Ethernet POWERLINK

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Outline

- Introduction
- Ethernet POWERLINK Protocol
- Ethernet POWERLINK Topologies
- Ethernet POWERLINK Redundancy
- Ring Redundancy
- Summary
Why Ethernet

- Old fieldbus technologies are limiting new demanding applications
  - Low bandwidth
  - Limited topologies

- Ethernet is a safe investment
  - High performance, higher productivity
  - Manufacturer independence
  - Proven technology
Why Real-time Industrial Ethernet

- Standard Ethernet is not deterministic
  - Not designed for industrial environment
  - Not for time-critical applications
- Real-time industrial Ethernet is required for
  - Critical processes, control and sensor systems
Ethernet POWERLINK (EPL)

- A real-time Ethernet (RTE) belonging to IEC 61784
- First designed by Austrian company B&R GmbH (Germany) in 2001
  Now managed by the Ethernet POWERLINK Standardization Group (EPSG)

- An open-source protocol

- Compliant with IANA real-time class 4 (highest performance)

- Application layer based on CANOpen standard
  - CANOpen is a widely used application protocol
  - EPL also called CANOpen over Ethernet
EPL Performance

- 0.1 us system synchronization
- 100 us cycle time
- 100 Mbps bandwidth
- One managing node supports up to 240 controlled nodes
Why POWERLINK

- Highest real-time class: reliability
- Based on legacy Ethernet: compatibility
- Open-source: low cost
- Designed for integrated automation
POWERLINK World Market

- 3,200 OEMs
- 1.1 millions POWERLINK systems installed

Source: IMS Research 2013
Chinese Official Standard
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PHY Layer

- Adopt IEEE 802.3 100BASE-X
- Half-duplex transmission mode
- AWG26 twisted pair cables with a protection foil shielding (S/UTP, commonly known as Cat5e) suggested
MAC Layer

- Adopt IEEE 802.3 MAC layer
- CSMA/CD
Application Layer

- Provides services to applications by means of service objects

- Service may be either local or remote
  - Local service: started by a request primitive issued by a specific application or by a local service object
  - Remote service: involves objects that reside on peer nodes connected to the network

- Ensures data exchange in several communication models, e.g. master/slave, server/client, and producer/consumer
Network Entities

- Managing node (MN)
  - Implements both automation and control tasks
  - Also taking care of network management
  - Only one MN in each EPL

- Controlled nodes (CNs)
  - Other device-like entities with communication capabilities
  - E.g. sensors and actuators
  - Up to 240 CNs in an EPL

- Switch/Hub
Data link layer
Slot Communication Network Management (SCNM)

- To allow both real-time and noncritical communications
  - Noncritical traffic: UDP, HTTP, FTP, etc.
EPL Cycle

- SoC (Start of Cycle): multicast frame by MN to trigger EPL cycle, also to maintain time sync.

- Isochronous period
  - For real-time data exchange
  - MN polls each CN by a poll request (PReq) frame (Unicast)
  - CN responses by a poll response (PRes) frame (Multicast)
  - MN also gathers information for asynchronous transmissions during this period
Continuous Polling and Multiplexed Polling

- Continuous polling: CNs belonging to this class are polled at every EPL cycle
- Multiplexed polling: data from a subset of CNs are gathered in multiple cycles
EPL Cycle

- **SoA:** multicast frame by MN to trigger asynchronous period, also to inform which node has been selected for async. communication

- **Asynchronous period**
  - Ensures the transmission of only one asynchronous message by a selected node
  - The selected node may transmit either a legacy Ethernet message or EPL-specific acyclic real-time data, such as alarms
EPL Cycle

- Idle period: to ensure that all the transmissions scheduled during other periods are concluded before the end of the EPL cycle, thus no activity is present on the network during this phase.
Encapsulation of EPL Frames

- An EPL message is inserted at the beginning of the data field of the Ethernet frame
EPL Data Unit

- Message type: 8 bits, first bit reserved

<table>
<thead>
<tr>
<th>Table 19.1 Ethernet POWERLINK Message Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet POWERLINK Frame</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Start of cycle</td>
</tr>
<tr>
<td>Poll request</td>
</tr>
<tr>
<td>Poll response</td>
</tr>
<tr>
<td>Start of asynchronous</td>
</tr>
<tr>
<td>Asynchronous send</td>
</tr>
</tbody>
</table>

- Destination address

- Source address

- payload
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Timing Considerations

- Hub: path delay < 460 ns, jitter < 70 ns
- MN PReq timeout = 25 us, upper bound of MN-CN RTT
EPL Network Using Combined Topologies
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EPS Redundancy Schemes

- Medium redundancy
- MN redundancy
- Ring redundancy (optional)
Medium Redundancy
Medium Redundancy

- Each device has a second/redundant cable
- A link selector decides which link to use based on a predefined algorithm
- The link selector of each CN is required to introduce in the PRes frame the information about the status of both its links
  - Link selector implemented by software
- The MN uses the gathered link status information to infer the quality of the network
MN Redundancy

- Active managing node (AMN)
- Standby managing node (SMN)
  - Constantly monitors the network status
  - Replace the AMN when failure happens
  - In case of multiple SMNs, an election algorithm is needed
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EPL Ring Redundancy
EPL Ring Redundancy

- Each device has two Ethernet ports
- Under regular conditions, each frame issued by the MN will traverse the ring until it reaches the MN again
- Under faulty conditions, the frame is not received back
OpenSAFETY Protocol

- Not exclusively designed for EPL
- First open and bus-independent safety standard for industrial ETH
OpenSAFETY Protocol

- Not exclusively designed for EPL
  - May be adopted by other RTE network, e.g. EtherNet/IP, Modbus

- Purpose: to ensure data transfer integrity
  - Against data duplications, loss of frames, etc.

- User data are duplicated in two adjacent subframes within the same frame

- In a single OpenSAFETY network (i.e. safety domain, SD), only one safety configuration manager (SCM) can exist, monitoring up to 1023 safety nodes (SNs).
EPL Basic Performance Analysis

- Cycle time: 
  \[ T_C = T_{SoC} + T_{Isoc} + T_{Async} + T_{Idle} \]

- Assume \( T_{SoC} = T_{SoA} \), the min \( T_c \) is achieved when the idle period is 0 and no acyclic transmission happens, thus

  \[ T_{C_{\text{min}}} = 2 \cdot (T_{SoC} + T_{EthIFG}) + T_{Isoc} \]

- Finally,

  \[ T_{C_{\text{min}}} = 2 \cdot (T_{SoC} + T_{EthIFG}) + \sum \{ T_{PReq} + T_{Pres} + 2 \cdot [T_{EthIFG} + T_{propag} + (N_{Hub,n} \cdot T_{Hub})] \} \]
Basic Performance Analysis

- Jitter
  - Two major causes
    - MN: related to both physical device and protocol implementation
    - Network components (e.g. hubs): independent from protocol

\[ J_{TOT} = J_{MN} + N_{Hubs} \cdot J_{Hub} \]
Summary

- A real-time industrial Ethernet
- Open-source
- Highest real-time class
Acknowledgment

http://www.ethernet-powerlink.org/

http://bul.ece.ubc.ca/Workshop06_YIN.pdf