Reti

(già “Reti di Calcolatori”)

Livello Rete
Indizzamento IP (v4) e inoltro dei pacchetti

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http://disi.unitn.it/locigno/index.php/teaching-duties/computer-networks

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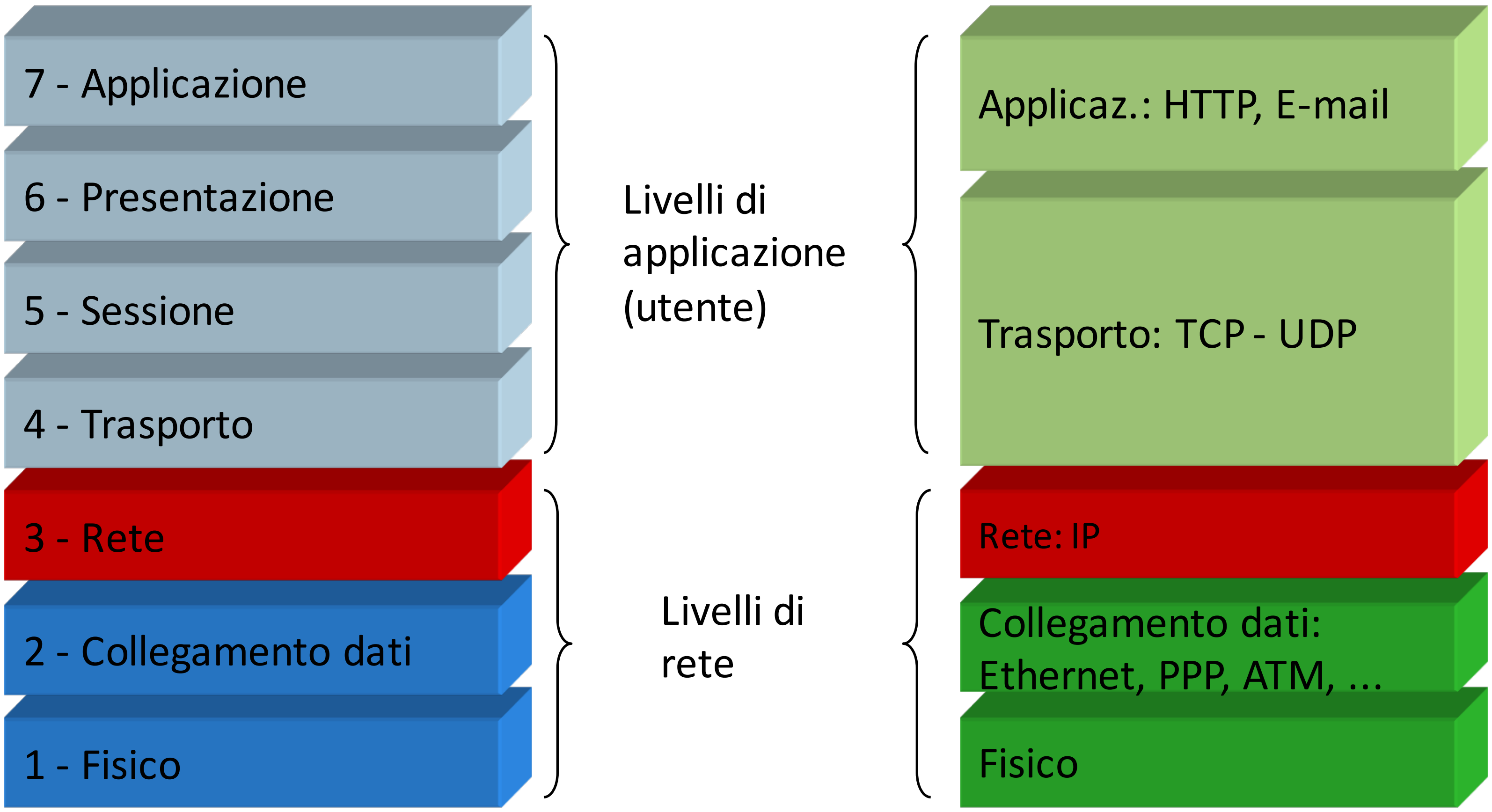
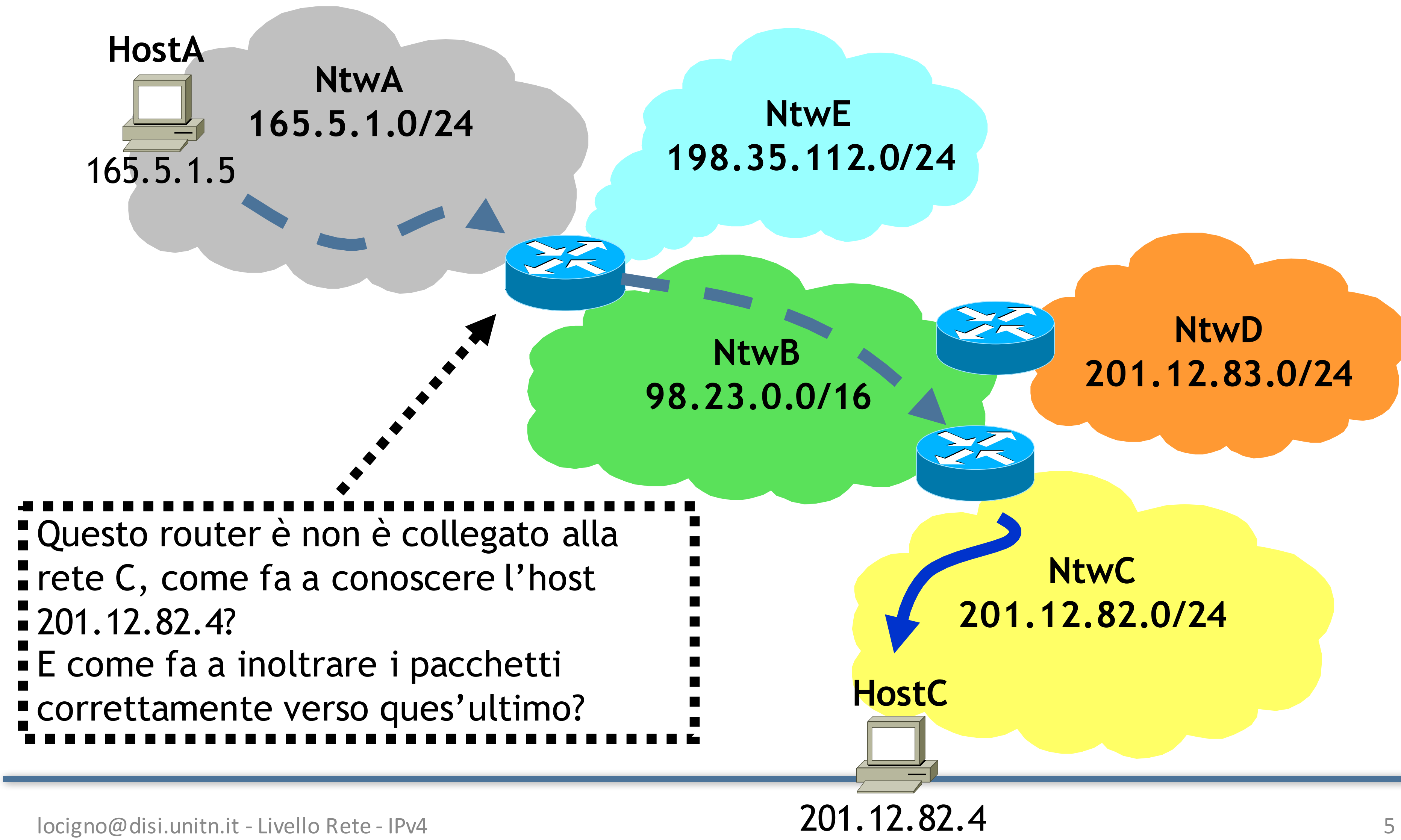
    - *Douglas Comer, "Computer Networks and Internets," 5th edition, Prentice Hall*
    - *Behrouz A. Forouzan, Sophia Chung Fegan, "TCP/IP Protocol Suite," McGraw-Hill*, January 2005
- La traduzione, se presente, è in generale opera (e responsabilità) del docente

