PROFINET Real-Time Communication

**Functional Scope**
- Requirements
- RT-Communication
- IRT-Communication
- Time-Synchronisation
- IRT-Schedule
- Unsych-Comm.
- Synchr.-Comm.
- Software-Stack
- RT and CBA

**Motion Control**

**Safety**

**Network Installation**

**Network Management**

**Real-time Communication**

**Verteilte Automation**

**Decentral Periphery**

**Fieldbus Integration**

**WEB Integration**

**MES**

**Process Automation**

**Security**

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Requirements on Real-Time Communication

- **Refresh times**
  - Refresh time: time duration from the switch over of an input signal to the reaction on the correspondent output signal
    - **Factory Automation**: 5-10 ms
    - **Motion Control**: cycle time 1 ms, Jitter <1µs

- **The processor is responsible for the application and should not be burdened by the real-time communication excessively**
  - Main task is to handling the application program

- **The Real-Time communication must be able to be used in existing Ethernet infrastructures**
  - No influence of the existing communication
  - Use of standard network components (e.g. Switches)
  - Use of standard Ethernet controllers in devices
• **PROFINET distinguishes between two real-time classes with differences regarding the performance:**

  • **Real-Time:**
    - Using standard components
    - Performance characteristics like fieldbuses today (e.g. PROFIBUS)
    - Typical application area: Factory Automation

  • **Isochronous Real-Time:**
    - Clock synchronized communication
    - Hardware support via Switch-ASIC
    - Typical application area: drive control in Motion Control applications
Improving Performance in the Communication Stack

- The time needed for the provision and processing of the data is independent of communication.
- Improved performance is possible only through optimization of the turnaround times in the stack.
- The transmission speed on the line can be regarded as negligible (100 Mb/s).

![Diagram showing communication stack with delays T1, T2, and T3 between producer and consumer.]

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**Real-Time Communication**

- **RT in PROFINET** provides similar Real-Time properties like PROFIBUS
- Cycle times can be realized in the range of 5 to 10 ms
- **PROFINET Real-Time** is fully compatible to TCP/IP standard without any restriction

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Real-Time Communication

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PROFINET Real-Time Communication

IT applications
- e.g.
  - HTTP
  - SNMP
  - DHCP...

PROFINET applications
1. Standard data
2. Real-Time data

Standard channel
- Device parameterization and configuration
- Reading of diagnostics data
- Negotiation of the communication channel for process data

Real-Time channel RT
- High-performance transmission of process data
- Event-controlled signals
**Construction of a PROFINET Real-Time-Frame**

- **Uniform Real-Time protocol for all applications**
  - Standardized frame format as defined in IEEE 802.3
  - Specific Ethertype for PROFINET Real-Time frames
    - 0x0800: IP frame
    - 0x8892: PROFINET Real-Time frame
  - Assignment of received data over frame-ID
    - cyclic transmission
    - a-cyclic transmission (Alarms and Events)
  - Status of device and data (e.g. run, stop, error)
## Construction of a PROFINET Real-Time-Frame

<table>
<thead>
<tr>
<th>Preamble</th>
<th>SYNCH</th>
<th>Dest Addr</th>
<th>Src Addr</th>
<th>Tag</th>
<th>Tag Control</th>
<th>Type 8892H</th>
<th>Frame ID</th>
<th>User data</th>
<th>Cycle Counter</th>
<th>Data Status</th>
<th>Transfer Status</th>
<th>FCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>56 Bits</td>
<td>8 Bits</td>
<td>6 Byte</td>
<td>6 Byte</td>
<td>2 byte</td>
<td>2 byte</td>
<td>2 byte</td>
<td>2 byte</td>
<td>40..1440 Bytes</td>
<td>2 byte</td>
<td>1 byte</td>
<td>1 byte</td>
<td>4 byte</td>
</tr>
</tbody>
</table>

**VLAN Tag**

- see next page
- Type the identification for RT-Frame is (0x8892)
- Frame-ID see next page
- Cycle Counter will be incremented from the provider in 31.25µs-dteps.
- Data Status backup, primary, valid, invalid …
- Transfer Status reserved

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Prioritization of Frames with the VLAN-Tag

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**RT-Frames are always marked with a VLAN-Tag**

<table>
<thead>
<tr>
<th>Frame</th>
<th>Dest Addr</th>
<th>Src Addr</th>
<th>Type</th>
<th>Frame ID</th>
<th>Application data</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preamble mit SFD</td>
<td>8 byte</td>
<td>6 byte</td>
<td>6 byte</td>
<td>2 byte</td>
<td>2 byte</td>
<td>&lt;= 36* ...1472</td>
</tr>
</tbody>
</table>

**VLAN-Tag**

- **Type 8100**
  - Priority: 0
  - VLAN-ID: 12-bit

*) maybe 40 byte because some switches remove the VLAN Tag
**Distribution of Refresh Times**

- **RT improvements against standard TCP/IP**
  - Optimization of the absolute transmission time: factor 6-10
  - Minimization of the variance of the transmission times: factor 5-8
  - Improved behavior at replacement value: factor 7
Demands on Motion Control applications

- Wood-, glass- and ceramic-processing machines
- Plastics injection molding machines
- Packaging machines
- Printing presses

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Isochronous Real-Time Communication (IRT)

**Requirements on Ethernet for Motion Control**

- Highest performance
- Time synchronization inclusive determinism
- Openness for unrestricted access to the IT world, which means no restrictions for TCP/IP
PROFINET and IRT

What are the pre-conditions?

