PROFINET

Design Guideline

Guideline

for PROFINET

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In this specification the following key words (in **bold** text) will be used:

may: indicates flexibility of choice with no implied preference.

should: indicates flexibility of choice with a strongly preferred implementation.

shall: indicates a mandatory requirement. Designers **shall** implement such mandatory requirements to ensure interoperability and to claim conformance with this specification.

Revision log

Ver	Date	Author	Changes/history
1.04	18.11.2010	Niemann	Final version
1.05	11.06.2013	Niemann	Internal version, not published
1.06 to 1.10	---	Niemann	Internal versions, not published
1.11	05.08.2014	Niemann	PoE and 4-pair cables. Enhancement of performance considerations. Layout change to DIN A4
1.12	16.11.2014	Niemann	Modifications and comments added the English version by A.V. Internal Version, not published
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1.24	07.09.2018	Niemann	Processing von Review comments, chapter network documentation added. Chapter EMC adapted to new EMC guideline. Chapter EMC deleted and reference to new guideline added. Table for cable distances corrected, missing multipliers added, example added. Internal word graphics replaced by png graphics to resolve Word stability problems
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1.26	08.09.2018	Niemann	Final review by WG Chair and last changes prior to WG review.
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1.38	17.09.2019	Niemann	Final editing. Disclaimer about min Cable Distances added
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1.40 to 1.50	13.06.2022	Niemann	Additions for Ethernet APL, Correction, Images updated to new style guide, Liability exclusion updated, standards and documents updated to recent versions. Error in device names fixed (Hyphens replaced by dash)
1.51	28.07.2022	Niemann	Review comments from Review meeting 13.06.2022 processed. Rate limiter added
1.52	31.07.2022	Niemann	Final Proof reading
1.53	23.09.2022	Niemann	Finalization for release of document
1.57	07.10.2024	Niemann (Stelljes)	Additions and changes for the introduction of TSN: Analysis of time requirements, CC-D, selection of CC, selection of data rate, network architecture, time synchronization, system examples. Further additions: Application profiles, basics of network technology, networks with multiple controllers, name assignment, GSD files. Functional equipotential bonding and redundancy have been replaced by a reference to the corresponding guideline. Adaptation to German document version.
1.58	01.11.2024	Niemann	Proof reading, Maximum length of fiber optical cable adjusted in Table 3.6 and 3.11. Chapter Security added.
1.59	30.01.2025	Niemann	Finalization, editorial corrections, disclaimer updated.

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1 Introduction

1.1 Preface

The goal of this PROFINET Design Guideline is to support engineers who have to design PROFINET automation systems, to facilitate the professional design of plants and to serve as a helpful guide for the step-by-step design of a plant.

The information is presented in a way which tries to be as brief and easy to understand as possible. It is nevertheless assumed that users have basic knowledge of PROFINET technology, electrical engineering and network technology.

This guideline is not intended as a PROFINET compendium. If you need more detailed information about PROFINET, please use the appropriate documents published by PROFIBUS Nutzerorganisation e.V. or comparable technical literature. This guideline does not cover the installation and commissioning of PROFINET. Please refer to the PROFINET Installation Guideline (Order No.: 8.072) and the PROFINET Commissioning Guideline (Order No.: 8.082) for more details. Information with respect to functional bonding and shielding for PROFIBUS and PROFINET can be found in the guideline with the same title Order No.: 8.102. The design of redundancy is explained in the PROFINET Redundancy Planning Guideline (Order No.: 8.132).

This Design Guideline does not replace any previous documents. It is intended as an application-oriented complement to the other guidelines. The previous PNO documents therefore continue to be valid.

1.2 Liability exclusion

PROFIBUS Nutzerorganisation e. V. (PROFIBUS user organization, hereinafter in this disclaimer referred to as “PNO”) has taken utmost care in the preparation of this document and compiled all information to the best of its knowledge. This document is nevertheless based on present knowledge, is of an informative character and is provided on the basis of liability exclusion. This document may be subject to change, enhancement or correction in the future without any expressive reference.

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1.3 PNO documents

[APL2021] Ethernet-APL Engineering Guideline

Order No.: 8.122, Version 1.11, Dec. 2021

[APS2021] Ethernet APL Port Profile Specification

Order No.: 2.662, Version 1.0, June 2021

[CCA2008] Conformance Class A Cabling Guideline

Order No.: 7.072, Version 1.0, July 2008

[CCS2011] Die PROFINET IO Conformance-Classes

Order No.: 7.042, Version 1.1, March 2011

[EMC2022] Functional Equipotential Bonding and Shielding of PROFIBUS and PROFINET

Order No.: 8.102, Version 3.1, Sept 2022

[GSX2024] GSDX Container Technical Specification for PROFINET

Order No.: 2.752, Version d1.2, Sept. 2024

[HIG2020] High Availability Guideline for PROFINET

Order No.: 7.242, Version 1.2, February 2020.