Contenuto e temi

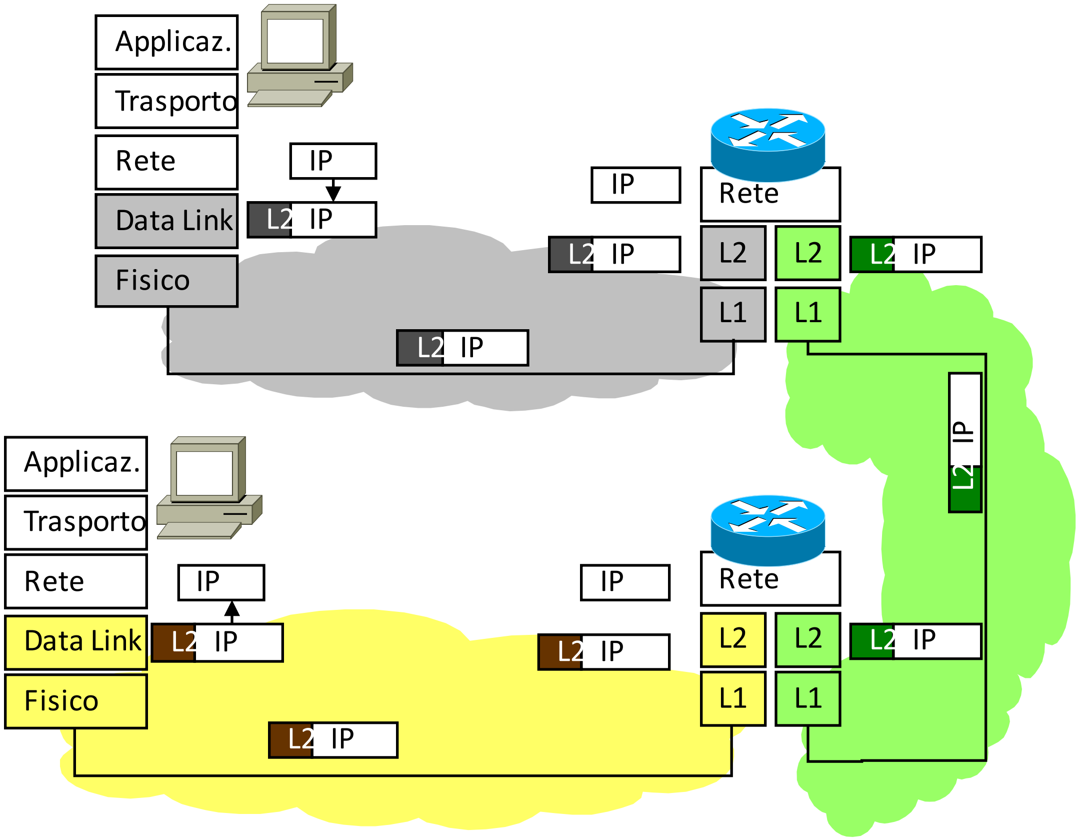
- **Spazio di indirizzamento**
- **Indirizzi IP e loro uso**
- **Consegna dei pacchetti**
- Configurazione dei PC e delle reti
- Instradamento e Routing

Livello Rete

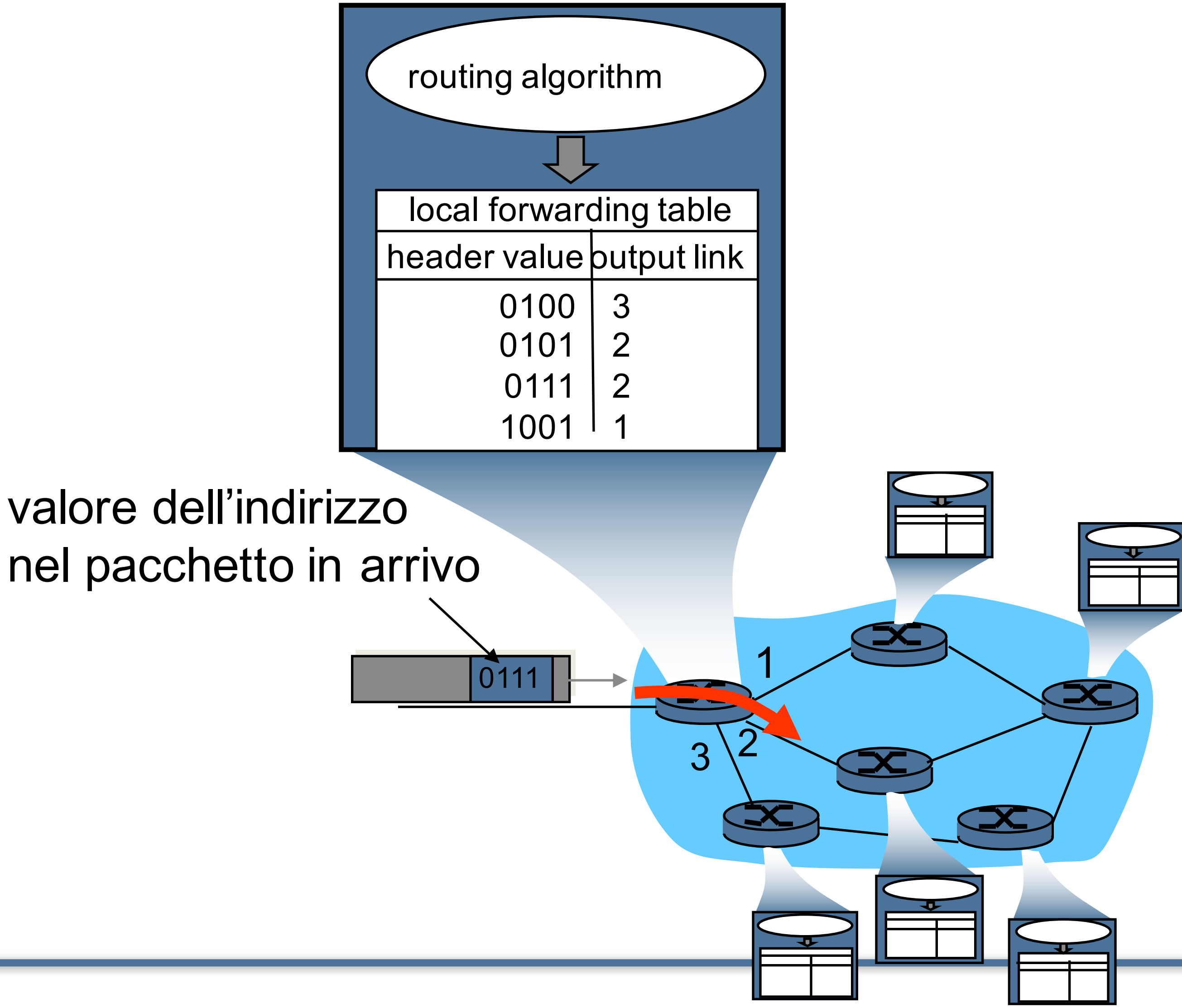



HostA
165.5.1.5
NtwA
165.5.1.0/24
NtwE
198.35.112.0/24
NtwB
98.23.0.0/16
NtwD
201.12.83.0/24
NtwC
201.12.82.0/24
HostC
201.12.82.4
Questo router è non è collegato alla rete C, come fa a conoscere l'host 201.12.82.4?
E come fa a inoltrare i pacchetti correttamente verso ques'ultimo?

