# Redes de Comunicação em Ambientes Industriais Aula 6

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# In the previous episode ...

- The physical layer:
  - Network topologies comparison:
    - Mesh, Tree, Ring and Bus
  - Physical medium
    - Copper, optical and wireless (IR & RF)
  - Effects of the propagation delay in a bus
  - Protocol efficiency in a bus
  - Collision detection techniques

# Data link layer

- <u>Issues related with the data link layer:</u>
  - **Addressing**
  - **Logical link control – LLC**
    - **Transmission error control**
  - **Medium access control – MAC (for shared medium)**

# Data link layer

- **Addressing**
  identification of the parts involved in a network transaction
  - **Direct addressing**
    The sender and receiver(s) are explicitly identified in every transaction, using **physical** addresses (as in Ethernet)
  - **Indirect (source) addressing**
    The message **contents** are explicitly identified (e.g. temperature of sensor X). Receivers that need the message, retrieve it from the network (as in CAN and WorldFIP)
  - **Indirect (time-based) addressing**
    The message is identified by the time instant at which it is transmitted (as in TTP)

# Data link layer

- **Logical link control (LLC)**
  Deals with the information transfer at this level
  Typical services are:
  - **Send with immediate acknowledge**
    Sender waits for acknowledge from receiver.
  - **Request data on reply**
  - **Send without acknowledge**
    No synchronization between sender and receiver
  - **Connection-oriented services**
    A connection must be established between parts before any communication (HDLC style)
- These services **define** the respective **communication transactions**, e.g., single/multiple packet, type of packets

# Data link layer

- **Transmission error control**
  (particularly useful for wireless networks)

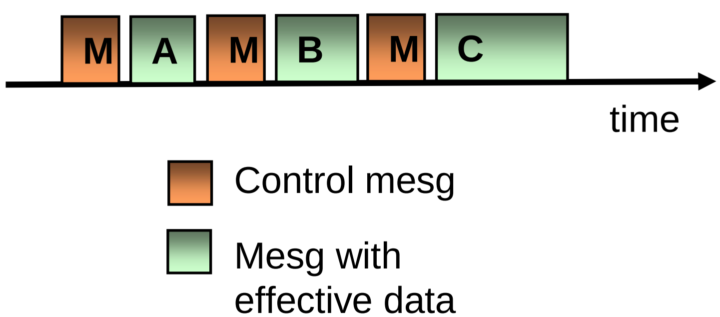
- Error detection and action upon it.Typical actions:
  - **Forward error correction (FEC)**
    - Error correcting codes (more related with the physical layer)
    - Or the receiver waits for the next periodic transmission
  - **Automatic Repeat reQuest (ARQ)**
    The receiver triggers a repeat request upon error
  - **Positive Acknowledge and Retry (PAR)**
    The sender resends if ACK is not received
  - From a **real-time** perspective, **ARQ** and **PAR** may induce **longer delivery delays** as well as extra **communication load**