[MRE2018] PROFINET Media Redundancy Guideline for PROFINET

Order No.: 7.212, Version 1.03, April 2018

[PCI2023] PROFINET Cabling and Interconnection Technology

Order No.: 2.252, Version 5.3, May 2023

[PDE2018] PROFINET System Description – Technology and Application

Order No.: 4.132, November 2018

[PLM2008] Physical Layer Medium Dependent Sublayer on 650 nm Fiber Optics

Order No.: 2.432, Version 1.0, January 2008

[PNC2022] PROFINET Commissioning Guideline

Order No.: 8.082, Version 1.53, Sept 2022

[PNI2022] PROFINET Installation Guideline

Order No.: 8.072, Version 2.12, Sept. 2022

[PNO2024a] Application Layer protocol for decentralized periphery

Order No.: 2.722, Version 2.4 MU5, March 2024

[PNO2024b] Application Layer services for decentralized periphery

Order No.: 2.712, Version 2.4 MU5, March 2024

[PNR2023] PROFINET Planning Redundancy

Order No.: 8132, Version 1.00, May 2023

[PRD2015] Profile Drive Technology PROFIdrive Profile

Order No.: 3.172, Version 4.2, October 2015

[PRE2021] Common Application Profile PROFIenergy

Order No.: 3.802, Version 1.3MU1, October 2021

[PRP2022] Profile for Process Control Devices

Order No.: 3.042, Version 4.02MU1, March 2022

[PRR2024] Profile Standard Robot Command Interface SRCI

Order No.: 3.252, Version 1.4, January 2024

[PRS2023] PROFIsafe – Profile for Safety Technology on PROFIBUS and PROFINET

Order No.: 3.192, Version 2.6MU2, February 2023

[PSA2013] PROFINET Security Guideline

Order No.: 7.002, Version 2.0, November 2013

[PSB2023] Security Class 1 for PROFINET-Security – Guideline for PROFINET

Order No.: 7.312 Version 1.1 – März 2023

[PSC202X] PROFINET Design Guideline Security

Order No.: 7.362 (Document in preparation, not yet published)

[PTS2020] PROFINET Time Synchronization

Order No.: 7.232, Version 1.0, November 2020

1.4 Referenced standards

[EN 50174-2]:2018

Information technology - Cabling installation - Part 2: Installation planning and practices inside buildings

[EN 50174-3]:2013 + A1:2017

Installation technology – Cabling installation - Part 3: Installation planning and practices outside buildings

[EN 50310]:2016 + A1:2020

Application of equipotential bonding in buildings with information technology equipment

[IEC 11801-3]:2017 + AMD1:2021 CSV

Information technology - Generic cabling for customer premises – Part 3: Industrial Premises

[IEC 60364-4-41]:2005+AND1:2017 CSV

Low voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock

[IEC 60364-5-54]:2011 + AMD1:2021 CSV

Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors

[IEC 60529]:1989 + AMD1:1999 + AMD2:2013

Degrees of protection provided by enclosures (IP Code)

[IEC 61140]:2016

Protection against electric shock - Common aspects for installation and equipment

[**IEC 61300-3-4]:2012**

Fiber optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-4: Examinations and measurements - Attenuation

[IEC 61156-13]: 2023

Multicore and symmetrical pair/quad cables for digital communications – Part 13: Symmetrical single pair cables with transmission characteristics up to 20 MHz – Horizontal floor wiring - Sectional specification.

[IEC 61158-2]:2014

Industrial communication networks – Fieldbus specification – Part 2: Physical layer specification and service definition

[IEC 61918]:2018

Industrial communication networks – Installation of communication networks in industrial premises.

[IEC 61784-5-3]:2018

Industrial communication networks - Profiles - Part 5-3: Installation of fieldbuses – Installation profiles for CPF 3

[IEE802.1Q]: 2022

IEEE 802 LAN/MAN Standards Committee, IEEE 802.1Q-2018: IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks, 2018. https://standards.ieee.org/ieee/802.1Q/10323/.

[IEEE802.1AS]: 2020

IEEE 802 LAN/MAN Standards Committee, IEEE Std 802.1AS-2020, IEEE Standard for Local and Metropolitan Area Networks – Timing and Synchronization for Time-Sensitive Applications, 2020. https://standards.ieee.org/ieee/802.1AS/7121/.

