PI PROFIBUS · PROFINET

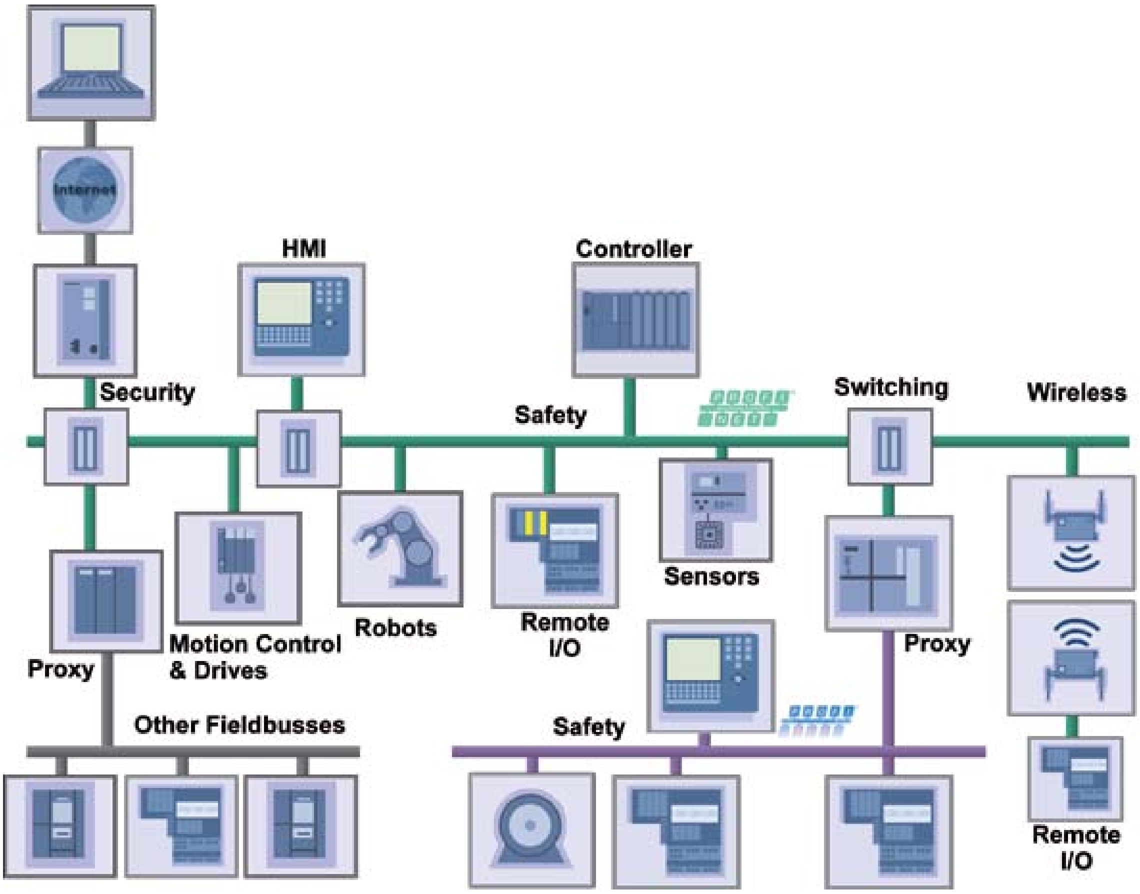
PROFINET
System Description

Technology and Application

Open Solutions for the World of Automation

PROFIBUS PROCESS FIELD BUS

PROFINET INDUSTRIAL ETHERNET



Introduction

The ever-shorter innovation cycles for new products makes the continuous evolution of automation technology necessary. The use of fieldbus technology has been a significant innovation in the past few years. It enabled the migration of centralized automation systems to distributed automation systems. PROFIBUS, as a global market leader, has set the benchmarks for 20 years.

In today's automation technology, moreover, Ethernet and information technology (IT) is increasingly calling the shots with established standards like TCP/IP and XML. The integration of information technology into automation is opening up opportunities for significantly improved communication between automation systems, far-ranging configurations and diagnostics, and network-wide service functions. These functions have been integral components of PROFINET from the outset.

PROFINET is the innovative open standard for Industrial Ethernet. PROFINET satisfies all requirements of automation technology. PROFINET enables solutions to be developed for factory automation, process automation, safety applications, and the entire range of drive technology up to and including isochronous motion control applications.

Besides the real-time capability and the use of IT technology, protection of investment also plays an important role in PROFINET. PROFINET allows existing fieldbus systems such as PROFIBUS DP, PROFIBUS PA, AS-Interface, INTERBUS, and DeviceNet to be integrated without changes to existing field devices. That means that the investments of plant operators, machine and plant manufacturers, and device manufacturers are all protected.

The use of open standards, simple handling, and the integration of existing system components has driven the definition of PROFINET from the beginning. PROFINET is standardized in IEC 61158 and IEC 61784.

The ongoing further development of PROFINET offers users a long-term view for the implementation of their automation tasks.

For plant and machine manufacturers, the use of PROFINET minimizes the costs for installation, engineering, and commissioning. For plant operators, PROFINET offers ease of plant expansion and high system availability due to autonomously running plant units and low maintenance requirements.

The mandatory certification for PROFINET devices ensures a high quality standard.

Contents

1. PROFINET at a Glance

PROFINET is the automation standard of PROFIBUS&PROFINET International (PI). PROFINET is 100% Ethernet-compatible as defined in IEEE Standards. With PROFINET, the following minimum data communication requirements are automatically established:

- 100 Mbps data communication with copper or fiber optic transmission (100 Base TX and 100 Base FX)
- Full duplex transmission
- Switched Ethernet
- Autonegotiation (negotiating of transmission parameters)
- Autocrossover (sending and receiving lines are crossed in the switch)
- Wireless communication (WLAN and Bluetooth)

PROFINET uses UDP/IP as the higher level protocol for demand-oriented data exchange. UDP (User Datagram Protocol) contains the non-secure, connectionless broadcast communication in conjunction with IP. In parallel to UDP/IP communication, cyclic data exchange in PROFINET is based on a scalable real-time concept.

1.1 PROFINET IO Highlights

The four key functions of PROFINET are:

- Performance: automation in real-time
- Safety: safety-related communication with PROFIsafe
- Diagnostics: high plant availability due to fast commissioning and efficient troubleshooting
- Investment protection: seamless integration of fieldbus systems

In addition, PROFINET offers a series of special functions.

Device replacement without ES tool
Failure of a PROFINET device is detected and signaled automatically. No special knowledge is required to replace the device. Any replacement device in the warehouse can be installed in the automation system. Addressing as well as loading of required parameters is carried out automatically. Devices having an incorrect degree of expansion are detected automatically during power-up.

Engineering
Through support of the Tool Calling Interface (TCI), any field device manufacturer can interact with any TCI-capable engineering system (ES) and communicate with „its" field devices (Device Tool) from the ES for purposes of assigning parameters and performing diagnostics.

Saving of individual parameters (iPar server)
Parameters determined on a plant-specific basis are saved and loaded autonomously. The iPar server allows vendor-neutral loading (e.g., via TCI) of individually-assigned parameters optimized for the specific plant as well as automatic archiving on a parameter server. Downloading also occurs automatically during device replacement.

Plant topology
Visualization of the plant topology in conjunction with informative diagnostics is integrated in PROFINET.

Plant diagnostics
PROFINET supports convenient plant diagnostics through a combination of basic services available as standard features in the higher-level controller
.

Isochronous data transmission
With PROFINET, deterministic and isochronous transmission of time-critical process data is possible within a period of a few hundred µs. PROFINET requires this deterministic communication, for example, for high-accuracy closed-loop control tasks.

Redundancy concept
PROFINET offers a scalable redundancy concept, which guarantees smooth changeover from one communication path to the other in the event of a fault. The redundancy concept defined in PROFINET increases the plant availability significantly.

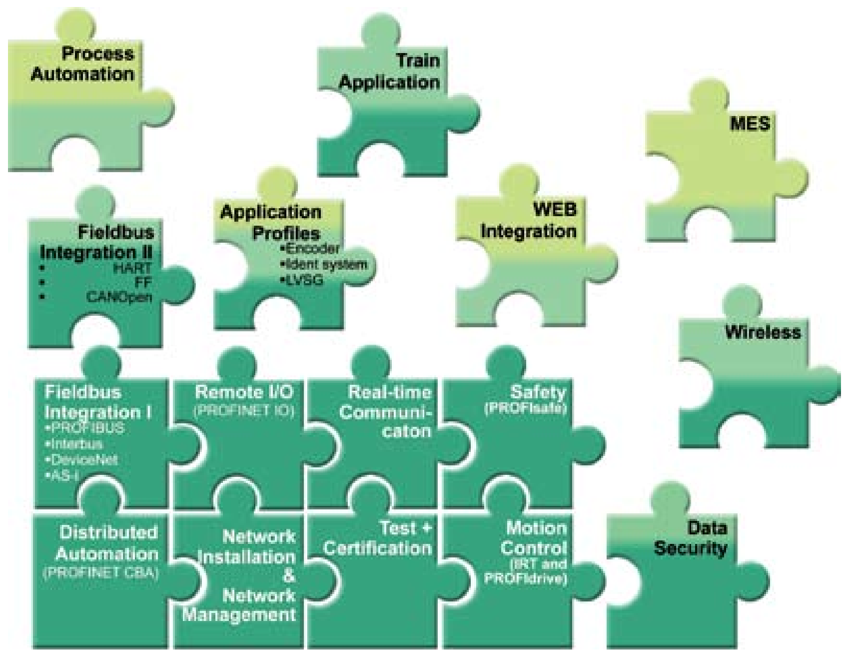


Figure 1.1: Functionality of PROFINET is scalable.

Very simple device replacement
The integrated neighborhood detection functionality enables PROFINET field devices to identify their neighbors. Thus, in the event of a problem, field devices can be replaced without additional tools or prior knowledge. This information can be used to represent the plant topology in a very easy to understand graphic display.

1.2 Standardization

PROFINET IO has been incorporated in the current edition of IEC 61158. IEC 61784 describes the subsets of the services specified in IEC 61158 that are to be applied for PROFINET.

The PROFINET concept was defined in close cooperation with end users. Additions to the standard Ethernet protocol as defined in IEEE 802 were made by PI only in cases where the existing standard could not meet the requirements in a satisfactory manner.

1.3 Scope of application of PROFINET

PROFINET satisfies all requirements of automation technology. The many years of experience with PROFIBUS and the widespread use of Industrial Ethernet have been rolled into PROFINET.

The use of IT standards, simple handling, and the integration of existing system components have driven the definition of PROFINET from the beginning. The figure below summarizes the functionality currently provided by PROFINET.

The ongoing further development of PROFINET offers users a long-term view for the implementation of their automation tasks.

For **plant and machine manufacturers**, the use of PROFINET minimizes the costs for installation, engineering, and commissioning.

The **plant operator** benefits from the ease of plant expansion and high availability due to autonomously running plant units.

Establishment of the proven certification process ensures a high standard of quality for PROFINET products.

Use of the user profiles defined up to now means that PROFINET can be used in virtually every sector of automation engineering. PROFINET profiles for the process industry and for train applications are currently under development.

1.4 Perspectives on PROFINET

The PROFINET concept is a modular concept that allows the user to chose the functionality he requires.

The functionality differs mainly in terms of the type of data exchange. This distinction is necessary to satisfy the very stringent requirements for data transmission speed that exist for some applications. Figure 1.2 shows the relationship between the PROFINET CBA and PROFINET IO perspectives. Both communication paths can be used in parallel.

PROFINET CBA is suitable for component-based machine-to-machine communication via TCP/IP and for real-time communication to meet real-time requirements in modular plant manufacturing. It enables a simple modular design of plants and production lines based on distributed intelligence using graphics-based configuration of communication between intelligent modules.

PROFINET IO describes an I/O data view on distributed I/O. PROFINET IO features real-time (RT) communication and isochronous real-time (IRT) communication with the distributed I/O. The designations RT and IRT are used solely to describe the real-time properties of communication.

PROFINET CBA and PROFINET IO can be operated separately and in combination such that a PROFINET IO unit appears in the plant view as a PROFINET CBA plant.

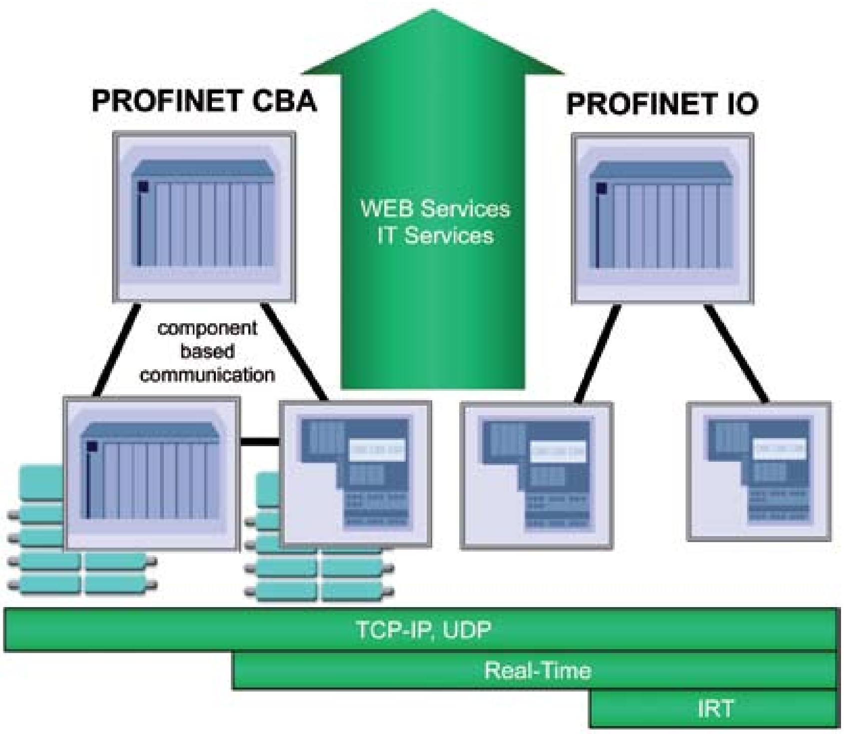


Figure 1.2: PROFINET perspectives.

1.5 Component model (PROFINET CBA)

This variant is defined in PROFINET CBA (Component Based Automation). Its strength is revealed in communication between Programmable Logic Controllers (PLC). The basic idea behind CBA is that whole automation systems can be often be grouped into autonomously operating and, thus, very clearly arranged units. The structure and functionality can be repeated in identical, or slightly modified, form in multiple plants. These so-called PROFINET components are generally controlled by an easily identified set of input signals. Within the component, a control program written by the user executes the required functionality of the component and sends the corresponding output signals to another controller. The engineering associated with this is vendor-neutral. Communication in a component-based system is configured rather than programmed. The communication with PROFINET CBA (without real-time) is suitable for bus cycle times of approximately 50 to 100 ms. Data cycles on the order of milliseconds are possible in the parallel RT channel - same as in PROFINET IO.

1.6 Distributed I/O (PROFINET IO)

PROFINET IO is used to connect distributed I/O for fast data exchange. The scalable real-time concept is the basis for this.

PROFINET IO describes the overall data exchange between controllers (devices with master functionality according to PROFIBUS) and devices (devices with slave functionality) as well as the parameterization and diagnostic options. A device developer can implement PROFINET IO with any commercially available Ethernet controller. The bus cycle times for the data exchange are in the milliseconds range. Configuring an PROFINET IO system has the same look and feel as in PROFIBUS. The real-time concept is included in PROFINET IO without exception.

1.7 PROFINET and real-time

Within PROFINET IO, process data and alarms are always transmitted in real time. Real-Time for PROFINET (RT) is based on the definitions of IEEE and IEC for high-performance data exchange of I/O data. RT communication constitutes the basis for data exchange in PROFINET IO.

Real-time data are handled with higher priority compared to TCP(UDP)/IP data. This method of data exchange allows bus cycle times in the range of a few hundred milliseconds to be achieved.

1.8 PROFINET and isochronous mode

Isochronous data exchange with PROFINET is defined in the Isochronous-Real-Time (IRT) concept. Data exchange cycles are normally in the range of a few hundred microseconds to 1 millisecond. Isochronous real-time communication differs from real-time communication mainly in its isochronous behavior, meaning that the bus cycles are started with maximum precision. The start of a bus cycle can deviate by a maximum of 1 µs. IRT is required in motion control applications (positioning operations), for example.

1.9 Device classes of PROFINET IO

PROFINET follows the Provider/Consumer model for data exchange. The provider (usually the field device at the process level) provides process data to a consumer (normally a PLC with a processing program). In principle, a PROFINET IO field device can contain any arrangement of functions (provider/consumer). Figure 1.3 presents the device classes (IO-Controller, IO-Supervisor, IO-Device) and the communication services.

The following devices classes are defined to facilitate structuring of PROFINET IO field devices:

IO-Controller
This is typically a PLC on which the automation program runs (corresponds to the functionality of a class 1 master in PROFIBUS).

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

IO-Device
An IO-Device is a distributed I/O field device that is connected via PROFINET IO (corresponds to the function of a slave in PROFIBUS).
A plant unit contains at least one IO-Controller and one or more IO-Devices. An IO-Device can exchange data with multiple IO-Controllers. IO-Supervisors are usually integrated only temporarily for commissioning or troubleshooting purposes.

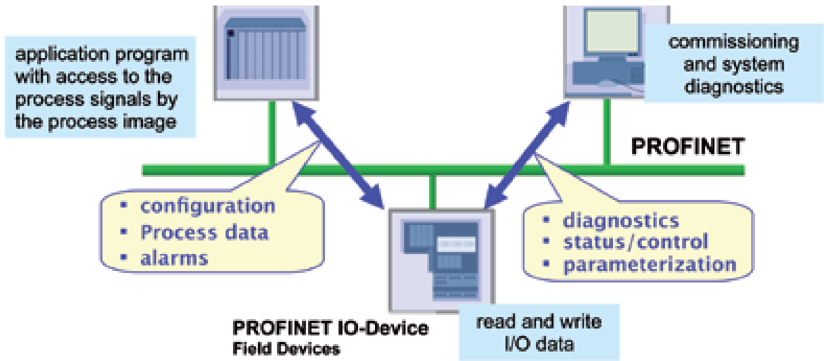


Figure 1.3: Clearly structured communication paths in PROFINET IO.

1.10 Addressing in PROFINET IO

PROFINET IO field devices are addressed using MAC addresses and IP addresses. Figure 1.4 shows a network that comprises two subnets. These are represented by the different network_IDs (subnet mask).

For PROFINET IO field devices, address resolution is based on the symbolic name of the device, to which a unique MAC address is assigned.

After the system is configured, the engineering tool loads all information required for data exchange to the IO-Controller, including the **IP addresses** of the connected IO-Devices. Based on the name (and the associated MAC address), an IO-Controller can recognize the configured field devices and assign them the specified IP addresses using the DCP protocol (Discovery and Configuration Protocol) integrated in PROFINET IO. Alternatively, addressing can be performed via a DHCP server.

Following address resolution, the system powers up and parameters are transmitted to the IO-Devices. The system is then available for productive data traffic.

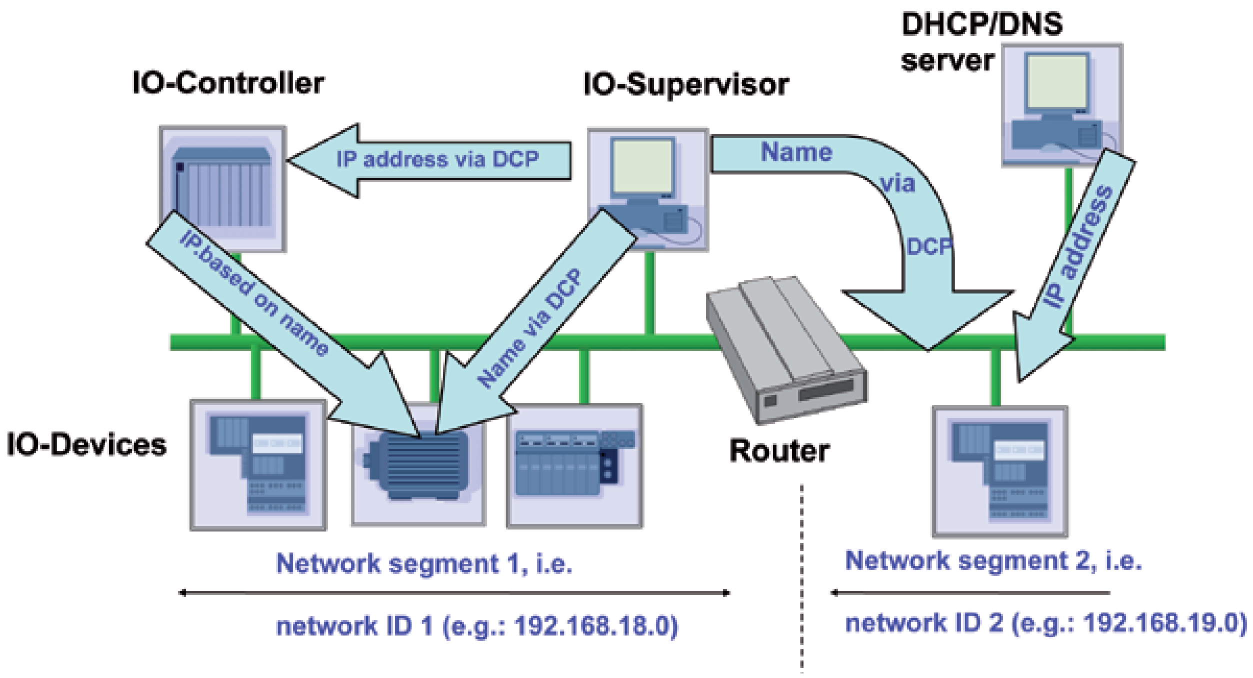


Figure 1.4: A PROFINET IO network can comprise several subnets.

2. PROFINET IO Basics

PROFINET IO field devices are always connected via switches as network components. This takes the form of a star topology with separate multiport switches or a line topology with switches integrated in the field device (2 ports occupied).

Within a network, a PROFINET IO field device is addressed by its device MAC address.

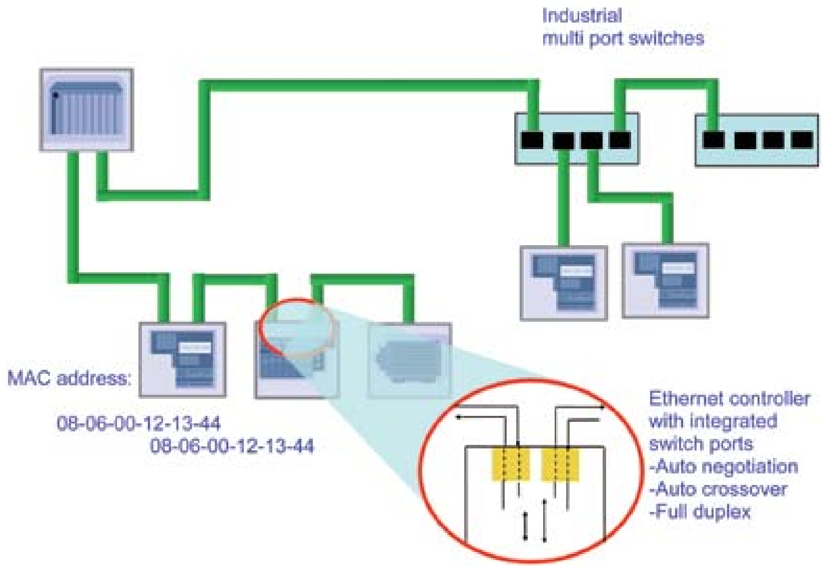


Figure 2.1 PROFINET IO field devices are always connected via switches.

PROFINET transmits some message frames (e.g., for synchronization, neighborhood detection) with the MAC address for the respective port and not the device MAC address. For this reason, each switch port in a field device requires a separate port MAC address. Therefore, a 2-port field device has 3 MAC addresses in the as-delivered condition. However, these port MAC addresses are not visible to users. Because the field devices are connected via switches, PROFINET always sees only point-to-point connections (same as Ethernet). That is, if the connection between two field devices in a line is interrupted, the field devices located after the interruption are no longer accessible. If increased availability is required, provision must be made for redundant communication paths when planning the system, and field devices/switches that support the redundancy concept of PROFINET must be used. PROFINET-suitable switches must support "Autonegotiation" (negotiating of transmission parameters) and "Autocrossover" (crossing of send and receive lines in the switch). As a result, communication can be established autonomously, and fabrication of the transmission cable is uniform. Only cables wired 1:1 are used.

