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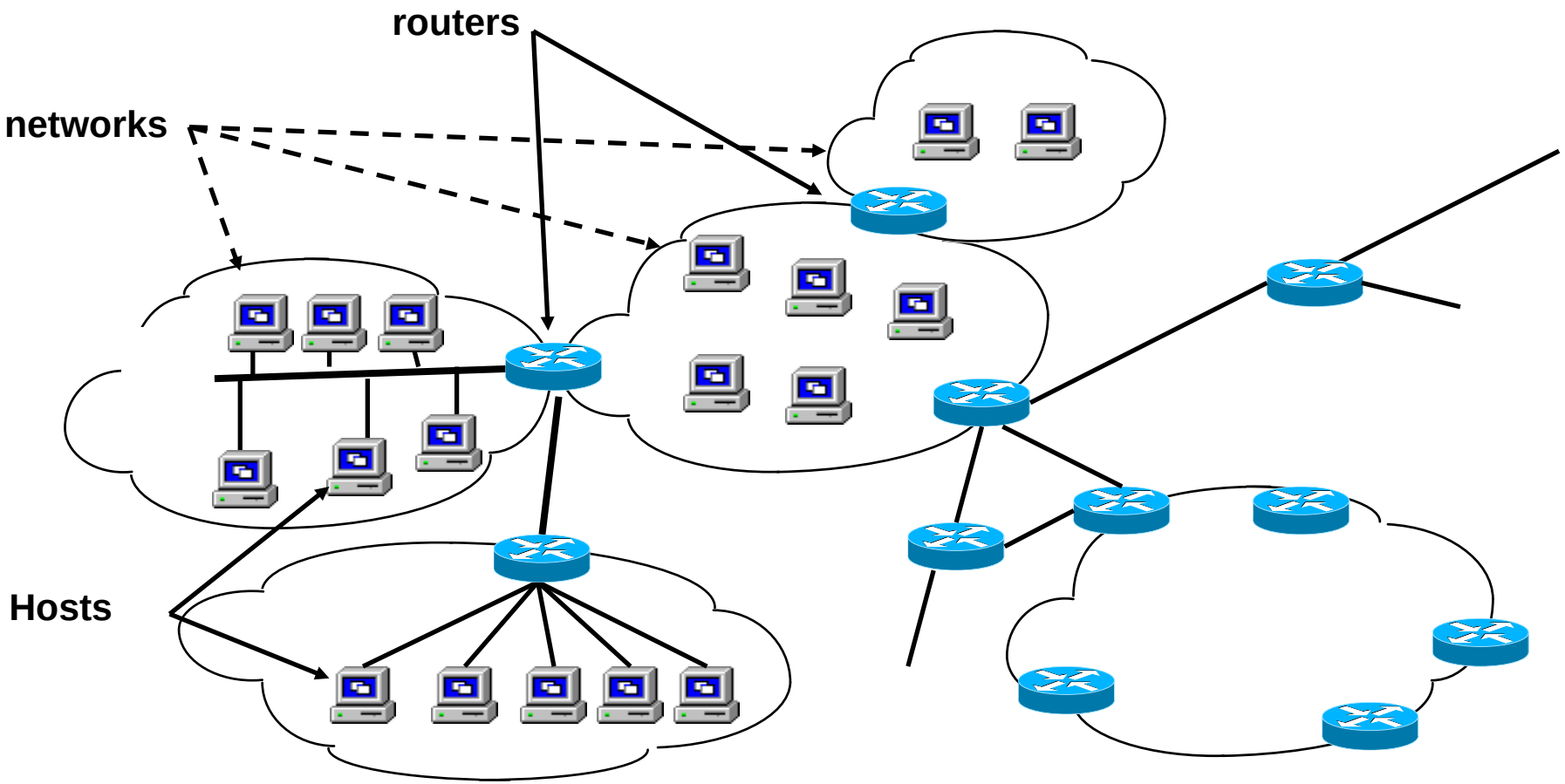
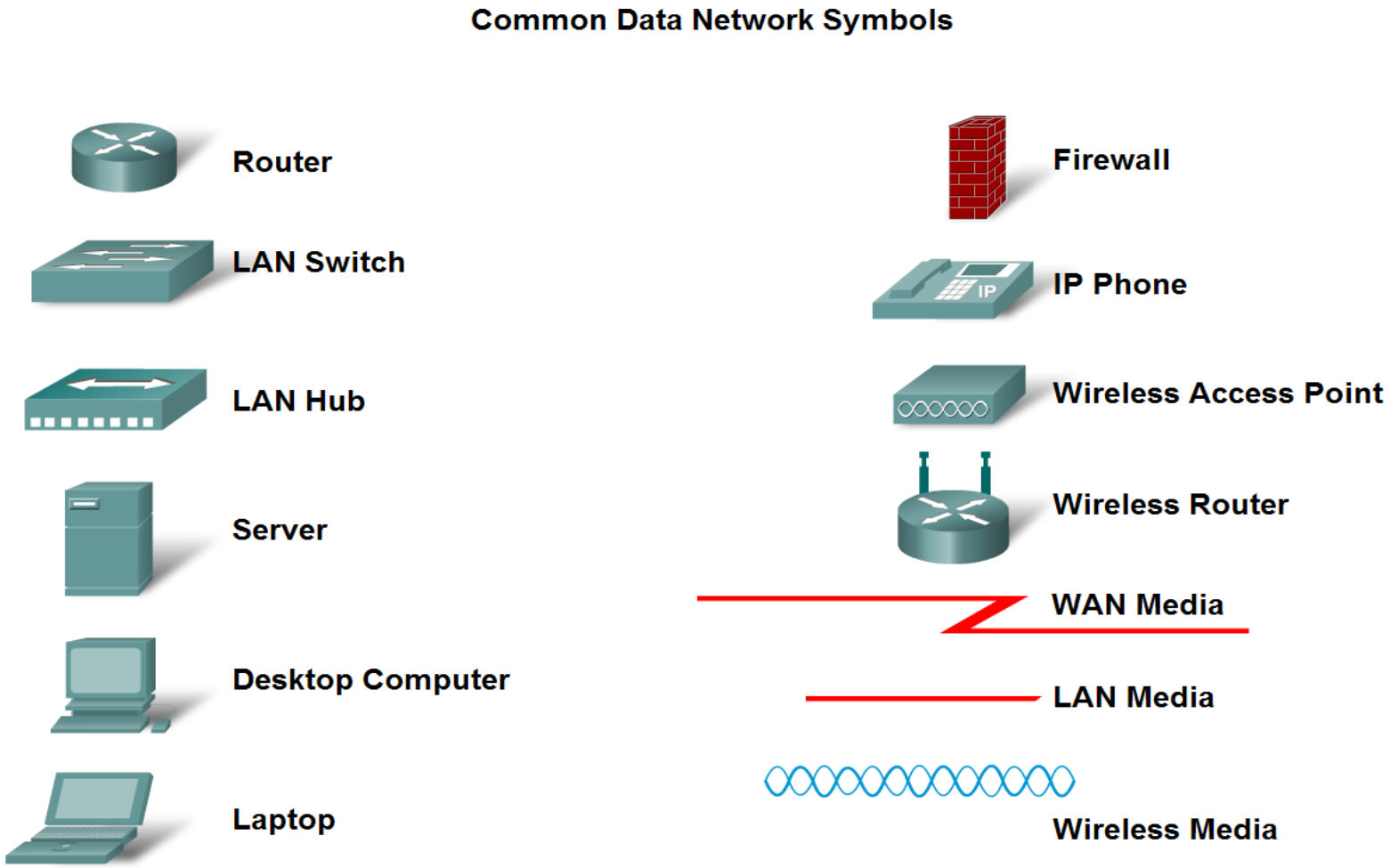
Fundamentals of IP Networking

