Redes de Comunicação em Ambientes Industriais
Aula 10

Luís Almeida lda@det.ua.pt

Electronic Systems Lab-IEETA / DET
Universidade de Aveiro
Aveiro, Portugal

In the previous episode ...

- WorldFIP
  - IEC standard 61158, type 7 (2000)
  - Typical in train control systems
  - Periodic and aperiodic traffic
  - Producer/Distributer/Consumer cooperation model
  - Table based scheduling (BAT)
    - any scheduling policy possible
    - BAT size may be a problem (LCM)

In the previous episode ...

- WorldFIP
  - Data temporal validity (promptness and refreshness)
  - Aperiodic requests handled in a shared dynamic window
    - Use the time left by periodic messages
    - Signalisation of aperiodic requests piggybacked in periodic messages
    - Pooled by the Distributor node
    - WCRT computation possible (dead interval + asynchronous busy window)

PROFIBUS
PROcess FIeldBUS

www.profibus.com

PROFIBUS

- Created in the late 80's by **Siemens,** in Germany
- Aims at **process control** and **factory automation**
- DIN standard 19245 1 to 19245 3 (90)
- CENELEC standard EN50170,vol.2 (96)
- IEC standard 61158, type 3 (2000)
- Dominant protocol in factory automation !

PROFIBUS

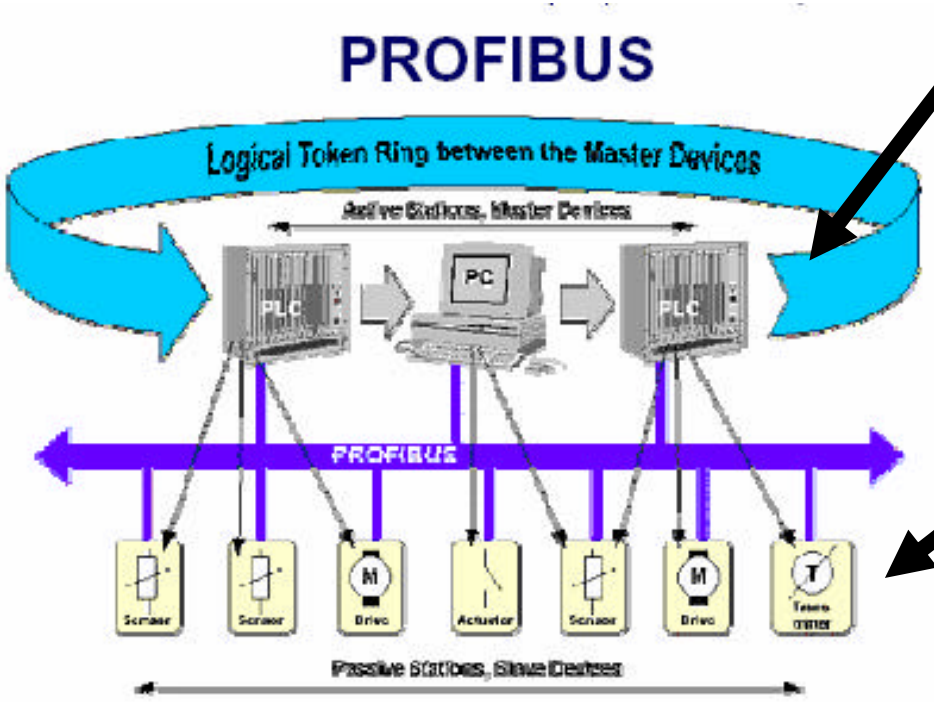
- **Broadcast** serial **bus**
- Asynchronous transmission based on UARTs
- Transmission rates up to **12 Mbit/s** over **RS-485**(-IS) on twisted pair, coaxial cable, optical fiber, power cable
- Maximum Length: **200m @ 1.5Mbit/s**, **1.2km @ 93.75kbit/s**. Extendable by repeaters
- Max. number of nodes **127** (32 masters)

PROFIBUS

- Two main application profiles:
  - **PROFIBUS / FMS** - Fieldbus Message Specification
  - **PROFIBUS / DP** - Decentralised Peripherals
- Data **payload** between **0** and **246 bytes**
- **Direct-addressing** (1 byte, possibly extended)
- **Hybrid** bus access control
  - **Token-passing** among masters
  - **Master-Slave** in each individual data transaction