2.1 Device model

To facilitate understanding of process data addressing in a PROFINET IO field device, an overview of the device modeling and, thus, addressing of I/O data in an automation system is advantageous.

For field devices, a distinction is made between:

- Compact field devices (the degree of expansion is defined in the as-delivered condition and cannot be changed to meet future requirements).
- Modular field devices (for different applications, the degree of expansion can be customized to the use case when configuring the system).

All field devices are described in terms of their available technical and functional properties in a GSD file (General Station Description) to be created by the field device developer. It contains among other things a representation of the device model that is reproduced by the DAP (Device Access Point) and the defined modules for a particular device family. A DAP is, so to speak, the bus interface (access point for communication) to the Ethernet interface and the processing program.

MAC address and OUI (organizationally unique identifier)

Each PROFINET device is addressed based on a MAC address. This address is unique worldwide. The company code (bits 47 to 24) can be obtained from the IEEE Standards Department free of charge. This part is called the OUI (organizationally unique identifier).

PI offers MAC addresses to device manufacturers that do not want to apply for their own OUI, in other words, a defined OUI and the manufacturer-specific portion (bits 23 to 0). This service allows components to acquire MAC addresses from the PI Support Center. The assignment can be completed in 4 K-ranges.

The OUI of PI is 00-0E-CF and is structured as shown in the table. The OUI can be used for up to 16,777,214 products.

Bit value 47 ... 24						Bit value 23 ... 0					
0	0	0	E	C	F	X	X	X	X	X	X
Company code → OUI						Consecutive number					

It is defined along with its properties and available options in the GSD file. A variety of I/O modules can be assigned to it in order to manage the actual process data traffic.

The proven device model of PROFIBUS has been largely applied for PROFINET IO and adapted to the requirements of the end user. This results in an additional nesting depth (slot and subslot) for PROFINET IO.

The following addressing options are standardized:
The **slot** designates the physical slot of an I/O module in a modular I/O field device in which a module described in the GSD file is placed. The configured modules containing one or more subslots (actual I/O data) for data exchange are addressed on the basis of the different slots.

Within a slot, the **subslots** form the actual interface to the process (inputs/outputs). The granularity of a subslot (bitwise, bytewise, or wordwise division of I/O data) is determined by the manufacturer. The data content of a subslot is always accompanied by status information, from which the validity of the data can be derived.

The **index** specifies the data within a slot/subslot that can be read or written acyclically via 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.

The device model is shown below for a modular IO-Device configuration (bus interface and three input/output modules).

The manufacturer uses definitions in the GSD file to describe the number of slots/subslots an IO-Device can process.

Cyclic I/O data are addressed by specifying the slot/subslot combination. These can be freely defined by the manufacturer.

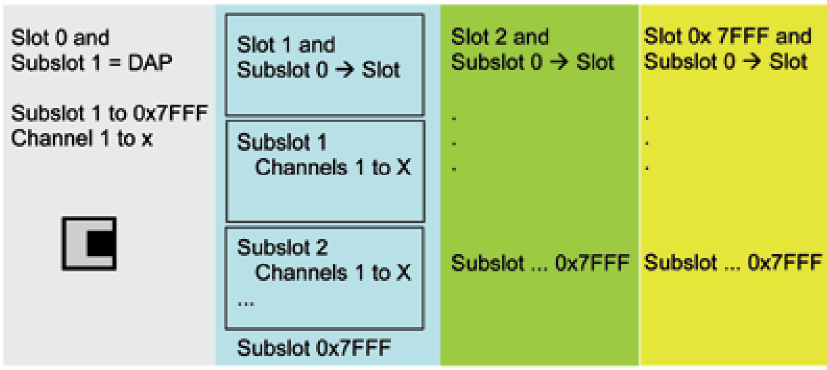


Figure 2.2: I/O data are addressed in PROFINET on the basis of slots and subslots.

For acyclic data traffic via read/write services, an application can specify the exact data to be addressed using slot, subslot. For demand-oriented data exchange, the third addressing level, i.e., the index is added. The index defines the function that is to be initiated via the slot/subslot combination (e.g., reading of input data of a subslot, reading of I&M functions, reading of actual/desired configuration, etc.).

2.2 Application process identifier (API)

To prevent the possibility of competing accesses in the definition of user profiles (e.g., for PROFIdrive, weighing and dosing, etc.), it is appropriate to define not only slots and subslots but also an additional addressing level, i.e., the API (**A**pplication **P**rocess Identifier/Instance). This degree of freedom enables different applications to be handled separately in order to prevent overlapping of data areas (slots and subslots).

2.3 Communication in PROFINET IO

PROFINET IO provides protocol definitions for the following services:

- Address resolution for field devices
- Cyclic transmission of I/O data (RT and IRT)
- Acyclic transmission of alarms to be acknowledged
- Acyclic transmission of data (parameters, detailed diagnostics, I&M data, information functions, etc.) on an as needed basis.
- Redundancy mode for realtime frames

The combination of these communication services in the higher-level controller makes it possible to implement convenient system diagnostics, topology detection, and device replacement, among other things.

Many communication services in PROFINET occur in real time. Therefore, a more detailed explanation of real-time communication in PROFINET will be provided next.

2.4 Principles of real-time communication in PROFINET IO

Standard Ethernet communication via TCP(UDP)/IP communication is sufficient for data communication in some cases. In industrial automation, however, requirements regarding time behavior and isochronous operation exist that cannot be fully satisfied using the UDP/IP channel.

A scalable real-time concept is the solution for this. With RT, this concept can be realized with standard network components, such as switches and standard Ethernet controllers. RT communication takes place without TCP/IP information.

The transmission of RT data is based on cyclical data exchange using a provider/consumer model. The communication mechanisms of layer 2 (according to the ISO/OSI model) are sufficient for this. For optimal processing of RT frames within an IO-Device, the VLAN tag according to IEEE 802.1Q (prioritization of data frames) has been supplemented with a special Ethertype that enables fast channelization of these PROFINET frames in the higher-level software of the field device.

Ethertypes are allocated by IEEE and are therefore an unambiguous criterion for differentiation among Ethernet protocols. Ethertype 0x8892 is specified in IEEE and is used for fast data exchange in PROFINET IO.

2.5 Real-time classes in PROFINET IO

To enable enhanced scaling of communication options and, thus, also of determinism in PROFINET IO, real-time classes have been defined for data exchange. From the user perspective, these classes involve unsynchronized and synchronized communication. The details are managed by the field devices themselves.

Real-time frames are automatically prioritized in PROFINET compared to UDP/IP frames. This is necessary in order to prioritize the transmission of data in switches to prevent RT frames from being delayed by UDP/IP frames. PROFINET IO differentiates the following classes for RT communication. They differ not in terms of performance but in determinism.

RT_CLASS_1: Unsynchronized RT communication **within a subnet**. No special addressing information is required for this communication. The destination node is identified using the ‚Dest. Addr.‘ only. Unsynchronized RT communication within a subnet is the usual data transmission method in PROFINET IO. If the RT data traffic has been restricted to one subnet (same network ID), this variant is the simplest. This communication path is standardized in parallel to UDP/IP communication and implemented in each PROFINET IO field device.

A deliberate decision was made here to eliminate the management information of UDP/IP and RPC. The RT frames received are already identified upon receipt using the Ethertype (0x8892) and forwarded to the RT channel for immediate processing.

Industrial standard switches can be used in this RT class.

RT_CLASS_2: frames can be transmitted via synchronized or unsynchronized communication. Unsynchronized communication in this case can be viewed exactly the same as RT_CLASS_1 communication.

In synchronized communication, the start of a bus cycle is defined for all nodes. This specifies exactly the allowable time base for field device transmission. For all field devices participating in RT_CLASS_2 communication, this is always the start of the bus cycle. PROFINET-suitable switches must support this synchronization for this communication class. This type of data transmission, which has been designed for performance, brings with it specific hardware requirements (Ethernet controller/switch with support of isochronous operation).

RT_CLASS_3: Synchronized communication within a subnet. During synchronized RT_CLASS_3 communication, process data are transmitted with maximum precision in an exact order specified during system engineering (maximum allowable deviation from start of bus cycle of 1 µs). With the aid of topology-optimized data transmission, this is also referred to as IRT functionality (Isochronous Real-Time). In RT_CLASS_3 communication, there are **no wait times**. In order to take advantage of the data transmission designed for maximum performance, special hardware requirements apply (Ethernet controller with support of isochronous operation).

RT_CLASS_UDP: The unsynchronized cross-subnet communication between different subnets requires addressing information via the destination network (IP address). This variant is also referred to as RT_CLASS_UDP. Standard switches can be used in this RT class.

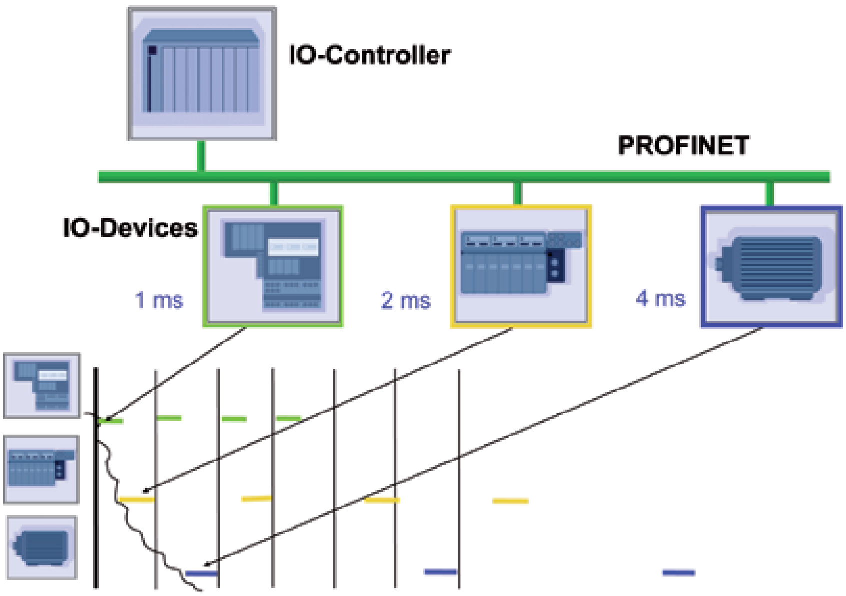


Figure 2.3: In non-synchronized real-time communication the start of a bus cycle is not synchronized.

For RT frames, data cycles of 5 ms at 100 Mbps in full duplex mode with VLAN tag are sufficient. This RT communication can be realized with all available standard network components.

2.6 Cyclic data traffic

Cyclic I/O data are transmitted unacknowledged as real-time data between provider and consumer in a parameterizable resolution. They are organized into individual I/O elements (subslots). The connection is monitored using a watchdog (time monitoring mechanism). During data transmission in the frame, the data of a subslot are followed by a provider status. This status information is evaluated by the respective consumer of the I/O 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. Diagnostics are no longer directly required for this purpose.

For each message frame, the ‚Data Unit' (trailer) is followed by accompanying information regarding the global validity of data, redundancy, and the diagnostic status evaluation (data status, transfer status). The cycle information (cycle counter) of the provider is also specified so that its update rate can be determined easily. Failure of cyclic data to arrive is monitored by the respective consumer in the communication relation. If the configured data fail to arrive within the monitoring time, the consumer sends an error message to the application.

2.7 Acyclic data traffic

Acyclic data exchange can be used to parameterize and configure IO-Devices or to read out status information. This is accomplished with read/write frames via standard IT services using UDP/IP.

In addition to the data records available for use by device manufacturers, the following system data records are also specially defined:

- **Diagnostic information** can be read out by the user from any device at any time.
- **Error log entries** (alarms and error messages), which can be used to determine detailed timing information about events within an IO-Device.
- **Identification information** as specified in PNO Guideline „I&M Functions".
- **Information functions** regarding real and logical module structuring.
- **Readback of I/O data.**

An index is used to distinguish which service is to be executed with the read/write services.

2.8 Multicast Communication Relation (MCR)

For data exchange with multiple parameters, Multicast Communication Relation (MCR) has been defined. This allows direct data traffic from a provider to multiple nodes (up to all nodes) as direct data exchange. MCRs within a segment are exchanged as RT frames. Cross-segment MCR data follow the data exchange of the RT class. ‚RT_CLASS_UDP'. Data that are exchanged via MCR are subject to the IO-Device model and are assigned to subslots. An M-provider subslot of an IO-Device can publish the input data both to the assigned IO-Controller via an input CR and via a multicast communication relation (M-CR). Different transmission methods (RT, IRT) can be used for the two CRs.

2.9 Event-oriented data traffic

In PROFINET IO, the transmission of events is modelled as part of the alarm concept. These include both system-defined events (such as removal and insertion of modules) and user-defined events detected in the control systems used (e.g., defective load voltage) or occurring in the process being controlled (e.g., temperature too high). When an event occurs, sufficient communication memory must be available for data transmission to ensure against data loss and to allow the alarm message to be passed quickly from the IO-Device. The application in the data source is responsible for this. Alarms are included in acyclic RT data.

3. Diagnostics Concept of PROFINET IO

PROFINET IO transmits high-priority events mainly as alarms. These include both system-defined events (such as removal and insertion of modules) and user-defined events (e.g., defective load voltage) detected in the control systems used or occurring in the process (e.g., boiler pressure too high).

Diagnostic and status messages represent another means of forwarding information regarding incorrect behavior in a system. These are not transmitted actively to the higher-lever controller.

In order to assign them explicitly, PROFINET distinguishes between process and diagnostic alarms.

Process alarms must be used if the message originates from the connected process, e.g., a limit temperature was exceeded. In this case, the IO-Device may still be operable. The data are not saved locally in the submodule.

Diagnostic alarms must be used if the error or event occurs within an IO-Device (or in conjunction with the connected components, such as a wire break). Diagnostic and process alarms can be prioritized differently by the user. In contrast to process alarms, diagnostic alarms are identified as incoming or outgoing.

3.1 Overview of the structure of an alarm message

To promote better understanding of the alarm processing in PROFINET, the structure of the alarm concept will be presented to start. The overview figure above shows the main structure of an alarm message or diagnostic entry used to signal an event.

Any fatal error is always signaled as an alarm. Every alarm triggers an entry in the diagnostic buffer.

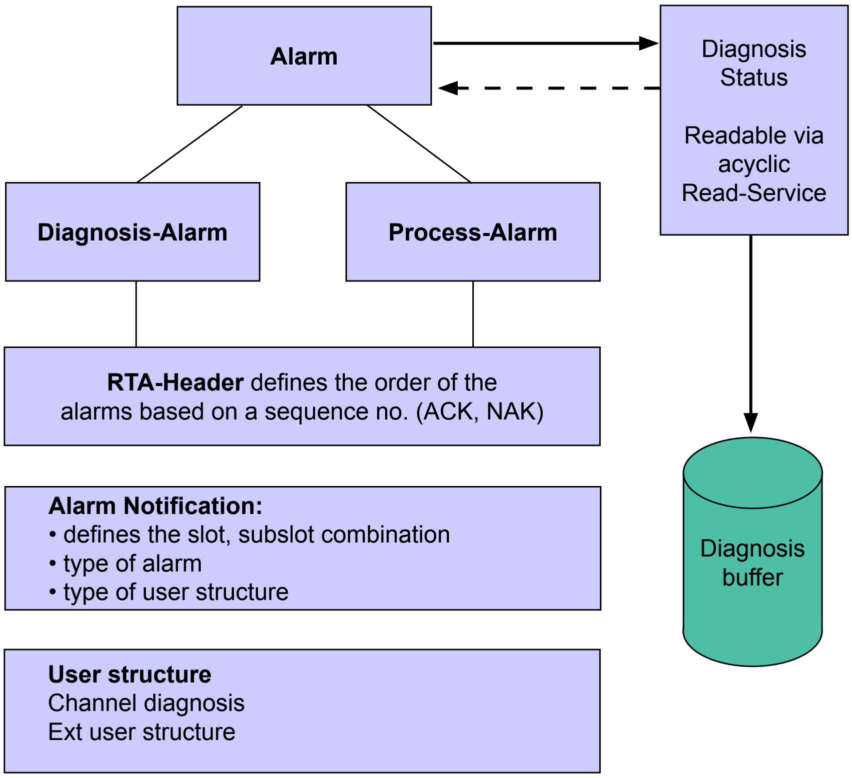


Figure 3.1: Structuring of alarm/diagnostic messages allows a variety of options

3.2 Diagnostics in PROFINET

The network diagnostics is part of the diagnostics management and contributes significantly to the reliability of the network operation. For maintenance purposes and for monitoring the network components, SNMP (Simple Network Management Protocol) has been established as the international standard. SNMP allows both read access and write access (for administration) of network components in order to read out statistical data pertaining to the network as well as port-specific data and information regarding the neighborhood detection. Integration of monitoring functions directly into network components such as switches represents another diagnostic means for networks. IEEE-compliant standard switches are designed exclusively for the purpose of forwarding diagnostic information of the connected field devices to an IO-Controller. Additional monitoring functions are not usually integrated. Switches designed as IO-Devices feature a higher level of integrated intelligence.

3.3 Monitoring functions in IO-Controller and IO-Device

For system power-up, the IO-Controller transfers the connect frame containing the ‚CMInactivityTimeout-Factor', which is used to monitor the system power-up. This monitoring time ends after the first valid data exchange between IO-Controller and IO-Device and is then replaced by the watchdog function.

In PROFINET IO communication, the cyclic data traffic between provider and consumer is monitored by the watchdog function, which is integrated by default. Cyclic data including status information are transmitted between the IO-Controller and IO-Device. A consumer detects failure of the communication connection based on expiration of the watchdog. The application in the consumer is thereby informed. The response to this must be defined on a user-specific basis.

4. Mode of Operation of PROFINET IO

System engineering and GSD

To enable system engineering, the GSD files (General Station Description) of the field devices to be configured are required. The field device manufacturer is responsible for supplying these. During system engineering, the configuring engineer joins together the modules/submodules defined in the GSD file to map them to the real system and to assign them to slots/subslots. The configuring engineer configures the real system, so to speak, symbolically in the engineering tool.

Device identification though name assignment

A logical name is assigned to every field device. It should reference the function or the installation location of the device in the plant and ultimately lead to assignment of an IP address during address resolution. The name can always be assigned with the DCP protocol (Discovery and Configuration Protocol) integrated by default in every PROFINET IO field device. Because DHCP (Dynamic Host Configuration Protocol) has found widespread use worldwide and, for example, address setting via DCP requires additional effort for MS Windows-based IO field devices, PROFINET provides the option for address setting via DHCP or other manufacturer-specific mechanisms. The addressing options supported by an PROFINET IO field device are defined in the GSD file for the respective device.

Each IO-Controller manufacturer also provides an engineering tool for configuring a plant.

Figure 4.1 shows the relationship between GSD definitions, the configuration, and the real plant view.

Download of plant information

After completion of the plant engineering, the configuring engineer downloads the plant data to the IO-Controller, which also contains the plant-specific application. As a result, an IO-Controller has all the information needed for addressing the IO-Devices and for data exchange.

Address resolution

Before it can perform data exchange with an IO-Device, the IO-Controller must assign the IO-Device an IP address based on the device name. This must take place prior to system power-up. System power-up refers to the startup/restart of an automation system after ‚Power on' or after a ‚Reset'. The IP address is assigned within the same subnet using the DCP protocol integrated by default in every PROFINET IO-Device.

System power-up

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 power-up, an IO-Controller establishes an explicitly specified communication relation (CR) and application relation (AR) with an IO-Device.

Data exchange

Following successful completion of system power-up, the IO-Controller and IO-Devices exchange process data, alarms, and acyclic data.

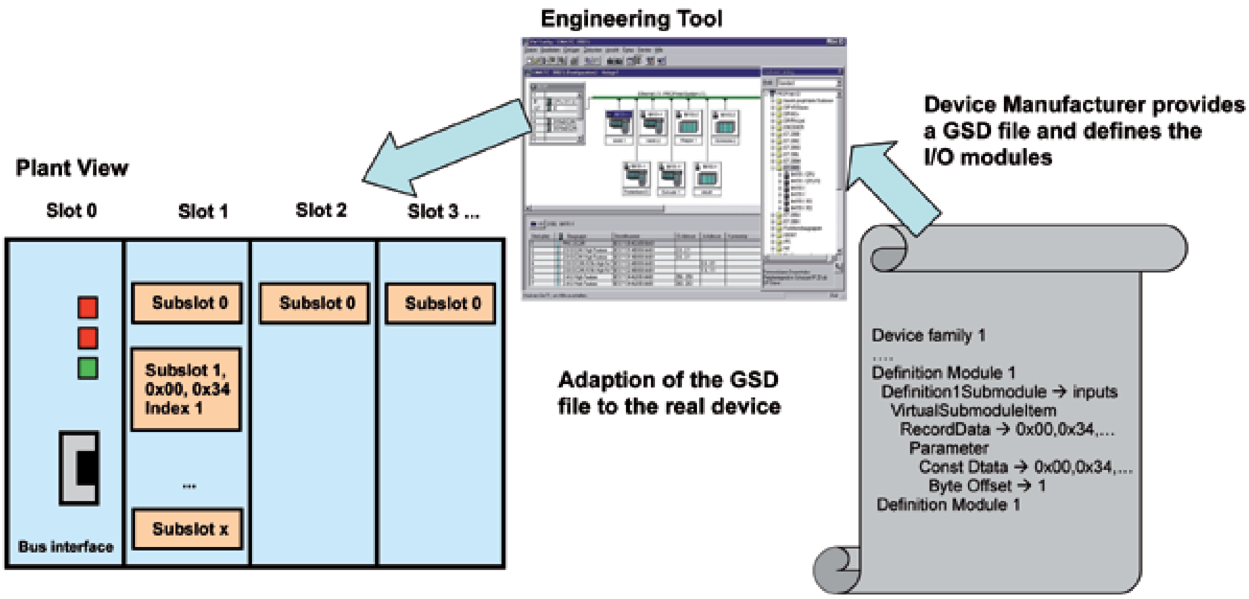


Figure 4.1: Definitions in the GSD file are assigned to IO-Devices when configuring the plant.

5. System Power-up

Following a ‚Power on', the following steps are performed in the field device:

- Initializing the physical interfaces in an IO-Device in order to accommodate the data traffic
- Negotiating the transmission parameters
- Determining the degree of expansion in the field device and communicating the information to the context management
- Starting the exchange of the neighborhood information
- Address resolution on the side of the IO-Controller
- Establishment of communication between IO-Controller and IO-Device
- Parameterizing the submodules in the device (write records)
- Retentive saving of port information to the physical device (PDev)
- Completing and checking the parameterization, and starting the data exchange

5.1 Application and 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 in the engineering system. This specifies the data exchange explicitly.

Every data exchange has an embedded ‚Application Relation' (AR). This establishes a precisely specified application (connection), i.e., the AR, between the higher-level controller (IO-Controller or IO-Supervisor) and the IO-Device. Within the AR, ‚Communication Relations'(CR) specify the data explicitly. An IO-Device can have multiple ARs established from various IO-Controllers.

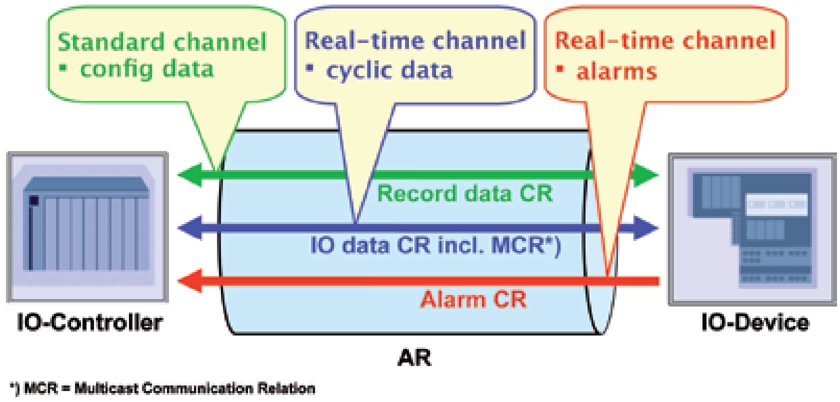


Figure 5.1: Data communication in PROFINET IO is encapsulated in ‚Application and Communication Relations'.

Setting up an application relation
The IO-Controller initiates setup of an application relation during system power-up. As a result, all data for the device modeling, including the general communication parameters, are downloaded to the IO-Device.

At the same time, the communication channels for cyclic/acyclic data exchange (IO data CR, record data CR), alarms (alarm CR), and multicast communication relations (MCR) are set up.

Setting up a communication relation (CR)
´**C**ommunication **R**elations´ (CR) for data exchange must be set up within an AR. These specify the explicit communication channel between a consumer and a provider.