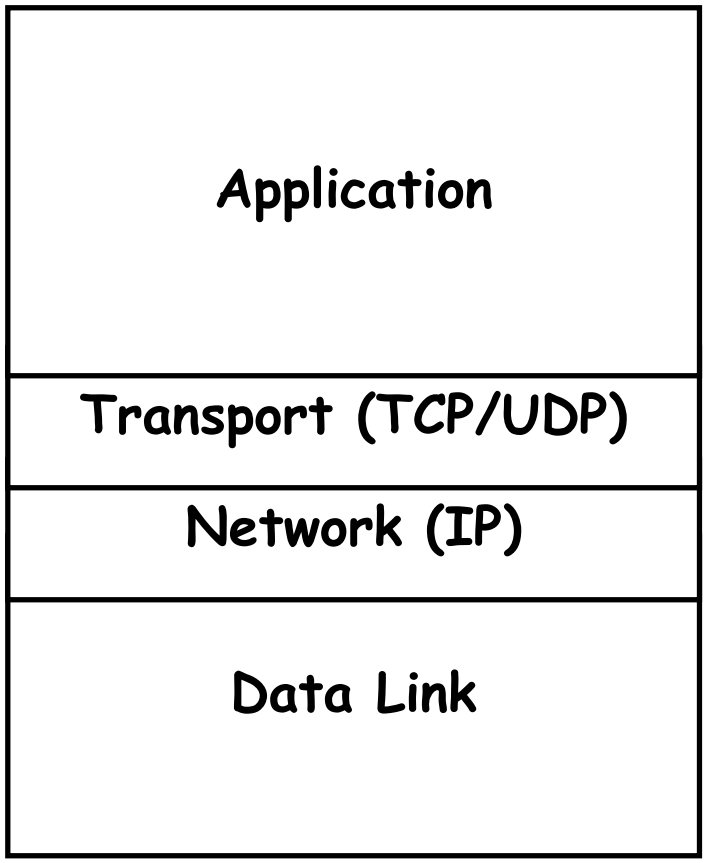
The Internet network



Network devices

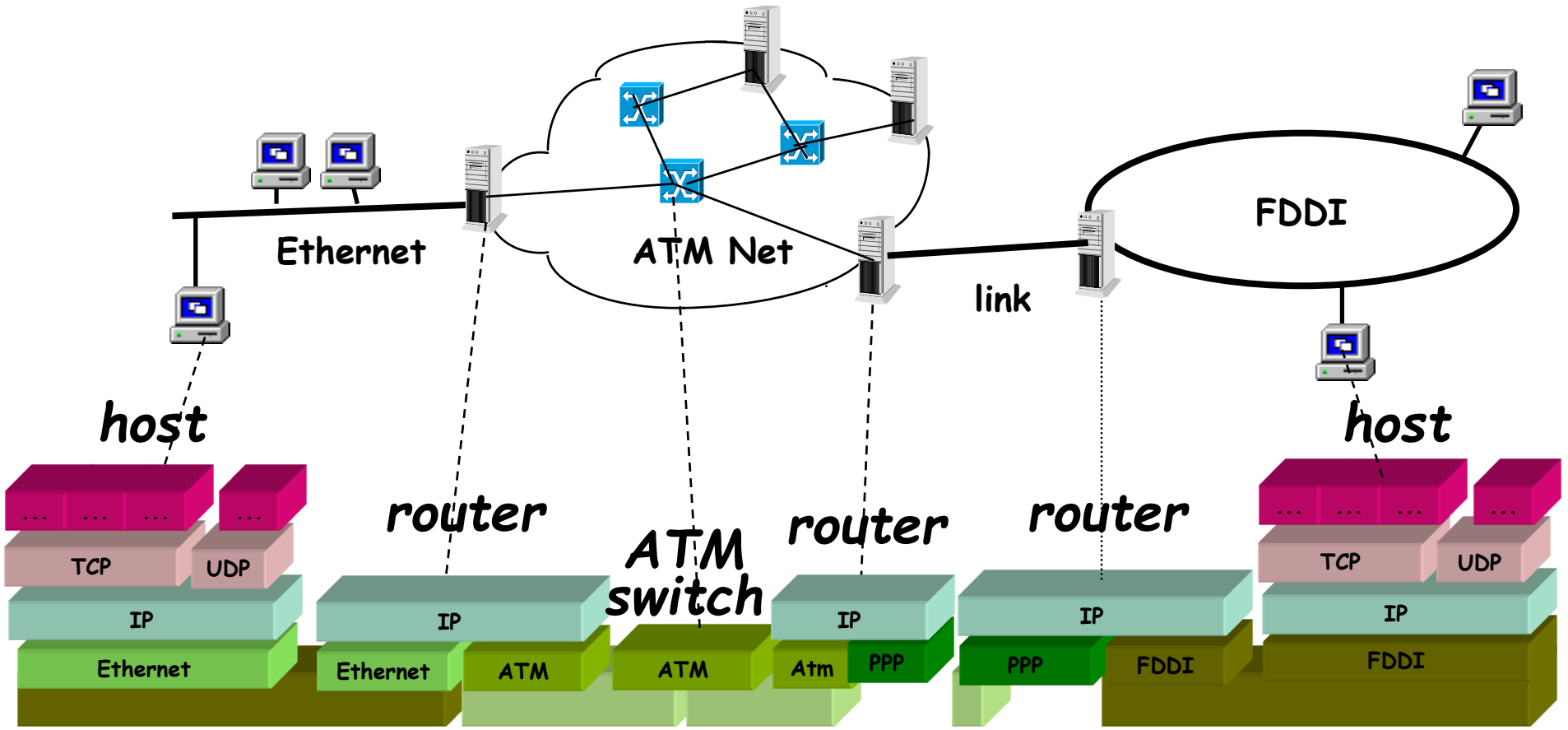


TCP/IP protocol stack



- Applications (HTTP, FTP, TELNET): distributed programs using the network to exchange data (messages).
- Transport layer: end-to-end communication service; UDP is connectionless, TCP is connection oriented (take care of segments re-orderding and recovery).
- Network layer main functions: addressing and forwarding/routing.
- Data Link layer: set of protocols for different physical networks/links (Ethernet, PPP,…)

TCP/IP stack in action



IP routers

Router: overview

- A router is very similar to a PC from an hardware point of view: CPU, memories, system bus and input/output interfaces.
- It has a dedicate operating System: IOS (Internetwork Operating System) for the Cisco devices.
- The IOS must be configured to properly work: IP addresses, routing protocols setting, security aspects…..
  - Configuration files

Router hardware components (1/4)

- **CPU**
  - Execute IOS instructions, such as initialization, routing functions and interfaces management.
  - High performance routers can have more than one CPU.
- **RAM**
  - Used to store the routing table, the cache fast switching, the configuration file and the packet queues.
  - It provides the run time space for the software executed by the IOS and it is composed of interfaces shared memory and main processor memory.
  - It stores the configuration file of the router while it is powered on: the running configuration file.

