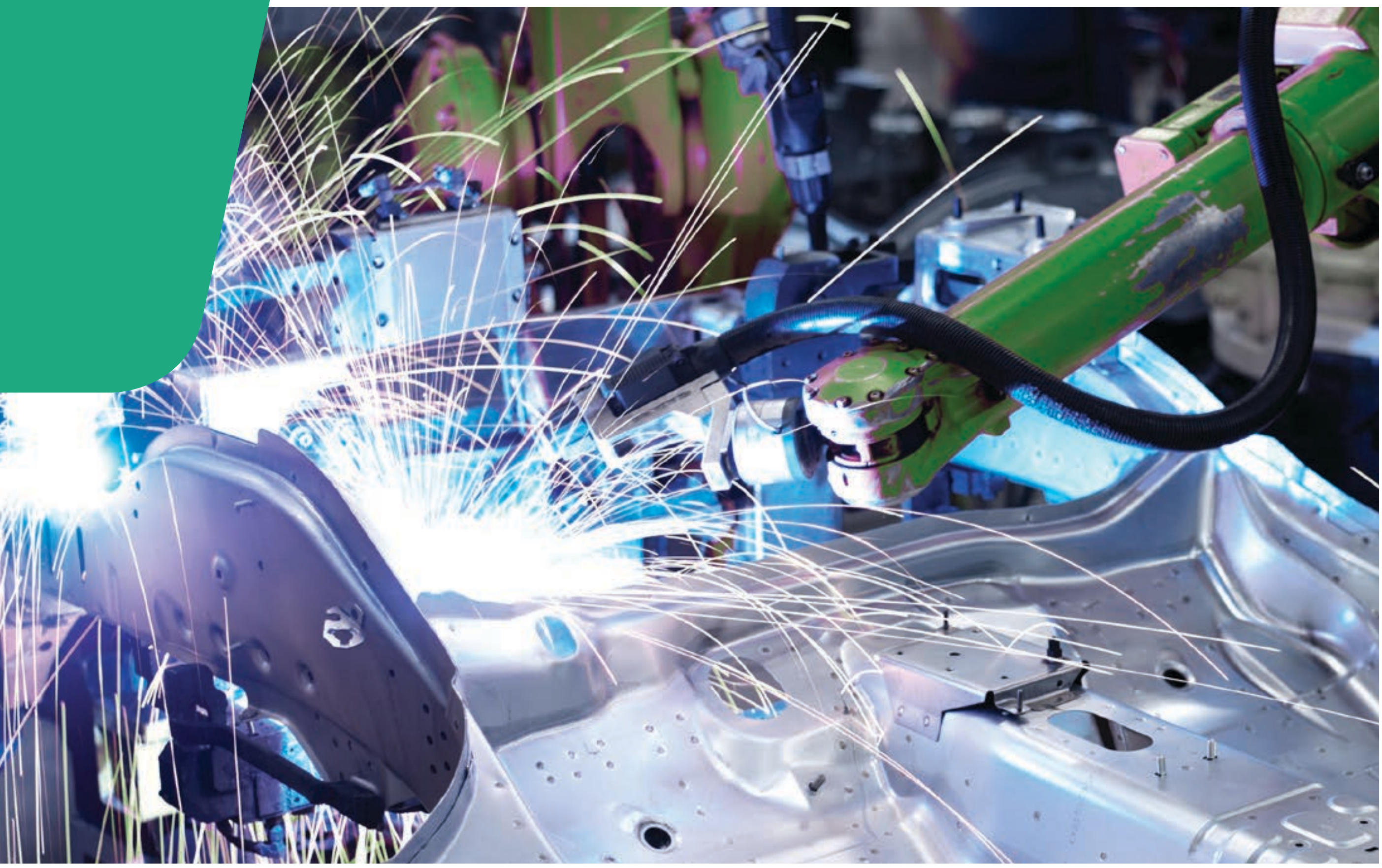

PROFINET System Description

Technology and Application

PROFIBUS • PROFINET

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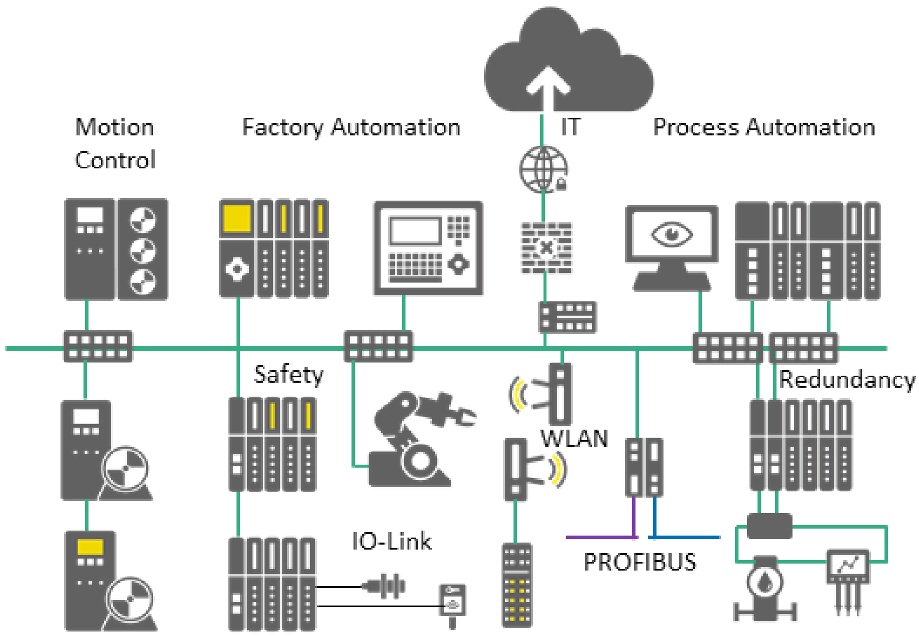

Fig. 1: PROFINET satisfies all requirements of automation technology

Introduction

Ever-shorter innovation cycles for new products makes the continuous evolution of automation technology a necessity. The use of fieldbus technology has represented a significant development since the early 90s. It has made it possible to migrate from centralized automation systems to decentralized ones. PROFIBUS, the global market leader, has set the benchmark here for more than 25 years.

In today's automation technology, Ethernet and Information Technology (IT) are calling the shots with established standards like TCP/IP and XML. Integrating information technology into automation opens up significantly better communication options between automation systems, extensive configuration and diagnostic possibilities and system-wide service functionality. The transition from PROFIBUS to the Ethernet-based PROFINET enables the integration of these functions as an integral component of PROFINET from the very beginning.

PROFINET is the open standard for industrial Ethernet, covering all the requirements of automation technology (Figure 1). Whether the application involves production automation, process automation or drives (with or without functional safety), PROFINET is the first choice across the board. This technology has become standard in the automotive industry, widely disseminated in machine building and well-proven in the food and packaging, logistics and process industries. PROFINET has found its way into every area of application. New application areas are constantly emerging, such as marine and rail applications and even day-to-day operations, such as in a beverage store.

PROFINET is currently the communication backbone for Industrie 4.0 in automation technology. Thanks to its open architecture, a PROFINET network makes all Ethernet-based IT functions fully available, enables open access to devices and enables the easy integration of other standards, such as OPC UA.

PROFINET is standardized in IEC 61158 and IEC 61784. The ongoing development of PROFINET offers users a long-term solution for the implementation of their automation tasks.

For system and machine manufacturers, the use of PROFINET minimizes the cost of installation, engineering and commissioning. For system operators, PROFINET offers ease of system expansion and high system availability through autonomously running system units and low maintenance requirements.

The mandatory certification of all PROFINET devices also ensures a high-quality standard.

Information on the Contents

This document describes all essential aspects of the PROFINET technology. Individual topics are explained, and references to detailed information are provided. It is not necessary to follow the many links in the guideline to have a general understanding of the system description.

A true-to-detail representation of a network is often omitted within the figures, with a simplified schematic representation being shown instead.

Chapter 1 introduces PROFINET and provides an overview of the market position and modular design.

Chapter 2 describes the underlying models and the engineering of a PROFINET system.

Chapters 3 to 5 cover the basic functions of PROFINET communication from the perspective of Conformance Classes.

Chapter 6 contains a brief description of optional features used in different applications.

Chapters 7 to 9 are dedicated to the integration of other technologies (such as fieldbuses), profiles and specific process automation topics with PROFINET and describe the additional benefits for PROFINET systems.

Chapter 10 describes relevant aspects of PROFINET networks, such as topologies, cables, connectors, web integration and security.

Chapter 11 is directed at product managers and provides information on product implementation and certification.

Chapter 12 provides an overview of the relevant standards for PROFINET.

Chapter 13 provides information on PROFIBUS & PROFINET International (PI), the world's largest interest group for industrial automation.

Chapter 14 considers future developments in the PROFINET environment.

1. PROFINET at a Glance

PROFINET is the communication standard for automation from PROFIBUS & PROFINET International (PI).

Its modular range of functions makes PROFINET a flexible system for all applications and markets. PROFINET is the networking solution of production and process automation, from applications with functional safety requirements and the entire spectrum of drive technology to isochronous motion control applications. The use of application profiles allows optimal usage of PROFINET in all areas of automation engineering.

1.1 Ten Reasons for PROFINET

1. Ease of use

The user-friendliness of PROFINET minimizes the costs of installation, engineering and commissioning for machine and system builders.

The system owner profits from ease of system expansion, high system availability and fast and efficient communication.

2. Flexible network topology

PROFINET is switched Ethernet. To make out cost-effective and easy, many PROFINET devices already have a switch with two or more ports integrated into them. PROFINET is 100% Ethernet-compatible as per IEEE standards and fullfills system requirements with its flexible topology. Line, ring and star structures are easy to implement with copper and fiber-optic cables. PROFINET enables wireless communication with WLAN and Bluetooth.

3. Integrated diagnostics

PROFINET includes intelligent diagnostic concepts for field devices and networks. Acyclically transmitted diagnostic data provides important information on the status of the devices and communication and enables a user-friendly representation of the network.

4. Integrated safety

PROFIsafe, the tried-and-tested technology for PROFIBUS functional safety, is also available for PROFINET. The ability to use the same cable for standard and safety-related communication yields savings for devices, engineering and setup.

5. High availability

PROFINET integrates automatically responding redundancy solutions. The defined concepts for system redundancy and Dynamic Reconfiguration (DR) increase system availability considerably.

6. Scalable real time

Communication takes place over the same cable in all applications, from simple control tasks to highly demanding motion control applications. For high-precision closed-loop control tasks, deterministic and isochronous transmission of time-critical process data with a jitter of less than 1 µs is possible.

7. A powerful system base

PROFINET fulfills the most wide-ranging requirements with its consistent, Ethernet-based communication. From data-intensive parameter configuration to extremely fast IO data transmission, PROFINET enables automation in real time and IT integration with a single system. This is a basic requirement for Industrie 4.0.

8. Support for energy optimization

With the PROFIenergy profile integrated into PROFINET devices, the energy use in an automation system can be measured using a standardized method and controlled by selectively switching functions on and off without additional hardware.

9. Sensor/actuator integration

IO-Link, the globally standardized IO technology (IEC 61131-9) for communicating with sensors and actuators, can be optimally integrated into PROFINET. This enables digital communication up to the sensor/actuator level.

The same applies for the established sensor/actuator interfaces in the process industry. For the 4 – 20 mA, HART and PROFIBUS PA interfaces, options for universal engineering, diagnostics and maintenance are available.

10. Global support

With its network of Competence Centers, the PROFIBUS & PROFINET International (PI) organization offers solid training and consultation across the globe. Establishment of the proven certification process achieves a high standard of quality for PROFINET products and their interoperability in systems.

1.2 Conformance Classes

As a broad standard, PROFINET offers a large number of functions. These functions are divided into Conformance Classes in a clear way. They provide a practical summary of the various different minimum property values.

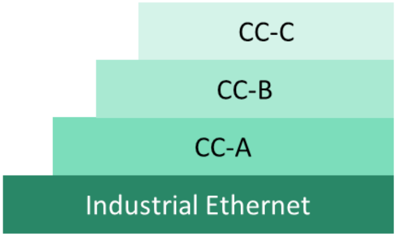

Fig. 2: Structure of Conformance Classes

There are three Conformance Classes (CC) which build upon one another (see Figure 2).

Conformance Class A (CC-A) provides basic functions for PROFINET with real-time (RT) communication. All IT services can be used without restriction. Typical applications are found, for example, in business automation. Wireless communication is specified for this class.

Conformance Class B (CC-B) expands PROFINET to include network diagnostics using IT mechanisms and topology information of the network.

Conformance Class C (CC-C) describes the basic functions for devices with hardware-supported bandwidth reservation and synchronization Isochronous Real-Time (IRT) communication and is thus the basis for isochronous applications.

The Conformance Classes also serve as the basis for certification and cabling guidelines.

Building upon the three Conformance Classes (A, B and C), which describe the basic communication properties, there are currently seven application classes which combine a required scope of functions for certain applications.