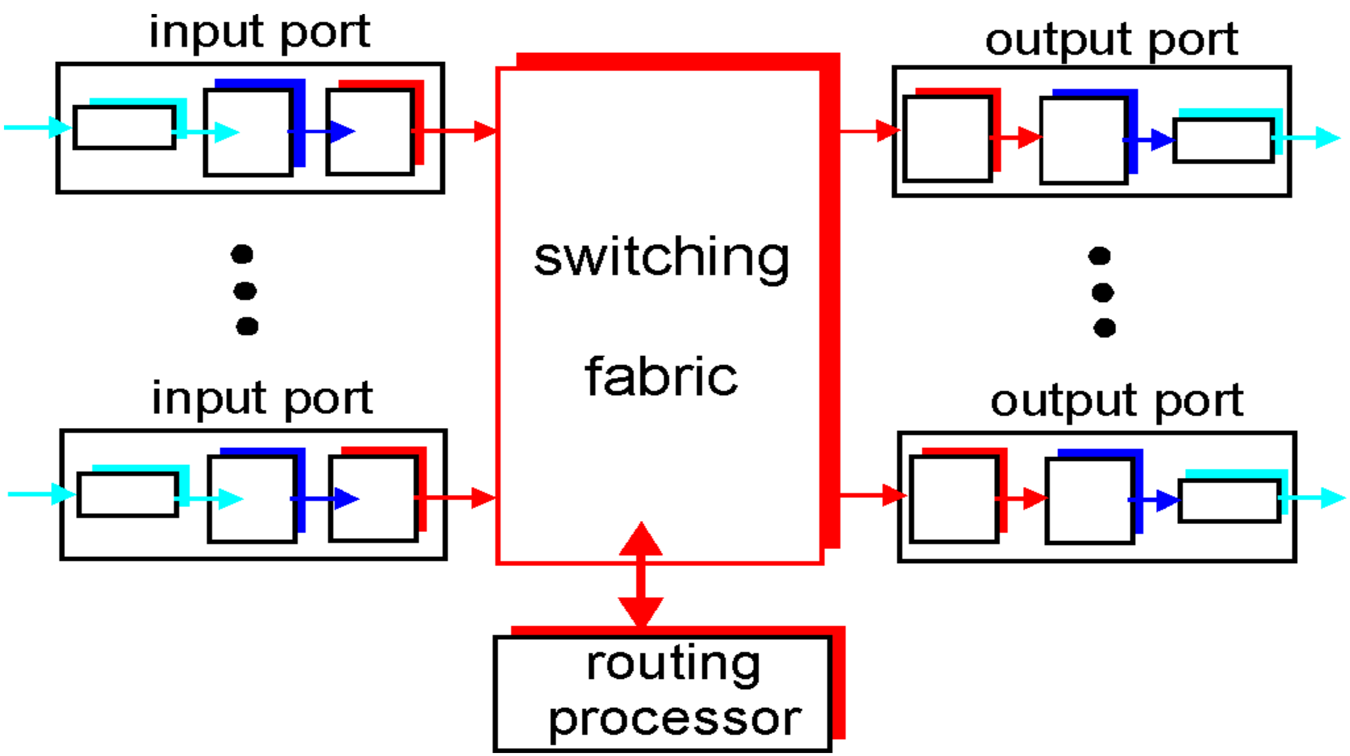
- Trasporto dei pacchetti da sorgente a ricevitore. I pacchetti contengono un segmento di livello trasporto
- I pacchetti sono incapsulati in trame L2
- Al ricevitore i segmenti sono estratti dai pacchetti e consegnati al livello trasporto
- **I protocolli di rete sono in tutti gli host e router**
- Un router deve esaminare l'intestazione di tutti i pacchetti che lo attraversano



- **Instradamento (Routing)**
  - Trovare il percorso dalla sorgente alla destinazione
  - ➔ Algoritmi di Routing
    - Simile a pianificare un viaggio: devo determinare le strade da fare e gli incroci in cui cambiare la mia strada
- **Inoltro (Forwarding)**
  - Funzione che esegue il trasporto dei pacchetti dagli ingressi alle uscite dei router ... dato che il percorso è già noto
    - Simile a prendere l'uscita giusta di una rotonda, sapendo che devo andare in una specifica direzione
- Entrambe richiedono uno spazio di indirizzamento appropriato ... e i relativi indirizzi


routing algorithm
local forwarding table
header value
output link
0100 3
0101 2
0111 2
1001 1
valore dell'indirizzo
nel pacchetto in arrivo
0111
1
2
3

- due funzioni fondamentali:
  - eseguire i protocolli e algoritmi di instradamento (RIP, OSPF, BGP)
  - inoltrare i datagrammi (pacchetti) dagli ingressi alle uscite



IL PROTOCOLLO IP

(VERSIONE 4)

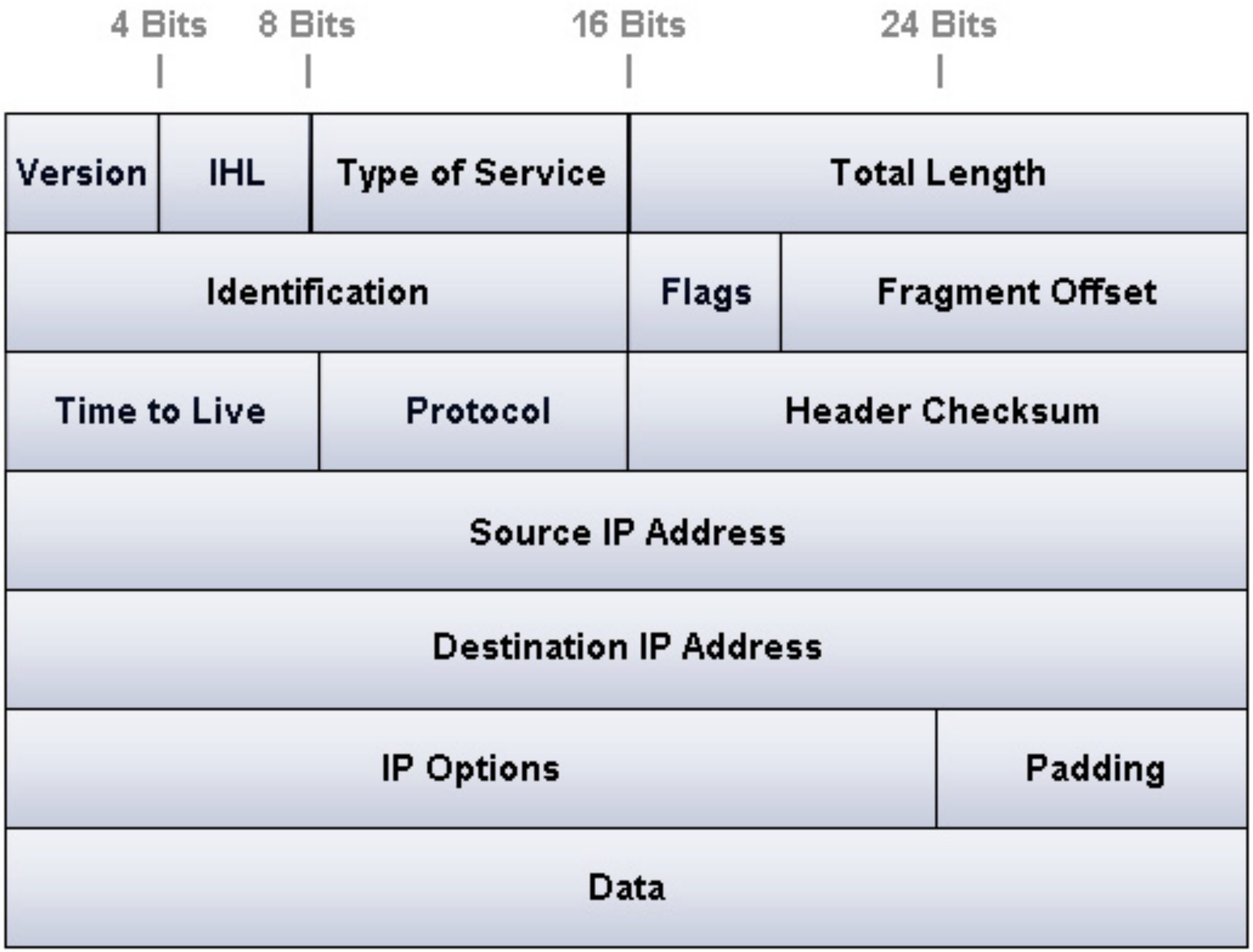
Il Datagramma IP

- TCP/IP usa il termine “IP datagram” per identificare un pacchetto di livello rete
- Ciascun datagramma è composto da una **intestazione** (header)
  - da 20 a 60 bytes che contengono le informazioni essenziali per l’instradamento e la consegna
- seguita dai **dati trasportati** (payload)
  - La dimensione dei payload non è fissa
  - La dimensione effettiva è determinata dall’applicazione e/o dal protocollo di trasporto
  - C’e` una dimensione massima di 64kB (65536)

Formato del Datagramma IP

- L'header contiene informazioni utili per l'instradamento del datagramma:
  - L'indirizzo della sorgente (chi ha inviato per primo il datagramma)
  - L'indirizzo della destinazione (chi riceverà il datagramma se tutto va bene)
  - Il tipo di protocollo che ha generato i dati
  - ...
- Gli indirizzi sono di tipo IP (ovvio)
- Gli indirizzi MAC sono "esterni" al datagramma
- I campi sono di dimensione fissa per efficienza di manipolazione

