Camada de Ligação (Data Link Layer)
Parte 1

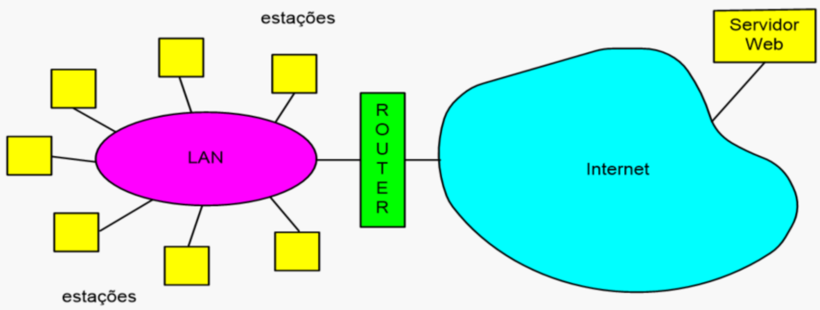
Fundamentos de Redes

Mestrado Integrado em Engenharia de Computadores e Telemática

DETI-UA, 2019/2020

LANs – Redes de área local

- **Permitem a comunicação direta entre estações próximas através de ligações partilhadas**
- **Tecnologias**
  - **IEEE 802.3 Ethernet, IEEE 802.11 WiFi, IEEE 802.5 Token Ring, …**

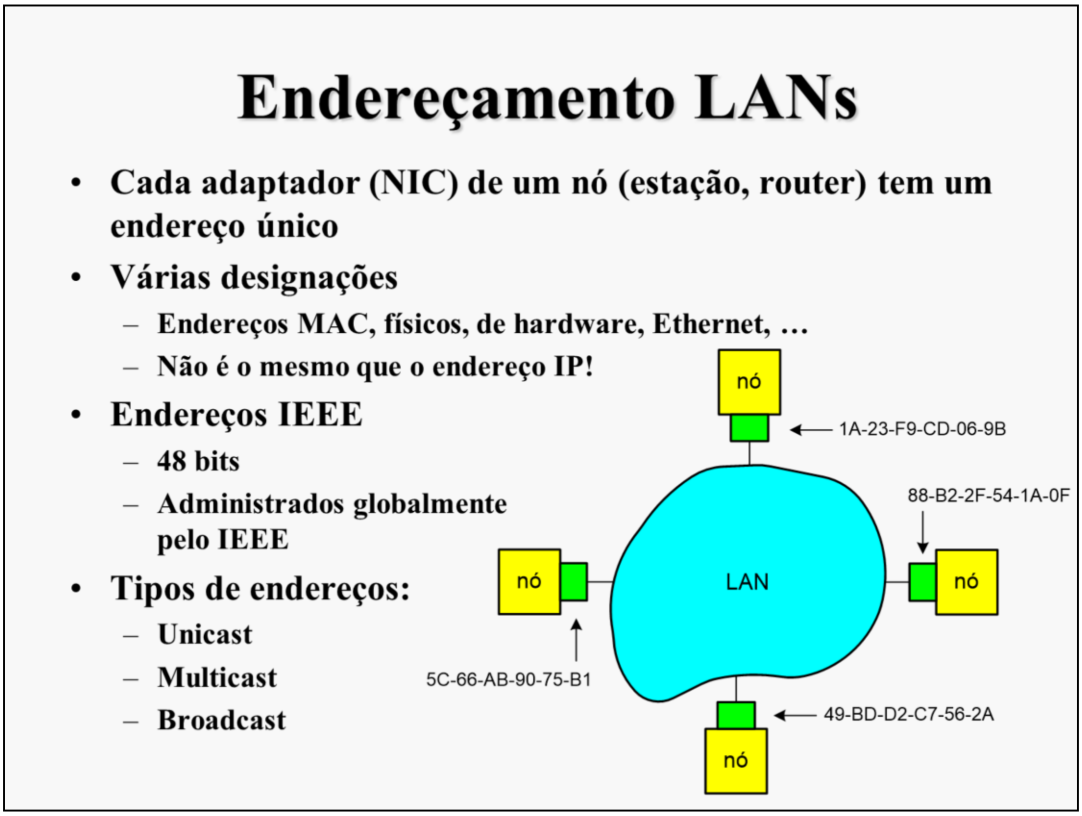


LANs – Local Area Network

Local Area Networks (LANs) are telecommunication systems enabling direct communications between terminal stations through a shared transmission medium.

Examples of LANs are the technologies standardized by IEEE like: Ethernet (IEEE 802.3), WiFi (IEEE 802.11), Token Ring (IEEE 802.5), …

In the above picture, a LAN network provides the means for all stations to communicate directly between them and the router is the network element used by the local stations to communicate with stations on other networks.