PROFIBUS

General architecture



Masters:
controllers,
regulators, …
(PC, PLC,…)

Slaves:
sensors,
actuators
(motors, valves,
thermometers…)

PROFIBUS

- **Data Link services:**

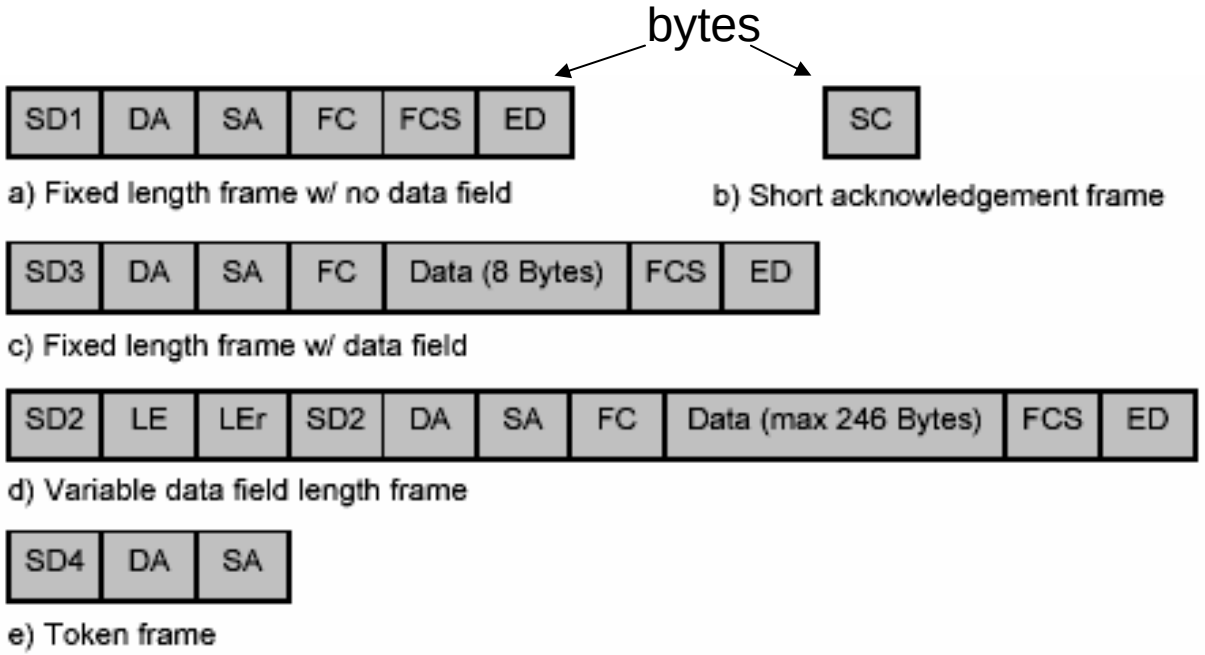
  Main data transfer services:

  - SDA – Send Data with Acknowledge
  - SDN – Send Data with No acknowledge
  - SRD – Send and Request Data
  - CSRD – Cyclic Send and Request Data

  - **Two priority levels!**

PROFIBUS

Data Link frames:



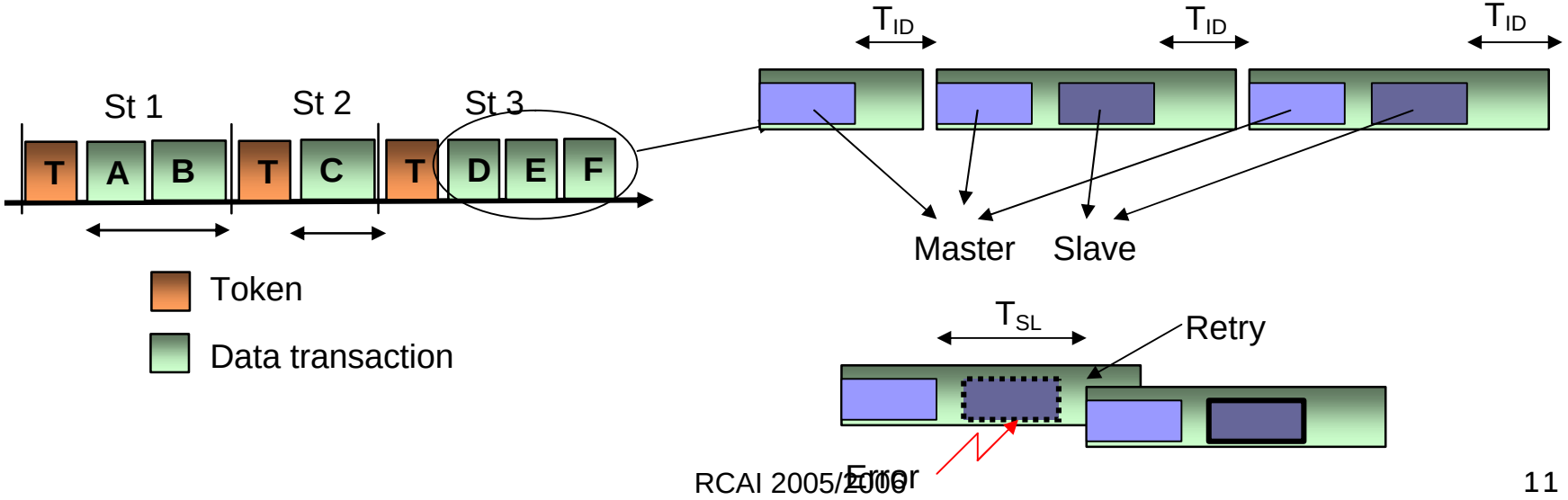
(figure by L. Ferreira, 2005)

PROFIBUS

- **Data Link services:**

  Main timings:

  - Idle Time (T_{ID}) – stations reaction time (turnaround)
  - Slot Time (T_{SL}) – timeout for detection of errors



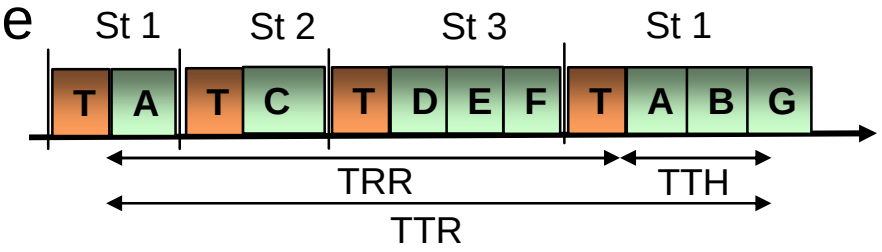
PROFIBUS

Token management:

Token rotation timing:

- **T_{TR} - Token Target Rotation Time**
- T_{RR} - Token Real Rotation Time
- T_{TH} - Token Holding Time

TTH = max(TTR-TRR, 0)



Token forwarding:

- PS – Previous Station
- TS – This Station
- NS – Next Station

GAPL – Gap List
LAS – List of Active Stations
LL – Live List

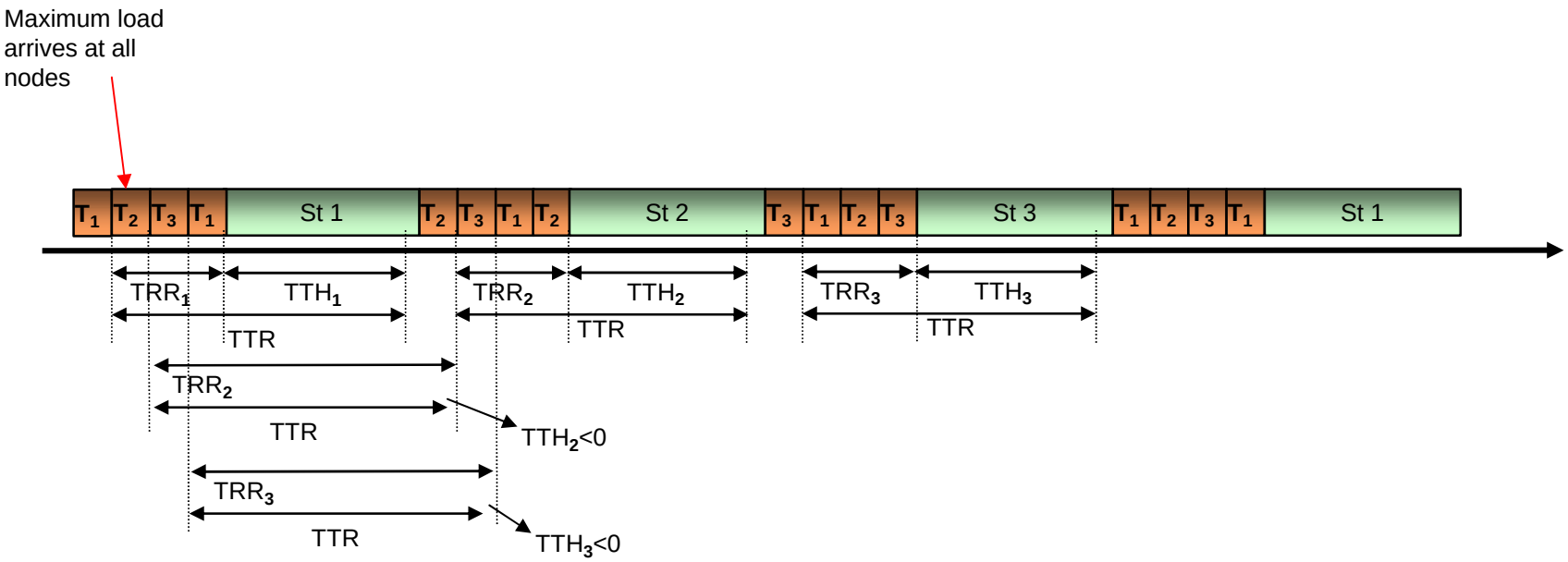
Addresses: 0 to 126, Dynamic lists

PROFIBUS

- **Traffic schedulabilty analysis:**
  - Requires determining the worst - case conditions
    - **Late arrival of the token**
      (other stations used it as much as possible)
    - **Token holding time overrun**
      (transactions started just before ending the holding time)
    - **High priority traffic ready for transmission**
      (highest interference)
  - For **single master** PROFIBUS / DP the analysis is similar to WorldFIP
    (the token mechanism is unused)

PROFIBUS

- **Traffic pattern under maximum load:**
  - Equal distribution of bandwidth among N nodes
  - Intervals of bus inaccessibility =~ TTR*(N - 1)



TTP
Time-Triggered Protocol
(TTP/C – for SAE class C)
www.tttech.com

TTP/C

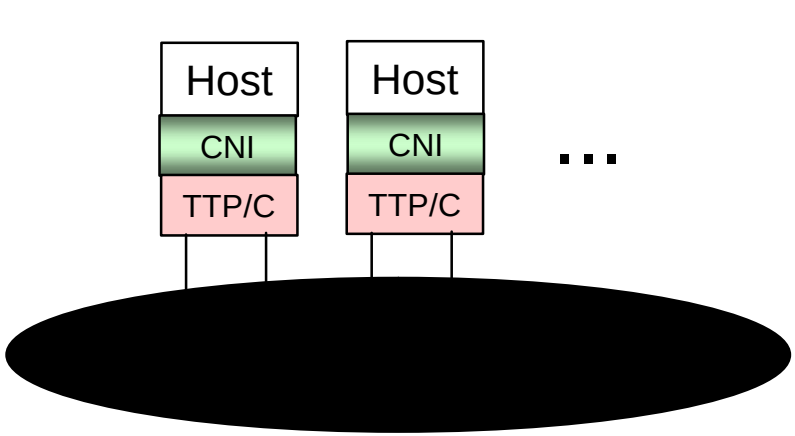
- Created around 1990 within the **MARS project** in the Technical University of Vienna
- Aims at **safety-critical** applications
- Considers an architecture with nodes integrated in **fault-tolerant units** (FTUs), interconnected by a **replicated bus**
- Includes support for prompt **error detection** and **consistency checks** as well as **membership** and **clock synchronization** services.