A detailed description of the Conformance Classes can be found in the document entitled "The PROFINET Conformance Classes" [7.041] (www.profibus.com/pncc).

2. Modeling and Engineering

This section presents the models of a PROFINET system and explains the addressing options.

2.1 System Model of a PROFINET System

PROFINET follows the provider/consumer model for data exchange. This means that both the IO controller and IO device spontaneously send cyclic data independently.

The following device classes are defined for PROFINET (Figure 3):

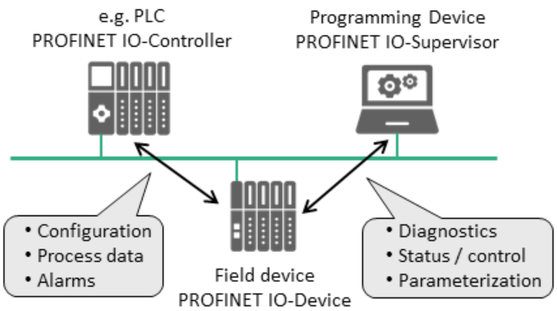

Fig. 3: Communication paths for PROFINET

IO controller: This is typically the Programmable Logic Controller (PLC) in which the automation program runs. The IO controller provides output data to the configured IO devices in its role as provider and is the consumer of input data.

IO device: An IO device is a distributed IO field device connected to one or more IO controllers via PROFINET. The IO device is the provider of input data and the consumer of output data from the IO controller.

IO supervisor: This can be a programming device (PG), personal computer (PC) or human machine interface (HMI) device for commissioning or diagnostic purposes.

A system unit contains at least one IO controller and one or more IO devices. IO supervisors are usually integrated only temporarily for commissioning or troubleshooting purposes.

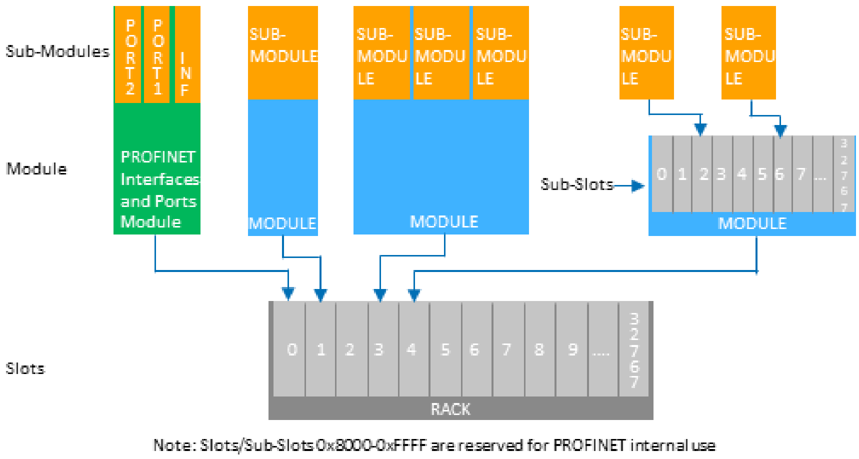

Fig. 4: Device model of a PROFINET field device

2.2 Device Model of an IO Device

The technical and functional options of all field devices are described using the device model, which is oriented toward a modular device (Figure 4).

PROFINET differentiates between **compact field devices**, in which the degree of expansion is already specified in the as-delivered condition and cannot be changed by the user, and **modular field devices**, in which the degree of expansion can be customized for a specific application when the system is configured. In its logical structure, a PROFINET field device is always modular in design. Modularity in the logical sense, however, does not require actual modularity in the electrical and mechanical design sense.

An IO device is usually comprised of a communication module with Ethernet interface and (physical or virtual) modules assigned to it. The assigned modules handle the actual process data traffic. The access point for communication (Ethernet interface with data processing) is called the DAP (**D**evice **A**ccess **P**oint).

The following structures are standardized for an IO device:

- The device model consists of slots, subslots, modules, submodules and channels.
- The **slot** designates the insertion slot of a **module** in an IO field device. A field device usually has two or more slots.
- A module is comprised of one or more **submodules** or provides available **subslots** into which submodules can be inserted.
- The modules themselves have no task other than to provide structuring. The actual inputs and outputs (channels) are implemented in its submodules. The granularity of the channels (bitwise, bytewise or wordwise division of IO data) is determined by the manufacturer. Acyclic services always address submodules. Therefore, a module always contains at least one submodule.
- The data content of a submodule is always accompanied by status information.

The **index** specifies the data within a submodule inserted into a slot/subslot which can be read or written acyclically using read/write services. For example, parameters can be written to a module, or manufacturer-specific module data can be read out on the basis of an index. Specific indexes are defined in the standard here. Additional indexes can be freely defined by the manufacturer.

The submodule is the owner of the user data, diagnostics, channels, actual configuration, records and I&M data. Cyclic IO data of the submodule in the device is addressed by specifying the slot/subslot combination of the insertion slot. They can be freely defined by the manufacturer. For acyclic data communication via read/write services, an application can specify the data of the submodule to be addressed using **slot**, **subslot** and **index** (Figure 5).

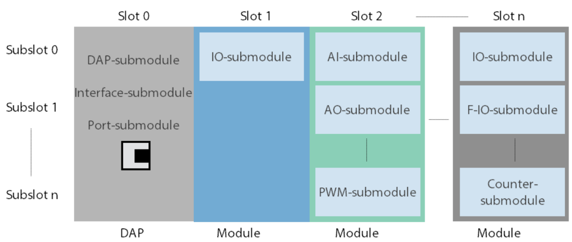

Fig. 5: Addressing of IO data in PROFINET on the basis of slots and subslots

To avoid user profiles (e.g. for PROFIdrive, weighing and dosing) from having competing definitions, each of the profiles is assigned its own application process identifier (API).

Additional information on the device model can be found in the design recommendation for PROFINET field devices, which is available as a free download (www.profibus.com/pnfd).

2.3 Device Descriptions

To enable system engineering, the GSD files (General Station Description) of the field devices to be configured are required. This XML-based GSD describes the properties and functions of the PROFINET field device, including its modules and submodules. It contains all data relevant for engineering as well as for data exchange with the field device.

In particular, GSD files enable the engineering of a PROFINET system or PROFINET application without the devices used having to be physically present.

The GSD is essential for a PROFINET field device, as engineering is impossible without it. Every manufacturer of a PROFINET field device must create an associated GSD file. It will be checked as part of the certification test.

The engineering tool obtains knowledge about the device using the GSD data. The GSD file is read into the engineering tool (e.g. programming device) once for this purpose (Figure 6). The field device can then be configured, for example, from the product catalog of the engineering tool.

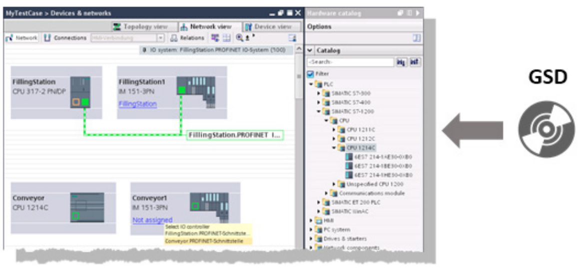

Fig. 6: GSD and engineering tool

Additional detailed information on the GSD can be found in the design recommendation for PROFINET field devices, which is available as a free download (www.profibus.com/pnfd).

2.4 Communication Relations

To establish communication between the higher-level controller and an IO device, the communication paths must be established. These are set up by the IO controller during system startup based on the configuration data received from the engineering system. This specifies the data exchange explicitly.

All data exchange is embedded into an AR (**A**pplication **R**elation) (Figure 7). Within the AR, CRs (**C**ommunication **R**elations) specify the data explicitly. As a result, all data for device modeling, including the general communication parameters, are downloaded to the IO device. An IO device can have multiple ARs established from different IO controllers, for example, for shared devices.

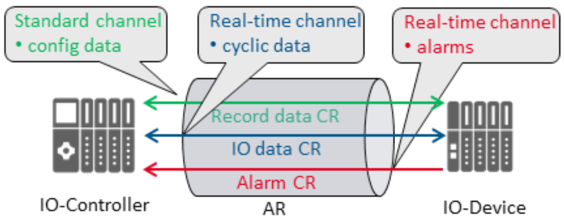

Fig. 7: Application and communication relations

The communication channels for cyclic data exchange (IO data CR), acyclic data exchange (record data CR) and alarms (alarm CR) are set up simultaneously.

Multiple IO controllers can be used in a PROFINET system (Figure 8). If these IO controllers are to be able to access the same data in the IO devices, this must be specified during parameter configuration (shared devices and shared inputs).

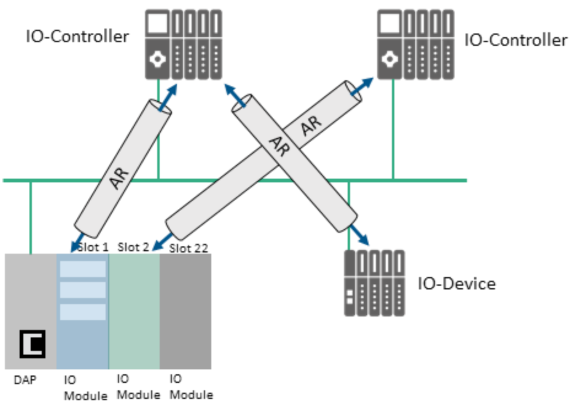

Fig. 8: A field device can be accessed by multiple application relations

An IO controller can establish one AR each with multiple IO devices. Within an AR, several IO CRs on different APIs can be used for data exchange. This can be useful, for example, if more than one user profile (PROFIdrive, encoder etc.) is involved in communication and different submodules are required.

MAC address and OUI (organizationally unique identifier)

Each PROFINET device is addressed using its globally unique MAC address. This MAC address consists of a company code (bits 24 to 47) as an OUI (Organizationally Unique Identifier) and a consecutive number (bits 0 to 23). With an OUI, up to 16,777,214 products of a single manufacturer can be identified.

Bit value 47 to 24			Bit value 23 to 0		
00	0E	CF	XX	XX	XX
Company code -> OUI			Consecutive number		

The OUI is available free of charge from the IEEE Standards Department.

PI provides all device manufacturers which do not want to apply for their own OUI with four K-areas of the PI OUI. This service allows companies to acquire MAC addresses directly from the PI Support Center. The OUI of PI is 00-0E-CF.

2.5 Addressing PROFINET Devices

Ethernet devices always communicate using their unique MAC address (see box).

In a PROFINET system, each field device receives a symbolic name which uniquely identifies the field device within the IO system (Figure 9). The device is identified and configured with this name within the engineering process. The exact MAC & IP addresses are resolved using this name when the PROFINET application is started.

The DCP protocol (Discovery and basic Configuration Protocol) is used for this. The device name is assigned to the individual IO device and thus to its MAC address by an engineering tool using the DCP protocol during commissioning (device initialization). Optionally, the name can also be automatically assigned by the IO controller to the IO device by means of a specified topology based on neighborhood detection. Assignment of the IP address occurs from the project via DCP, using the generally common and internationally widespread DHCP (Dynamic Host Configuration Protocol) or using manufacturer-specific mechanisms. In the latter two cases, the IP addresses are read out of the controller automatically via DCP so that no manual access is required here either. The options supported by a field device are defined in the GSD file for the respective field device.

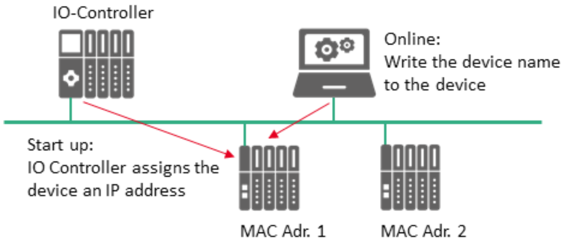

Fig. 9: Name assignment

2.6 Engineering of an IO System

Each IO controller manufacturer also provides an engineering tool for configuring a PROFINET system.

During parameter configuration, the IO controllers and IO devices are defined in a PROFINET system. The desired properties of the cyclic data exchange within the communication relations are specified for this.

For each IO device, the intended population of the slots and subslots with modules and submodules must be defined. The possible population variations are saved in the GSD. At the same time, more precise behavior and properties of the devices and modules/submodules can be specified using parameters. The configuring engineer configures the real system, so to speak, symbolically in the engineering tool. Figure 10 shows the relationship between GSD definitions, the configuration and the real device view.

During commissioning, the configuration of the PROFINET IO system is downloaded to the IO controller. This means that the IO controller has all the information for addressing and data exchange with the IO devices.