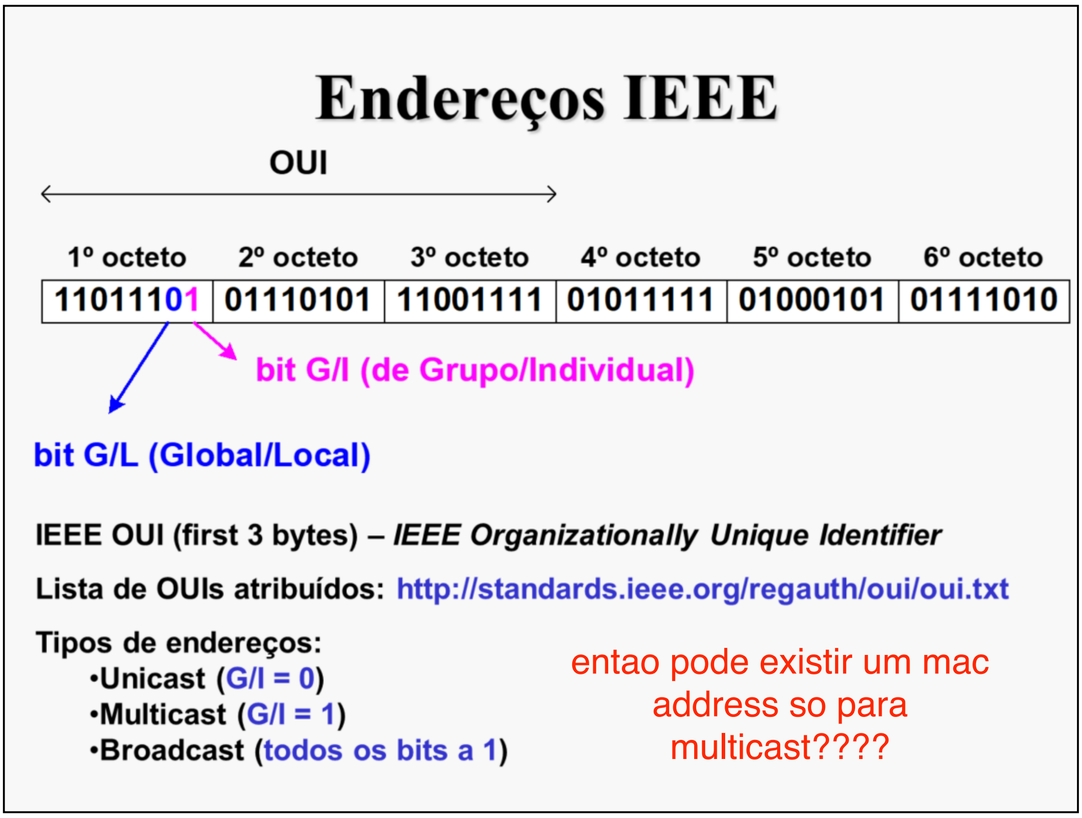
Addressing in LANs

LANs are implemented on hardware. A Network Interface Card (NIC) is an hardware device that is plugged to a terminal station, or a router, and that implements all means to communicate with the other stations on the same LAN.

Each NIC has an address. This address is referred to by multiple names: hardware address, MAC address, physical address, etc…

All IEEE technologies have the same addressing scheme: they are 48 bit long and are globally administrated by IEEE. These addresses are coded by manufacturers on NICs and are guaranteed to be unique. Unlike IP addresses, physical addresses are represented in hexadecimal notation.

There are three types of addresses: unicast addresses (an unicast address identifies a NIC), multicast addresses (used for multicast communications) and the broadcast address (a special address used as destination address when an origin station wants to send a frame to all other terminal stations attached to the same LAN).



IEEE Addresses

IEEE is the global authority responsible for assigning blocks of IEEE addresses to NIC manufacturers. The 3 first bytes are used for this assignment and are named the IEEE Organizationally Unique Identifier (OUI). When a block is assigned to a manufacturer, it uses the 3 last bytes to assign different addresses to different NICs. Note that a manufacturer can be assigned more than one block, depending on its needs.

The last two bits of the first byte have special meanings:

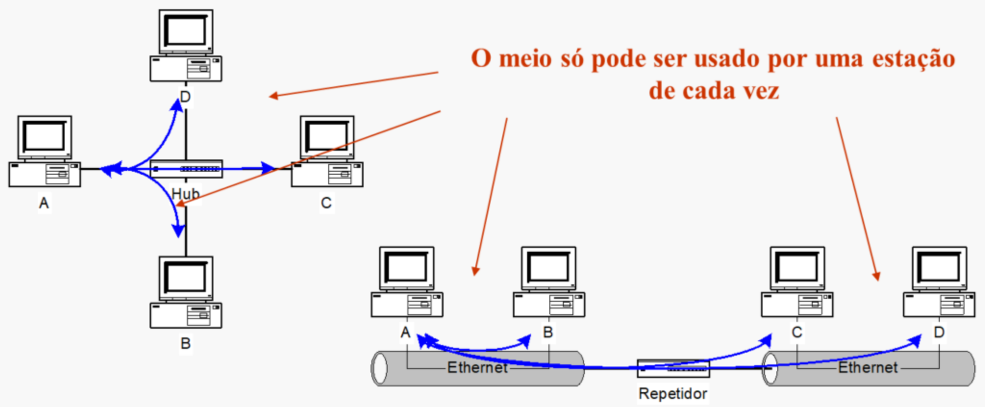
- The 7th bit is 0 if it is a globally assigned address or 1 if it is a locally administered address (IEEE assigned blocks have always this bit set to 0).
- The 8th bit is 0 if it is a unicast address or 1 if it is a multicast address (IEEE assigned blocks have always this bit set to 0).

The special broadcast address is defined by all bits equal to 1: the address FF-FF-FF-FF-FF-FF.

The list of IEEE assigned blocks is public (http://standards.ieee.org/regauth/oui/oui.txt , for example).

Repetidores/Hubs definem Domínios de Colisão

- **Os repetidores interligam segmentos do mesmo tipo de LANs;**
- **A largura de banda agregada é limitada pela taxa de transmissão da LAN;**