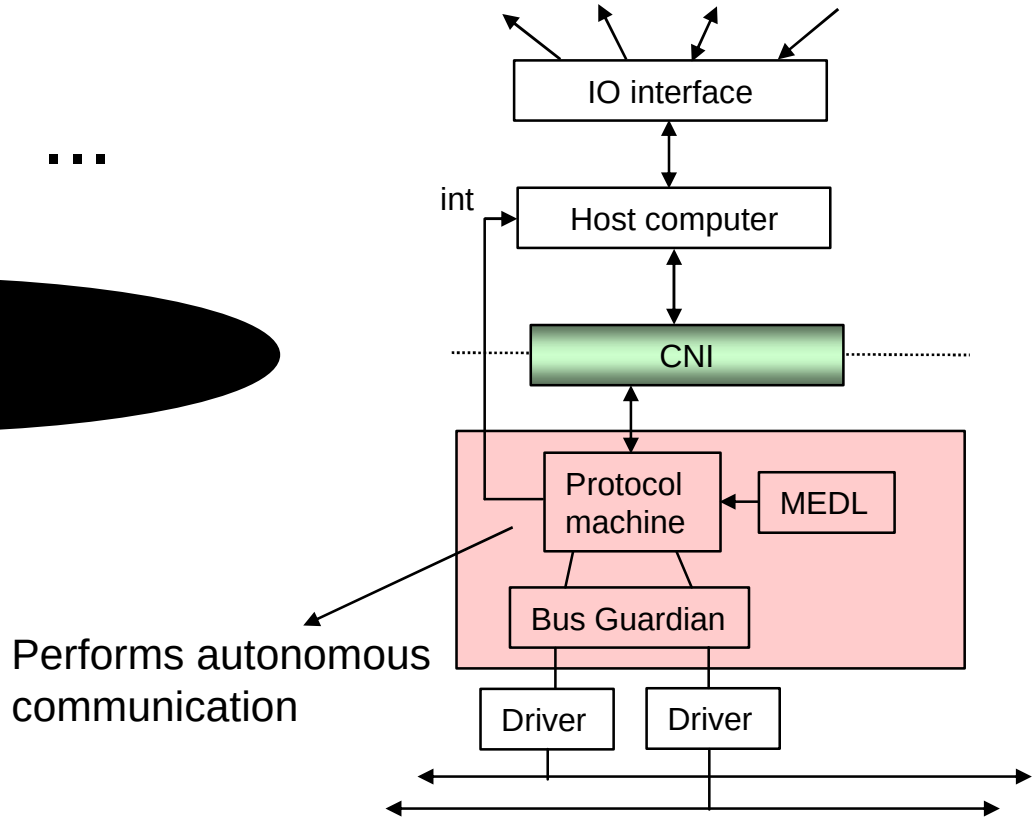
TTP/C

- **Multi-master**, **broadcast**, serial **bus**
- Transmission rate of **0.5, 1, 2** Mbit/s with **MFM** (modified frequency modulation) bit encoding
- Higher tx rates with Ethernet PHY (e.g. **25**Mbit/s)
- Max. number of nodes is **64** (possibly larger if some share the access to the network)
- CNI based on **Dual-port RAM**