The IP Datagram Header Format



The IP Datagram Header Format

- **VERS:** Each datagram begins with a 4-bit protocol version number
- **H.LEN**: 4-bit header specifies the number of 32-bit quantities in the header
  - If no options are present, the value is 5
- Type of Service (**ToS**)
  - 8-bit field that carries a class of service for the datagram
    - potentially used for DiffServ and ECN (Explicit Congestion Notification)
    - seldom used in practice
- **TOTAL LENGTH**: 16-bit integer that specifies the total number of bytes including both the header and the data

The IP Datagram Header Format

- IDENTIFICATION
  - 16-bit number (usually sequential) assigned to the datagram
    - used to gather all fragments for reassembly to the datagram
- FLAGS
  - 3-bit field with individual bits specifying whether the datagram is a fragment
    - If so, then whether the fragment corresponds to the last piece of the original datagram
- FRAGMENT OFFSET
  - 13-bit field that specifies where in the original datagram the data in this fragment belongs
  - the value of the field is multiplied by 8 to obtain an offset

The IP Datagram Header Format

- **TIME TO LIVE (TTL)**
  - 8-bit integer initialized by the original sender
  - it is decremented **by each router** that processes the datagram
  - if the value **reaches zero (0) the datagram is discarded** and an error message is sent back to the source
- PROTOCOL
  - 8-bit field that specifies the type of the payload, i.e., the protocol above (e.g., 6 for TCP, 17 for UDP)
- HEADER CHECKSUM
  - 16-bit ones-complement checksum of header fields
- SOURCE IP ADDRESS
  - 32-bit Internet address of the original sender

The IP Datagram Header Format

- DESTINATION IP ADDRESS
  - The 32-bit Internet address of the ultimate destination
- IP OPTIONS
  - Optional header fields used to control routing and datagram processing
  - Most datagrams do not contain any options
- PADDING
  - If options do not end on a 32-bit boundary
    - zero bits of padding are added to make the header a multiple of 32 bits

FRAMMENTAZIONE DEI PACCHETTI IP

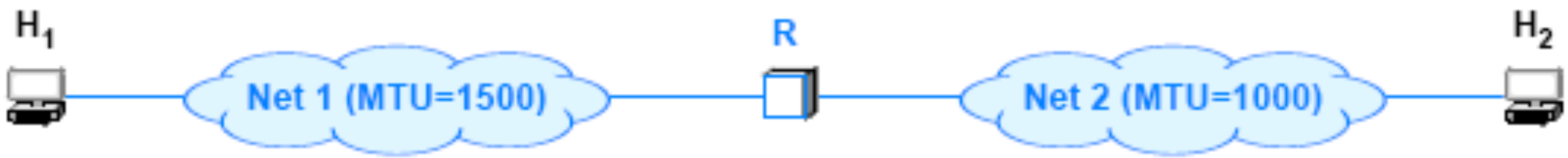
L'USO DELLA FRAMMENTAZIONE È "DEPRECATO". MOLTI ROUTER SEMPLICEMENTE NON LA IMPLEMENTANO E SCARTANO IL PACCHETTO.

MTU and Datagram Fragmentation

- Each hardware technology specifies the maximum amount of data that a frame can carry
  - The limit is known as a Maximum Transmission Unit (MTU)
- Network hardware is not designed to accept or transfer frames that carry more data than the MTU allows
  - A datagram must be smaller or equal to the network MTU
    - or it cannot be encapsulated for transmission
- In an internet that contains heterogeneous networks, MTU restrictions create a problem
- A router can connect networks with different MTU values
  - a datagram that a router receives over one network can be too large to send over another network

MTUs for some networks

Protocol	*MTU*
Hyperchannel	65,535
Token Ring (16 Mbps)	17,914
Token Ring (4 Mbps)	4,464
FDDI	4,352
Ethernet	1,500
X.25	576
PPP	variabile



- Example: a router interconnects two networks with MTU values of 1500 and 1000
  - Host H_1 attaches to a network with an MTU of 1500
    - and can send a datagram that is up to 1500 octets
  - Host H_2 attaches to a network that has an MTU of 1000
    - which means that it cannot send/receive a datagram larger than 1000 octets
  - If host H_1 sends a 1500-octet datagram to host H_2
    - router R will not be able to encapsulate it for transmission across network 2

MTU and Datagram Fragmentation

- When a datagram is larger than the MTU of the network over which it must be sent
  - the router divides the datagram into smaller pieces called fragments
  - and sends each fragment independently
- A fragment has the same format as other datagrams
  - a bit in the FLAGS field of the header indicates whether a datagram is a fragment or a complete datagram
- Other fields in the header are assigned information for the ultimate destination to reassemble fragments
  - to reproduce the original datagram
- The FRAGMENT OFFSET specifies where in the original datagram the fragment belongs

MTU and Datagram Fragmentation

- A router uses the network MTU and the header size to calculate
  - the maximum amount of data that can be sent in each fragment
  - and the number of fragments that will be needed
- The router creates the fragments
  - It uses fields from the original header to create a fragment header
  - It copies the appropriate data from the original datagram into the fragment
  - Transmits the result

Flags field

D: Do not fragment
M: More fragments

- Example: packets sent from H1 to H2
  - if host H1 sends a 1500-octet datagram to host H2, router R1 will divide the datagram into two fragments, which it will forward to R2
  - Router R2 does not reassemble the fragments
    - Instead R uses the destination address in a fragment to forward the fragment as usual
  - The ultimate destination host, H2, collects the fragments and reassembles them to produce the original datagram

- Requiring the ultimate destination to reassemble fragments has two advantages:
  - It reduces the amount of state information in routers
    - When forwarding a datagram, a router does not need to know whether the datagram is a fragment
  - It allows routes to change dynamically
    - If an intermediate router were to reassemble fragments, all fragments would need to reach the router
- By postponing reassembly until the ultimate destination
  - IP is free to pass some fragments from a datagram along different routes than other fragments

The Consequence of Fragment Loss

- A datagram cannot be reassembled until all fragments arrive
- The receiver must save (buffer) the fragments
  - In case missing fragments are only delayed
  - A receiver cannot hold fragments an arbitrarily long time
- IP specifies a maximum time to hold fragments
- When the first fragment arrives from a given datagram
  - the receiver starts a reassembly timer
- If all fragments of a datagram arrive before the timer expires
  - the receiver cancels the timer and reassembles the datagram
- Otherwise the receiver discards the fragments

GLI INDIRIZZI DI INTERNET: IPV4

Gli indirizzi di Internet

- Lo spazio di indirizzamento è un componente critico
- Tutti gli host e i router devono usare uno schema di indirizzamento **uniforme**
- Gli indirizzi Unicast, che identificano una specifica interfaccia devono essere **unici**
- Esistono due spazi di indirizzamento specificati per Internet
  - **IPv4**: quello attualmente in uso con indirizzi a 32 bit
  - IPv6: il sistema di indirizzamento che avrebbe dovuto sostituire IPv4, ma che continua a non farlo
    - indirizzi a 128 bit
    - funzioni "avanzate"
    - esistono molte "isole" IPv6 e ormai tutti i router dei maggiori vendor lo supportano

The IP Addressing Scheme

- IP addresses are supplied by protocol software
- Each network interface is assigned a unique 32-bit number
  - The interface IP address or Internet address
- When sending a packet across the Internet, sender's protocol software must specify
  - its own 32-bit IP address (the source address)
  - and the address of the intended recipient (the destination address)
- Routers only use the destination address for forwrding and routing

Dotted Decimal Notation

- Instead of writing 32 bits, a notation more convenient for humans to understand is used, known as dotted decimal notation
  - express each 8-bit section of a 32-bit number as a decimal value
  - use periods to separate the sections
- Dotted decimal treats each octet (byte) as an unsigned binary integer
  - the smallest value, 0
    - occurs when all bits of an octet are zero (0)
  - the largest value, 255
    - occurs when all bits of an octet are one (1)
  - dotted decimal addresses range

0.0.0.0 through 255.255.255.255

Dotted Decimal Notation: examples

32-bit Binary Number	Equivalent Dotted Decimal
10000001 00110100 00000110 00000000	129 . 52 . 6 . 0
11000000 00000101 00110000 00000011	192 . 5 . 48 . 3
00001010 00000010 00000000 00100101	10 . 2 . 0 . 37
10000000 00001010 00000010 00000011	128 . 10 . 2 . 3
10000000 10000000 11111111 00000000	128 . 128 . 255 . 0