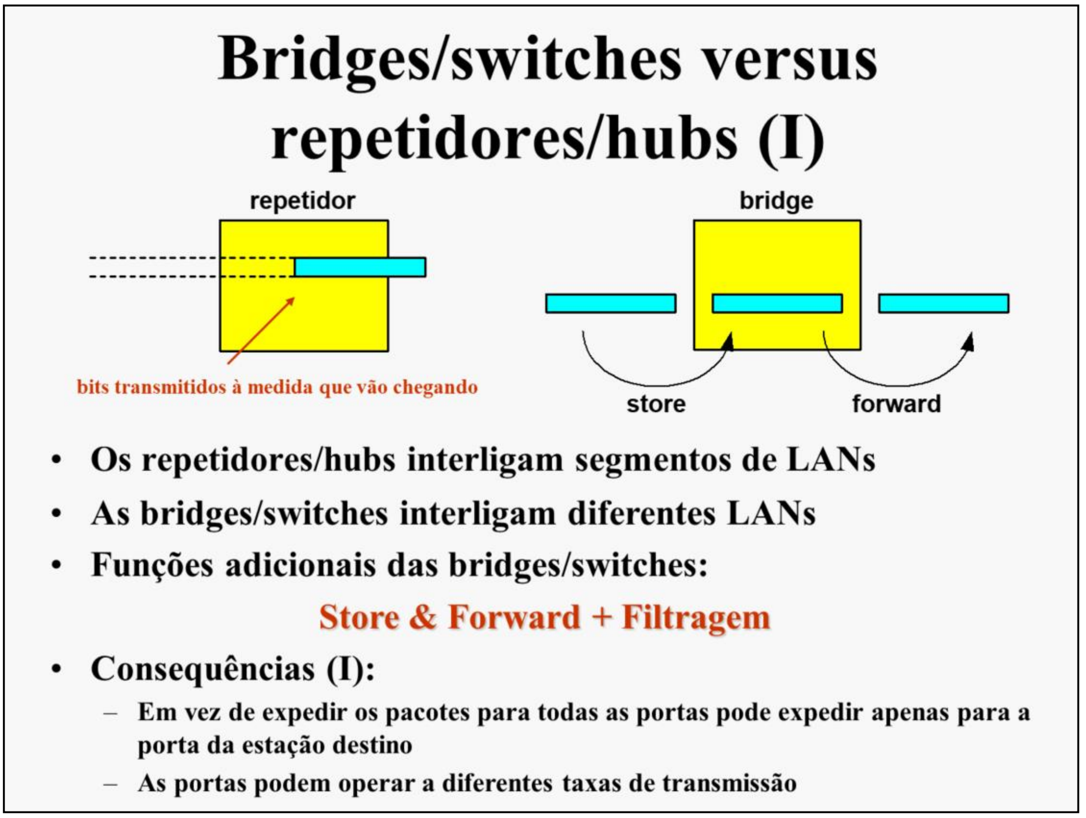


Repeaters/Hubs define Collision Domains

Hubs propagate all incoming signals to all output ports. Therefore, hubs act as propagation devices and require that only a single terminal station can be transmitting a frame at any time (left picture above).

Repeaters interconnect different segments and retransmit the input frames to all other output ports. Therefore, a single terminal station can be transmitting a frame in all their attached segments (right picture above).

A **collision domain** is a section of a network where simultaneous transmitted frames collide with one another. Therefore, a network section based on hubs or based on shared media interconnected with repeaters form a collision domain.



Bridges/Switches versus Repeaters/Hubs (I)

In a repeater / hub, the frame bits are regenerated and retransmitted to the output ports as soon as they are received on the input ports. We say that repeaters / hubs interconnect different LAN segments.

Bridges / switches are more complex devices than repeaters / hubs. Bridges /switches implement the store & forwards function: each incoming frame is first completely stored (in the local memory) and, then, it is forward to the appropriate output ports. Moreover, bridges /switches implement the filtering function: each incoming frame can be forward to only some of the output ports.

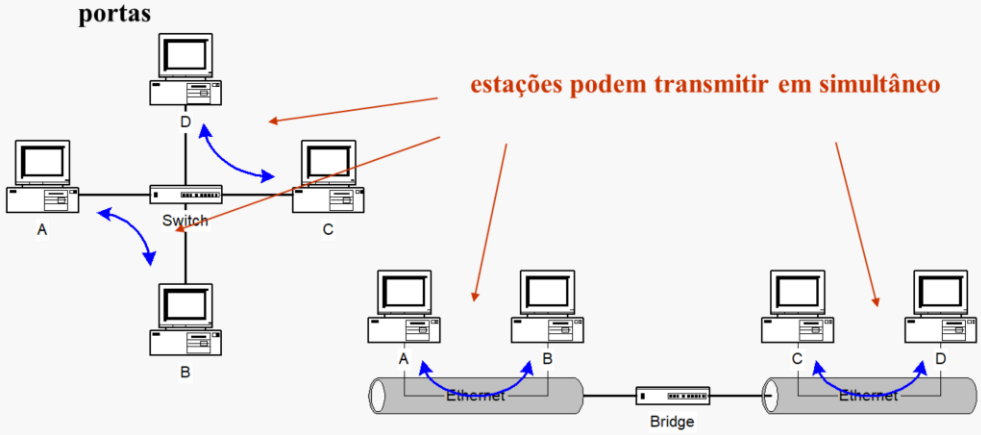
We say that bridges / switches interconnect different LANs.

Some positive consequences of these more complex functions are:

- They can forward an incoming frame to a single output port if they know “where” is the destination station of the frame.
- Ports can operate at different transmission rates.
- (more in the next slide)

Bridges/switches versus repetidores/hubs (II)

- **Consequências (II):**
  - As colisões deixam de ser um problema
  - A largura de banda agregada não é limitada pela taxa de transmissão das portas



Bridges/Switches versus Repeaters/Hubs (II)

Other positive consequences are:

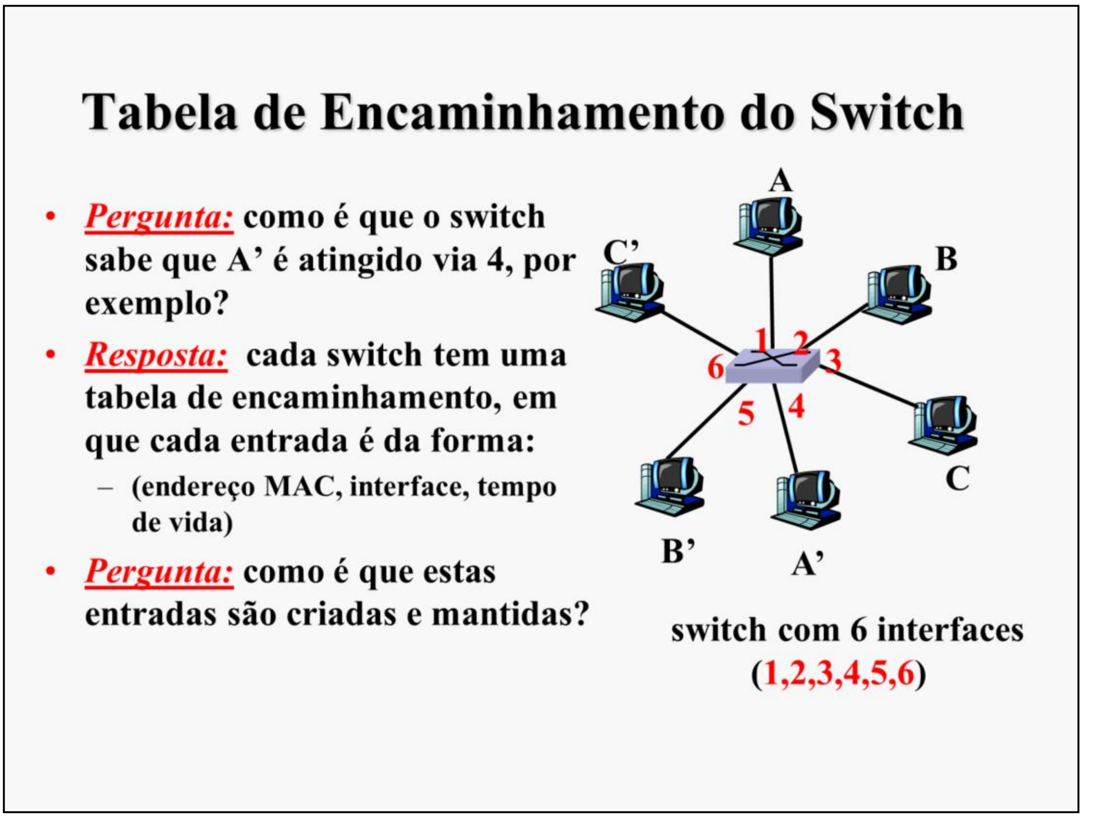
- Collisions are eliminated (bridges / switches can be simultaneously receiving frames and sending frames in different ports)
- The total transmission rate of the equipment is not constrained to the transmission rate of a single port but, instead, it is given by the sum of the transmission rates of all ports

