- Scope: allows devices to define the range of the multicast packet
  - how broadly to propagate the packet

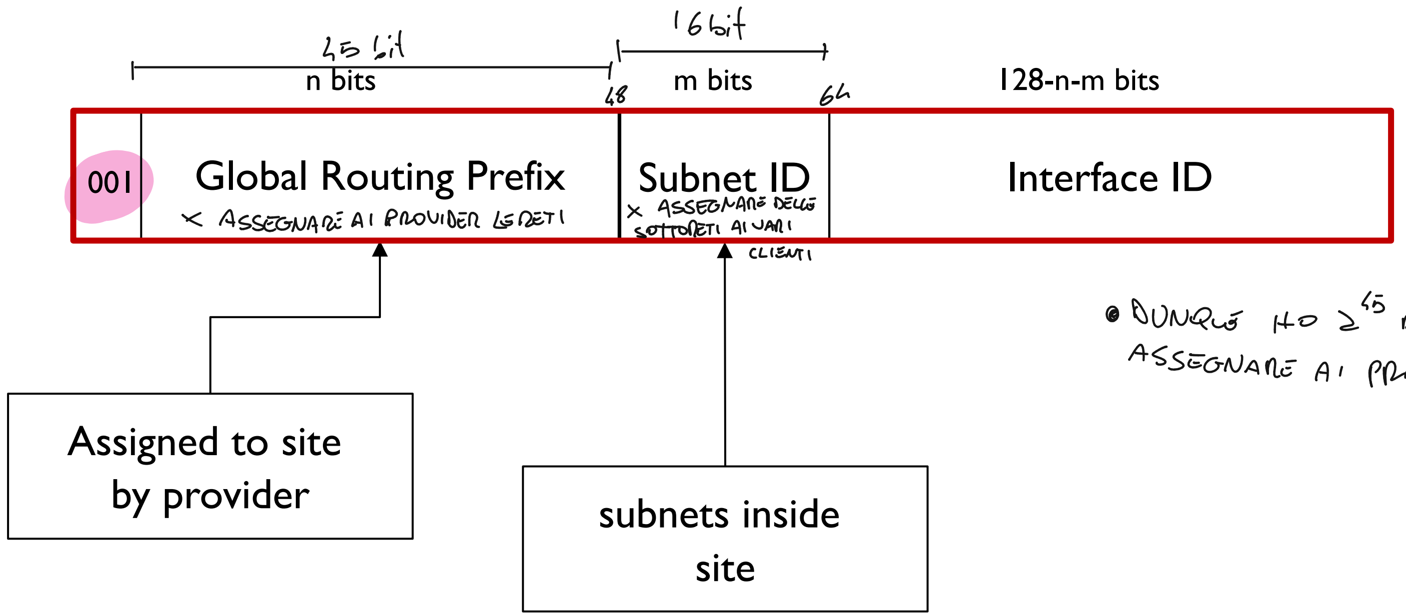


IPv6 Address Space - Unicast

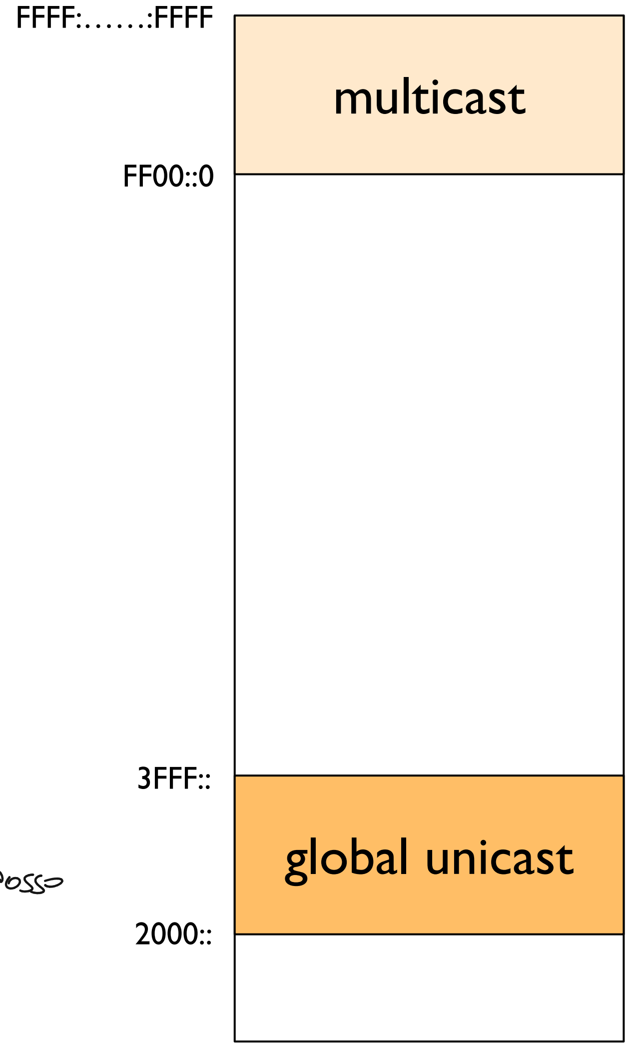


Global Unicast Addresses (IPV6 pubblici) 001

- also known as aggregatable global unicast addresses
- globally routable and reachable
- Plug and play
- equivalent to public IPv4 addresses
- Topology-based assignment with effective aggregation

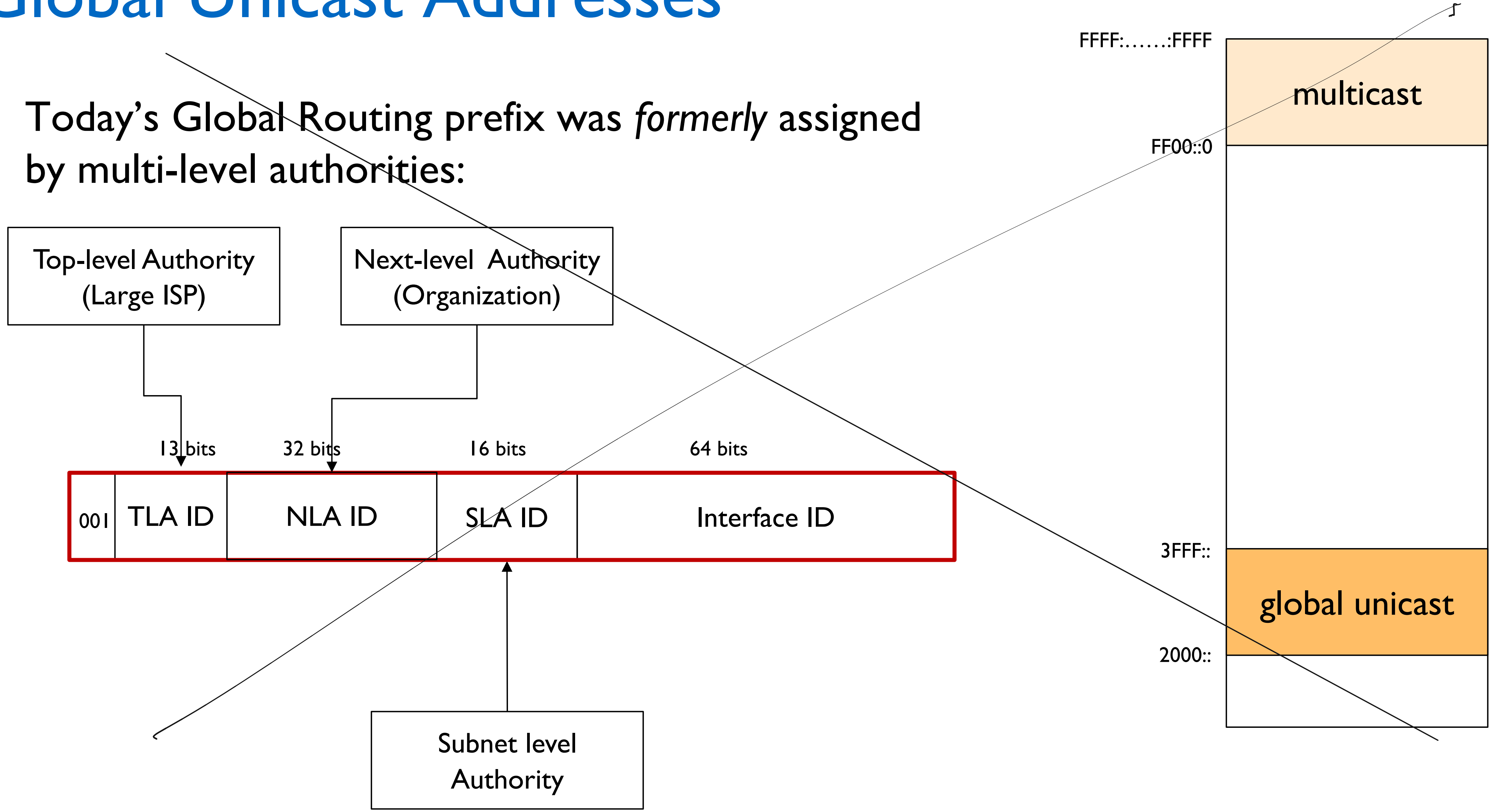


- DUNQUE HO 2^{45} RETI CHE POSSO ASSEGNARE AI PROVIDER



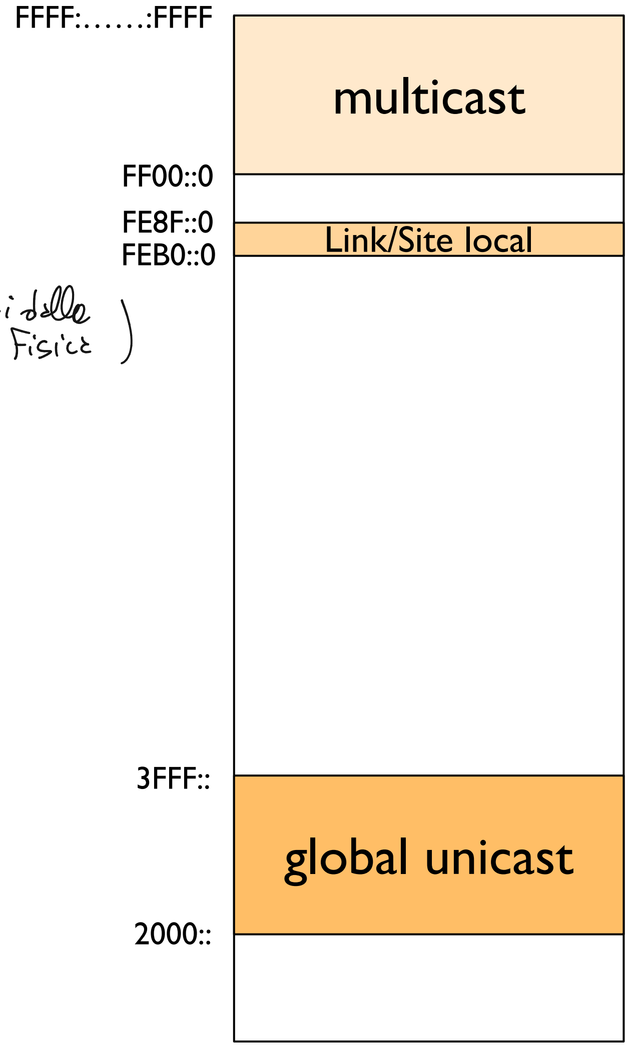
Global Unicast Addresses

- Today's Global Routing prefix was *formerly* assigned by multi-level authorities:



Link local/site local addresses

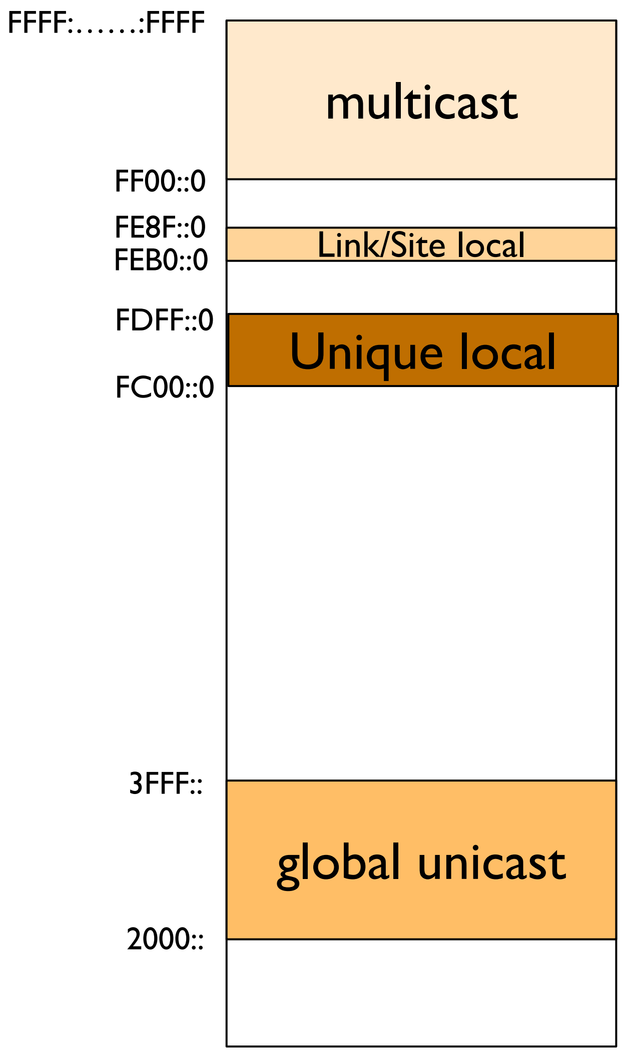
- Link/site local
  - 1111 1110 1….
- Link local (All'interno della rete locale: non posso usarlo x comunicare fuori dalla mia rete Fisica)
  - Used for addresses on a single link for auto-address configuration, neighbor discovery, or when no routers are present
  - Packets sent to these addresses are not supposed to be forwarded across local links
  - 1111 1110 10….
  - FE80::/64 → FE80 e poi ∅ FINO AL 64° LINK
- Site local
  - Deprecated → SI CONSIGLIA DI NON USARLI
  - FEC0::/10



NON POSSO ACCEDERE AD INTERNET DIRETTAMENTE CON QUESTO IP → HO BISOGNO DELLA NAT

Unique Local Addresses

- ULA addresses can be used similarly to global unicast addresses but are for private use and should not be routed in the global Internet
- FC00::/7
- Used for devices that never need access to the Internet and never need to be accessible from the Internet
- The 8th bit is the "Local (L) Flag", dividing the range in:
  - fc00::/8 (1111 1100): If L flag is 0, may be defined in the future
  - fd00::/8 (1111 1101): If L flag is 1, the address is locally assigned
  - fd00::/8 are the only valid ULA addresses today! → PRIVATI

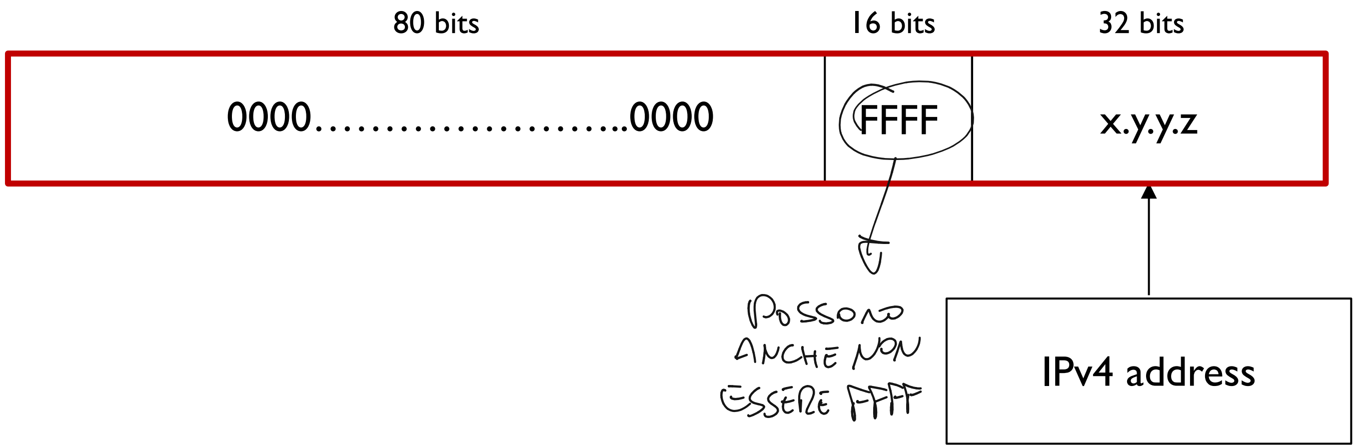


	40 bits	16 bits	64 bits
1111 1101 ULA	Randomly generated ALGORITMO CHE MINIMIZZA PROBABILITÀ DI ASSEGNARE A DUE UTENTI LO STESSO IP LOCALE.	Subnet ID ALL'INTERNO DEL MIO ADDRESS RANGE PRIVATO POSSO CREARE PIÙ SOTTORETI	Interface ID

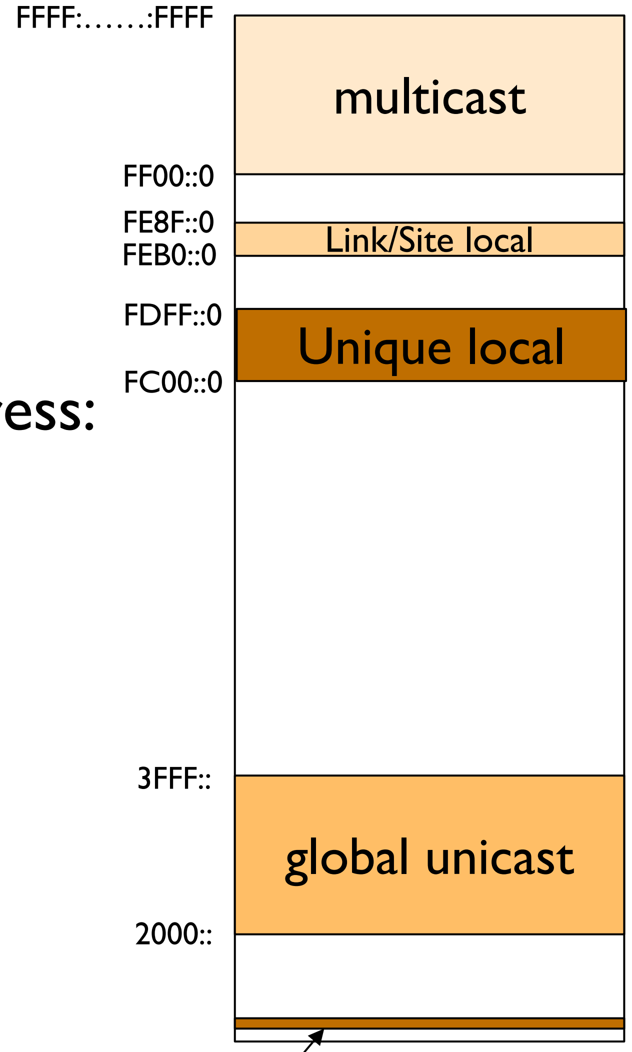
IPv4 Embedded Addresses

MODO PER RAPPRESENTARE IPV4 SU IPV6

- used to represent an IPv4 address inside an IPv6 address
- aid the transition from IPv4 to IPv6
- IPv4 address carried in the low-order 32 bits
- e.g., IPv6 compressed format of IPv4-mapped 20.10.4.3 address:
  - ::ffff:20.10.4.3



→ IN BASE A COSA C'È IN QUESTI 16 BIT CAPISCO COSA FARE



Loopback Addresses

(NON MI DILUNGO)

- Used by a node to send an IPv6 packet to itself for testing reasons
- ::1 (000…1)
- Equivalent to IPv4 address: 127.0.0.1
- Same rules as IPv4:
  - cannot be assigned to a physical interface.
  - packets with a loopback address should never be sent beyond the device.
  - routers can never forward packets with a destination address that is a loopback address.
  - device must drop a packet received on an interface if the destination address is a loopback address.

Unspecified Addresses

- An unspecified unicast address is an all-0s address
- An unspecified unicast address is used as a source address to indicate the absence of an address.
- It cannot be assigned to an interface.
- Used in duplicate address detection in ICMPv6

Anycast address

INDIRIZZI CHE RAPPRESENTANO PIÙ HOST → servono tecniche x far sì che i pacchetti giungano ad uno di quei particolari host

- Address that can be assigned to more than one interface (typically different devices).
  - multiple devices can have the same anycast address
- A packet sent to an anycast address is routed to the “nearest” interface having that address, according to the router’s routing table
- Initially designed for DNS but still in the experimental stages (although first RFC dates back to 1993!)

IPv6

Modified Protocols

What changes in the protocol architecture?

