

IEEE Standard for Industrial Hard Real-Time Communication

IEEE Industrial Electronics Society

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3 Park Avenue
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USA

IEEE Std 61158™-2017
(Adoption of EPSG DS 301)

IEEE Standard for Industrial Hard Real-Time Communication

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Industrial Electronics Society Standards Committee
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IEEE Industrial Electronics Society

Approved 18 May 2017

IEEE-SA Standards Board

Abstract: IEEE Std 61158™ is an adoption of the EPSG DS 301, Ethernet POWERLINK—Communication Profile Specification.

Ethernet POWERLINK is a communication profile for Real-Time Ethernet (RTE). It extends Ethernet according to IEEE Std 802.3™ with mechanisms to transfer data with predictable timing and precise synchronisation. The communication profile meets timing demands typical for high-performance automation and motion applications. It does not change basic principles of the Fast Ethernet Standard IEEE Std 802.3 but extends it towards RTE. Thus it is possible to leverage and continue to use any standard Ethernet silicon, infrastructure component, or test and measurement equipment like a network analyzer.

Keywords: adoption, EPSG, Ethernet POWERLINK, IEEE 61158™, Industrial Automation, Industrial Ethernet, Real-time Ethernet

The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 978-1-5044-4114-8 STD22640
Print: ISBN 978-1-5044-4115-5 STDPD22640

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Acknowledgments

The Industrial Real-Time Communication Working Group of the Industrial Electronics Society acknowledges the permission granted by the Ethernet POWERLINK Standardization Group for the IEEE adoption of EPSG DS 301.

Introduction

This introduction is not part of IEEE Std 61158-2017, IEEE Standard for Industrial Hard Real-Time Communication.

Industrial automation in most cases relies on deterministic exchange of process data among various communication partners, e.g., PLCs, drives, and IOs. However, the industry currently suffers from a multitude of different communication technologies that implement the important OSI layers incompatibly in various manners featuring various key data.

This standard hence will generate a standard for industrial real-time communication that is restricted to mainly scheduling of frames on layer 2, the data link layer. Any media can be utilized as well as any existing application protocol, which makes it a universal solution across industries and technologies.

This is achieved by adopting the EPSG Standard DS 301.

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IEEE Standard for Industrial Hard Real-Time Communication

1. Scope

Ethernet POWERLINK is a communication profile for Real-Time Ethernet (RTE). It extends Ethernet according to IEEE Std 802.3™ with mechanisms to transfer data with predictable timing and precise synchronization.¹ The communication profile meets timing demands typical for high performance automation and motion applications. It does not change basic principles of IEEE Std 802.3 but extends it towards RTE. Thus it is possible to leverage and continue to use any standard Ethernet silicon, infrastructure component, or test and measurement equipment like a network analyzer.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

EPSC Draft Standard 301 (EPSC DS 301), Ethernet POWERLINK, Communication Profile Specification, Version 1.3.0, 2016.²

EPSC Draft Standard 302-A (EPSC DS 302-A), Ethernet POWERLINK, Part A: High Availability, Version 1.1.0, 2013.

EPSC Working Draft Proposal 302-B (EPSC WDP 302-B), Ethernet POWERLINK, Part B: Multiple-ASnd, Version 1.0.2, 2013.

EPSC Draft Standard 302-C (EPSC DS 302-C), Ethernet POWERLINK, Part C: PollResponse Chaining, Version 1.0.0, 2012.

EPSC Draft Standard 302-D (EPSC DS 302-D), Ethernet POWERLINK, Part D: Multiple PReq/Pres, Version 1.0.0, 2013.

EPSC Draft Standard 302-E (EPSC WDP 302-E), Ethernet POWERLINK, Part E: Dynamic Node Allocation, Version 1.0.0, 2013.

¹ Information on normative references can be found in Clause 2.

² EPSC publications are available from the Ethernet Powerlink Standardization Group (<http://www.ethernet-powerlink.org/>).

IEC 61918, Industrial communication networks—Installation of communication networks in industrial premises.³

IEC 61784-5-13, Industrial communication networks—Profiles—Part 5-13: Installation of fieldbuses—Installation profiles for CPF 13.

IEEE Std 802.3™, IEEE Standard for Ethernet.^{4, 5}

IEEE Std 1588™-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IEEE Std 754™-2008, IEEE Standard for Floating-Point Arithmetic.

IEEE Std 802.1Q™, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks.

IEEE Std 802.1X™, IEEE Standard for Local and metropolitan area networks—Port-Based Network Access Control.

3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁶

3.1 Definitions

ageing: A common mechanism to maintain (cache) tables. Entries that are not used or refreshed are removed after a specified time.

application process: The task on the Application Layer.

async-only controlled node (CN): A node operated in a way that it is not accessed cyclically in the isochronous slot by the managing node (MN). It is polled during the asynchronous period by a StatusRequest message.

asynchronous data: Data in a POWERLINK network that is not time critical. Within the POWERLINK cycle, there is a specific period reserved for Asynchronous Data, which is shared by all nodes. Each node connected to the network can send asynchronous data by requesting it to the managing node. The managing node keeps a list of all asynchronous data requests and will subsequently grant the network access to one node after the other.

asynchronous period: The second part of the POWERLINK cycle, starting with a Start of Asynchronous (SoA) frame.

asynchronous scheduling: The scheduling system where the managing node's (MN's) asynchronous scheduler decides when a requested asynchronous data transfer will happen.

³ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).

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⁶ *IEEE Standards Dictionary Online* subscription is available at: <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

Basic Ethernet Mode: The mode that provides the Legacy Ethernet communication.

CANopen: A network technology optimized for the usage in industrial control environments, in machine internal networks, and in embedded systems (any control unit deeply “embedded” in a device with electronics). The lower-layer implementation of CANopen is based upon CAN (Controller Area Network).

continuous: A POWERLINK communication class where isochronous communication takes place every cycle (the opposite to multiplexed).

controlled node (CN): A node in a POWERLINK network without the ability to manage the Slot Communication Network Management (SCNM) mechanism.

Cycle State Machine: The state machine that controls the POWERLINK cycle on the data link layer and is itself controlled by the Network Management (NMT) state machine defining the current operating mode.

cycle time: The time between two consecutive Start of Cycle (SoC) frames, i.e., repeating, process. The Cycle Time includes the time for data transmission and some idle time before the beginning of the next cycle.

Destination NAT (D-NAT): The Network Address Translation (NAT) that changes the destination address of the Internet Protocol or Internet Control Message Protocol (IP/ICMP) packet.

Deterministic Communication: A communication process whose timing behavior can be predicted exactly; i.e., the time when a message reaches the recipient is predictable.

device configuration file (XDC): The file where configuration parameters of a specific device are stored.

device description file (XDD): The file where all device-dependent information for a specific device is stored.

domain: (A) In the context of CANopen: A data object of arbitrary type and length that can be transferred over a POWERLINK network. **(B)** In the context of internet protocols: A part of the internet name space that is supported by the Domain Name System (DNS).

Ethernet POWERLINK (EPL): An extension to Legacy Ethernet on layer 2, to exchange data under hard real-time constraints. It was developed for deterministic data exchange, short cycle time, and isochronous operation in industrial automation.

IdentRequest: A POWERLINK frame sent by the managing node (MN) in order to identify active controlled nodes (CNs) waiting to be included into the network.

IdentResponse: A special form of an ASnd frame in response to an IdentRequest.

Idle Period: The time interval remaining between the completed asynchronous period and the beginning of the next cycle.

IEEE Std 1588-2008: The standard that defines a network protocol enabling accurate and precise synchronization of the real-time clocks of devices in networked distributed systems.

isochronous: Pertaining to processes that require timing coordination to be successful. Isochronous data transfer assures that data flows continuously and at a steady rate in close timing with the ability of connected devices.

isochronous aata: Data in a POWERLINK network that is to be transmitted every cycle (or every n^{th} cycle for multiplexed isochronous data).

isochronous period: The period of a POWERLINK cycle that offers deterministic operation; i.e., it is reserved for the exchange of (continuous or multiplexed) isochronous data.

legacy Ethernet: Ethernet as standardized in IEEE Std 802.3 (non-deterministic operation in non-time-critical environments).

managing node (MN): A node capable of managing the Slot Communication Network Management (SCNM) mechanism in a POWERLINK network.

Media Access Control (MAC): One of the sublayers of the data link layer in the POWERLINK reference model that controls who gets access to the medium to send a message.

multiplexed: A POWERLINK communication class where cyclic communication takes place in such a way that m nodes are served in s cycles (the opposite to continuous).

multiplexed controlled node (CN): A node that is allowed to send isochronous data every n^{th} cycle.

multiplexed timeslot: A slot destined to carry multiplexed isochronous data; i.e., the timeslot is shared among multiple nodes.

NetTime: The managing node's (MN's) clock time that is distributed to all controlled nodes within the Start of Cycle (SoC) frame.

Network Management (NMT): The functions and services in the POWERLINK model that perform initialization, configuration, and error handling in a POWERLINK network.

NMT State Machine: The state machine controlling the overall operating mode and status of a POWERLINK node.

object directory: The repository of all data objects accessible over POWERLINK communications.

PollRequest: A frame that is used in the isochronous part of the cyclic communication. With this frame, the managing node (MN) requests the controlled node (CN) to send its data.

PollResponse: A frame that is used in the isochronous part of the cyclic communication. The controlled node (CN) responds with this frame to a PollRequest frame from a managing node (MN).

POWERLINK command layer: The layer that defines commands to access parameters of the Object Dictionary. This layer is on top of the sequence layer and distinguishes between an expedited and a segmented transfer.

POWERLINK cycle: The fix interval in which data exchange within a POWERLINK network is structured. The cycle is subdivided into the isochronous period and the asynchronous period and is organized by the managing node (MN).

POWERLINK Mode: The mode that includes all Network Management (NMT) states in which POWERLINK cycles are run.

POWERLINK NodeID: An 8-bit identifier (ID) by which a POWERLINK node (managing node, controlled node, and router) is addressed on the POWERLINK layer. This identifier (ID) has only local significance (i.e., it is unique within a POWERLINK segment).

Precision Time Protocol (PTP): *See:* IEEE Std 1588-2008.

Process Data Object (PDO): An object for isochronous data exchange between POWERLINK nodes.

reserved: Bits that are reserved for future use. They shall be set to 0 by the sender and shall not be interpreted by the receiver.

NOTE—The use of such bits is reserved for further development or by extensions of this specification.⁷

Router type 1: A coupling element in a network that allows Internet Protocol (IP) communication between a POWERLINK segment and any other datalink layer protocol carrying IP, legacy Ethernet, POWERLINK, etc. It is usually a separate network element acting as a controlled node (CN) within the POWERLINK segment.

Router type 2: A router between a POWERLINK segment and a CANopen network.

Sequence layer: The POWERLINK layer that provides the service of a reliable bidirectional connection that helps guarantee that no messages are lost or duplicated and that all messages arrive in the correct order.

Service Data Object (SDO): Peer-to-peer communication with access to the Object Dictionary of a device.

Slot Communication Network Management (SCNM): Assures that there are no collisions during physical network access of any of the networked nodes thus providing deterministic communication via Legacy Ethernet. In a POWERLINK network, the managing node allocates data transfer time for data from each node in a cyclic manner within a given cycle time. Within each cycle there are slots for Isochronous Data, as well as for Asynchronous Data for ad-hoc communication.

Source NAT (S-NAT): A Network Address Translation (NAT) that changes the source address of the Internet Protocol or Internet Control Message Protocol (IP/ICMP) packet.

StatusRequest: A special Start of Cycle (SoA) frame used to poll the status of a node.

StatusResponse: A frame transmitted by a controlled node (CN) upon assignment of the asynchronous slot via the StatusRequest in the Start of Cycle (SoA) frame.