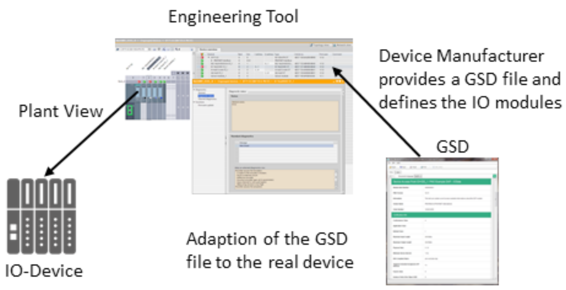

Fig. 10: Assignment of definitions in the GSD file to IO devices when configuring the system

Either the devices of the PROFINET system are now assigned to the device name with the engineering tool or the IO controller is informed of the planned topology. Based on the topology information, the IO controller automatically provides the device names and gives all planned IO devices their IP address during system startup. An IO controller always initiates system power-up after a startup/restart based on the configuration data without any intervention by the user. During system startup, the IO controller establishes a uniquely specified Application Relation (AR) with the associated Communication Relations (CR) for each configured IO device. This specifies the cyclic IO data, alarms, exchange of acyclic read/write services and the expected modules/submodules. .

2.7 Web Integration

PROFINET expands Ethernet to include automation-specific functions without restricting existing properties. This enables, among other things, the use of web technologies such as access to an integrated web server on the field devices. Depending on the implementation in the devices, diagnostic information can be called up beyond network boundaries with standard web browsers, for example. PROFINET itself does not define any specific content or format. Rather, it allows for an open and free implementation.

3. Basic Functions

The basic functions of Conformance Class A include:

- The cyclical exchange of IO data with real-time properties.
- Acyclic data traffic for reading and writing need-based data (parameters and diagnostic data), including the identification and maintenance function (I&M) for reading out device information.
- A flexible alarm model for signaling device and network errors with three alarm levels (maintenance requirement, urgent maintenance requirement and diagnostics).

Requirement	Technical function/ solution
Cyclic data exchange	PROFINET with RT communication
Acyclic parameter data/ Device identification (HW/FW)	Read Record/ Write Record IM0, 1, 2, 3 IM 4 (F-submodules) IM 5 (communication module)
Devices/Network diagnostics (alarms)	Diagnostics and maintenance

Tab. 1: List of basic functions

3.1 Cyclic Data Exchange

Cyclic IO data is transmitted via the "IO data CR" unacknowledged as real-time data between the provider and consumer in a parameterizable time frame. The update time can be specified individually for connections to the individual devices and are thus adapted to the requirements of the application. Likewise, different update times can be selected for the input and output data within the range of 250 µs to 512 ms (Figure 11).

The connection is monitored using a time monitoring setting derived from a multiple of the update time. During data transmission in the frame, the data of a submodule is followed by a provider status. This status information is evaluated by the respective consumer of the IO data. It can use this information to evaluate the validity of the data from the cyclic data exchange alone. In addition, the consumer statuses for the counter direction are transmitted. The data in the message frames is followed by accompanying information about their validity and redundancy and which evaluates the diagnostic status (data status and transfer status). The cycle information (cycle counter) of the provider is also specified so that its update time can be determined easily. Failure of cyclic data to arrive is monitored by the respective consumer in the communication relation. If the configured data fails to arrive within the monitoring time, the consumer sends an error message to the application.

The cyclic data exchange can be realized with standard Ethernet controllers and takes place without any TCP/IP information directly on layer 2 with Ethertype 0x8892.

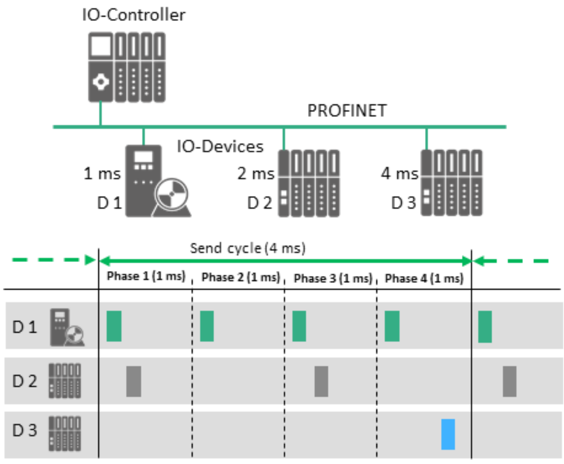

Fig. 11: Real-time communication with cycle time monitoring

For the network infrastructure with CC-A devices, commercially available switches which meet at least the following requirements can be used:

- Support of 100 Mbps full duplex with auto crossover and auto negotiation according to IEEE 802.3.
- Prioritization of cyclic data with VLAN tag priority 6 according to IEEE 802.1Q or TCI.PCP in the latest IEEE 802.1.
- Support of neighborhood detection with the Link Layer Discovery Protocol (LLDP) according to IEEE 802.1AB, i.e. these messages with their special Ethertype may not be forwarded by the switch.

3.2 Acyclic Data Exchange

Acyclic data exchange using the "record data CR" can be used for parameter configuration and other configuration of the IO devices or reading out status information. This is accomplished with read / write services based on UDP, in which the data records are distinguished by the index. In addition to this access, the devices can be accessed manufacturer-specifically via web server, OPC UA,… These access variants, which are not specified in PROFINET, are summarized under the synonym TCP / IP. In addition to the data records which are freely definable by device manufacturers, the following system data records are defined:

Diagnostic information about the network and the devices can be read out by the user from any device at any time.

Identification and Maintenance (I&M) data supports unique identification of the devices, modules and submodules and their versions. This identification information is an important basis for maintaining the system and for asset management. For example, this allows inferences to be drawn regarding incorrect behavior or unsupported functionality in a field device. This information is specified in the I&M data structures. The I&M functions are subdivided into six different blocks (IM0 to IM5) and can be addressed separately using their index.

IThe IM0 function provides information about the hardware and firmware versions of the field device and must be supported by each device.

The IM1 – 3 data contain system-dependent information, such as the installation location and date, and are created during configuration and written to the device.

IM4 is used for a signature with PROFIsafe.

IM5 is mandatory if the PROFINET device contains a separate communication module with its own hardware/firmware (see Figure 23). The IM5 data provides information about the communication module of a field device, comparable to an electronic nameplate. A differentiation can thus be made between the HW/FW versions of the communication module and the actual device. The actual device reports its HW/FW versions via IM0.

The I&M guideline entitled "Identification & Maintenance Functions" [3.502] provides further information on this concept and is available for download free of charge for members (www.profibus.com/imf).

IM0	Main function	HW/FW version
IM1	TAG_FUNCTION TAG_LOCATION	System designation, location designation
IM2	INSTALLATION_ DATE	Installation date
IM3	DESCRIPTOR	Comment
IM4	SIGNATURE	Signature
IM5	Communication modul	HW/FW version

Tab. 2: List of I&M data 0-5

3.3 Device/Network Diagnostics

A status-based maintenance approach is currently gaining relevance for operation and maintenance. It is based on the capability of devices and components to determine their state and to communicate them using agreed-upon mechanisms. A system for reliable signaling of alarms and status messages by the IO devices to the IO controller was defined for PROFINET for this purpose.

This alarm concept covers both system-defined events (such as removal and insertion of modules) as well as signaling of faults which were detected in the controller technology utilized (e.g. defective load voltage or wire break). This is based on a state model which defines "good" and "defective" states as well as (optionally) the "maintenance required" and "maintenance demanded" pre-warning levels. A typical example of "maintenance required" is the loss of media redundancy. When a redundant connection is lost, "maintenance required" is signaled, but all nodes can still be reached.

Diagnostic alarms must be used if the error or event occurs within an IO device or in conjunction with the connected components. They can signal an incoming or outgoing fault status (Figure 12).

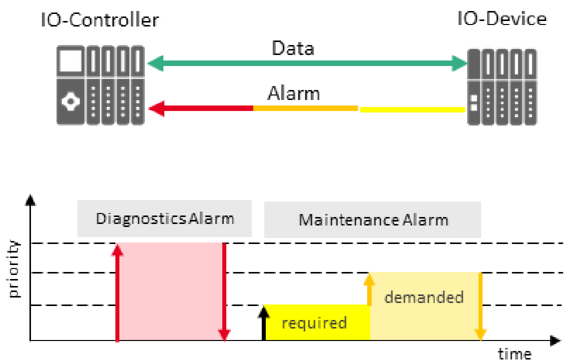

Fig. 12: Diagnostic model for signaling faults with different priority

In addition, the user can define corresponding **process alarms** for messages from the process, e.g. limit temperature exceeded. In this case, the IO device may still be operable. These process alarms can be prioritized differently from the diagnostic alarms.

The "Diagnosis for PROFINET IO" [7.142] documentation provides additional information on these concepts and is available for download free of charge for members (www.profibus.com/dpn).

4. Network Diagnostics and Management

In Conformance Class B, the network diagnostics of all PROFINET devices is expanded and topology detection is introduced. This information is compiled in the management information base (MIB) and the extensions to the Link Layer Discovery Protocol (LLDP-EXT MIB) and can be read out from each PROFINET device using the Simple Network Management Protocol (SNMP) or the acyclic PROFINET services for the physical device object (PDEV).

4.1 Network Management Protocol

In existing networks, SNMP has established itself as the de facto standard for maintenance and monitoring of network components and their functions. For diagnostic purposes, SNMP can access network components in order to read out network-specific statistical data as well as port-specific data and information for neighborhood detection. In order to monitor PROFINET devices even with established management systems, the implementation of SNMP is mandatory for devices of Conformance Classes B and C.

4.2 Neighborhood Detection

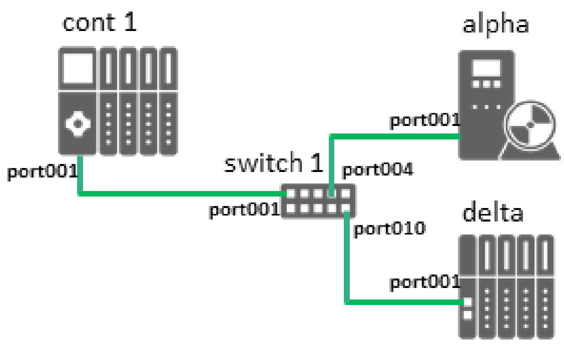

Fig. 13: PROFINET field devices know their neighbors

Automation systems can be flexibly constructed as a star, tree, line or ring structure.

PROFINET field devices use the LLDP protocol according to IEEE 802.1AB to exchange the available addressing information over each port. This allows the respective port neighbor to be uniquely identified and the physical structure of the network to be determined. In Figure 13 – as an example – the "delta" device is connected to "port010" of "switch1" via "port001".

With this neighborhood detection, a preset/actual comparison of the topology is possible and changes to topology during operation can be recognized immediately. This is also the basis for automatic naming during device replacement.

4.3 Representation of the Topology

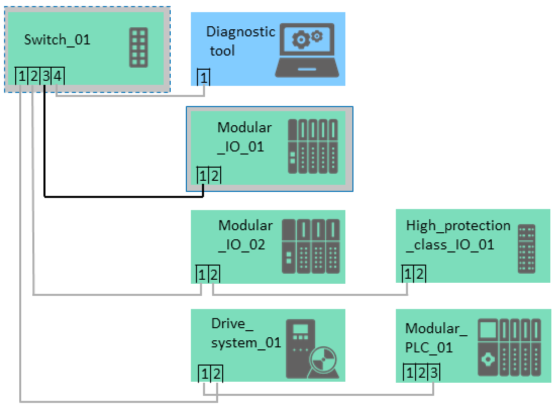

Fig. 14: System topology

A system owner can use a suitable tool to graphically display a system topology and port-granular diagnostics (Figure 14). The information found during neighborhood detection is collected using the SNMP protocol for this purpose. This provides the system owner with a quick overview of the system status.

4.4 Device Replacement

If a field device fails in a known topology, it is possible to check whether the replacement device has been reconnected in the proper position. It is even possible to replace devices without the use of an engineering tool. When replaced, a device at a given position in the topology receives the same name and parameters as its predecessor (Figure 15).

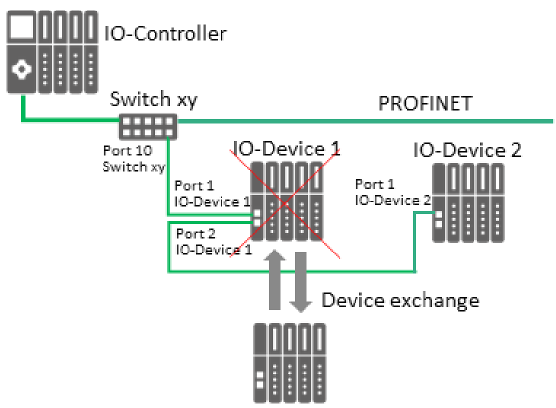

Fig. 15: PROFINET IO supports convenient device replacement without an engineering tool

The controller knows the "neighborhood" of the devices and checks it following a device replacement. Using this information and the degree of expansion of the device, it identifies whether or not it is a replacement device.