- IP
- ICMP
- ARP
  - Integrated in ICMP
- IGMP
  - Integrated in ICMP

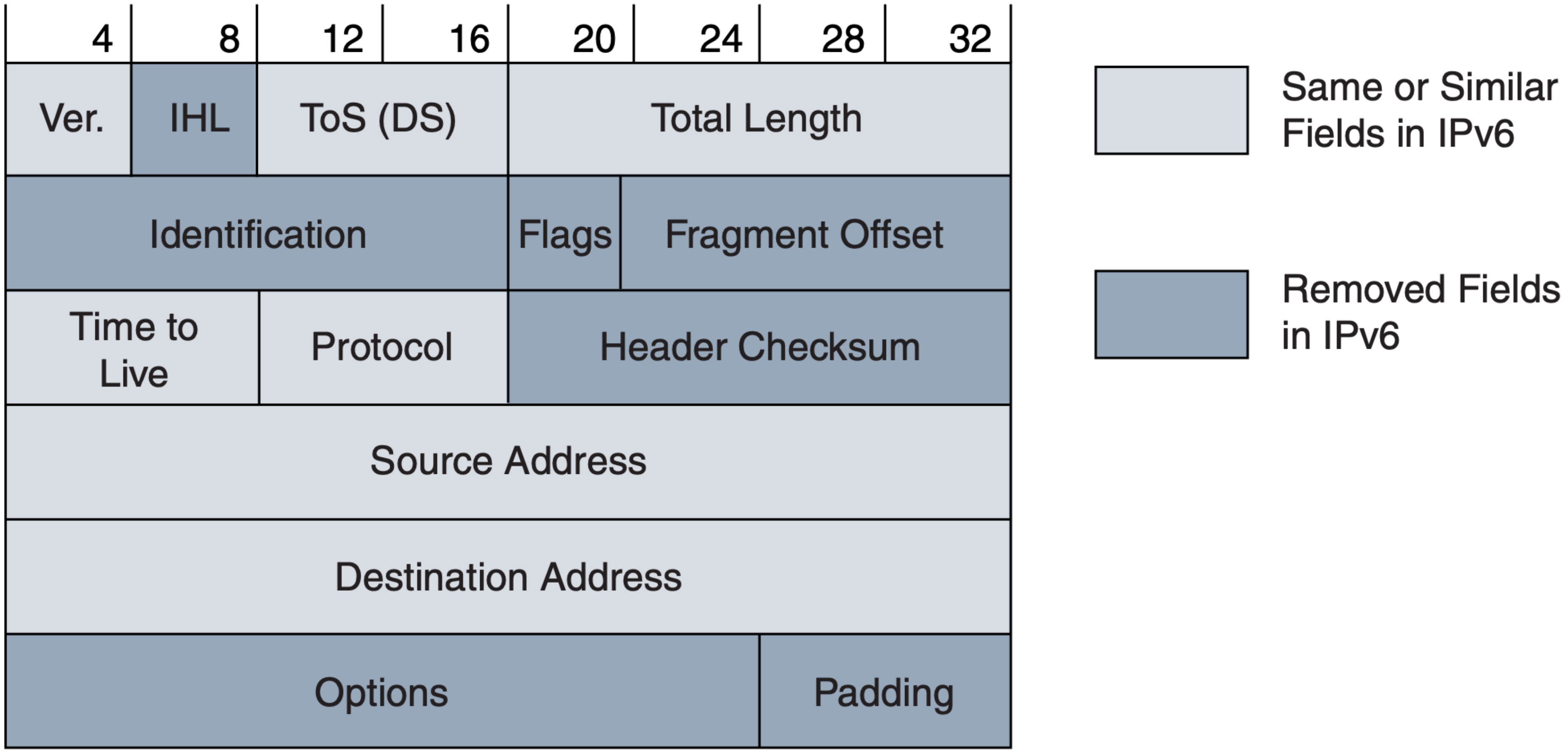
Upgraded but not changed

- DNS (type AAAA record) → CORRISPONDENTE ALL'IPV6 (QUERY AAAA) (QUERY DI TIPO A era per IPV4)
- RIP and OSPF
- BGP and IDRP
- TCP and UDP
- Socket interface

What about
layer independence?

Packet Header Format

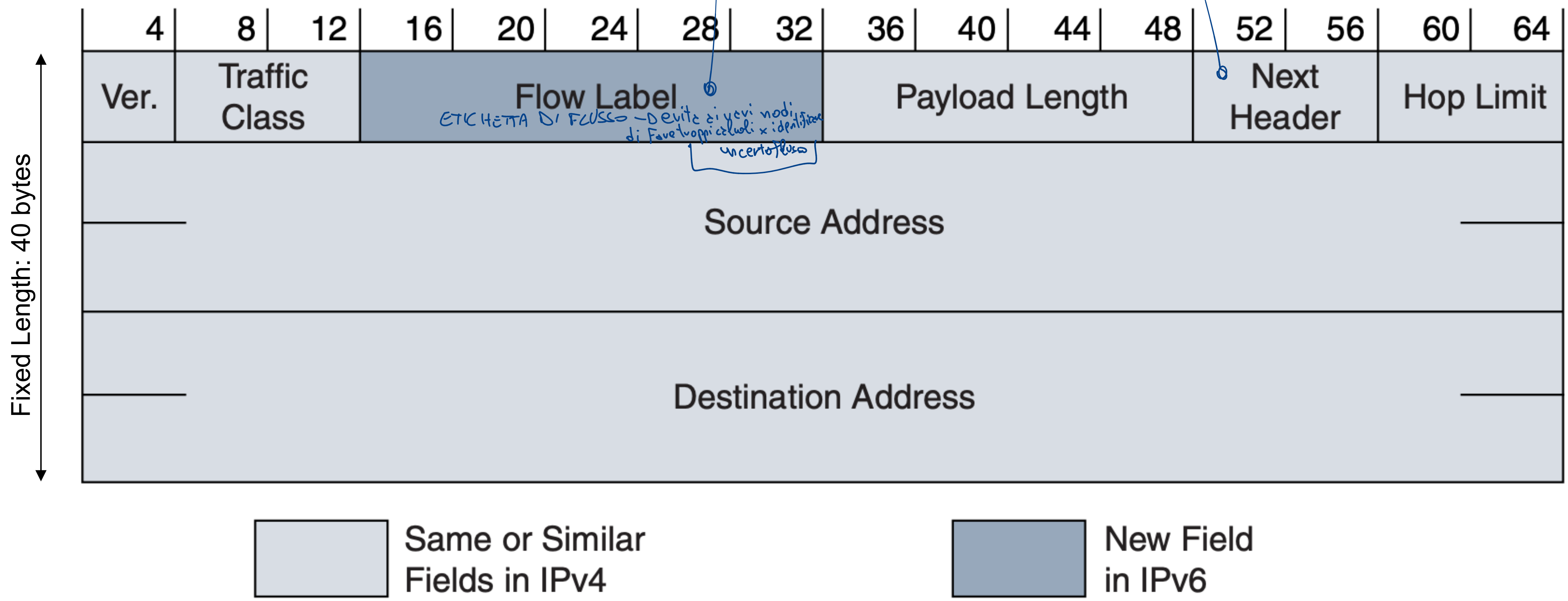
Recall the IPv4 header



IPv6 Header

AGGIUNTO X AIUTARE GLI AMMINISTRATORI DI RETE A GARANTIRE QUALITÀ DI SERVIZIO

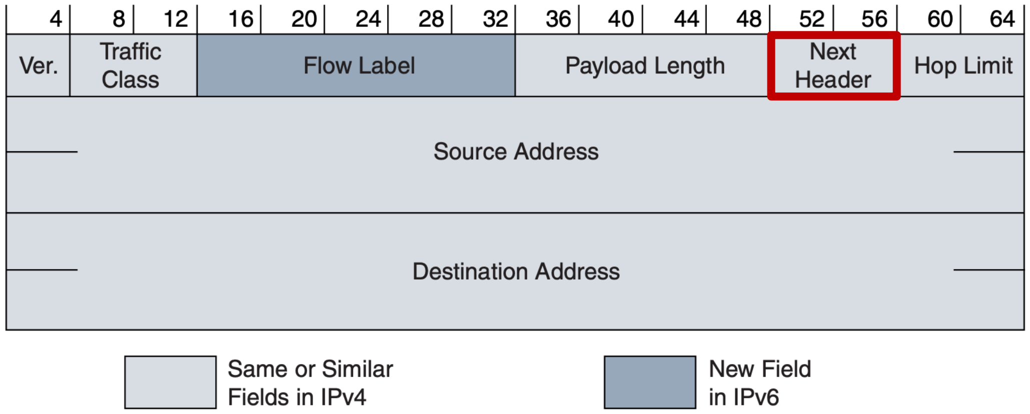
DOPO DI NOI C'È L'OPZIONE (ES:) AUTENTICAZIONI



Removed fields

- Header Checksum
  - Redundant: Layer 2 data link technologies perform own checksum and error control.
  - Upper-layer protocols such as TCP and UDP have their own checksums
  - Note: UDP checksum becomes *mandatory* in IPv6
- Fragmentation
  - IPv6 routers do not fragment a packet unless they are the source of the packet
  - Packets larger than MTU are dropped and an ICMPv6 Packet Too Big message is returned to source
- Header Length
  - Fixed to 40 bytes

Extension headers



- Next Header: similar to IPv4 "Protocol" field
  - It specifies the protocol carried in the data portion of the IPv6 packet
- Additional "Next Header" fields are added in header extensions to allow chaining
- Protocols coded using same values as IPv4 (plus some)
  - 0: Hop by Hop option 6: TCP 17: UDP 43: Routing extension 44: Fragment header 50: Encapsulating Security Payload 51: Authentication 60: Destination option ……
  - 59: no next header

Estensioni degli header
n Next Header: simile al campo "Protocol" di IPv4
n Specifica il protocollo trasportato nella parte dati del pacchetto IPv6
n Vengono aggiunti ulteriori campi "Next Header" nelle estensioni degli header per consentire l'inserimento di più estensioni
n I protocolli sono codificati utilizzando gli stessi valori di IPv4 (più alcuni)
n 0: Opzione Hop by Hop 6: TCP 17: UDP 43: Estensione di routing 44: Header di frammentazione
50: Payload di sicurezza incapsulato 51: Autenticazione 60: Opzione di destinazione ...
n 59: nessun prossimo header

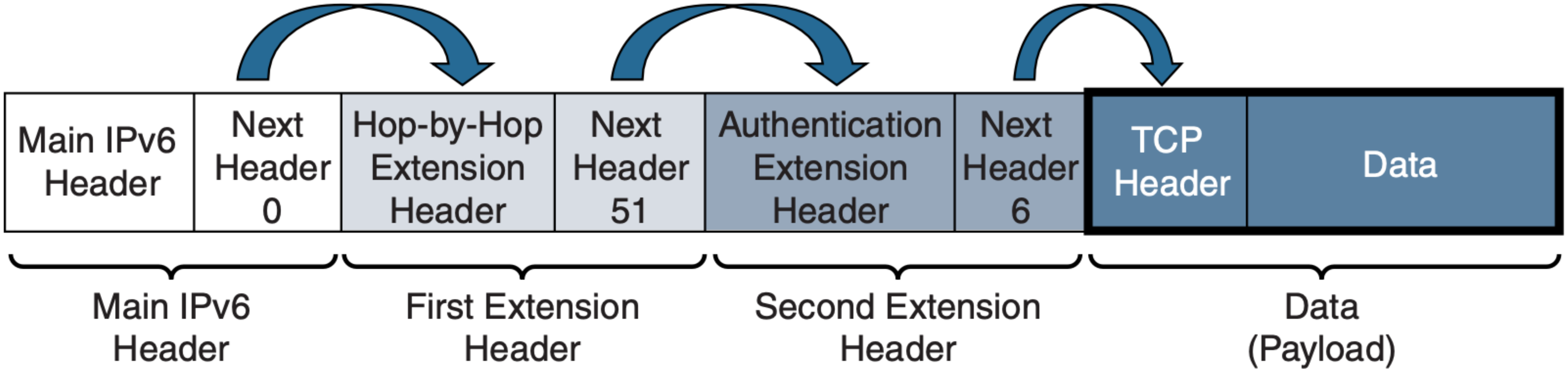
Extension Header Format

8	16	32
Next header DI CO QUALE SARÀ IL PROSSIMO	Length	Extension data
Extension data		

Header Chaining

-> CONCATENAZIONE DI HEADER

Semplifica operazioni di Processing



Nel caso in cui ci sia un Encription Header sarà l'ultimo

Hop-by-Hop Extension Header

- Used to carry optional information that should be examined by every router along the path of the packet
- Each option contains a set of Options Type, Options Length, and Options Value fields (TLV triplets)
- If present, it immediately follows the IPv6 header

