Conversion of Fieldbusses regarding Industrial Internet of Things

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Overview

• Development of fieldbusses in Factory Automation

• Requirements from Industrial Internet of Things / Industrie 4.0

• Future impact of Time Sensitive Networks on Industrial Ethernet
History of Fieldbusses

1980s

- Replacement of hardwired I/O connection to reduce wiring cost
- Data exchange between automation controllers
- Synchronized motion systems
Central I/O

Cabinet 1
- PLC
- IO Rack 1
- IO Rack 2

Parallel bus

Serial connection

N -times

Cabinet 2
- IO Rack 3
- IO Rack 4
- IO Rack 5

Parallel bus
I/O via Fieldbus
DeviceNet

- Introduced in 1995
- Based on CAN (ISO11898)
  - widely used in vehicles
- Variety of application
  - Master / Slave
  - Client / Server
  - Peer to Peer
  - Cyclic, Change of State
  - Unicast or Multicast
- Object oriented design
- Routing and bridging
Controller to Controller Communication

- Automation driven by automotive industries
- The 1980s: CIM, MAP/MMS driven by GM, initial point of Industrie 4.0
- Vertical integration
- Profibus/FMS was defined as a subset of MMS, main use C2C
- PC used for HMI and control → Ethernet, TCP/IP
CNC, RC and Motion Control

• First applied in machine tools
• High precision and fast control loops needed
  – Local control loops preferred
  – Distribution of control loops depends on application
• Commissioning mostly online
Servo drive control loops

Position control interface (Standard interface for SERCOS)

Classical analog speed control interface ±10V

Momentum/current control (used for non-cartesian systems, e.g. robotics)

Position control loop

Speed control loop

Momentum/current control loop

\[ X_{\text{cmd}} \]

\[ X_{\text{crnt}} \]

\[ n_{\text{cmd}} \]

\[ n_{\text{crnt}} \]

\[ d/dt \]

\[ U, I \]

indirect

direct feedback
CNC, RC and Motion Control

• First applied in machine tools
• High precision and fast control loops needed
  – local control loops preferred
  – Distribution of control loops depends on application
• Commissioning mostly online
• First digital interface: Sercos
  – Fiber optics for EMC
  – TDMA for real time high precision timing
  – Initially only drives
  – Specialized for synchronized motion
Differences in Application Properties

- Different usage → different properties
- Offline configuration → EDS
- Machine only working with all drives → error if one is missing

<table>
<thead>
<tr>
<th></th>
<th>I/O</th>
<th>C2C</th>
<th>Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offline configuration</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Online configuration</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Config at connection</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cycle time</td>
<td>5-10ms</td>
<td>5-100ms</td>
<td>0.5-4ms</td>
</tr>
<tr>
<td>Synchronization</td>
<td>&lt; ±5%</td>
<td>-</td>
<td>&lt;1µs</td>
</tr>
<tr>
<td>Browse</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Migration to Ethernet

- Reasons and requirements
  - Data rate insufficient in fieldbusses
  - Eliminate separate interface for commissioning
  - Enable IT integration into devices
    - Web server
      - Diagnostics
      - Change settings
    - Firmware download
    - SNMP
- How to become Ethernet deterministic
Real Time Behavior (1)

- Traditional Ethernet using CSMA/CD is not deterministic
  - Collision is detected and packets are repeated after random time
  - But can be made deterministic by a Master/Slave MAC layer (PowerLink)
- Switched Ethernet and packet prioritization achieves soft real time behavior
  - Packet delay up to 122 µs per hop
  - Still danger of overload and switches not supporting enough priorities
  - Not suitable for synchronized motion
  - Synchronized motion can be achieved using synchronization with IEEE1588
- Ultra low latency and Ethernet
  - Scheduled transfer (TDMA) and multi-device packets (Sercos, Profinet IRT)
  - Future: Time Sensitive Networks (TSN)
Real Time Behavior (2)

Software Architecture

Real Time Class

1. Best-effort, Real Time, TCP/UDP, IP, Ethernet MAC
   - e.g. Modbus, FF HSE

2. Best-effort, Real Time, TCP/UDP, IP, Prioritizing, Ethernet MAC
   - Profinet RT, EtherNet/IP

3. Best-effort, Real Time, TCP/UDP, IP, Scheduling, Ethernet MAC
   - Profinet IRT, Sercos, PowerLink, EtherCAT

Adapted from: J. Jasperneite, FH Lemgo
Market Requirements

Minimum product variation

Ford Motor Company

High variation of products, minimum buffers

Toyota

Future: Individual products in mass production
SmartFactory Demo Line

- Product: card holder
- Product contains individual manufacturing steps and quality data
- Plan to use Machine Data Model of ODVA Machinery SIG
Ubiquitous availability of information