In a 10BaseT network, when an hub is replaced by a switch (left picture above), all attached terminal stations can be simultaneously transmitting and receiving frames (no CSMA/CD is required and the interfaces can operate in full duplex mode).

In a 10Base2 (or 10Base5) network, when a repeater is replaced by a bridge (right picture above), simultaneous frames can be transmitted on the different attached segments. Note, however, that in this case CSMA/CD is still required on each segment (why?).

tem a ver com a topologia da rede. Na esquerda, o cabo 10BaseT usa uma topologia de star, onde evita colisões, já que todos os clientes estão conectados ao switch. Normalmente é full_duplex.

NA 10base2 ou 5 usa uma topologia bus system com um cabo coaxial half_duplex e que entao temos que utilizar CSMACD.



MAC Address Table of a Switch

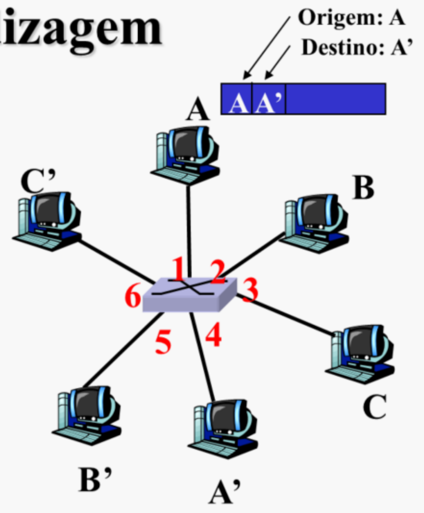
How can switches perform the filtering function, i.e., how do switches know "where" is the destination station of each incoming frame? First, switches assign a port ID value to each of its ports. In the above picture, if the switch receives a frame destined to host A', how does it know that the frame must be forward through port 4?

To perform this task, switches have a routing table (commonly named MAC Address Table) where each entry has: (i) a MAC address, (ii) a port number (iii) and a time-to-live (TTL) value.

How is the MAC Address Table managed? See next slide.

Switch: auto-aprendizagem

- O switch *aprende* que estações podem ser atingidas por cada uma das suas interfaces
  - quando uma trama é recebida numa interface, o switch regista na tabela de encaminhamento uma entrada com o endereço MAC origem da trama e a interface de entrada



MAC addr	interface	TTL
A	1	60

Tabela do switch (inicialmente vazia)

Switch: self-learning process

Switches learn which terminal stations can be reached through which ports: when a frame is received on an incoming port, the switch includes in the MAC Address Table an entry with the MAC origin address of the frame, the incoming port and a pre-defined TTL value.

In the above example, host A sends a frame with the origin MAC address of A and destination MAC address of A'. Upon reception of this frame on port 1, an entry is inserted in the MAC Address Table associating MAC address of A with port 1.

Switch: filtragem/forwarding

Quando uma trama é recebida por um switch:

1. regista na tabela de encaminhamento a interface do emissor da trama
2. procura na tabela de encaminhamento uma entrada com o endereço MAC destino
3. if entrada encontrada
   then {
      if destino na mesma interface em que a trama foi recebida
         then descarta a trama
         else encaminha a trama pela interface indicada (forwarding)
   }
   else envia para todas as interfaces exceto a de entrada (flooding)

Switch: filtering/forwarding process

When a frame is received on an incoming interface, the switch performs the following operations:

1. it registers in the MAC Address Table the origin MAC address of the frame with the incoming port
2. it searches in the MAC Address Table for an entry with the frame destination MAC address
3. if entry exists
   then {
      if port of the destination is equal to the incoming port of the frame
         then discards the frame
         else forwards the frame through the output port (forwarding process)
   }
   else forwards the frame to all ports except its incoming port (flooding process)