The IP Address Hierarchy

- IP address is divided into two parts:
- A prefix ➔ identifies the physical network to which the host is attached (also known ad NetID)
  - Each network in the Internet is assigned a unique network number
- A suffix ➔ identifies a specific interface on the network (also known ad HostID)
  - Each NIC on a given network is assigned a unique suffix
- IP address scheme guarantees two properties:
  - Each computer is assigned a unique address
  - Network numbers (prefix) must be coordinated globally
  - Suffixes are assigned locally without global coordination

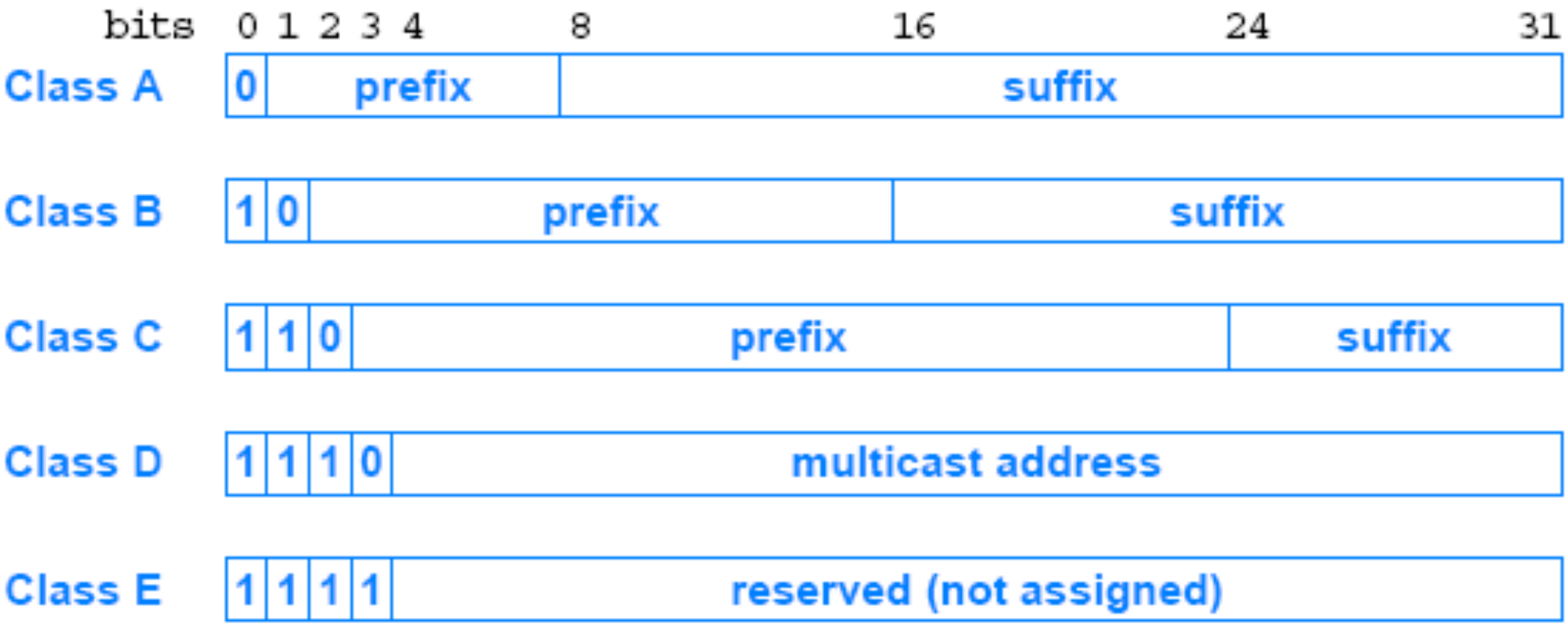
INDIRIZZAMENTO CON CLASSI (OBSOLETO)

Schema di organizzazione degli indirizzi usato fino alla metà degli anni ‘90 e basato su una divisione statica tra NetID e HostID

È uso ancora oggi riferire l’organizzazione degli indirizzi ad un concetto (e terminologia) di classe

Original Classes of IP Addresses

- Internet contains a few large physical networks and many small networks
  - the designers chose an addressing scheme to accommodate a combination of large and small networks
- The original classful IP addressing divided the IP address space into 3 primary classes
  - each class has a different size prefix and suffix
- The first four bits of an IP address determined the class to which the address belonged
  - It specifies how the remainder of the address was divided into prefix and suffix


bits 0 1 2 3 4 8 16 24 31
Class A
0
prefix
suffix
Class B
1 0
prefix
suffix
Class C
1 1 0
prefix
suffix
Class D
1 1 1 0
multicast address
Class E
1 1 1 1
reserved (not assigned)

Division of the Address Space

- The classful scheme divided the address space into unequal sizes
- The designers chose an unequal division to accommodate a variety of scenarios
  - For example, although it is limited to 128 networks, class A contains half of all addresses
    - The motivation was to allow major ISPs to each deploy a large network that connected millions of computers
    - But A classes were assigned to small networks all in the US ...
  - Similarly, the motivation for class C was to allow an organization to have a few computers connected on a LAN

Division of the Address Space

Address Class	Bits In Prefix	Maximum Number of Networks	Bits In Suffix	Maximum Number Of Hosts Per Network
A	7	128	24	16777216
B	14	16384	16	65536
C	21	2097152	8	256

Authority for Addresses

- Internet Corporation for Assigned Names and Numbers (ICANN) authority has been established
  - to handle address assignment and adjudicate disputes
- ICANN does not assign individual prefixes
  - Instead, ICANN authorizes a set of registrars to do so
- Registrars make blocks of addresses available to ISPs
  - ISPs provide addresses to subscribers
- To obtain a prefix
  - a corporation usually contacts an ISP

INDIRIZZAMENTO SENZA CLASSI E CIDR

Schema in uso attuale con divisione dinamica tra NetID e HostID

CIDR (Classless Inter-Domain Routing) consente l'instradamento globale senza usare la nozione di classe

Subnets and Classless Addressing

- As the Internet grew the original classful addressing scheme became a limitation
- Everyone demanded a class A or class B address
  - So they would have enough addresses for future growth
    - but many addresses in class A and B were unused
- Two mechanisms, closely related, were designed to overcome the limitation
  - Subnet addressing
  - Classless addressing
- Instead of having three distinct address classes, allow the division between prefix/suffix on an arbitrary bit boundary