4.5 Integration of Network Diagnostics into the IO System Diagnostics

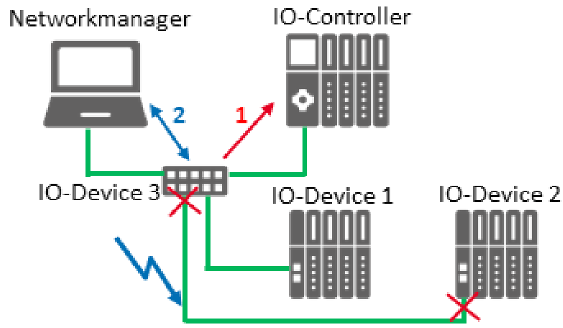

Fig. 16: Integration of network diagnostics into the IO system diagnostics

For the integration of network diagnostics into the IO system diagnostics, it must also be possible to model a switch as a PROFINET IO device. Acting as an IO device, this type of switch can signal identified network errors of a lower-level Ethernet line and specific operating states to its IO controller by transmitting acyclic alarms using the "alarm CR" (number 1 in Figure 16). In this way, network diagnostics can be integrated into the IO system diagnostics. Access from a network manager (number 2 in Figure 16) remains possible.

5. Synchronous Real-Time

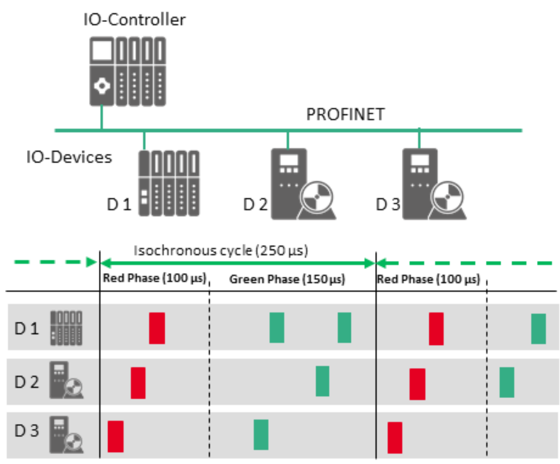

Fig. 17: IRT communication divides the bus cycle into a reserved interval (red) and an open interval (green)

Conformance Class C includes all necessary network-wide synchronization functions for applications with the most stringent requirements for deterministic behavior. Networks based on Conformance Class C enable applications having a jitter of less than 1 microsecond (1 µs). The cyclic data packets are transferred as synchronized packets during a reserved bandwidth (red phase) (Figure 17). All other packets, such as packets for diagnostics or TCP/IP, share the remaining Ethernet bandwidth (green phase).

By default, the minimum update rate is defined at 250 µs in Conformance Class C. For maximum control performance, this can be reduced to as low as 31.25 µs, depending on the hardware used. In order to expand quantity structures when cycle times are set at less than 250 µs, a message frame optimization method (Dynamic Frame Packing, or DFP) is incorporated. With this method, nodes which are wired together in a line structure are addressed with one frame. In addition, for cycle times less than 250 µs, TCP/IP communication is fragmented and transmitted in smaller packets.

The isochronism (Greek "iso" = same + "chronos" = time) can be related to the communication itself as well as to the application.

These concepts and the planning procedure are explained in detail in the "PROFINET IRT Engineering" [7.172] document. This is available for download free of charge for members (www.profibus.com/pnirt).

The most important elements are summarized as follows.

5.1 Cycle Synchronization

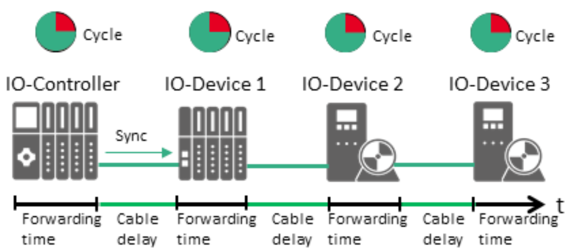

Fig. 18: Synchronization of the cycles in an IRT domain

In order for the bus cycles to run synchronously (at the same time) with a maximum deviation of 1 µs, all devices involved in synchronous communication must have a common clock. A clock master uses synchronization frames to synchronize all local clock pulse generators of devices within a clock system (IRT domain) to the same clock (Figure 18).

For this purpose, all of the devices involved in this type of clock system must be connected directly to one another without crossing through any non-synchronized devices. Multiple independent clock systems can be defined in one network.

To achieve the desired accuracy for the synchronization and synchronous operation, the run-time on each connecting cable (cable delay) must be determined via measurement using defined Ethernet frames. Together with the forwarding times of the device or switches, all time ratios in the IRT system are known and can be figured into the synchronization. If the IO controller (clock master) in Figure 18 sends out a synchronization frame with the time of the clock master which reaches IO device 3 after 10 µs, IO device 3 experiences the frame having been underway for 10 µs and that the conveyed time of the clock master is 10 µs old and can set its own clock to it as the clock slave. IO controllers and IO devices derive the cycle from this time. Special hardware precautions must be taken for implementing this clock synchronization.

The high-precision time synchronization of all communication nodes is a requirement for division of the bandwidth and the transmission times in the red and green phase (Figure 17). In each cycle, the synchronous data is first transmitted in the red phase. This red phase is protected from delays caused by other data and allows a high level of determinism. In the subsequent open green phase, all other data are transmitted according to IEEE 802.1Q and the specified priorities. The division of the individual phases may vary. If forwarding of the data before the start of the next reserved phase is not assured, these frames are stored temporarily and sent in the next green phase.

5.2 Mixed Operation

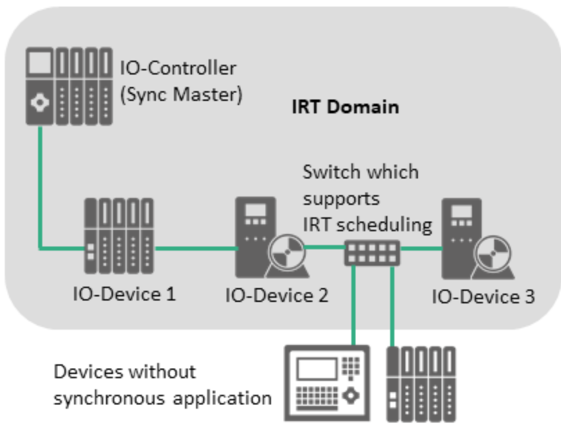

Fig. 19: Mixed operation of synchronized and unsynchronized applications

A combination of synchronous and asynchronous communication within an automation system is possible if certain preconditions are met. Figure 19 shows an expample of a mixed operation. In this example, a synchronizable switch has been integrated in the field device for devices 1 to 3. The other two devices are connected via a standard Ethernet port and thus communicate asynchronously. The switch ensures that this occurs only during the green phase.

5.3 Optimized IRT Mode

When the timescales are subject to stringent requirements, the efficiency of the topology-oriented synchronized communication can be optimized using Dynamic Frame Packing (DFP) (Figure 20). For a line structure, the synchronous data of several devices is optionally combined into one Ethernet frame. In addition, the individual cyclic real-time data can be extracted for each node so that the remaining frame, and thus the delivery time, are shortened. Because the data from the field devices to the controller is also strictly synchronized, this data can be assembled by the switch in a single Ethernet frame. Ideally, only one frame is then transmitted for all involved field devices in the red phase. This frame is disassembled or assembled in the corresponding switch, if required.

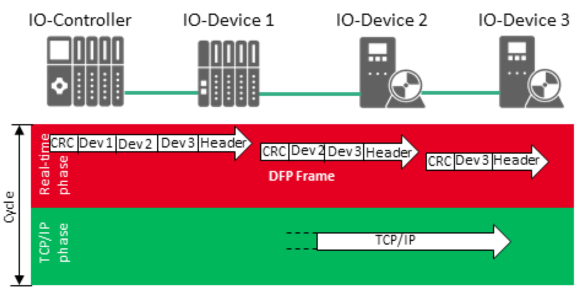

Fig. 20: Packing of individual frames into a group frame

DFP is optional for systems with stringent requirements. The functionalities of the other phases are retained, i.e. mixed operation is also possible here. To achieve short bus cycles as low as 31.25 µs, however, the green phase must also be sharply reduced. To accomplish this, the standard Ethernet frames for the application are transparently disassembled into smaller fragments, transmitted in small pieces and reassembled.

6. Optional Functions

PROFINET also offers a variety of optional functions not included in devices as standard by way of Conformance Classes and application classes (Table 3). If additional functions are to be used, this must be checked on a case-by-case basis using the device properties (data sheet, manuals and General Station Description file, GSD file).

Requirement	Technical function/solution
Multiple access to inputs by various controllers	Shared input
Division of device functions across multiple submodules on different controllers	Shared device
Extended device identification	Asset Management Record (AMR)
Automatic parameter configuration of devices using parameter sets	Individual parameter server
Configuration changes during operation	Dynamic Reconfiguration (DR)
Time stamping of IO data	Reporting system
Fast restart after voltage recovery	Fast Start Up (FSU)
Higher availability through ring redundancy	MRP/MRPD
Call of a device-specific engineering tool	Tool Calling Interface (TCI)

Tab. 3: List of possible optional functions

6.1 Multiple Access to Field Devices

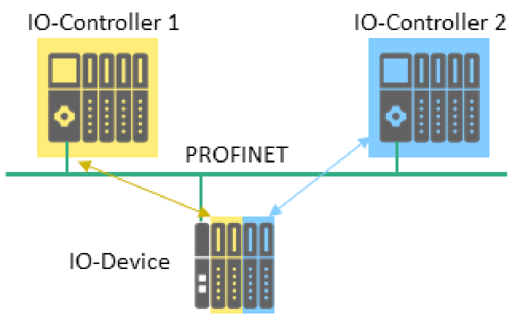

Fig. 21: Shared device: Access by multiple controllers to different modules in a device

The starting point for **shared devices** is the parallel and independent access of two (or more) different controllers to the same device (Figure 21). In the case of a shared device, the user configures a fixed assignment of different submodules used in a device to a selected controller. One possible application of a shared device is in applications with functional safety in which a fail-safe CPU controls the safe portion of the device and a standard controller controls the standard IO within the same station. In the safety scenario, the F-CPU uses the fail-safe portion to safely switch off the supply voltage of the outputs or activate drive-based safety functions (e.g. Safe Torque Off, STO), for example.

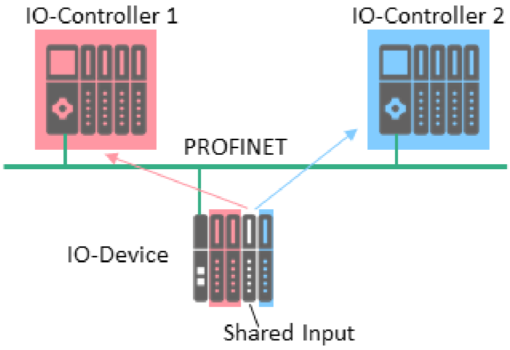

Fig. 22: Shared input: Multiple controllers read the same inputs on a device

In the case of a shared input, there is parallel access to the same input by two different controllers (Figure 22). Thus, an input signal which must be processed in two different controllers of a system does not have to be wired twice or transferred via CPU-to-CPU communication.

6.2 Extended Device Identification AMR

Asset Management Record (AMR)

AMR data is data from externally connected devices. The differences between I&M data and AMR data are shown in Figure 23.

Internal components (firmware and/or hardware) of a device with a PROFINET interface which can be replaced or updated for maintenance or repair purposes can be represented either using I&M data or an AM record. Using the Asset Management Record (AMR), it is thus possible to integrate device information outside the PROFINET application space into PROFINET mechanisms, e.g. HW/FW versions of locally connected devices or driver versions.

The structure of the AMR is based on IM0 but offers additional options for representing versions with a text string field.

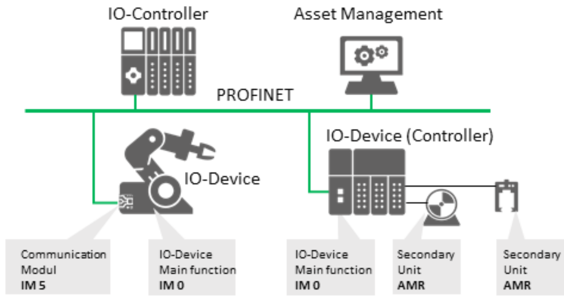

Fig. 23: Clarifying I&M and AMR data roles

6.3 Individual Parameter Server

The individual parameter server functionality is available for backing up and reloading other optional individual parameters of a field device (Figure 24).

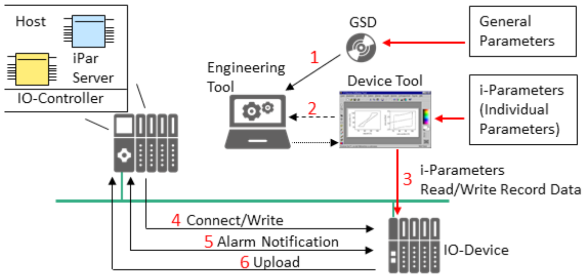

Fig. 24: A parameter server can be used to automatically reload backed-up data during device replacement

The basic parameter configuration of the submodules of an IO device is carried out using the parameters defined in the GSD file of the IO device. A GSD file contains module parameters of the peripheral modules described as submodules, among other things. They are stored as static parameters and can be loaded from the IO controller to an IO device during system power-up. With some IO devices, it is either impossible or insufficient to initialize parameters using the GSD approach due to the quantities, the user guidance or the security requirements involved. Such data for specific devices and technologies is referred to as individual parameters (iPar). Often, these parameters can be specified only during commissioning. If a submodule of such an IO device fails, the parameters must be reloaded into the new submodule after the submodule is replaced. An additional tool is not needed for this. The individual parameter server provides the system owner with a convenient and standardized solution for this which saves the current individual parameters and loads them into the new submodule(s) after replacement.