[IEEE P802.3cg]: 2019

IEEE Standard for Ethernet Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors. https://standards.ieee.org/standard/802_3cg-2019.html.

[RFC_3492]

Costello: Punycode: A Bootstring encoding of Unicode for Internationalized Domain Names in Applications (IDNA). https://datatracker.ietf.org/doc/html/rfc3492.

[RFC_5681]

Allman, et al.: RFC 5681 - TCP Congestion Control.

https://datatracker.ietf.org/doc/html/rfc5681.

[RFC_5905]

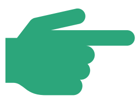
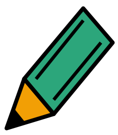
Mills, et al.: RFC 5905: Network Time Protocol Version 4: Protocol and Algorithms Specification. https://datatracker.ietf.org/doc/html/rfc5905

1.5 Symbols and their meaning

The figures used in this guideline will help you better understand the text. In addition, symbols for text structuring will be used. These symbols highlight important text passages or summarize certain sections.

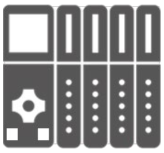
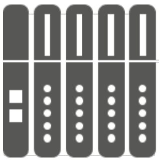
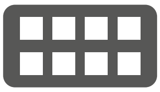
1.5.1 Symbols for structuring the text

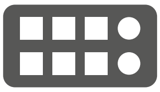
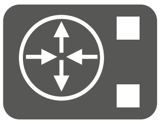
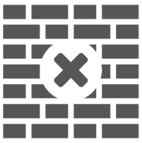
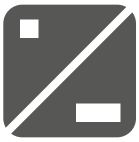
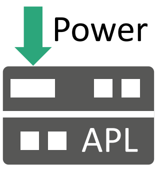
Table 1-1: Symbols for structuring the text

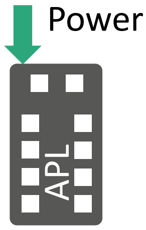
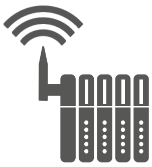
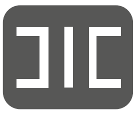
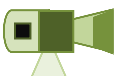
Symbol	Name	Meaning
	**Tip**	Used to mark a recommendation and / or summary of the current topic.
	**Important**	Used for information which, if not observed, may result in malfunctions during operation.
	**Instruction**	Used for direct instructions.
	**Danger!**	Used to mark a danger to life and health. The observance of an instruction marked in this way is extremely important!

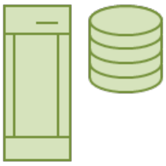
1.5.2 Symbols for components

Table 1-2: Symbols for components

Symbol	Name	Meaning
	**Operator console**	Command and control station
	**Supervisor**	An engineering station or PC with commissioning and diagnostic functions for PROFINET
	**Controller**	A device (typically a control unit) that initiates the IO data traffic.
  	**Device**	A locally assigned field device that is allocated to a PROFINET controller. This can be e. g. a remote IO, a drive or a panel display.
 	**Switch**	Device for the interconnection of several PROFINET devices. Eight respective four ports for copper media.

	**Switch**	Device for the interconnection of several PROFINET devices. Six ports for Copper-Media plus two ports for fiber optic media
	**Router**	Network component for interconnecting data traffic between different sub-networks.
	**Firewall**	Device for controlling and filtering data between different subnetworks.
	**Gateway**	Device for connecting different network technologies, for example PROFINET and PROFIBUS DP.
	**APL field device**	APL field device, (e.g. temperature transmitter, pressure transmitter, flow transmitter, positioner), with Ethernet-APL interface. The device is powered and communicates via Ethernet-APL. Transmitters with external power supply (four wire transmitters) are possible, but will not be handled separately
	**APL power switch**	Ethernet switch. Converts Industrial Ethernet to Ethernet-APL. Needs auxiliary power to power the subordinate APL network. Indicated by thick green arrow.
	**APL field switch without auxiliary power supply**	This Ethernet-APL field switch connects to the APL Trunk to Ethernet-APL field devices (Spurs) and provides power for the APL field devices connected to the switch. Receives energy via a powered trunk

	**APL field switch with auxiliary power supply**	This Ethernet-APL field switch with auxiliary power supply connects the Industrial Ethernet or the unpowered APL trunk with the Ethernet-APL field devices (Spurs) and provides power for the APL field. The switch is connected to auxiliary power and does receive power neither via the unpowered APL trunk nor the industrial Ethernet.
	**WLAN access point**	A device that allows changing over from wired to wireless communication.
	**Device with WLAN**	Local field device with WLAN.
	**Media converter**	Converter from one physical medium to another, e. g. from copper to fiber optic media.
	**TAP**	Abbreviation of “Test Access Point”. Device for reading the network traffic without causing any impact
	**Time receiver**	Obtains an absolute time via satellite or radio signal receivers to define synchronous time control of PROFINET devices. Typical time signal sources are GPS and DCF 77.
	**Video camera**	Device for image-based monitoring