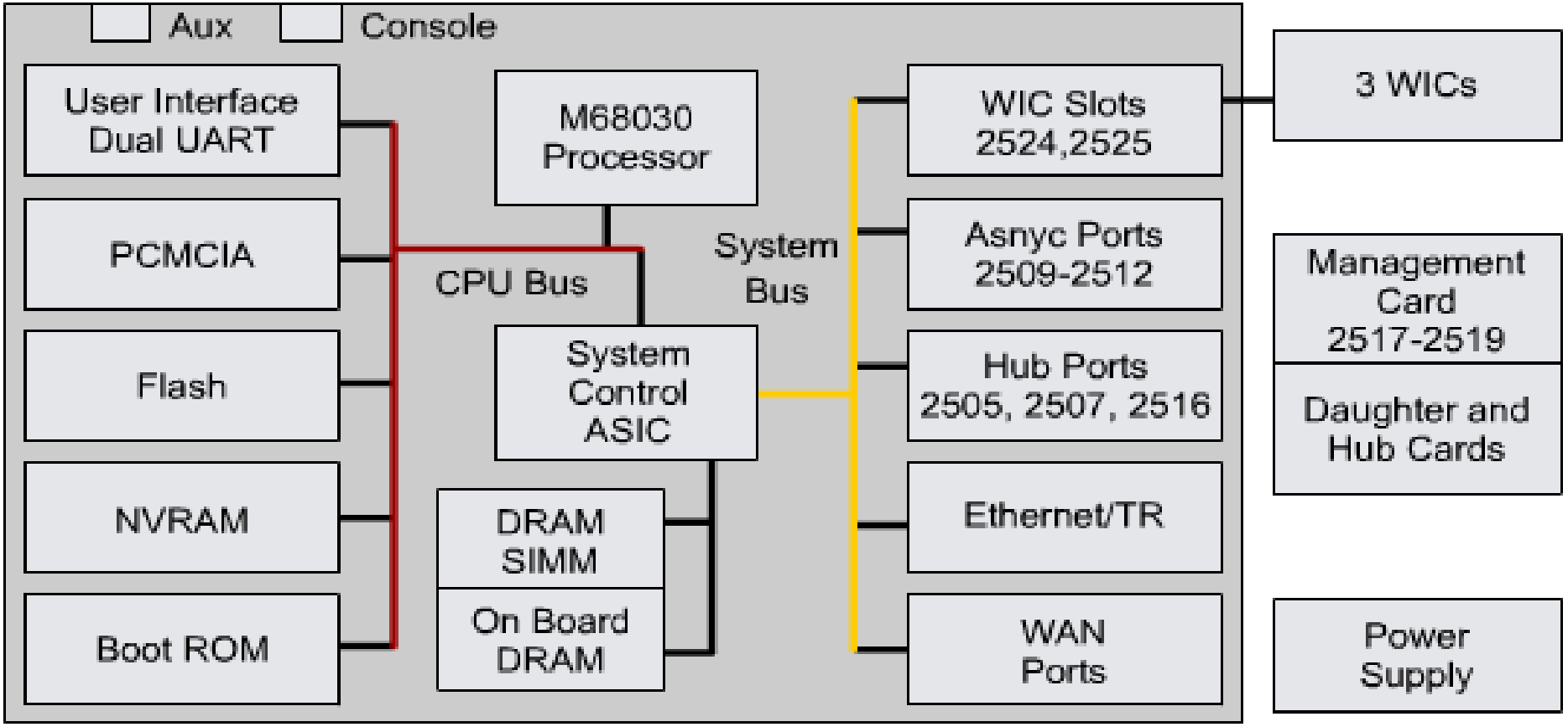
Router hardware components (2/4)

- **Flash**
  - Used to store the image of the IOS (the image will be loaded every time the router is powered on)
- **NVRAM**
  - It store the configuration to be used at startup: the startup configuration file.
- **Bus**
  - Usually two buses: the system bus and the CPU bus.
  - The system bus is the one providing communication among CPU and interfaces and used to forward packets among ingress and egress interfaces.

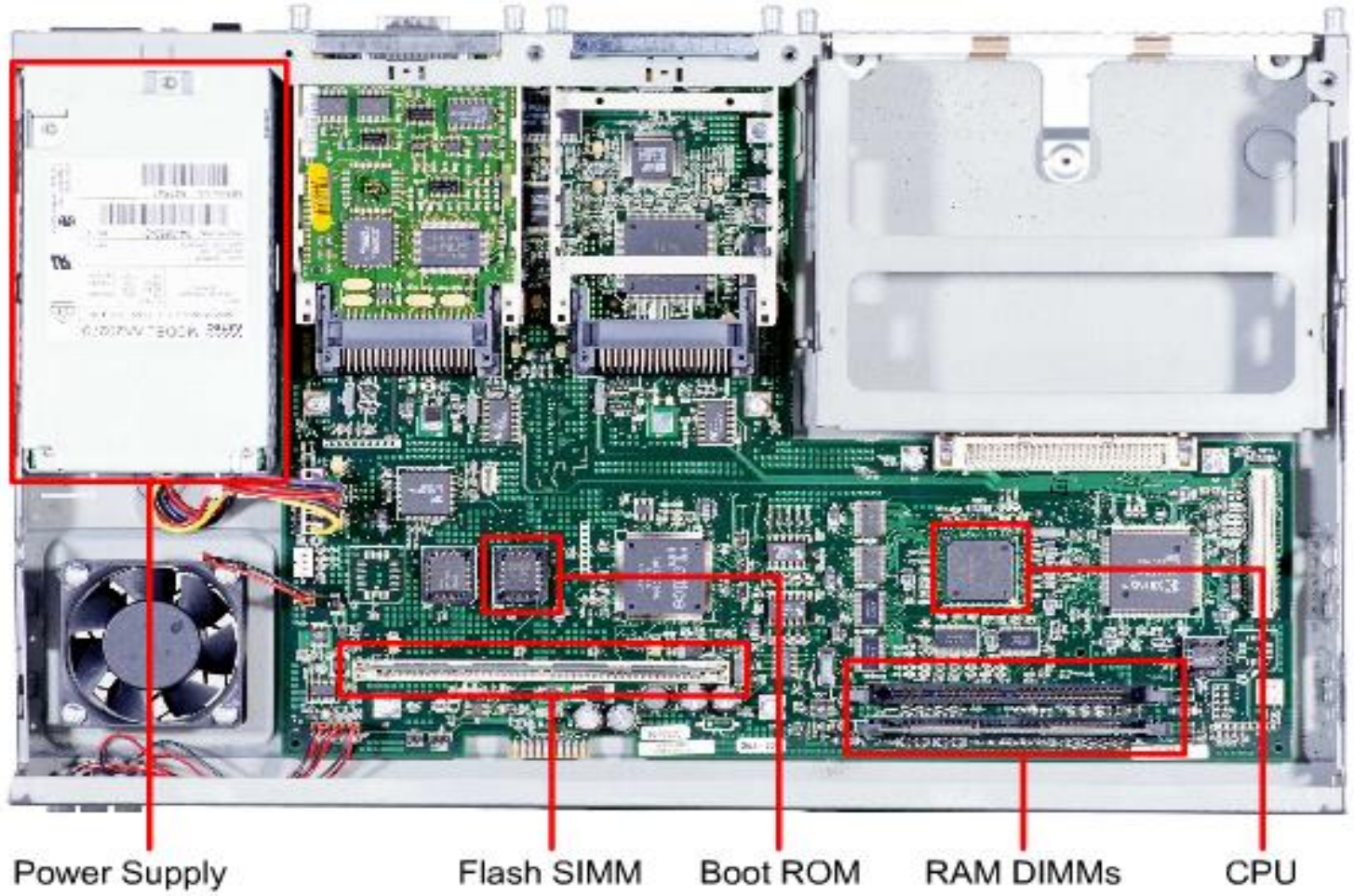
Router hardware components (3/4)