Figure 5.2 shows an example IO-Device configuration and the possible application relations with multiple controllers.

5.2 Neighborhood detection

Neighborhood detection with LLDP according to IEEE 802.1 AB and the PNO-specific additions is part of the overall concept „Device replacement without engineering tool". This requires the ability to determine the data of neighboring devices on a port-by-port basis using LLDP services and to provide these data to the higher-level controller. Together, these conditions enable modeling of a plant topology and convenient plant diagnostics as well as device replacement without additional tools.

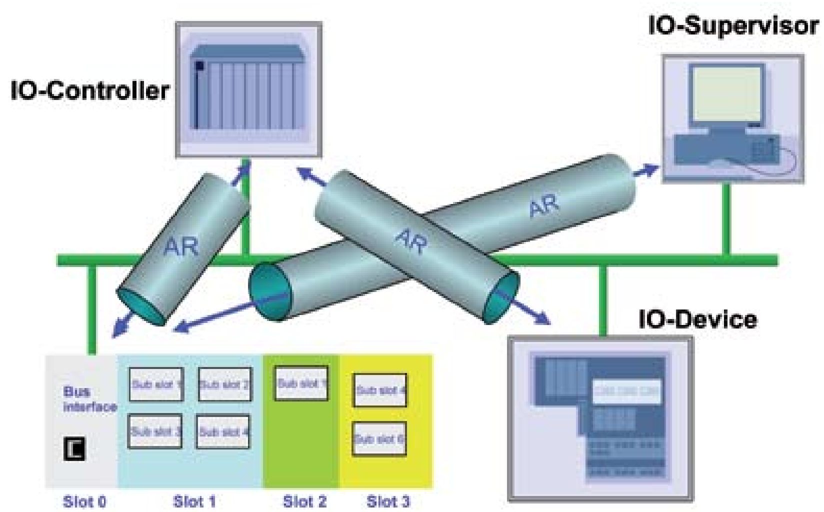


Figure 5.2: In PROFINET IO multiple controllers can access a single field device.

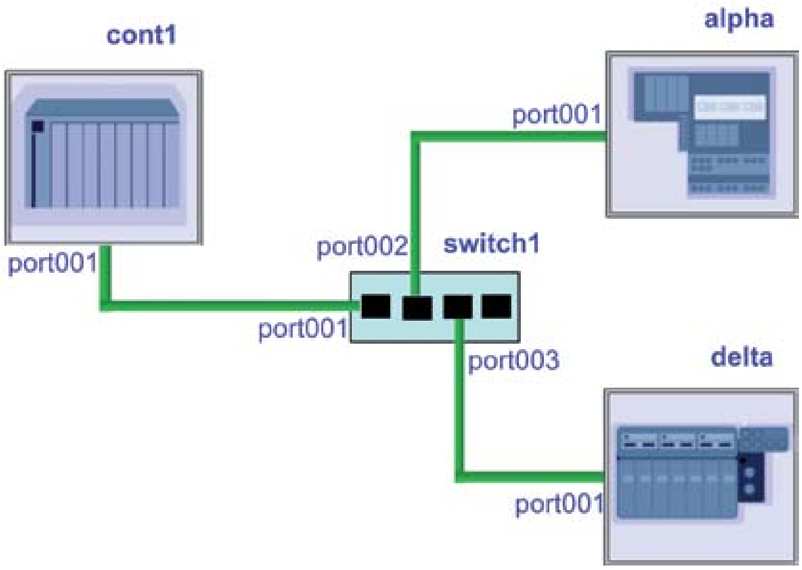


Figure 5.3: PROFINET field devices know their neighbors

The **L**ink **L**ayer **D**iscovery **P**rotocol (LLDP protocol) was used to apply the principle of neighborhood detection in PROFINET IO.

PROFINET field devices exchange existing addressing information with connected neighbor devices over each switch port. The neighbor devices are thereby unambiguously identified and their physical location is determined. (example in Figure 5.3: the delta device is connected to port003 of switch 1 via port001).

The LLDP protocol is implemented in software and therefore requires no special hardware support. LLDP is independent of the network structure (line, star, etc.).

5.3 Topology detection

Automation systems can be configured with a line, star, or tree structure. For this reason, it is important to know which field devices are connected to which switch port and the identity of the respective port neighbor. The higher-level controller can then reproduce the plant topology accordingly. In addition, if a field device fails it is possible to check whether the replacement device has been reconnected in the proper position. Plant operators also demand the ability to replace devices without an additional engineering tool. This condition can be met very conveniently through the use of PROFINET field devices.

5.4 Application example for LLDP

As mentioned in the previous sections, a plant operator can use standard functionality in PROFINET to represent a plant topology and port-granular diagnostics in a graphics-based format. This provides the plant operator a quick overview of the plant status. For an example representation of plant topology in STEP 7, refer to Figure 5.5.

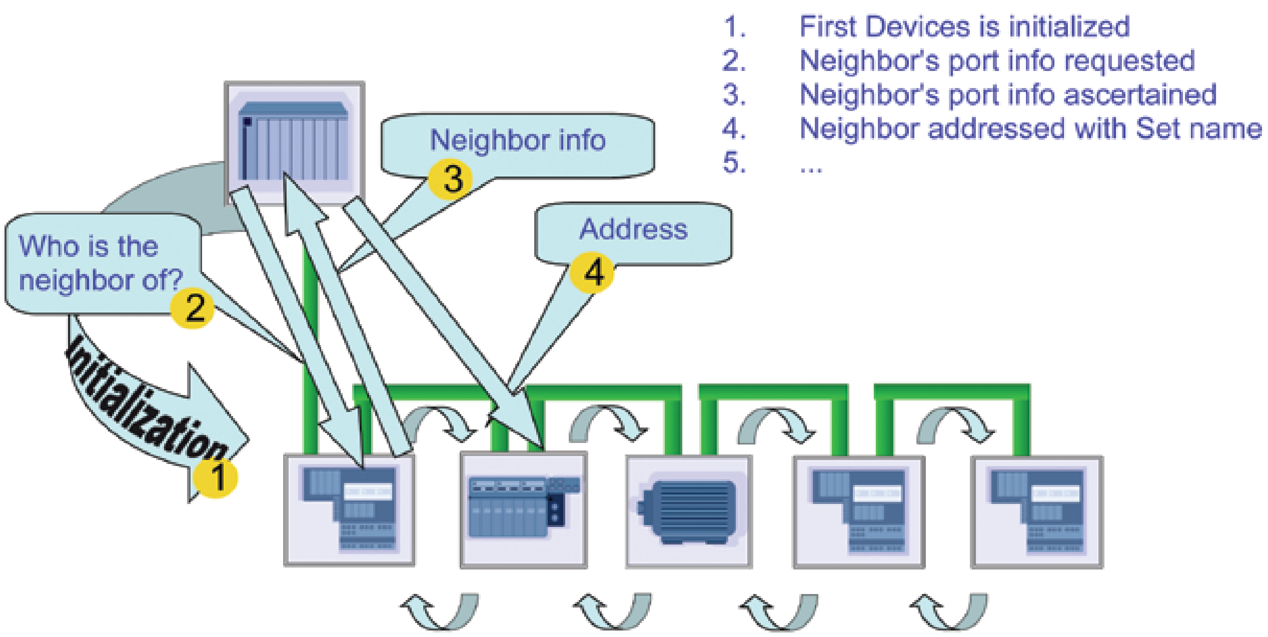


Figure 5.4: PROFINET supports convenient device replacement and display of plant topology.

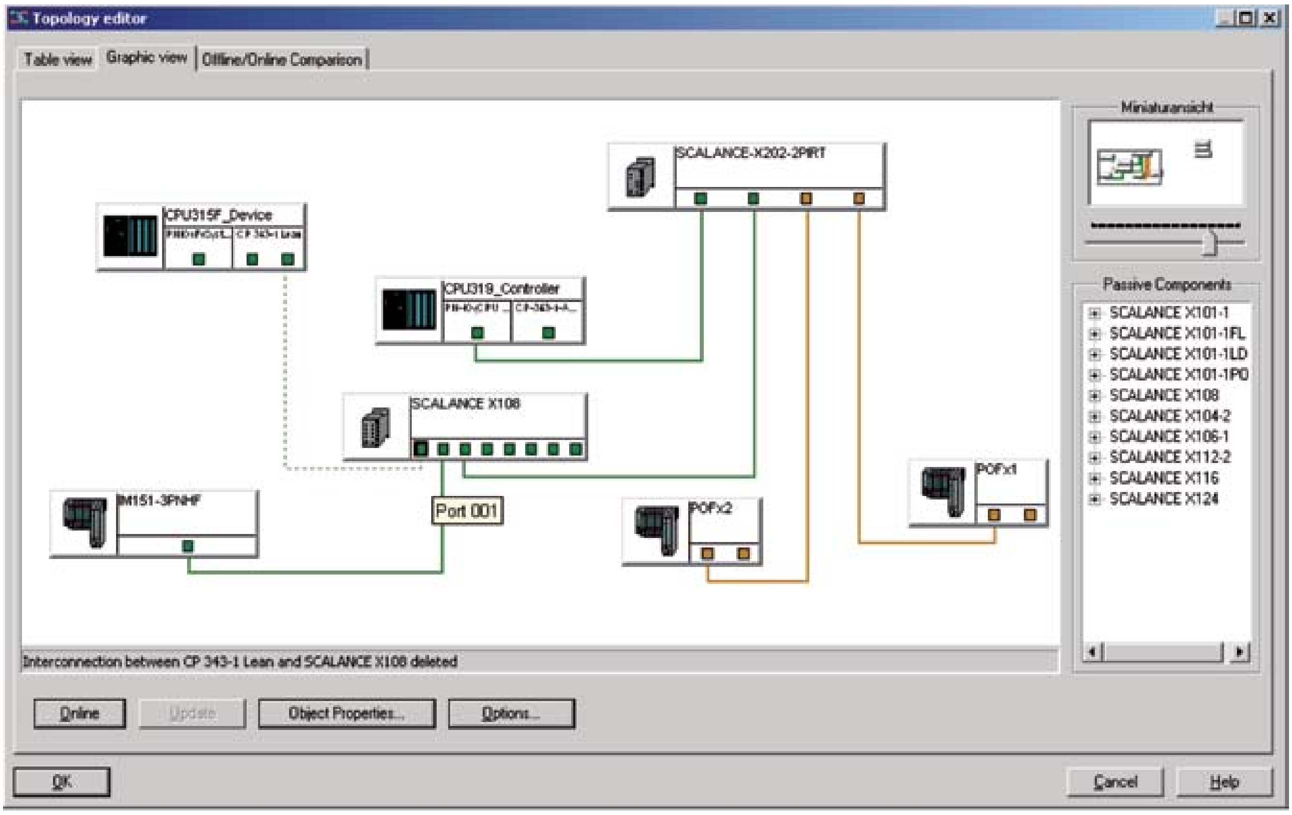


Figure 5.5: Representation of plant topology provides a quick overview of the structure and quality of the plant.

5.5 Communication during connection establishment and parameterization

System power-up in an automation system with PROFINET IO is initiated by the IO-Controller. The frames presented below are always transacted via the UDP/IP channel according to the following scheme:

- **Connect frame:** Establishment of an AR and the configured CRs.
- **Write frame:** Parameterizing of all configured submodules.
- **DControl frame:** End detection of parameterization of the IO-Controller (also called ‚EndOfParameterization‘).
- **CControl frame:** End detection of parameterization of the IO-Device (also called ‚Application Ready‘).

Figure 5.6 shows the power-up sequence of an IO-Device.

During system power-up, the following is established: cyclic I/O data, alarms, exchange of acyclic read/write services, expected modules/submodules, and any needed cross connections between IO-Devices.

The IO-Controller or IO-Supervisor uses the ‚Connect frame‘ to start the connection establishment and to transfer all data required to establish an AR and the necessary CRs. It contains the relevant parameterization data as well as the order, the process data traffic, and the monitoring time for the power-up. The transmission frequency of cyclic I/O data is specified during plant engineering.

The IO-Controller uses the subsequent ‚Write frames‘ to parameterize the configured submodules that serve as the data interface to the process.

If all parameters are loaded to the IO-Device, the IO-Controller marks its end of parameterization with the ‚DControl.req‘ frame (‚EndOfParameterization‘). The user software then creates the ultimate data structures and updates the status of the submodules.

If all data structures are created in the IO-Device and the necessary checks have been made, it sends a ‚CControl.req‘ to the IO-Controller to signal its readiness for productive data traffic (‚Application Ready‘. From the perspective of the IO-Device, communication is now established. When the IO-Controller acknowledges the

‚Application Ready‘, communication is established from the perspective of the IO-Controller as well. If the IO-Device has discovered errors during parameterization, it signals these errors to the IO-Controller. The first successful exchange of I/O data marks the end of the power-up.
Following successful system power-up, the following can be exchanged:

- Cyclic process data
- Alarms
- Acyclic data traffic

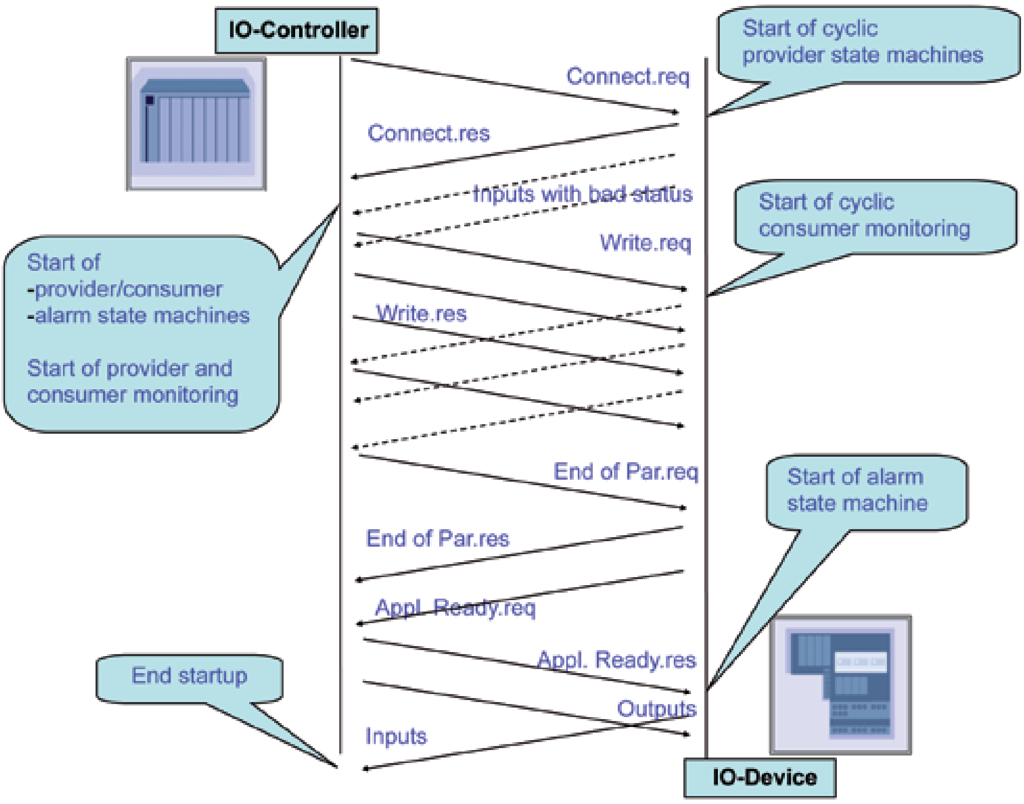


Figure 5.6: During system power-up all configured data are checked and transmitted to the submodules.

5.6 Optimized connection establishment (‚Fast Start Up')

In PROFINET IO, system power-up currently uses many functions that enable reliable power-up of all field devices involved in communication. This process can last several seconds until a field device is ready to operate. During a tool changeover of industrial robots, for example, these power-up times are not acceptable because the associated wait times directly affect the process (cycle time of conveyor). For this reason, the plant operator demands the ability to achieve a system power-up in significantly under 1 second. PROFINET therefore includes optimizations for fast operational readiness.

Optimizations for Fast Start Up
‚Fast Start Up' (FSU) is an optimized communication path for achieving data exchange in significantly less time during the second to nth power-up (for example, after re-parameterization). It is based on the fact that many parameters are already stored in the field devices. This optional path can be used in parallel to standard power-up (which is still used after power is switched on and during the first power-up or reset). This means that communication parameters must be saved retentively.

The port configuration allows the user to decide whether a patch cable (1:1 wired cable) or crossed cable is to be used.

6. IRT Communication in PROFINET IO

PROFINET IO provides scalable real-time classes for cyclic transmission of process data. In addition to the requirements for real-time capability, there are also processes that require isochronous I/O data transfer with maximum performance. Isochronous means that the start of a bus cycle is timed exactly, i.e., with a maximum permissible deviation and with constant synchronization. Only in this way can the time intervals of transmitted I/O data be ensured with the highest accuracy.

For this reason, synchronized PROFINET communication, also called IRT communication (Isochronous Real-Time Communication) or isochronous communication, was introduced.

IRT achieves bus cycles of significantly under 1 millisecond with a maximum deviation from the bus clock of 1 µs. For isochronous data exchange, PROFINET offers a scalable concept that, on the one hand, provides a very flexible method of communication. From the technical point of view, this takes the form of a synchronized RT_CLASS_2 communication.

On the other hand, PROFINET offers communication designed for maximum performance, which requires precise planning of communication paths in advance. The available bandwidth is utilized optimally in this case because waiting times can never occur during data transmission. Technically speaking, this takes the form of a synchronized RT_CLASS_3 communication.

However, the determinism is the same for both variants. They differ only in the data throughput. The data transmission designed for maximum performance requires hardware support for the switches used. In addition, the communication is divided into a reserved interval and an open interval.
Only the time-critical I/O data are transferred in the reserved interval, while all other data are sent in the open phase. No additional lower-level protocol is required for this.A defined ‚Clock master‘, which is generally integrated in the IO-Controller, performs the node synchronization.

Requirements for IRT control
All field devices participating in IRT communication are synchronized by the same clock master. IRT communication is based on the following conditions:

A.) Due to the real-time capability, communication takes place exclusively within one subnet since there are no addressing options via TCP/IP. The existing addressing mechanisms have been reduced (also for unsynchronized communication) such that addressing of field devices within a subnet on the basis of the MAC address is sufficient.

B.) The bus cycle is divided into a reserved IRT phase and an open phase. These are defined as follows:

- In the ‚reserved interval‘ (IRT phase), only IRT jobs can be processed.
- In the ‚open interval‘, job processing is managed according to the rules in IEEE 802 (based on priorities).

C.) The stringent requirements for accuracy mean that all field devices within an IRT domain must support isochronous operation, even if the application is not operating synchronously. The time synchronization is accurate to under 1 microsecond.
The associated monitoring functions must be supported due to the stringent accuracy requirements for the hardware used.
The division of the individual phases can vary. The transition from the ‚green interval‘ to the ‚reserved interval‘ is preceded by a ‚yellow interval‘ in which an IRT-suitable switch accepts only jobs that can be completely transported before the start of the next “reserved interval‘. If the forwarding of these jobs before the start of the next reserved interval is not assured, these frames are stored temporarily and sent in the next ‚green interval‘. The maximum frame length in Ethernet/PROFINET yields a minimum duration of the green interval of 125 µs (4 * 31.25 µs).

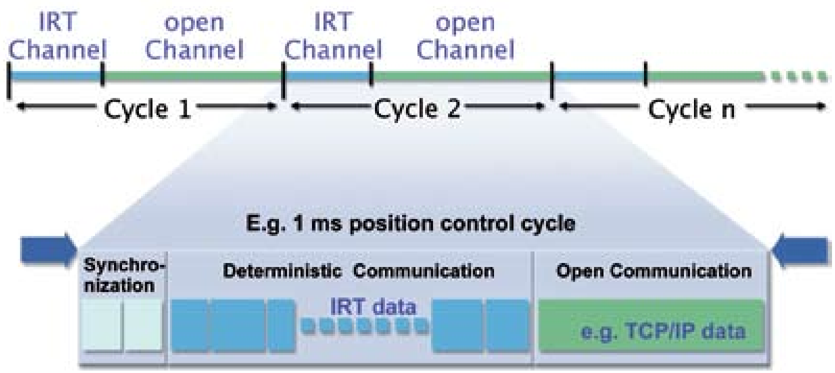


Figure 6.1: Bus cycle is divided into an IRT communication part and an open communication part.

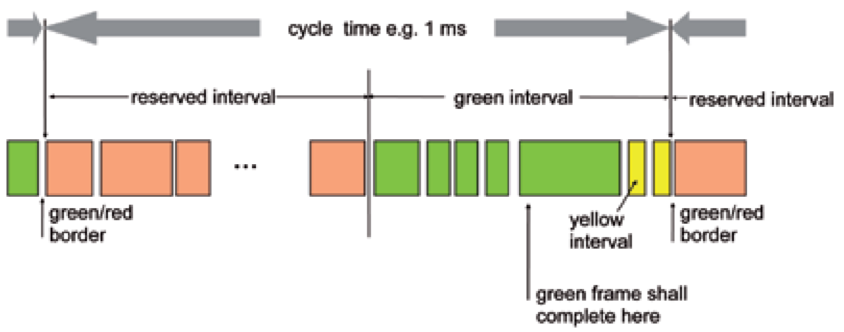


Figure 6.2: IRT communication divides the bus cycle into a reserved phase and an open phase.

The following intervals are defined along with their properties in PROFINET:

Red interval
Only RT_CLASS_3 frames may be forwarded through switches in this interval. The forwarding rules defined in IEEE 802.1D do not apply here. Instead, the forwarding rules defined in IEC 61158 are used. The start time of the red interval is constantly synchronized. The chronological sequence of all RT_CLASS_3 frames is defined during engineering. If UDP/IP frames arrive or are generated (because the application is not IRT-capable) during a ‚red interval', they are temporarily saved in an IRT-capable switch and are sent only after completion of the ‚reserved interval'. The frame IDs used to identify the different frames are specified during plant configuration in the engineering tool. The receipt of the cyclic data is timed exactly such that the synchronous application can be started directly without delays.

Orange interval
Only RT_CLASS_2 frames may be forwarded through switches in this interval. The forwarding rules defined in IEEE 802.1D are used here. The ‚orange interval' starts (if present) immediately at the start of a ‚Send clock' or after the ‚red interval'. RT_CLASS_2 frames require no prior planning. As a result, the available band width is not optimally used. Receipt of the cyclic data is not timed exactly. A safety reserve must therefore be included.

Green interval
For forwarding of data frames in switches, the rules defined in IEEE 802.1D apply. Prioritization can occur based on IEEE 802.1Q (VLAN tag).
If IRT frames arrive during the ´green interval´, they are destroyed and an alarm message is generated. The important thing is that no jobs are still active at the end so that the reserved interval can start unhindered. A ´green interval´ does not have to exist within a phase.

Yellow interval
For forwarding data frames in switches, the rules defined in IEEE 802.1D may be disabled to ensure the start of the next reserved phase. Prioritization can occur based on IEEE 802.1Q (VLAN tag).

6.1 Definition of an IRT domain

The main focus of IRT is on the ´Timing´ of communication, which requires a precise synchronization of the bus cycle. Because IRT communication poses maximum requirements for isochronous operation, it is absolutely essential that all IRT devices be synchronized to a common clock system. This synchronization is performed by a ´clock master´.

6.2 Clock synchronization for IRT communication

In a network for high-precision applications, all nodes with a configured IRT port must be synchronized with the utmost precision.
In order to synchronize nodes to a common clock, the ´line delay´ between the neighboring nodes and the current synchronization must be determined.

6.3 Flexible RT_CLASS_2 communication

For communication during the ´orange interval´ in ´switched Ethernet networks´, the configuration of end nodes is sufficient. During the power-up phase, all network components (switches) in between set up address tables that can be used to forward the received frames to their appropriate destinations. The communication is trained in a quasi manner using ´Src. and Dest. MAC addresses´. The rules defined in IEEE 802.1D are used here.

In the ´orange interval´, data must always be exchanged in conjunction with bus synchronization (synchronized RT_CLASS_2). Frames are transmitted within one SendClock in the

´orange interval´, in which communication can be implemented flexibly. It only has to be ensured that all IRT frames can be sent within the ´orange interval´. The synchronized ´Send Cycle' causes all nodes participating in IRT communication to start transmitting input/output data at the start of the ´orange interval´. As a result, all possible wait times are reduced to a minimum, same as in unsynchronized communication.