3.2 Acronyms and abbreviations

The following acronyms and abbreviations are used in this standard:

ACL	Access Control List
ARP	Address Resolution Protocol
ASnd	Asynchronous Send (POWERLINK frame type)
CAN	Controller Area Network
CiA	CAN in Automation
CN	POWERLINK controlled node
CSMA/CD	carrier sense multiple access with collision detection
DCF	device configuration file
DLL	data link layer

⁷ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

EA	Exception Acknowledge (flag in POWERLINK frame)
EMC	electromagnetic compatibility
EN	Exception New (flag in POWERLINK frame)
EPL	Ethernet POWERLINK
EPG	Ethernet POWERLINK Standardization Group
FTP	File Transfer Protocol
ICMP	Internet Control Message Protocol
ID	identifier
IP	Internet Protocol
MAC	media access control
MIB	Management Information Base
MN	POWERLINK managing node
MS	Multiplexed Slot (flag in POWERLINK frame)
MSS	Maximum Segment Size
MTU	Maximum Transmission Unit
NAT	Network Address Translation
NIL	Not in List (Basic Data Type)
NMT	network management
PDO	Process Data Object
PR	Priority (bit field in POWERLINK frame)
PReq	PollRequest (POWERLINK frame type)
Pres	PollResponse (POWERLINK frame type)
PS	Pre-scaled Slot (flag in POWERLINK frame)
PTP	Precision Time Protocol
RD	Ready (flag in POWERLINK frame)
RFC	Requests for Comments
RPDO	Receive Process Data Object
RS	Request to Send (flag in POWERLINK frame)

SCNM	Slot Communication Network Management
SDO	service data object
SNMP	Simple Network Management Protocol
SoA	Start of Asynchronous (POWERLINK frame type)
SoC	Start of Cycle (POWERLINK frame type)
TCP	Transmission Control Protocol
TPDO	Transmit Process Data Object
UDP	User Datagram Protocol
VPN	virtual private network
XDC	XML device configuration file
XDD	XML device description file

4. Introduction

Ethernet POWERLINK is a communication profile for Real-Time Ethernet (RTE). It extends Ethernet according to IEEE Std 802.3 with mechanisms to transfer data with predictable timing and precise synchronization. The communication profile meets timing demands typical for high-performance automation and motion applications. It does not change basic principles of the Fast Ethernet Standard IEEE 802.3™ but extends it towards RTE. Thus it is possible to leverage and continue to use any standard Ethernet silicon, infrastructure component, or test and measurement equipment like a network analyzer.

4.1 Slot communication network management

POWERLINK provides mechanisms to achieve the following:

- Transmit time-critical data in precise isochronous cycles. Data exchange is based on a publish/subscribe relationship. Isochronous data communication can be used for exchanging position data of motion applications of the automation industry.
- Synchronize networked nodes with high accuracy.
- Transmit less time-critical data asynchronously on request. Asynchronous data communication can be used to transfer Internet Protocol (IP)-based protocols like Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) and higher layer protocols such as Hypertext Transfer Protocol (HTTP) or File Transfer Protocol (FTP).

POWERLINK manages the network traffic in a way that there are dedicated time-slots for isochronous and asynchronous data. It takes care that always only one networked device gains access to the network media. Thus transmission of isochronous and asynchronous data shall not interfere and precise communication timing can be achieved. The mechanism is called Slot Communication Network Management (SCNM) (see Figure 1). SCNM is managed by one particular networked device—the managing node (MN)—which includes the MN functionality. All other nodes are called controlled nodes (CNs).

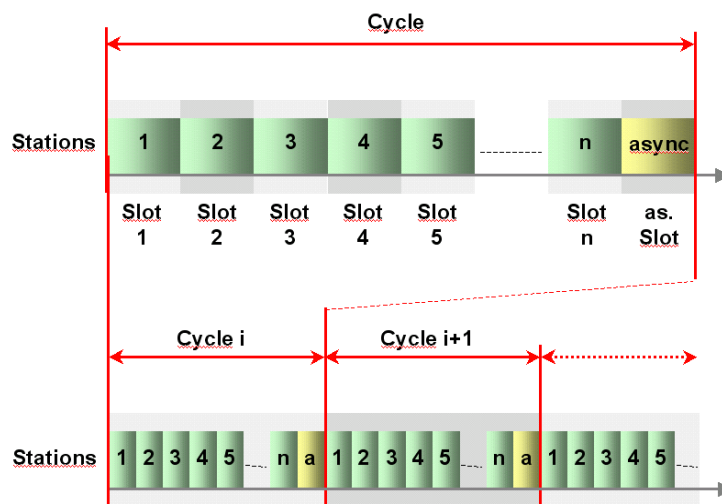


Figure 1—Slot Communication Network Management (SCNM)

4.2 POWERLINK key features

POWERLINK provides the following key features:

- a) Ease-of-use to be handled by typical automation engineers without in-depth Ethernet network knowledge.
- b) Up to 240 networked real-time devices in one network segment
- c) Deterministic communication
 - 1) Down to 100 μ s cycle times
 - 2) Ultra-low jitter (down to <1 μ s) for precise synchronization of networked devices
- d) Standard compliant
 - 1) IEEE 802.3 Fast Ethernet
 - 2) IP based protocols supported (TCP, UDP,...)
 - 3) Integration with CANopen Profiles EN 50325-4 [B5] for device interoperability⁸
 - 4) Implementation based on standard Ethernet Chips—No special ASICs necessary
- e) Direct peer-to-peer communication of all nodes (publish/subscribe)
- f) Hot plugging
- g) Seamless IT-integration—Routing of IP protocols

POWERLINK is based on the ISO/OSI layer model and supports Client/Server and Producer/Consumer communications relationships.

The Ethernet POWERLINK Standardization Group (EPSG) is working closely with the CiA (CAN in Automation) organization to integrate CANopen with POWERLINK. CANopen standards define widely deployed communication profiles, device profiles, and application profiles. These profiles are in use millions of times all over the world. Integration of POWERLINK with CANopen combines profiles, high performance data exchange and open transparent communication with TCP/UDP/IP protocols.

⁸ The numbers in brackets correspond to the numbers in the bibliography in Annex E.

The POWERLINK communication profile is based on CANopen communication profiles DS 301 [B1] and DSP 302 [B3]. Based on this communication profile, the multitude of CANopen device profiles can be used in a POWERLINK environment without changes.

A main focus of POWERLINK is ease of use. Ethernet technology can be quite complex and confusing for machine and plant manufacturers who are not necessarily networking experts. The following features have been implemented:

- Easy wiring, flexible topologies (line structures, tree structures or star structures). The network is adapting to the needs of the machine.
- Utilization of well-known industrial infrastructure components.
- Simple address assignment by switch is possible.
- Easy replacement of devices in case of failure.
- Straightforward network diagnostics.
- Basic security features.
- Simple engineering separated from end user IT infrastructure.
- Easy integration of RTE network with IT infrastructure.

4.3 Integration

The advantages listed previously result from protecting the POWERLINK RTE network segment from regular office and factory networks. This matches typical machine and plant concepts. Hard real time requirements are met within the machine with POWERLINK. Full transparency to the factory network and above is provided, yet protection against hacker attacks on machine level is provided. Modification efforts through machine integration into existing IT infrastructures are reduced. To achieve this, POWERLINK provides a private Class-C IP segment solution with fixed IP addresses. A router establishes the connection to factory floor networks or company networks. NAT mechanisms allow the assignment of any IP address to RTE networked nodes.

RTE based on POWERLINK is ideal to support modern modular machine concepts. Producer/consumer and client/server communication relationships enable centralized master/slave as well as decentral multi-master structures (see Figure 2).

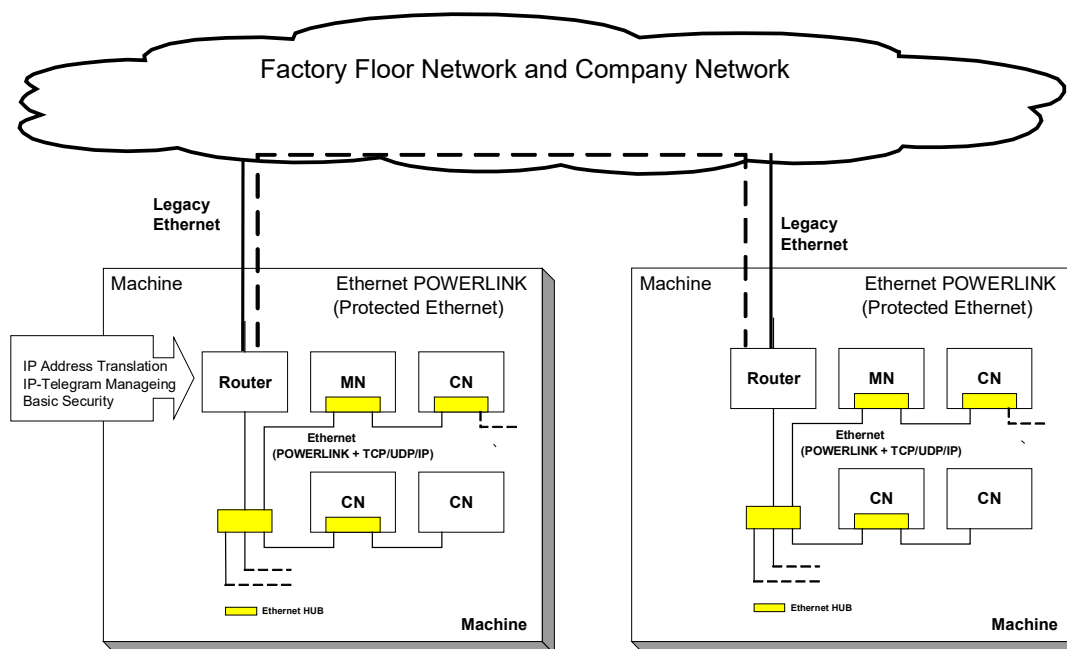


Figure 2—Integration POWERLINK based machines into the IT infrastructure of end customer

4.4 Modular machines

A machine concept with autonomous machine modules is illustrated in Figure 3. Every machine module can be designed separately with its own internal communication relationships. The assembling of the machine can be done in a flexible way by adding additional direct communication relationships between machine modules.

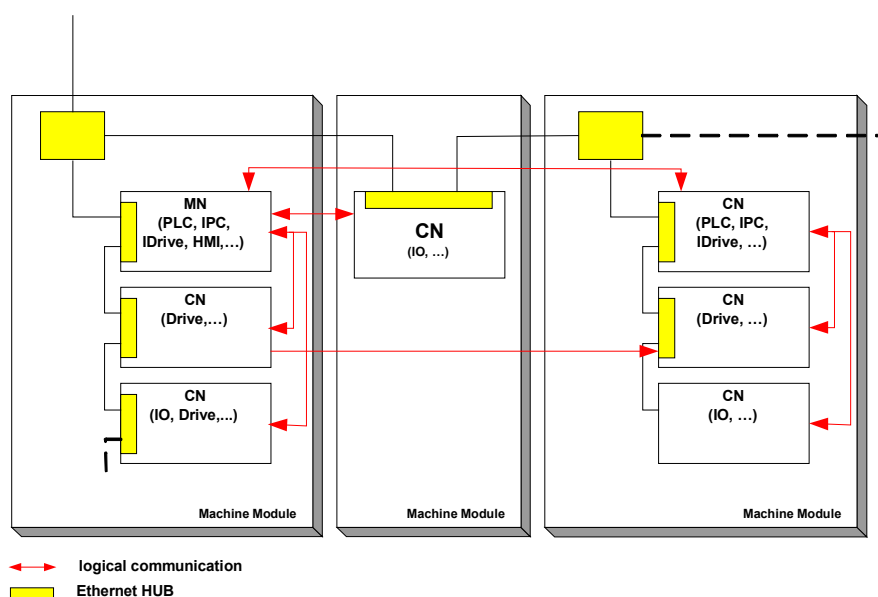


Figure 3—Typical centralized and decentralized controller structures

5. Modelling

POWERLINK-based networks use the reference model, device model, and communication model shown in the 5.1, 5.2, and 5.3.

5.1 Reference model

The communication concept can be described with reference to the ISO-OSI Reference Model (right-hand side of Figure 4).