6.4 Dynamic Reconfiguration (DR)

As with redundancy, uninterrupted system operation also plays a critical role in process automation in the case of configuration changes to devices and the network or for the insertion, removal or replacement of devices or individual modules (Figure 25).

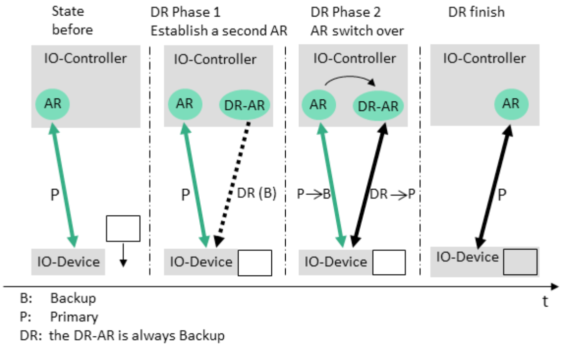

Fig. 25: Configuration changes without interruption of operation thanks to redundant connection

All of these Dynamic Reconfiguration (DR) measures are carried out in PROFINET without any interruption and without adversely affecting network communication. This ensures that system repairs, modifications and expansions can be performed without a system shutdown during continuous production processes.

This concept is described in detail in the "PN High Availability" [7.242] document and is available as a free download for members (www.profibus.com/hapn).

6.5 Reporting System – Time Stamping

In large systems, the ability to assign alarms and status messages to a sequence of events is often required. For this purpose, optional time stamping of these messages is possible in PROFINET IO. In order to time stamp data and alarms, the relevant field devices must have the same time of day. To accomplish this, a master clock and the time synchronization protocol IEEE 802.1 AS are used to set the clocks to the same time (Figure 26).

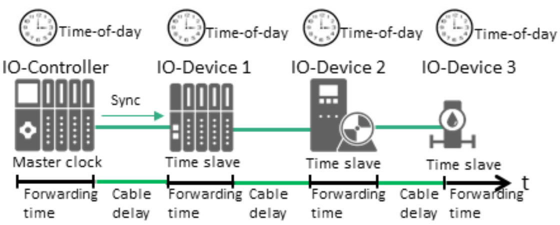

Fig. 26: Principle of time synchronization

The time-of-day master sends synchronization frames to the time-of-day slaves at certain time intervals. The cable and switch delay times are taken into account during their path through the network. As a result, the time-of-day slaves know how long the synchronization message took to go from the master clock to the slave and can take this into account in the time-of-day setting.

For time-of-day synchronization, PROFINET uses the generalized precision time protocol (gPTP), which is specified in IEEE 802.1 AS.

Cycle synchronization for IRT and drive control (Chapter 5) generally occurs according to the same procedure. A network-wide cycle and the relative times based on the clock master are of importance, too. However an absolute time of day is not required, here.

6.6 Fast Start Up

Fast **S**tart **U**p (FSU) defines an optimized system power-up in which data exchange begins much faster starting with the second power-up, as many parameters are already stored in the field device. This optional feature can be used in parallel with standard power-up (which is still used after a power-on in the case of the first power-up or reset). The communication parameters are stored persistently for this. A typical application would be the changing of robot tools, for example. .

6.7 Higher Availability through Media Redundancy

Wherever a production disruption can lead to high economic losses or a risk to the environment, high availability is required. To minimize the risk of a system standstill, redundant structures are selected. PROFINET provides various different options for communication, from simple media redundancy to complete system redundancy. Media redundancy is based on ring structures which quickly enable an alternative communication path in case of a fault. A variety of different options are available for system redundancy, depending on the requirement.

Media redundancy

Daisy chaining multiport switches allowed the star topology widely used in Ethernet to be effectively combined with a line structure. This combination is especially well-suited for control cabinet connection, i.e. line connection between control cabinets and star connection to the process-level field devices. If the connection between two field devices in a line is interrupted, the field devices situated after the interruption are no longer accessible. If increased availability is required, provisions must be made for redundant communication paths when planning the system, and field devices/ switches which support the redundancy concept of PROFINET must be used.

A redundant communication path can than be formed efficiently by closing a line to form a ring. In the event of an error, the connection to all nodes is ensured via the alternative connection. This achieves a tolerance for one fault. Organizational measures must be taken to ensure that this fault is eliminated before a second one occurs.

PROFINET has the following two mechanisms for setting up ring-shaped media redundancy, depending on the requirements:

Media Redundancy Protocol (MRP)

The MRP protocol according to IEC 62439-2 describes PROFINET redundancy with a typical reconfiguration time of less than 200 ms for communication paths with TCP/IP and RT frames after a fault. Error-free operation of an automation system involves a Media Redundancy Manager (MRM) and several Media Redundancy Clients (MRC) arranged in a ring as shown in Figure 27.

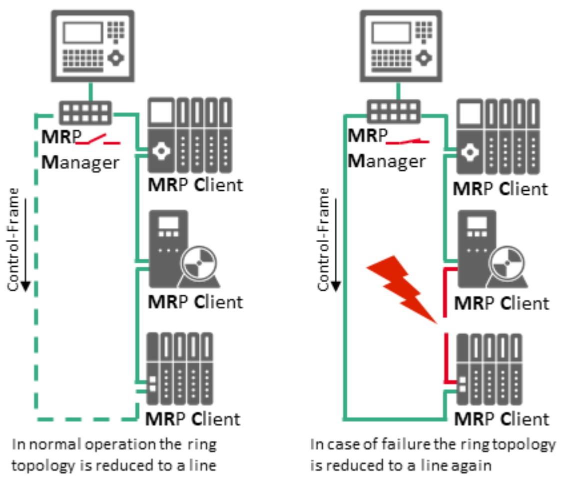

Fig. 27: Preventing circulation of frames through logical separation of the bus

The task of a Media Redundancy Manager (MRM) is to check the functional capability of the configured ring structure. This is done by sending out cyclic test frames (control frames). As long as it receives all of its test frames back, the ring structure is intact. For all other frames, the redundancy manager logically opens the ring. Through this behavior, an MRM converts a ring structure into a line structure and thus prevents the circulation of frames.

A Media Redundancy Client (MRC) is a switch that acts only as a "passer" of frames and generally does not assume an active role. In order for it to be integrated into a ring, it must have at least two switch ports.

Media Redundancy for Planned Duplication (MRPD)

IEC 61158 describes the redundancy concept MRPD (**M**edia **R**edundancy for **P**lanned **D**uplication) for IRT communication, which enables smooth switchover from one communication path to another in the event of a fault and is used together with MRP. This concept is based on ring redundancy. The IO controller sends the IO data to the devices in both directions of the ring at the same time. During system power-up, the IO controller loads the information of the communication paths for both communication channels (directions) in to the individual nodes in the ring. Thus it is immaterial which node fails because the loaded "schedule" for both paths is available in the field devices and is monitored and adhered to without exception. Loading of the "schedule" alone is sufficient to exclude frames from circulating in this variant: the recipient rejects the second (duplicate) frame.

6.8 Higher Availability through System Redundancy

Higher availability of the system is achieved when critical components are doubled. This is why the controllers are always designed with redundancy and, in most cases, coupled closely to one another on a company-specific basis to increase system availability. If a controller should fail, the second controller takes over operation within a very short period of time, usually without interrupting the process. For redundant communication between the controllers and the devices, PROFINET offers a scalable solution (see Figure 28).

S2 redundancy

Simple and easy communication with a redundant controller is achieved with S2 redundancy. The redundant IO controller is connected at the respective end of a PROFINET line. The IO devices establish two connections to the redundant controller: one to the "left" and one to the "right." One of the connections is active and connects the IO device to the active part of the redundant controller. If the active connection is interrupted or the active IO controller fails, switching to the second connection occurs in a very short period of time.

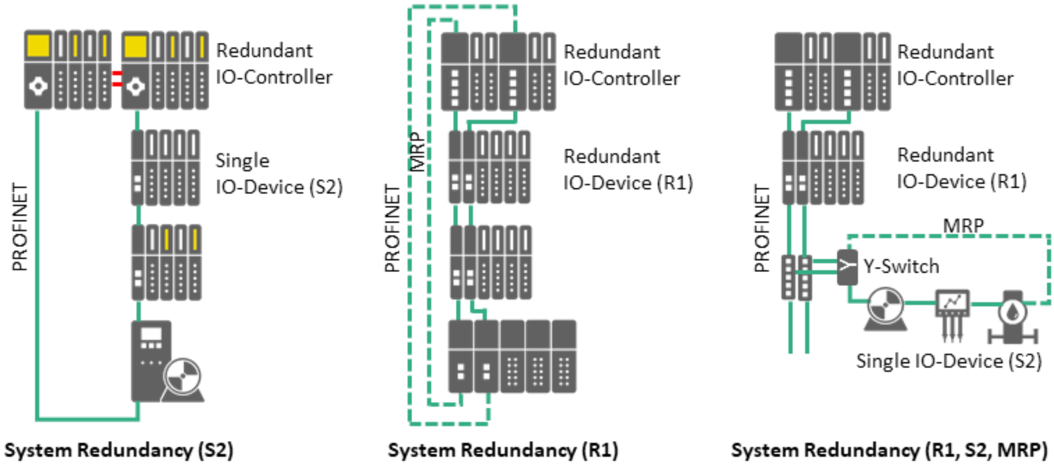

Fig. 28: Scalable system redundancy with PROFINET

R1 redundancy

With R1 redundancy, two PROFINET networks are installed. One network is assigned to each part of the redundant IO controller. The IO devices feature a separate communication interface for each network, i.e. their communication interfaces are designed for redundancy. To increase availability even further, both PROFINET networks can also be implemented as MRP rings. This enables the system to handle more than one fault, to an extent.

A combination of S2, R1 and MRP

Using a "Y-switch", an R1 system can be connected to an S2 system. The S2 system can also be an MRP ring if necessary. This makes it possible to connect IO devices (S2) which do not feature a redundant communication interface to an R1 system.

Additional information on system redundancy can be found in the "PN High Availability" [7.242] guideline (www.profibus.com/hapn).

6.9 Calling an Engineering Tool

Complex devices such as drives, laser scanners, etc. often have their own tools (engineering software and other tools) for changing settings on these IO devices. With the Tool Calling Interface (TCI), these device tools can now be called directly from the engineering system for parameter configuration and diagnostics. In this case, the communication of PROFINET is used directly to control the settings in the field device. In addition to the directly integrated device tools, other technologies such as the Electronic Device Description Language (EDDL) and the Field Device Tool (FDT) can also be used with appropriate adaptation software. TCI consists of the following main components:

Call interface: The user can call up various field device user interfaces (Device Tools, or DT) from the engineering system. Functions are primarily initiated in the device tools through user interaction.

Communication interface: The TCI communication server allows the field device user interface (DT) to communicate with the field device.

7. Integration of other Communication Systems

7.1 Integration of Fieldbuses

PROFINET specifies a model for integrating existing PROFIBUS systems and other fieldbus systems such as INTERBUS and DeviceNet (Figure 29). This means that any combination of fieldbus and PROFINET-based systems can be configured. Thus, a continuous technology transition from fieldbus-based systems to PROFINET is possible. The following requirements are taken into consideration here:

- The system owner would like to be able to easily integrate existing installations into a new PROFINET system to be installed.
- System and machine manufacturers would like the ability to use their proven and familiar devices for PROFINET automation projects without any modifications as well.
- Device manufacturers would like the ability to integrate their existing field devices into PROFINET systems without the need for costly modifications.

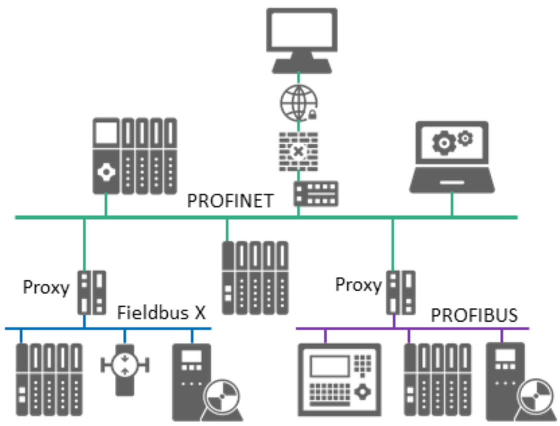

Fig. 29: Integration of fieldbus systems

Fieldbus solutions can be easily and seamlessly integrated into a PROFINET system using proxies and gateways. The proxy acts as a representative of the fieldbus devices. It integrates the nodes connected to a lower-level fieldbus system into the higher-level PROFINET system. This makes it possible to use the features of the fieldbuses in the world of PROFINET as well. The devices and software tools are also supported in the usual manner and integrated into the handling of the PROFINET system.