	**Control station**	Standard PC with control functions
	**Server**	Server computer, e.g. for backup tasks.

1.5.3 Symbols for PROFINET cables

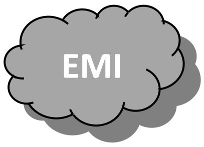
Table 1-3: Symbols for PROFINET cables

Symbol	Name	Meaning
	Standard Ethernet	Standard Ethernet connection which does not involve the PROFINET protocol
	**PROFINET copper cable**	PROFINET Industrial Ethernet cable with copper wires Sheath color: green The dotted line indicates a connection with increased determinism requirements.
	**FO**	Fiber-optic cable Sheath color: green Note: for easier differentiation between copper and FO, the FO are highlighted orange in this guideline although the cable sheath is usually green. The dotted line indicates a connection with increased determinism requirements.

APL	**Ethernet-APL cable without Ex qualification**	Ethernet-APL connection without Ex qualification. (used for Trunk and Spur) The dotted line indicates a connection with increased determinism requirements. Sheath color: not defined.
APL Ex e	**Ethernet-APL with increased safety (Ex e)**	Ethernet-APL connection that can run in areas with explosive atmosphere. Increased safety (Ex e / non incendive). (used for Trunk) The dotted line indicates an inactive ring redundancy connection for increased availability requirements.
Ex i or I.S.	**Ethernet-APL with intrinsic safety (Ex i)**	Ethernet-APL connection that can run in areas with explosive atmosphere. Intrinsic safety. (Used for APL-spurs)
●	**Conductive link**	Electrically conductive link

1.5.4 Symbols for areas

Table 1-4: Symbols for areas

Symbol	Name	Meaning
	**EMI**	Area where the occurrence of electromagnetic interference (EMI) must be expected.

1.6 About the structure of this guideline

The structure of this guideline corresponds to the design process. This process will be followed step by step, while each modification in a later process shows a possible implication on the previous steps. Figure 1-1 shows the structure of the design process.

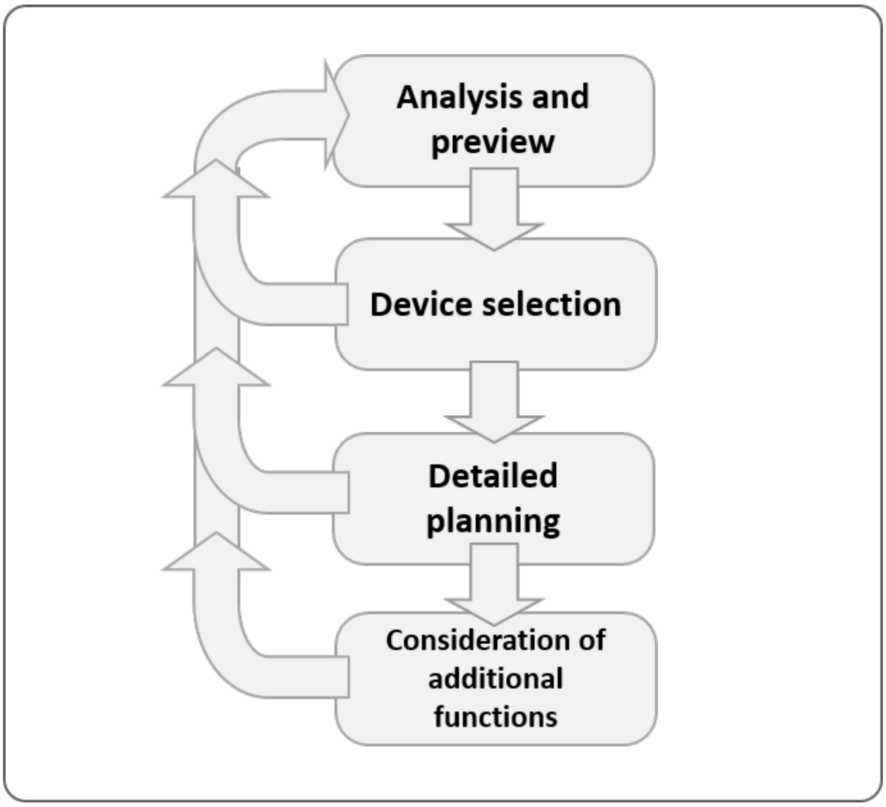


Figure 1-1: Design structure

The chapters of this design document follow this procedure. While chapter 1 contains an introduction, the following chapters go from general issues to the details of the design process. The chapters highlight the following issues:

Chapter 2: This chapter starts with a preview and analysis of the process to be automated. The properties and the placement of the automation components are described.