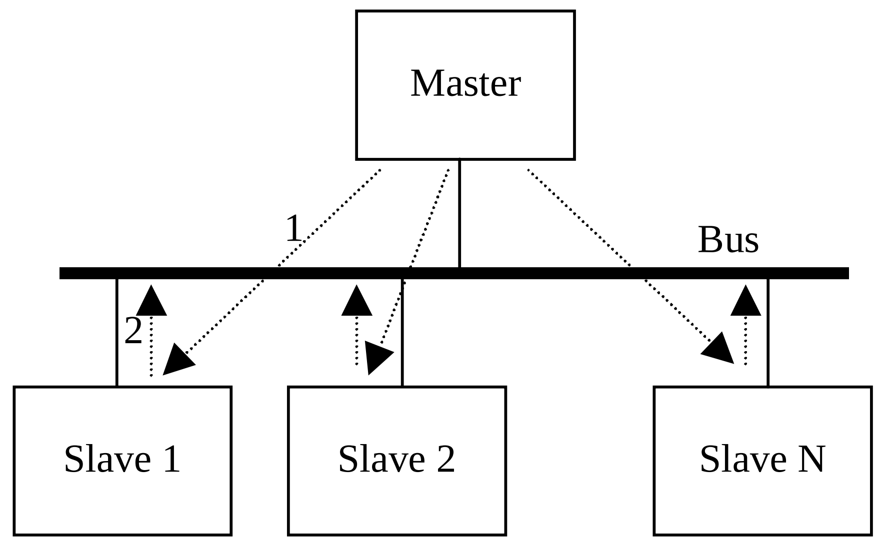
# Data link layer

- **Medium access control (MAC)**
  - Determines the order of network access by contending nodes and thus the network access delay
  - It is of paramount importance for the **real-time behavior of networks** that use a shared medium

# Data link layer

- Medium access control - **Master-slave**
  - Access granted by the Master
  - Nodes synchronized with the master
  - Requires one control message per data message



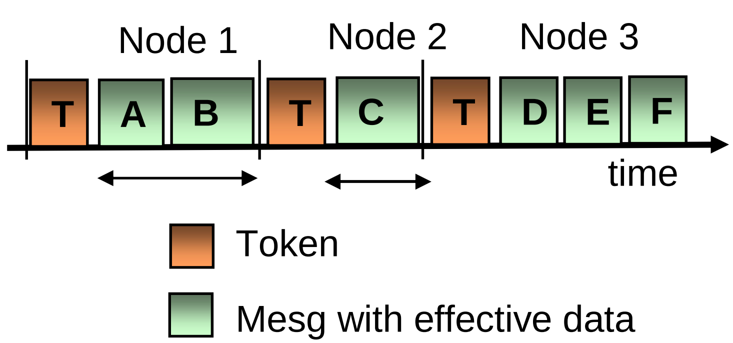



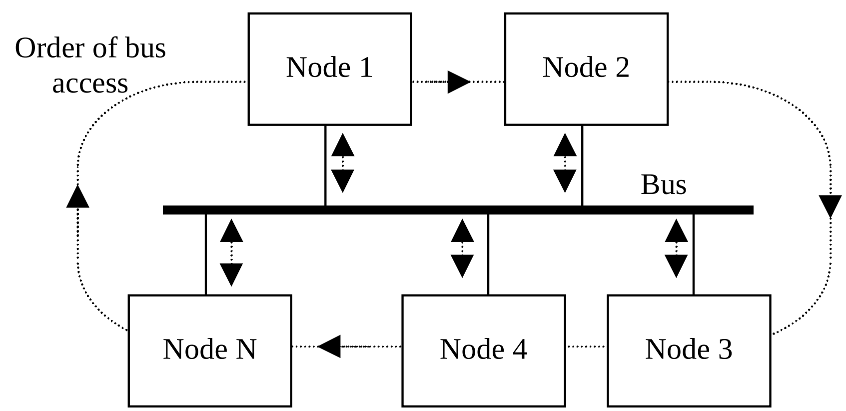
# Data link layer

- Medium access control - **Master-slave**
  - The **traffic scheduling** problem becomes **local to the master** → good flexibility wrt scheduling algorithms (on-line or off-line, any type of processor scheduling)
  - For high reliability the master must be **replicated**
  - Master messages are natural synchronization points → supports **precise tx triggering**
    - Att: reception instants may vary from node to node, depending on the distance to the master
  - Ex: WorldFIP, Ethernet Powerlink, Bluetooth within each piconet

# Data link layer

- Medium access control – **Token-passing**
  - Access granted by the possession of the token
  - Order of access enforced by token circulation
  - Asynchronous bus access (generally impossible to determine a priori the exact access instants)
  - Real-time operation requires bounded token holding time