7.2 Integration of IO-Link

An IO-Link system provides the advantage of simple, uniform wiring and a considerably reduced variety of interfaces for the connection of sensors/actuators. This enables consistent communication between sensors/actuators and the controller.

IO-Link is a serial, bi-directional point-to-point connection for signal transmission and energy supply underlying any desired network, such as PROFINET (Figure 30).

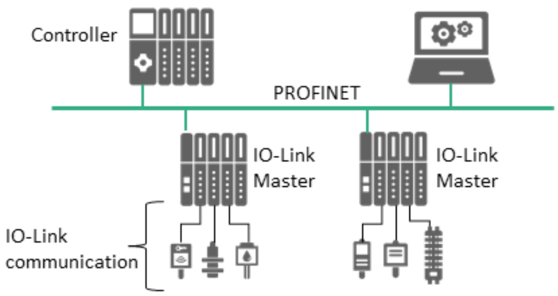

Fig. 30: Integration of IO-Link

In the configuration of the automation system, the IO-Link system is represented by the IO-Link master and integrated into the PROFINET system using the appropriate device description (e.g. GSD file). The IO-Link master itself can be a PROFINET node or part of a modular IO system connected to PROFINET. In both cases, the number of ports, the address range and the module properties are described in the device description of the IO-Link master.

The IO-Link system description provides a comprehensive overview and is available as a download (www.profibus.com/iolsd).

8. Application Profiles

By default, PROFINET transfers the specified data transparently. It is up to the user to interpret the sent or received data in the user program of a PC-based solution or Programmable Logic Controller individually.

Application profiles are joint specifications concerning certain properties, performance characteristics and behavior of devices and systems developed by manufacturers and users. The term "profile" can apply to a few specifications for a particular device class or a comprehensive set of specifications for applications in a particular industry sector.

Application profiles specify the form, i.e. syntax and meaning, in which process data and selected device parameters and device functions are exchanged between the nodes via the communication system. Application profiles thus describe the set of properties which must be implemented by "profile-compliant" devices in this class.

In general, a differentiation is made between two groups of application profiles:

General application profiles which can be used for different applications (examples of these include the PROFIsafe and PROFIenergy profiles).

Specific application profiles which were developed in each case only for a specific type of application, such as PROFIdrive or devices for process automation.

These application profiles are specified by PI based on market demand and are available on the PI website (www.profibus.com/download/profiles).

8.1 PROFIsafe

The PROFIsafe designation refers to the protocol defined in IEC61784-3-3 for the implementation of functional safety (fail-safe) and is recognized by IFA and TÜV. PROFIsafe can be used with PROFIBUS and PROFINET alike. Fail-safe (F) is the ability to reliably protect a system from hazards or to reduce the risk to an acceptable level with corresponding technical and organizational measures.

The use of PROFIsafe enables elements of a fail-safe controller to be transferred directly to standard, non-safety-related process data on the same network. The need for additional wiring is eliminated.

For PROFIsafe, the transmission channels are merely "black channels" as illustrated in Figure 31.

F-messages between an F-host (safety control) and its F-submodules are transported as the payload in PROFINET frames. The PROFIsafe protocol spares users from having to conduct the safety assessment of their individual backplane bus system and other channels beyond PROFINET. It thus guarantees the functional safety of the complete path, from the sender of an F-signal (e.g. F-submodule in a remote bus terminal) to the receiver (F-host) and vice versa. This is achieved through additional safety measures of the F-messages.

The measures include: consecutive numbering of F-messages ("sign-of-life"), a time expectation with acknowledgment ("watchdog"), an identifier between sender and recipient ("F-address") and a data integrity check (Cyclic Redundancy Check, or CRC).

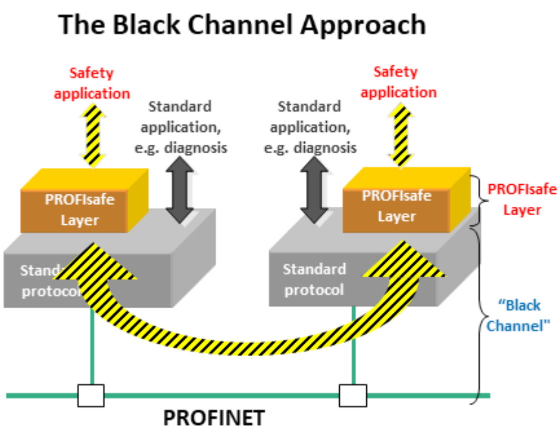

Fig. 31: The "black channel" principle

An introduction to PROFIsafe can be found in the "PROFIsafe System Description" [4.341], which is available as a free download (www.profibus.com/pssd).

The specification for PROFIsafe [3.192] is available as a free download for members (www.profibus.com/download/profisafe).

8.2 PROFIdrive

The PROFIdrive designation refers to the specification of a standardized drive interface for PROFIBUS and PROFINET. This application-oriented profile, which has been standardized in IEC 61800-7, contains standard definitions (syntax and semantics) for the communication between drives and automation systems, thus assuring manufacturer independence (Figure 32), interoperability, investment protection and simplified commissioning.

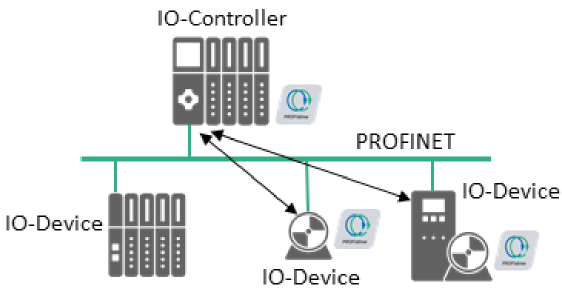

Fig. 32: Interoperability through PROFIdrive

The PROFIdrive application profile provides the foundation for many drive tasks in the field of industrial automation engineering. It defines the device behavior and the procedure for accessing the drive data of electric drives and also optimally integrates the additional PROFIsafe and PROFIenergy profiles.

An introduction to PROFIdrive can be found in the "PROFIdrive System Description" [4.321], which is available as a free download (www.profibus.com/pdsd).

The specification is available under [3.172] and is offered as a download for members (www.profibus.com/pdpdt).

8.3 PROFIenergy

The high cost of energy and compliance with legal obligations are compelling the industry to engage in energy conservation. Recent trends toward the use of efficient drives and optimized production processes have been accompanied by significant energy savings. However, in today's systems and production units, it is common for numerous energy consuming loads to continue running during pauses. PROFIenergy addresses this situation.

PROFIenergy enables active and effective energy management. By purposefully switching off unneeded consumers, energy demand and thus energy costs can be significantly reduced. PROFINET nodes in which PROFIenergy functionality is implemented can use the commands to react flexibly to idle times. In this way, individual devices or unneeded portions of a machine can be shut down during short pauses, while a whole system can be shut down in an orderly manner during long pauses. Using PROFIenergy, it is also possible to measure and optimize the energy consumption of production (reading out energy values). The specification for PROFIenergy is available under [3.802]. Members can obtain it directly as a download (www.profibus.com/download/profienergy).

9. PROFINET for Process Automation

Compared to factory automation, process automation has a few special characteristics which significantly influence the use of automation.

Extra-long service life:

Systems can have a service life of many decades. This results in system owners' demanding the functional coexistence of older and newer technologies and for consistent technology transitions for the integration of existing devices. Consistency is also based on the existing engineering, diagnostics and maintenance tools.

Extreme reliability:

In addition, requirements for the reliability of process systems, particularly in continuous processes, are often considerably greater than in production systems. In classical applications in the process industry, system standstills can lead to considerable disruptions and downtimes and lead to damage to systems or the environment.

Figure 33 shows an example of the solution options for the process industry.

Powerful gateways enable the consistent integration of PROFIBUS DP and PROFIBUS PA fieldbuses and the existing development of the wide product spectrum available there. Communication includes the exchange of cyclic and acyclic data, the integration and parameter configuration of the devices, diagnostics and maintenance.

Available devices with 4 – 20 mA or HART interfaces can communicate using corresponding remote IO systems over PROFNET.

Devices in hazardous zones can also be integrated in these ways.

Field devices in the process industry without explosion-prevention requirements are increasingly being networked directly via PROFINET. This applies in particular for devices with high data volumes or short response times.

Solutions are in development to use Ethernet (Advanced Physical Layer or APL) for the limited-energy bus feed of devices in hazardous areas (Zone 1).

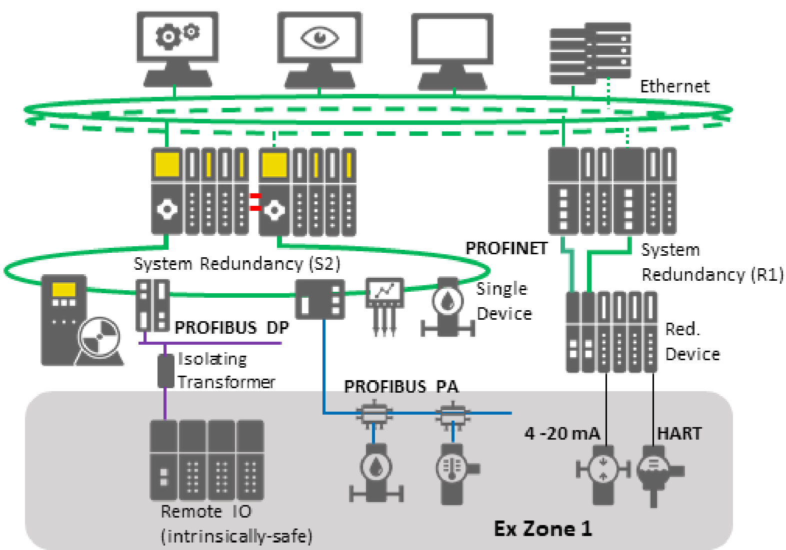

Fig. 33: PROFINET in process automation

The reliability of the system is achieved through redundancy solutions extending from simple media redundancy to complete system redundancy, depending on the process-technical requirements.

A white paper in which the current and future technological developments are described is available for PROFINET in process automation. It is available as a download (www.profibus.com/pnipa).

The PA profile for PROFINET specifies typical functions of process control devices and is available as a free download for members (www.profibus.com/pcd).

For a CC-A network, complete networking with active and passive components according to ISO/IEC11801 is allowed, taking the CC-A cabling guideline into consideration. Likewise, active infrastructure components (e.g. switches) according to IEEE 801.x can be used if they support the VLAN tag with prioritization.

Easy-to-understand and systematically structured instructions have been prepared to enable problem-free planning, installation and commissioning of PROFINET networks: [8.061], [8.071] and [8.081]. These are available to any interested party on the PI website. These manuals should be consulted for further information (www.profibus.com/pnig).

10. Network Installation

PROFINET is based on a 100 Mbps, full-duplex Ethernet network. Faster communication is also possible on all transmission sections (e.g. between switches, PC systems and camera systems).

PROFINET defines not only functionality, but the passive infrastructure components (cabling and connectors) as well. Communication may take place via copper or fiber-optic cables. In a conformance Class A (CC-A) network, communication is also allowed over wireless transmission systems (Bluetooth and WLAN) (Table 4).

The cabling guideline defines 2-pair cabling according to IEC 61784-5-3 for all Conformance Classes. For transmission systems with Gigabit cabling requirements, 4-pair cabling may also be used.

10.1 Network Configuration

PROFINET field devices are always connected as network components via switches. Switches integrated in the field device are typically used for this. Using an integrated switch, the field device can make two (or more) ports available externally. This makes devices like this ideal for line, star, tree and ring structures. PROFINET-suitable switches must support "auto negotiation" (negotiation of transmission parameters) and "auto crossover" (autonomous crossing of send and receive lines). As a result, communication can be established automatically and fabrication of the transmission cable is uniform: 1:1 wired cables can be used throughout.

In addition, the switches must support VLAN tagging with prioritization.

VLAN tagging with prioritization is the basis for reliable RT communication in PROFINET networks.