- Every information at any place at any time
- Wireless is the key
  - Already available via mobile devices
  - In some applications also at device level
- CIP is ready
  - Objects and services
  - Bridging and routing
  - Future extension
    - DeviceNet of Things
    - EtherNet/IP in resource constrained devices
    - I/O-Link integration
• IIoT needs information to be found online
• OPC (and OPC UA) offers a browse service
• Industrial systems based on offline configuration → EDS files
• Systems originating from online configuration → built in object directory, e.g. Sercos: S-0-0017, Parameter structure contains units, names, data type, …
• Solution: link to EDS from device
• Set of Standards
  – 1588, 802.1AS, 801.2ASrev
• Time Synchronization
  – 802.1Qbu, 802.3br
  – 802.1AB (LLDP)
• Latency reduction
• Scheduling traffic
  – 802.1Qbv
• Redundancy
  – 802.1CB
• Nearly all systems use some variant of IEEE1588
• Transparent clocks have been introduced to minimize degrading of accuracy over hop count
• Redundancy issues have been solved by sophisticated methods
• Only Sercos uses synchronization by telegram
Latency Reduction – Frame Preemption

- Long frames can’t be interrupted in traditional Ethernet
- Qbu (Frame Preemption) and 3br (Interspersing Express Traffic) solve this
- Maximum delay by low priority traffic can be reduced from 123µs to 12µs @100Mbit/s
- But this still allows this delay to be introduced at each hop
Latency Reduction – Scheduled Traffic

- Problem: large number of hops
  - Scheduling can reduce latency significantly
- IEEE802.1Qbv Time aware shaper
  - Block non-express traffic in the guard window immediately before cycle start
- Only in large networks
  - Probably not in EtherNet/IP
  - Needed in Sercos
• Industrial networks support redundancy already
• Change to 802.1CB would introduce different procedures
  – Incompatibilities
• No need, if no requirement from application
100Mbit/s versus 1Gbit/s

• What happens going from 100 Mbit/s to 1Gbit/s?
  – Transmission speed increases by factor 10
  – Propagation delay stays constant (no increase in speed of light)
  – Signal conversion delay decreases insignificantly

<table>
<thead>
<tr>
<th></th>
<th>Packet size</th>
<th>100 Mbit/s</th>
<th>1 Gbit/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission time¹)</td>
<td>64</td>
<td>6.7µs</td>
<td>0.67µs</td>
</tr>
<tr>
<td></td>
<td>1518</td>
<td>123µs</td>
<td>12.3µs</td>
</tr>
<tr>
<td>Delay per hop²)</td>
<td></td>
<td>1.5µs</td>
<td>1.5µs</td>
</tr>
</tbody>
</table>

¹) Including Start of Frame and Inter Packet Gap
²) 1 µs node delay and 0.5µs accounting for 100 m cable length

Topology matters!
100Mbit/s versus 1Gbit/s – cut through

- Total delay with Cut through
  - Transmission time important at 100Mbit/s
  - Node delay dominant at 1Gbit/s

\[ t_D = t_{DN} \times n + t_r \]

- \( t_{DN} \): Node Delay
- \( t_r \): transmission time
100Mbit/s versus 1Gbit/s – store & forward

- Total delay with store & forward
  - 100Mbit/s:
    * Transmission time dominant for large packets
    * Large number of hops lead to large delay
    * Not useful for closed loop control
    * But for small packets only systems may be acceptable
    * TSN Frame preemption would be helpful
  - 1Gbit/s
    * Small packets: node delay and transmission time in same range
100Mbit/s versus 1Gbit/s – store & forward

- Total delay with store & forward
  - Low number of hops
  - 100Mbit/s:
    - Transmission time still important
    - closed loop control
    - But for small packets only systems may be acceptable
    - TSN Frame preemption would be helpful
  - 1Gbit/s
    - Small packets: node delay and transmission time in same range

\[
t_D = t_{DN} \times n + t_r
\]

- \( t_{DN} \): Node Delay
- \( t_r \): transmission time

![Graph showing delay vs number of hops for 100Mbit/s and 1Gbit/s networks.](attachment:image.png)
Summary

• Automation technology developed in several application fields
• Ethernet was introduced for transmission rate and IT connectivity
• ODVA uses COTS technology and supports internetworking in its specification
• CIP is ready for the Industrial Internet of Things
• Discovery service could be added
• When TSN becomes available EtherNet/IP could be easier to apply in time critical applications in the presence of IT traffic
• The formerly separated application fields can be merged into one network (this is already true for EtherNet/IP)
THANK YOU