- **ROM**
  - Stores in a permanent way the code used to perform hardware integrity checking (performed at startup)
- **Interfaces**
  - the connections among the router and the "external world"
  - different types of interfaces
  - Can be classified in: LAN, WAN and console/AUX

Router hardware components (4/4)

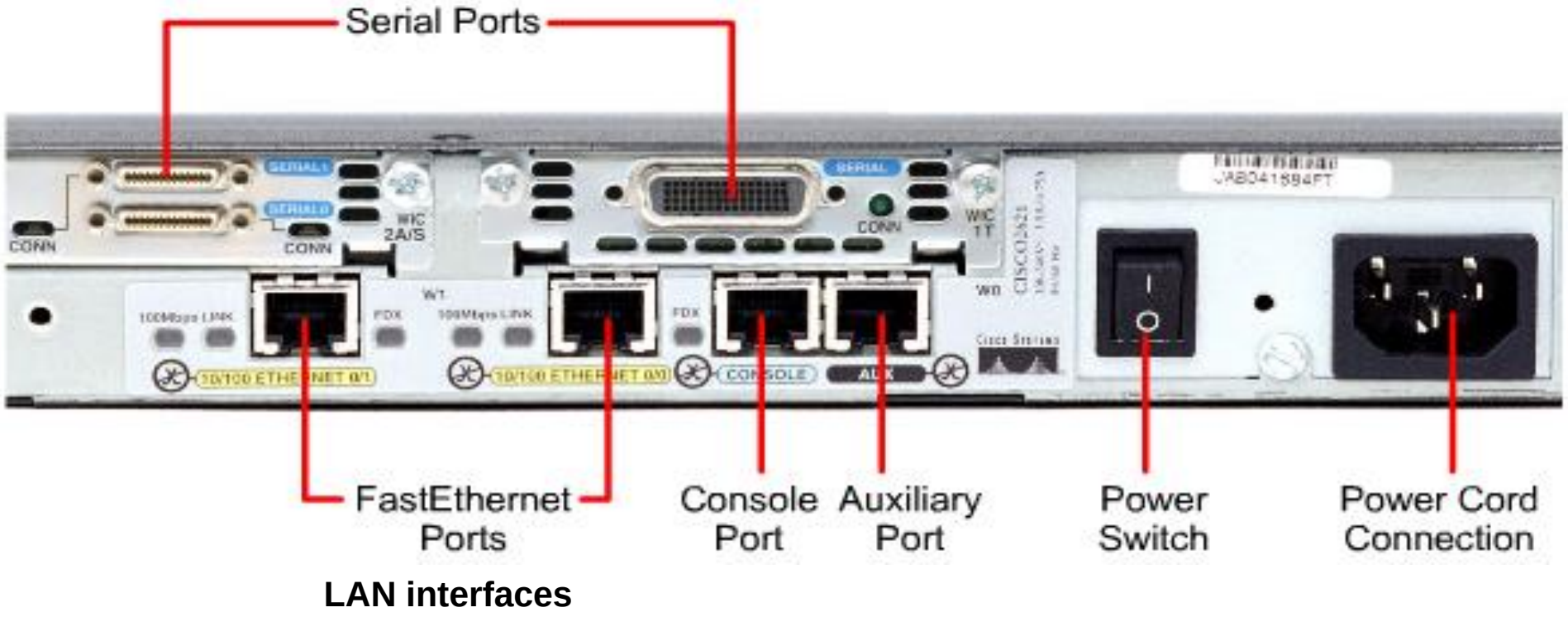


Cisco 2600 router



Cisco 2600 router interfaces

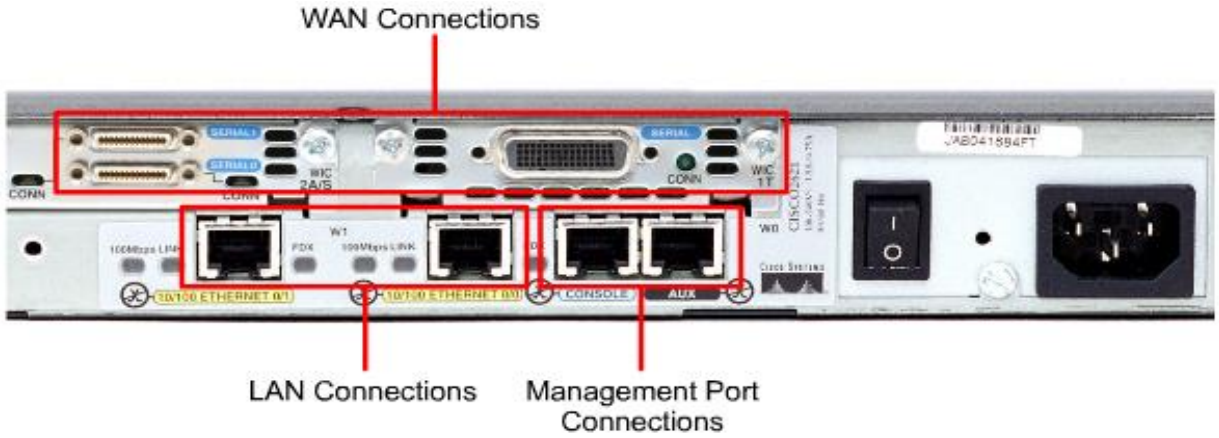
WAN interfaces



LAN interfaces

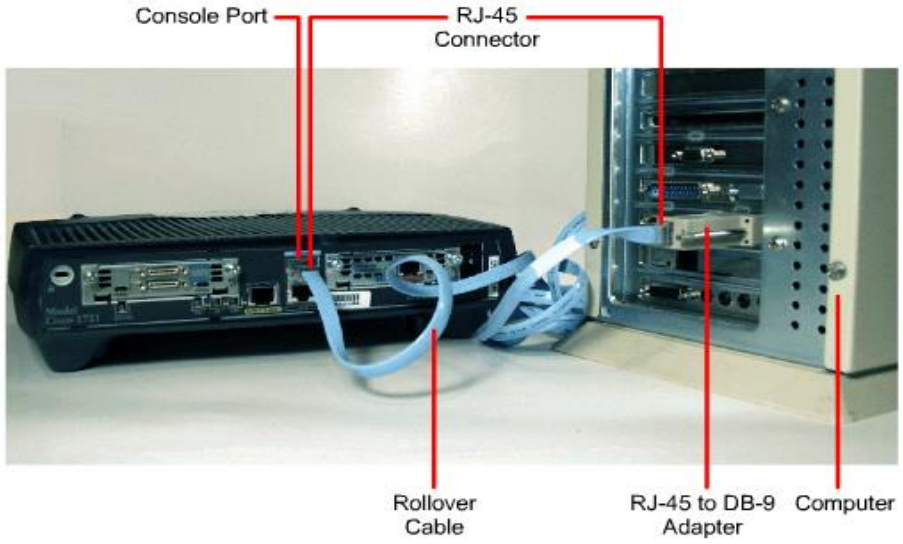
Router interfaces

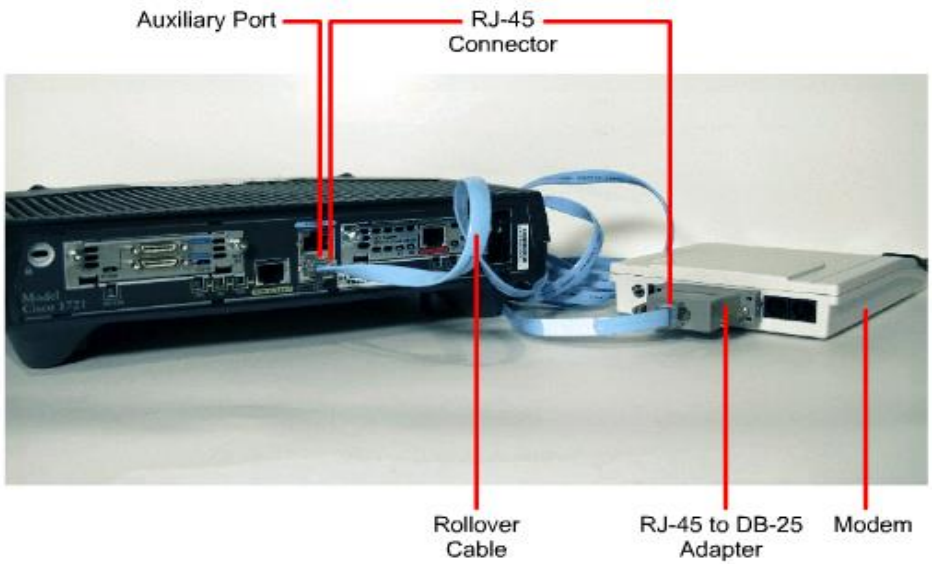
- **LAN:** provide connectivity toward a Local Area Network (LAN); the de-facto LAN standard is Ethernet
- **WAN:** provide connectivity toward a Local Area Network (WAN); there is no de-facto standard (many different protocols); this is usually the connection toward an Internet Service Provider.