Network cabling and infrastructure components	Solution	Conformance Class
Passive network components (connectors and cables)	RJ45, M12 and M8	A, B and C
Copper and fiber-optic transmission systems	TX, FX and LX	A, B and C
Wireless connections	WLAN and Bluetooth	A
IT switch	With VLAN tag according to IEEE 802.x	A
Switch with device function	PROFINET with RT	B
Switch with device function and bandwidth reservation	PROFINET with IRT	C

Tab. 4: Network installation for different Conformance Classes

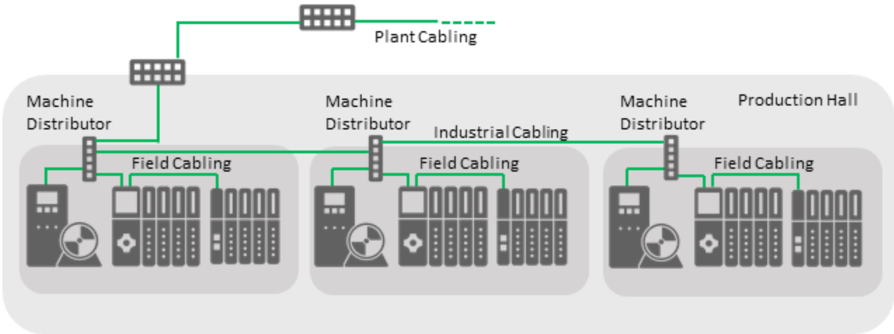

Fig. 34: Ethernet networks in industrial environments usually have line topology

PROFINET supports the following topologies for Ethernet communication:

- Line topology, which primarily connects terminals with integrated switches in the field (Figure 34).
- Star topology, which requires a central switch located preferably in the control cabinet.
- Ring topology, in which a line is closed to form a ring in order to achieve media redundancy.
- Tree topology, in which the topologies mentioned above are combined.

10.2 Cables for PROFINET

The maximum segment length for **electrical data transmission** with copper cables between two nodes (field devices or switches) is 100 m. The copper cables are implemented uniformly in AWG 22. The installation guideline defines different cable types that have been optimally adapted to their respective industrial applications. Sufficient system reserves allows installations that are suitable for industraial use with no limitation on transmission distance.

PROFINET cables types conform to the cable types required in industry:

PROFINET type A: Standard permanently-routed cable, no movement after installation

PROFINET type B: Standard flexible cable, occasional movement or vibration

PROFINET type C: Special applications: Highly-flexible, constant movement (tow-chain or torsion, for example)

PROFINET type R: Robot applications, tested specifically for this application

Fiber-optic data transmission with fiber-optic cable has several advantages over copper:

- Electrical isolation when equipotential bonding is difficult to achieve
- Immunity against extreme Electromagnetic Compatibility (EMC) disturbances
- Transmission over distances of up to several kilometers without using repeaters

For short distances, the use of 1 mm Polymer Optic Fibers (POF) is supported, the handling of which conforms optimally to industrial applications.

10.3 Connectors

Connectors are classified based on their degree of environmental protection. They have been subdivided into one class for use inside protected environments, such as in a control cabinet, and one class for use outside of control cabinets such as those located directly in the field (Figure 35).

The selection of suitable PROFINET plug connectors is dependent upon the application. If the emphasis is on a universal network which is to be office-compatible, electrical data transmission occurs via RJ 45, which is prescribed universally for 'inside' environmental conditions. For 'outside' environments, a push-pull plug connector also fitted with the RJ 45 connector for electrical data transmission has been developed. M12 and M8 variants are also specified for PROFINET.

For **optical data transmission** with Polymer Optic Fibers, the SCRJ plug connector based on the SC plug connector is specified. The SCRJ is used both for inside environments as well as in combination with a push-pull housing for use in outside environments.

At the same time, plug connectors are also specified for the **power supply**, depending on the topology and the supply voltage. Besides the push-pull plug connector, a 7/8" plug connector, a hybrid plug connector, an M12 A or an M12 L plug connector can be used. The differences between these connectors lie in their connectible cross sections and thus their maximum amperages.

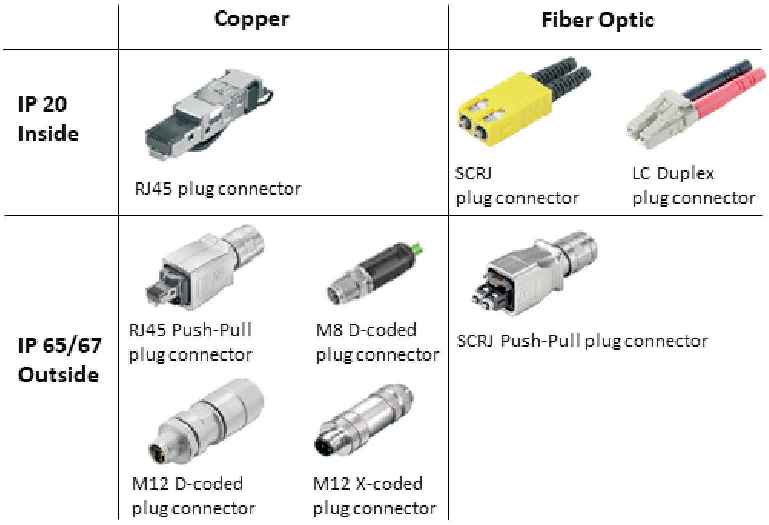

Fig. 35: PROFINET offers a range of industrial plug connectors

Detailed information on PROFINET plugs can be found in the "PROFINET Cabling and Interconnection Technology" guideline available for download (www.profibus.com/pncit).

10.4 Security

For networking within a larger production facility or over the Internet, PROFINET relies on a layered security concept. This recommends a security concept optimized for the specific application case, with one or more upstream security zones (see Figure 36). On the one hand, this unburdens the PROFINET devices, and on the other, it allows the security concept to be optimized to changing security requirements in a consistent automation engineering solution.

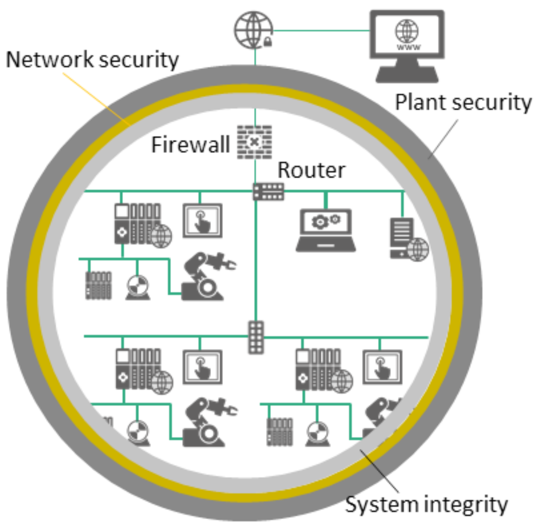

Fig. 36: Security concept with multiple security zones

The security concept provides for the protection of both individual devices as well as whole networks from unauthorized access. In addition, there are security modules that will allow networks to be segmented and thus also separated and protected from a safety standpoint. Only explicitly identified and authorized messages reach the devices located inside such segments from the outside. Additional information regarding security can be found in the "PROFINET Security Guideline" [7.002], which is available for download (www.profibus.com/pnsg).

11. PROFINET Technology and Certification

PROFINET is standardized in IEC 61158 and IEC 61784-2. It enables devices in industrial systems to be networked together and exchange their data with one another in a standardized way. Appropriate quality assurance measures are required to ensure interoperability in automation systems. For this reason, PI has established a certification process for PROFINET devices in which certificates are issued based on test reports from accredited test labs. While PI certification of a field device is not yet required for PROFIBUS, the guidelines for PROFINET have changed such that any field device bearing the name PROFINET must be certified. Since 1990, experience with PROFIBUS has shown that a very high-quality standard is needed in order to protect automation systems as well as system owners and field device manufacturers.

11.1 Technology Support

Device manufacturers who wish to develop an interface for PROFINET can develop field devices based on existing Ethernet controllers. Alternatively, member companies of PI offer many options for efficient implementation of a PROFINET interface. To make development easier for device manufacturers, PI Competence Centers and member companies offer PROFINET base technology (enabling technology). Consulting services and special developer training programs are also available. Before starting a PROFINET development project, device manufacturers should always perform an analysis to determine whether internal development of a PROFINET device is cost-effective or whether the use of a ready-made communication module will satisfy their requirements.

More detailed information on this topic can be found in the "PROFINET Technology – The Easy Way to PROFINET" [4.271] (www.profibus.com/pntb) and "PROFINET Field Devices – Recommendations for Design and Implementation" [8.201] (www.profibus.com/pnfd) brochures , which can be downloaded from the PI website.

Targeted information on implementation is also available here: www.profibus.com/pni.

11.2 Tools for Product Development

Software tools are made available to device manufacturers for the development and checking of their products. A GSDML editor assists the manufacturer when creating the GSD file for its product. With this GSDML editor, these files can be created properly and checked.

For PROFINET, free of charge test bundle with test descriptions and testing tools is available for PI members. This same test bundle is used by the test labs for certification testing as well. Visit: www.profibus.com/certification).

11.3 Certification Test

Accredited PI Test Labs perform the largely automated certification test to all manufacturers. Test experts at PI Test Labs are available to provide support in carrying out tests and evaluating the results. The test scope is described in a test specification. The tests are implemented as so-called black box tests in which the tester acts as a real application.

The defined test cases developed for use during a certification test are real world-oriented and are based on industrial automation. This affords all users the maximum possible assurance for use of the field device in a system from the beginning.

PI awards the PROFINET certificate to the manufacturer based on the test report from an accredited PI Test Labs. A product must have this certificate in order use the PROFINET designation. For the system manufacturer/operator, the use of certified products means time savings during commissioning and stable behavior for the entire service life. For this reason, end-users are encouraged to request certificates from their suppliers for the field devices used in accordance with the utilized Conformance Class, application class and profiles.

12. Standardization

The PROFINET concept was defined in close collaboration with end-users based on standard Ethernet according to IEEE 802 in IEC 61158 and IEC 61784. Figure 37 lists additional specifications of other functionalities in the form of different joint profiles. These form the basis for device- and application-specific profiles. Instructions are then created for the necessary planning, engineering and commissioning steps. The bases of these form the guidelines used in the engineering of PROFINET systems.

13. PROFIBUS & PROFINET International (PI)

As far as maintenance, ongoing development and market penetration are concerned, open technologies need a company-independent institution which can serve as a working platform. This was achieved for the PROFIBUS and PROFINET technologies through the founding of the PROFIBUS Nutzerorganisation e.V. (PNO) in 1989 as a non-profit interest group for manufacturers, users and institutions. The PNO is a member of PI (PROFIBUS & PROFINET International), an umbrella group which was founded in 1995. With its 25 Regional PI Associations (RPA) and approximately 1,400 members, PI is represented on every continent and is the world's largest interest group in the field of industrial communication (Figure 38).

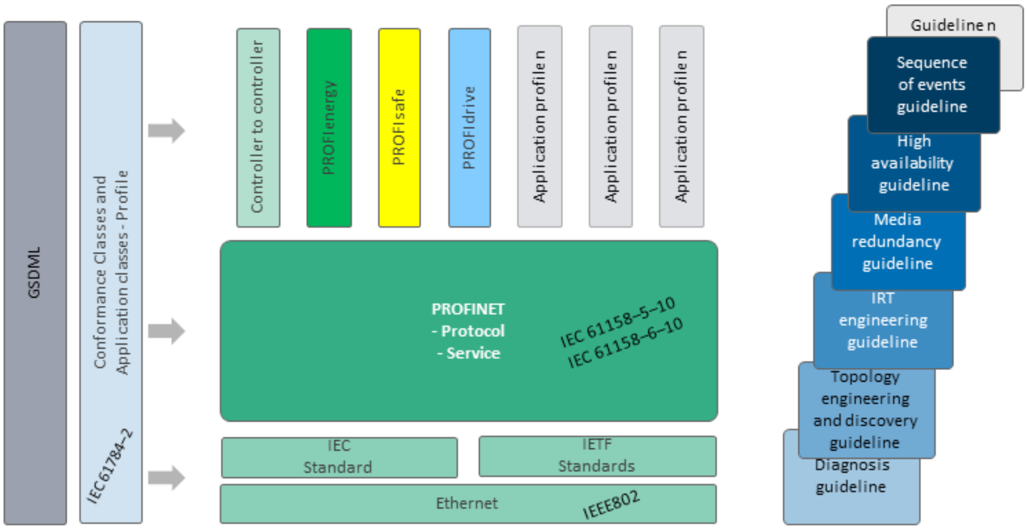

Fig. 37: Structure of standards

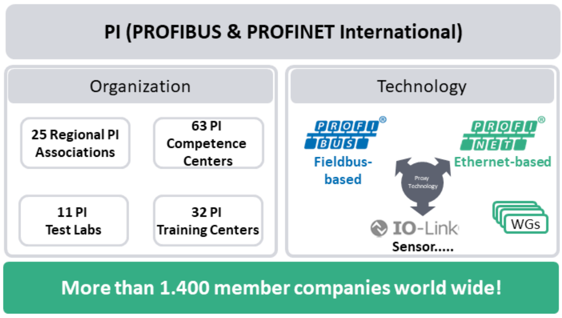

Fig. 38: PROFIBUS & PROFINET International (PI)

The key tasks performed by PI are:

- Maintenance and ongoing development of PROFIBUS and PROFINET
- Promotion of the worldwide use of PROFIBUS and PROFINET
- Protection of investment for users and manufacturers by influencing the development of standards
- Representation of the interests of members to standards bodies and unions
- Worldwide technical support of companies through PI Competence Centers (PICC)
- Quality assurance through product certification based on conformity tests at PI Test Labs (PITL)
- Establishment of a worldwide training standard through PI Training Centers (PITC)

Technology development

PI has handed responsibility for technology development over to PNO Germany. The advisory board of PNO Germany oversees development activities. Technology development takes place in the context of more than 40 Working Groups (WG) with input from approximately 1,000 experts, mostly from engineering departments of member companies.