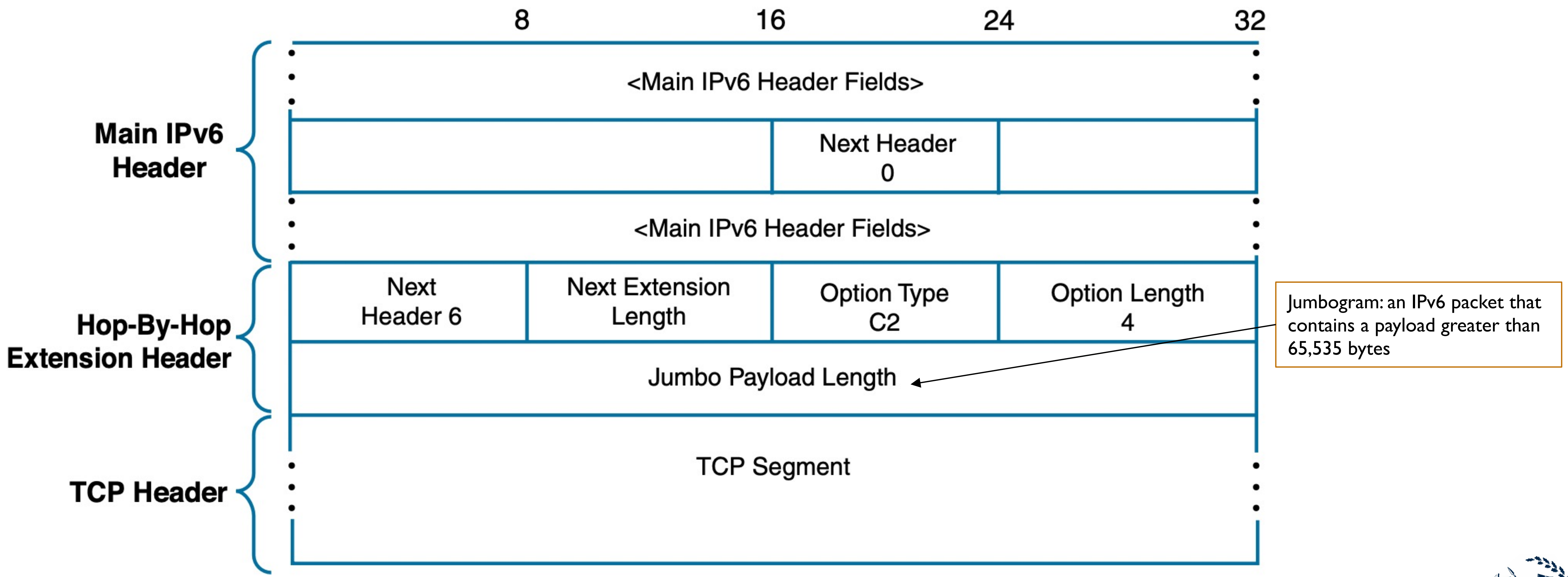
Dx poter aggiungere facilmente opzioni

8	16	24	32
Next header	Length	Option Type	Option Length
Option Value			

→ vari campi di implementazioni

DOPO OPTION VALUE POSSO AVERE ALTRI: • OPTION TYPE - OPTION LENGTH - OPTION VALUE ...

Hop-by-Hop Extension Header - Example



NOTA: Se il pacchetto è troppo grande, ICMP MANDA INDIETRO e DICE CHE LO È TROPPO GRANDE → SOLITAMENTE SORGENTE REAGISCE AGGIUNGENDO EXTENSION HEADER

More extension headers…

- Routing Extension Header
  - source routing
- Fragment Extension Header
  - used when the source needs to divide the packet into fragments, each with its own main IPv6 header and a Fragment extension header
  - the recipient of the packet reassembles the fragments,
  - Recall: unlike in IPv4, an IPv6 router does not fragment a packet unless it is the source of the packet
- Authentication and Encapsulating Security Payload Extension Headers ESP
  - used by IPsec, a suite of protocols for securing delivery of packets in IP networks
  - the Authentication Header (AH) is used to guarantee the authenticity and integrity of a packet
  - the Encapsulating Security Payload (ESP) provides authentication, integrity, and encryption.

Interfacing with Lower Layer

Encapsulation

- IPv6 packets are encapsulated in layer-2 frames
  - For Ethernet, Type: 86DD → ≠ DA IPV4

- They are treated as a new protocol
  - Enables dual stack (IPv4/IPv6) approach : DUE STACK DIVERSI IPV4 / IPV6 — APRENDO DUE STRADE DIVERSE NELLA MACCHINA → QUANDO, DOPO AVER ESTRATTO IL DATAGRAM, DEVI PASSARLO AL LIVELLO SUPERIORE
  - Keeps running IPv4 as-is

Address Mapping

- How is the destination MAC address set when an IPv6 packet is encapsulated?

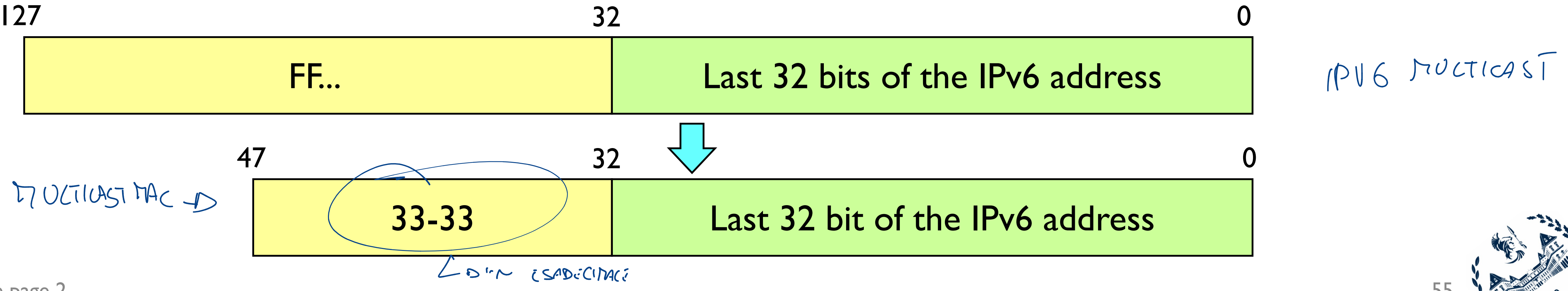
- IP unicast address (HO BISOGNO DI RICAVARE LA MAC → MI AIUTA ICMP)
  - Procedural (protocol-based) discovery
  - Neighbor Discovery (see later)

- IP multicast address (DEVO RIUSCIRE A CREARE UNA TRAMA DI LIVELLO 2 CHE ABBIA UN MULTICAST)
  - Algorithmic mapping

IPv6 Multicast transmission

- Based on Ethernet multicast
  - Unlike an Ethernet broadcast, an Ethernet multicast can be filtered by the NIC

- IPv6 multicast address mapped to MAC address
  - 33-33-xx-xx-xx-xx is the reserved Ethernet MAC address when carrying an IPv6 multicast packet (RFC 7042)
  - the lower 32 bits of the MAC address (xx-xx-xx-xx) are copied from the lower 32 bits of the IPv6 multicast address



Example

- When sending a packet to the IP multicast address FFOC::89:AABB:CCDD
- The packet is encapsulated in a MAC frame with address 33:33:AA:BB:CC:DD

Neighbor Discovery
and
Address Resolution

New function in ICMPv6

- It substitutes ARP
  - Based on multicast
    - Leverages the Solicited-node Multicast Address

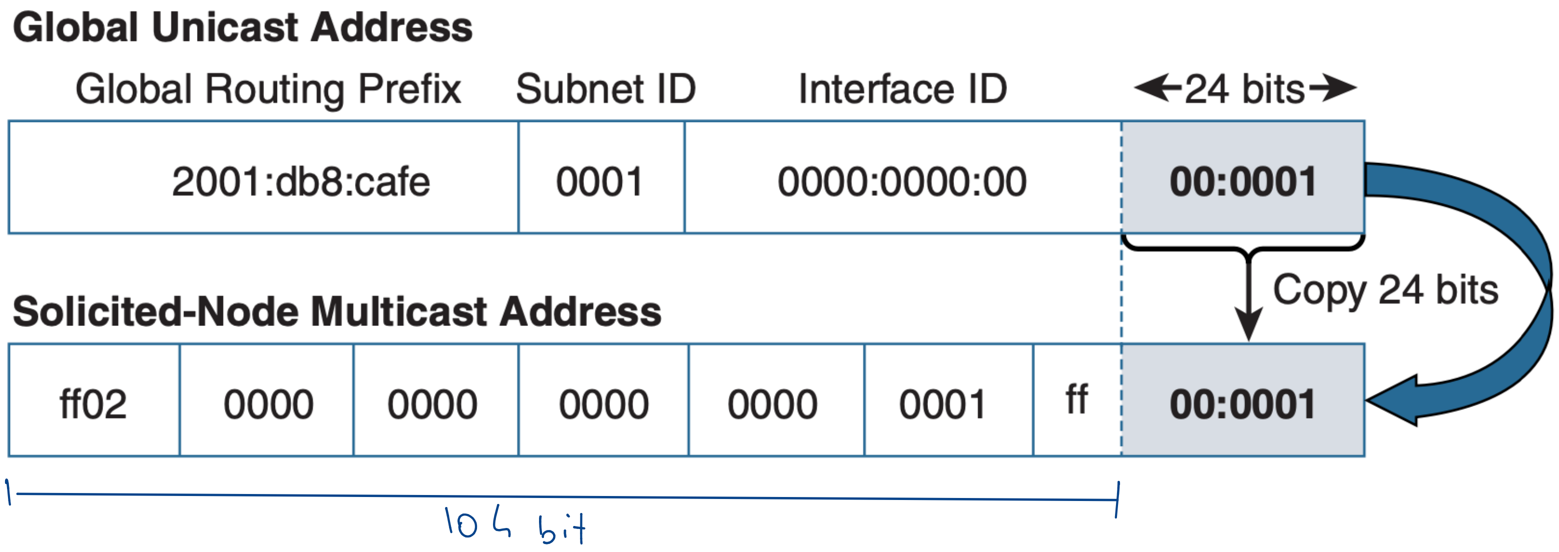
INDIRIZZO MULTICAST → MOLTO PROBABILE CHE SOLTANTO UNA STAZIONE SIA ISCRITTA AL MULTICAST IN QUESTIONE.

