CANopen on real-time Ethernet

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Both CAN- and Ethernet-based networks are widely deployed in millions of nodes and applications world-wide. CAN was initialy developed for automotive and is nowadays very popular in the automation industry, too. For many years, Ethernet based networks are used in automation on higher levels. Due to newly developed real-time protocol extensions, this IT network technology becomes more and more popular on sensor and actuator level as well. CANopen is one of the most extensive selection of industrially applied device and application profiles. So far it was only used on CAN bus systems. With the growing demand for Ethernet on machine level, it was logical to integrate CANopen with Ethernet protocols in general and real-time Ethernet in particular

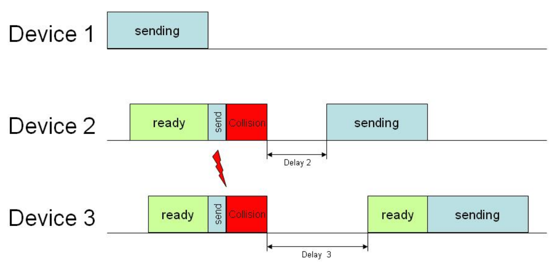
Motivation for Industrial Ethernet

Due to the worldwide deployment of Ethernet in office environments, there is increasing demand for using this technology for networking time-critical embedded applications, too. Seamless transparent communication from within the application to the outside world, based on one single standard, device availability and familiarity with this technology are the main advantages. However, there are some technical issues to be solved in order to use Ethernet for real-time applications.

Ethernet and Real-Time

Current Ethernet standards promise transfer speeds of 100Mbit/s (Fast Ethernet) and more (e.g. Gbit Ethernet). This is significantly faster than most of the established fieldbus systems and embedded networks. Therefore Ethernet also seems to be a good choice for connecting industrial devices with hard real-time requirements. However, deterministic behaviour of data transfer is sometimes more crucial than the simple network bandwidth. With Ethernet in particular, data communication can be delayed unpredictably. This is not acceptable for dynamic applications like in industrial control.

The reason for Ethernet being non-deterministic is its stochastic media access mechanism CSMA/CD (Carrier Sense Multiple Access /Collision Detect, Picture 1). With this method, all ready-to-send devices on a network segment first check if any other data is currently being transmitted on the network. If this is not the case, one or more devices start sending their data. If there is more than one device trying to gain access, a collision occurs. Thus the data telegrams are not valid anymore and the devices involved interrupt their transmission. After



Picture 1 CSMA/CD mechanism of Ethernet

a randomly calculated delay, each device starts checking the network again for free access.

The random delay should reduce the probability of further collisions. If subsequent collisions occur, delays for the involved nodes will be incremented respectively. It is obvious that this method is not suitable for real-time networking.

ETHERNET Powerlink Introduction

ETHERNET Powerlink is a standards based real-time Ethernet system (EtherType $88AB_H$). It was introduced to the market in 2001 and is used in serial machinery and process automation worldwide. ETHERNET Powerlink is managed by the EPSG (ETHERNET Powerlink Standardization Group), an open vendor and user group. The protocol can be implemented on standard hardware. No proprietary ASICs are needed. Standard Ethernet network components, like fiber-optic transceivers can also be used with ETHERNET Powerlink.

ETHERNET Powerlink meets timing demands typical for high performance industrial applications like in automation and motion control. Current implementations have reached 200µs cycle time with a timing deviation (jitter) below 1µs. Until now, this was only possible with dedicated motion bus systems.

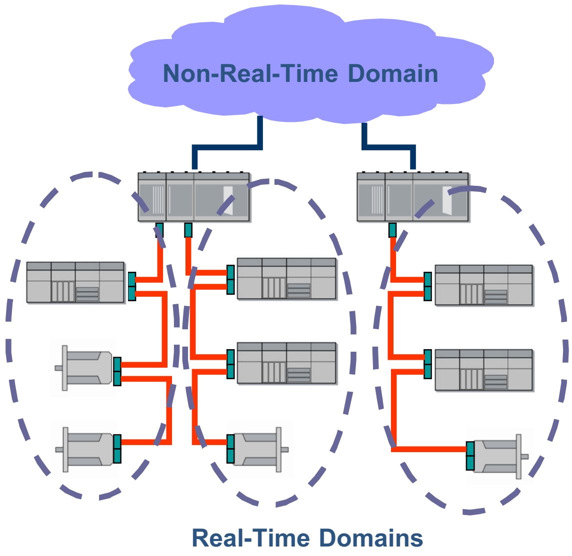
Due to its standard compliancy it is possible to leverage standard test and measurement equipment with ETHERNET Powerlink. In particular the following standards are used with ETHERNET Powerlink:

- IEEE 802.3 Fast Ethernet
- IP-based protocols
- CANopen EN50325-4
- ISO 15745-4 device description language
- Any Ethernet chip and hardware
- IEEE 1588 in future extensions

ETHERNET Powerlink Network Structure

ETHERNET Powerlink distinguishes between real-time domains and non real-time domains (Picture 2). This separation matches typical machine and plant concepts. It also satisfies the increasing security demands to prevent hacker attacks at the machine level or harm through erroneous data communication on higher network hierarchies.

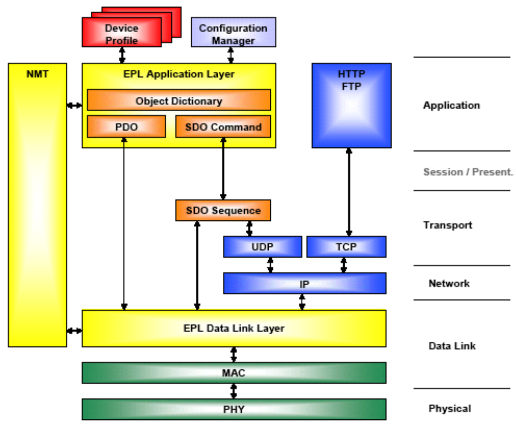
True real-time requirements are met within the real-time domain. Less time critical data is routed transparently between the real-time domain and non-real-time domain using standard IP frames. A clear boundary between a machine and factory network prevents potential security flaws from the very beginning while keeping full data transparency.



Picture 2 ETHERNET Powerlink Networking Domains

Physical and Data Link Layer

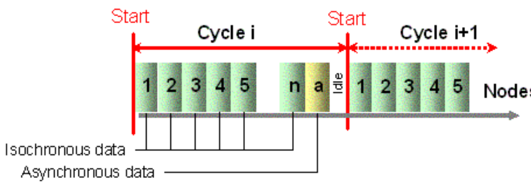
The protocol is based on the standard IEEE 802.3 layers according to ISO/OSI (Picture 3). The current physical layer is 100BASE-X (see IEEE 802.3). In the future however, it could also be based on faster Ethernet variants such as Gbit Ethernet, if necessary.



Picture 3 ETHERNET Powerlink ISO/OSI Layers

To minimize path delay and frame jitter it is recommended to use repeating hubs instead of switching hubs within the real-time domain. ETHERNET Powerlink references the IAONA Industrial Ethernet Planning and Installation Guide[i] for proper wiring of industrial networks. Both RJ45 and M12 industrial Ethernet connectors are specified.

Deterministic timing is achieved by applying a cyclic timing schedule for all connected nodes to access the physical layer (Picture 4). The schedule is divided into an isochronous phase and an asynchronous phase. During the isochronous phase, time-critical data is transferred, the asynchronous phase reserves bandwidth for non time-critical data. The Managing Node frees access to the physical medium via explicit messages. As a result, just one single node has access to the network at all times, thereby preventing collisions. The CSMA/CD mechanism, which causes non-deterministic Ethernet behavior, is not activated when ETHERNET Powerlink operates free of disturbances.



Picture 4 ETHERNET Powerlink Basic Cycle

Application Layer Protocol Requirements

Manufacturers and users are looking on interoperability and exchangeability of devices from various manufacturers. A broad component market with plenty of alternatives and second sources enables them to produce competitive automation solutions without depending on unique or proprietary systems.

The objective of independence can only be achieved by using standard solutions which provide widely understood and used data exchange mechanisms. CANopen, as application layer (layer 7) for CAN systems, has already proven the market power of a standardized, vendor independent standard which gives numerous device manufacturers the opportunity to participate in sophisticated communication mechanisms.