- **management:** provide text-based connection toward a PC to configure the router



Management interfaces

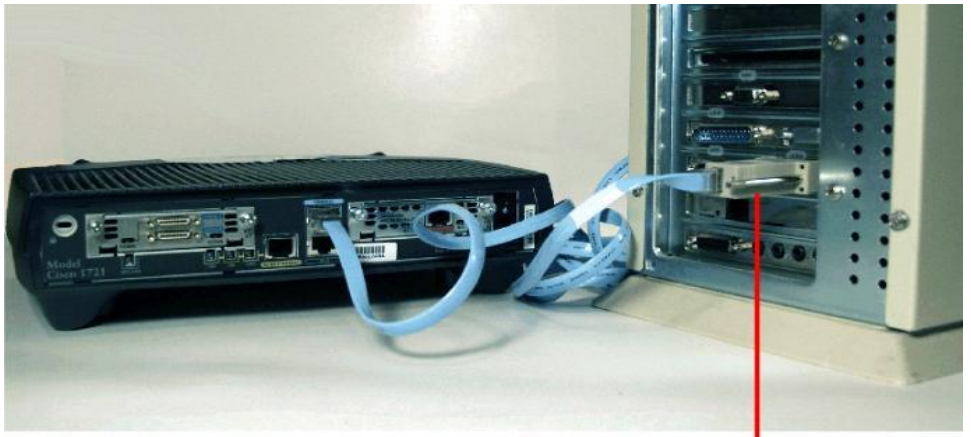
- The console and AUX (auxiliary) interface are dedicated to router management operations.
- There must be already one (the console) for the initial router configuration.



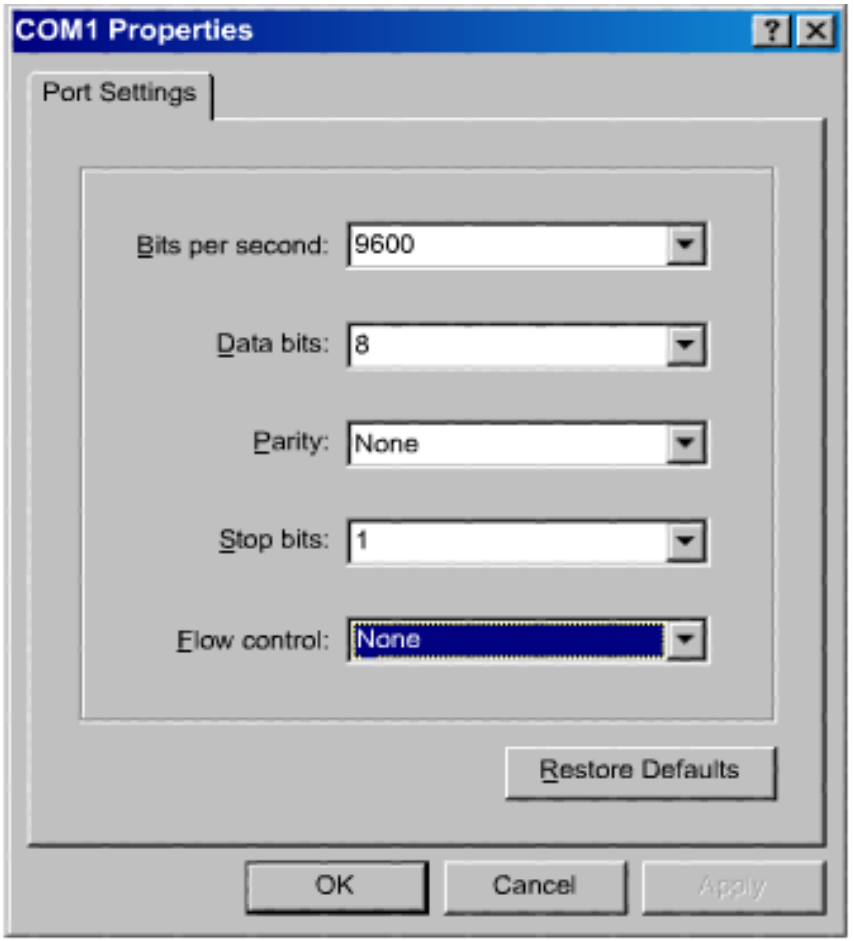


Console interface

- The access provided by the console interface is defined as out-of-band
- It is used for the initial configuration, for troubleshooting, for monitoring and for disaster recovery procedures.
- A rollover cable and a "RJ-45 to DB-9" adapter are needed to connect to a console port.
- The PC must support the terminal emulation (Hyperterminal).