  - Given the way multicast solicited address are constructed, most likely only one station gets involved

(traffico arriverà a tutte le stazioni di rete ma con altissima probabilità soltanto una lo processerà e analizzerà il pacchetto)

Solicited Node Multicast Address

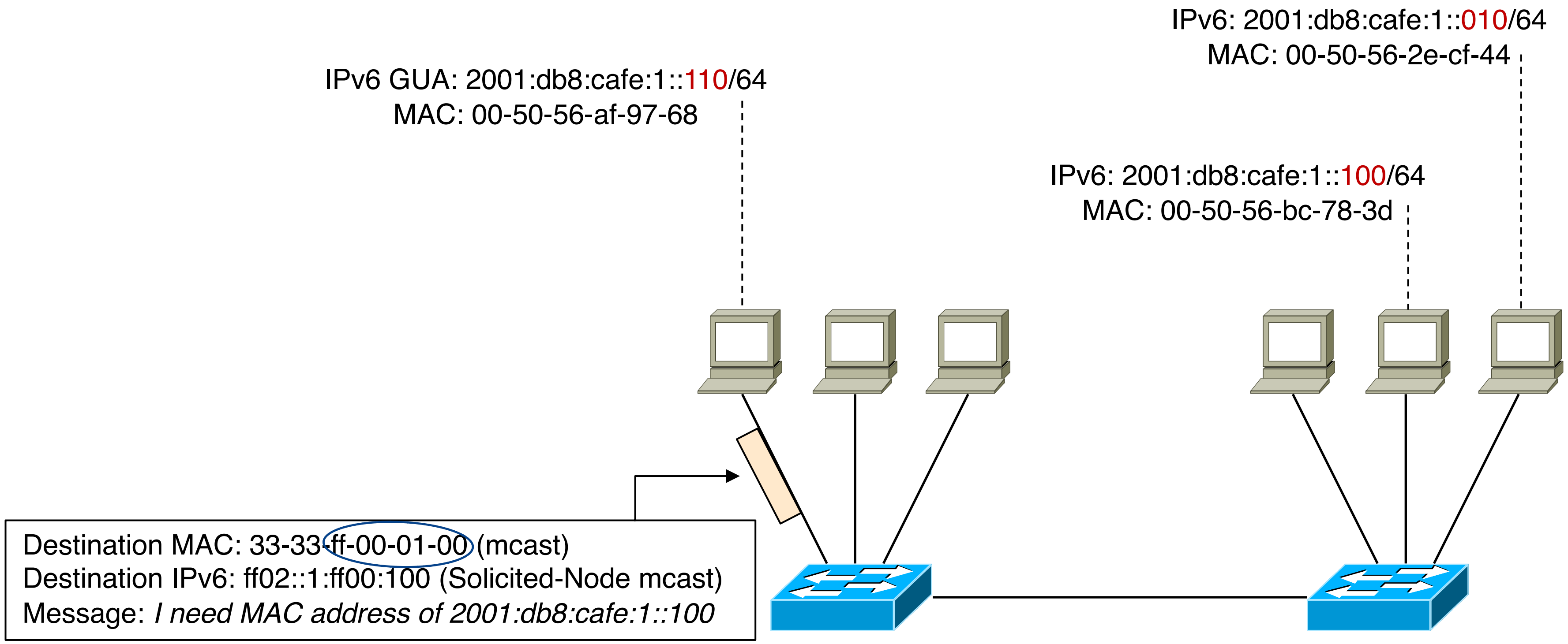
- address automatically created for *every unicast address* on the interface.
- subscribed to by all hosts
- mapped as
  - FF02::1:FF/104 | 24 least significant bits of IP address
  - Likely one host per group



Address Resolution

→ PRIMA PARTE DELLA NEIGHBOR DISCOVERY

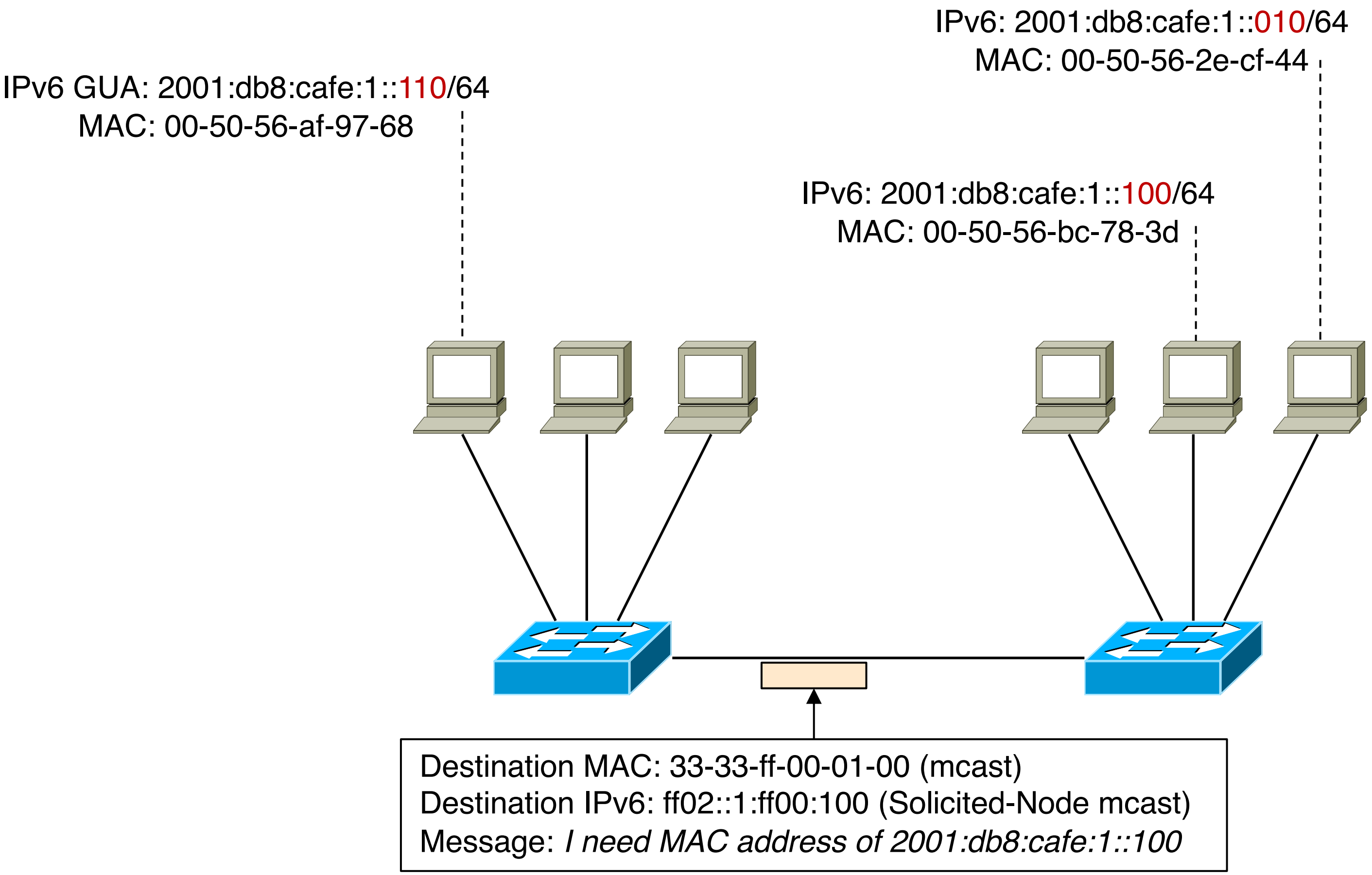
- ICMP Neighbor Solicitation : DATAGRAM IP → RICHIESTA CON IND. IPV6 DESTINAZIONE L'INDIRIZZO IP DI UN GRUPPO MULTICAST A CUI CON ALTISSIMA PROBABILITÀ C'È SOLO LA STAZIONE CON QUEL IPV6 DI CUI VOGLIO SAPERE MAC
  - Requester sends frame to Solicited Node Multicast Address of target IPv6 address



- TUTTE LE STAZIONI SU UNA STESSA RETE DI LIVELLO 2 CHE HANNO GLI ULTIMI 24 bit UGUALI SONO MAPPATE CON STESSO MULTICAST ⇒ MOLTO IMPROBABILE

Address Resolution

- ICMP Neighbor Solicitation
  - Requester sends frame to Solicited Node Multicast Address of target IPv6 address



Address Resolution

- ICMP Neighbor Solicitation
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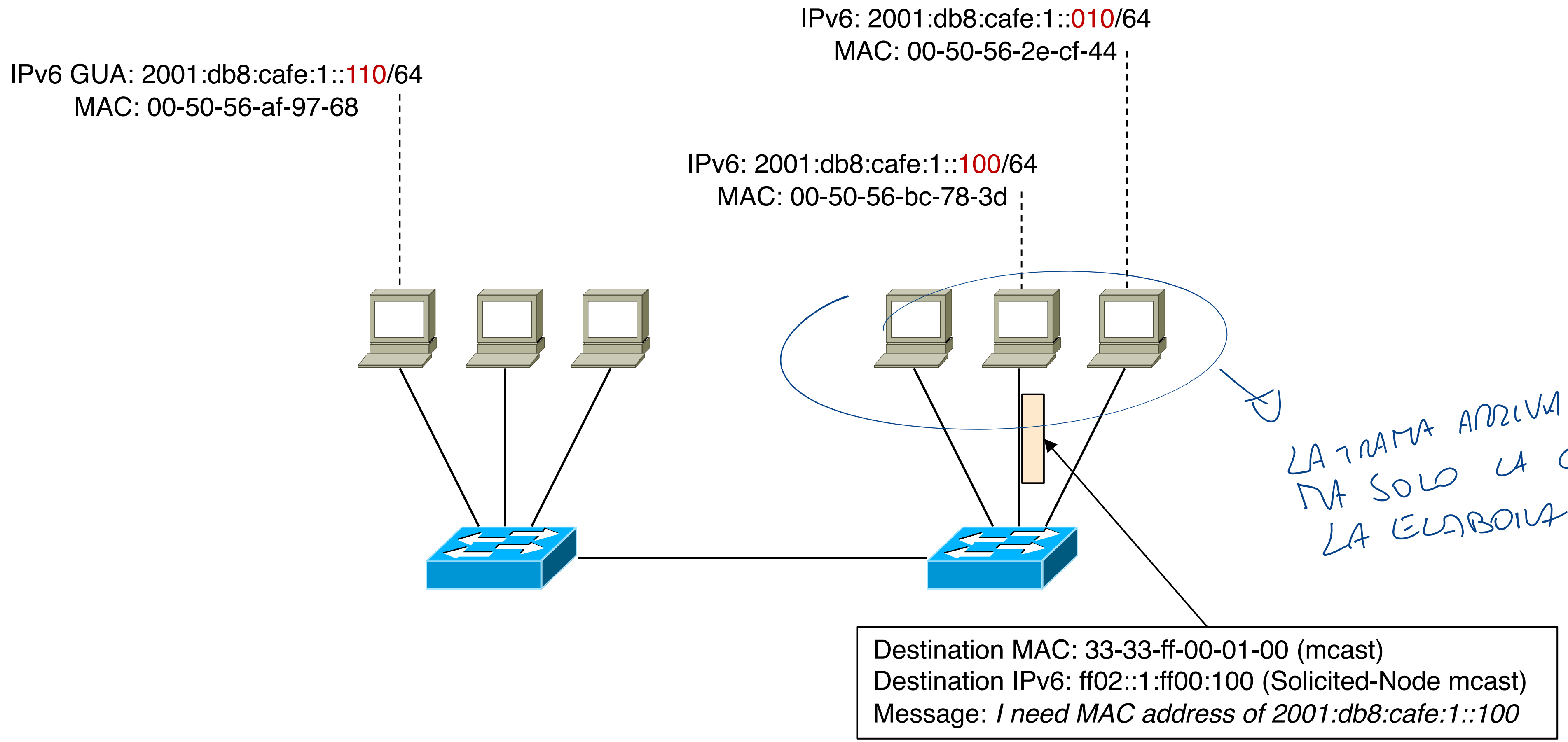


LA TRAMA ARRIVA A TUTTI I
MA SOLO LA CENTRALE
LA ELABORA

Address Resolution

- ICMP Neighbor Solicitation
  - Requester sends frame to Solicited Node Multicast Address of target IPv6 address
- ICMP Neighbor Advertisement (IN UNICAST)
  - Sent back to requester's unicast address

- Mapping between IPv6 and MAC address stored in host cache → SALVO IN MODO TALE DA NON DOVER CALCOLARE OGNI VOLTA
  - Equivalent to ARP cache

ICMPv6

What is it used for?