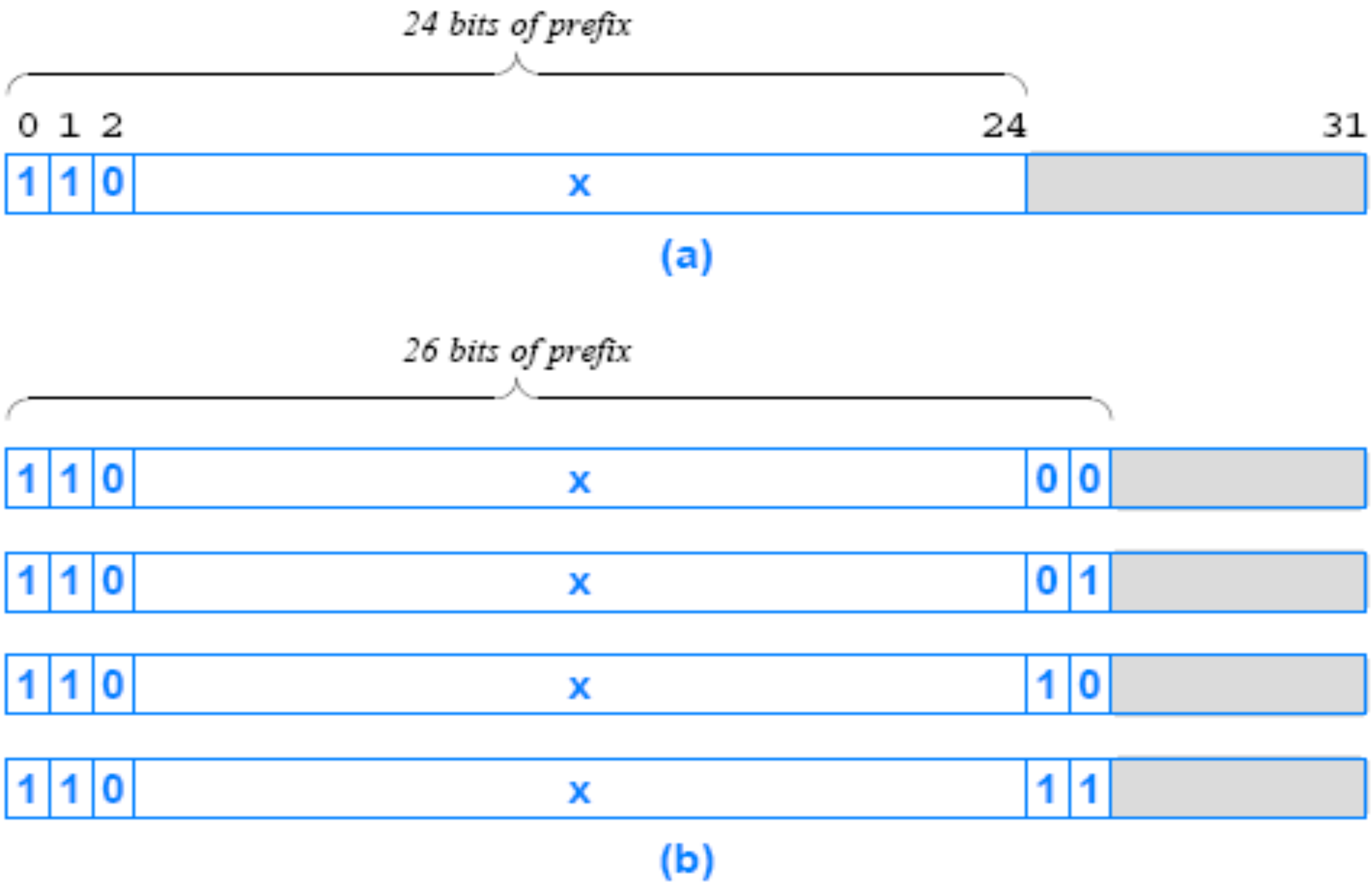
Classless Addressing: Motivation

- Consider an ISP that hands out prefixes. Suppose a customer of the ISP requests a prefix for a network that contains 55 hosts
  - classful addressing requires a complete class C prefix
  - only 6 bits of suffix are needed to represent all possible host values
    - means 190 of the 254 possible suffixes would never be assigned
  - most of the class C address space is wasted
- For the above example
  - classless addressing allows the ISP to assign
    - a prefix that is 26 bits long
    - a suffix that is 6 bits long

Classless Addressing: Example

- Assume an ISP owns a class C prefix
  - Classful addressing assigns the entire prefix to one organization
- With classless addressing
  - the ISP can divide the prefix into several longer prefixes
- For instance, the ISP can divide a class C prefix into 4 longer prefixes
  - each one can accommodate a network of up to 62 hosts
    - all 0s and all 1s are reserved
- The original class C address has 8 bits of suffix
  - and each of the classless addresses has 6 bits of suffix
- Thus, instead of wasting addresses
  - ISP can assign each of the 4 classless prefixes to a subscriber

Classless Addressing: Example



Address (subnet) Masks

- How can an IP address be divided at an arbitrary boundary?
- The classless and subnet addressing schemes require hosts and routers to store an additional piece of information:
  - a value that specifies the exact boundary between prefix and suffix
- To mark the boundary, IP uses a 32-bit value
  - known as an address mask, also called a subnet mask
- Why store the boundary size as a bit mask?
  - A mask makes processing efficient
- Hosts and routers need to compare the network prefix portion of the address to a value in their forwarding tables
  - The bit-mask representation makes the comparison efficient

Address Masks

- Suppose a router is given
  - a destination address, D
  - a network prefix represented as a 32-bit value, N
  - a 32-bit address mask, M
- Assume the top bits of N contain a network prefix, and the remaining bits have been set to zero
- To test whether the destination lies on the specified network, the router tests the condition:

$$N == (D \& M)$$

- The router
  - uses the mask with a “logical and (&)” operation to set the host bits of address D to zero (0)
  - and then compares the result with the network prefix N

- Consider the following 32-bit network prefix:

  10000000 00001010 00000000 00000000 → 128.10.0.0
- Consider a 32-bit mask:

  11111111 11111111 00000000 00000000 → 255.255.0.0
- Consider a 32-bit destination address, which has a

  10000000 00001010 00000010 00000011 → 128.10.2.3
- A logical & between the destination address and the address mask extracts the high-order 16-bits

  10000000 00001010 00000000 00000000 → 128.10.0.0

CIDR Notation

- Classless Inter-Domain Routing (CIDR)
- Consider a mask defining a subnet with 2^6 nodes
  - It has 26 bits of 1s followed by 6 bits of 0s
  - In dotted decimal, the mask is: 255.255.255.192
- The general form of CIDR notation is: ddd.ddd.ddd.ddd/m
  - ddd is the decimal value for an octet of the address
  - m is the number of one bits in the mask
- Thus, one might write the following: 192.5.48.69/26
  - which specifies a mask of 26 bits

A CIDR Example

- Assume an ISP has the following block 128.211.0.0/16
- Suppose the ISP has 2 customers
  - one customer needs 12 IP addresses and the other needs 9
- The ISP can assign
  - customer1 CIDR: 128.211.0.16/28
  - customer2 CIDR: 128.211.0.32/28
  - both customers have the same mask size (28 bits), the prefixes differ

A CIDR Example (cont'd)

- The binary value assigned to customer1 is:
  - 10000000 11010011 00000000 00010000
- The binary value assigned to customer2 is:
  - 10000000 11010011 00000000 00100000
- There is no ambiguity
  - Each customer has a unique prefix
  - More important, the ISP retains most of the original address block
    - it can then allocate to other customers

CIDR Host Addresses

- Once an ISP assigns a customer a CIDR prefix
  - the customer can assign host addresses for its network users
- Suppose an organization is assigned 128.211.0.16/28
  - the organization will have 4-bits to use as a host address field
- Disadvantage of classless addressing
  - Because the host suffix can start on an arbitrary boundary, values are not easy to read in dotted decimal

CIDR Host Addresses

Network Prefix 128.211.0.16 / 28

0 ... 28 31

1 0 0 0 0 0 0 0 : 1 1 0 1 0 0 1 1 : 0 0 0 0 0 0 0 0 : 0 0 0 1 | 0 0 0 0

Address Mask 255.255.255.240

0 ... 28 31

1 1 1 1 1 1 1 1 : 1 1 1 1 1 1 1 1 : 1 1 1 1 1 1 1 1 : 1 1 1 1 | 0 0 0 0

Lowest Host Address 128.211.0.17

0 ... 28 31

1 0 0 0 0 0 0 0 : 1 1 0 1 0 0 1 1 : 0 0 0 0 0 0 0 0 : 0 0 0 1 | 0 0 0 1

Highest Host Address 128.211.0.30

0 ... 28 31

1 0 0 0 0 0 0 0 : 1 1 0 1 0 0 1 1 : 0 0 0 0 0 0 0 0 : 0 0 0 1 | 1 1 1 0

INDIRIZZI PRIVATI, SPECIALI E INDIRIZZI DEI ROUTER

Non tutti gli indirizzi IP sono utilizzabili, alcuni indirizzi hanno significato solo interno al computer e altri consentono di fare il bootstrap delle macchine prima che abbiano un indirizzo IP con cui comunicare.
I Router sono macchine con più indirizzi IP ... anche se non sempre con più interfacce fisiche di comunicazione.

Indirizzi pubblici e privati

- Non tutti gli indirizzi IP Unicast validi sono uguali
- Alcuni indirizzi sono stati definiti “privati” e non sono instradabili in Internet
  - Possono essere usati per costruire Intra-net private
- Un host con indirizzo IP privato ha bisogno di una apparato attivo che traduca opportunamente i suoi pacchetti per accedere a Internet
- NAT: Network Address Translator
  - Mappa la 5-tupla che identifica un flusso su un’altra 5-tupla con indirizzo pubblico, lavora a livello L3/L4
- Proxy
  - Gateway di L7, che interconnette a livello di singola applicazione

Indirizzi Privati

- 10.0.0.0 – 10.255.255.255
- 172.16.0.0 – 172.31.255.255
- 192.168.0.0 – 192.168.255.255

- Un indirizzo privato può essere riutilizzato in molti posti diversi
- All'interno di una stessa rete devono essere unici e possono essere "routati" fino a un "border router" che invece impedisce di andare verso Internet
- Normalmente sono assegnati tramite DHCP e non sono assegnati staticamente a un host
- Non c'è una reale differenza tra i tre gruppi di indirizzi, ma in genere i router "domestici" usano 192.168.x.y/24

Special IP Addresses

- IP defines a set of special address forms that are reserved
  - That is, special addresses are never assigned to hosts
- Examples:
  - Network Address
  - Directed Broadcast Address
  - Limited Broadcast Address
  - This Computer Address
  - Loopback Address
  - Multicast addresses