- Segmentation of the communication
- Use of time based communication
- Clock-synchronization
Isochronous Real-Time Ethernet

- Scheduling of communication systems
  - High accurate cycle synchronization
  - Separate time areas for real-time and TCP/UDP

![Diagram showing isochronous communication with high accurate cycle synchronization and separate time areas for real-time and TCP/UDP.]
Time based Communication with IRT

- Synchronized communication
- Time based
- **No VLAN-Tag** necessary

<table>
<thead>
<tr>
<th>Preamble</th>
<th>SYNCH</th>
<th>Dest Addr</th>
<th>Src Addr</th>
<th>Ether type</th>
<th>Frame ID</th>
<th>RT.-User data</th>
<th>FCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>56 Bits</td>
<td>8 Bits</td>
<td>6 Byte</td>
<td>6 Byte</td>
<td>2 byte</td>
<td>2 byte</td>
<td>36..1490 bytes</td>
<td>4 byte</td>
</tr>
</tbody>
</table>

Ethertype is 0x8892

PROFINET Real-Time Communication

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PROFINET and IEEE 1588

IEEE 1588 describes the clock synchronization

- PROFINET is compatible to IEEE 1588

- but that’s not always enough

- Extensions to IEEE 1588 → better accuracy
- The Precision Time Protocol has been implemented → < 1µs Jitter
- Exact determination of the time during send and receive
**Principle of the Time Synchronization**

Sync-Master

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>Sync-Req</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_2$</td>
<td>FollowUp-Req</td>
</tr>
</tbody>
</table>

Sync-Slave

<table>
<thead>
<tr>
<th>$T_4$</th>
<th>Delay-Req</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_3$</td>
<td>Delay-Rsp</td>
</tr>
</tbody>
</table>

Synchronization

$T_{err} = T_2 - (T_1 + T_{ld})$

Line Delay Measurement

(not every Sync-Frame)

Calculation line delay:

$T_{ld} = \frac{(T_4 - T_1) - (T_3 - T_2)}{2}$
**Time Synchronization: Example**

1. **Calculation line delay:**
   
   \[ T_{ld} = \frac{(T_4 - T_1) - (T_3 - T_2)}{2} \]

2. **Adjust time**
   
   time in Follow up + line delay + local Timer from the time T2
PROFINET Real-Time Communication

Time Scheduling with PROFINET

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Cycle time e.g. 1 ms

- Red interval
- Reserved IRT-area

- Green interval

- Green/red border

- Green frame shall complete here

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Behavior of Real-Time Switches

Characteristics:

- Real-Time networks can be compared with autobahns equipped with a passing lane, on which the NRT frames are passed by the RT frames.
- The cycle synchronization communicates the point of time to the switches to pass through the RT frames.
- In the Real-Time phase the RT frames have “green light”.

Real-Time networks can be compared with autobahns equipped with a passing lane, on which the NRT frames are passed by the RT frames. The cycle synchronization communicates the point of time to the switches to pass through the RT frames. In the Real-Time phase the RT frames have “green light”.

Cycle Synchronization
Unsynchronized Real-Time-Communication

- **RT** = Real-Time-Communication
- **aRT** = acyclic Real-Time-Communication (e.g., Alarms)
- **NRT** = Non-Real-Time-Communication

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Synchronized Real-Time-Communication

Time based communication
Address based Communication

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Distribution of Refresh Times

IRT  0,25...1,0 msec
RT   10 msec
TCP/IP 100 msec

IRT Communication
RT Communication
TCP/IP Communication

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**Isochronous Real-Time Communication**

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**Requirements**

**RT and CBA**

**PROFINET Real-Time Communication**

**IT applications**
- Device parameterization and configuration
- Reading of diagnostics data
- Negotiation of the communication channel for user data

**PROFINET applications**
- Real-Time channel RT
  - Performant cyclic transfer of process data
  - Event-controlled signals/alarm

**PROFINET applications**
- Real-Time channel IRT
  - Isochronous transmission of process data
  - Jitter <1µsec

**Standard channel**
- Standard data
- Real-Time data

**Communication Channels**
- Standard channel
- Real-Time channel RT
- Real-Time channel IRT

**PROFINET Real-Time Communication**
PROFINET CBA: Real-Time between Components

- The user chooses the QoS „Real-Time Data Transmission“ in the configuration tool
- The Communication relationships between the devices is established over TCP/IP
- Subsequently, process data are transmitted cyclically between devices via the Real-Time channel