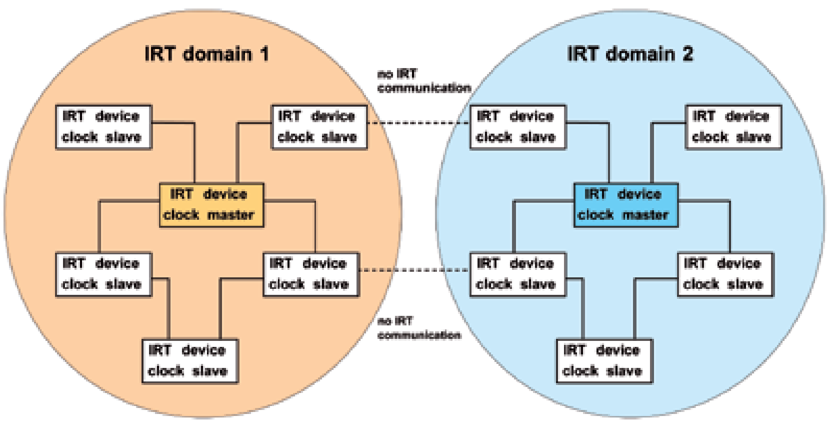


Figure 6.3: Each IRT domain uses its own clock to synchronize the nodes.

The data frames are transmitted to the end node via the respective destination port solely on the basis of their MAC address (and corresponding Frame_ID). This enables a very flexible method of communication that is not subject to any special rules. Changes in the plant topology have no effect here. However, based on the concept, the enhanced flexibility and resulting ease of adaptability of a system is made possible at the expense of incomplete optimization of the bandwidth utilization, because a small reserve is provided for in the ´orange interval´. This ensures that all frames have been sent. Frames within the ´orange interval´ can be transmitted with or without VLAN tag.

The advantage of this is that the I/O traffic is secured against other data traffic.

6.4 RT_CLASS_3 communication

This communication could be compared to a subway network in a city. Many routes are available to reach the destination station from the starting station. In between are one or more intermediate stations. If the most favorable path is considered in advance, it is certain that the destination will be reached faster. This is also the case when it comes to IRT communication in a network. The communication paths are therefore planned during engineering.

Communication in the ´red interval´ is based on a schedule configured in advance, i.e., in addition to the information for the end nodes, the network components located in between require information defining the forwarding of frames. Frames are forwarded based exclusively on the planning algorithm defined in IEC 61158. As a result of planning, an Ethernet controller (or more precisely, the integrated switch in an Ethernet controller) knows exactly which frame arrives at which port and when it must be forwarded to where.

If a system requires RT_CLASS_3 communication, the bus cycle must be divided into a ´red interval´ and a UDP/IP part (´green interval´) during engineering. Here, the timing and length of each frame to be sent is specified on a port-by-port basis. The plant topology, the respective frame length, and the cable lengths between the individual nodes are critical factors in the timing for the purpose of its optimal utilization. If the system is changed, the planning algorithm must therefore be repeated. Data transmission in the IRT portion is always scheduled. The „schedule“ is geared only to the sequence of arriving frames, which is determined by their Frame_ID and the frame length. The time-controlled processing of jobs within the ´red interval´ aids in eliminating the final sources of inaccuracies. Since RT_CLASS_3 communication is oriented only on the basis of timing, the throughput times of data frames through a switch are significantly shorter. Likewise, the performance in branched networks can be increased by optimized use planning of the same communication path.

The topology information is sent to the respective IO-Controller during system power-up. It can then check the real configuration in an automation system. Each IO-Device knows its configured neighbors on a port-specific basis. Knowledge of the network topology forms the basis for scheduling of message frame transmission. An IRT node compares this information with the neighborhood information it determines itself (according to the LLDP protocol) during every cycle.
This enables a very high utilization of the bandwidth available, and wait times for frames can never occur. RT_CLASS_3 frames are always sent without VLAN tag since the chronological position is always the determining factor for data transmission.

6.5 System power-up with IRT

System power-up with IRT communication can be regarded exactly the same as power-up with real-time communication. For this purpose, 1 AR and 2 IOCRs are required. In addition, the IO-Controller still transmits the following:

- Loading of the synchronization data for the red and orange intervals
- Forwarding information for the red interval
- If necessary, loading of information for any existing isochronous application

Before the actual power-up can begin, the individual field devices determine the respective ´Line delay´ on a port-by-port basis. By sending out at least two ´Line delay´ frames in a row, the nodes can determine the quartz frequency deviations and compensate the times determined in the RTSync frame. At the start of power-up, all connected field devices are in the „green“ interval.

During the subsequent power-up, the IOCRs for the inputs/outputs are set up in the ´Connect frame´ within the AR to be established. The input/output data are then exchanged with provider status ´bad´, because synchronism has not yet been achieved in the respective field device.

After the IOCRs are set up, the IO-Controller parameterizes the individual modules/submodules (´Write frames´) in the IO-Devices and transfers the data for parameterizing the IRT portion in the individual IO-Devices.
The transmission of synchronization data follows for the IO-Devices involved within the IRT domain. The IO-Controller transmits data for the synchronization within the frame.

6.6 Tips for communication

In order to carry out efficient data communication involving different real-time classes, it is necessary to define certain „mirroring rules“ in order to ensure that the timing and the isochronous operation are adhered to in every configuration. The general rule is that at least 2 TCP/IP frames with maximum length can be sent per millisecond. This corresponds to a transmission time of approximately 250 µs. For bus cycles <= 500 µs, the rule is reduced to 1 TCP/IP frame. Furthermore, the transmission time of cyclic data should not exceed 60% of the bus cycle in order to allow sufficient time for TCP/IP communication.

Only field devices that support synchronization measures can participate in synchronized communication (bus synchronization). Otherwise, the timing of the different phases cannot be adhered to.

Figure 6.4 shows how the data transmission is divided within a send cycle. The data are transmitted according to the defined intervals.

The system advantage of the device-granular update specification is that the bandwidth can be shared by fast nodes and slow nodes. As a result, the update rate is no longer determined by the total number of nodes but instead can be adapted according to the application.

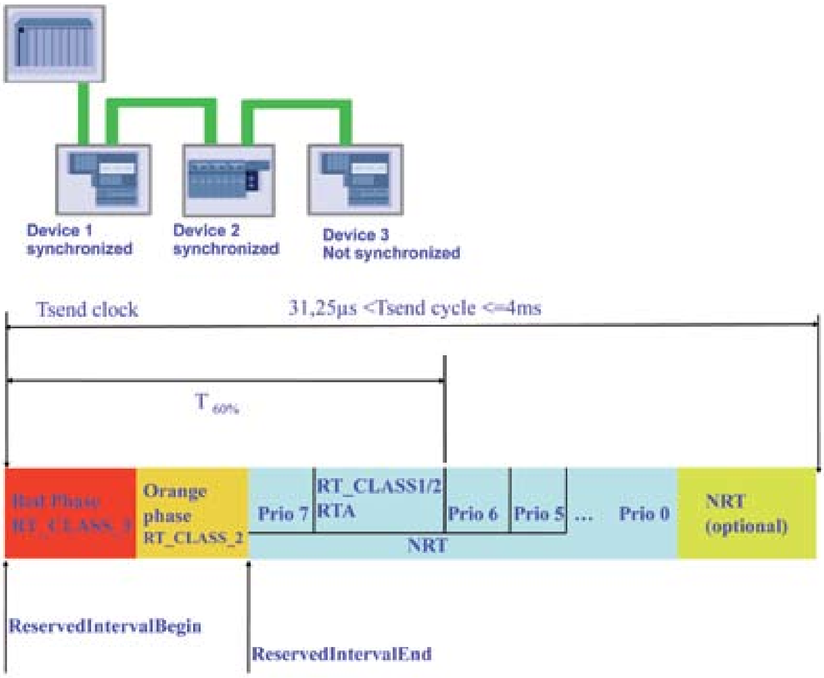


Figure 6.4: The exact order of data transmission within a Send Clock ist controlled in PROFINET IO.

6.7 Mixed operation of synchronized and unsynchronized applications

Under certain conditions, it is possible to have a mixture of isochronous and non-isochronous applications in field devices in one automation system.

Figure 6.5 shows a mixed operation. In this example, devices 1 to 3 have an IRT-suitable switch (for example, ERTEC 200/400) integrated in the field device. This allows the exact ´Line delay´ to be determined and the exact timing of the individual phases to be adhered to. The other two devices are connected via an IRT-suitable multiport switch.

Applications that run isochronously cannot be integrated in these field devices unless they also have an IRT-capable switch. If not, these applications do not disturb the rest of the isochronous data traffic because the multiport switch to which they are connected recognizes the time behavior of the individual phases (reserved, green, etc.). In addition, forwarding information and timing are loaded to this multiport switch during system power-up.

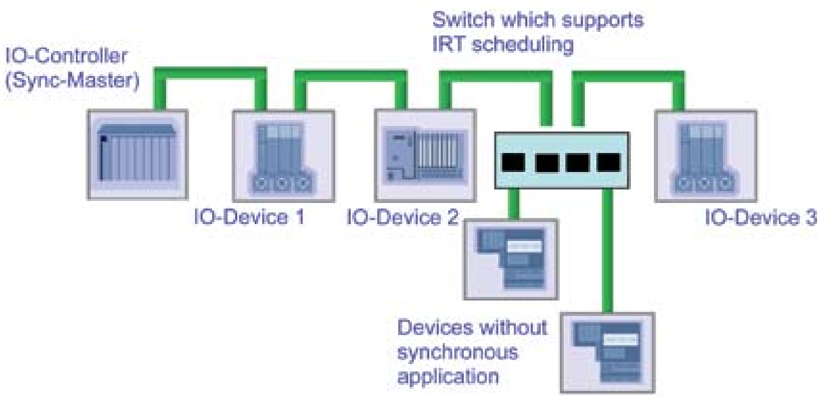


Figure 6.5: Mixed operation of synchronized and undsynchronized applications.

7. PROFINET IO Controller

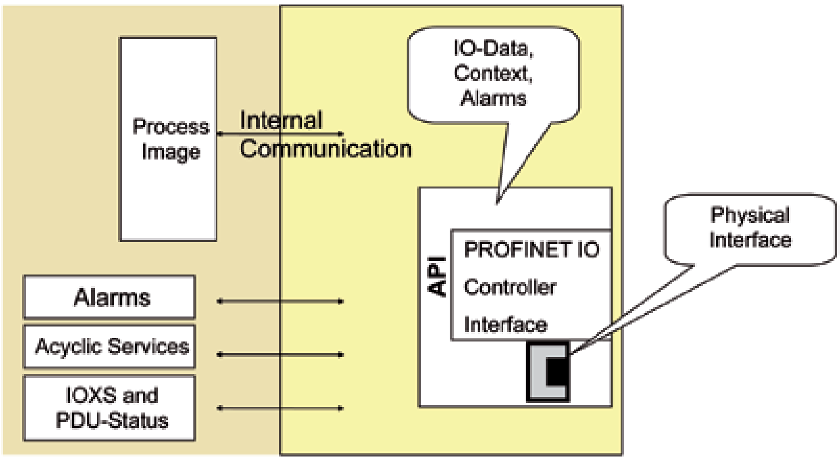


Figure 7.1: A PROFINET IO-Controller carries out the process data traffic with IO-Devices.

A PROFINET IO-Controller is the station in an automation system on which the control program runs. It requests the process data (inputs from the configured IO-Devices during power-up), processes its control program, and transfers the process data to be output (outputs) to the respective IO-Devices. To perform this data exchange, it requires the system configuration data containing all the communication data. The following data are defined during system configuration:

- Degree of expansion of an IO-Device
- Parameterizations for an IO-Device
- Transmission frequency
- Degree of expansion of the automation system
- Information regarding alarms and diagnostics

Multiple IO-Controllers can be used in a PROFINET system. If these IO-Controllers are to be able to access the same data in the IO-Devices, this must be specified when configuring (shared devices, shared inputs). The term „shared devices“ refers to access by multiple controllers to a single IO-Device. Shared inputs describe the access by multiple controllers to the same slot in an IO-Device.

The IO-Controller receives the configuration data of the automation system and establishes the application relations and the communication relations with the configured IO-Devices autonomously. Figure 7.1 shows the structural configuration of an IO-Controller.

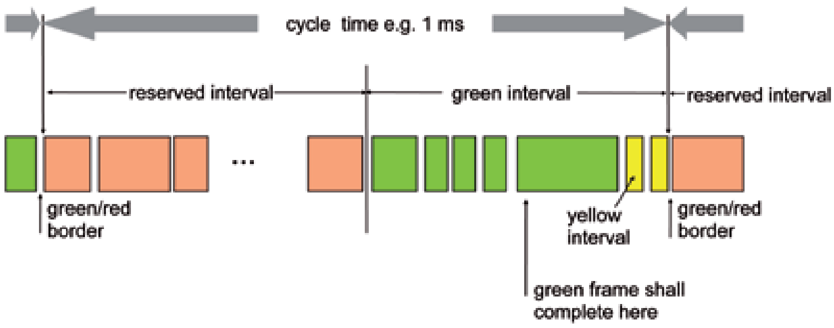


Figure 7.2: An IO-Device can have multiple ARs established from various controllers.

An IO-Controller can establish one AR each with multiple IO-Devices. Within an AR, several IOCRs and 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 the communication and different subslots are required. Within an IOCR, the specified APIs (Application Process Identifier) are used for differentiation purposes. As a result, co-mingling of data between the APIs is not possible. Access to user data must be coordinated by the user program. PROFINET IO allows more than one user profile to be defined within the same AR.

One IO-Controller must support the following functions

- Alarm handling
- Process data exchange (IO-Device in I/O area of host)
- Acyclic services
- Parameterizing (transmitting power-up data, transmitting recipes and user parameterization of the assigned IO-Devices)
- Diagnostics of configured IO-Devices
- Initiator for establishing context for an IO-Device
- Address assignment via DCP (including the automatic detection of device failures and acceptance of a replaced field device during user data mode)
- API (Application process instance)

7.1 Parameter server

The parameter server functionality is available for backing up and reloading dynamic parameters of a field device. The basic parameterization of a field device is carried out using the parameters defined in the GSD file for the field device. A GSD file contains module parameters for I/O modules, among other things. These are stored as static parameters and can be loaded from the IO-Controller to an IO-Device during system power-up. For many field devices it is either impossible or inappropriate 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 are referred to as individual parameters (iPar). Often, they can also be specified only during commissioning. If such a field device fails and is replaced, these parameter must also be reloaded automatically to the new field device. In the past, proprietary solutions had to be used to back up and reload these parameters because no standard approach was available, i.e., the user was confronted with a wide range of solutions and operations or none at all. It was necessary to change this situation in order to offer plant operators a convenient and uniform solution.

The iPar server solution

The problem described gave rise to the so-called iPar server for saving and automatic loading of so-called dynamic device parameters. The iPar server can be viewed as an optional program section in the host/IO-Controller. It is not safety-oriented and serves to ensure that a field device stores its iParameters without additional intervention and that a replacement device can retrieve them again.
In order to better classify the function of an iPar server in the overall PROFINET context, the mode of operation will be explained using a simple application. The interaction between a TCI application, the device replacement, and the iPar server is also revealed.

During the initial commissioning, the following sequence occurs:

1. The static data from the GSD file are read into a configuring tool. General configuration is carried out as previously. In addition, the requirement for the iPar server function and the iParameter scope in Kbytes can now be declared from special GSD parameters.

2. During system power-up (connect and write services), an IO-Controller initializes the field device with the data generated from the GSD in order to place the field device in data exchange and prepare it for acyclic communication.

3. By means of a parameterization tool, the iParameters can now be assigned for the corresponding field device via a user dialog. It‘s up to the device manufacturer to determine the approach by which the iParameters reach the device, e.g., via an interface such as TCI (Tool Calling Interface), direct point-to-point connection such as RS 232, infrared connection, or local teach-in.

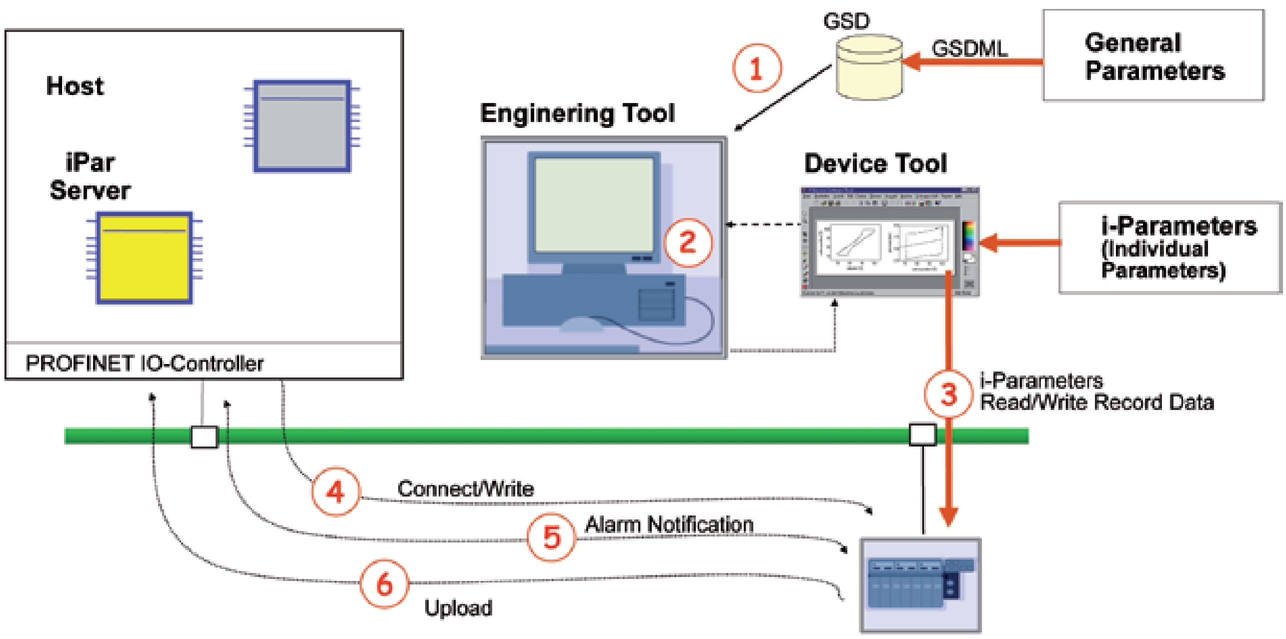


Figure 7.3: An iPar server allows backed up data to be reloaded automatically when a device is replaced.

4. The most convenient approach involves connection of the parameterization tool to the field device via an interface such as TCI using the TCI Communication Server.

5. Following the iParameter assignment and, if necessary, verification, the field device answers with an alarm notification and requests an upload of the iParameters.

6. The iPar server in the host/IO-Controller reads the iParameters from the field device acyclically and saves them so that they can be reloaded if required (e.g., during device replacement).

What happens during device replacement?
Following device replacement and subsequent power-up (connect and write sequences), the IO-Controller loads all GSD-based data in order to place the replaced field device into data exchange again. After the basic initialization, the replaced field device determines that it still needs iParameters. An alarm notification is then generated (Update & Retrieval alarm). The iPar server then loads the saved iParameters of the predecessor device to the field device.

The detailed chronological sequence is as follows:

1. The defective field device is replaced, and the replacement device is switched on.

2. Following the automatic address resolution, the IO-Controller establishes an AR with the field device and loads the GSD-based static parameters.

3. The new field device determines that it still needs (dynamic) i-Parameters and signals this via an alarm notification (´iPar request´).

4. The iPar server loads the requested iParameters into the new field device.

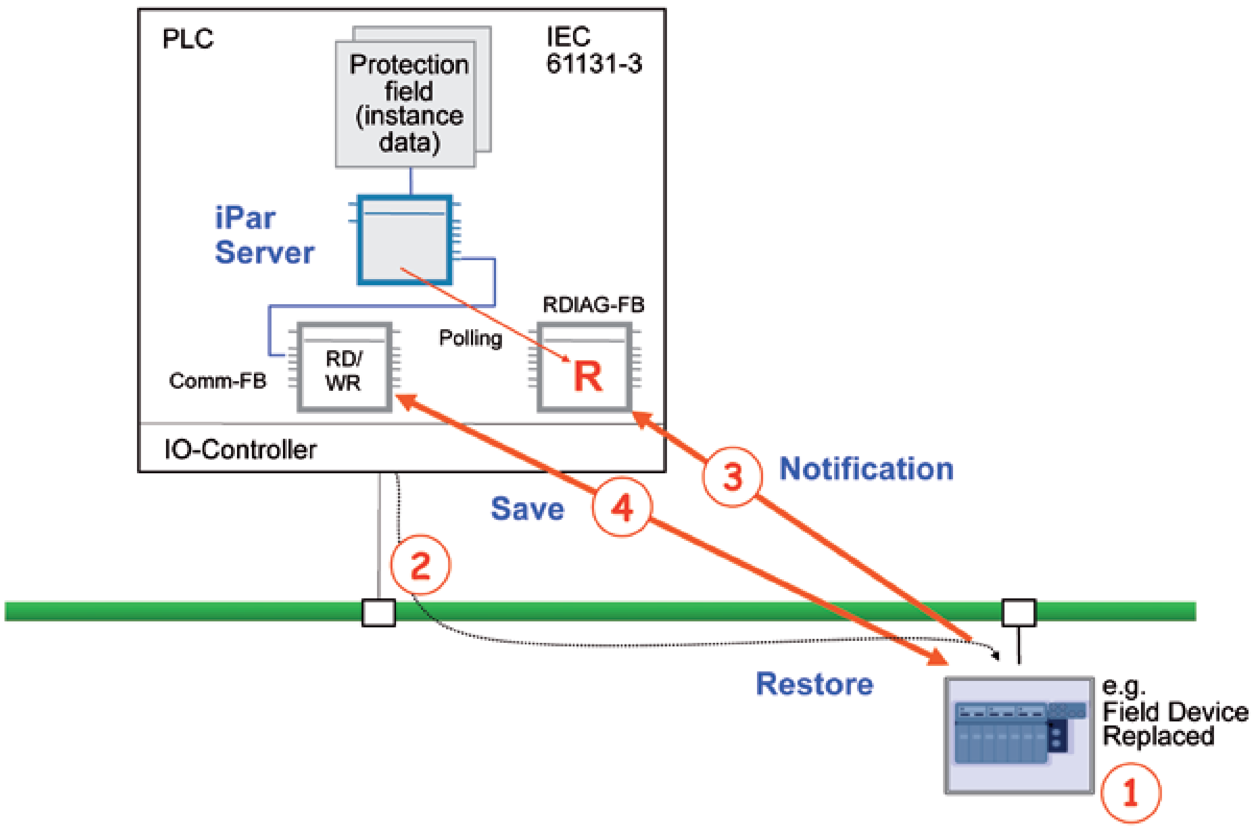


Figure 7.4: During device replacement the iPar server parameterizes the new field device.

8. Device Description (GSD file)

The functionality of a PROFINET IO-Device is always described in a GSD file. This file contains all data that are relevant for engineering as well as for data exchange with the IO-Device.

PROFINET IO-Devices can be described using XML-based GSD. The description language of the GSD file, i.e., GSDML (**G**eneral **S**tation **D**escription **M**arkup **L**anguage) is based on international standards. As the name suggests, the GSD file is a language-independent XML file (e**X**tensible **M**arkup **L**anguage). Many XML parsers are currently available on the market for interpreting XML files.

Every manufacturer of an PROFINET IO-Device must supply an associated GSD file according to the GSDML specification. This file is tested as part of certification testing.

To describe PROFINET IO-Devices, PI provides an XML schema to each manufacturer. This allows a GSD file to be created and tested easily. The need for numerous subsequent input checks is therefore omitted.
In addition, the device model of PROFINET IO exhibits a further hierarchy level for data addressing when compared to PROFIBUS. Thus, for example, addressing within a field device (in PROFIBUS: slot and index) has been expanded to include the identifier of a subslot. In PROFINET IO, addressing within a field device can be performed with finer granularity (slot and subslot). In addition, this type of addressing could not be described with the GSD file for PROFIBUS.

9. I&M Functions (Identification & Maintenance)

The ability to read out basic information from a field device is very helpful in many cases. For example, this allows inferences to be drawn in response to incorrect behavior or regarding unsupported functionality in a field device. These information functions are specified in the data structures of IM0 to IM4. I&M data are read out via read services. Therefore, IO-Devices must supply at least the following data:

- Order ID
- MAC address
- Hardware revision
- Software revision
- Device type
- VendorID
- All I&M0 data

These data are necessary for addressing the field device as well as for reading out the I&M functions.

The I&M functions are subdivided into 5 different blocks (IM0 to IM4) and can be addressed separately. A separate index is available for addressing for each I&M. Each IO-Device must support the I&M0 function.