Chapter 3: This chapter includes the topology definition of the automation plant based on the findings gathered in chapter 2.

Chapter 4: The existing basic design is extended by such cases which are typically not part of PROFINET.

Chapter 5: In this chapter, the physical layer Ethernet APL is explained and included into the planning if required.

Chapter 6: PROFINET offers a multitude of possible applications for additional functions which require a special consideration. The chapter provides an overview of these functions.

Chapter 7: In order to ensure the performance in a PROFINET network, based on the previous chapters, the PROFINET design aspects relevant for the performance are considered.

Chapter 8: This chapter describes a careful planning of name and address assignment

Chapter 9: This provides a short summary of design results.

The annex (chapter 10) of this document also provides additional information about different components and their properties which are used in a PROFINET network. This includes information such as cable parameters or application examples for cable design and many more.

An index is provided in chapter 10 to facilitate the search for topic-related information in the guideline.

1.7 Goal of the guideline

The main goal of this guideline is to help you to select devices and networking components for a PROFINET system, and to design and layout the system to give reliable performance and allow easy installation, commissioning and maintenance.

After completion of the design process, the following information should be available or be generated:

- Plant design
- Topology
- Selection of components
- Selection of transmission medium
- Selection of connectors
- Communication relations
- Estimate of data volumes to be transmitted

In case any of this information should be missing, the design process has to be restarted at the relevant position.

2 Device selection

Before you can start …

…you need an overview of your project. For example, this may include the physical layout, a plan of the plant or the plant schematics. This information provides a first idea of the extent of the PROFINET network to be designed.

The first step is to determine which device types are required to solve the automation task. The device types are then placed in the system. A layout plan is created, which is the basis for further planning.

The devices are then selected. The selected devices must be able to solve the automation task at hand. The analysis of the time requirements arising from the process to be automated is central to this. Based on these requirements, the following characteristics of the devices are determined:

- The real-time channel (RT, IRT or TSN
- The usage of a free-running or clock-synchronous application
- The Conformance Class

In addition to the time requirements, there are further criteria to consider when selecting devices. These include:

- PROFINET application profiles
- Functional safety with PROFIsafe
- Specifications of end customer
- Type of connection of the device
- Protection class of the devices
- Other requirements

Devices are selected on the basis of these requirements.

Selecting the devices according to the above criteria ensures that the automation task can be solved. In addition, check the manufacturer's specifications of the devices you have selected for restrictions and boundary conditions.

2.1 Determination and positioning of device types

First, the device types required to solve the automation task must be determined. Examples of device types that can be connected to PROFINET are:

- **Drives/frequency inverters** for conveyor belts, pumps, compressors, ...
- **Remote I/O's** for connecting sensors and actuators
- **Operating panels or PCs** for operating the system
- **Controller** for controlling the system
- Other network nodes

In the following step, the designer has to determine the components for plant automation. First, each component needs to be appropriately placed based on the plant design information or the building floor plan.

For example:

- The controller can be placed in a separate control cabinet away from the process, or together with other devices close to the process.
- An operating panel can be placed close to the process for control or in a remote-control room for monitoring.