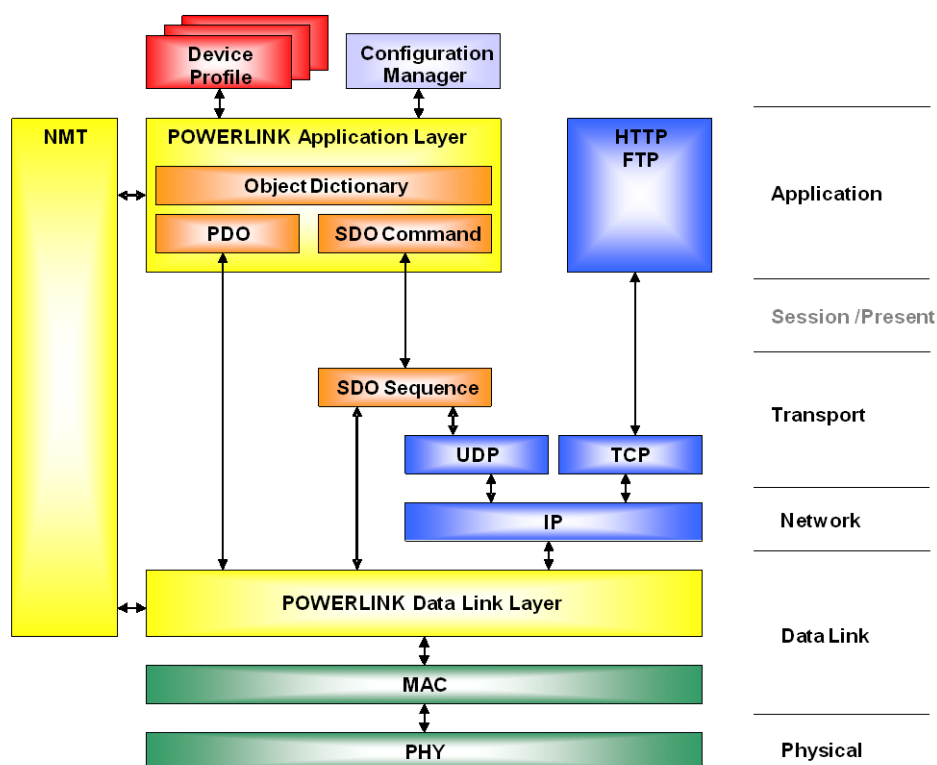


Figure 4—Reference model

5.1.1 Application layer

The application layer comprises a concept to configure and communicate real-time data as well as the mechanisms for synchronization between devices. The functionality the application layer offers to an application is logically divided over different *service data objects* (see SDOs) in the application layer. A service object offers a specific functionality and all related services.

Applications interact by invoking services of a service object in the application layer. To realize these services, the service object exchanges data via the Network with a peer service object(s) via a protocol. This protocol is described in the *Protocol Specification* of that service object.

5.1.1.1 Service primitives

Service primitives are the means by which the application and the application layer interact. There are four different primitives as follows:

- A *request* is issued by the application to the application layer to request a service.
- An *indication* is issued by the application layer to the application to report an internal event detected by the application layer or indicate that a service is requested.
- A *response* is issued by the application to the application layer to respond to a previous received indication.
- A *confirmation* is issued by the application layer to the application to report the result of a previously issued request.

5.1.1.2 Application Layer service types

Application Layer service types are shown in Figure 5.

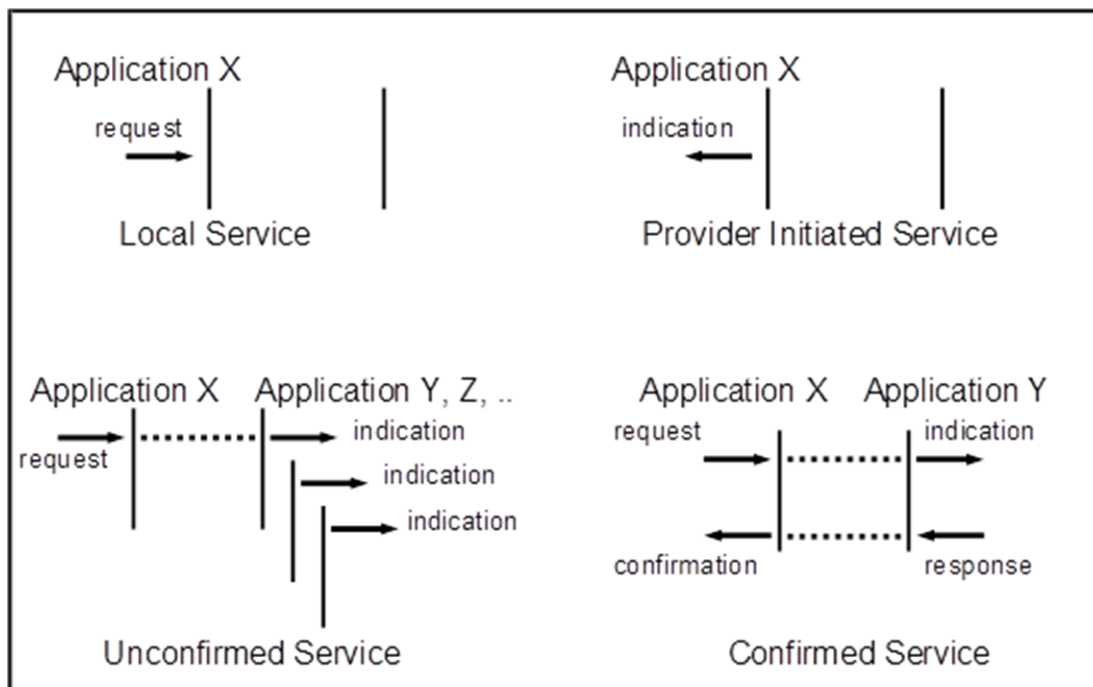


Figure 5—Service types

A *service type* defines the primitives that are exchanged between the application layer and the co-operating applications for a particular service of a service object.

- A *Local Service* involves only the local service object. The application issues a request to its local service object that executes the requested service without communicating with (a) peer service object(s).
- An *Unconfirmed Service* involves one or more peer service objects. The application issues a request to its local service object. This request is transferred to the peer service object(s) that each pass it to their application as an indication. The result is not confirmed back.
- A *Confirmed Service* can involve only one peer service object. The application issues a request to its local service object. This request is transferred to the peer service object that passes it to the

other application as an indication. The other application issues a response that is transferred to the originating service object that passes it as a confirmation to the requesting application.

- A *Provider Initiated Service* involves only the local service object. The service object (being the service provider) detects an event not solicited by a requested service. This event is then indicated to the application.

Unconfirmed and confirmed services are collectively called *Remote Services*.

5.2 Device model

5.2.1 General

A device is structured as follows (see Figure 6):

- *Communication*: This function unit provides the communication objects and the appropriate functionality to transport data items via the underlying network structure.
- *Object Dictionary*: The Object Dictionary is a collection of all the data items that have an influence on the behavior of the application objects, the communication objects and the state machine used on this device.
- *Application*: The application comprises the functionality of the device with respect to the interaction with the process environment.

Thus the Object Dictionary serves as an interface between the communication and the application. The complete description of a device's application with respect to the data items in the Object Dictionary is called the *device profile*.

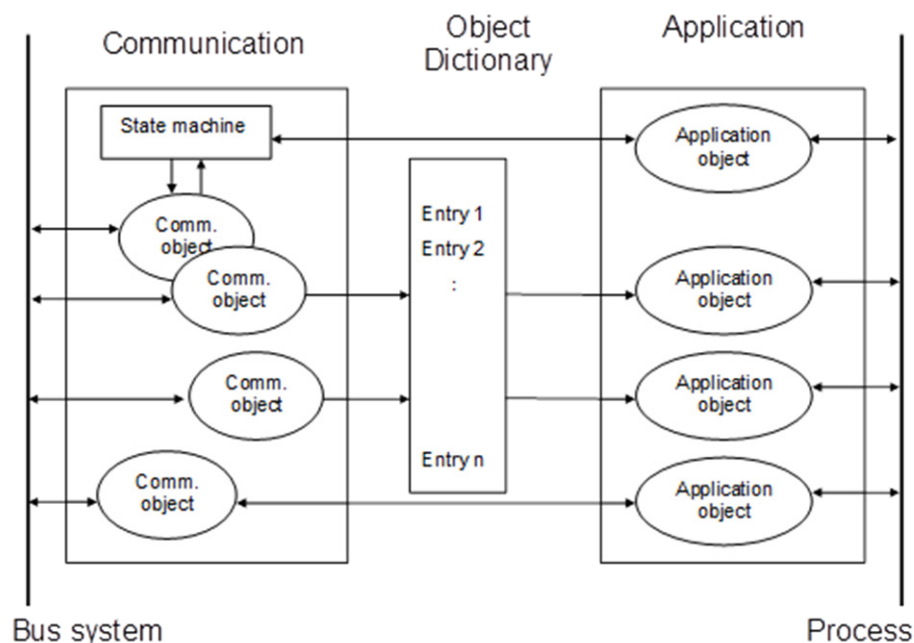


Figure 6—Device model

5.2.2 The Object Dictionary

The most important part of a device profile is the Object Dictionary. The Object Dictionary is essentially a grouping of objects accessible via the network in an ordered, pre-defined fashion. Each object within the dictionary is addressed using a 16-bit index.

The overall layout of the standard Object Dictionary is shown by Table 1. This layout closely conforms to other industrial serial bus system concepts.

The Object Dictionary may contain a maximum of 65 536 entries, which are addressed through a 16-bit index.

The Static Data Types at indices 0001_h through 001F_h contain type definitions for standard data types like BOOLEAN, INTEGER, floating point, string, etc. These entries are included for reference only; they cannot be read or written.

Table 1—Object Dictionary structure

Index	Object
0000 _h	Not used
0001 _h .. 001F _h	Static Data Types
0020 _h .. 003F _h	Complex Data Types
0040 _h .. 005F _h	Manufacturer Specific Complex Data Types
0060 _h .. 007F _h	Device Profile Specific Static Data Types
0080 _h .. 009F _h	Device Profile Specific Complex Data Types
00A0 _h .. 03FF _h	Reserved for further use
0400 _h .. 041F _h	POWERLINK Specific Static Data Types
0420 _h .. 04FF _h	POWERLINK Specific Complex Data Types
0500 _h .. 0FFF _h	Reserved for further use
1000 _h .. 1FFF _h	Communication Profile Area
2000 _h .. 5FFF _h	Manufacturer Specific Profile Area
6000 _h .. 9FFF _h	Standardized Device Profile Area
A000 _h .. BFFF _h	Standardized Interface Profile Area
C000 _h .. FFFF _h	Reserved for further use

Complex Data Types at indices 0020_h through 003F_h are pre-defined structures that are composed of standard data types and are common to all devices.

Manufacturer Specific Complex Data Types at indices 0040_h through 005F_h are structures composed of standard data types but are specific to a particular device.

Device Profiles may define additional data types specific to their device type. The static data types defined by the device profile are listed at indices 0060_h .. 007F_h, the complex data types at indices 0080_h .. 009F_h.

A device may optionally provide the structure of the supported complex data types (indices 0020_h .. 005F_h and 0080_h .. 009F_h) at read access to the corresponding index. Sub-index 0 provides the number of entries at this index, and the following sub-indices contain the data type encoded as UNSIGNED16 according to 9.1.4.5.

POWERLINK Specific Static Data Types shall be described at indices 0400_h .. 041F_h. These entries are included for reference only; they cannot be read or written. POWERLINK Specific Complex Data Types shall be described at indices 0420_h .. 04FF_h.

The Communication Profile Area at indices 1000_h through 1FFF_h contains the communication-specific parameters for the POWERLINK network. These entries are common to all devices.

The standardized device profile area at indices 6000_h through 9FFF_h contains all data objects common to a class of devices that can be read or written via the network. The device profiles may use entries from 6000_h to 9FFF_h to describe the device parameters and the device functionality. Within this range up to eight different devices can be described. In such a case the devices are denominated Multiple Device Modules. Multiple Device Modules are composed of up to eight device profile segments. In this way, it is possible to build devices with multiple functionality. The different device profile entries are indexed at increments of 800_h.