Hyperterminal interface

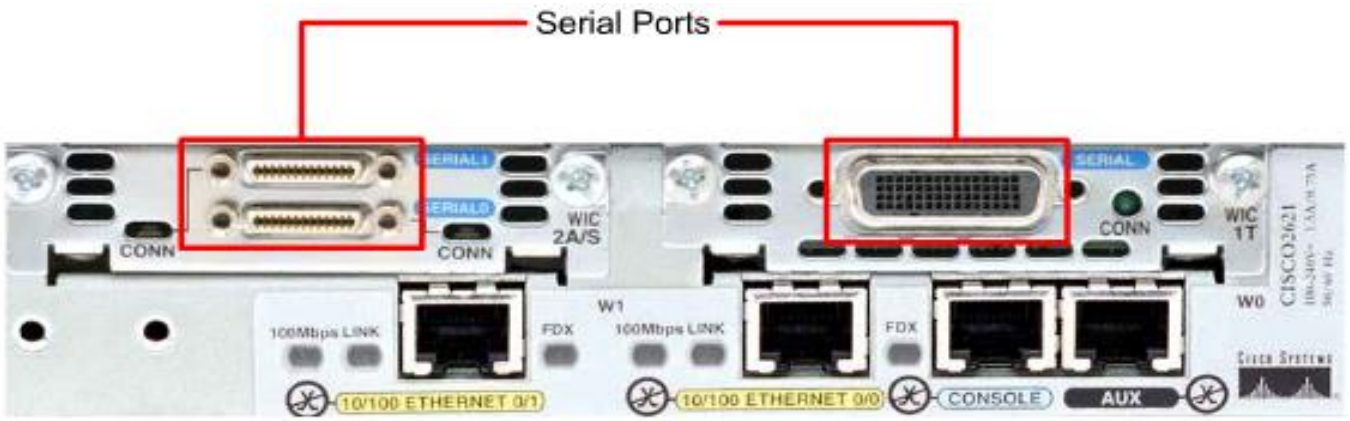


The LAN interface

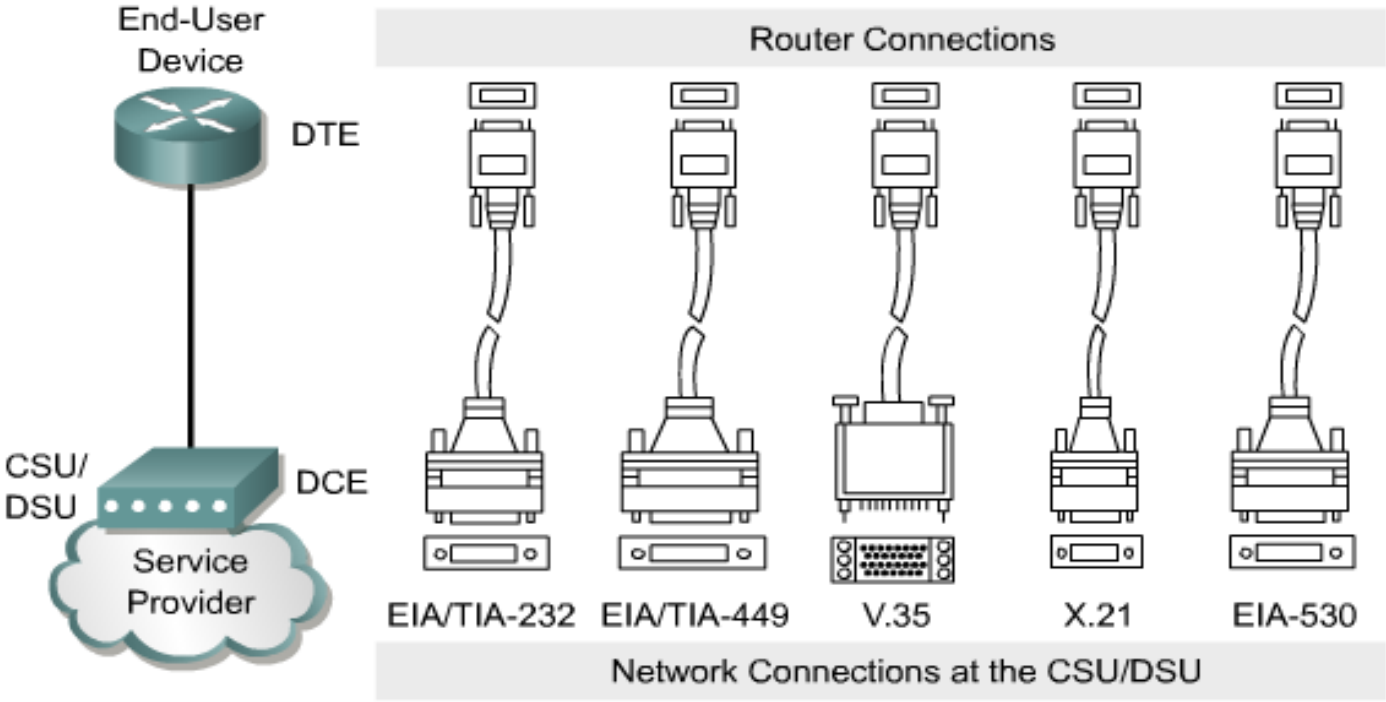
- The router is connected to a LAN using the Ethernet (FastEthernet) interface.
- The router is connected by its LAN interface to a switch, a hub or a host/router (very rare).
- For connections with a switch or hub, a straight – through cable is used.
- For connections with a router or a host, a crossover cable is used
- The LAN interface allows the in-band router configuration: TELNET

The WAN interface (1/2)

- The WAN connections (also defined as "Serial Ports") can be of different types since different technologies (protocols) can be used.



The WAN interface (2/2)



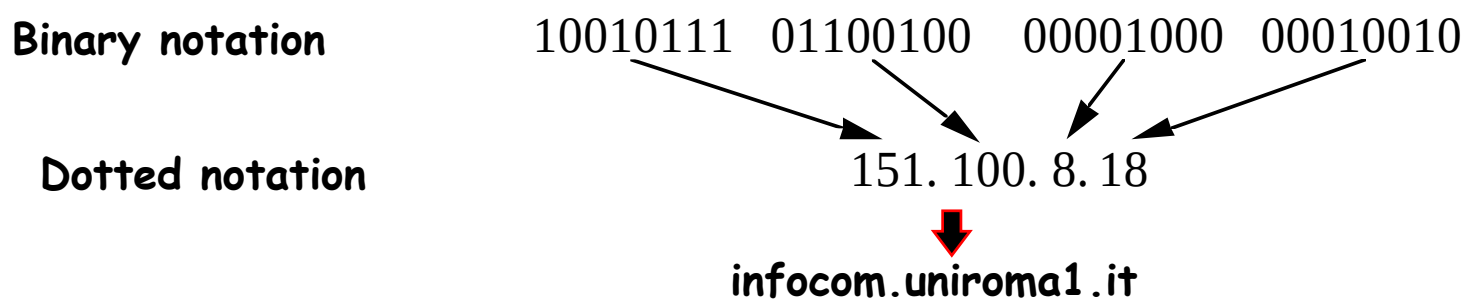
The IP routers: fundaments

Router functions

- A router makes possible the interconnections among different subnetworks
- A router implements the first 3 layers of the TCP/IP protocol stack. The main functions performed are the ones of **Network layer**.
- Main protocol of Network layer: Internet Protocol (IP).
- The IP layer (RFC 791, 919, 922, 950, 1349) executes the following functions:
  - **Addressing**
  - **Forwarding**
  - **Fragmentation**
- A router must be properly configured by the network administrator

Addressing (1/3)

- An IP Address identify routers and hosts:
  - a host connected to more than a subnetwork (multi-homed) has an IP address for each subnetwork;
  - a router has an IP address for each interface.
- An IP address is unique in the Internet (one exception, NAT)
  - it is 32 bits long;
  - a decimal dotted notation is used for easiness.



Addressing (2/3)

- IP addresses have a **hierarchical** structure.

- The addressing space is divided into blocks: a block of addresses is assigned to each subnetwork

IP_Address=Net_Id.Host_Id

  - The Net_Id identifies the subnetwork (block): Prefix
  - The Host_Id identifies the specific address of the block

- It allows for a scalable forwarding management
  - Each subnetwork is represented by its Net_Id prefix

Addressing (3/3)

- To identify the Net_ID lenght, the **Subnet Mask** (**Mask**) is introduced: a 32 bit string having 1s for Net_Id bits and 0s for Host_Id bits

Address = Net_Id . Host_Id

Mask= 1111….11 . 00….000

The address used to identify the whole block (subnet)

Block Address(S)= Net_Id . 0….000

Mask= 11……..11 . 0….000

- Given the IP address of an host (Add(H)) and a subnet S represented by (Add(S),Mask(S)), to verify if H belongs to S (Matching):