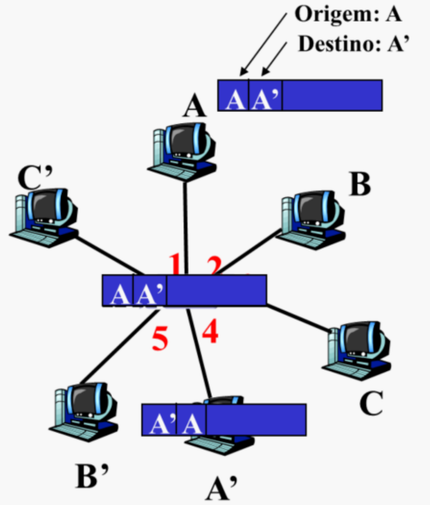
Exemplo

- **Destino da trama A' desconhecido:**

  flooding

- **Destino da trama A conhecido:**

  forwarding



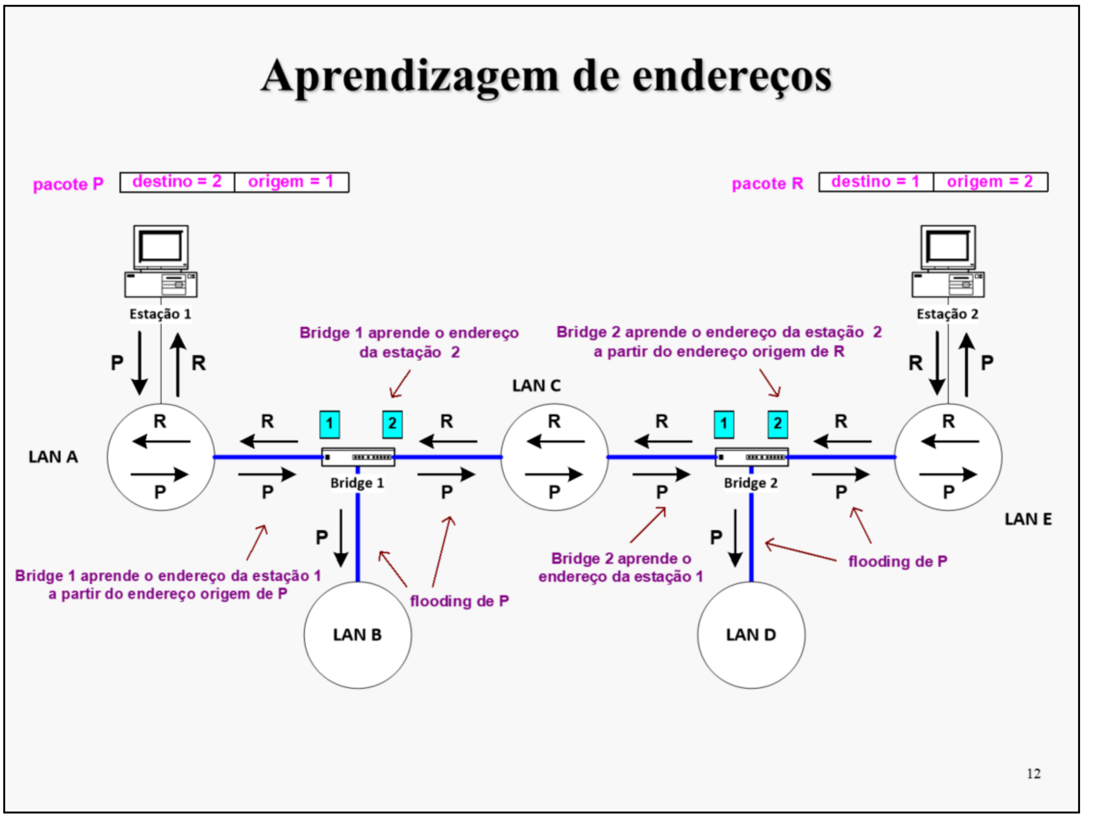
MAC addr	interface	TTL
A	1	60
A'	4	60

Tabela do switch (inicialmente vazia)

Example

Consider the above example where at the beginning the MAC Address Table is empty.

- First, station A sends a frame with the origin MAC address of A and destination MAC address of A'.
- Upon reception of this frame on port 1, an entry is inserted in the MAC Address Table associating MAC address of A with port 1.
- This frame is flooded to ports 2, 3, 4, 5 and 6 because the MAC Address Table does have any entry with the MAC address of A'.
- Then, station A' sends a frame with the origin MAC address of A' and destination MAC address of A.
- Upon reception of this frame on port 4, an entry is inserted in the MAC Address Table associating MAC address of A' with port 4.
- This frame is forwarded to port 1 because the MAC Address Table have an entry specifying that the MAC address of A is reachable through port 1.

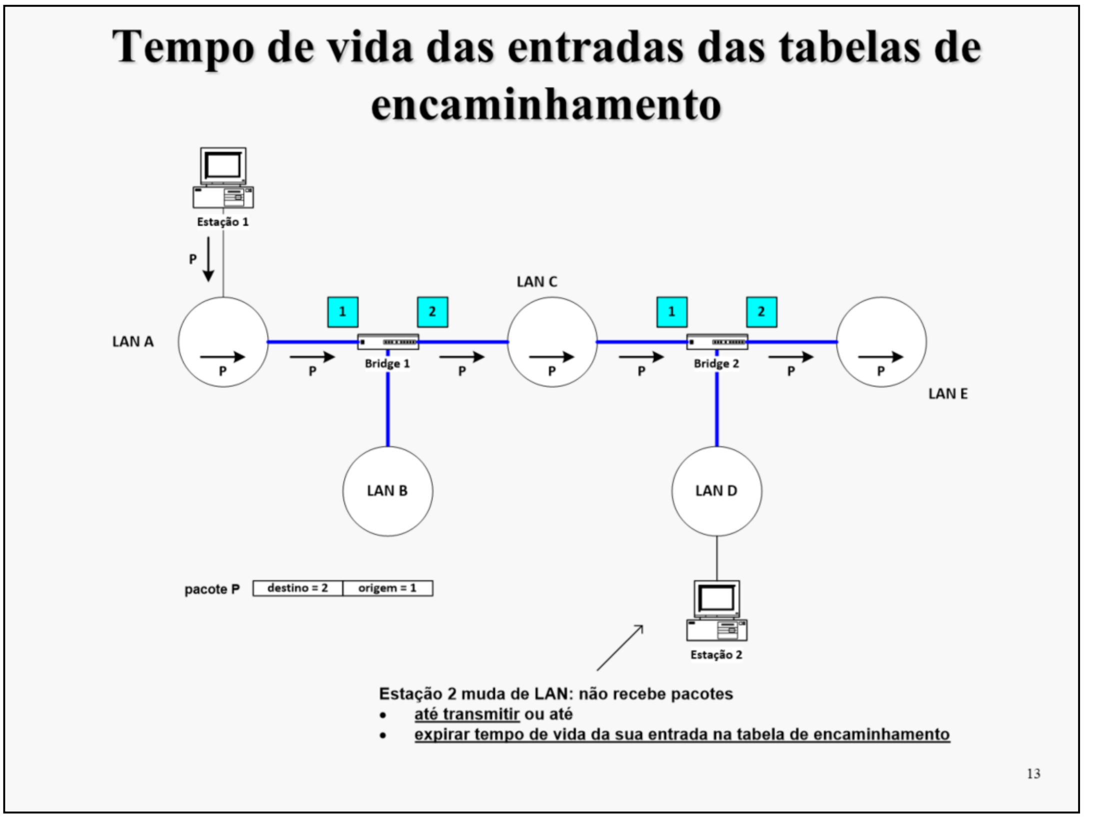


MAC Address Learning Process

What happens when a network is composed by multiple switches / bridges? The self-learning and forwarding processes work exactly the same as in the single element case.