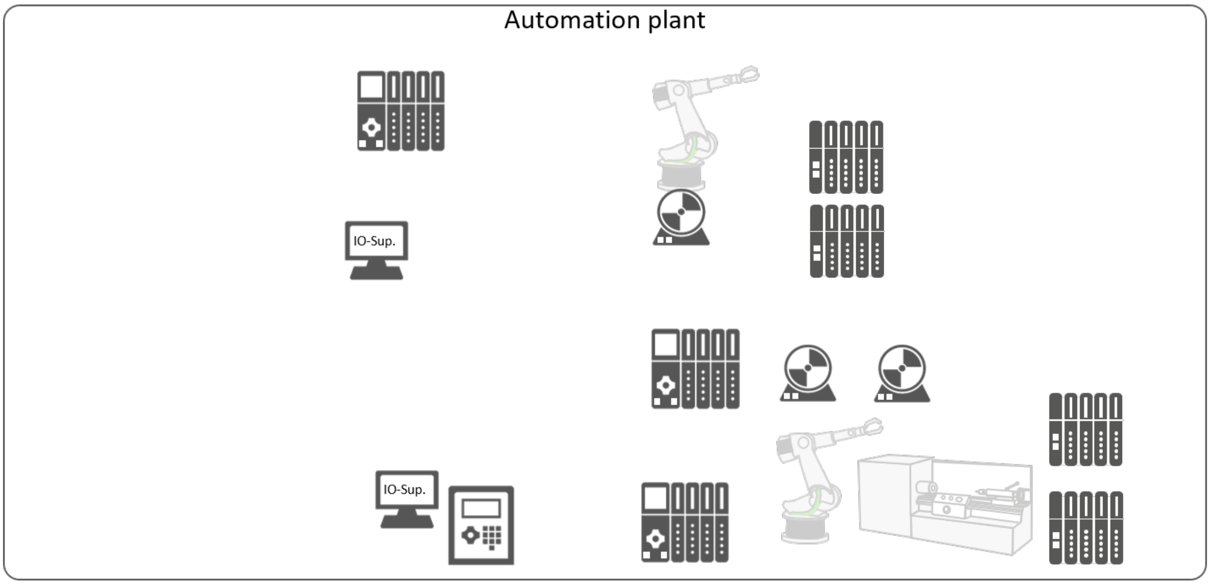


Figure 2-1: Floor plan of a plant with pre-placed components

The required components must then be drawn in a floor plan of the automation plant. Figure 2-1 shows such a layout plan for an example plant. The plant example is also used in the subsequent planning steps to explain the planning steps.

The components should then be grouped in such a way that a spatial and functional grouping of the components is created.

The spatial grouping is usually created via the local proximity in the site plan. The functional grouping is determined via common control tasks and specifies the devices with which a controller must communicate.

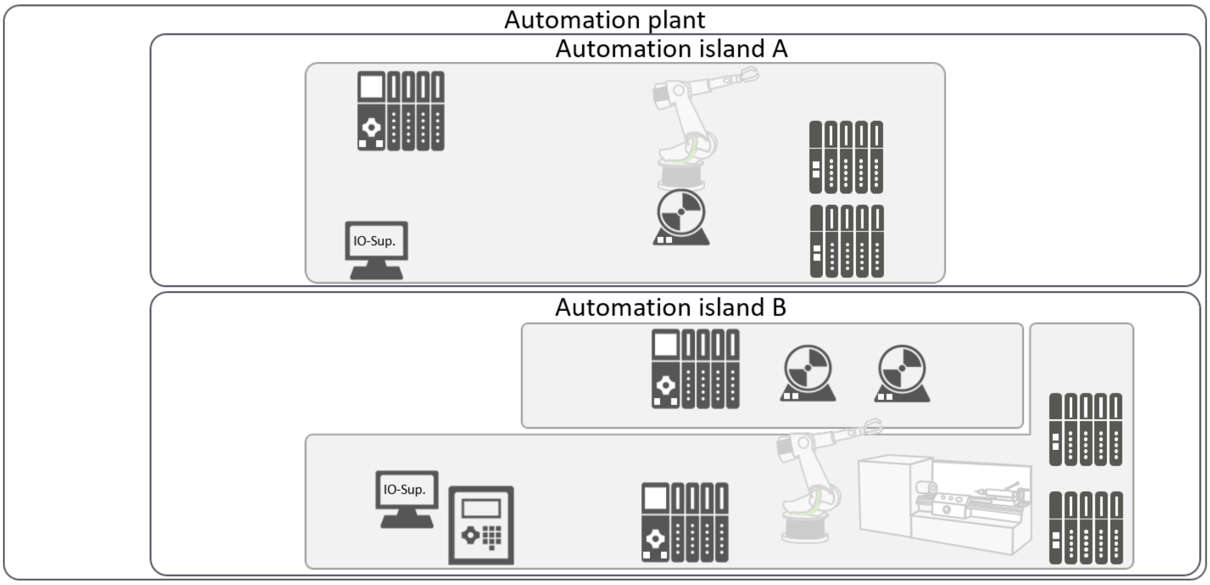


Figure 2-2: plant example with spatial and functional clustering

Figure 2-2 shows spatial and functional grouping. The facility was divided into two islands. The division is based on the spatial conditions, as may be the case in different hall areas, for example.

The controller in island A communicates with the devices in island A, which is why the functional grouping is the same as the spatial grouping.

There are two controllers in island B, each of which requires a functional grouping. One controller controls two drives and forms a functional groups with them. The remaining devices communicate with the second controller in island B and thus form another functional group.

At this point, the components are not interconnected but only positioned in the automation plant and combined to groups.

Mark the areas with increased requirements, e.g. determinism, to ensure they can be considered separately during the design.

2.2 Analysis of the time requirements of the process

The goal of this chapter is to determine the time requirements for the PROFINET network. The time requirements are determined by the technical process that is to be automated. The time requirements are then used to determine which properties the devices must have in order to meet the requirements.