$Add(H) \in S \Leftrightarrow Add(H) \,\&\, Mask(S) = Add(S)$

AND

Classfull addressing

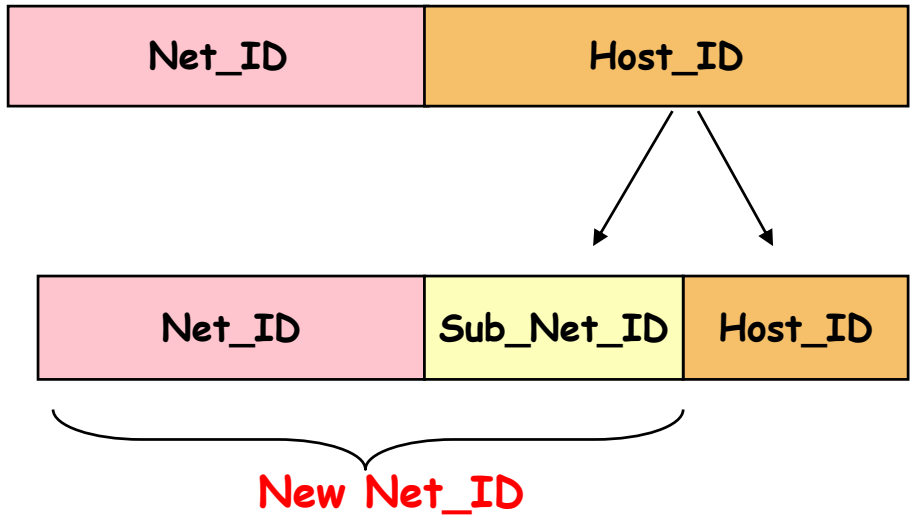
IP Address Classes

Address Class	1st octet range (decimal)	1st octet bits (green bits do not change)	Network(N) and Host(H) parts of address	Default subnet mask (decimal and binary)	Number of possible networks and hosts per network
A	1-127**	00000000-01111111	N.H.H.H	255.0.0.0	128 nets (2^7) 16,777,214 hosts per net (2^24-2)
B	128-191	10000000-10111111	N.N.H.H	255.255.0.0	16,384 nets (2^14) 65,534 hosts per net (2^16-2)
C	192-223	11000000-11011111	N.N.N.H	255.255.255.0	2,097,150 nets (2^21) 254 hosts per net (2^8-2)
D	224-239	11100000-11101111	NA (multicast)		
E	240-255	11110000-11111111	NA (experimental)		

** All zeros (0) and all ones (1) are invalid hosts addresses.

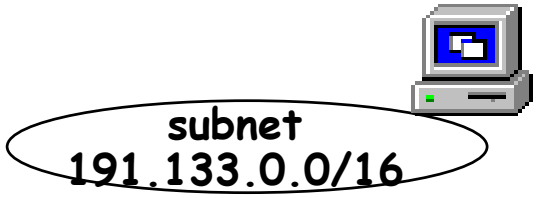
Classless and subnetting

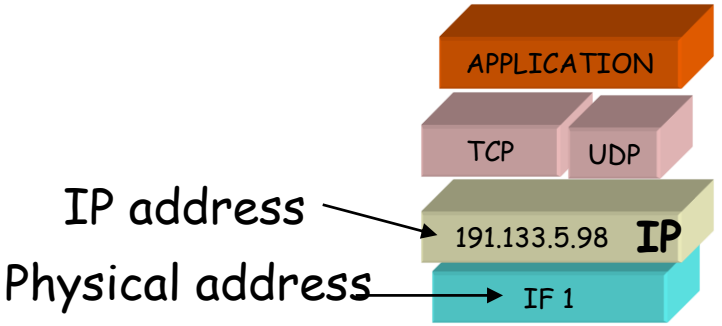
- Subnetting allows for the use of netmask different than classfull ones:
  Esempio.: subnetting starting from a class C block:
  255.255.255.128 (10000000) /25
  255.255.255.192 (11000000) /26
  ……



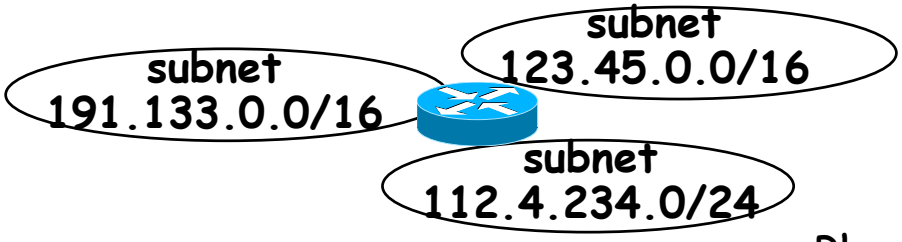
Host vs router

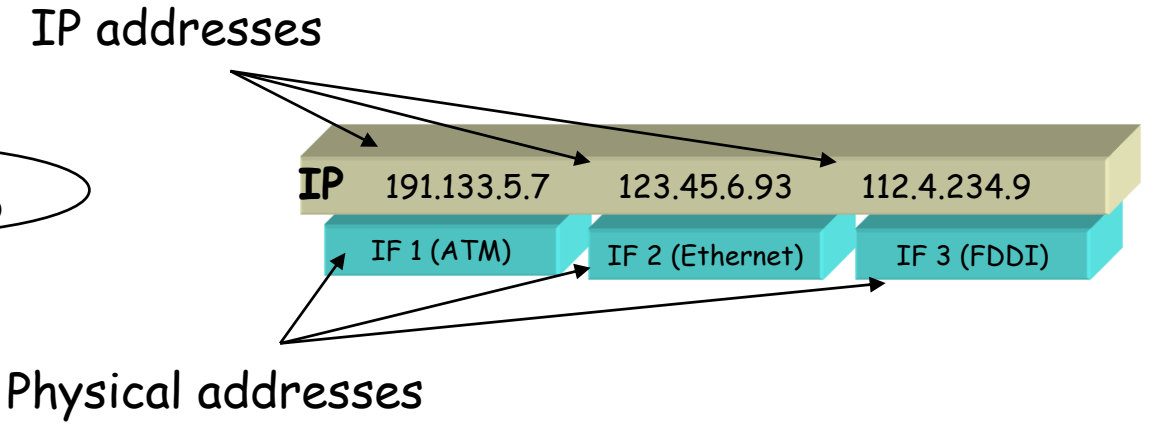
- host)





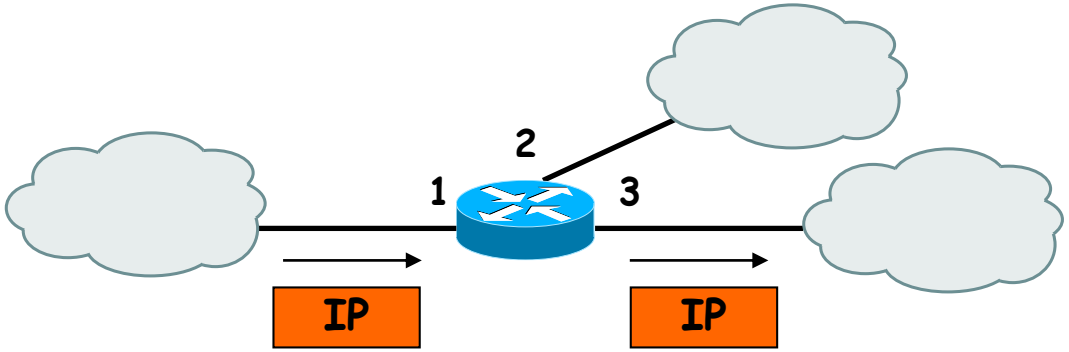
- Router





IP Forwarding and routing

- The IP routers perform packet forwarding:

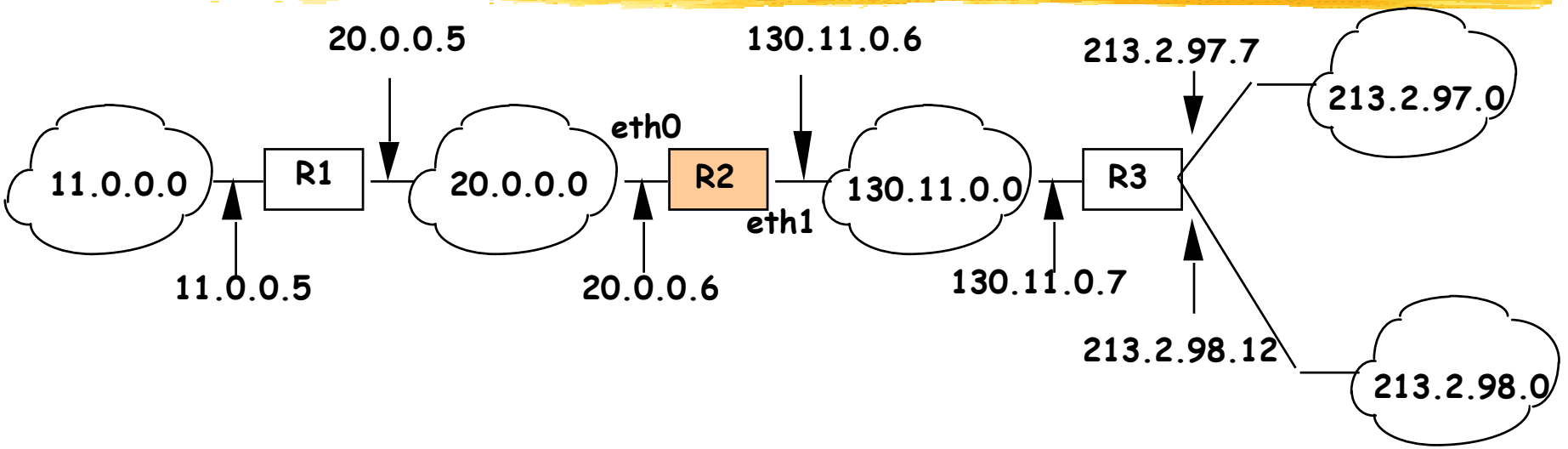


- Routing: the path form a source host to a destination host is composed of routers and networks crossed.

Routing table

- IP routing is based on the routing table (each host and router has its own one): routing information about known destinations
- A routing table is composed of (N, M, NH, I) entries:
  - N is the IP address of the destination network,
  - M is the subnet mask of the destination network having N as address
  - NH is the next-hop router toward the destination
  - I is the router/host interface to which forward the packets directed to network N
- **Longest Prefix Matching rule**

Example



R2 routing table

N	M	NH	I
20.0.0.0	255.0.0.0	d.c. (20.0.0.6)	eth0
130.11.0.0	255.255.0.0	d.c. (130.11.0.6)	eth1
11.0.0.0	255.0.0.0	20.0.0.5	eth0
213.2.97.0	255.255.255.0	130.11.0.7	eth1
213.2.98.0	255.255.255.0	130.11.0.7	eth1

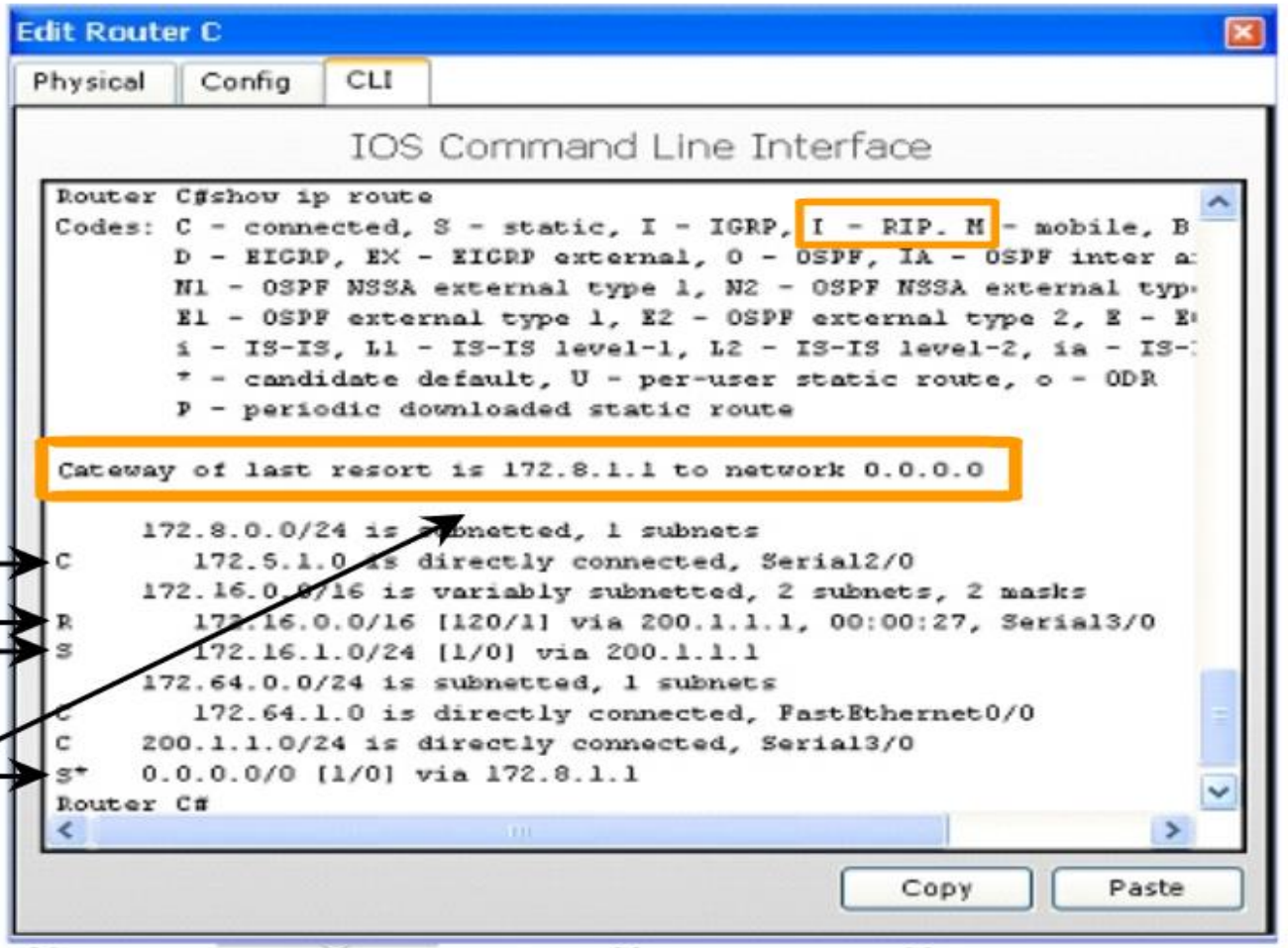
Default router/gateway

- Router to use as next hop for traffic directed to an unknown network (not present in the routing table)
- Not mandatory but often used.

- It is representd by all 0s for columns N and M.

Destinazione N	Maschera M	Next hop NH	Interfaccia I
20.0.0.0	255.0.0.0	d.c. (20.0.0.6)	eth0
130.11.0.0	255.255.0.0	d.c. (130.11.0.6)	eth1
0.0.0.0	0.0.0.0	20.0.0.5	eth0

Routing table of a Cisco router



Host configuration

- Any host connected to an IP network must be properly configured
  - Host name
  - IP address
  - Subnet mask
  - Default router
  - Server DNS
- DHCP protocol
- Private IP addresses: NAT