The above picture illustrates these processes resorting to a network of bridges (the same thing happens with a network of switches):

- First, station 1 sends a frame to station 2
- Bridge 1 learns that station 1 is reachable through its port connected to LAN A and floods the frame to LAN B and LAN C.
- Bridge 2 learns that station 1 is reachable through its port connected to LAN C and floods the frame to LAN D and LAN E.
- Then, Station 2 sends a frame to station 1
- Bridge 2 learns that station 2 is reachable through its port connected to LAN E and forwards the frame to LAN C.
- Bridge 1 learns that station 2 is reachable through its port connected to LAN C and forwards the frame to LAN A.



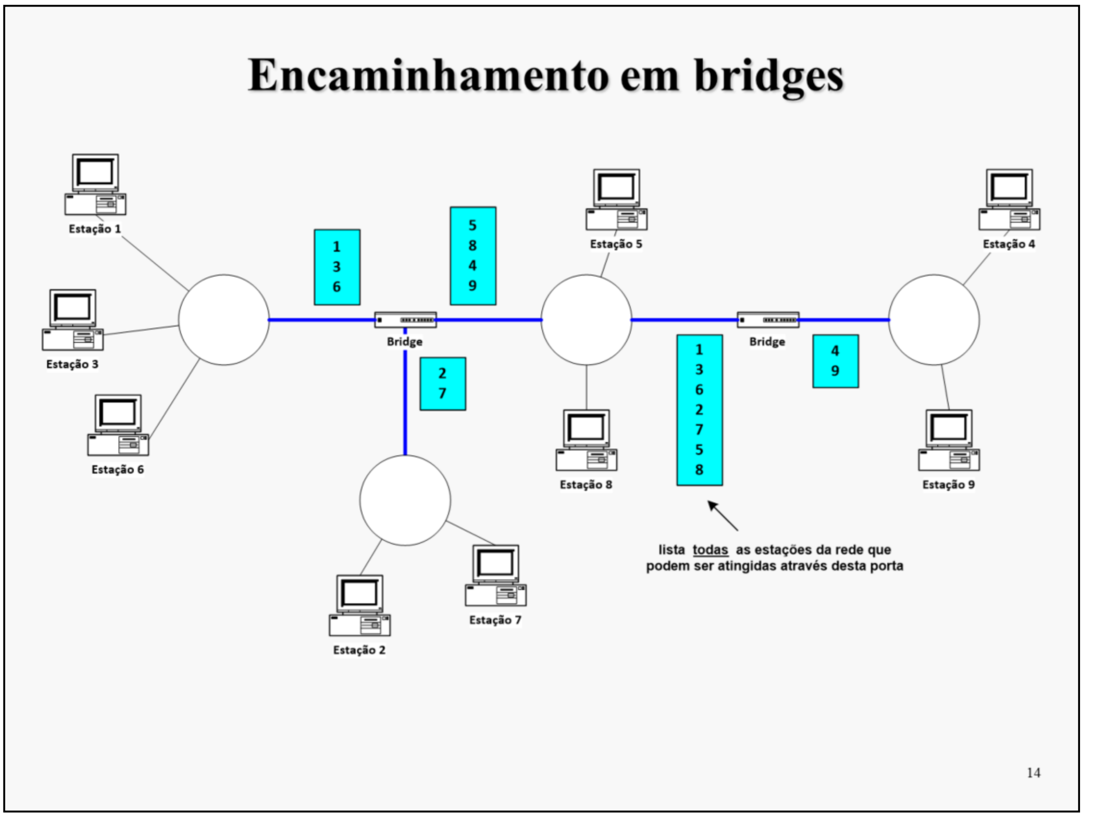
TTL of MAC Address Table Entries

Remember that each entry of the MAC Address Table has an associated time-to-live (TTL) value. This value is set to a pre-defined value every time that the switch receives a frame from the origin terminal station. Then, the entry is deleted if no frames are received from the origin station during TTL seconds (we say that the time of the entry has expired).

Consider the example of the previous slide where, meanwhile, station 2 changes its point of attachment from LAN E to LAN D (above figure). In this case, the MAC Address Table of bridge 2 becomes wrong and frames sent by station 1 to station 2 will not reach their destination (causing lost of connectivity).

If, meanwhile, station 2 sends a frame to the network, it will enable bridge 2 to update its MAC Address Table associating the MAC address of station 2 to the new port and connectivity is recovered.

Otherwise, the connectivity will be recovered when the entry of the bridge 2 in the MAC Address Table expires, which will cause the flooding of frames to station 2.



Routing on Bridges/Switches

Bridges / switches use data frames to learn which terminal stations can be reached by each of its own ports.

Exercício

- Considere a seguinte tabela de encaminhamento de um Switch com 8 portas:

  00:01:42:b5:45:f1 – port 4
  00:0e:0c:3e:45:c3 - port 1
  00:11:52:a5:45:f2 - port 4
  00:1F:02:1e:34:B1 - port 2

Das afirmações que se seguem, assinale as afirmações verdadeiras e as falsas:

a) Se na porta 1 do Switch chegar uma trama Ethernet com endereço MAC de destino 00:00:00:00:AA:AA esta será reenviada por todas as portas do Switch

b) Se na porta 5 do Switch chegar uma trama Ethernet com endereço MAC de destino 00:00:00:00:AA:AA será adicionada à tabela de encaminhamento a entrada "00:00:00:00:AA:AA port 5"

c) Se na porta 4 do Switch chegar uma trama Ethernet com endereço MAC de origem 00:00:00:00:AA:AA será adicionada à tabela de encaminhamento a entrada "00:00:00:00:AA:AA port 4"

d) Se na porta 8 do Switch chegar uma trama Ethernet com endereço MAC de origem 00:1F:02:1e:34:B1, a 4ª entrada da tabela será substituída por "00:1F:02:1e:34:B1 port 8"

e) Se na porta 1 do Switch chegar uma trama Ethernet com endereço MAC de destino 00:11:52:a5:45:f2 esta será reenviada apenas pela porta 4 do switch