For Multiple Device Modules, the object range 6000_h to 9FFF_h is sub-divided as follows:

- 6000_h to 67FF_h device 0
- 6800_h to 6FFF_h device 1
- 7000_h to 77FF_h device 2
- 7800_h to 7FFF_h device 3
- 8000_h to 87FF_h device 4
- 8800_h to 8FFF_h device 5
- 9000_h to 97FF_h device 6
- 9800_h to 9FFF_h device 7

The Object Dictionary concept caters for optional device features: a manufacturer does not have to provide certain extended functionality on his/her devices but if he/she wishes to do so, it shall be done in a pre-defined fashion.

Space is left in the Object Dictionary at indices 2000_h through 5FFF_h for truly manufacturer-specific functionality.

5.2.2.1 Index and sub-index usage

A 16-bit index is used to address all entries within the Object Dictionary. In the case of a simple variable the index references the value of this variable directly. In the case of records and arrays, however, the index addresses the whole data structure.

To allow individual elements of structures of data to be accessed via the network a sub-index is defined. For single Object Dictionary entries such as an UNSIGNED8, BOOLEAN, or INTEGER32, the value for the sub-index is always zero. For complex Object Dictionary entries such as arrays or records with multiple data fields, the sub-index references fields within a data-structure pointed to by the main index. The fields accessed by the sub-index can be of differing data types.

5.3 Communication model

The communication model specifies the different communication objects and services and the available modes of frame transmission triggering.

The communication model only specifies the POWERLINK-specific communication objects of the POWERLINK Mode and Basic Ethernet Mode (7.2 and 7.3). The mechanism for Legacy Ethernet communication in Basic Ethernet mode is not within the scope of this specification.

The communication model supports the transmission of isochronous and asynchronous frames. Isochronous frames are supported in POWERLINK Mode only, asynchronous frames in POWERLINK Mode and Basic Ethernet Mode.

By means of isochronous frame transmission, a network-wide coordinated data acquisition and actuation are possible. The isochronous transmission of frames is supported by the POWERLINK Mode cycle structure. The system is synchronized by SoC frames. Asynchronous frames may be transmitted in the asynchronous slot of POWERLINK Mode cycle upon transmission grant by the POWERLINK MN, or at any time in Basic Ethernet Mode.

With respect to their functionality, the following three types of communication relationships are distinguished:

- Master/slave relationship (Figure 7 and Figure 8).
- Client/server relationship (Figure 9).
- Producer/consumer relationship (Figure 10 and Figure 11).

5.3.1 Master/slave relationship

Master/slave communication is illustrated in Figure 7 and Figure 8.

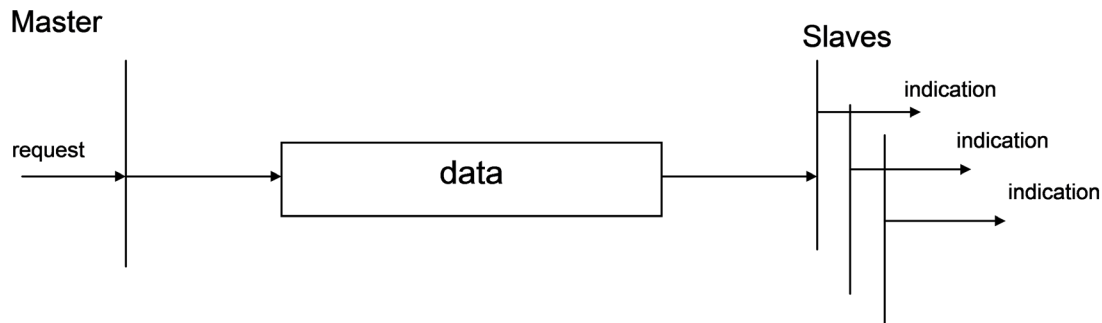


Figure 7—Unconfirmed master/slave communication

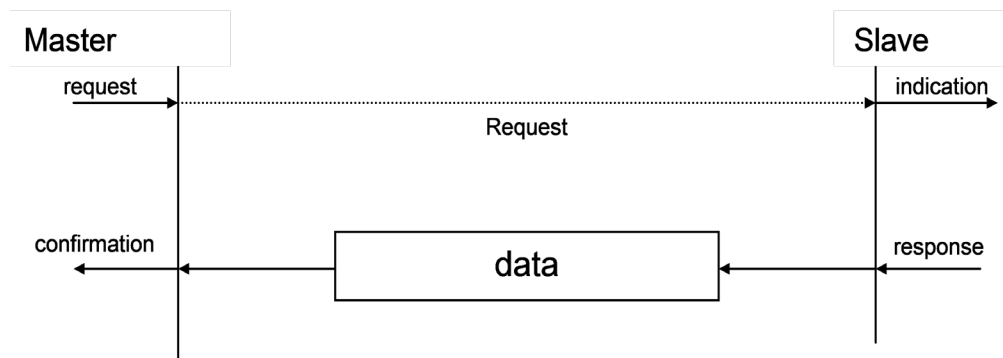


Figure 8—Confirmed master/slave communication

At any time there is exactly one device in the network serving as a master for a specific functionality. All other devices in the network are considered as slaves. The master issues a request, and the addressed slave(s) respond(s) if the protocol requires this behavior.

5.3.2 Client/server relationship

This is a relationship between a single client and a single server. A client issues a request (upload/download) thus triggering the server to perform a certain task. After finishing the task the server answers the request.

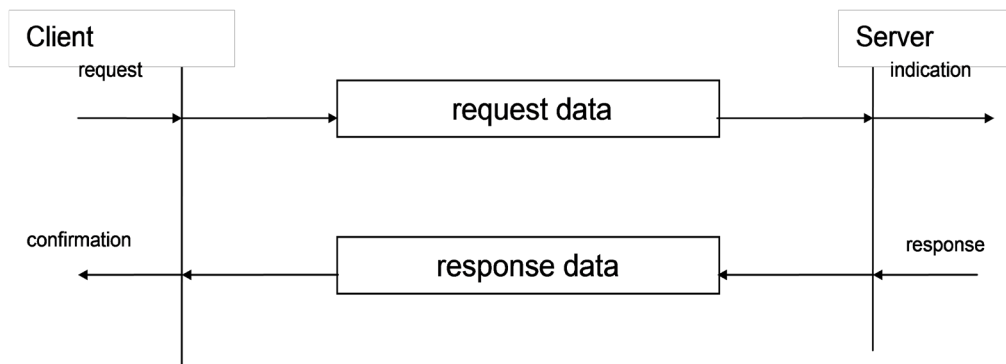


Figure 9—Client/server communication

5.3.3 Producer/consumer relationship—Push/pull model

The producer/consumer relationship model involves a producer and zero or more consumer(s). The push model is characterized by an unconfirmed service requested by the producer. The pull model is characterized by a confirmed service requested by the consumer.

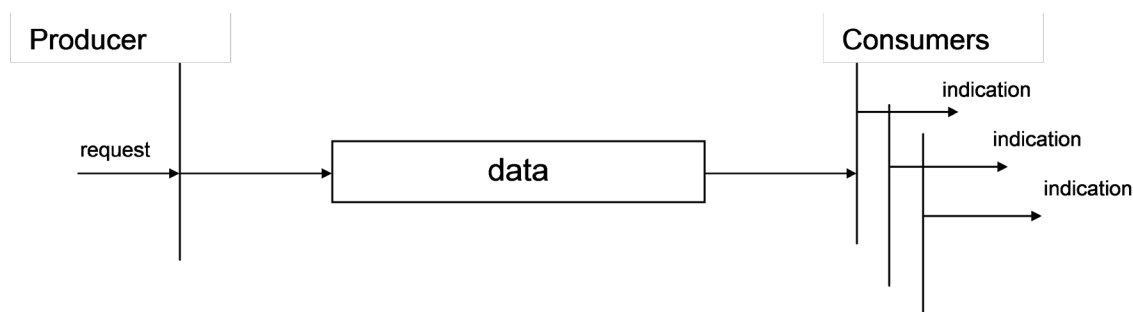


Figure 10— Push model

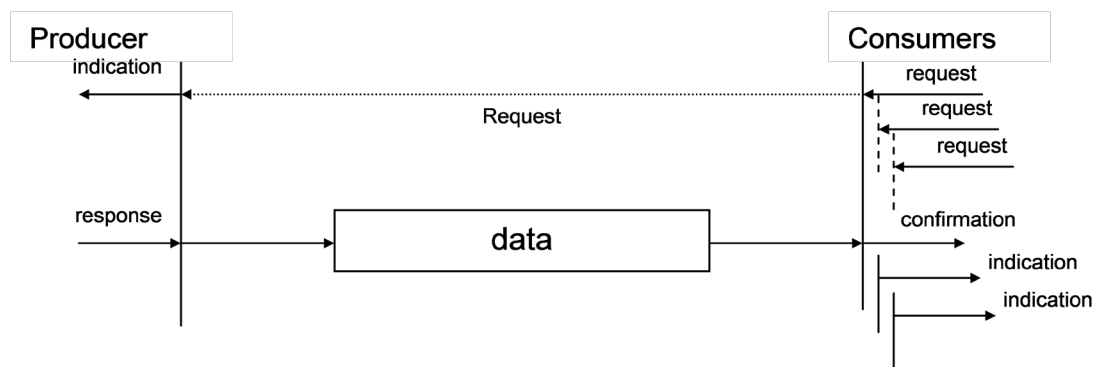


Figure 11— Pull model

5.3.4 Superimposing of communication relationships

POWERLINK collects more than one function into one frame (refer to 7.6). It is therefore not usually possible to apply a single communication relationship to the complete frame, but only to particular services inside the frame.

The PollResponse frame for example (refer to 7.6.1.1.4) transmitted by the CN includes several services:

- Transmission of the current NMT status of the CN is the response part of a confirmed master/slave relationship triggered by the MN.
- Request of the asynchronous slot is the request part of a client/server relationship.
- Transmission of PDO data occurs in conformance to a push model Producer/Consumer relationship.

6. Physical Layer

POWERLINK is a protocol residing on top of the standard IEEE 802.3 MAC layer. The physical layer is 100BASE-X (copper and fiber; see IEEE Std 802.3). Half-Duplex transmission mode shall be used.

Autonegotiation is not recommended.

POWERLINK uses Ethernet as it is, without any modifications. Hence, any advancement in Ethernet technology can be exploited (e.g., Gigabit Ethernet).

NOTE—The following subclauses describe physical layers based on twisted pair Ethernet copper cables that use no more than two pairs, e.g., 100BASE-TX. For available fiber specifications, refer to IEC 61918 and IEC 61784-5-13 [B15]. In principle any physical layer can be utilized, but due to lack of prevalence in the industrial market other physical layers are out of scope of this standard.

6.1 Topology

6.1.1 Hubs

To fit POWERLINK jitter requirements, it is recommended to use hubs to build a POWERLINK network. Class II Repeaters shall be used in this case (see 1.4.132 in IEEE Std 802.3).

Hubs have the advantage of reduced path delay value (indicated by D_PHY_HubDelay_U32) and have small frame jitter (indicated by D_PHY_HubJitter_U32).

Hubs may be integrated in the POWERLINK interface cards.

Hub integration shall be indicated by D_PHY_HubIntegrated_BOOL. The number of externally accessible POWERLINK ports provided by a device shall be indicated by D_PHY_ExtEPLPorts_U8.

6.1.2 Switches

Switches may be used to build a POWERLINK network. The additional latency and jitter of switches has to be considered for system configuration.

It has to be considered that any POWERLINK network constructed with anything but Class II Repeater Devices does not conform to the POWERLINK standard as defined in this document.

6.2 Network guidelines

POWERLINK does not cause collisions. This is why the most extreme topology guideline of IEEE Std 802.3 (5120 ns maximum round trip signal runtime) does not apply.

Due to this leniency in the topology, line structures that are required in field applications are made possible. Nodes may use integrated hubs, further simplifying construction in the field. A mixed tree and line structure is available when a large number of nodes are being used. See Figure 12.