- Diagnostics
- Neighbor Discovery
- Multicast group management
- Issue notification

- Includes functions that in IPv4 were delegated to
  - ARP (Address Resolution Protocol)
  - IGMP (Internet Group Membership Protocol)

Message Format

- Encapsulated in IPv6 packets
  - Next Header = 58
- At most 576 bytes

8	8	16
Type	Code	Checksum
Message Body		

Type Field

Error messages (<128)

Informational messages (>=128)

1	Destination Unreachable
2	Packet too big
3	Time exceeded
4	Parameter Problem
128	Echo Request
129	Echo Reply
130	Multicast Listener Query
131	Multicast Listener Report
132	Multicast Listener Done
133	Router Solicitation
134	Router Advertisement
135	Neighbor Solicitation
136	Neighbor Advertisement
137	Redirect

→ AUTO CONFIGURAZIONE DEI NODI
CHE MI PERMETTONO DI CAMBIARE IP FACILMENTE QUANDO CAMBIO PROVIDER

Error Messages

8	8	16
Type	Code	Checksum
Parameter		
Header of the IP packet that caused the error		

- Destination Unreachable (type = 1)
  - Usually generated by router or firewall
  - Code field provides reason (no route, wrong scope, address/port unreachable)
- Packet too big (type = 2)
  - IPv6 routers no longer fragment packets!
- Time exceeded (type = 3)
  - If router receives a packet with Hop Limit = 0
- Parameter Problem (type = 4)
  - generated when a device finds a problem with a field in the main IPv6 header or an extension header
  - example: invalid value in the Next Header field.

Messaggi di errore
n Destinazione irraggiungibile (tipo = 1)
n Di solito generato da router o firewall
n Il campo del codice fornisce il motivo (nessun percorso, porta o indirizzo irraggiungibile, ambito errato)
n Pacchetto troppo grande (tipo = 2)
n I router IPv6 non frammentano più i pacchetti!
n Tempo scaduto (tipo = 3)
n Se un router riceve un pacchetto con Hop Limit = 0
n Problema di parametro (tipo = 4)
n Generato quando un dispositivo trova un problema con un campo nell'intestazione principale IPv6 o in un'intestazione di e
n Esempio: valore non valido nel campo Next Header.

Informational Messages: Echo

- Echo request (type= 128)
- Echo reply (type= 129)
- Used by `ping`

8	8	16
Type	Code	Checksum
Identifier		Sequence Number
Data		

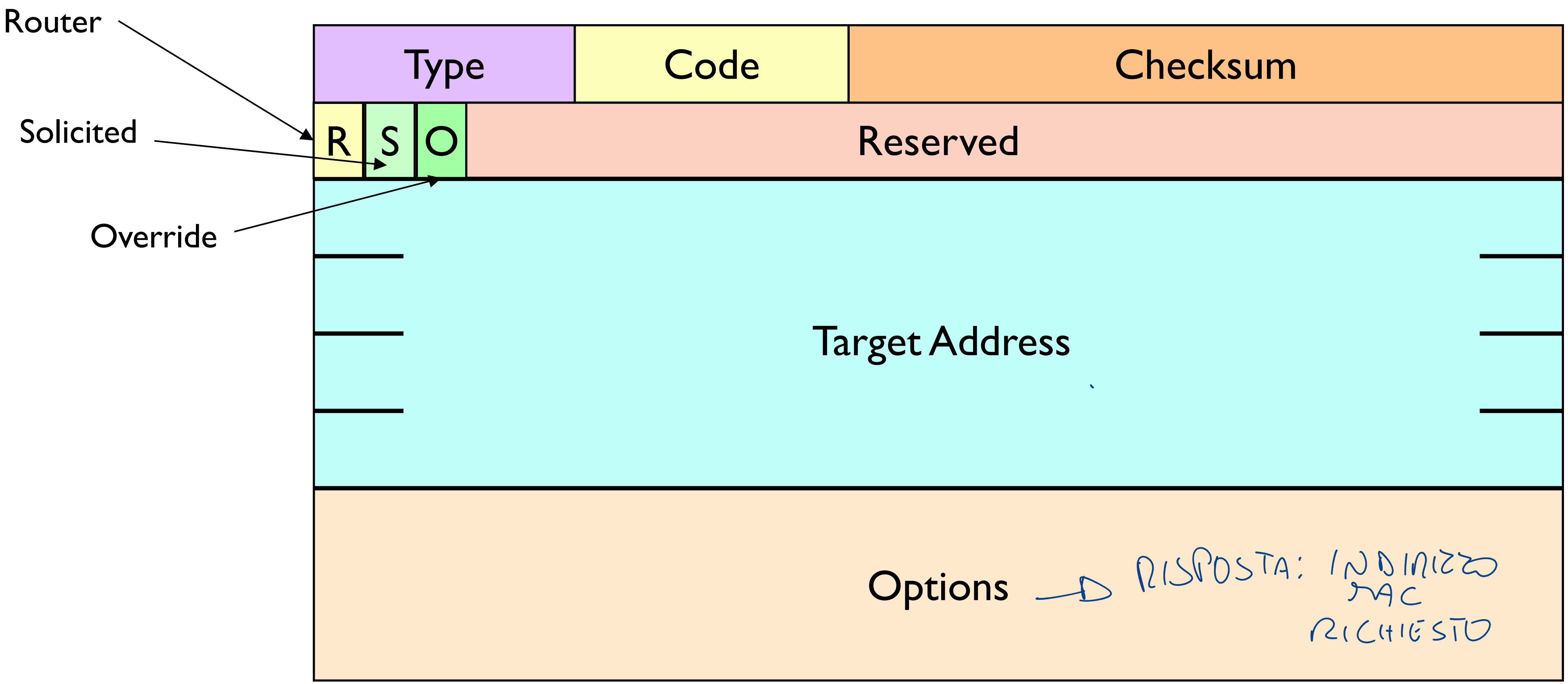
Informational Messages: Neighbor Solicitation

Type	Code	Checksum
Reserved		
Target Address		
Options		

→ PRE-VISTO x ICMP

Dove la stazione che manda la NS scrive l'indirizzo IP della stazione che gli interessa

Informational Messages: Neighbor Advertisement



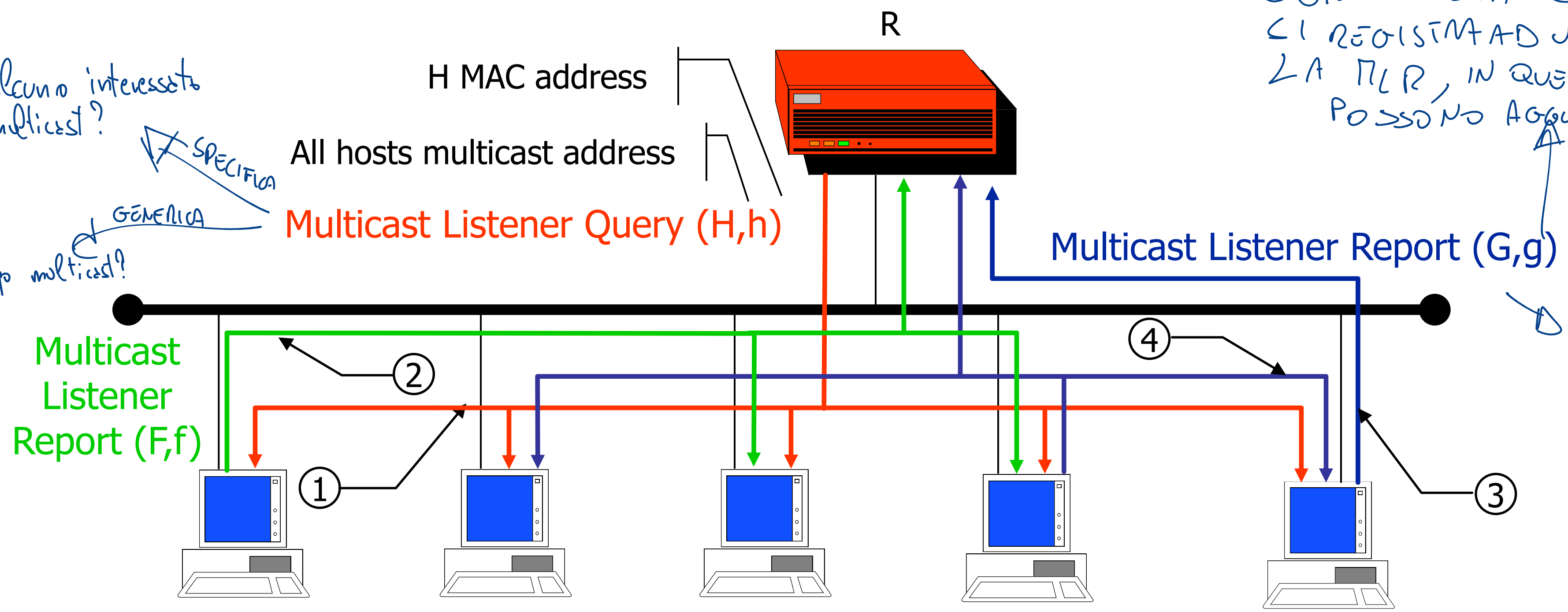
Multicast Group Management using ICMPv6

- Within a link, rely on data link layer multicasting service
  - Mapping of IPv6 multicast addresses onto MAC multicast addresses
- Among links, packets routed by routers
  - ICMPv6 to know on-link members
    - Hosts interests in receiving packets
  - Multicast routing protocols to know where there are off-link members

Host Membership Discovery

C'è ancora qualcuno interessato a questo gruppo multicast?
SPECIFICA

GENERICA
C'è qualcuno che è interessato a qualche gruppo multicast?



OGNI VOLTA CHE UN NODO IPV6 SI REGISTRA AD UNA MULTICAST INVIA LA MLR, IN QUESTO MODO I ROUTER POSSONO AGGIORNARE LA TABELLA DEI GRUPPI MULTICAST

OGNI TANTO VA RIPETUTA (quando scade il timer)

- R to announce multicast groups G and F
- R to forward packets to G and F

Informational Messages: Group Management

- Multicast Listener Query (type=130), sent by router
  - General
  - Multicast group (address) specific
- Multicast Listener Report (type=131), sent by Listener to all-router multicast address
- Multicast Listener Done (type=132), sent by Listener to all-router multicast address

Type	Code	Checksum
Maximum Response Delay		Unused
Multicast Address		

Device Configuration in IPv6

What information is needed?