Network Address

- It is convenient to have an address that can be used to denote the prefix assigned to a given network
- IP reserves host address zero
  - and uses it to denote a network
- Thus, the address 128.211.0.16/28 denotes a network
  - because the bits beyond the 28 are zero
  - 10000000 11010011 00000000 00010000
- A network address should never appear as the destination address in a packet

Directed Broadcast Address

- To simplify broadcasting (send to all)
  - IP defines a directed broadcast address for each physical network
- When a packet is sent to a network's directed broadcast
  - a single copy of the packet travels across the Internet
    - until it reaches the specified network
  - the packet is then delivered to all hosts on the network
- The directed broadcast address for a network is formed by adding a suffix that consists of all 1 bits to the network prefix
  - <u>10000000 11010011 00000000 0001</u>1111

Limited Broadcast Address

- Limited broadcast refers to a broadcast on a directly-connected network:
  - informally, we say that the broadcast is limited to a “single LAN” meaning that it will never be forwarded by a router, even if the “LAN” can be a huge Campus LAN with hundreds of computers
- Limited broadcast is used during system startup
  - by a computer that does not yet know the network number
- IP reserves the address consisting of 32-bits of 1s
  - 11111111 11111111 11111111 11111111
- Thus, IP will broadcast any packet sent to the all-1s address across the local network

This Computer Address

- A computer needs to know its IP address
  - before it can send or receive Internet packets
- TCP/IP contains protocols a computer can use to obtain its IP address automatically when the computer boots
  - … but the startup protocols also use an IP to communicate
- When using such startup protocols
  - a computer cannot supply a correct IP source address
  - To handle such cases IP reserves the address that consists of all 0s to mean this computer
  - 00000000 00000000 00000000 00000000

Loopback Address

- Loopback address used to test network applications
  - e.g., for preliminary debugging after a network application has been created
- A programmer must have two application programs that are intended to communicate across a network
- Instead of executing each program on a separate computer
  - the programmer runs both programs on a single computer
  - and instructs them to use a loopback address when communicating
- When one application sends data to another
  - data travels down the protocol stack to the IP software
  - then forwards it back up through the protocol stack to the second program

Loopback Address (cont'd)

- IP reserves the network prefix 127/8 for use with loopback
- The host address used with 127 is irrelevant
  - all host addresses are treated the same
  - programmers often use host number 1
  - so it makes 127.0.0.1 the most popular loopback address
- During loopback testing no packets ever leave a computer
  - the IP software forwards packets from one application to another
- The loopback address never appears in a packet traveling across a network

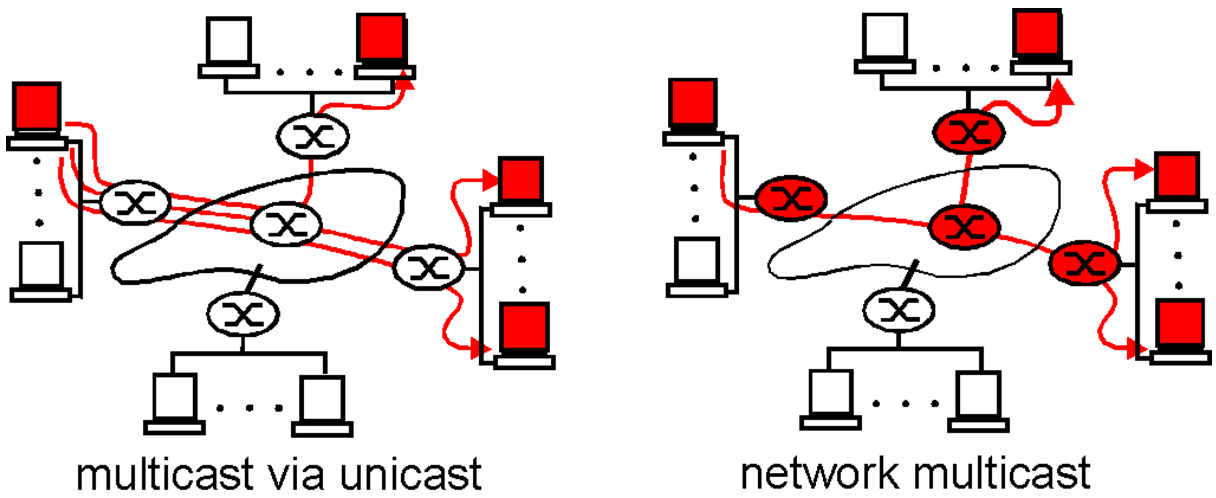
Summary of Special IP Addresses

Prefix	Suffix	Type Of Address	Purpose
all-0s	all-0s	this computer	used during bootstrap
network	all-0s	network	identifies a network
network	all-1s	directed broadcast	broadcast on specified net
all-1s	all-1s	limited broadcast	broadcast on local net
127 / 8	any	loopback	testing

Indirizzo Multicast

- Internet ammette l'invio di pacchetti a "molti"
- I router si preoccupano (complesso, non lo vediamo in questo corso) di capire il punto ottimo dove duplicare l'informazione
- Un pacchetto multicast è inviato a un indirizzo di "gruppo"
- In IPv4: Class D, iniziano per 1110
- 224.0.0.0 – 239.255.255.255
- Esistono gruppi multicast "well known"
- 224.0.0.1: All Hosts on this Subnet
- 224.0.0.2: All Routers on this Subnet
- Gli altri possono essere usati per applicazioni proprietarie o nuove
- Purtroppo non tutti gli ISP permettono traffico multicast se non per la gestione dei protocolli di routing stessi

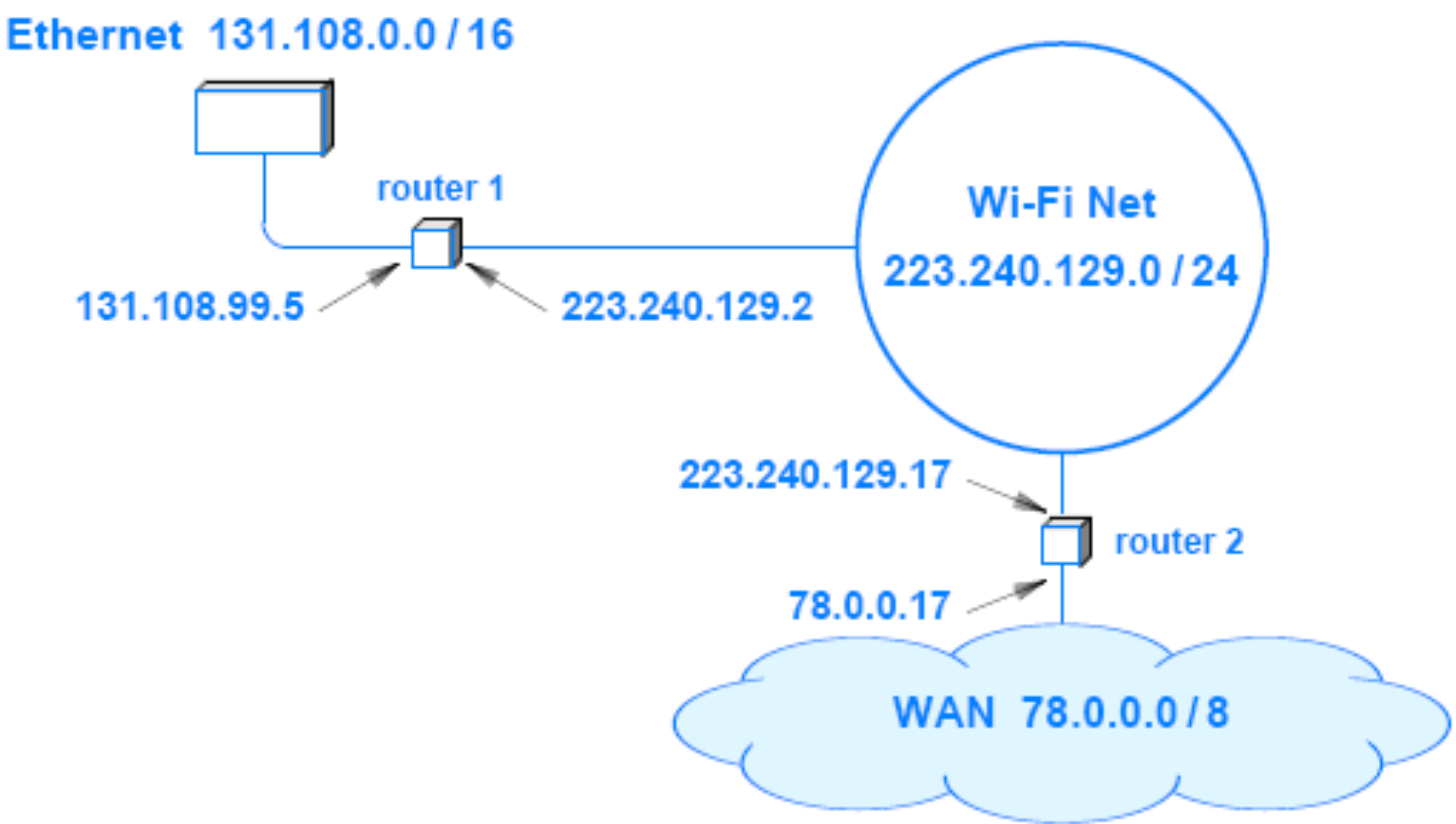
- Multicast: delivery of same packet to a group of receivers with the minimum overhead
- Multiple unicast vs. multicast
  - Host based vs. network based