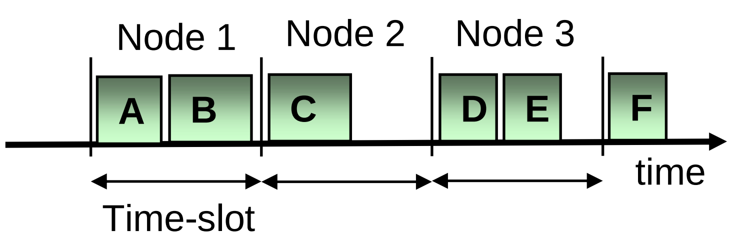
# Data link layer

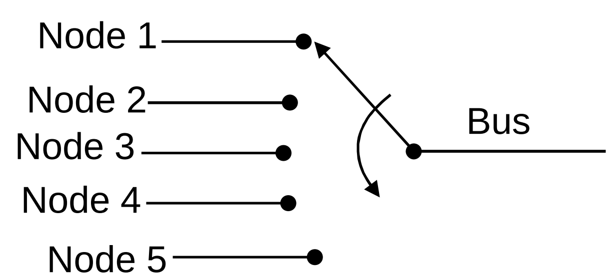
- Medium access control – **Token-passing**
  - **TTRT** – **Target** Token Rotation Time
    fundamental configuration parameter that determines the time the token should take, under heavy traffic, in one round
  - **RTRT**- **Real** Token Rotation Time
    time effectively taken by the token in the last round
  - **THT** – Token **holding** time
  - **ST** – Synchronous time
  - High tx jitter
  - Requires mechanisms to handle **token losses**
  - Similar to **Round-Robin Scheduling**
  - Ex: IEEE 802.4, FDDI, PROFIBUS

$$\boxed{\begin{gathered}\Delta = TTRT - RTRT \\ THT = \begin{cases} \Delta, & \Delta > ST \\ ST, & \Delta \leq ST \end{cases}\end{gathered}}$$

# Data link layer

- Medium access control – **TDMA**
  **Time-Division Multiple Access**
  - Access granted in dedicated time-slot
  - Time-slots are pre-defined in a cyclic framework
  - Tight synchronization with bus time
    (bus access instants are predetermined)
  - Requires global (clock) synchronization



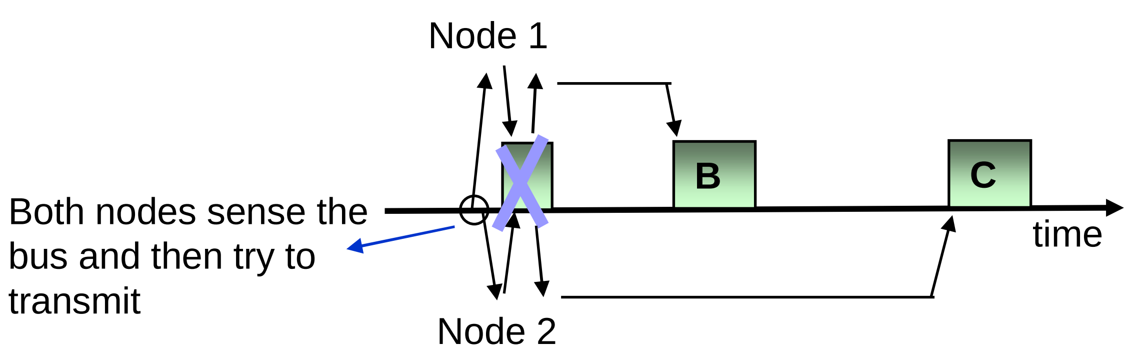



# Data link layer

- Medium access control – **TDMA**
  **Time-Division Multiple Access**
  - Addressing can be based on time → **High data efficiency**
  - Quality of synchronization bounds efficiency (length of **guarding windows** between slots)
  - Typically uses **static table-based scheduling**
  - Ex: TTP/C, FlexRay-sync, TT-CAN, PROFINET

# Data link layer

- Medium access control – **CSMA**
  **Carrier-Sense Multiple Access**
  - Set of protocols based on sensing bus inactivity before transmitting (asynchronous bus access)
  - There may be collisions
  - Upon collision, nodes back off and retry later, according to some specific rule (this rule determines, to a large extent, the real-time features of the protocol)