In many automation plants, the time requirements are low, so there are no special requirements for the devices.

High time requirements are characterized by fast processes, highly dynamic control loops and high-precision sensors or actuators.

2.2.1 PROFINET communication description

The central function of PROFINET is the transmission of process data. These are transmitted cyclically. The cycle time is called the **update time**. In addition to cyclic communication, there is also data that is transmitted non-cyclically. This includes alarms, parameters, diagnostic and status information.

The PROFINET network can also be used to transmit any other data as it is based on Ethernet. For example, IP-based protocols such as MQTT or OPC UA client servers can be used in the PROFINET network.

Time requirements apply to the transmission of process data and alarms. They are therefore transmitted via a Real-Time channel. The remaining data is transmitted via the Non-Real-Time channel.

Table 2-1: PROFINET communication types

Non-real-time channel	Real-time channel		
Non-Real-Time **(NRT)**	**Real-Time** **(RT)**	**Isochronous Real-Time** **(IRT)**	**Time Sensitive Networking** **(TSN)**
-	Free-running	Free-running or clock-synchronized	
Parameters Diagnostic & Status TCP/IP and UDP/IP	Process data Alarms		

Table 2-1 shows an overview of the communication and data types of PROFINET. It can be seen that there are three Real-Time channels: RT, IRT and TSN. These Real-Time channels differ in their Real-Time properties. The choice is therefore made on the basis of the time requirements.

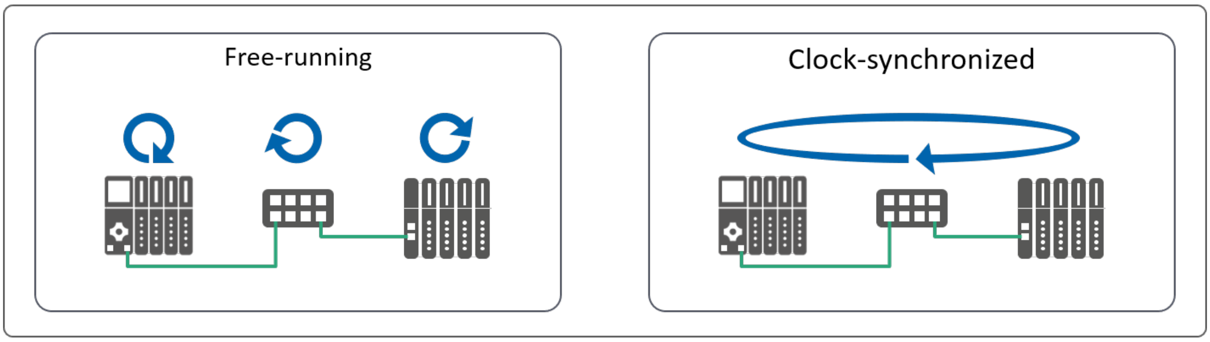


Figure 2-3: Difference between free-running and clock synchronized application

Another difference is whether the application is free-running or clock-synchronous. The application is **clock-synchronous** if the program sequence is synchronized in different devices. If this is not the case, the application is called **free-running**. Figure 2-3 shows both variants.

2.2.2 Determining the time requirements

The time requirements are always determined by the technical process and the automation task. Time requirements can vary, including requirements for reaction time, sample time or jitter.

Every plant has different timing requirements. However, there are often similar timing requirements within certain application areas, which enables the classification shown in Table 2-2. Please note that this classification only provides an overview of typical automation tasks. An individual estimation of the time requirements is necessary.

Table 2-2: Typical applications and their time requirements and implementation

<table>
<tr><th>Area of application</th><th>Typical application</th><th>Time requirement</th><th>Typical realization</th></tr>
<tr><td>Process industry</td><td>Level control
Temperature control</td><td>Low</td><td rowspan="2">RT or TSN with free-running application</td></tr>
<tr><td rowspan="2">Manufacturing industry
or
mechanical engineering</td><td>Conveyor belt
High-bay warehouse</td><td>Medium</td></tr>
<tr><td>Servo drive
Multi-axis systems
Robot control</td><td>High</td><td>IRT or TSN with clock-synchronous application</td></tr>
</table>

The time requirements can be enabled by selecting the appropriate real-time channel and application. In addition, the update time and the cycle time of the user program influence which time requirements the PROFINET system can meet. A more detailed description of these relationships can be found in Chapter 7. An approximate and abbreviated classification is as follows:

- Time requirement > 10 ms: RT or TSN with free-running application
- Time requirement < 5 ms and > 250 µs: IRT or TSN with clock-synchronous application
- Time requirement < 250 µs: Manufacturer-specific solution

High time requirements are characterized by fast processes, highly dynamic controls and high-precision sensors or actuators.