Routers and IP Addresses

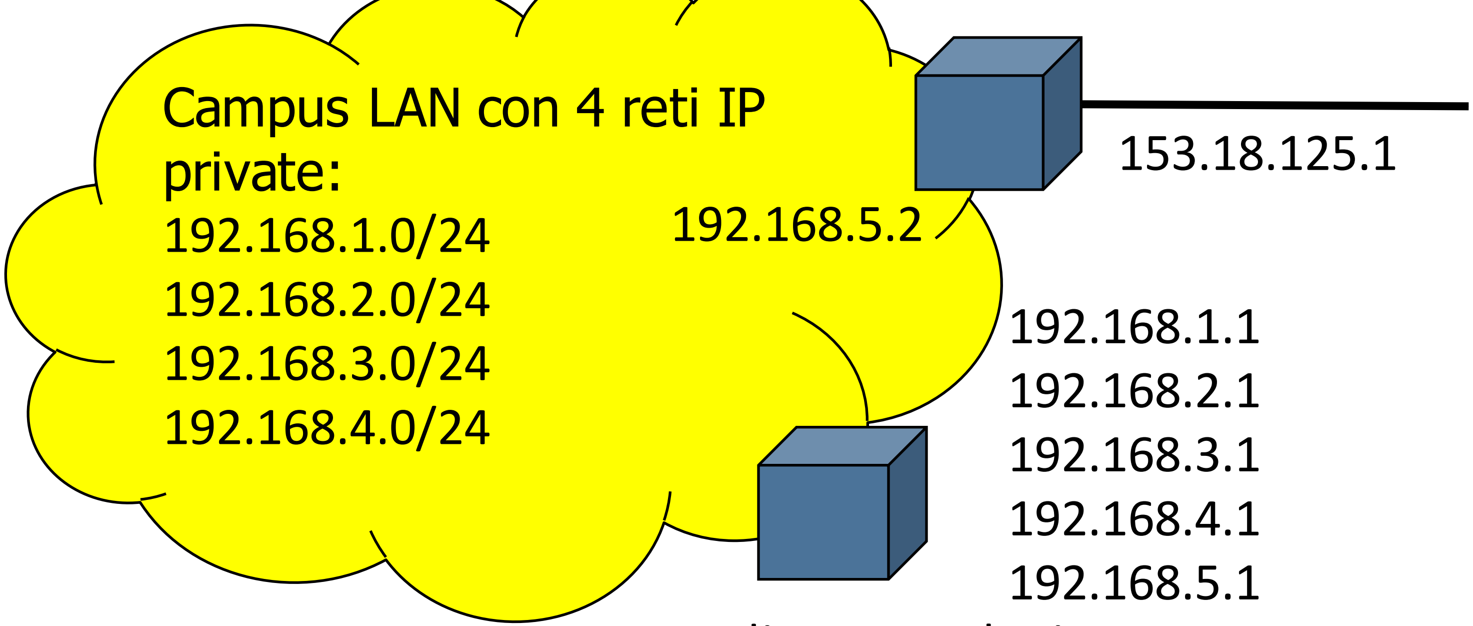
- Each router is assigned two or more IP addresses
  - one address for each logical network to which the router attaches
- To understand why, recall two facts:
  - A router connects multiple IP networks (by definition)
  - Each IP address contains a prefix that specifies a logical network
- A single IP address does not suffice for a router
  - because each router connects to multiple networks
  - and each network has a unique prefix
- The IP scheme can be explained by a principle:
  - An IP address does not identify a specific computer
  - each address identifies in interface, i.e., a logical connection between a computer and a network
  - A computer with multiple network connections (e.g., a router) must be assigned one IP address for each connection

An Example


Ethernet 131.108.0.0 / 16
router 1
131.108.99.5
223.240.129.2
Wi-Fi Net
223.240.129.0 / 24
223.240.129.17
router 2
78.0.0.17
WAN 78.0.0.0 / 8

Un altro esempio

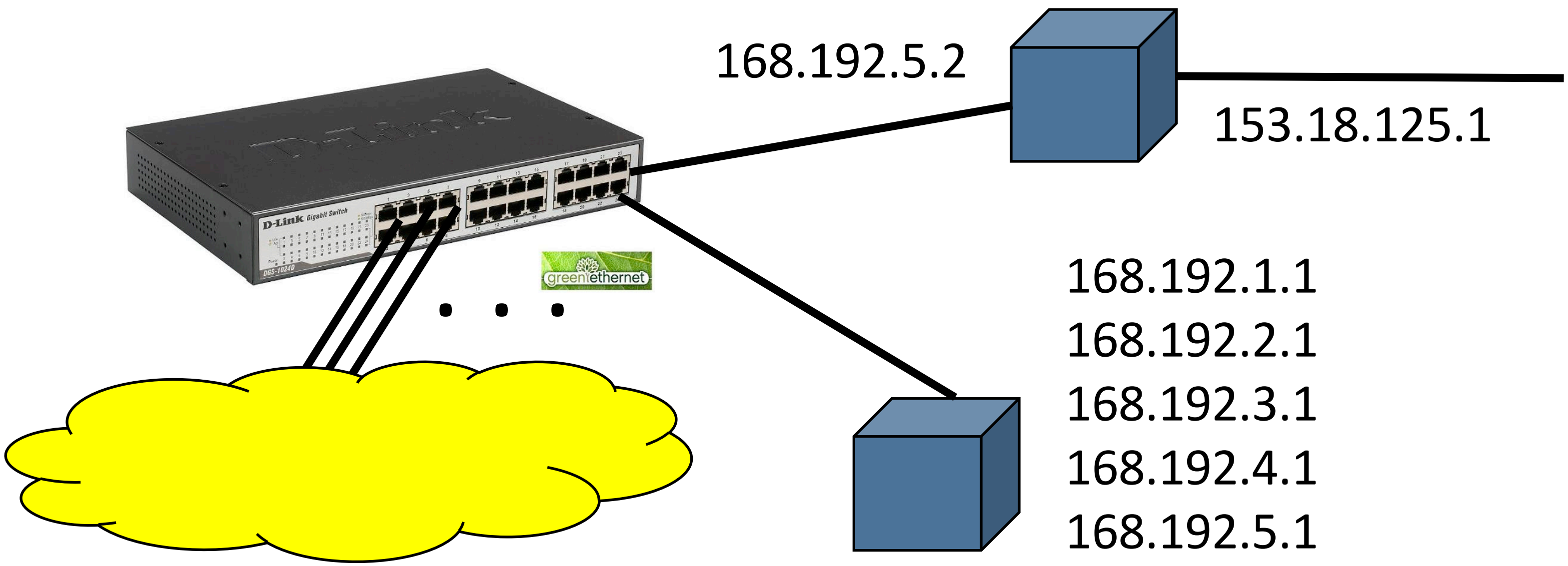
Router, NAT Firewall per accesso a Internet 2 indirizzi IP su due interfacce diverse



Router di campus che interconnette le 4 reti ed inoltra al Router NAT di collegamento verso Internet: 5 indirizzi IP tutti sulla stessa interfaccia fisica della campus LAN

Un altro esempio (cont)

Collegamento a livello ethernet



Router di campus che interconnette
le 4 reti ed inoltra al Router NAT di
collegamento verso Internet: 5 indirizzi IP
tutti sulla stessa interfaccia fisica della campus LAN