Fiber optic transducers may be used. However, they should be tested to establish whether they cause more jitter and latency than normal hubs. When designing the network infrastructure, some timing constraints shall be considered. The MN uses a timeout after sending a PollRequest frame to detect transmission errors and node failures. The round trip latency between the MN and a CN shall not exceed the timeout value. The timeout value can be set for every single node.

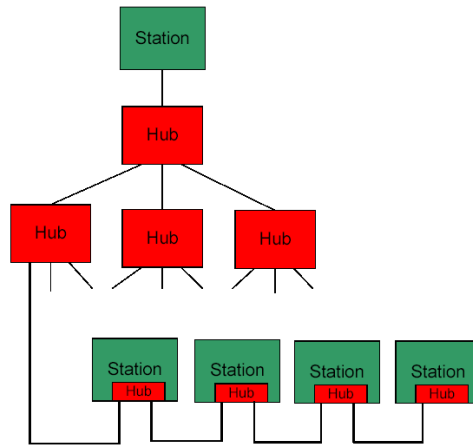


Figure 12—Star topology and line topology

6.2.1 Jitter

Every hub level introduces additional Jitter (equal or below 70 ns). Only the number of hub levels between MN and farthest CN is relevant. If the MN is located in the center of line or a star topology, the number of hub level between the farthest CNs is irrelevant for synchronization jitter.

6.3 Ports and connectors

To connect POWERLINK devices one of the following two types of connectors shall be used:

- a) RJ-45: for light duty environments.
- b) M12: for heavy duty environments.

Both types may be mixed on the same cable.

For further information, refer to IEC 61918 and IEC 61784-5-13 [B15].

6.3.1 RJ-45

Pin assignment as defined by T568B in EIA/TIA T568 [B5].

Figure 13 is provided for convenience; refer to the corresponding international standard.

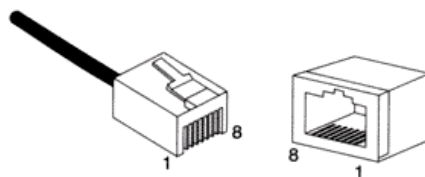


Figure 13—RJ45 pin assignment (left: connector, right: port)

The picture shows an RJ45 connector on the cable and a port (on the device or hub).

The pin assignment on each node shall be that of a hub/switch port. Therefore, the port pins are assigned as shown in Table 2.

Table 2—Pin assignment RJ45 port

Pin	Wire color code	Assignment 100BASE-TX
1	WHT/ORG	Rx+
2	ORG	Rx−
3	WHT/GRN	Tx+
4	BLU	
5	WHT/BLU	
6	GRN	Tx−
7	WHT/BRN	
8	BRN	

6.3.2 M12

For IP67 requirements, four-pin D-coded is recommended in IEC 61076-2-101 [B13].

Male side is fitted on the cable; female is fitted on the device or hub.

Figure 14 is provided for convenience; refer to the corresponding international standard.

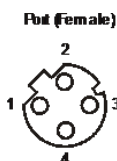


Figure 14—IP67 port pin assignment

The port pins are assigned as shown in Table 3.

Table 3—Pin assignment IP67 port

Pin	Wire color code	Assignment 100BASE-TX
1	BLU/YEL	Tx+
2	YEL/WHT	Rx+
3	WHT/ORG	Tx−
4	ORG/BLU	Rx−

6.3.3 Crossover pin assignment

The pin assignment shall be that of a crossover cable configuration.

Therefore, all devices can be interconnected by one type of cable. The pin assignment of a crossover cable is defined as follows:

- Tx+ to Rx+
- Tx− to Rx−
- Rx+ to Tx+
- Rx− to Tx−

6.3.3.1 RJ45 to RJ45

Figure 15 and Figure 16 illustrate recommended and not recommended pin assignments.

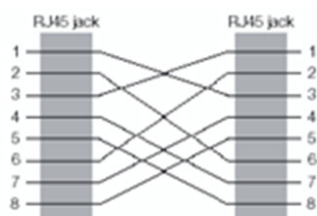


Figure 15— Recommended RJ45 to RJ45 pin assignment

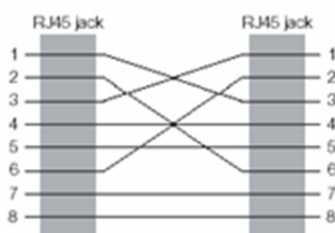


Figure 16— Not recommended RJ45 to RJ45 pin assignment

6.3.3.2 M12 to M12

Figure 17 shows M12 to M12 pin assignment.

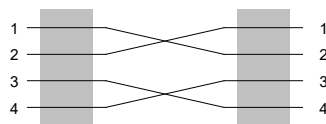


Figure 17 — M12 to M12 pin assignment

6.3.3.3 M12 to RJ45

Figure 18 shows M12 to RJ45 pin assignment.

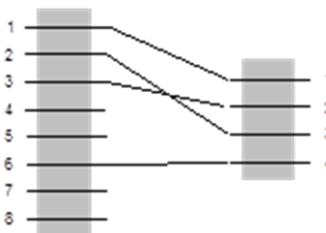


Figure 18 — M12 to RJ45 pin assignment

6.4 Cables (recommendation)

Refer to IEC 61918 and IEC 61784-5-13 [B15].

The following is provided for convenience; refer to the corresponding international standards.

To increase noise immunity only S/FTP or SF/FTP cables should be used (Cat5). The maximum cable length (100 m) predefined by Ethernet 100Base-TX shall apply.

The pin assignment shall be that of a crossover cable configuration.

Regarding wiring and EMC measures, IEC 61918 and IEC 61784-5-13 [B15] shall be considered.

7. Data link layer

7.1 Modes of operation

Two operating modes are defined for POWERLINK networks:

- *POWERLINK mode*: In POWERLINK Mode network traffic follows the set of rules given in this standard for Real-time Ethernet communication. Network access is managed by a master, the POWERLINK managing node (MN). A node can only be granted the right to send data on the network via the MN. The central access rules preclude collisions, the network is therefore

deterministic in POWERLINK Mode.

In POWERLINK Mode most communication transactions are via POWERLINK-specific messages. An asynchronous slot is available for non-POWERLINK frames. UDP/IP is the preferred data exchange mechanism in the asynchronous slot; however, it is possible to use any protocol.

- *Basic Ethernet mode:* In Basic Ethernet Mode network communication follows the rules of legacy Ethernet (IEEE Std 802.3). Network access is via CSMA/CD. Collisions occur, and network traffic is non-deterministic.

Any protocol on top of Ethernet may be used in Basic Ethernet mode; the preferred mechanisms for data exchange between nodes being UDP/IP and TCP/IP.

7.2 POWERLINK mode

7.2.1 Introduction

POWERLINK Mode is based on the standard Ethernet CSMA/CD technique (IEEE Std 802.3) and thus works on all legacy Ethernet hardware.

Determinism is achieved with a pre-planned and organized message exchange where messages are grouped in cycles that are subdivided into the isochronous phase and the asynchronous phase.

Each node gets permission for sending its own frames by the POWERLINK MN. Therefore, no collisions should occur, and the collision-resolving retransmission of messages defined by IEEE Std 802.3, which is responsible for the non-deterministic behavior of legacy Ethernet, is not used.

7.2.2 POWERLINK nodes

The node managing the permission to send messages to the Ethernet is called the POWERLINK managing node (MN).

All other nodes transmit only within communication slots assigned by the MN. They are thus called controlled nodes (CNs).

7.2.2.1 POWERLINK MN

Only the MN may send messages independently, i.e., not as a response to a received message. Controlled nodes shall be only allowed to send when requested to by the MN.

The Controlled nodes shall be accessed cyclically by the MN. Unicast data shall be sent from the MN to each configured CN (frame: PReq), which shall then publish its data via multicast to all other nodes (frame: PRes).

Optionally, the last frame in the isochronous phase may be a multicast PRes frame of the MN (see Figure 19). With this frame the MN may publish its own data to all other nodes.

All available nodes in the network shall be configured on the MN.

Only one active MN is permitted in a POWERLINK network.

The ability of a node to perform MN functions shall be indicated by the device description entry `D_DLL_FeatureMN_BOOL`.

7.2.2.2 POWERLINK CN

CNs shall be passive bus nodes. They shall only send when requested by the MN.

The ability of a node to perform CN functions shall be indicated by the device description entry `D_DLL_FeatureCN_BOOL`.

7.2.2.2.1 Isochronous CN

Each isochronous CN shall receive a unicast PReq frame from the MN in the POWERLINK cycle and shall send back a PRes frame to the MN. PReq and PRes frames may transport isochronous data.

CNs may be accessed every cycle or every n^{th} cycle (multiplexed nodes, $n > 1$).

PReq can only be received by the specifically addressed CN. However, PRes frames shall be sent by the CN as multicast messages, allowing all other CNs to monitor the data being sent.

Additional data from the MN may be received by a multicast PRes message transmitted by the MN.

Isochronous CNs shall request the right to transmit asynchronous data from the MN, if required.

The ability of a CN to perform isochronous communication shall be indicated by a feature flag in the Object Dictionary entry `NMT_FeatureFlags_U32` (1F82_h) and the device description entry `D_NMT_Isochronous_BOOL`.

No POWERLINK CN device shall rely on being polled as isochronous CN, when the network performs the isochronous POWERLINK cycle (7.2.4.1), async-only CN type communication shall be supported. Application level function limitations may occur when a device enabled to perform isochronous functions is operated in async-only mode.

7.2.2.2.2 Async-only CN

CNs may be operated in such a way that they are not accessed cyclically in the isochronous phase by the MN.

The MN shall cyclically poll each async-only CN during the asynchronous phase with a StatusRequest—a special form of the SoA frame. The CN shall respond with a StatusResponse, special form of Asynchronous Send frame. The poll interval shall be at least `C_NMT_STATREQ_CYCLE`. It is affected by the asynchronous scheduling and is thus non-deterministic.

Async-only CNs shall request the right to transmit asynchronous data from the MN, if required.

Async-only CNs shall actively communicate during the asynchronous phase only. Nevertheless, they may listen to the multicast network traffic, transmitted by the MN and the isochronous CNs.

7.2.3 Services

POWERLINK provides the following three services:

- *Isochronous Data Transfer*: One pair of messages per node shall be delivered every cycle, or every n^{th} cycle in the case of multiplexed CNs.

Additionally, there may be one multicast PRes message from the MN per cycle. Isochronous data transfer is typically used for the exchange of time critical data (real-time data).

- *Asynchronous Data Transfer*: There may be one asynchronous message per cycle. The right to send shall be assigned to a requesting node by the MN via the SoA message.

Asynchronous data transfer is used for the exchange of non time-critical data.

- *Synchronization of all nodes*: At the beginning of each isochronous phase, the MN transmits the multicast SoC message very precisely to synchronize all nodes in the network.

7.2.4 POWERLINK cycle

The POWERLINK cycle shall be controlled by the MN.

7.2.4.1 Isochronous POWERLINK cycle

Isochronous data exchange between nodes shall occur cyclically. It shall be repeated in a fixed interval, called POWERLINK cycle (see Figure 19).

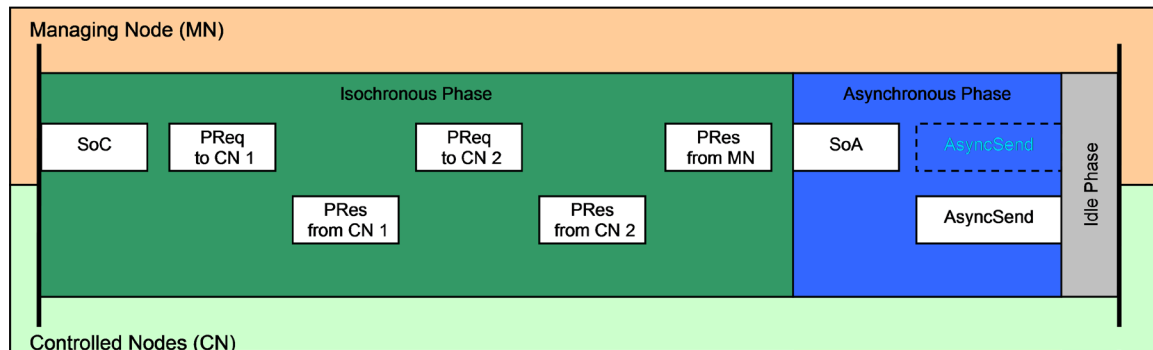


Figure 19 — POWERLINK cycle

The following time phases exist within one cycle:

- Isochronous phase (see Figure 20)
- Asynchronous phase
- Idle phase

It is important to keep the start time of a POWERLINK cycle as exact (jitter-free) as possible. The length of individual phases can vary within the preset phase of a POWERLINK cycle.