Technical support

PI supports more than 60 accredited PI Competence Centers (PICC) worldwide. These facilities provide users and manufacturers with various types of advice and support. As institutions under PI, they are independent service providers and adhere to mutually agreed-upon rules. PICCs are regularly checked for their suitability as part of an individually tailored accreditation process. Contact information for each can be found on the website.

Certification

PI supports approximately. 10 accredited PI Test Labs (PITL) worldwide, which assist in the certification of products with a PROFIBUS/PROFINET interface. As institutions under PI, they are manufacturer independent test service providers and adhere to mutually agreed-upon rules. The testing services provided by the PITLs are regularly audited in accordance with a strict accreditation process to ensure that they meet the necessary quality requirements. Contact information for each can be found on the website.

Training

More than 30 PI Training Centers have been set up with the aim of establishing a global training standard for engineers and technicians. Accreditation of the Training Centers and the experts based there ensures the quality of the training and thus the quality of the engineering and installation services for PROFIBUS and PROFINET. Current addresses can be found on the website.

Internet

Current information on PI and the PROFIBUS and PROFINET technologies is available on the PI website www.profibus.com or www.profinet.com . This includes, for example, an online product finder, a glossary, a variety of web-based training content and the download area containing specifications, profiles, installation guidelines and other documents.

14. Outlook

Current further developments in industrial automation are predominantly engaged with the topic of Industrie 4.0. This primarily concerns industrial communication, as IT networks and automation networks are increasingly merging. Two important building blocks for Industrie 4.0 are TSN and OPC UA.

14.1 Time-Sensitive Networking (TSN)

The goal of TSN is the provision of means for implementing real-time-capable Ethernet. While PROFINET was developed for automation, TSN targets a larger area of application and is fully specified in the IEEE 802 organization, which is relevant for Ethernet. Future areas of application will include audio/video streaming and real-time networks in the automotive field and in industrial systems. TSN is comprised of many individual IEEE standards, not all of which are required for a TSN network. To define a TSN profile for optimal use in industrial plants, the IEC an IEEE hafe formed a Joint Working Group with the aim of publishing it as standard IEC/IEEE 60802.

To achieve open, real-time-capable Ethernet, TSN uses principles comparable to those with IRT:

- High-precision time synchronization
- Processing of communication in cycles
- Division of communication cycles into a real-time phase and a phase for the remaining traffic
- Communication planning
- Consideration of alternate communication paths

Detailed information on TSN is available on the IEEE website: https://1.ieee802.org/tsn/.

14.2 Open Platform Communications Unified Architecture (OPC UA)

OPC is a standardized interface for data exchange between different technological systems in industrial networks and is based on the client/server principle. An OPC client requests data from an OPC server and provides it to its application. The OPC server receives data and maps it to OPC objects (see Figure 39). OPC drivers for the various different communication methods used in the automation system mask those differences below the OPC server.

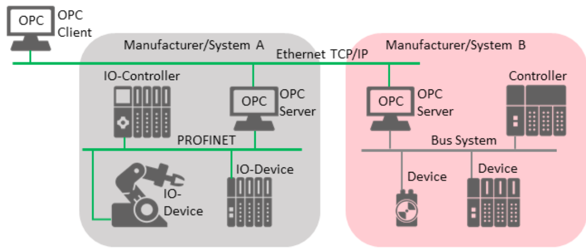

Fig. 39: OPC enables uniform communication with different systems

The latest specification for OPC is OPC Unified Architecture (OPC UA). As opposed to the OPC Classic specification, it is platform-independent. With OPC UA, the transmission of machine data, interfaces, security mechanisms and the semantic structure of data are described. OPC UA uses a service-oriented, Internet-friendly architecture.

For Industrie 4.0 and the interaction with TSN, expansions were made to OPC UA to enable a publish/subscribe mechanism, for example.

OPC UA is described in a series of IEC standards. The coordination and further development of these standards occur at the OPC Foundation. Detailed information on OPC UA can be found on the OPC Foundation website: https://opcfoundation.org.

14.3 Industrie 4.0

With Industrie 4.0, the digitalization of industrial production is to be improved through the use of the latest communication technologies. Intelligently networked systems are to enable production which is as self-organizing as possible. In addition, networking is to allow the entire life cycle of a product to be recorded, from the initial idea to development, production, maintenance and recycling. The basis for this is internationally standardized communication technologies, interfaces and object descriptions. The networking of machines, devices, sensors, actuators and people is of great importance.

To ensure standardized communication among machines and with higher-level systems and cloud services, uniform international communication standards are required. OPC UA and TSN are two building blocks for achieving this goal.

14.4 The Procedure of PI

TSN and PROFINET

PI is currently working on the use of TSN for PROFINET. The advantages:

- Use of future-proof IEEE technology with data rates from 10 Mbps to 10 Gbps
- Scalable integration
- User interaction remains unchanged
- Network convergence through support of the IEC/IEEE 60802 TSN industrial automation profile

Based on the ISO/OSI model, an additional real-time-capable foundation is provided by the TSN extensions to Ethernet, which can be used by the protocol layers above. Thus, the PROFINET stack can also use TSN as its foundation. This is why the tried-and-tested PROFINET user view of data, parameter configuration, diagnostics and profiles such as PROFIsafe and PROFIdrive can be used without modification (see Figure 40).

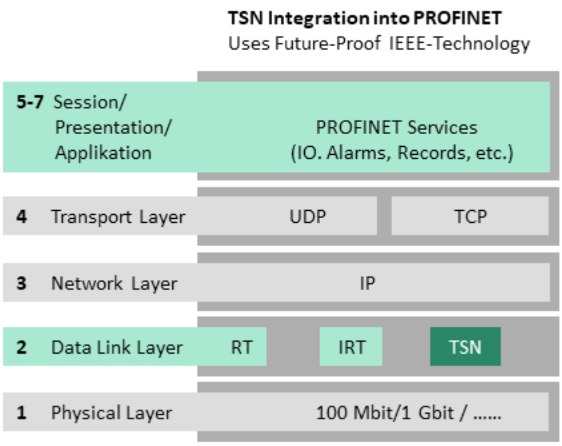

Fig. 40: TSN integration in PROFINET

OPC UA and PROFINET

Thanks to its open system structure, OPC UA and PROFINET can use the same network and form an ideal combination for Industrie 4.0. Typical applications include:

- Provisioning asset management and diagnostic information
- Controller-to-controller communication
- Vertical communication
- Linking to cloud services

The required information is presented using the objects defined in the OPC UA standard and can be used by any manufacturer (see Figure 41).

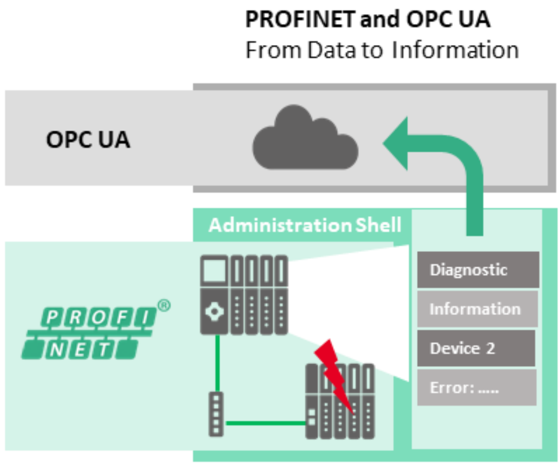

Fig. 41: PROFINET and OPC UA

Furthermore, PI is leveraging its application profiles in its joint working group with the OPC Foundation with the aim of creating open information models. These can be made easily available to IT systems via OPC UA. PI's application expertise is resulting in the development of companion specifications for OPC UA. Companion specifications describe the data objects and sequences for certain areas of application, comparable to the application profile definitions. The first companion specifications describe the mapping of the diagnostic and asset management information and deal with the topic of PROFIsafe over OPC UA for controller-to-controller communication.

Additional information on Industrie 4.0 and the procedure used by PI can be found on the PI website (www.profibus.com/i40):

15. Glossary

Abbreviations used in this document:

AMR	Asset Management Record
APL	Advanced Physical Layer
API	Application Process Identifier/Instance
AR	Application Relation
ASIC	Application-specific integrated circuit
CC	Conformance Class
CR	Communication Relations
DAP	Device access point
DFP	Dynamic Frame Packing
DR	Dynamic Reconfiguration
DT	Device Tool
EDDL	Electronic device description language
EMC	Electromagnetic compatibility
F	Fail-safe
FDT	Field Device Tool
FSU	Fast Start Up
gPTP	Generalized Precision Time Protocol
GSD	General Station Description
GSDML	GSD Markup Language
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IO controller	Controller in which the automation program runs
IO device	Decentralized field device
IO-Link	Communication standard for actuators and sensors
IO supervisor	PC/PG for commissioning and diagnostic purposes
IP codes	International Protection codes
IP20	Protected against solid foreign objects with diameter of 12.5 mm or more
IP65	Protected from dust and water jets
IP67	Protected from dust and temporary immersion
IRT	Isochronous Real-Time
IT	Information Technology
I&M	Identification and Maintenance
LC	Lucent Connector
LLDP	Link Layer Discovery Protocol
FOC	Fiber-Optic Cable
MAC	Media Access Control
M12	Circular connector with metric thread
MRP	Media Redundancy Protocol
MRPD	Media Redundancy for Planned Duplication
OPC	Open Platform Communication
OPC UA	OPC Unified Architecture

OUI	Organizationally Unique Identifier
PC	Personal computer
PDEV	**P**hysical **Dev**ice
PG	Programming device
PI	PROFIBUS & PROFINET International
PICC	PI Competence Center
PITL	PI Test Lab
PNO	PROFIBUS Nutzerorganisation e.V. (www.profibus.de)
POF	Polymer Optical Fibers
RJ	Registered jack (standardized socket)
RJ45	Standardized connector for Ethernet
RPA	Regional PI Association
SCRJ	Connector for FOC transmission
SIL	Safety Integrity Level
SNMP	Simple Network Management Protocol
SoE	Sequence of Events
PLC	Programmable Logic Controller
TCI	Tool Calling Interface
TCP/IP	Transmission Control Protocol/Internet protocol
TSN	Time-Sensitive Networking
VLAN	Virtual Local Area Network
WG	Working Group
XML	Extensible Markup Language

16. References

This system description is based on the PI documents listed below, which can be downloaded from the PI website (some of these documents are only free of charge for members). In addition, useful manuals for system planners and owners are also listed. The materials can also be ordered through the following link: www.profibus.com/OrderForm.

PROFINET Installation Guidelines:

[8.061] PROFINET Design Guideline

[8.071] PROFINET Guideline for Cabling and Assembly

[8.081] PROFINET Guideline for Commissioning

www.profibus.com/download/profinet-installation-guidelines/

System descriptions, guidelines and recommendations from PI:

[4.321] PROFIdrive Technology and Application - System Description
www.profibus.com/pdsd

[4.341] PROFIsafe Technology and Application - System Description
www.profibus.com/pssd

[4.271] The easy Way to PROFINET Technology
www.profibus.com/pntb

[7.002] PROFINET Security Guideline
www.profibus.com/pnsg

[7.041] PROFINET IO Conformance Classes, Guideline for PROFINET IO
www.profibus.com/pncc

[7.242] High Availibility for PROFINET
www.profibus.com/hapn

[7.142] Diagnosis for PROFINET, Guideline for PROFINET
www.profibus.com/dpn

[7.162] Fiber Optic Diagnosis, Guideline for PROFINET
www.profibus.com/download/fiber-optic-diagnosis

[7.172] PROFINET IRT Engineering, Guideline for PROFINET
www.profibus.com/pnirt

[7.182] Topology and Asset Discovery for PROFINET, Guideline for PROFINET
www.profibus.com/download/topology-and-asset-discovery-for-profinet/

[8.201] PROFINET Field Devices, Recommendations for Design and Implementation
www.profibus.com/pnfd

[10.391] IO-Link Technology and Application - System Description
www.profibus.com/iolsd

[2.252] PROFINET Cabling and Interconnection Technology
www.profibus.com/pncit

Profile secification:

[3.172] PROFIdrive - Profile Drive Technology
www.profibus.com/pdpdt

[3.192] PROFIsafe
www.profibus.com/download/profisafe

[3.502] Profile Guidelines Part 1: Identification & Maintenance Functions
www.profibus.com/imf

[3.802] PROFIenergy
www.profibus.com/download/profienergy

[3.042] Process Control Devices
www.profibus.com/pcd

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Technology and Application

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For additional information go to:
www.profinet.com/technology/profinet/

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