The I&M Specification entitled ´Identification and Maintenance Functions´ can be downloaded from the PI server at www.profinet.com in the Downloads section.

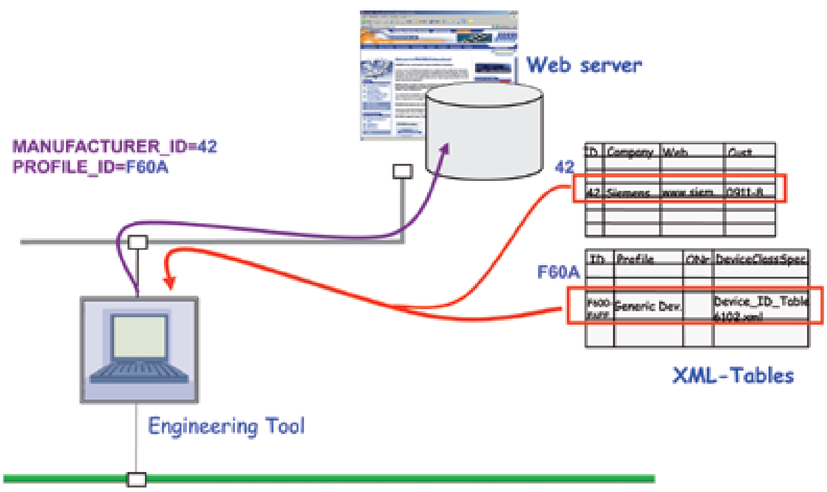


Figure 9.1: Operating principle of I&M functions.

10. Redundancy

Chaining of 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 connections, i.e., line connection between control cabinets and star connection to process-level field device (see figure below).

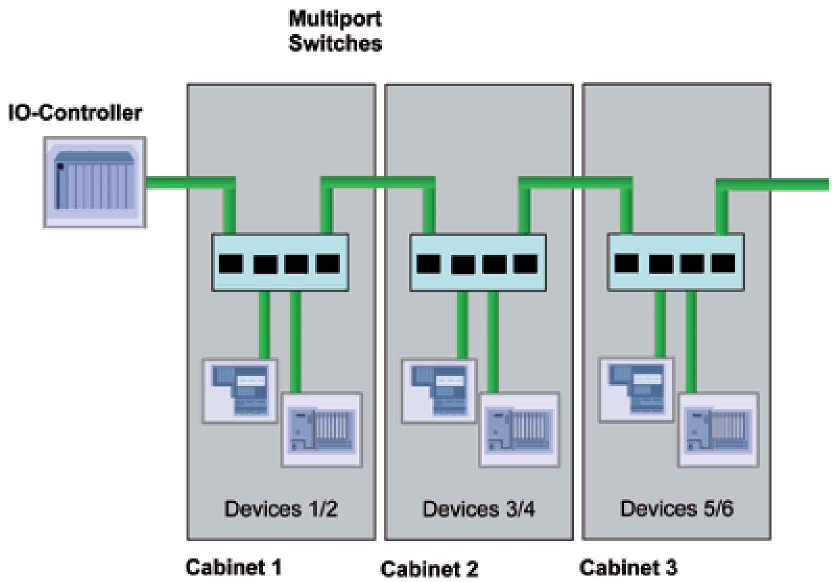


Figure 10.1: Star and line topologies can be combined with Ethernet/PROFINET connection systems.

Redundant communication paths are necessary in an automation system in certain cases in order to increase the system availability significantly. Of the available network structures, the line structure is currently preferred in automation systems.

A redundancy manager and several clients contribute to correct operation of an automation system.

10.1 Media Redundancy Protocol (MRP)

The MRP protocol according to IEC 61158 describes PROFINET redundancy with a typical reconfiguring time of communication paths with TCP/IP and RT frames after a fault of < 200 ms.

In principle, the same data transmission mechanisms as described previously are used in PROFINET. The only difference is the communication path used to transmit the frames (UDP/IP and RT frames). These frames are only transmitted via the „healthy" channel (single-channel). The redundancy manager is the coordinator. IEC 61784 specifies the method for using MRP.

The redundancy manager (RM)
The task of a redundancy manager is to check the functional capability of the configured ring structure. This is done by sending out cyclic test frames. As long as it receives all the test frames again, the ring structure is intact.

This procedure allows an RM to prevent frames from circulating and to convert a ring structure into a line structure. The RM must communicate changes in the ring to all clients involved (switches as so-called „passers") through special ´Change in topology´ frames.

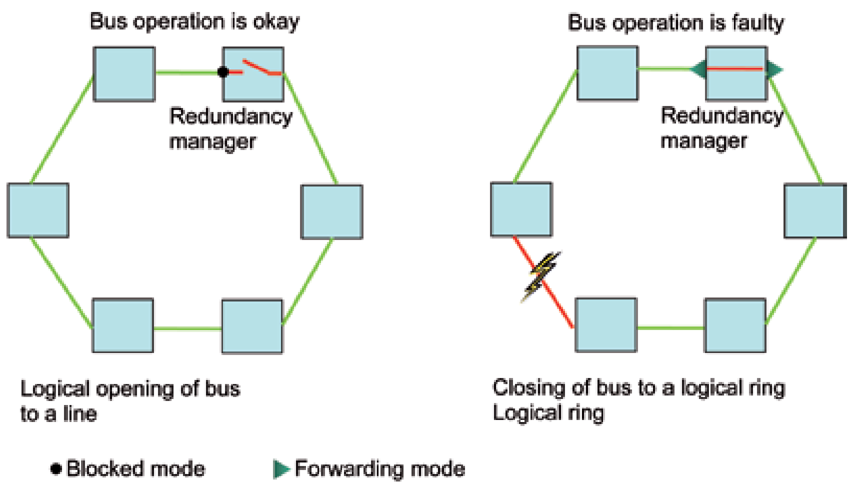


Figure 10.2: Logical separation of the bus prevents circulating frames.

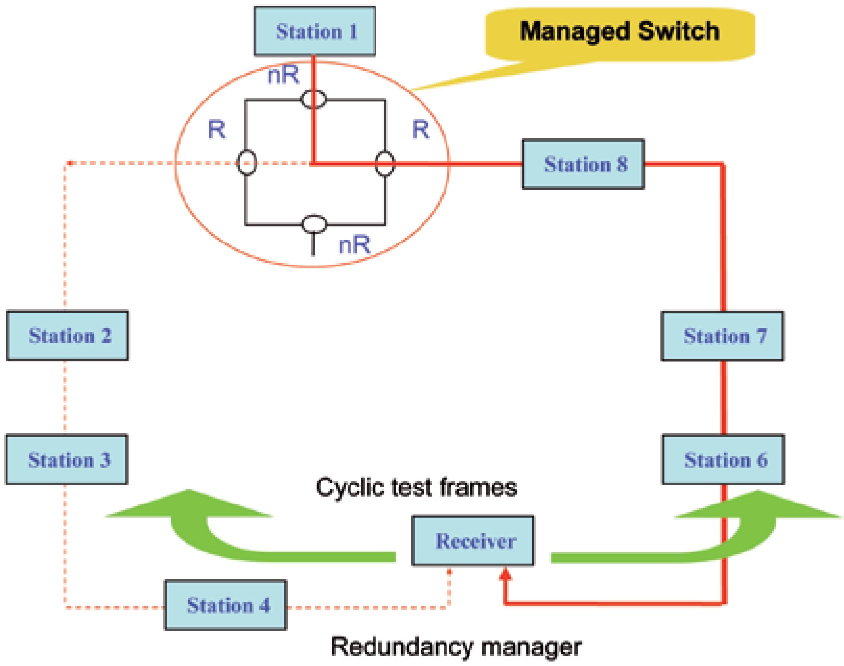


Figure 10.3: Media redundancy with MRP increases the plant availability.

The redundancy clients

A redundancy client is a switch that acts only as a „passer" of frames and generally does not assume an active role. It must have two switch ports in order to connect to other clients or the RM in a single ring.

In PROFINET IO, only ´managed Switches´ that support MRP and can be configured, for example, via SNMP or Web services are used for implementing media redundancy. Data are exchanged only via the communication path selected by the redundancy manager.

10.2 Media redundancy for RT frames (MRRT)

The MRRT protocol (´Media Redundancy for Real-Time´) defined in IEC 61158 describes the handling of RT frames of RT_CLASS_1 and RT_CLASS_2 for redundancy operation. Operation of MRP is always a prerequisite for operation of MRRT. IEC 61784 describes the procedure for using the MRRT protocol. With RT communication, the MRRT protocol enables a virtually smooth switchover of communication paths if a fault occurs. This is accomplished by redundant transmission of RT frames (i.e., via two channels) if the destination port is designed as a redundant port.

On the receiving side, 2 RT frames always arrive, provided the redundant transmission is error-free. Only the first frame to arrive is forwarded to the application. In this case, the RM must also check the functional capability of the system.

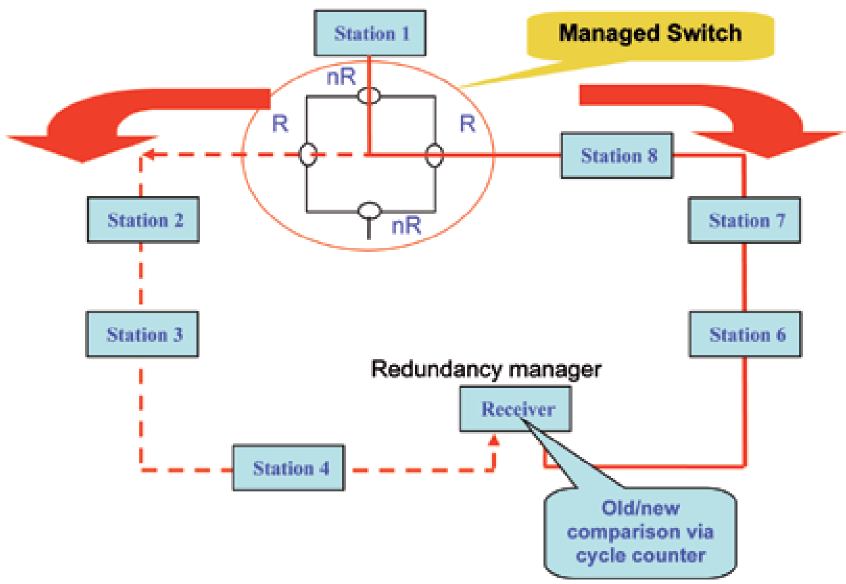


Figure 10.4: Media redundancy for RT frames includes smooth switchover of communication paths if a fault occurs.

10.3 Media redundancy for RT_CLASS_3 frames (MRPD)

IEC 61158 describes the redundancy concept for RT_CLASS_3 frames as ´Media Redundancy for planned duplication´. IEC 61784 describes the use of redundancy class 3 for RT_CLASS_3 communication with smooth switchover of communication paths if a fault occurs. During system power-up, the IO-Controller loads the data of the communication paths for both communication channels (directions) in a communication ring to the individual nodes. 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, because the destination ports are explicitly defined.

11. Conformance Classes (CC)

PROFINET IO is a performance-optimized, future-oriented communication system that fulfills all the requirements of automation engineering. It integrates an increased scope of functions in the transmission protocol to meet the requirements of industrial applications. However, the complete scope of functions is not required in every automation system, so PROFINET IO can be scaled with regard to the functionality supported.

To this end, PI has classified the scope of functions in PROFINET IO into conformance classes/application classes. The objective is to simplify the application areas of PROFINET IO. The resulting application classes enable plant operators to easily select field devices and bus components with explicitly defined minimum properties. This is a further step in the quality assurance of all field devices involved in communication, which is certified by passage of a certification test.

The minimum requirements for 3 conformance classes (CC-A, CC-B, CC-C) have been defined from the perspective of the plant operator. In addition to the three application classes, additional specifications have been made for the following:

- Device types
- Type of communication
- Transmission medium used
- Redundancy behavior

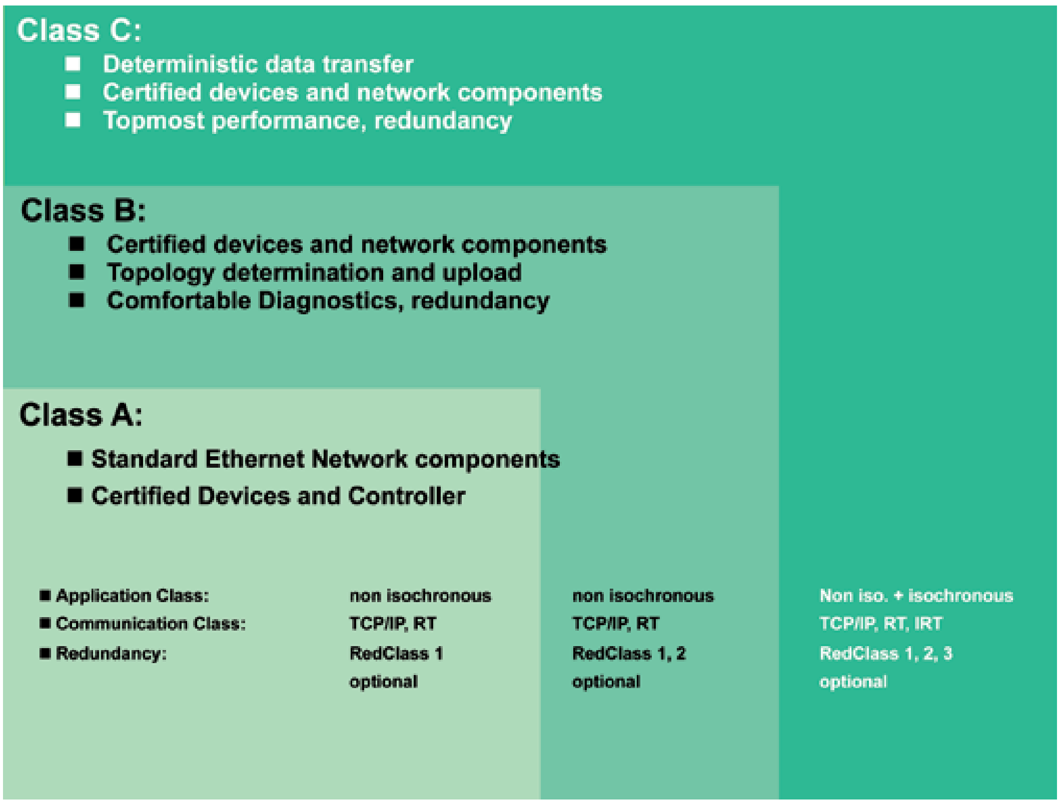
This specification ensures the interoperability in an automation system with regard to the scope of functions and performance parameters. This gives plant operators an advantage in that when selecting components to be used, they simply need to select a CC appropriate for the system and do not need to worry about any other details. It is assured that all field devices within the selected CC meet the same minimum requirements. A detailed description of the CCs can be found in PNO Document ´PROFINET Conformance Classes´.

Application areas

CC-A: Use of the infrastructure of an existing Ethernet network including integration of basic PROFINET functionality. All IT services can be used without restrictions. Examples of typical applications are in building automation and process automation. Wireless communication is only possible in this class.

CC-B: In addition to the functions of CC-A, the scope of functions of CC-B supports easy and user-friendly device replacement without the need for an engineering tool. Examples of typical applications are in automation systems with a higher-level machine controller that place relatively low demands for a deterministic data cycle.

CC-C: In addition to the functions of CC-B, the scope of functions of CC-C supports high-precision and deterministic data transmission, including for isochronous applications. The integrated media redundancy enables smooth switchover of the I/O data traffic if a fault occurs. An example of a typical application is the field of motion control.



12. Application Profiles for PROFINET IO

Application profiles are specifications of certain properties, performance features, and behavior of devices and systems, which have been developed jointly by manufacturers and users. The use of application profiles for standardization offers the following advantages:

- **Operator**
  The existence of certified, profile-compliant devices provides a high level of independence of individual device manufactures while maintaining a basic set of functionalities.

- **System integration and installation**
  The use of certified devices ensures a high degree of conformity and interoperability, because these devices pass comprehensive tests that are developed and coordinated within PI.

- **Planner**
  Standardization of the basic functionality of devices means that a uniform nomenclature exists, which greatly simplifies device selection.

- **Device manufacturer**
  Simplified use and increase in the achievable integration depth of devices in different automation systems.

The profile definition ranges from a few specifications for a particular device class to comprehensive specifications for applications in a particular industry. The term Application profiles is used as a generic description.

In general, two groups of application profiles are distinguished:

- General application profiles available for use in different applications (for example, the PROFIsafe profile).

- Specific application profiles developed for a very specific type of application, e.g., PROFIdrive, Encoder, Identification systems, or PA devices.

PROFIBUS offers many such profiles and can thus be used in an application-oriented manner. These profiles are being incorporated into PROFINET step by step as required.

By default, PROFINET transmits the specified data transparently in the data unit. The user is responsible for individually interpreting the sent or received data in the user program of a PC-based solution or in the function block of a programmable logic controller. In a few sectors, e.g., in drive engineering or safety-related data transmission, etc., application profiles have already been defined by leading interest groups. These define both the data format and the scope of functions and are registered with PI.

An application profile is defined uniquely by the ´Profile_ID´ assigned by PI and an associated API (Application Process Identifier). The API is used to identify the application profile. The list of current ´Profile_ID's´ for PROFIBUS and PROFINET is available at:
www.profibus.com/IM/Profile_ID_Table.xml

API 0 is manufacturer-specific and must be supported by every field device. Through the use of APIs, there is always a clear separation of data ares within a field device because a slot/subslot combination can only ever be assigned to one API.

Currently, the application profiles PROFIsafe, PROFIdrive, Encoder, Low Voltage Switch Gear, and Identification Systems are available for PROFINET. These profiles were all available originally for PROFIBUS.

In addition, the scalable communication and the modular structure of PROFINET enable it to be used in other application areas such as power engineering and vehicle automation. The Train Applications profile represents the first profile that was developed exclusively for use with PROFINET.

“Train Applications“ specifies the application layer for devices used in train automation. Through the use of PROFINET, Ethernet-based real-time and IT communications are made available for applications in rail vehicles.

Building on the available basic specifications (standard elements and WTB gateway) as well as a Development Guideline, additional profile documents for diverse subsystems of rail automation will follow, e.g., profile for door control.

13. PROFINET for PA

In most cases, process systems have areas where discrete input and output signals dominate and manufacturing technology components are predominantly used. Typical examples of such system areas include: equipment for stocking and storage of raw materials; packaging, filling, or palletizing processes for end products; as well as transport equipment with its drive and control components. Technical innovations and further developments of these components will increasingly include furnishing an Ethernet interface (e.g., PROFINET).

In such systems, automation is referred to as „hybrid automation“. Examples of applications include:

- In the pharmaceuticals industry, the manufacture of medicines is a process control procedure, but packaging, e.g., of tablets, is a discrete manufacturing procedure using complex packaging machines.
- In a brewery, the process control tasks typical of the brewhouse and fermenting cellar are followed by discrete manufacturing tasks such as bottle cleaning and filling, as well as the stacking of crates for delivery, a task for which robots are used.
- In automotive manufacturing, the paint shop with its process system requirements is otherwise part of a typical manufacturing system production sequence.

Requirements
Compared with production automation, process automation has a few particularities that co-define the use of automation to a large extent: Systems can have a service life of many decades. In addition, systems are often associated with a high hazard potential and therefore require special safety considerations. As a result, devices and systems with well-proven field records are used preferentially. This gives rise to a requirement, on the part of systems operators, for older and newer technologies to coexist in such a way that they are functionally compatible.

In addition, requirements for reliability of process systems, particularly in continuous processes, are often considerably greater. Combined, these two aspects mean that decisions to invest in new process automation technologies tend to be more conservative than for production automation.

In addition to direct connection of process devices to the field bus, remote IO technology has also become established. Analog and binary input and output signals are thereby collected in a remote IO that is in turn connected via the fieldbus to the control system. With HART-capable remote IOs, the field devices are then parameterized via HART communication.

For optimal use of PROFINET in all sectors of process automation, PI has created a requirements catalog in collaboration with users.

Protection of investment for the end user is a salient consideration here because, as mentioned previously, instrumentation in a process-control system typically has a life cycle of several decades.

In this manner, it is ensured that operators of plants having an existing future-proof system based on PROFIBUS can change to PROFINET at any time.

The requirements mainly include the functions for cyclic and acyclic data exchange, integration of fieldbuses, integration and parameterization of devices including Configuration in Run, diagnostics and maintenance, redundancy, and time stamping.

The energy-limited bus feed of devices in hazardous areas on Ethernet has not been formulated as a requirement as there is already an ideal, proven solution with PROFIBUS PA. In addition, proven, field-tested Ethernet solutions currently do not exist for this.

The primary objective when formulating the requirements was to take advantage of opportunities offered by the use of Ethernet in automation. In addition to the basic virtues already mentioned, PROFINET has advantages in terms of significantly expanded topologies, greater data quantities, and higher performance.

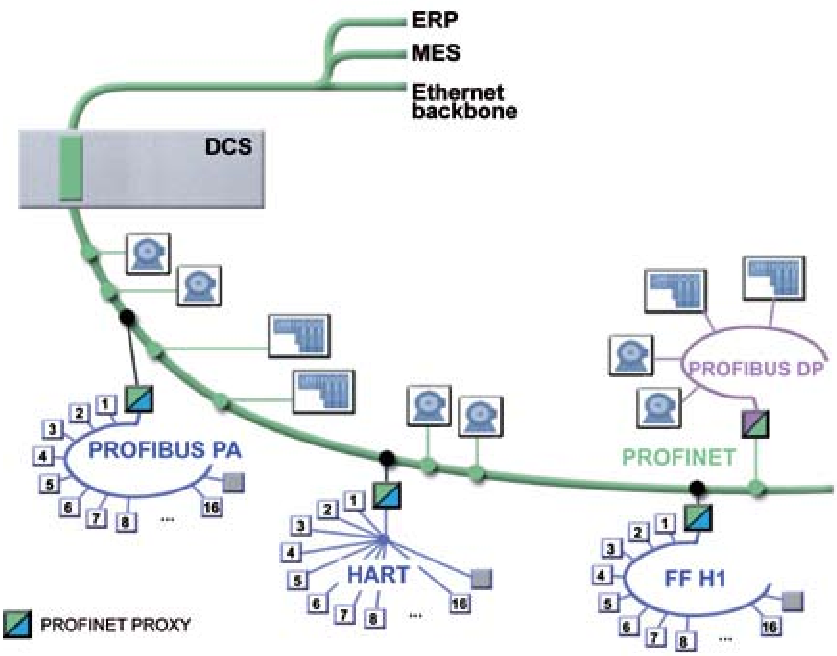


Figure 13.1: Example architecture for use of PROFINET in process automation.

14. Tool Calling Interface (TCI)

In PROFINET, device data for configuring intelligent field devices are stored in a general station description file (GSD file). During engineering, a configuring engineer can define which parameters are to be written to the corresponding field device during system power-up or during operation, in order to ensure operation with pre-assigned, static parameters. There are some cases, however, in which GSD files, although user-friendly, are not able to meet prevailing requirements. The configuring engineer must accept an additional limitation if he wants to write comprehensive parameters to a field device and the field device and the engineering tool for the automation system (ES) are from different manufacturers. In most cases, this transfer requires a proprietary solution because it cannot be carried out directly by the engineering tool of the automation system.

The TCI describes a scalable, easy-to-operate interface that allows operations such as loading parameters to a field device and exchanging convenient diagnostics with a field device. TCI consists of the following main components:

- Invocation interface: The user can invoke various field device user interfaces (Device Tools = DT) from the engineering system (ES). 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.

Thanks to the freely available TCI specification, every manufacturer can create a DT that works autonomously and integrate it into any TCI-capable ES. This approach has already been implemented with the FDT interface (Field Device Tool). PI then took the next step toward providing a simpler interface with a reduced scope of functions. The use of TCI is well-suited for field devices in the lower price bracket as well as complex devices already equipped with a user interface, because the effort is manageable.

TCI supports the communication paths of PROFINET. In addition, proprietary solutions for communication between field device user interface (DT) and field device can be used.

Mode of operation

Figure 14.1 presents an example of the structure and interaction between an ES and a DT. To integrate a DT into a TCI-capable ES, the manufacturer must supply a GSD file, a PID file, the field device user interface (Windows application), and an installation program.

The GSD file contains the device identification for the field devices involved, including the relevant I/O modules. The (Program Interface Description) defines the functionality for which the DT can be used.

In order to use a DT, both the ES and the DT must support a TC interface. In essence, it describes the invocation interface between the ES and DT and the communication interface between the DT and the TCI communication server, which undertakes the communication between the field device and the DT.