In 2003, the EPSG had to decide for an application protocol to be put on top of the existing lower ETHERNET Powerlink layers. There were many similarities between ETHERNET Powerlink and CANopen, like the target applications, operating principles, component suppliers and the organisations behind it. Both groups therefore came quickly to an agreement to integrate ETHERNET Powerlink with CANopen profiles in a joint technical working group. The goal was to offer complete uniformity, extending from simple sensors and high-speed drive systems to Ethernet-based factory networks. By using CANopen profiles, machine builders are provided with an easy migration path between CANopen and ETHERNET Powerlink and vice versa. Inexpensive gateways should make it possible to integrate ETHERNET Powerlink subsystems with CANopen networks and to connect CANopen networks to ETHERNET Powerlink networks.

There are a number of further requirements for a communication system arising when distributed automation systems shall be built with different types of devices or devices from different manufacturers :

- Network Management: A common mechanism for controlling and monitoring the network consistency during boot-up and runtime of the network
- Object Dictionary and Device Model: A common method for specifying and referencing data, parameters and functions of a certain device or device type provides to the system
- Error Signalling: A common method for signaling errors and indicating error conditions to the system independent of the device type or manufacturer
- Process Data Object – PDO: A common mechanism enabling the user to specify the data exchanged between different devices
- Service Data Object – SDO: A common mechanism for transmitting larger amounts of arbitrary data like configuration data
- Device Profiles: Standardized definitions of data, parameters and functions for certain device types

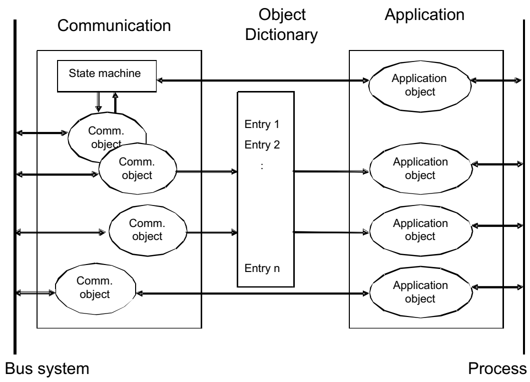
like drives, I/O modules, encoders, PLCs, etc.

For the EPSG, all these requirement were perfectly met by CANopen.

Integrating CANopen with ETHERNET Powerlink

In the joint technical working group of the EPSG and CiA CANopen's DS301 and DS302 communication profiles have been integrated with ETHERNET Powerlink. ETHERNET Powerlink can tranfer up to 1490 byte net data per frame. Therfore there is only one Transmit PDO (TxPDO) in ETHERNET Powerlink. The adaption of CANopen to ETHERNET Powerlink was therefore only necessary for the mapping of the process data. Other joint areas of work are the device description language.

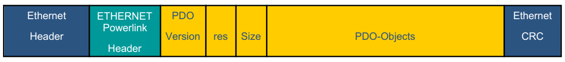
Every ETHERNET Powerlink device is described by the standardized CANopen Device Model (Picture 5)with its central element, the Object Dictionary, containing a list of descriptions of all data, parameters and functions of the device that can be accessed or controlled remotely via Ethernet. Furthermore, all configurable communication parameters are listed in the Object Dictionary. By means of the Object Dictionary each data of a device can be easily accessed form any device of the network by a unique 24-bit reference consisting of a 16-bit index and a 8-bit sub-index.



Picture 5 CANopen Device Model

Process Data Objects and ETHERNET Powerlink

Real-time critical exchange of process data is handled by the Process Data Objects (PDO). PDOs are transmitted in the isochronous period of the ETHERNET Powerlink Cycle using a Consumer/Producer oriented communication model. In ETHERNET Powerlink there is only one TxPDO capable of transfering up to 1490 bytes of net data (Picture 6). Due to the limits of the sub-index, there is a maximum of 254 data octets within one PDO.