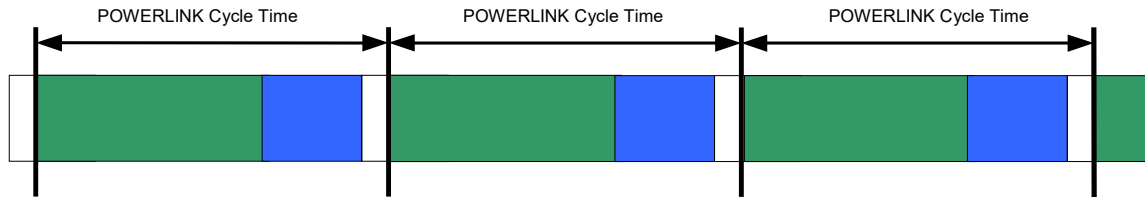


Figure 20 — POWERLINK—an isochronous process

The network shall be configured in a way that the preset cycle time is not exceeded. Adherence to the cycle time shall be monitored by the MN.

All data transfers shall be unconfirmed; i.e., there is no confirmation that sent data has been received. To maintain deterministic behavior, protecting the isochronous data (PReq and PRes) is neither necessary nor desired. Asynchronous data may be protected by higher protocol layers.

7.2.4.1.1 Isochronous phase

At the beginning of a POWERLINK cycle, the MN shall send a SoC frame to all nodes via Ethernet multicast. The send and receive time of this frame shall be the basis for the common timing of all the nodes.

Only the SoC frame shall be generated on a periodic basis. The generation of all other frames shall be event controlled (with additional time monitoring per node).

The MN shall start the isochronous data exchange after the SoC frame has been sent.

A PReq frame shall be sent to every configured and active node. The accessed node shall respond by a PRes frame.

PReq shall be an Ethernet unicast frame. It is received by the target node only. PRes shall be sent as an Ethernet multicast frame.

Both the PReq and the PRes frames may transfer application data. The MN only sends PReq data to one CN per frame. PReq transfer is dedicated to data relevant for the addressed CN only.

In contrast, the PRes frame may be received by all nodes. This makes communication relationships possible according to the producer/consumer model.

The PReq/Pres procedure shall be repeated for each configured and active isochronous CN.

The MN may send a multicast PRes frame to all nodes. This frame is dedicated to transfer data relevant for groups of CNs.

Support of PRes transmission by the MN is optional. The ability of an MN to transmit PRes shall be indicated by the device description entry `D_DLL_MNFeaturePresTx_BOOL`. If the feature is provided, transmission shall be enabled by `NMT_NodeAssignment_AU32[C_ADR_MN_DEF_NODE_ID].Bit 12`.

The isochronous phase shall be calculated from start of SoC to start of SoA.

The size of the POWERLINK cycle is predominantly affected by the size of the isochronous phase. When configuring the POWERLINK cycle, the sum of the times required by the PReq/Pres accesses to each configured CN shall be taken into account; i.e., the time needed to access all configured nodes in one cycle

has to be accounted for. Use of the multiplexed access technology (7.2.4.1.1.1) may reduce the amount of time.

When operating the isochronous phase, the length of this phase may vary according to the number of active CNs.

The order in which CNs are polled may be implementation specific or controlled by object NMT_IsochrSlotAssign_AU8 if supported by the MN. An implementation should pack the performed PReq/PRes packages to the beginning of the isochronous phase. It should provide means to rearrange the poll order, to avoid location of the nodes having the worst SoC latency time value (D_NMT_CNSoC2PReq_U32) at the slot following SoC.

Isochronous phases may be counted by the device. If implemented, counting shall be performed on base of transmitted or received SoC frames. The counter value may be accessed via DIA_NMTTelegrCount_REC.IsochrCyc_U32.

7.2.4.1.1.1 Multiplexed timeslots

POWERLINK supports CN communication classes that determine the cycles in which nodes are to be addressed.

- *Continuous*: Continuous data shall be exchanged in every POWERLINK cycle.
- *Multiplexed*: Multiplexed data to and from one CN shall not be exchanged in every POWERLINK cycle.

The accesses to the multiplexed CNs shall be dispersed to the multiplexed cycle that consists of a number of POWERLINK cycles. See Figure 21.

The dispersion allows the isochronous access to a large number of CNs without elongating the POWERLINK cycle to an unacceptable amount. However, multiplexed CN access reduces the poll frequency to the particular CN.

The configuration of the multiplexed cycle is shown in 7.2.4.4.

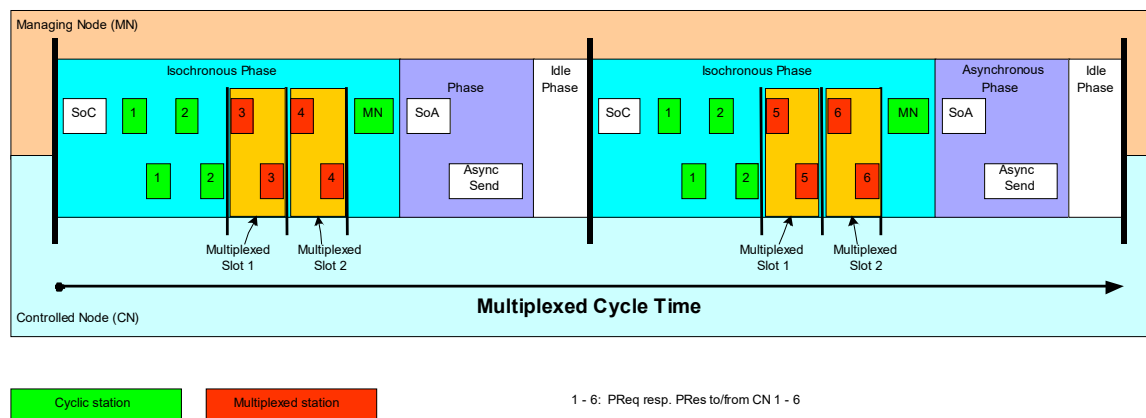


Figure 21 — Multiplexed POWERLINK cycle

Continuous and multiplexed access may be operated in parallel during one POWERLINK cycle. The apportionment of the isochronous phase to continuous and multiplexed slots shall be fixed by configuration (NMT_MultiCycleAssign_AU8, NMT_IsochrSlotAssign_AU8).

Although the multiplexed nodes are not processed in each cycle, they can monitor the entire data transfer of the continuous nodes because all PRes frames are sent as multicast frames.

For example, in Motion Control, multiplexed timeslots can be used for a large number of slave axes to receive position data from few master axes. The master axes are configured to communicate continuously, accesses to the slave axes multiplexed. In this way, the master axes transmit their data to the (monitoring) slave axes in each cycle, while the slave axes also take part in the communication in a slower cycle.

The size of each particular multiplexed slot shall be equal to the maximum time necessary for the PReq/Pres access of the CN assigned to the slot.

For MN cycle loss, the multiplexed access sequence shall be continued on a per time base, after the cycle loss error phase is over. For example, CNs shall be skipped to maintain time equidistance of access to nodes not affected by the cycle loss.

The ability of an MN enabled node to perform control of multiplexed isochronous operation shall be indicated by the device description entry D_DLL_MNFeatureMultiplex_BOOL. The ability of a CN enabled node to be isochronously accessed in a multiplexed way shall be indicated by the device description entry D_DLL_CNFeatureMultiplex_BOOL.

7.2.4.1.2 Asynchronous phase

In the asynchronous phase of the cycle, access to the POWERLINK network may be granted to one CN or to the MN for the transfer of a single asynchronous message only.

There shall be two types of asynchronous frames available:

- The POWERLINK ASnd frame shall use the POWERLINK addressing scheme and shall be sent via unicast or broadcast to any other node.
- A legacy Ethernet message may be sent.

If no asynchronous message transmission request is pending at the MN scheduling queues (7.2.4.1.2.1), the MN shall issue a SoA without assignment of the right to send to any node. No ASnd frame will follow to the SoA frame in this case.

The MN shall start the asynchronous phase with the SoA. The SoA shall be used to identify CNs, request status information of a CN, poll async-only CNs, and grant the asynchronous transmit right to one CN.

The SoA frame is the first frame in the asynchronous phase and is a signal to all CNs that all isochronous data have been exchanged during the isochronous phase.

The asynchronous phase shall be calculated from the start of SoA to the end of the asynchronous response. If no asynchronous response is allowed for any node, the asynchronous phase shall be terminated by the end of SoA.

This definition is valid from the network's point view. It may be different from the node's application point of view. Due to the ASend addressing scheme, the asynchronous phase may be terminated by the end of SoA on those nodes not being addressed, whereas it ends at the end of the asynchronous response on the addressed nodes.

Asynchronous frames may be counted by the device. If implemented,

- Received frames shall be indicated by DIA_NMTTelegrCount_REC.AsyncRx_U32.
- Transmitted frames shall be indicated by DIA_NMTTelegrCount_REC.AsyncTx_U32.

7.2.4.1.2.1 Asynchronous scheduling

The MN handles scheduling of all asynchronous data transfers. See Figure 22.

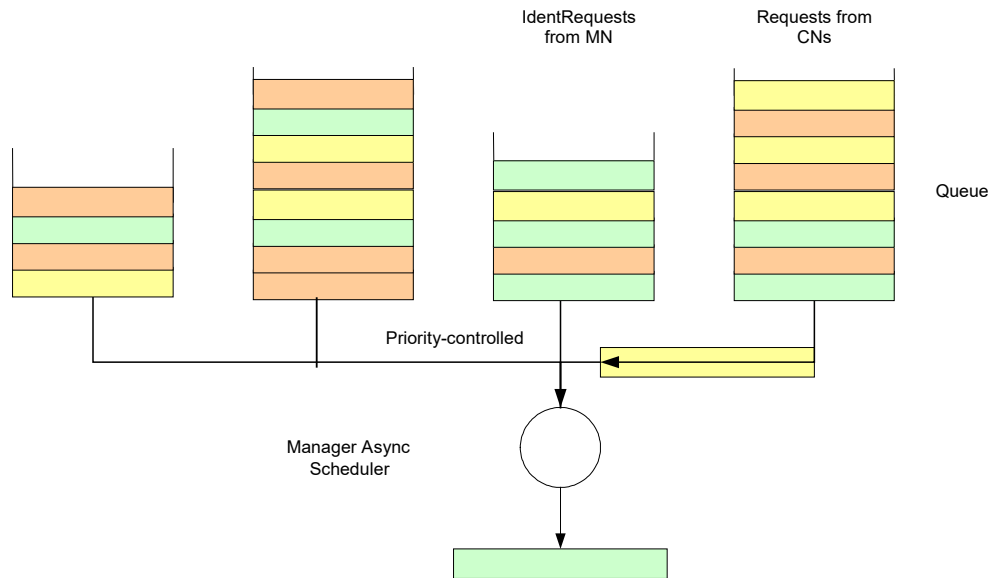


Figure 22 — Asynchronous scheduling

If a CN wants to send an asynchronous frame, it shall inform the MN via the PRes or the StatusResponse frame.

The asynchronous scheduler of the MN shall determine in which cycle the right to send the asynchronous frame will be granted. It shall compute it in a way that no send request will be delayed for an indefinite amount of time, even if network load is high.