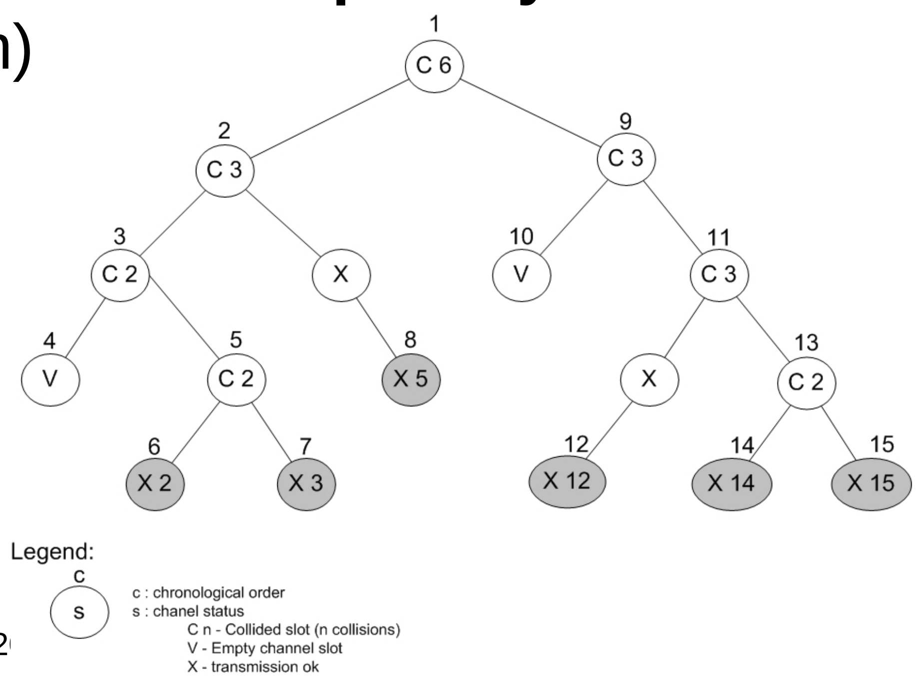


# Data link layer

- Medium access control – **CSMA/CD**
  **Carrier-Sense Multiple Access with Collision Detection**
  - Used in shared Ethernet (hub-based)
  - Collisions are **destructive** and are detected within **collision windows** (*slots*)
  - Upon collision, the retry interval is **random** and the randomization window is doubled for each retry until 1024 slots (BEB - Binary Exponential Back-off)
  - Non-deterministic (particularly with chained collisions)

# Data link layer

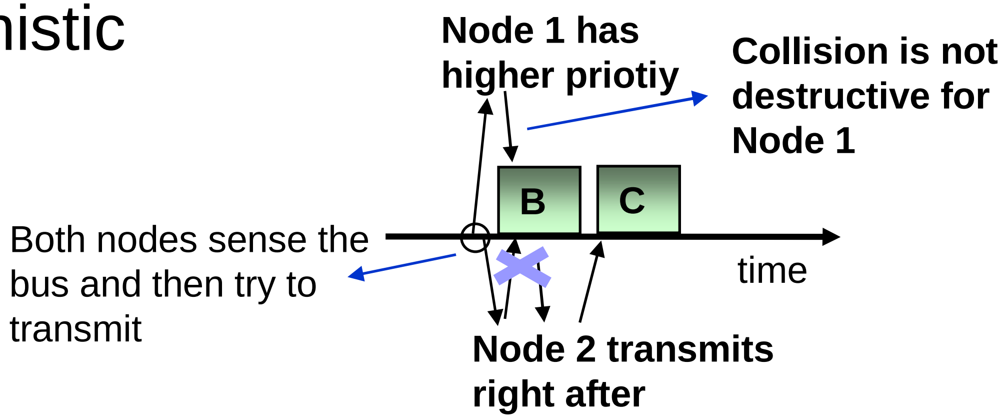
- Medium access control – **CSMA/DCR**
  **Carrier-Sense Multiple Access with Deterministic Collision Resolution**
  - Collisions are destructive
  - **back off and retry based on priority** (binary tree search)
  - Deterministic
  - Ex. G. Le Lann's modified Ethernet
    (figure by Pedreiras)