TTP/C

Network and nodes architecture





Performs autonomous communication

TTP/C

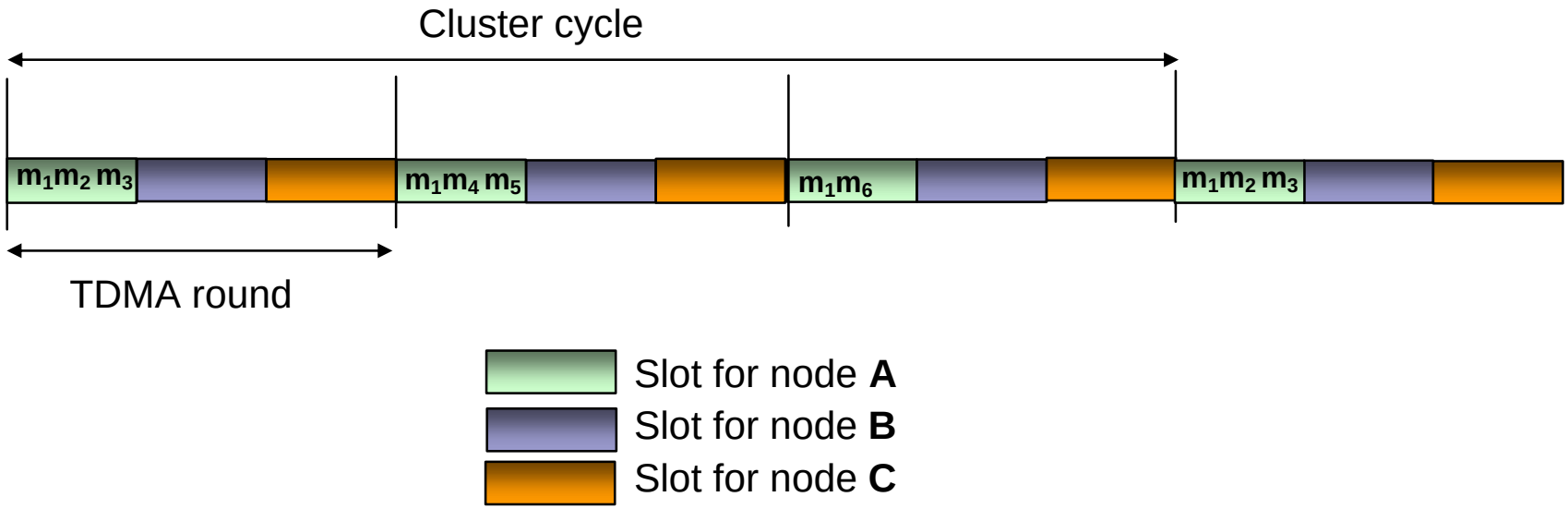
- **TDMA** access scheme with **one slot** allocated **per node** and **per round**
- The periodic sequence of slots is a **TDMA round** (typical values 1-10ms)
- In **each slot** the respective node may send **one frame** (up to 240 bytes)
- Each frame may contain **several messages**

TTP/C

- All message transmission instants are stored in a **distributed static table**, the **MEDL**
- The messages cycle may span over several TDMA rounds. It is called the **Cluster Cycle**
- The Cluster Cycle may have **up to 512** slots
- Up to **30 modes** can be pre-programmed in the MEDL