The MN shall select a node from all queued send requests (including its own). It shall send a SoA frame with a Requested Service Target identifying which node is allowed to send an asynchronous frame.

The MN shall manage the dispatching of the asynchronous phase using different queues:

- Generic transmit requests from the MN
- IdentRequest frames from the MN to identify CNs
- StatusRequest frames to poll CNs
- Transmit requests from the CNs

7.2.4.1.2.2 Distribution of the asynchronous phase

With the PRes, IdentResponse or StatusResponse RS flag (3 bits; see 7.6.1.1.4, 10.3.3.2.1, 10.3.3.3.1) the CN shall indicate the number of send-ready packages in its queues.

An RS value of 0 (000_b) shall indicate that the queues are empty, and an RS value of 7 (111_b) shall indicate that seven or more packages are queued.

The assignment of the asynchronous phase shall decrement the MN-administered number of frames requested by the respective CN. If the MN queue length reached zero, no more further asynchronous phases are assigned.

The algorithm that is used to assign the asynchronous phase when there are multiple requests pending shall be manufacturer specific.

7.2.4.1.2.3 Asynchronous Transmit Priorities

Asynchronous transmit requests may be prioritized by 3 PR bits in the PRes, the IdentResponse, and StatusResponse frame (see 7.6.1.1.4, 10.3.3.2.1, 10.3.3.3.1).

POWERLINK supports eight priority levels. Two of these levels are dedicated to POWERLINK purpose:

- PRIO_NMT_REQUEST: This is the highest priority that shall be exclusively applied if a CN requests an NMT command to be issued by the MN
- PRIO_GENERIC_REQUEST: Medium priority that is the standard priority level for non-NMT command requests. SDO via asynchronous communication (see 9.3.2) requests shall apply this priority level. Application requests may apply PRIO_GENERIC_REQUEST

The remaining priority levels above and below PRIO_GENERIC_REQUEST are available for application purpose.

Requests with the high priority level shall be preferentially assigned by the MN compared to those with low priority numeric value.

Requests of different priorities shall be handled by independent priority-specific queues on the CN.

The PRes PR flags shall indicate the highest priority level containing pending requests. The RS flags shall indicate the number of pending requests at the reported priority level. Lower priority request indication shall be suspended until all high priority requests have been assigned.

Figure 23 shows an example of priority-related asynchronous request handling.

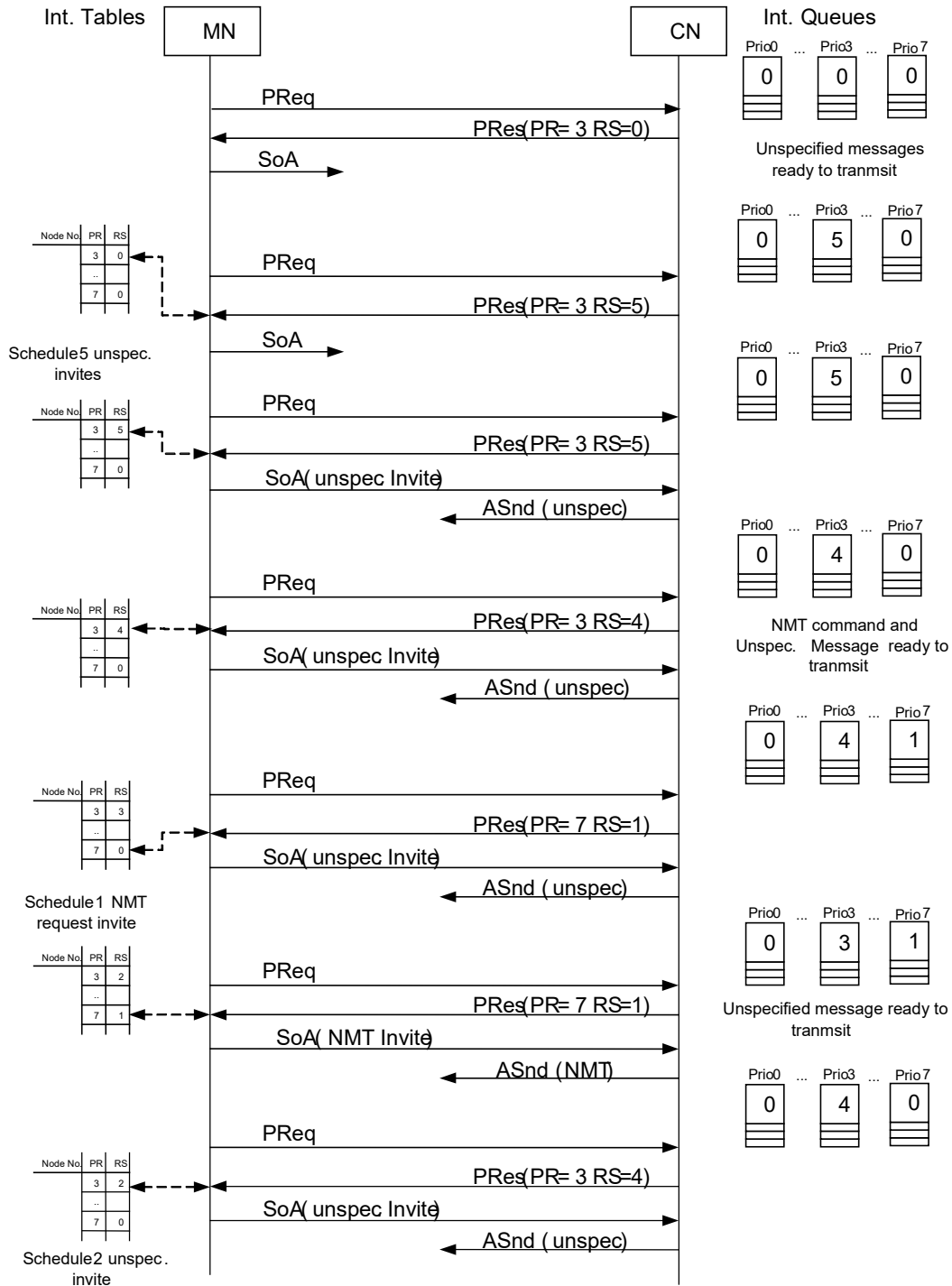


Figure 23— Asynchronous transmit priority handling
(Priority level PR: 7 = PRIO_NMT_REQUEST, 3 = PRIO_GENERIC_REQUEST)

7.2.4.1.3 Idle Phase

The Idle Phase is the remaining time interval between the end of the asynchronous phase and the beginning of the next cycle.

During the Idle Phase, all network components shall “wait” for the beginning of the following cycle. The duration of the Idle Phase may be 0; i.e., an implementation shall not rely on an existing or fixed Idle Phase.

The idle phase shall be calculated from end of SoA or ASnd (see 7.2.4.1.2) to start of SoC.

7.2.4.2 Reduced POWERLINK cycle

During system start-up (NMT state NMT_MS_PRE_OPERATIONAL_1), a reduced POWERLINK cycle shall be applied to diminish network load, while the system is being configured via SDO communication.

The Reduced POWERLINK cycle shall consist of queued asynchronous phases only. The duration of the asynchronous phase and thus the duration of the Reduced POWERLINK cycle may vary from one cycle to the next.

If a CN is assigned to send and there is no information about the length of the expected AsyncSend frame available at the MN, the next Reduced POWERLINK cycle shall not start until at least the timeout given by the length of a maximum size Ethernet frame NMT_CycleTiming_REC.AsyncMTU_U16) plus the maximum response time to the SoA invite message required by the CNs (NMT_CycleTiming_REC.ASndMaxLatency_U32) elapsed.

If the MN is aware of the AsyncSend length information, i.e., if the MN assigns the Asynchronous Slot to itself or if the MN is the target node of the asynchronous message, it may reduce the Reduce POWERLINK cycle length (Figure 24).

If there is no assignment to any node (MN included), the next Reduced POWERLINK cycle may follow without any timeout.

The assignment mechanism used for the asynchronous phase of the isochronous POWERLINK cycle (7.2.4.1.2) shall also be applied to the Reduced POWERLINK cycle.

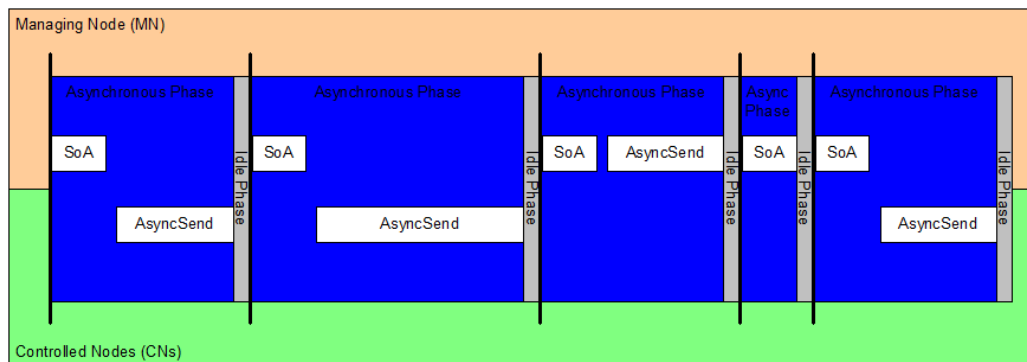


Figure 24 — Reduced POWERLINK cycle

The Reduced POWERLINK cycle shall be robust to collisions. Collisions shall be resolved by CSMA/CD. In case of collision, the next Reduced POWERLINK cycle shall start after a timeout given by the double length of a maximum size Ethernet frame (1518 bytes).

7.2.4.3 POWERLINK cycle timing

Figure 25, Figure 26, and Figure 27 show the timing of the isochronous POWERLINK cycle. The figures show a system of three nodes. The MN is physically located between two isochronously accessed CNs.

The figures are a schematic approach. They are valid for the NMT states NMT_MS_READY_TO_OPERATE and NMT_MS_OPERATIONAL or states NMT_CS_READY_TO_OPERATE and NMT_CS_OPERATIONAL. The amount of time shown does not reflect the realistic timing relationships of a real system.

Figure 25 shows the typical sequence of messages in the isochronous phase. The PRes frames from one CN are received by the other CN (cross traffic). Figure 26 depicts the timing of a transmission of an asynchronous frame by a CN, and Figure 27 shows the less critical case of asynchronous transmission by the MN.

Table 4 provides the description of the timing parameters introduced by the figures, the source of the data, special handling of the data, and Object Dictionary entries containing the parameters.

The node located verifications proposed by Table 4 are optional on the node if not mentioned otherwise. A POWERLINK network configuration tool shall perform all the verifications during configuration process.

NOTE—The timing parameters introduced by this subclause allow a sophisticated fine tuning of the cycle timing, required by notably cycle time sensitive high-end applications. The majority of applications will apply default values for most of the parameters. Only a few variables will remain to be set up to configure a typical POWERLINK network.