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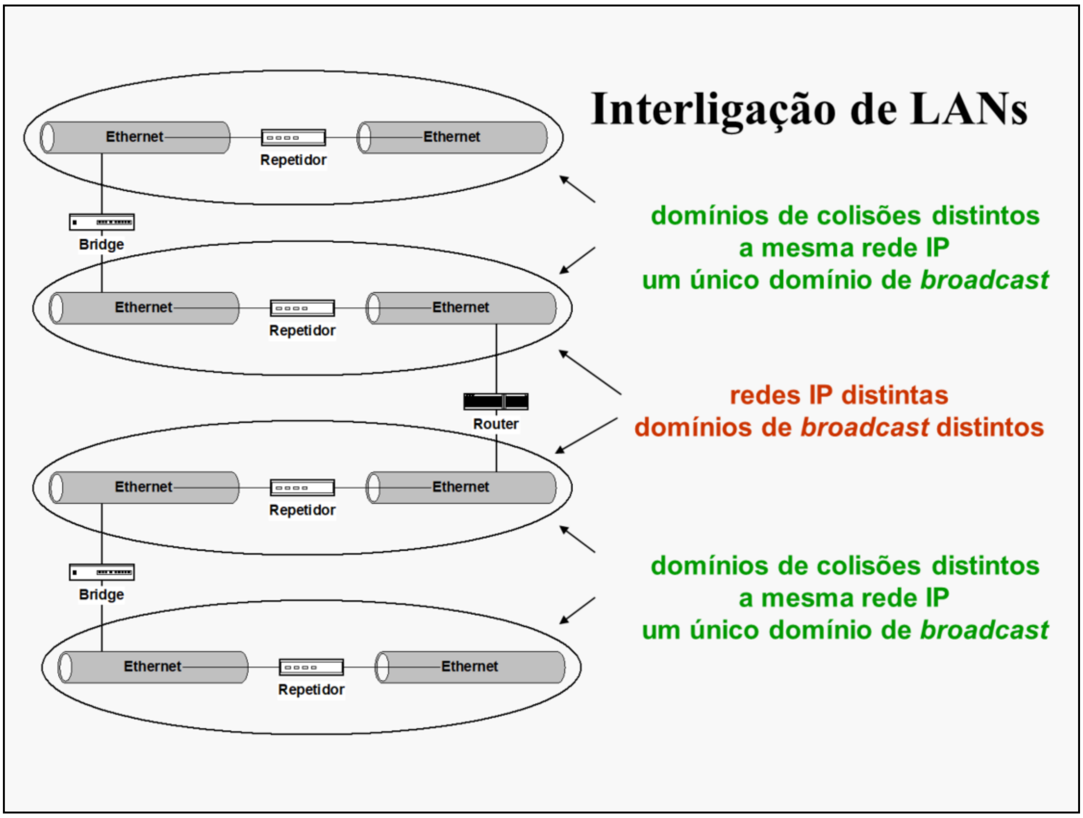


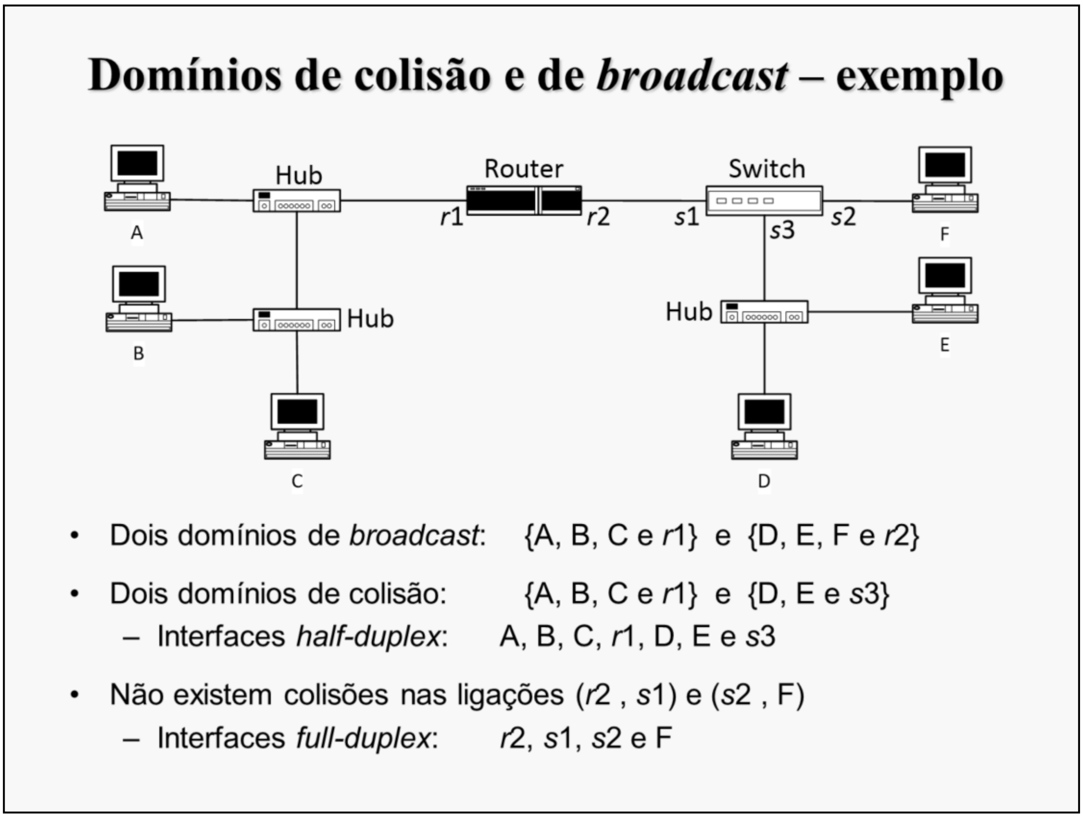
Interconnection of LANs

Different types of equipment define different types of network domains.

Hosts interconnected by repeaters (or hubs) are within the same collision domain (as previously explained).

A bridge (or a switch) separates the network in different collision domains but define a single broadcast domain. A broadcast domain is a network section where all stations communicate directly (or, in other words, a network section where all stations receive the frames sent to the broadcast address FF-FF-FF-FF-FF-FF by any of them).

A router separates the network in different broadcast domains assigning to each broadcast domain a different IP network address. Stations in different broadcast domains cannot communicate directly (they communicate via the IP default gateway).