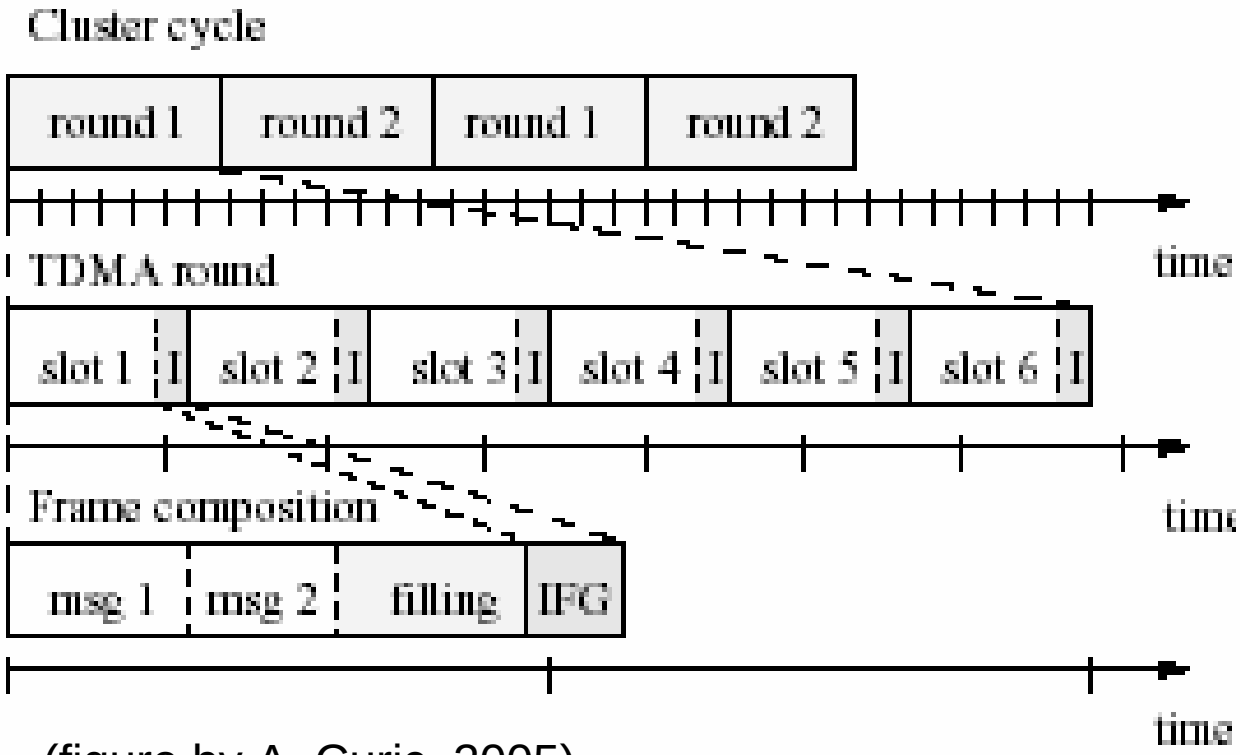
TTP/C

TDMA round and Cluster Cycle



TTP/C

TDMA round and Cluster Cycle



(figure by A. Curic, 2005)

TTP/C

- **Frame structure**
  - **I-Frame**: Protocol information frame (carries the C-state)
    - C-State: Controller state information (clock, MEDL position, membership view)
  - **N-Frame**: Normal data frame (carries application data but CRC is calculated together with C-state – **prompt detection of inconsistent states**)
  - **Protocol overhead** per frame: 4 bits header, 3 bytes CRC

TTP/C

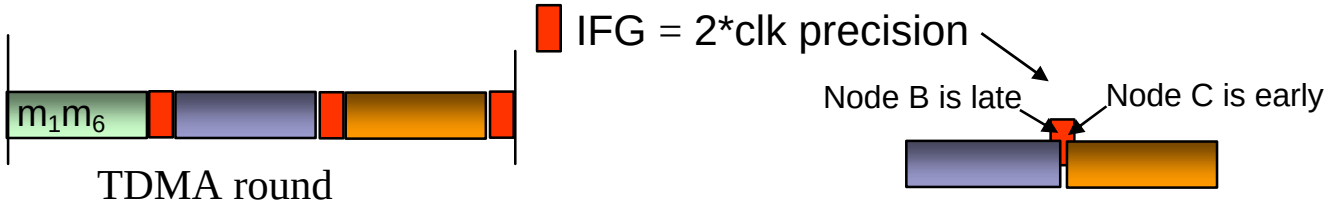
- **Frame durations**
  - Notice that frames are transmitted **without addresses**. Messages are identified by the respective **transmission time instant**.
  - This results in a **high protocol efficiency**
  - Total transmitted bits:
    SOF(3) + header(4) + data + CRC(24)
  - Total slot size:
    transmitted bits + IFG (10-100μs)

TTP/C

Data efficiency

- **Per transaction** (frame)
  - tx_rate=500Kbit/s, IFG=20?s, Data bits=16, Data_eff=28%
  - tx_rate=500Kbit/s, IFG=20?s, Data bits=64, Data_eff=61%
  - tx_rate=500Kbit/s, IFG=20?s, Data bits=640, Data_eff=94%
  - tx_rate=2Mbit/s, IFG=20?s, Data bits=640, Data_eff=90%

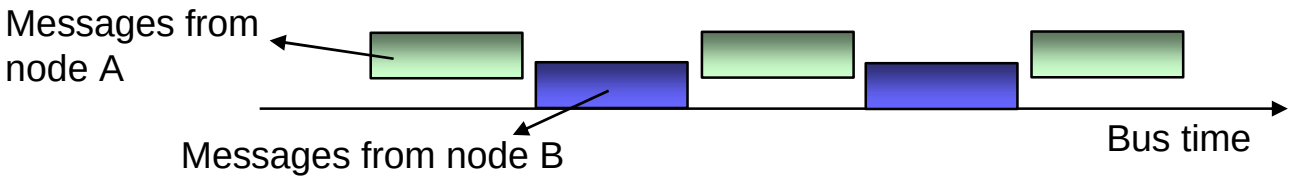
Efficiency decreases with increasing tx rate because of the IFG.
Higher efficiency requires **shorter IFG** (better clock sync)



TTP/C

Schedulability analysis

- TTP/C is **table based** and, as for WorldFIP, schedulability is implicitly verified when **building the schedule table** (cluster design).
- An important aspect is that different nodes access the bus in **exclusive slots** and thus, **do not interfere**.
- Thus, schedulability can be **tested separately** for each node