When a DT is invoked, the following steps occur in the order given:

- Based on the device identification (1) in the GSD file, the ES can use the entries in the registry of a Windows-based engineering tool to find the PID file (Program Interface Description) for the corresponding DT (2). The PID file (XML file) describes the available options for the associated DT.
- The engineering tool then creates a TPF file (Temporary Parameter File) containing all transfer parameters to the DT (3). This saves the step of transferring a large number of parameters to the DT when invoked. The engineering tool then invokes the DT (4) and transfers the path where the TPF file can be found. The path for the data storage is transferred in the TPF file, among other things. The DT is responsible for organizing the data.
- When the invocation is complete, the DT deletes the TPF file (5).
- The DT interprets the content of the TPF files and, if necessary, establishes the communication on the basis of the selected field device with the TCI communication server (if supported) or directly with the device (proprietary solution).
- The user performs the desired function with the device (parameterization or diagnostics, etc.).
- The DT saves the data relevant to the project in the path on the project drive disclosed via the TPF file.

This action assures a separate data management by the DT as well as assignment to the project in the engineering system.

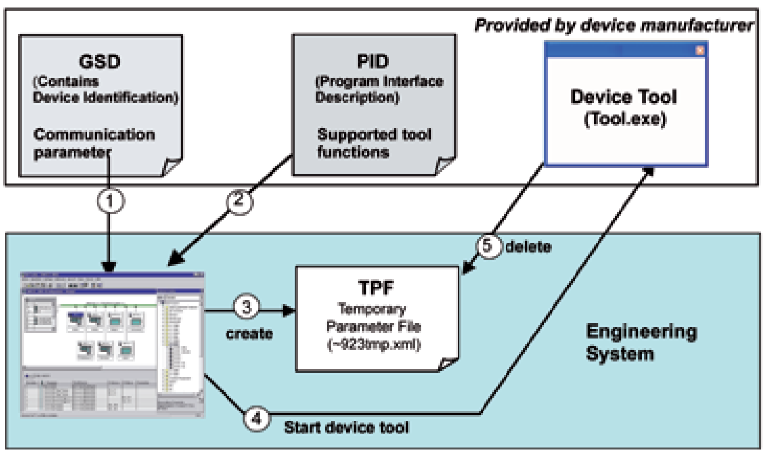


Figure 14.1: Structure of TCI.

15. PROFINET CBA

Within the framework of PROFINET, PROFINET CBA (Component Based Automation) is an automation concept for implementation of applications with distributed intelligence. In addition to the simple input/output-based data exchange in automation systems with PROFINET IO, the trend in automation engineering in some sectors is also producing processing structures that represent an overall production system divided into intelligent and logical subunits in the form of control sequences. An automation system that appears complex at first glance can thus be organized into manageable groups of subunits. Each subunit undertakes independent, stand-alone work steps. These logical functional units each form a technological system module that can be reused in different systems in identical or modified form as a so-called PROFINET component. A PROFINET component is nothing more than a standardized portion of an automation system. Plants configured in this way are significantly easier to handle.

A very simple example of such a plant structure is a conveyor belt on which different sequences are performed at corresponding work stations. Each downstream work step assumes that the upstream work step was performed properly. In modern production lines, such sequences (plant units) are automated. Figure 15.1 shows a section of such a production plant in the beverage industry.

The different plant units (machines) can be developed, tested, and commissioned by one or more manufacturers.

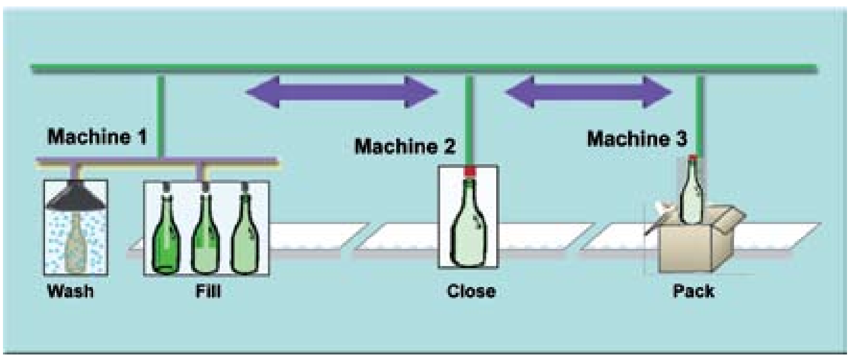


Figure 15.1: Example of a control sequence in production.

Now, only the respective input signals and the output signals required for data exchange between the partners still have to be defined within the control sequence. The actual processing is then carried out within the respective technological module (here, machines 1, 2, and 3). The processing within the technological module during the production sequence is invisible to the plant operator. Outside the technological module, only the interface is of interest and it can be reduced in many cases to a few control signals. Such systems are significantly more economical to create and maintain over their entire life cycle.

In similar industrial sectors such as the beverage industry, automotive manufacturing, etc., the sequences are quite similar among different plants such that plant units can be adopted in some cases with only minor modifications or, ideally, without modifications.

The definitions of technological modules promote clearly arranged plants and, of course, contribute to cost-effective operation due to the high degree of reusability.

15.1 Technological modules in a plant

The PROFINET approach assumes that the function of an automated plant or machine is fulfilled by a specified interaction of mechanics, electrics/electronics, and the controller logic/software as part of the manufacturing process of products. For this reason, PROFINET defines the functional aspects associated with a logical production step, consisting of

- mechanics,
- electrics/electronics, and
- controller logic/software,

as a related unit, i.e., the technological module. A technological module thus represents a plant-specific portion of the mechanical system, the required controller electronics, and the associated software program.

When defining technological modules, their reusability in different plants as well as their costs and availability must be examined in more detail. In this process, plant/machine manufacturers can assemble one or more electronic device/software components to form an overall machine (technological module). The objective is always to define individual components according to the modular design principle to allow

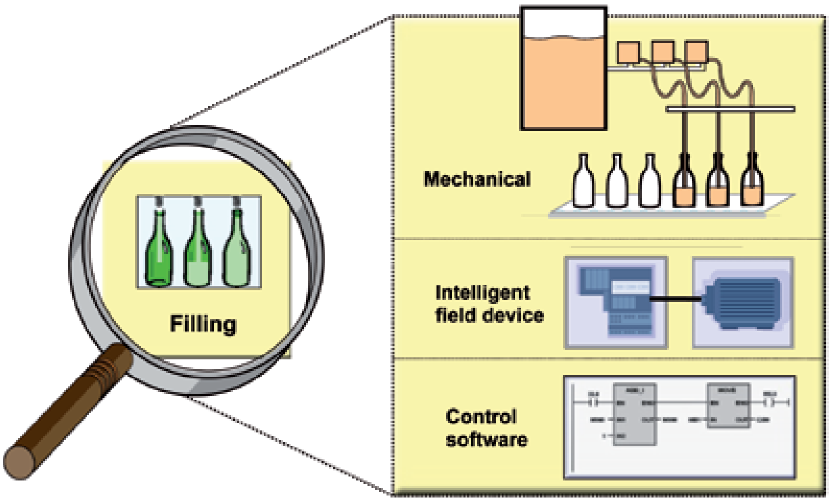


Figure 15.2: Technological module consists of mechanics, electronics, and software.

them to be combined with as much flexibility as possible. If the modules are defined too finely with too much functionality, the plant will no longer be straightforward from the technological perspective because too many input/output parameters may have to be defined. This, in turn, drives up the engineering costs.

15.2 Technological module and PROFINET component

A technological module represents a particular unit of a plant. For the plant/machine manufacturer and commissi-

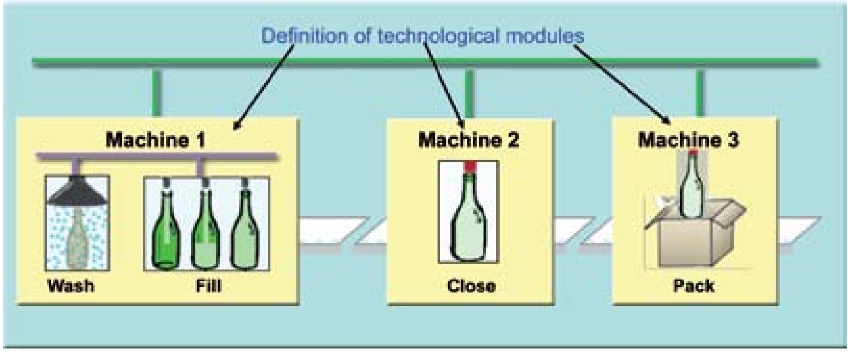


Figure 15.3: In PROFINET individual plant units can be combined to form technological modules.

oner, however, only the portion of the technological module that is necessary for interaction of the individual plant units is visible. This functionality is provided in the software of the respective field devices.

Therefore, the only thing that matters here is which input and output data are required for the technological module to function. From the user perspective, a technological module in a plant is represented by the so-called PROFINET component. Thus, it can be regarded simply as the defined functionality of the technological module from the user perspective (input/output data). This can be influenced externally via the software interface.

Each PROFINET component has an interface that contains the technological variables that can be exchanged with other components or controlled. This interface (properties) describes the functionality of the inputs/outputs. In this process it is immaterial how the application program processes the input data in the component and which logical operations are used to control the outputs of the component. The interface of a PROFINET component is specified according to IEC 61499. The mechanisms for accessing the component interfaces are defined uniformly in PROFINET CBA.

PROFINET CBA provides no information about the internal processing of data within a PROFINET component. Device developers can use their existing development systems without restrictions.

The interface of the PROFINET components corresponds to the standardized COM/DCOM technology. COM/DCOM represents an advancement in object orientation (as used by Microsoft for years) and enables development of applications based on ready-made components. The user can combine components flexibly as modular blocks and reuse them in different plants independent of their internal design.

The PROFINET component includes a self-contained functionality of a portion of a plant. This is normally created by the machine manufacturer after the user program for the technological module has been written and the data to be exchanged with other technological modules have been defined. The functionality for creating a component is normally contained in the programming environment, so that the machine manufacturer does not require detailed knowledge of the description structure of a component.

The previous figure shows an overview of the many options for component formation in PROFINET CBA. However, only the individual components are shown in the network view when configuring. Here, it cannot be recognized to which lower-level bus system the respective component is assigned. Several devices can also be combined to form a component, the same as a whole bus system.

15.3 PROFINET engineering in the component model

For vendor-neutral configuration of a PROFINET system, a PROFINET engineering concept has been created. This concept allows configuration tools to be developed that are capable of processing components of different manufacturers and also allows additional functions to be developed on a manufacturer-specific and user-specific basis.

PROFINET components are described by a standardized PCD (PROFINET Component Description). This description takes the form of an XML file with a schema specified by PROFINET CBA. The PCD gives rise to the component description. It contains all data required for communication of the engineering system. This means that each PROFINET-compliant engineering tool can process the component description data. A PCD is created by the plant/machine manufacturer using the development environment provided by the device manufacturer.

The engineering model makes a distinction between the programming of the controller logic of the individual

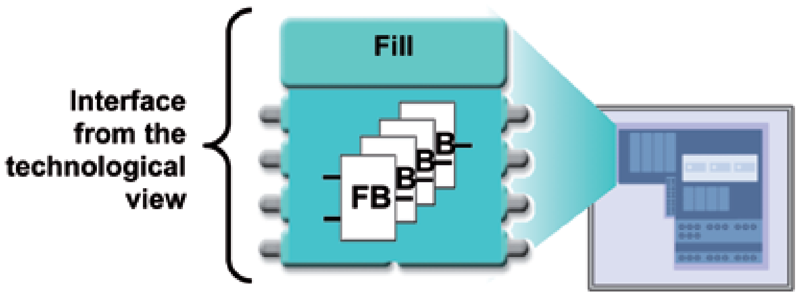


Figure 15.4: A PROFINET component represents a technological module.

technological modules and the technological configuration of the overall plant. A plant-wide application is thus built in three phases:

- Creating components
- Interconnecting the components
- Downloading the interconnection information to the field devices

In a PROFINET interconnection editor, the configuring engineer interconnects PROFINET components from a library to an application with a mouse click. This interconnecting replaces the previous costly programming of communication relations with simple graphics-based configuring. Detailed knowledge regarding the integration and sequence of the communication functions in the device is not required. The configuring engineer uses the interconnection editor to combine the individual, distributed applications on a plant-wide basis. This editor is vendor neutral, i.e., it interconnects PROFINET components of any manufacturers. Through the interconnecting, the user also specifies the frequency of the transmission. At the same time, the interconnection editor checks that only the same data types are interconnected.

15.4 Downloading to the field devices

Once the configuring engineer has completed the component interconnection and address assignment, the engineering tool loads all data required for communication to the respective field devices (components). Two types of download must be differentiated here.

Interconnection information is loaded to the consumer of the communication relation. Thus, each device knows its communication partners and communication relations and the information to be exchanged. Then, the consumer establishes the communication relation with its partners autonomously. The distributed application can now be executed.

15.5 Real-time communication in the component model

In many cases, the transmission rate of the component model without real-time capability is insufficient. Update rates of approximately 100 ms are often too low. Therefore, real-time communication was added to the component model in PROFINET. Real-time applications in production automation require update and response times in the range of 5 to 10 ms. The update time refers to the time period that elapses after a variable is formed in a device application and sent to a partner device via the communication system until it is, in turn, provided from there to the application.

In Fast Ethernet applications, the transmission rate is 100 Mbps. Therefore, when the potential for savings is examined, the transmission time on the bus alone can be disregarded. Likewise, the application cannot be affected by the software kernel when providing data and evaluating received data. Thus, it is obvious that the throughput times of the individual layers must be optimized in the standard software.

The real-time channel (RT) uses Ethernet (layer 2). This solution minimizes the throughput times in the communication stack significantly and increases performance in terms of the process data update rate. The determination of whether the data are real-time data or non-real-time data (NRT) is made when the RT driver evaluates the EtherType (0x800 for NRT and 0x8892 for RT) of the frame and the appropriate communication channel is selected.

15.6 Device description for the component model (PCD)

The PCD is an XML file. It is created by manufacturer-specific tools. The assumption here is that the tool has a component generator (e.g., STEP 7 Simatic Manager of Siemens) with the „Create component“ function. The result is then a PCD that can be processed by the PROFINET engineering tool (e.g., iMap of Siemens).

In PROFINET CBA, each component is described by a PROFINET device description (PCD). A PCD is usually created by the plant/machine manufacturer following the user software (project). This generally happens with the development tool for the respective field device.

The PROFINET component with its technological interface is described with Extended Markup Language (XML) and saved in an XML file.

All PROFINET engineering tools understand XML format. Before the configuring engineer can interconnect the components in the engineering tool, a PCD must be available in the engineering system (ES tool).

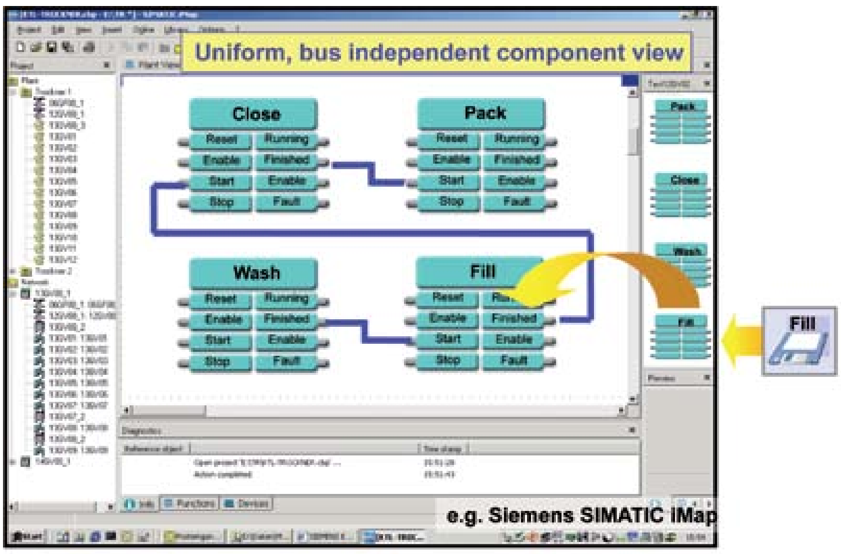


Figure 15.6: In PROFINET, communication is configured instead of programmed. Here: example using iMap of Siemens.

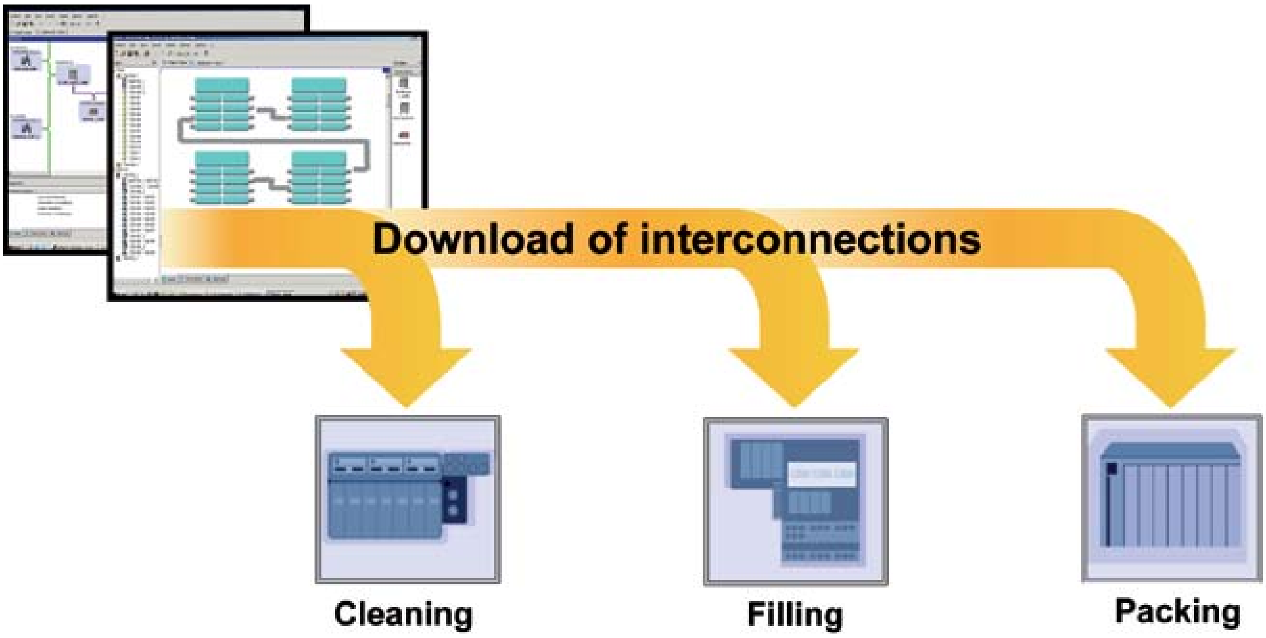


Figure 15.7: Interconnection information is downloaded to the consumer.

15.7 Software stack for the component model

A software stack (runtime software) for the component model is available from PI. It is free of charge for PI members. In addition to the software stack, there is a Windows 32 example application, which is available in the source code. This version is more suited to test systems since a Windows version is a rather infrequent occurrence in automation engineering. If the software must be adapted to another operating system, the associated implementation instructions guide you step by step through the individual adaptation modules for integrating the software into the target system. A component editor and a test tool complete the PROFINET software stack for the component model.

The PROFINET kernel, DCOM, and RPC are an integral part of the runtime software for the component model. The user can also select whether to use the DCOM wire protocol integrated in the PROFINET stack or the original DCOM of Microsoft. If real-time capability is also desired in the application, the software can be expanded to include the real-time channel. During the system power-up, the respective communication partner then negotiates the desired communication path (component-oriented or real-time). In the data frame, the EtherType indicates the frame type involved.

15.8 PROFINET CBA and PROFINET IO

In some automation systems, it may be appropriate to combine the strengths of both perspectives on PROFINET. For example, a subunit can be implemented with deterministic communication via PROFINET IO with IRT functionality. The subunits are then combined to form an overall PROFINET unit using PROFINET CBA. The advantages are easy to appreciate, since subunits can be prepared and tested accordingly. The graphics-based configuration in the vendor-neutral engineering tool for PROFINET CBA can then be used to easily combine the units locally. This ensures problem-free commissioning.

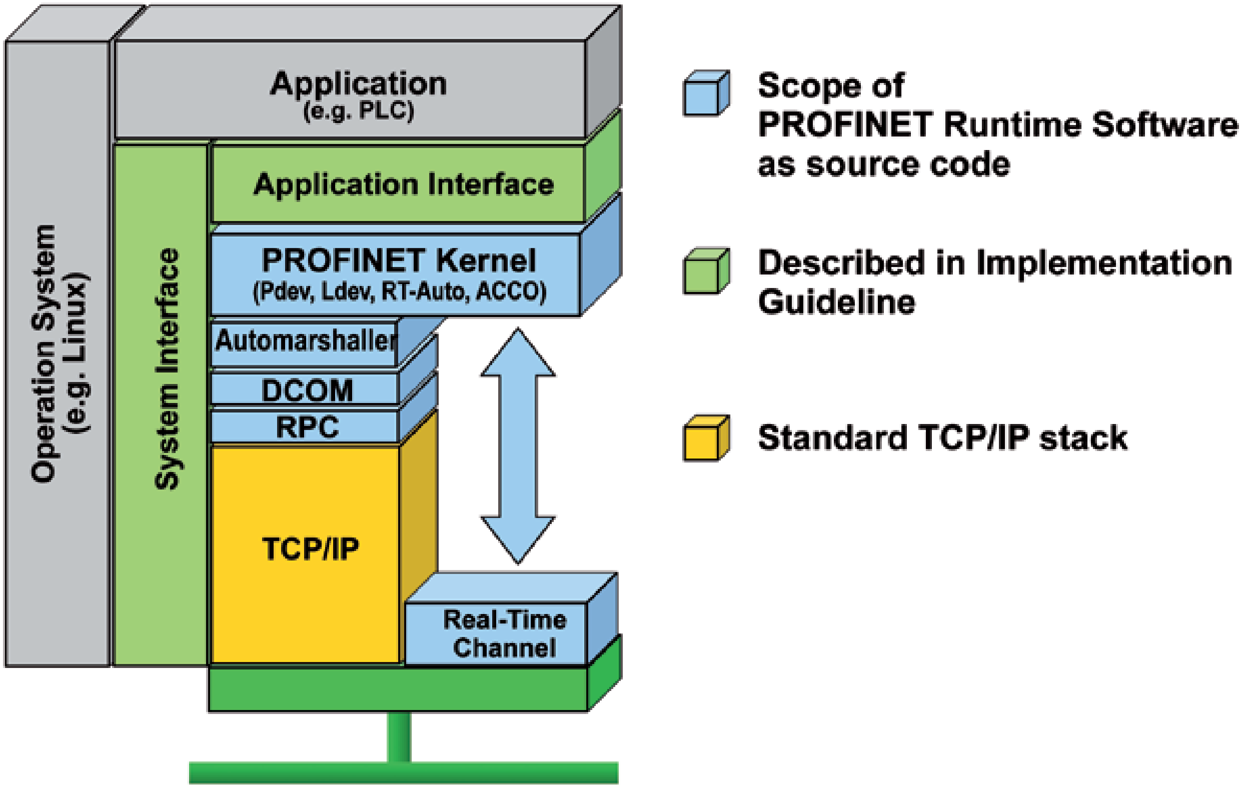


Figure 15.8: The software stack is available for the component model in the source code.

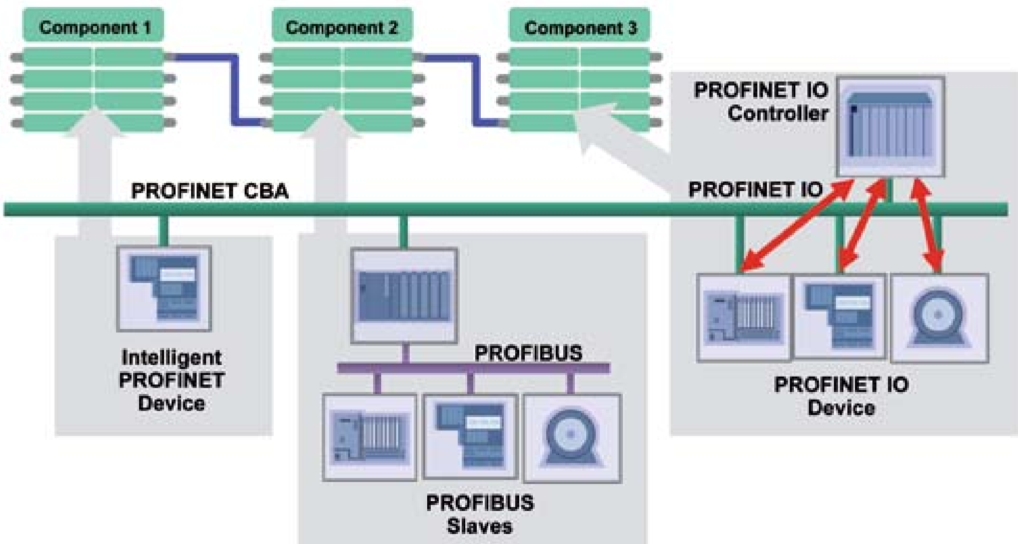


Figure 15.9: Combining PROFINET IO and PROFINET CBA provides maximum flexibility in plant configuration.