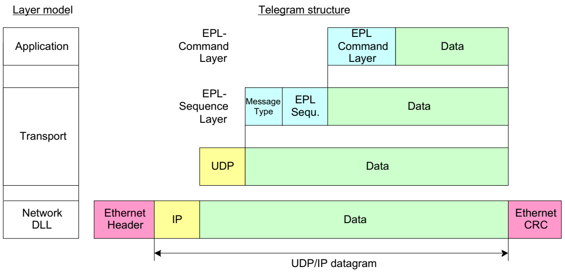
Picture 6 ETHERNET Powerlink Frame Format for PDO Transfer

Each device is able to communicate its process data directly with all other devices in the system. The contents of a PDO (process data which is to be transmitted or received) can be configured during system start-up. This allows to optimise and adjust the real-time data exchange to the requirements of the application. The real-time critical data is transmitted in PDOs without any overhead.

Service Data Objects and ETHERNET Powerlink

The exchange of parameters, functions, files or less real-time critical process data is handled by Service Data Objects (SDO). SDOs are based on a Client/Server oriented communication model where every device can access or can be accessed from any other device by an SDO. SDO Addressing is done with index/sub-index numbers or via names.

An SDO allows a client to implicitly address any entry in the Object Dictionary of the server. The length of data to be transferred is not limited. SDOs are transferred either via UDP/IP datagrams (Picture 7), directly in the ETHERNET Powerlink asynchronous frame or in a container within a PDO.



Picture 7 SDO transfer via UDP/IP

Since SDOs can be transmitted using UDP/IP, an ETHERNET Powerlink device can also be accessed via generic Internet which is connected via a router with the ETHERNET Powerlink real-time domain.

Network Management

The ETHERNET Powerlink network management describes the mode of operation, state transitions and boot-up behaviour of a device. The network manager in the managing node is responsible for system consistency checks during boot-up and for monitoring the status of all devices during run-time. The communication behaviour of each ETHERNET Powerlink device is defined by a local state machine which is controlled by certain system events and by commands from the Network Manager.

Configuration Management

The Configuration Manager is the central intelligence in an ETHERNET Powerlink system, which is able to maintain the configuration data for its application and all devices locally and download the configuration data during system startup. This approach enables the set-up of plug&play systems which allow initial installation and replacement of failed devices very easily.

XML Device Description

For describing an ETHERNET Powerlink device, a standardized file format is under development in form of an XML-based Electronic Data Sheet (EDS). The work is done together with other organisations in an ISO working group developing the ISO 15745-4 standard[ii].

Network Migration and Integration

Since the ETHERNET Powerlink Application Layer provides the same mechanisms as CANopen, all CAN device profiles can directly be reused. Thus a wide range of profiles for different device types, like I/Os, encoders or drives, and applications already exists.

Users and vendors of CANopen enabled devices are able to migrate their applications from the well established CAN bus to an Ethernet environment which is in principle a hundred times faster. Furthermore, CAN bus and Ethernet networks can transparently be combined wherever needed.

Implementing ETHERNET Powerlink

ETHERNET Powerlink can be implemented on any standard Ethernet silicon. How it is implemented most efficiently depends on the individual requirements, guidelines and preferences. The device manufacturer is free to decide if an ETHERNET Powerlink stack runs in the software on the preferred processor, a system-on-chip approach is used, or an FPGA or ASIC is developed. The properties of the technology are open. For the initial testing, prefabricated evaluation boards are available on various processor architectures, like ARM, XScale, ColdFire,166 or Hyperstone.

Further Development

ETHERNET Powerlink provides a standard protocol for Fast Ethernet, which has proven its real-time characteristics in thousands of applications (Picture 8). The EPSG ensures openness and continuous advancement. Based on mature standards the EPSG is working on further development of the specifications to add even more capabilites in areas like safety, security or system redundancy. Like it was with the integration of ETHERNET Powerlink with CANopen, ease-of-use and openness will continue to be the focal point for any future additions.

Picture 8 Example of a Packaging Machine networked with ETHERNET Powerlink

Conclusion

Integrating CANopen with ETHERNET Powerlink offers complete uniformity, extending from simple sensors and high-speed drive systems to Ethernet-based factory networks. By using CANopen profiles, machine builders are provided with an easy migration path between CANopen and real-time Ethernet and vice versa.

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[i] IAONA Industrial Ethernet Planning and Installation Guide: www.iaona-eu.org

[ii] ISO 15745-4 Industrial automation systems and integration — Open systems application integration framework — Part 4: Reference description for Ethernet-based control systems