TTP/C

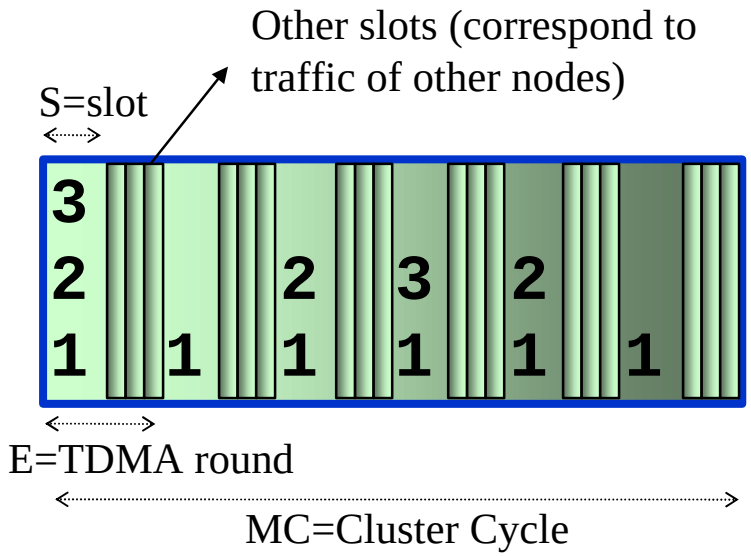
Schedulability analysis

- The analysis for TTP/C can use the same techniques as for WorldFIP:
  - The messages in a slot can be considered as messages in one Elementary Cycle (EC)
  - The duration of the slot can be considered as a periodic phase shorter than the EC
  - The TDMA round can be considered as the EC
  - The Cluster Cycle can be considered as the Macro Cycle
  - **Inserted idle-time** must be considered because of the **strict isolation** between slots in the TDMA round

TTP/C

Schedulability analysis

- Mapping the Cluster Cycle onto a WorldFIP BAT for each node (just to illustrate equivalence of analysis)



Summary:

PROFIBUS

- 80's by **Siemens, aims Process control** and **factory automation**
- Standards DIN/CENELEC/IEC
- **Broadcast** serial **bus**
  - asynchronous transmission based on UARTs,
  - transmission rates up to **12 Mbit/s**
  - Max. length: **200m @ 1.5Mbit/s**, **1.2km @ 93.75kbit/s**. Extendable by repeaters
  - Max. number of nodes **127** (32 masters)

Summary:

- Two main application profiles:
  - **PROFIBUS / FMS** - Fieldbus Message Specification
  - **PROFIBUS / DP** - Decentralised Peripherals
- **Hybrid** bus access control
  - **Token-passing** among masters, **Master-Slave** in each individual data transactions
- DLL services
  - SDA – **Send** Data with **Acknowledge**
  - SDN – **Send** Data with **No acknowledge**
  - SRD – **Send** and **Request** Data
  - CSRD – **Cyclic Send** and **Request** Data

Summary:

TTP/C

- 1990's in the Technical University of Vienna
- **Safety-critical** applications (nodes integrated in **fault-tolerant units** (FTUs), interconnected by a **replicated bus)**
- Prompt **error detection** and **consistency checks, membership** and **clock synchronization** services
- **Multi-master**, **broadcast**, serial **bus**
- Several tx rates (e.g. **0.5Mb/s** with **MFM to 25Mb/s** on Ethernet PHY)
- Up to **64** nodes, CNI based on **Dual-port RAM**
- **TDMA** access scheme with **one slot** allocated **per node** and **per round**

Summary:

- In **each slot** nodes may send **one frame** (up to 240 bytes). Each frame may contain **several messages.**
- All message transmission instants are stored in a **distributed static table (MEDL).** The messages cycle may span over several TDMA rounds **(Cluster Cycle).**
- Frames:
  - **I-Frame**: Protocol information frame (carries the C-state / Controller state information: clock, MEDL position, membership view)
  - **N-Frame**: Normal data frame
- TTP/C is **table based** (schedulability is implicitly verified when **building the schedule table**).
- An important aspect is that different nodes access the bus in **exclusive slots** and thus, **do not interfere**.