# Data link layer

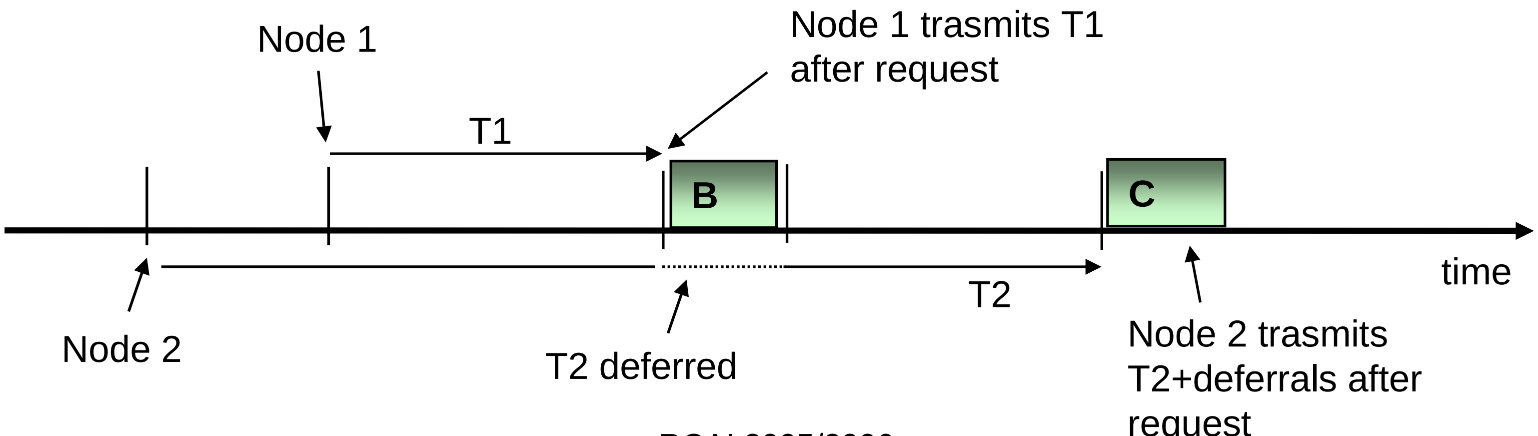
- Medium access control – **CSMA/BA** **(CA?)**
  **Carrier-Sense Multiple Access with Bit-wise Arbitration**
  - **Bit-wise** arbitration with **non-destructive** collisions.
  - Upon collision, highest priority node is unaffected. Nodes with lower priorities retry right after.
  - Deterministic

(e.g. CAN)



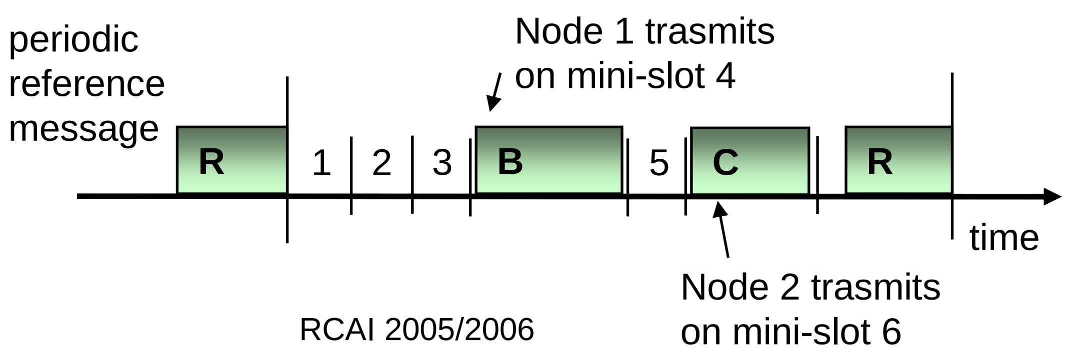
# Data link layer

- Medium access control – **CSMA/CA**
  **Carrier-Sense Multiple Access with Collision Avoidance (async)**
  - Access based on sensing bus inactivity during a synchronization interval plus a uniformly distributed random access interval with probability p (*p-persistent*)
  - Not collision-free (Ex: IEEE 802.11)