- Address prefix
- Interface identifier
- Default gateway
- DNS server
- Hostname
- Domain name
- MTU (Maximum Transmission Unit)
- …

Options

- Manual configuration
- Stateful configuration
  - All information obtained through DHCP
- Stateless configuration
  - Autogenerated
  - Address prefix obtained from router
- Hybrid (Stateless DHCP)
  - Information other than address obtained through DHCP

Interface Identifier

- Manually configured
- Obtained through DHCPv6
- Automatically generated → DALLA BASE DELLA MODALITÀ STATELESS
  - From EUI-64 MAC address → POSSO USARE IL MAC COME INTERFACE ID
  - Privacy aware

EUI-48 to EUI-64 mapping

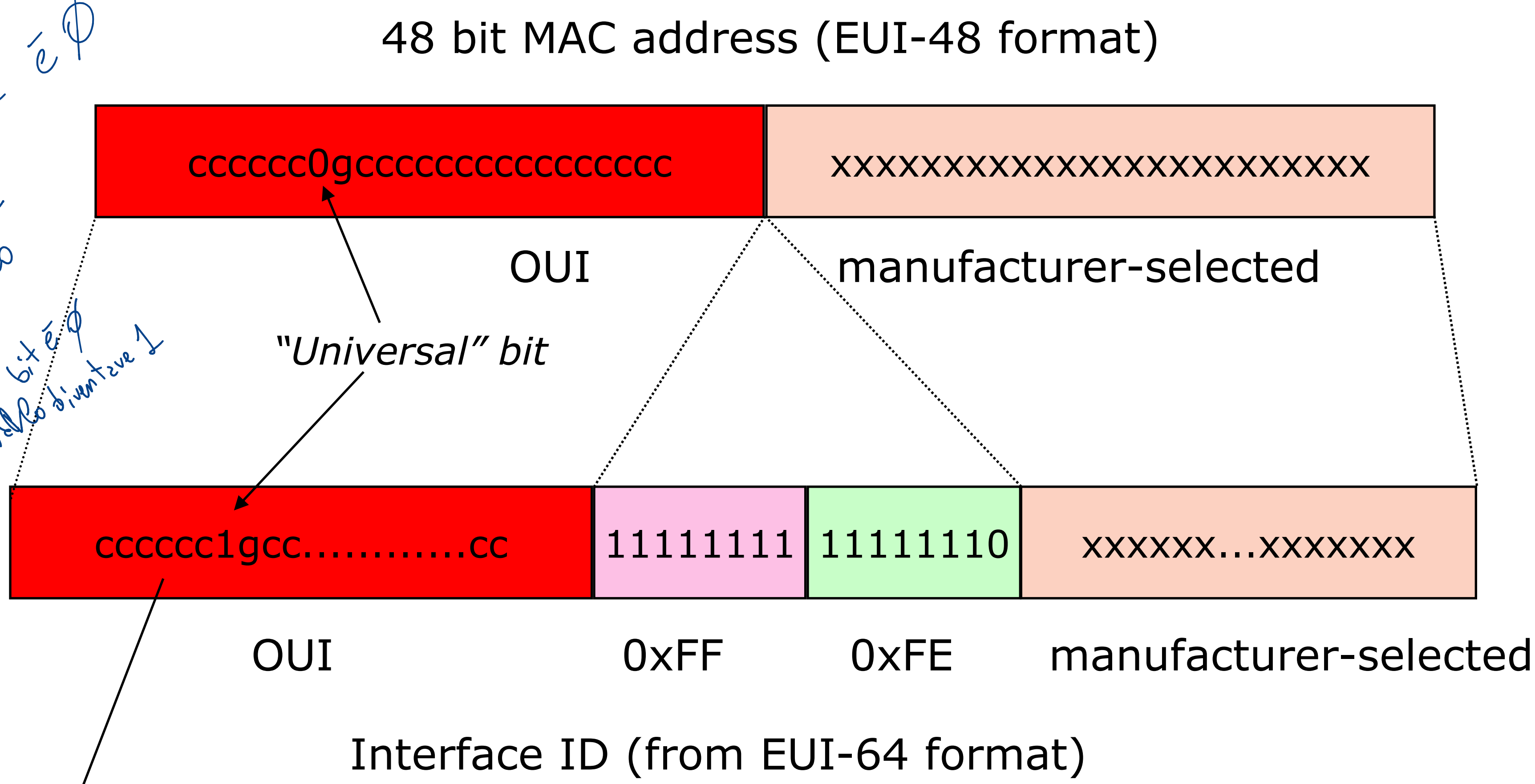
MAC 7° bit
Ø univoco
1 non univoco

IPv6 7° bit
1 univoco
0 non univoco

EUI = Extended Unique Identifier

Settimo bit x MAC è Ø
↓
Devo farlo diventare 1
xké serve IPv6 univoco

Se invece il 7° bit è Ø
→ devo farlo diventare 1



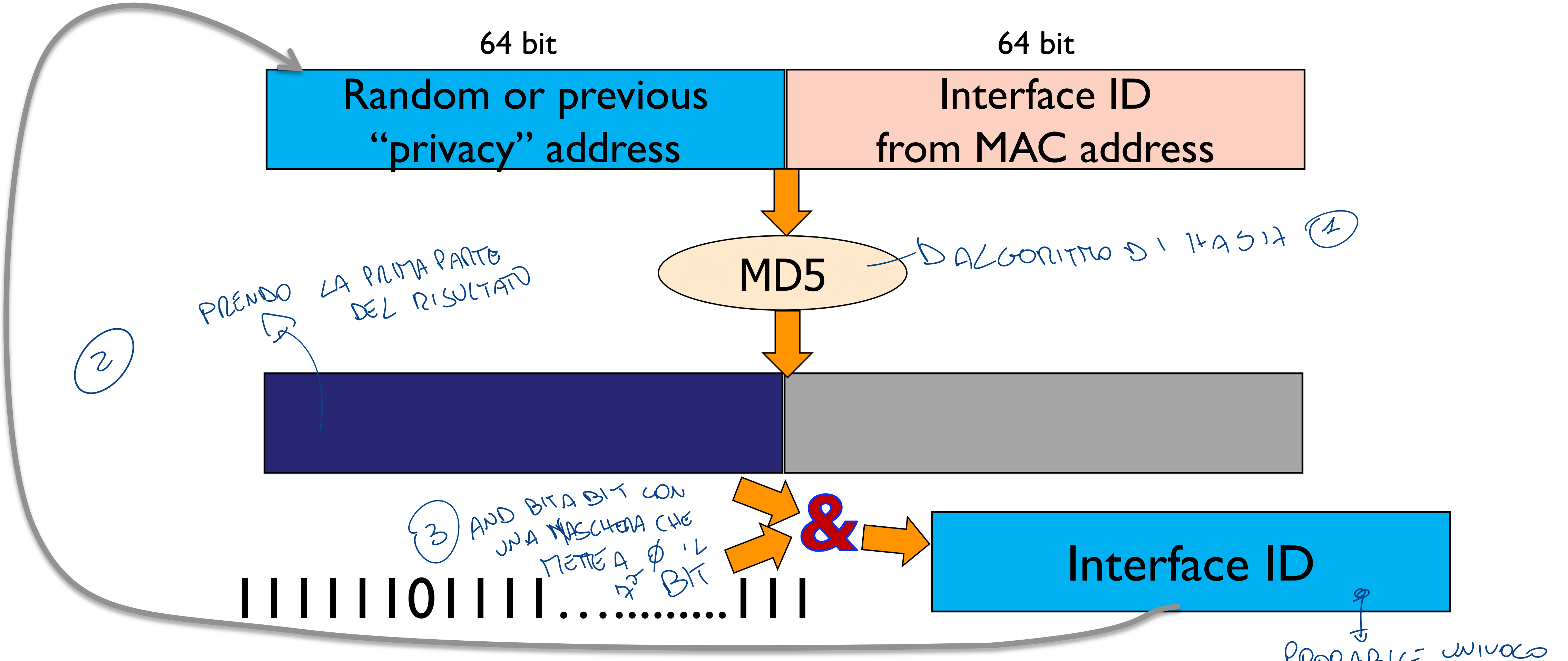
To make manually configured address (local) easier to write

Privacy Concerns

- Traceability
  - The least significant 64 bits of the IPv6 address of an interface never change when MAC address is used
- RFC 4941, “Privacy Extensions for Stateless Address Autoconfiguration in IPv6”

Privacy Extension Algorithm

(other options are possible)



Stored for next configuration

Address Usage

- A host may have several different addresses → SI POSSONO AVERE PIÙ IPV6 SULLA STESSA INTERFACCIA
  - "default"
  - "privacy aware" → M voglio evitare di essere rintracciato facilmente

↓ LE APPLICAZIONI SCELGONO QUALE USARE

- Usable to accept/initiate connections
- Selection of address may be available to the user/application

Address Prefix

- Manually configured
- Obtained from DHCPv6
- Automatically generated
  - Link local
- Obtained from a router

Router/Prefix Discovery

- ICMP Router Advertisement message in risposta ad una Router Solicitation oppure Unsolicited
  - Sent by routers
- Solicited
  - Answering to Router Solicitation by host
- Unsolicited: periodicamente x informare tutti i nodi dello stato attuale della rete

Router Solicitation

Type	Code	Checksum
Reserved		
Options		

Sent to the all-routers multicast address
(FF02::2)

Router Advertisement

<table>
<tr><td colspan="2">Type</td><td colspan="3">Code</td><td colspan="2">Checksum</td></tr>
<tr><td>Cur Hop Limit</td><td>M</td><td>O</td><td colspan="2">Reserved</td><td colspan="2">Router Lifetime</td></tr>
<tr><td colspan="7">Reachable Time</td></tr>
<tr><td colspan="7">Retrans Timer</td></tr>
<tr><td colspan="7">Options</td></tr>
</table>

- M (Managed Address Configuration)
  - 1 – address available through DHCP

1: INFORMA GLI HOST CHE DEVONO ACQUISIRE L'INFORMAZIONE DA UN ROUTER DHCP

- O (Other configuration)
  - E.g., DNS server

Options → DOVE TROVIAMO LE INFO CHE CI SERVONO

- General Format
- Length in multiple of 8 bytes

Type	Length	. . .
. . .		

Prefix Information Option

⇒ mi permette di comunicare agli HOST i prefissi

Type (3)	Length	Prefix Length	L	A	Reserved
Valid Lifetime					
Preferred Lifetime					
Reserved					
Prefix					

x INFORMARE L'HOST CHE ALCUNE INFORMAZIONI SONO VALIDE SOLO x UN INTERVALLO DI TEMPO

Con FLAG L: Quel prefisso c'è nella rete e il Router può raggiungerlo ma l'HOST in questione non lo può usare

CON FLAG A: SULLA RETE IN CUI C'È QUELL'HOST C'È QUEL PREFISSO QUINDI L'HOST LO PUÒ UTILIZZARE COME PREFISSO DEL SUO IPV6

- L – prefix is ~~on-link~~ ON NETWORK
- A – prefix can be used for autonomous configuration