16. Integration of Fieldbus Systems

PROFINET specifies a model for integrating existing PROFIBUS and other fieldbus systems such as INTERBUS and DeviceNet. This means that any combination of fieldbus and Ethernet-based subsystems can be configured. Thus, a continuous technology transition from fieldbus-based systems to PROFINET is possible.

For protection of investment of the large number of existing fieldbus systems, a simple means of integrating these systems into PROFINET is needed. The following requirements are taken into consideration here:

- The plant operator would like the ability to easily integrate his existing installations into a newly installed PROFINET system.
- The plant and machine manufacturer would like the ability to use the well-proven devices it is familiar with for PROFINET automation projects, as well, without the need for any modifications.
- The device manufacturer would like the ability to integrate its existing field devices into PROFINET systems without expending any effort for modifications.

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 on the Ethernet. It integrates the nodes connected to a lower-level fieldbus system into the higher-level PROFINET system. As a result, the advantages of fieldbuses, such as high dynamic response, pinpoint diagnostics, and automatic system configuration without settings on devices, can be utilized in the PROFINET world, as well. These advantages simplify planning through the use of known sequences. Likewise, commissioning and operation are made easier through the comprehensive diagnostics properties of the fieldbus system. Devices and software tools are also supported in the accustomed manner and integrated into the handling of the PROFINET system.

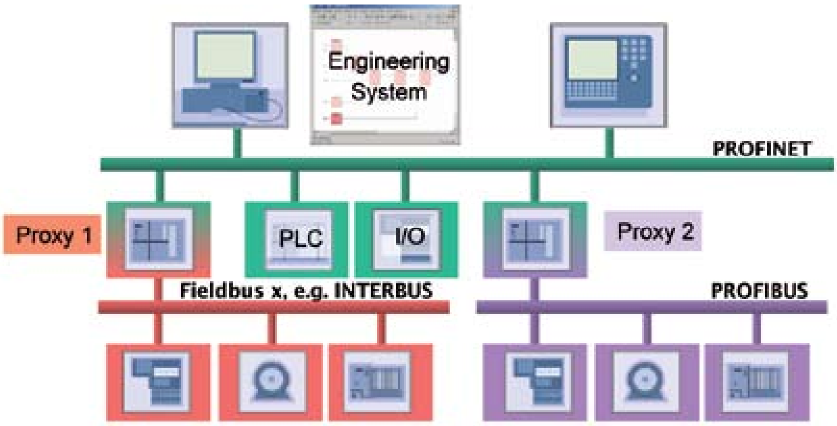


Figure 16.1: Fieldbus systems can be easily integrated in PROFINET

PI can look back on an installed base of over 28 million PROFIBUS nodes. Including the INTERBUS field devices installed in the field, approximately 15 million field devices have been counted (as of end of 2007). The market leader position afforded by this comes with an obligation to offer a simple, seamless strategy for connecting existing fieldbus systems to PROFINET. From the outset, PROFINET was developed on the premise that installed field devices could be integrated into PROFINET without modifications.

16.1 Integration via proxy

In simplest terms, a proxy is a representative for a lower-level fieldbus system. In PROFINET, a proxy represents a fieldbus (e.g., PROFIBUS, Interbus, etc.). It thus coordinates the Ethernet data traffic and the fieldbus-specific data traffic.

On the PROFINET, the proxy represents one or more fieldbus devices. This proxy ensures transparent implementation of communication (no tunneling of protocols) between networks. For example, it forwards the cyclic data coming from the Ethernet to the fieldbus devices in a transparent manner.

In PROFIBUS DP, for example, the proxy works as a PROFIBUS master that exchanges data with PROFIBUS nodes. At the same time, it is an PROFINET node with Ethernet-based PROFINET communication. For example, proxies can be implemented as PLCs, PC-based controllers, or pure gateways.

16.2 PROFIBUS and other fieldbus systems

The integration methods presented enable other fieldbus systems besides PROFIBUS, such as INTERBUS, Foundation Fieldbus, DeviceNet, etc., to be integrated into PROFINET. In this process, the Ethernet communication is already defined by the available software. Only the initialization of the process data previously provided from the lower-level fieldbus to PROFINET still has to be ensured. As a result of this concept, fieldbuses of any type can be integrated into PROFINET with minimal effort, whereby a proxy is used to represent the lower-level bus system.

17. Web Integration

The PROFINET Web integration was designed mainly with the aspects of commissioning and diagnostics in mind. Web-based concepts can be used particularly effectively within this area of application. WEB services thus describe mechanisms for integrating PROFINET devices into the Internet/intranet world. The main features for this are:

Standard protocols (e.g., http) are used to access a PROFINET device from the Internet or an intranet. Data are transmitted in standard formats such as HTML or XML. Standard front ends (browsers such as Netscape or Internet Explorer) are used for the display.

Due to worldwide accessibility, the manufacturer of the application can easily support the user during commissioning.

Data are accessed via standardized „Web pages“ with a standard look and feel.
Possible applications for WEB integration include:

- Testing and commissioning
- Overview of device data (PROFINET IO)
- Device diagnostics and system/device documentation

The information provided should be represented in a format readable by humans (e.g. using a browser) and in a machine-readable form (e.g. an XML file). Using PROFINET Web integration, both variants are consistently available. For certain information, PROFINET Web integration also provides standardized XML schemas.

Technical characteristics
The basic component of Web integration is the Web server. It forms the interface between the PROFINET object model (in CBA) and the basic technologies for Web integration.

Web integration in PROFINET can be scaled as a function of the performance capability and characteristics of the Web server. This means that even simple PROFINET devices, equipped only with an „embedded Web server“, have the same rights as a PROFINET device with an „MS Internet Information Server“ or the „Apache Web server“ when participating in Web integration.
WEB integration can be integrated optionally for each PROFINET device. The individual functions can be implemented depending on the performance capability of the device. This allows solutions to be customized to each use case. The PROFINET-specific elements can be integrated seamlessly into an existing Web implementation of a component.
Based on uniform interfaces and access mechanisms, the manufacturer of a PROFINET device can provide its data via the Web. The name space specified in the PROFINET Web integration and the addressing concept allows CBA elements as well as I/O data to be referenced by the Web server. That allows the user to create dynamic Web pages constructed using current data from the components.

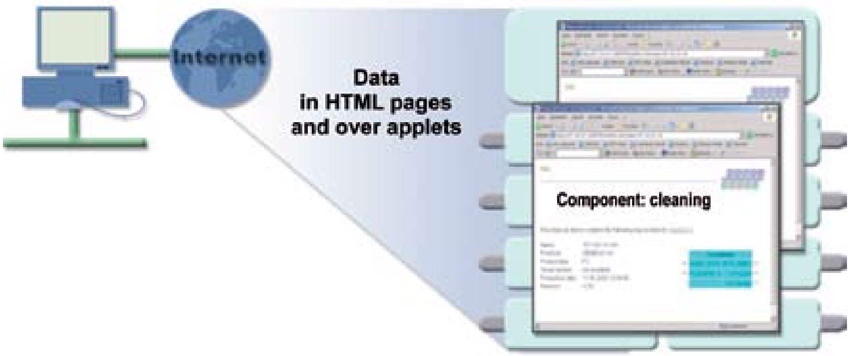


Figure 17.1: Access to PROFINET data is possible via standard Web services.

17.1 Security

The PROFINET Web integration is specified in such a way that access to PROFINET devices is identical whether it takes place from the Internet or an intranet. This allows all the advantages of Web integration to be used even if the device itself is not connected to the Internet. For these local accesses, the risk of an unauthorized access is very low and comparable with modern HMI systems.

For networking within a larger production facility or over the Internet, PROFINET Web integration relies on a phased security concept. It recommends a security concept optimized for the specific application case, with one or more upstream security zones. No structural limitations are placed on the Web integration concept by this, since the security measures are always located outside of the PROFINET devices. 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. The currently developed security concept provides for both individual devices as well as whole networks to be protected from unauthorized access. In addition, there will be security modules that will allow networks to be segmented and, thus, also separated and protected in terms of safety engineering. Only uniquely identified and authorized messages will be allowed to reach devices within such segments from outside.

The best-practice suggestions of PROFINET Web integration include scenarios and examples of how requirements-dependent security mechanisms can be implemented all around PROFINET devices.

For instance, security mechanisms can be used in the transport protocols (TCP/UDP and HTTP). In addition, encryption, authentication, and access administration are scalable in the Web servers used. Advanced security elements, such as application gateways, can be added for Web services as needed.

17.2 Segmentation

The core of the security concept is in the security-motivated segmentation of the automation network. Thus, protected automation cells are formed. The network nodes within a cell are protected by special security network components (e.g., switches or security appliances) that control the data traffic from and to the cell and check access privileges. Only authorized data traffic is allowed to pass. A special security client software can be used for the access with client PCs to secure automation devices. The terminals thus require no security functionality of their own.

17.3 Network management

Network management includes all functions for the administration of the network, such as configuration (assignment of IP addresses), error monitoring (diagnostics), and performance optimization.

17.4 IP management

The use of TCP/UDP and IP in PROFINET requires that PROFINET devices, as network nodes, be assigned an IP address.

Address assignment with manufacturer-specific configuring system: This alternative is required since a network management system is not always available. In PROFINET, the DCP protocol (Discovery and Configuration Protocol) is specified, which enables IP parameters to be assigned with manufacturer-specific configuring/ programming tools or during system-wide engineering. As an integral component for PROFINET devices, DCP guarantees uniform behavior of all PROFINET devices.

Automatic address assignment with DHCP: In networks with network management systems, the Dynamic Host Configuration Protocol (DHCP) has been established as the „de-facto standard". PROFINET provides for use of this standard and describes appropriate ways of applying DHCP in the PROFINET environment. Implementation of DHCP in PROFINET devices is optional.

17.5 Diagnostics management

The reliability of the network operation has a very high priority in network management. In existing networks, the Simple Network Management Protocol (SNMP) has been implemented as the „de-facto standard" for maintenance and monitoring of network components and their functions. In order to monitor PROFINET devices with established management systems as well, it is useful to implement SNMP. SNMP provides for both read access (monitoring, diagnostics) and write access (administration) to a device.

In PROFINET, only read access to device parameters has been initially specified. Like the DHCP of IP management, SNMP will also be optional (mandatory for CC-B and CC-C). When SNMP is implemented in components, only the standard information usual for SNMP (MIB 2) is accessed. Specific diagnostics of PROFINET components is possible using the mechanisms described in the PROFINET specification. In this regard, SNMP will not open another diagnostic path but rather enable integration into network management systems that generally do not process PROFINET-specific information. The SNMP software can be integrated in the PROFINET stack at the user level and used without restrictions.

When standard switches are used, the switch directly forwards the diagnostic information from the connected PROFINET devices to the controller. However, a switch can also be configured as a IO-Device and relay the detected network errors of a lower-level Ethernet line directly to the controller. The user can also use an additional SNMP channel for transmitting the diagnostics data.

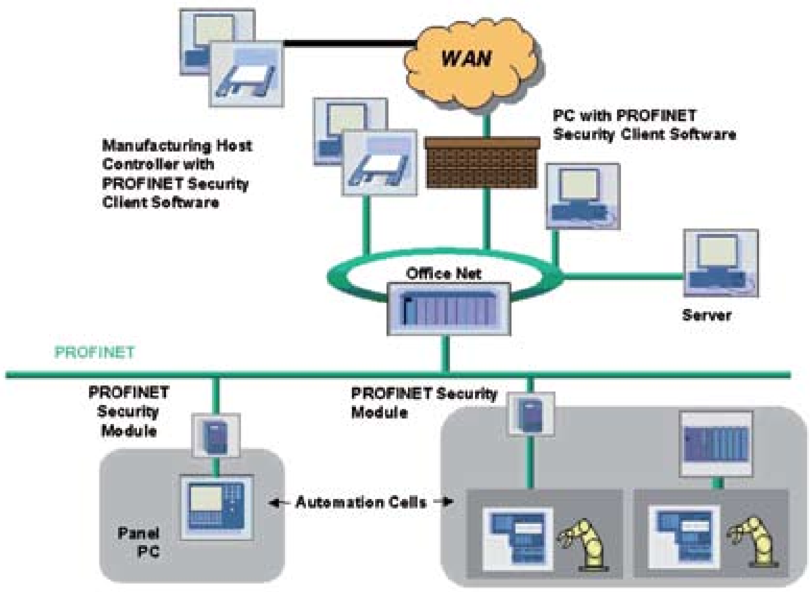


Figure 17.2: Segmentation of automation network.

18. PROFINET and MES

The integration of automation systems, Manufacturing Execution Systems (MES), and Enterprise Resource Planning (ERP) is gaining importance in company-wide, universal information systems. While the interfaces between MES and ERP are defined as part of the IEC 62264 specification, until now there has been no specification for interfaces between MES and automation systems.

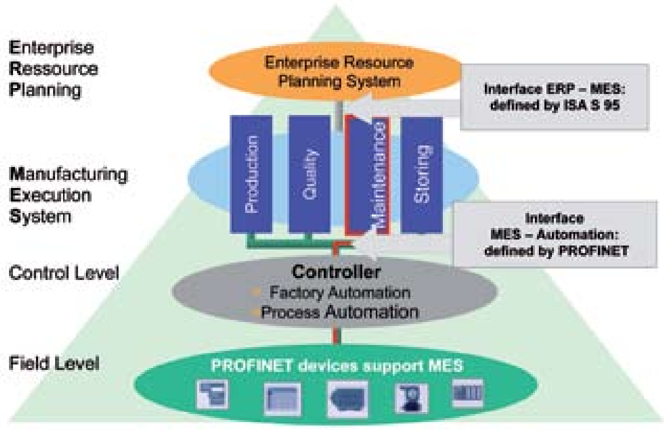


Figure 18.1: Maintenance operations.

18.1 Operations in MES

IEC 62264 divides MES into the following four operations:

- Maintenance operations
- Production operations
- Quality operations
- Inventory operations

Since the topic of maintenance has great significance in both production and process automation, maintenance operations are supported by PROFINET. The result is a corresponding document in which, among other things, the information content important for an MES interface is defined.

18.2 Maintenance state

In terms of maintenance, the approach of state-based maintenance is currently gaining significance. It is based on the capability of devices and components to determine their states and to communicate them by means of agreed mechanisms.
PROFINET devices signal their state to higher-level devices in a standardized format. This is based on a state model, which besides the states „good" and „defective" also defines the two pre-warning levels „maintenance needed" and „maintenance required."

18.3 Identification

Besides the maintenance state, the capability of devices and components to provide up-to-date „type plate information" and the information needed for functional and local assignment is an important requirement for support of MES maintenance operations.
The functions defined in the „Identification & Maintenance Functions (I&M)" document are therefore also mandatory for PROFINET devices.

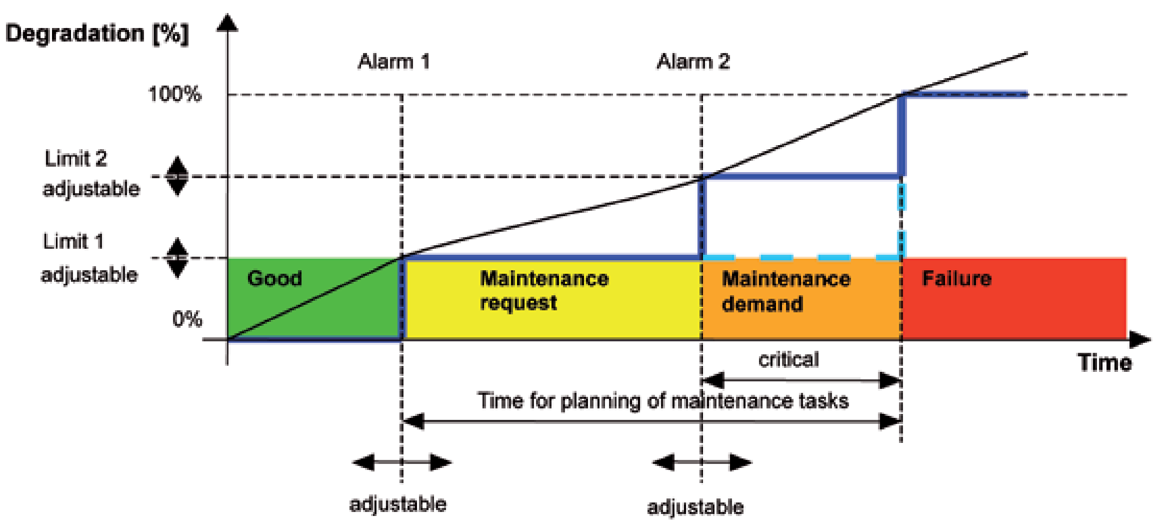


Figure 18.2: Maintenance states.

19. Network Installation

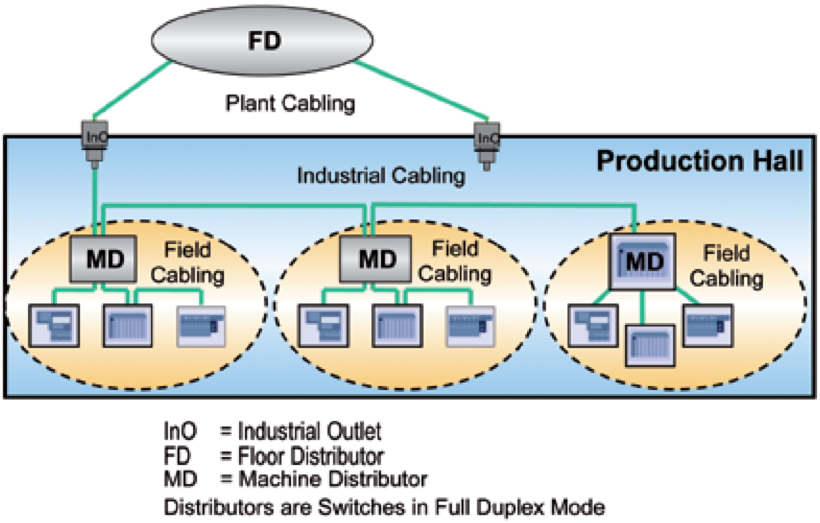


Figure 19.1: Ethernet networks in industrial environments usually have linear topology.

The international standard ISO/IEC 11801 and its European equivalent EN 50173 define an application-neutral information technology standard networking for a building complex. This cabling standard forms the backbone of the requirements for Ethernet cabling in industrial automation, as well.

PROFINET cabling is based on IEC 61918. PROFINET-specific definitions are contained in IEC 61784-5-3.

However, if the user is already using networks that meet the requirements of ISO/IEC 11801, these networks can also be used for PROFINET as long as the relevant boundary conditions are met. ISO/IEC 24702 governs the design of networks conforming to ISO/IEC 11801 in industrial buildings.

The openness of PROFINET also means that shielded, generic cabling according to ISO/IEC 24702 can be used for Conformance Class A.

However, in order to meet performance and availability requirements, the properties of PROFINET cabling must be retained in all automation applications of Conformance Classes B and C.

PROFINET cabling is characterized by:

- High performance with significant system reserves
- Simple planning and installation
- Optimal adaptation to industrial applications

To achieve these objectives, the channel is defined, in addition to classifying the environmental conditions simply as either an inside enclosure or outside enclosure. The channel connects two active devices.

Prefabricated system cables with identical ends are always used. When connecting the cables, the crossing step is eliminated since PROFINET network components support autocrossing. In addition to system cables, there are passive connectors that are used for passing through the control cabinet wall or as a coupling. This allows all transmission lines to be implemented easily. To reduce the complexity of on-site fabrication, a universal two-pair system is specified for cables and plug connectors. The copper cables are executed uniformly in AWG 22. This also provides sufficient system reserve for many cable/plug connector transitions.

For fiber-optic transmission, the use of 1-mm polymer optic fibers (POF) is supported, whose handling conforms optimally to industrial applications.

19.1 PROFINET component approach

For cabling, PROFINET uses a defined component approach with simple selection rules.

This approach is based on the principle: „Take PROFINET cables and PROFINET plug connectors and assemble them carefully to form a network". Factors to be considered are the total length of the cabling and the number of transitions between cable and plug connector.

This approach results in transmission lines that meet the requirements for PROFINET cabling in a reliable manner, i.e., with significant system reserves. Time-consuming planning, calculations, and measurements are not required in this case.

The component approach requires harmonized PROFINET plug connectors and cables. In order to document PROFINET conformity, the manufacturer is obliged to provide PI manufacturer's declaration.

19.2 Network topologies

PROFINET considers both the networking of Ethernet communication and the supply of devices with 24-volt voltage and 400-volt power.

Communication (PROFINET data)
PROFINET supports the following topologies for Ethernet communication:

- Line topology, which can be connected to a ring and links the preferential terminals to integrated switches in the field.
- Star topology, which requires a central switch located preferably in the control cabinet

These two topologies can be combined to form complex tree topologies.

In this case, the PROFINET line topology represents a distinguishing feature since extended lines comparable to PROFIBUS can be realized with PROFINET technologies.

Voltage supply 24 V, power 400 V
Line and star topologies are supported for supplying devices with 24 volts. The 24-volt voltage supply and Ethernet communication can also be combined with a hybrid plug connector and cable.

Line and star topologies are also supported for supplying devices with 400-volt power.

19.3 Environmental classes

PROFINET has divided the environmental conditions into just two classes. This eliminates unnecessary complexity and allows for the specific requirements of automation. The PROFINET environmental classes defined for automation application are divided into an Inside enclosure class within protected environments, such as in a control cabinet, and an outside enclosure class outside of control cabinets for applications directly in the field.

19.4 PROFINET cabling

Industrial-strength cables can be subjected to extreme mechanical stresses. They require special construction. The Installation Guide defines different cable types that have been optimally adapted to the respective industrial boundary conditions. Sufficient system reserves allow an industrial-strength installation with no limitation on transmission distance.

Some nodes must be supplied 24 volts in addition to data. A hybrid cabling structure is well-suited for this. Hybrid cables include lines not just for signal transmission, but for power transmission as well.

Fiber-optic cables are not sensitive to electromagnetic influences and allow longer network spans than symmetrical copper cable in some cases.

19.5 Plug connectors for data

The selection of suitable PROFINET plug connectors conforms to the application. If an office-compatible universal network is the priority, the electrical data transmission is via the RJ 45 connector, which is prescribed universally for inside environments. For the „outside“ environment, a push-pull plug connector has been developed that is also fitted with the RJ 45 connector for electrical data transmission. The M12 connector is also specified for PROFINET.

In automation, polymer optic fibers are predominantly used for optical data transmission due to their ease of installation. For PROFINET, the SCRJ connection has been specified, which is based on the SC plug connector. The SCRJ is used both in the inside environment as well as in connection with the push-pull housing in the outside environment.

An optical plug connector specified for PROFINET is available for the M12 family and can also be used for the 1-mm polymer optic fibers (POF).

19.6 Data cables

The PROFINET cables conform to the cable types used 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: for example, highly-flexible, constant movement (tow chain or torsion)

The cables are designed such that they are suitable for use in industrial environments in both inside and outside areas. For types A and B, the PROFINET component approach is valid without restrictions. For Type C, the restrictions of the relevant product must be taken into consideration.