# Data link layer

- Medium access control – **CSMA/CA**
  **Carrier-Sense Multiple Access with Collision Avoidance (with sync)**
  - Access based on sensing bus inactivity during a number of predefined time-slots (mini-slots) after reception of a synchronous reference message
  - Corresponding mini-slot determines priority
  - Collision-free and deterministic
  - (Ex: FlexRay-async (Byteflight), ARINC629-async)



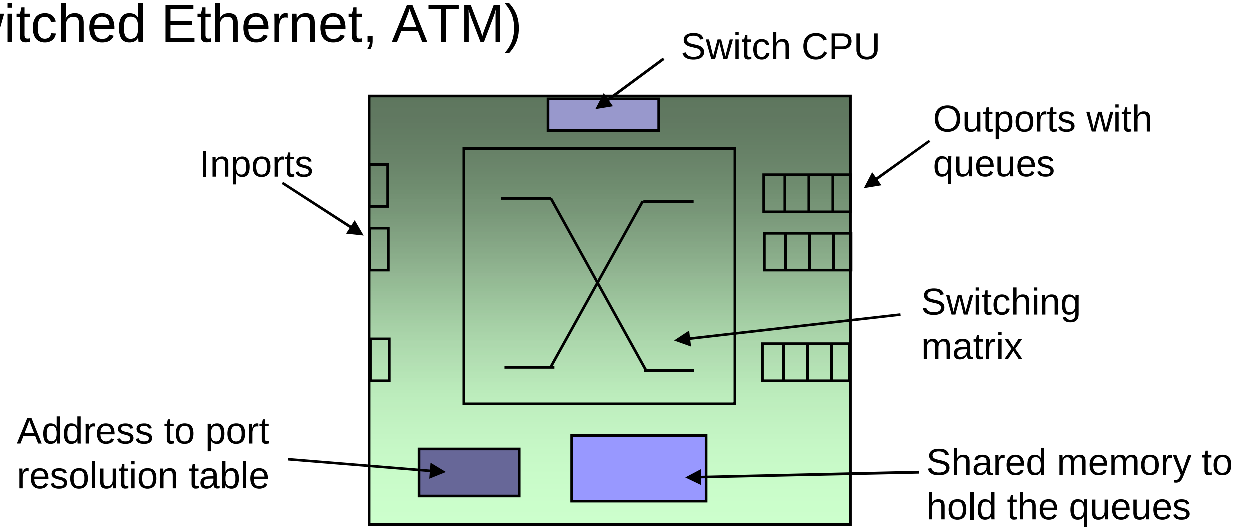
# Data link layer

- Medium access control – **switched**

  **micro-segmented network with central switching hub**

  - Nodes send asynchronously messages to the switch using point-to-point links – **no collisions**
  - Contention at the network access is replaced by contention at the output ports