⇒ L'HOST ATTRAVERSO QUEL ROUTER PUÒ DIALOGARE CON QUELLA RETE

MTU Option

- Ensures all hosts on-link use the same MTU value

Type (5)	Length	Reserved
MTU		

Link Layer Address Option

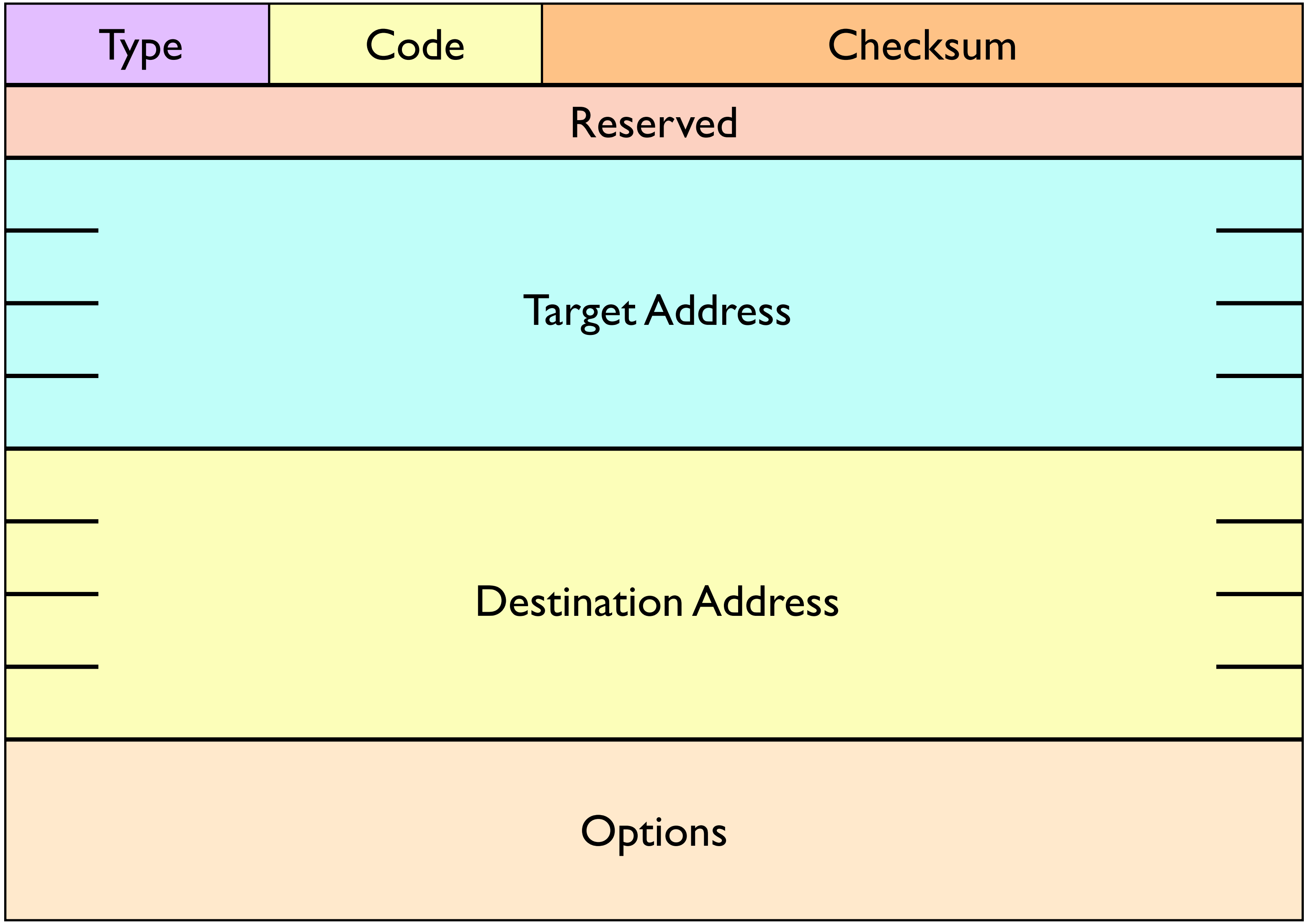
Type	Length	Link-Layer Address
Link-Layer Address . . .		

ICMP Redirect → Percorso migliore per raggiungere una determinata situazione/scenario

- Sent by a router to advise a host about a best first-hop
- The first-hop is always on-link, irrespective of prefix

UN ROUTER CHE SI ACCORGE CHE UNA CERTA ROTTA PUÒ ESSERE RAGGIUNTA IN MODO DIRETTO DAL RICHIEDENTE, PUÒ INFORMARE IL RICHIEDENTE (sono su stessa interfaccia, inutile router)

ICMP Redirect Message Format



Redirect Header Option

Information about the packet being redirected

Type (4)	Length	Reserved
Reserved		
IP header + data		

MINUTO 120 -->fatto

Duplicate Address Detection (DAD)

→ capire se qualcun'altro sta usando il mio stesso IPv6

↓

PRIMA DI USARE UN INDIRIZZO IP

- calcolo il sollicited-node multicast address
- MANDO NEIGHBOR SOLLICITATION per quell'indirizzo IP

→ se ricevo l'ADVERTISEMENT

↓

IPv6 già in uso

→ se non la viceversa

↓

POSSO USARE IPv6

- Probe uniqueness of an IPv6 address
- Neighbor solicitation with address being probed as target
  - Sent to corresponding IPv6 Solicited Node Multicast Address
  - Corresponding MAC multicast address
- Wait for a response for at least 1 sec
  - If no answer is received, the address is considered valid
  - If there is an answer, stop

Stateless Configuration: Basic Step

- Generate a link local address
- Probe for its uniqueness (DAD) → SÌ → POSSO USARLO; → NO → DEVO CAMBIARE IPV6
- Subscribe to the corresponding IPv6 Solicited Node Multicast Address → AVVISO CHI SONO E DOVE SONO ↓ ABILITO LA MIA SCHEDA A RICEVERE A QUELL'INDIRIZZO MULTICAST
  - Configure reception of corresponding multicast MAC
  - Send ICMP Multicast Listener Report
- On-link communication enabled

Stateless Configuration: With Router

- Possibly send Router Solicitation
- Listen to Router Advertisements
- Create address from advertised prefix
- Probe for its uniqueness (DAD)
- Subscribe to the corresponding IPv6 Solicited Node Multicast Address
  - Configure reception of corresponding multicast MAC
  - Send ICMP Multicast Listener Report

Stateless Configuration: Renumbering

→ CAMBIO DEL PIANO DI INDIRIZZAMENTO SULLA RETE

- CAMBIO
- CAMBIO PREFISSI
- AVVISO GLI HOST ATTRAVERSO I CAMPI AGGIUNTIVI DELL'ICMP (LIFETIME)

- Keep listening to Router Advertisements
  - Host can be re-configured any time
  - State of addresses
    - Preferred
    - Deprecated
  - Easier renumbering
    - Possible to switch from a previous (ISP) global address to a new one

Stateful Configuration: Dynamic Host Configuration Protocol

- Client/server model
- M flag = 1 in Router Advertisement
- Messages:
  - Solicit (to all-agents address: FF02::1:2)
  - Advertise
  - Request (all-agents address: FF02::1:2)
  - Reply
  - Release
  - Reconfigure

DHCP Stateless Configuration

- M flag = 0 in Router Advertisement
  - Address autoconfigured from prefix in Router Advertisement
- O flag = 1 in Router Advertisement
  - Other information configured through DHCP

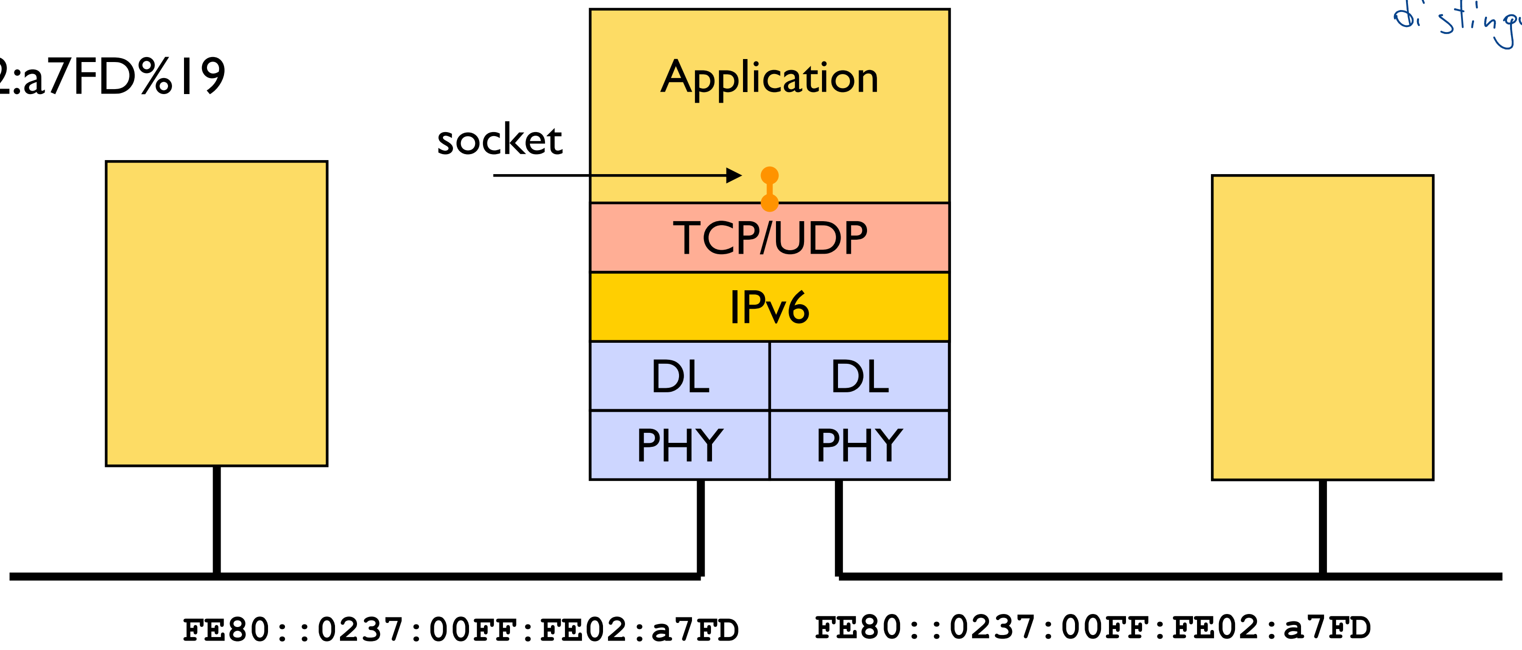
Scoped addresses

- A scoped address is composed of an IPv6 address followed by a % and a number identifying the interface
- Used by the operating system to discriminate among IPv6 addresses on different interfaces with the same prefix (and possibly with the same interface ID)

xké le app che stanno al piano sopra devono distinguere i due prefissi

- Example:
  - FE80::0237:00FF:FE02:a7FD%19

Stesso prefisso su interfacce diverse ⇒ non è un problema xké non comunicano con quell'indirizzo



Examples of Scoped Addresses

```
c:\>netsh interface ipv6 show address
Interface 1: Loopback Pseudo-Interface 1
Addr Type  DAD State   Valid Life Pref. Life Address
---------  ----------- ---------- ---------- ------------------------
Other      Preferred     infinite   infinite ::1
Interface 10: Wireless Network Connection
Addr Type  DAD State   Valid Life Pref. Life Address
---------  ----------- ---------- ---------- ------------------------
Other      Preferred     infinite   infinite fe80::9832:45b1:96e9:f444%10
Interface 9: Local Area Connection
Addr Type  DAD State   Valid Life Pref. Life Address
---------  ----------- ---------- ---------- ------------------------
Other      Deprecated    infinite   infinite fe80::9158:6fc2:4155:356d%9
Interface 12: Local Area Connection* 12
Addr Type  DAD State   Valid Life Pref. Life Address
---------  ----------- ---------- ---------- ------------------------
Public     Preferred     infinite   infinite 2001:0:5ef5:79fd:14b0:f4d:f50d:a9a9
Other      Preferred     infinite   infinite fe80::14b0:f4d:f50d:a9a9%12
Interface 27: Bluetooth Network Connection
Addr Type  DAD State   Valid Life Pref. Life Address
---------  ----------- ---------- ---------- ------------------------
Other      Deprecated    infinite   infinite fe80::9961:aca4:ff3:3374%27
Interface 31: Local Area Connection* 25
Addr Type  DAD State   Valid Life Pref. Life Address
---------  ----------- ---------- ---------- ------------------------
Other      Deprecated    infinite   infinite fe80::5efe:10.242.86.86%31

c:\>
```

Routing Phases

- On-the-fly routing: use the routing table (*a.k.a., forwarding*)
- Proactive routing: build routing tables (*a.k.a., routing*)
  - Manual configuration
    - Static routing
  - Distribute destination information throughout the network
    - Routing protocols

- Support for both IPv4 and IPv6

Routing protocols

- Integrated Routing
  - A single protocol to advertise destinations of both protocol families
- Ships in the night
  - Each address family uses a distinct protocol IPv4 IPv6
    - Protocols are completely independent one from the other