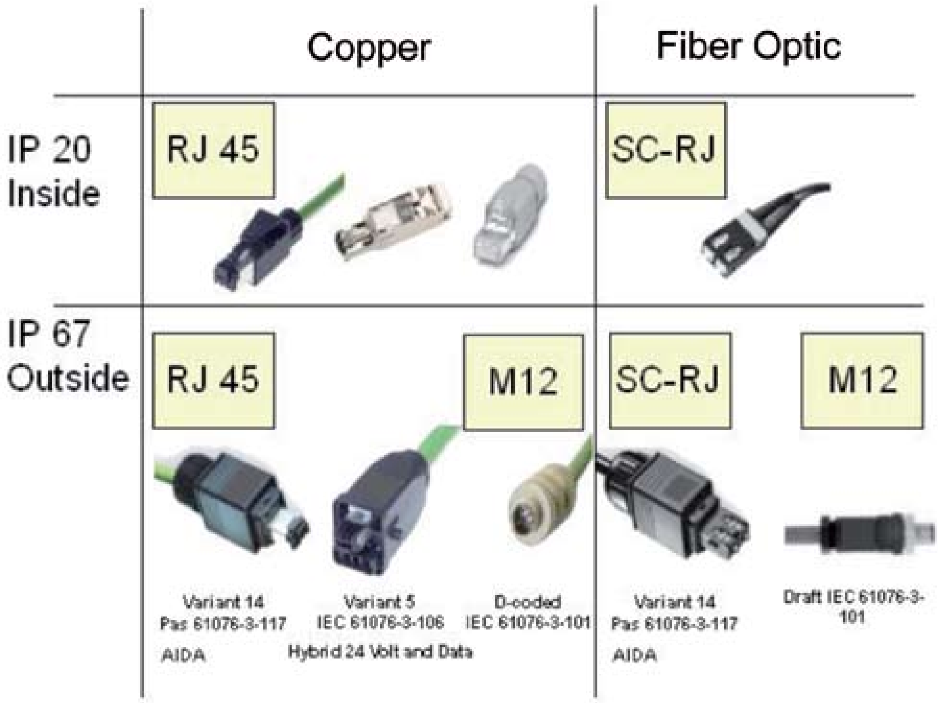


Figure 19.2: PROFINET offers a range of industrial plug connectors.

Types A and B conform to the component properties of Category 5 for horizontal cables. The large conductor cross-section (AWG 22) allows channel lengths of 100 m to be realized.

Due to their electrical isolation, the use of fiber-optic cables for data transmission is suitable especially if equipotential bonding between individual areas of the plant is difficult to establish. Optical fibers also offer advantages over copper in the case of extreme EMC requirements.

19.7 Plug connectors

Depending on the topology, 24V plug connectors divided into two power classes have been defined.

Line topology:
Push-pull plug connector
A push-pull plug connector has been specified to meet the demand for a voltage supply in line with German automotive production requirements. This push-pull plug connector contains a 4-pin insert plus functional ground. Here, up to 5 conductors can be connected using field-fabricated spring-loaded connection technology. The maximum conductor cross-section is 2.5 mm². The plug connector is designed for a current carrying capacity of 16 amperes. This high current carrying capacity enables longer line structures to be configured, i.e., a large number of devices can be supplied over long transmission lines via tee units.

7/8" plug connector
As an alternative to the push-pull plug connector, the 7/8" plug connector can also be used.

Hybrid plug connector
The 3 A hybrid plug connection RJ45 enables hybrid feeding of devices.
For this purpose, it includes 4 additional power contacts for 16 A in addition to the RJ45 insert. These contacts are used for two separate circuits.

Star topology:
M12 plug connector
According to the specification of PI, the A coded M12 plug connector can be used to supply individual devices in a star topology. It is limited to one circuit and a current of 4 A.

400 V power connectors
A plug connector with high current carrying capacity was defined for configuring a power bus. For the 400-volt supply, PROFINET uses the internationally standardized power bus according to ISO 23570-3.

19.8 Network components

PROFINET devices are connected via an active network component, i.e., the switch, which is preferably integrated in the field device. The specification of network components ensures easy installation. Because network components in PROFINET support autocrossover and autonegotiation, transmission cables are prefabricated at both ends with the same pin assignment.

When data are transmitted via copper cables, the maximum segment length between two nodes (field devices or switches) is 100 m. With fiber-optic cables, lengths of up to 14 km are possible.

19.9 PROFINET installation

The PROFINET Installation Guide supports the work of installers of PROFINET cabling and provides practical help for simplifying professional installation. Information is presented in a very simple manner and illustrated with graphics. Accordingly, no prior knowledge about PROFIBUS installation is required.

The combination of these simple installation guidelines and the PROFINET component approach offers optimum ease of installation with a minimum of planning effort.

19.10 Industrial Wireless

The advantages of wireless data transmission are increasingly being applied in the industrial arena. The flexibility and mobility of wireless network infrastructures also enable completely new solutions in areas where electrical lines cannot be used, or can only be used with limitations, due to mechanical restrictions, security requirements, or other environmental considerations. Applications include the integration of moving system parts into the communications infrastructure or the connection of difficult to reach sensors, but also mobile operator control and monitoring, driverless transport systems, and the like.

PROFINET enables communication across such wireless communication networks. PROFINET is able to handle different radio technologies for a wide variety of application areas, each with specific parameters regarding transfer rate, range, node count, and the like. Thus, profiles are specified for each technology that describe how integration into PROFINET is done, which topologies and performance values can be achieved with the technology, and what boundary conditions apply, for instance, regarding security requirements.

Regarding Industrial Wireless profiles, PROFINET uses WLAN and Bluetooth according to the standards from areas IEEE 802.11 and 812.15, respectively.

20. PROFINET IO Technology and Certification

PROFINET is standardized in IEC 61158. It is on this basis that devices in industrial plants can be networked together and exchange data without errors. Appropriate quality assurance measures are required to ensure interoperability in automation systems. For this reason, the PI has established a certification process in which certificates are issued by the PI for PROFINET devices based on test reports according to DIN ISO 9001 from accredited test laboratories. While PI certification of PROFIBUS field devices was not required, the guidelines for PROFINET have changed such that any field device bearing the name PROFINET must be certified. And for good reason, as a look back on the more than 15 years of experience with PROFIBUS reveals. Experience has shown that a very high quality standard is needed to protect automation systems, plant operators, and field device manufacturers.

20.1 Technology support

Device manufacturers that want to develop an interface for PROFINET IO have the choice of developing field devices based on existing Ethernet controllers. Alternatively, PI member companies offer a variety of options for fast development of a PROFINET IO interface based on proven basic technology components.

Support from the outset
To make development of a PROFINET IO interface easier for device manufacturers, the PROFINET Competence Center and PI member companies offer the full range of PROFINET IO basic technology (enabling technology). Consulting services and special developer training programs are also available.

Before starting a PROFINET IO development project, device manufacturers should always perform a analysis to determine whether internal development of a PROFINET IO-Device is cost-effective or whether the use of a ready-made communication module will satisfy their requirements.

Independent of the technical implementation of the communication interface in the field device, services for PROFINET ranging from consulting to implementation are available that will support and safeguard projects for products with PROFINET, from the perspective of „time to market", development risks, and core competency.

Detailled information can be found in the brochure "PROFINET Technology – The Easy Way to PROFINET" which can be downloaded from:
www.profinet.com

Test support for development
The freeware tool Wireshark is suitable for use in capturing Ethernet frames. This tool interprets standard Ethernet frames as well as the data unit of PROFINET frames. The software shows the essential data in an easy-to-read format on the display.

PROFINET field devices are connected via switches. The advantage here is that only those transmission paths are used for which the transmitted frames are also defined.

For test purposes, however, this advantage becomes a disadvantage because, when frames are captured via a switch, the only frames that are displayed are those that are also defined for the connected test device. Therefore, the Wireshark bus monitor must be connected to the bus via a hub, TAP or Mirror Port. This allows you to capture frames in both directions.

20.2 Certification test

A certification test is a standardized test procedure that is performed by specialists whose knowledge is kept up to date at all times and who are able to interpret the relevant standards unequivocally. The test scope is described in binding terms in a test specification for each laboratory. The tests are implemented as so-called black box tests in which the tester is the first real user.

Certified devices guarantee worldwide conformity of a PROFINET product in a plant with nodes from different manufacturers.

All the defined test cases that are run through in a certification test are field-oriented and are reflected in industrial requirements. Only test cases that can occur on a daily basis at any facility are tested. This affords all users the maximum possible security for the use of their field devices in a system. In very many cases, the dynamic behavior of a system can be simulated in the test laboratory.

For the plant manufacturer/operator, the use of certified products means time savings during commissioning and stable behavior during the entire service life. They therefore require certificates for the field devices used, in accordance with the utilized conformance class.

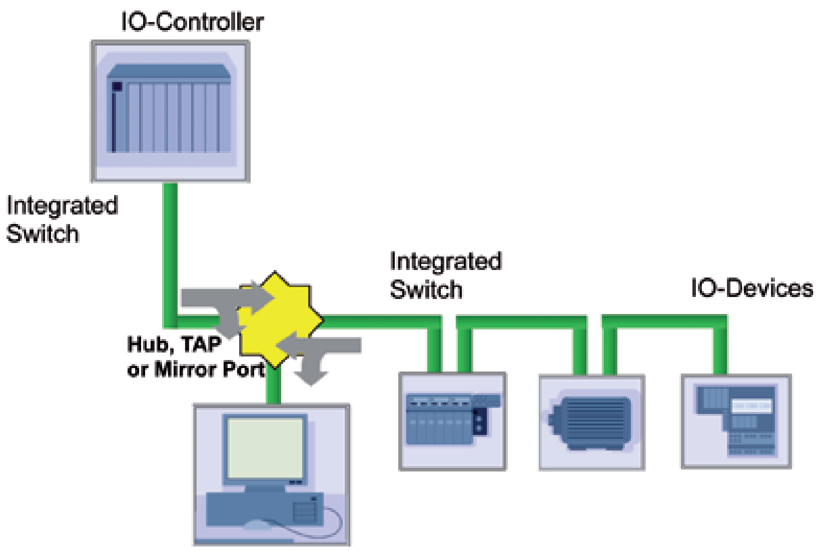


Figure 20.1: Test setup for capturing Ethernet frames.

The well-proven PROFIBUS model has been adopted in PROFINET IO, and the entire behavior of a field device is defined in the form of state machines. This granularity allows each basic component provider to create its own firmware stack containing some or all of the basic functionality of PROFINET IO (RT, IRT). During development of PROFINET field devices, the user can take advantage of software stacks and standard Ethernet ASICs, which greatly simplify the development process. Accordingly, the certification tests must also be designed differently and geared toward the conformance classes.

Functional scope of a certification
The functionality of PROFINET IO is divided into so-called conformance classes in order to maintain a clearly defined minimum scope of functions in each system. The manufacturer indicates the supported conformance class in the GSD file. In addition to the specific functionality defined by the specified conformance class, there are basic tests that must be supported by each field device, for example:

- Basic hardware tests, including check of autocrossover, autonegotiation
- Startup behavior, error-free power-up, address assignment
- Read-in and test of GSD file, test with an IO-Controller, download
- IO-Device test, with and without IO-Supervisor
- Test of IO-Device with two IO-Controllers
- Interoperability tests; interaction of available IO-Devices
- Trigger of diagnostics and alarms, standard faults (network Off/On at IO-Device and IO-Controller, removal/insertion)
- Comprehensive negative tests
- Load tests
- Check of EMC tests

The path to PROFINET certification
In PROFINET, all field devices must be certified. Certification is obtained following the sequence below:

The manufacturer develops a PROFINET device and creates the required GSD file.

The manufacturer applies for a Vendor ID from PI (required only for PROFINET IO). This only has to be applied for once, since the Vendor ID is always identical among the products of a company.

The manufacturer registers for a certification test at a test laboratory certified for PROFINET (PITL) by submitting a completed test application. The manufacturer should find out in advance if the test laboratory it selected offers the required tests.

After the test is complete, the party ordering the test receives a test report.

If the test result is positive, the manufacturer then applies for a certificate from PI.

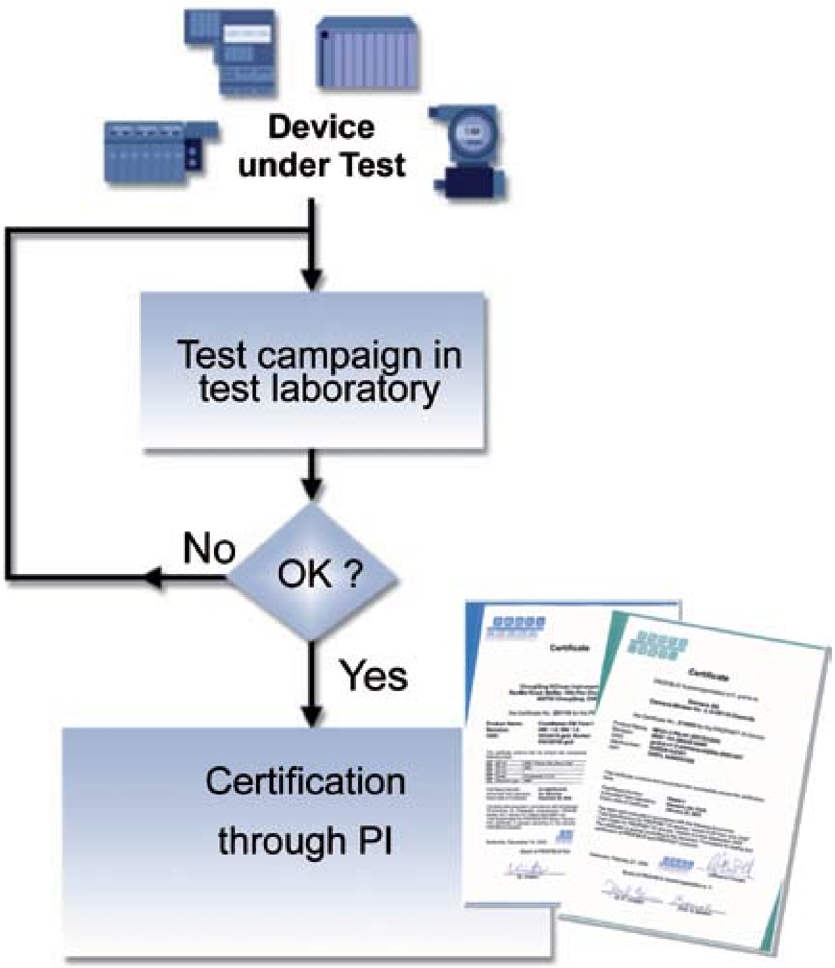


Figure 20.2: Sequence for PROFINET certification.

21. PI – The Organization

For its maintenance, ongoing development, and market penetration, an open technology needs a company-independent institution as a working platform. For these reasons, the PROFIBUS Nutzerorganisation e.V. (PNO) was founded in 1989 as a nonprofit interest group of manufacturers, users, and institutions. The PNO is a member of PROFIBUS&PROFINET International (PI), an international umbrella organization founded in 1995. With 25 regional PROFIBUS/PROFINET associations (RPA) and approximately 1400 members, including in the USA, China, and Japan, PI represents the world‘s largest community of interest in the area of industrial communications. The RPAs organize trade fairs and information sessions and make sure that new requirements in the marketplace are considered in further development activities.

21.1 Duties

The main duties of PI are:

- Maintenance and further development of the PROFIBUS and PROFINET technologies
- Promotion of widespread use of the technologies worldwide
- Protection of investment for users and manufacturers by influencing the development of standards
- Advocacy on behalf of members before standards bodies and organizations
- Technical support worldwide through Competence and Training Center
- Quality assurance through device certification

21.2 Membership

Membership is organized regionally. It is open to all companies, organizations, institutions, and persons wanting to participate constructively in the development and spread of the PROFIBUS and PROFINET technologies. The cooperative actions of its members, who come from a wide range of often very different industries, produce significant synergy effects and widespread information exchange. This leads to innovative solutions, effective use of resources, and finally to competitive advantages on the market.

21.3 Organization for technology development

Technology development activities are controlled by the Advisory Board.
The development teams are organized into technical committees (TC) with over 50 permanent working groups (WG). There are also a changing number of ad-hoc WGs taking on specific topics for a limited time period.
The WGs develop new specifications and profiles, look after quality assurance and standardization matters, participate in standards bodies, and carry out effective marketing activities (exhibitions, presentations) for spread of technologies. The PI Support Center coordinates all incidental activities.

More than 500 experts participate in working groups engaged in development and spread of technology.

The subdivision into over 50 WGs allows very efficient development work, concentrating on particular topics and industries.

All members are entitled to participate in working groups and can thus influence the further development of the technology. All new working results are presented to the members for comment before being released by the Advisory Board.

21.4 Technical support

PI supports over 35 Competence Centers (PICC) as well as over 15 Training Centers (PITC) and has accredited 10 Test Laboratories (PITL) for certification activities. The facilities advise, train, and support users and manufacturers in a variety of ways, or perform tests for certification of devices. As PI facilities, they are vendor-neutral service providers and adhere to the mutually agreed rules and regulations. They are regularly checked for their suitability using an accreditation processes customized for each group. Current addresses can be found on the organization‘s Web site.

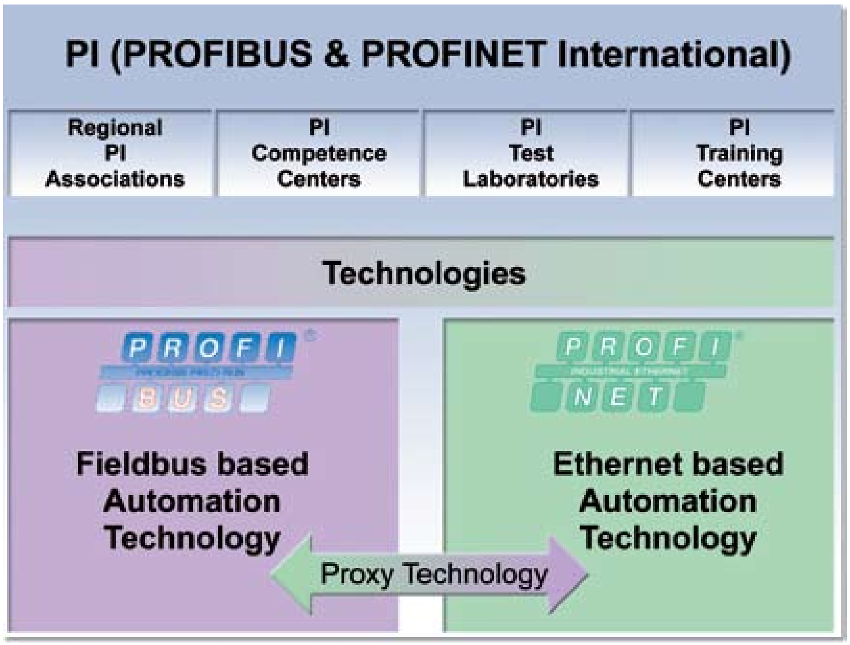


Figure 21.1: PROFIBUS & PROFINET International (PI) provides support wordwide.

21.5 Documentation

As support for users and manufacturers, PI provides a wide variety of documentation. This is available in English.

PROFINET Standard
Contains the basic specifications of PROFINET CBA and PROFINET IO, along with a selection from other documentation, like the GSDML device description for PROFINET IO.

PROFINET Guidelines
Includes specifications for, for example, implementation, test procedures, and installation.

PROFINET Profiles
Include the approved profile specifications. There is a distinction drawn here between industry-specific and general application profiles.

Brochures and books
Significant topics are presented in brochures from a marketing standpoint. There is a corresponding brochure available for PROFINET.

The documents can be downloaded from the Web site at www.profinet.com. If needed, they can also be ordered electronically or on CD-ROM. A list of available documents is also found on the Web site.

The book „Industrial Communication with PROFINET“ is available from: PROFIBUS Nutzerorganisation e.V., Order No. 4.182

21.6 Web site

PI maintains a shared Web site in English for both the PROFIBUS and PROFINET technologies (www.profibus.com and www.profinet.com). The RPAs additionally provide their own Web sites in local languages; these are accessible through the PI Web site.

These local sites present current topics/events (news and events, press releases), provide information on the technologies (short technical descriptions, FAQs, WBT), have a series of application reports, and provide a location for members to download all technical and marketing documents free of charge.

For discussion of technical questions, there are two open forums for PROFIBUS and PROFINET.

The product catalog for PROFIBUS and PROFINET products gives an excellent overview of the performance capabilities of member companies.

22. Glossary

AR	Application Relation	Logical application relation between two nodes; can include one or more communication relations.
Client/ Server	Principle of establishment of connections	The network node that accepts the connection is called the client. Whereas, a server is the node for which a connection is established.
Component	PROFINET Component	Software representation of a technological module with defined functionality. An automation system consists of various PROFINET components. A PROFINET component generally contains a technological function that is supplied by a device or machine.
Component Generator		Functional extension of a manufacturer-specific configuration tool to generate the XML-based PROFINET Component Description (PCD).
CR	Communication Relation	Logical communication relation (channel) between two nodes that are operated with a specific protocol.
DCP	Discovery and Basic Configuration	Defines the assignment of IP parameters using manufacturer-specific configuration/programming tools or during system-wide engineering, e.g. in the PROFINET interconnection editor.
DHCP	Dynamic Host Configuration Protocol	De facto standard for the dynamic assignment and administration of IP addresses from a predefined range.
ERP	Enterprise Ressource	
Ethernet	Protected trademark of Xerox	Ethernet is standardized and describes the physical and data link layers of a network.
Ethertype		Component of an Ethernet frame that indicates the protocol type. Ethertypes are allocated by IEEE and are therefore a unique criterion for differentiation among Ethernet protocols. In PROFINET, RT communication within a network is identified by Ethertype 0x8892.
Gateway		Connection between two networks with different software and hardware
GSD	General Station Description	A GSD (General Station Description) contains the GSDML-based description of the characteristics of I/O devices, such as communications parameters, as well as the number, type, configuration data, parameters, and diagnostic information of modules.
GSDML	General Station Description Markup Language	GSDML is the description markup language for creating a GSD file for PROFINET IO-Devices. It is XML-based.
HMI	Human Machine Interface	Appearance of a system on the operator control and monitoring platform
HTML	Hypertext Markup Language	Document description language
HTTP	Hypertext Transfer Protocol	Application protocol used on the Internet.
I&M Functions	Identification and Maintenance Functions	I&M functions are general information functions about devices, such as manufacturer, version, ordering data, etc.
Interconnection editor		Manufacturer-independent engineering tool for the configuration of system-wide applications. The interconnection editor combines the individual distributed applications together system wide using a graphics-based format.
IO-Controller		Device (typically a controller) that initiates the I/O data traffic.
IO-Device		Decentrally located field device assigned to an IO-Controller.
IO-Supervisor		Programming device/PC with commissioning and diagnostic functionality in PROFINET IO.
IP	Internet Protocol	Connectionless protocol for transmission of data frames. IP is often used in combination with TCP in order to ensure secure data transmission.
IRT	Isochronous Real-Time	Isochronous real-time channel for particularly stringent requirements of, for instance, motion control applications (clock-synchronized applications). When implemented in hardware, clock rates of under 1 ms and a jitter precision of 1 µs can be achieved.

MAC Adresse	Media Access Control Address	Also referred to as Ethernet address; used to identify an Ethernet node. The Ethernet address has a length of 6 bytes and is assigned by IEEE
MES	Manufacturing Execution System	
Objekt		Information container having a temporally changeable state and for which the reaction to incoming messages is defined.
OLE	Object Linking and Embedding	Mechanism for the generation and editing of documents containing objects created by different applications.
OPC	OLE for Process Control	Generally accepted interface introduced in 1996 for the exchange of data between Windows-based applications in automation technology.
PCD	PROFINET Component Description	XML-based file containing information about the functions and objects of PROFINET components.
PROFINET Component Editor		Stand-alone tool for the generation of XML-based PROFINET Component Description (PCD) files; available for download at www.profibus.com
Proxy		A representative object in the object model which stands for a field device or a field device group from the point of view of PROFINET. The proxy represents one or more PROFIBUS devices on the Ethernet.
RPC	Remote Procedure Call	Defined interface that allows programs on remote devices to be invoked.
Runtime	Runtime	Name of the status of a system „in operation“, as opposed to the status of the system „during engineering“.
SNMP	Simple Network Management Protocol	A TCP/IP-based communications protocol for maintenance and monitoring of network components.
RT	Real-Time	Real-time channel for the transmission of time-critical process data within the production system in the area of factory automation. May be implemented in software based on existing controllers.
Switch-Technology		Technology for the segmentation of an Ethernet network into different subnets; serves to avoid collisions and to better utilize bandwidth.
TCP	Transmission Control Protocol/Internet Protocol	Communication protocol for the transfer of data between local networks. TCP is connection-oriented and is used for communications on the Internet. TCP is usually used in combination with IP (TCP/IP).
UDP	User Datagram Protocol	Transport protocol with broadcast characteristics, suitable for transmission of time-critical I/O data
VLAN Tag	Virtual local network	For preferential communication of RT data, a so-called VLAN tag is inserted containing a priority level for the frame, thereby bringing about the preferred forwarding in switches.
XML	Extensible Markup Language	Definition of a structured data description

Additional information, along with PROFIBUS and PROFINET documentation, profiles, and the PROFINET Runtime Software, is available on the Web site at www.profinet.com.

PROFINET

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