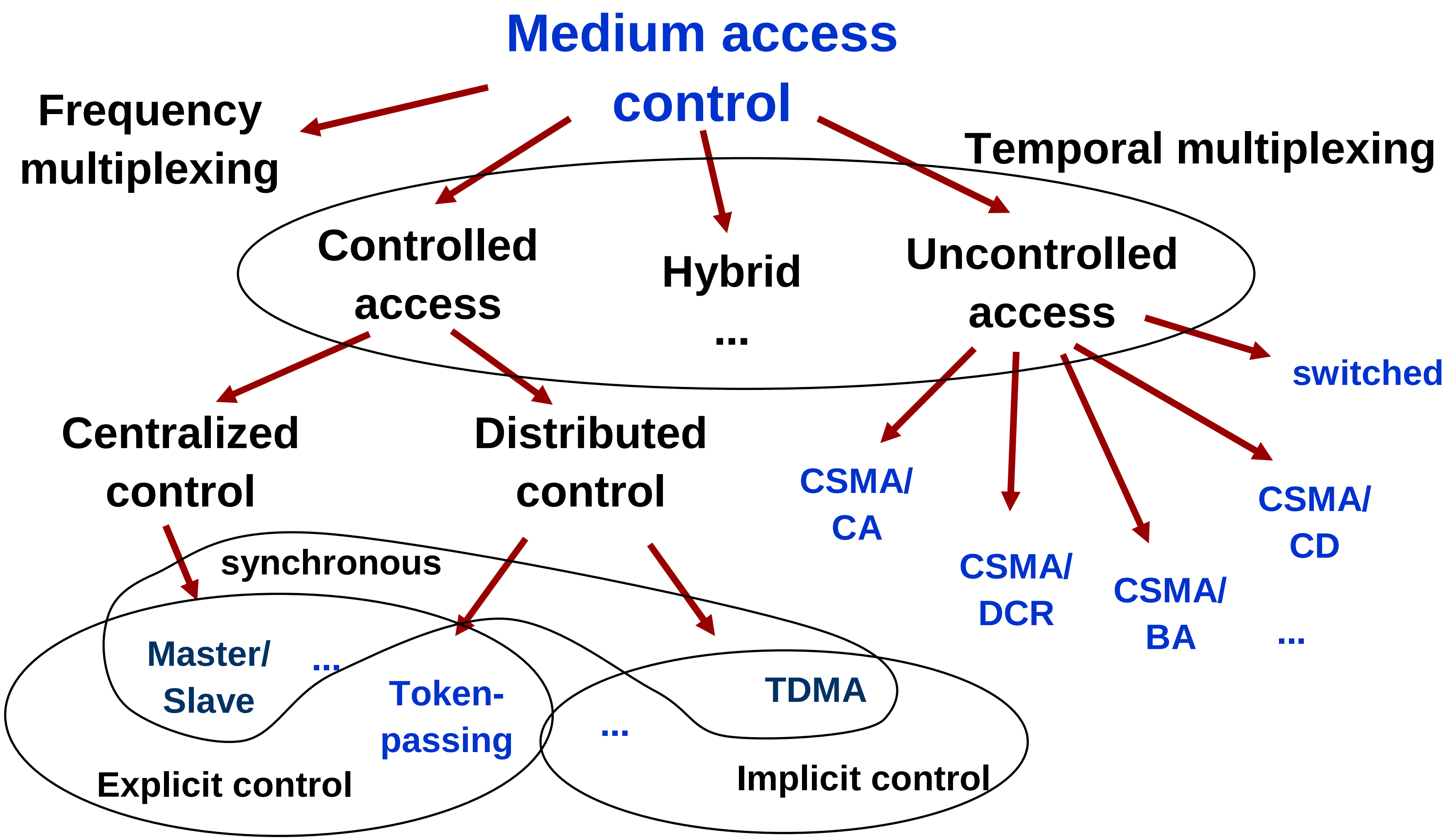
  (e.g. Switched Ethernet, ATM)



# Data link layer

- Medium access control – **switched**
  **micro-segmented network with central switching hub**
  - The switch handles incoming messages, interprets the destination address and, if known, routes the message to the respective outport (**forwarding**)
  - For multicasts, broadcasts or unknown addresses, the switch forwards to all outports (**flooding**)
  - No collisions, concurrent messages for the same port are queued in memory and sent in sequence
  - **In principle, it is deterministic but**
    - Possible **priority inversions** in queues!
    - There may be **queue overflows**!

# Data link layer



# Summary:

- ✓ **Addressing:**
  - ✓ **Direct and indirect (source, time-based)**
- ✓ **Logical link control – LLC**
  - ✓ **Services: send with(out) ack., request data, connection-oriented**
  - ✓ **Transmission error control : Forward Error Correction (FEC), Automatic Repeat reQuest (ARQ), Positive Acknowledge and Retry (PAR)**
- ✓ **Medium access control – MAC (for shared medium)**
  - ✓ **master/slave, token passing, TDMA, CSMA/CD, CSMA/BA(CA), micro-segmentation**