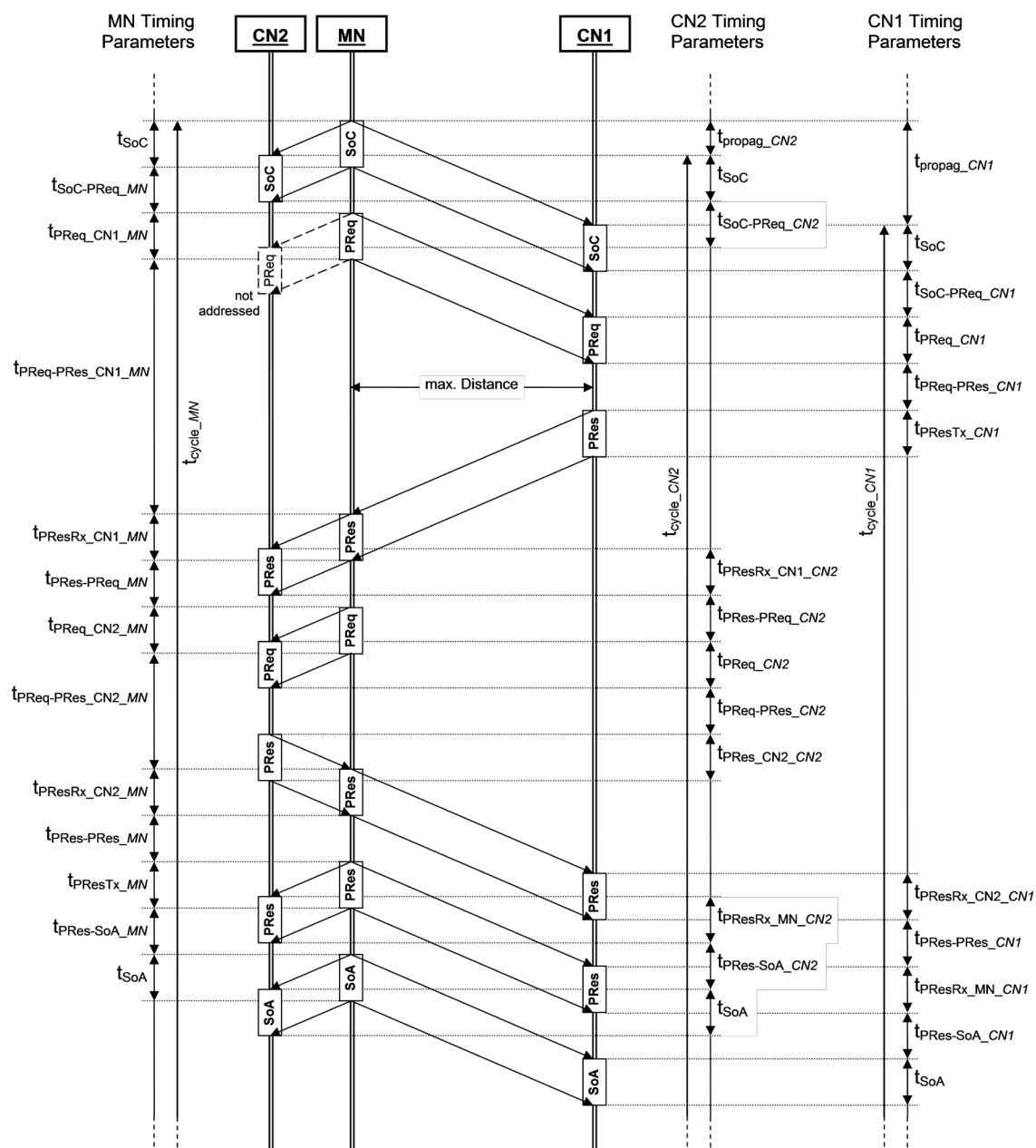
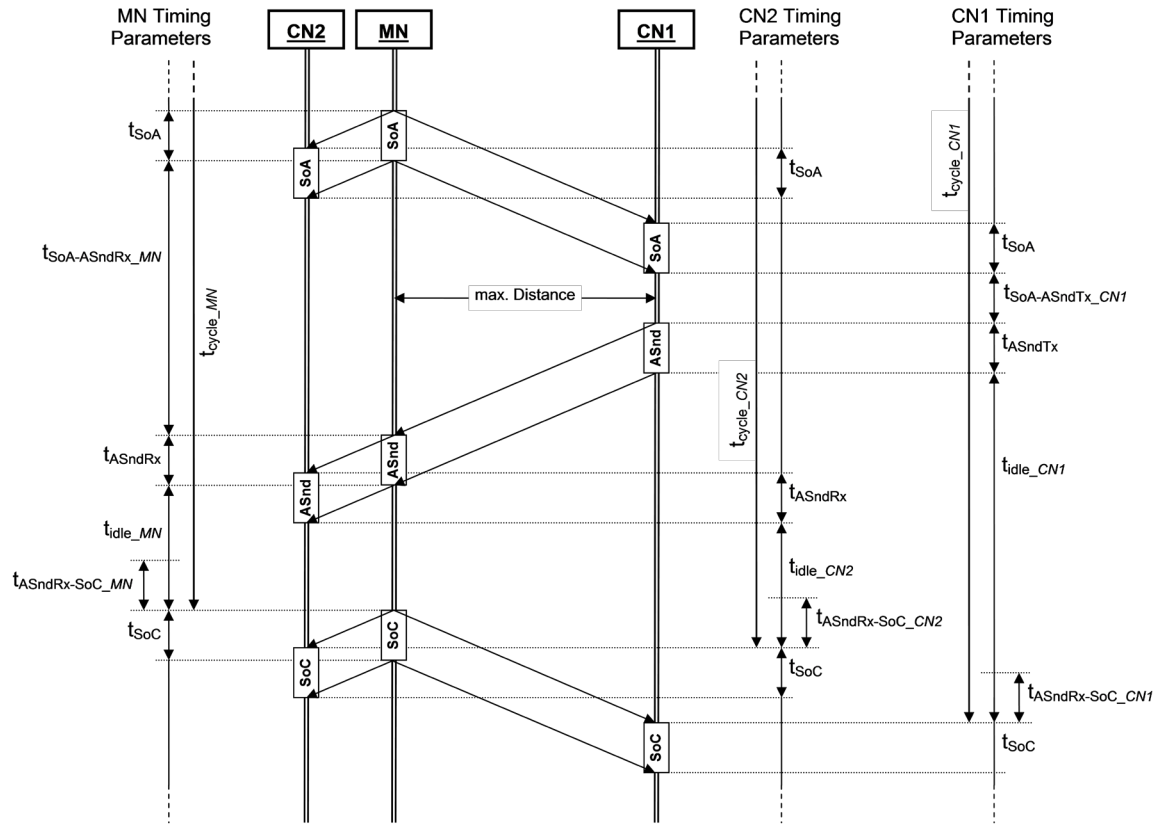
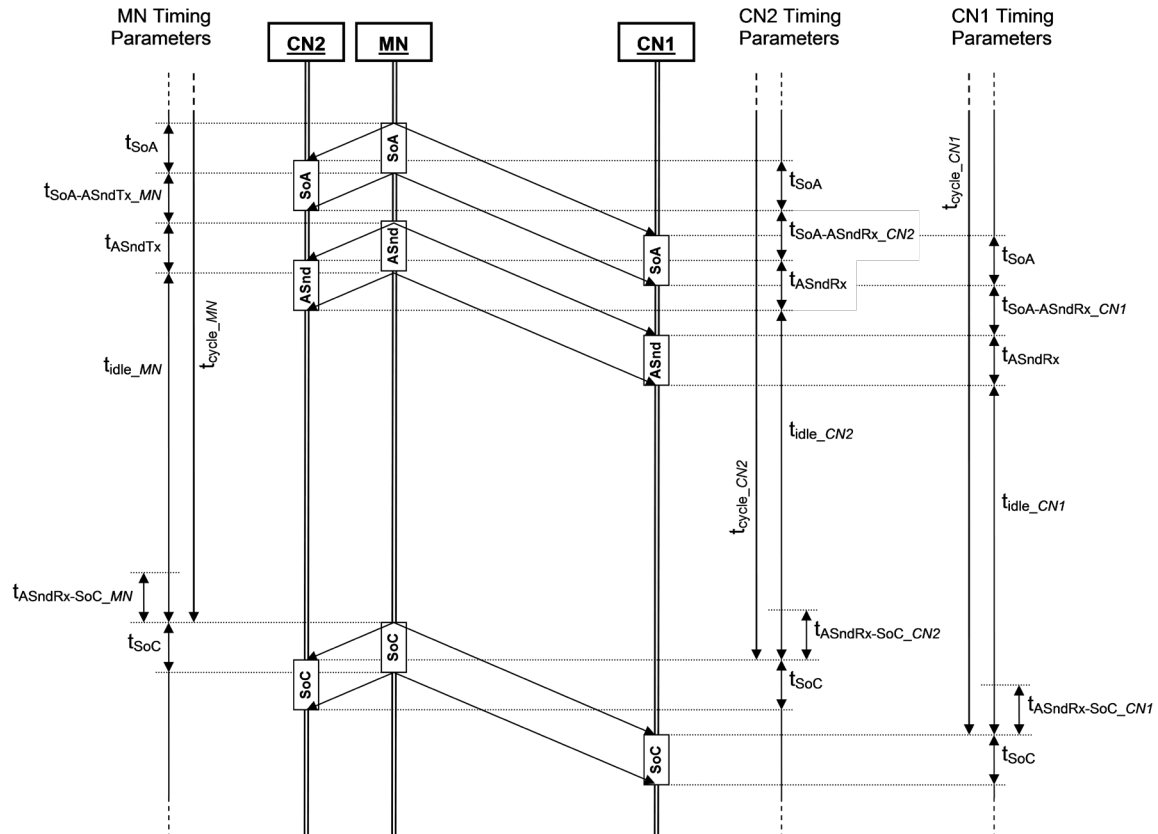


Figure 25— POWERLINK cycle timing, start phase, and isochronous phase



NOTE—ASnd refers to POWERLINK ASnd frames and non-POWERLINK frames.

**Figure 26— POWERLINK cycle timing, asynchronous phase,
AsyncSend transmission by CN**



NOTE—ASnd refers to POWERLINK ASnd frames and non-POWERLINK frames.

Figure 27 — POWERLINK cycle timing, asynchronous phase, AsyncSend transmission by MN

Table 4— POWERLINK cycle timing parameters

NOTE—Table 4 does not differentiate between frame size and the time required to transmit the frame. Both quantities shall be regarded to be equivalent. The transmission time shall be calculated from the size by multiply with transmit time per byte.

When regarding the supporting indices, the frame-type-specific protocol overhead in frame size shall be considered by time calculation (see 7.6).

No	Parameter	Description	Data Source	Handling ^a	Index
1	t_{cycle_MN} , t_{cycle_CNn}	length of POWERLINK isochronous cycle	system configuration	MN may verify before isochronous access to CN _n : $t_{cycle_MN} = t_{cycle_CNn}$	NMT_CycleLen_U32
2	t_{SoC}	SoC frame time consumption	constant $t_{SoC} = C_DLL_T_MIN_FRAME + C_DLL_T_PREAMBLE$	—	—
3	t_{propag_CNn}	signal propagation time MN → CN _n and vice versa	system configuration	$t_{propag_CNn} = (t_{PReq_PRes_CNn_MN} - t_{PReq_PRes_CNn}) / 2$	—
4	$t_{SoC_PReq_MN}$	delay between end of SoC transmission and start of PReq transmission	system configuration	depends on implementation of NMT_MNCycleTiming_REC. WaitSoCPReq: a) $t_{SoC_PReq_MN} = \max(t_{SoC_PReq_CNn}, t_{SoC_PReq_Min_MN})$ b) $t_{SoC_PReq_MN} = t_{SoC_PReq_Min_MN}$	a) NMT_MNCycleTiming_REC. WaitSoCPReq b) —
5	$t_{SoC_PReq_Min_MN}$	MN minimum delay between end of SoC transmission and start of PReq transmission	MN device description D_NMT_MNSoC2PReq_U32	$t_{SoC_PReq_Min_MN} \geq C_DLL_T_IFG$	—
6	$t_{SoC_PReq_CNn}$	minimum delay required by CN _n between end of SoC reception and start of PReq reception	CN _n device description D_NMT_CNSoC2PReq_U32	$t_{SoC_PReq_CNn} \geq C_DLL_T_IFG$	—
7	$t_{PReq_CNn_MN}$ t_{PReq_CNn}	time consumption of PReq frame to be transmitted to CN _n	$t_{PReq_CNn_MN} = (t_{PReqPL_CNn_MN} + C_DLL_T_EPL_PDO_HEADER + C_DLL_T_ETH2_WRAPPER) * 8 * C_DLL_T_BITTIME + C_DLL_T_PREAMBLE$	—	—
8	$t_{PReqPL_CNn_MN}$	payload of PReq frame to be transmitted to CN _n	system configuration	MN may verify at start-up: $t_{PReqPL_CNn_MN} \leq t_{PReqPL_Max_MN}$ MN may verify before isochronous access to CN _n : $t_{PReqPL_CNn_MN} = t_{PReqPL_CNn}$	NMT_MNPReqPayloadLimitList_AU16[NodeIDCN _n]