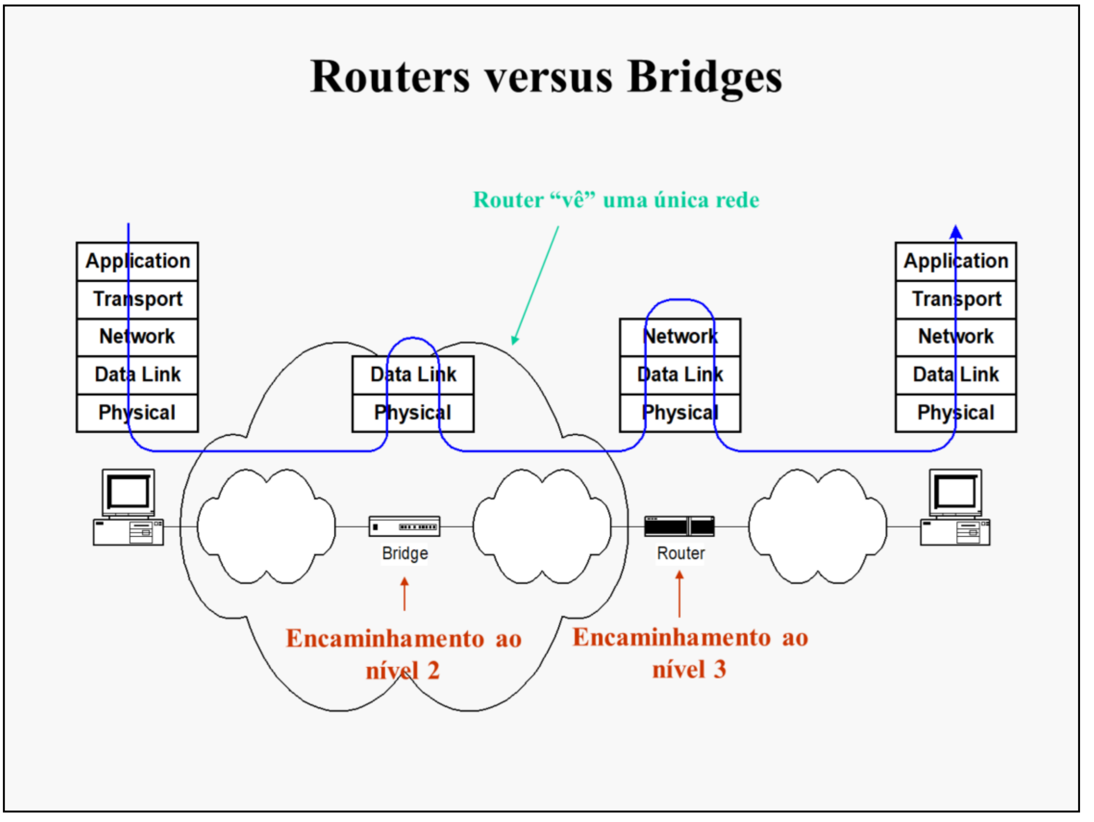


Collision and broadcast domains - example

In the above example, we can identify two broadcast domains. The first broadcast domain is composed by the interfaces of hosts A, B and C and the router interface *r*1. The second broadcast domain is composed by the interfaces of hosts D, E and F and the router interface *r*2. Note that the router is the network element that defines the frontier between the two domains.

In the above example, we can also identify two collision domains. The first collision domain is composed by the interfaces of hosts A, B and C and the router interface *r*1. The second collision domain is composed by the interfaces of hosts D, E and the switch interface *s*3. All interfaces on a collision domain are set in half-duplex mode: they can be either transmitting or receiving frames.

Since the Switch is a store-and-forward element, there is no collisions in the connections not involving hubs (the connections between *r*2 and *s*1 and between *s*2 and the interface of host F). Such interfaces are set in full-duplex mode: they can be transmitting and receiving frames at the same time.



Routers versus Switches/Bridges

Networks are organized in layers (to be detailed later on this course). In the origin and destination hosts, all layers are used to compose the frame (for example, an ICMP Echo Request that is encapsulated on an IP datagram that is encapsulated on an Ethernet frame).

Bridges (and switches) forward frames based on the data link layer, i.e., they forward frames based on their MAC addresses.

Routers forward frames based on the IP network layer, i.e., they forwards IP datagrams based on their IP addresses.

Text Store-and-Forward: Store-and-Forward switching will wait until the entire frame has arrived prior to forwarding it. This method stores the entire frame in memory. Once the frame. is in memory, the switch checks the destination address, source address, and the CRC. If no errors are present, the frame is. forwarded to the appropriate port. This process ensures that the. destination network is not affected by corrupted or truncated. frames.

Equipamentos de Interligação

- **Repetidor/hub:**
  - opera no nível físico;
  - regenera os sinais;
  - hub = repetidor com múltiplas portas;
- **Bridge/switch:**
  - tipo *store-and-forward;*
  - opera ao nível da camada da ligação (camada 2);
  - interliga dois ou mais domínios de colisões;
  - comuta com base nos endereços MAC;
  - switch = bridge com múltiplas portas;
- **Router:**
  - tipo store-and-forward;
  - opera no nível de rede (camada 3);
  - comuta com base nos endereços de nível 3 (ex. IP, IPX, AppleTalk);

Interconnection Network Equipment

Repeaters / hubs

- Work at physical layer (incoming bits are broadcasted to outgoing ports)
- Regenerate the binary signals
- Generally speaking, one hub is a repeater with many ports (a repeater is used to interconnect a few shared buses while a hub is used to connect directly each terminal station)

Bridges / switches

- Store and forward devices
- Work at data link layer
- Interconnect different collision domains
- Forward frames based on MAC addresses
- Generally speaking, one switch is a bridge with many ports (a bridge is used to interconnect a few shared buses while a switch is used to connect directly each terminal station)

Router

- Store and forward devices
- Work at the IP network layer
- Forward datagrams based on IP addresses

FINAL NOTE: Shared bus technologies became obsolete and, therefore, repeaters and bridges also became obsolete. Moreover, with the evolution of the technology and the decrease of equipment prices, hubs are now very rare and most of LAN deployments are already based only on switches (generally speaking, it is not possible to buy hubs in the market since switches are now of low cost).