Manufacturers can develop and distribute special technologies to enable high time requirements. In this case, contact the manufacturer and discuss your requirements with them.

Document high time requirements that you have determined in this step. Also document how these high time requirements are made possible.

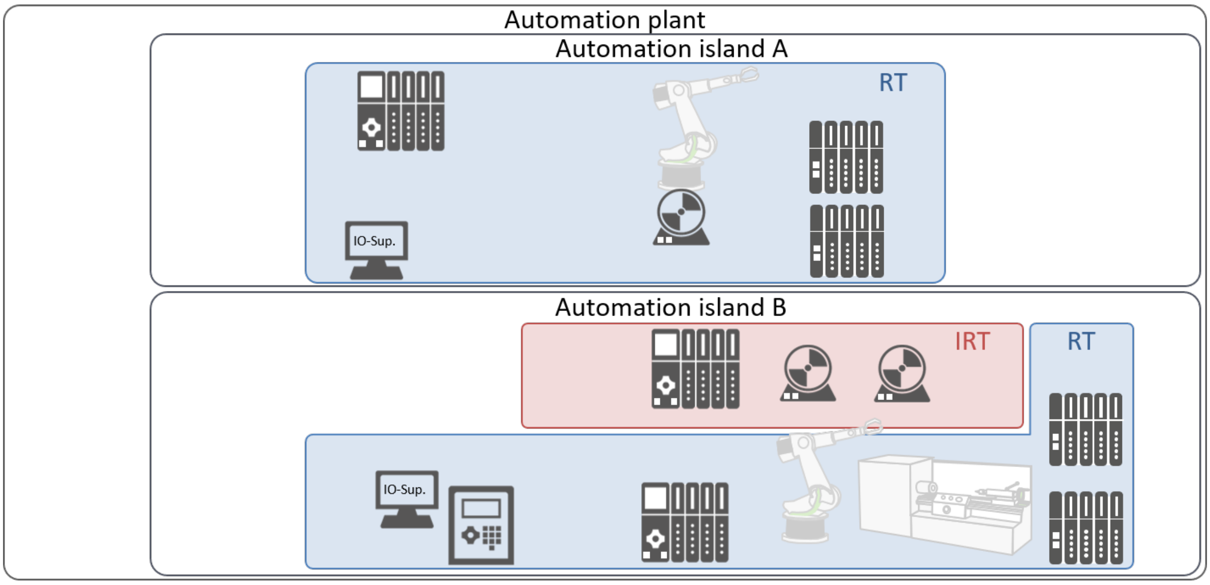


Figure 2-4: Plant example with real-time channels

Figure 2-4 shows the system example after determining the time requirements and defining the real-time channels. In island B, IRT with clock-synchronous application is used in one section, as several drives have to be controlled by the controller.

2.3 The Conformance Classes

The functional scope of PROFINET components is divided into four so-called **Conformance Classes (CC)**. The goal of this classification is to define useful functional scopes in order to limit the decision criteria for plant operators when using PROFINET components. The CCs are described below. The CCs for the components are then defined.

For detailed information on the individual conformance classes, please use the document “The PROFINET IO Conformance Classes” (Order No.: 7.042) from the PROFIBUS user organization.

2.3.1 Description of conformance classes

All CCs contain certain basic functions. These are:

- Standard Ethernet communication
- Use of twisted-pair copper cable or fiber optic cable
- Cyclical communication
- Process data with update times between 1 ms and 512 ms
- Acyclic communication
- Alarms, parameters, diagnostic and status information
- Certified controllers and devices

The CCs supplement these basic functions. There are four CCs: CC-A, CC-B, CC-C and CC-D. Table 2-3 shows the functions that are defined by the CCs.

Table 2-3: The functional scope of the conformance classes

CC	A	B	C	D
Real-time channel	RT	RT	IRT	TSN
Clock synchronicity	No	No	Optional	Optional
Certified switches	No	Yes	Yes	Yes
Network management with SNMP	No	Yes	Yes	Yes
Topology detection with LLDP	No	Yes	Yes	Yes
Bumpless media redundancy	No	Optional with MRPD	Optional with MRPD	Optional with FRER
Isolation of real-time traffic	No	No	Yes	Yes
Clock synchronization	Optional	Optional	Optional	Optional
Wireless communication	Optional	Optional	No	Optional
Data rate[a]	10 Mbit/s to 10 Gbit/s	10 Mbit/s to 10 Gbit/s	100 Mbit/s	10 Mbit/s to 1 Tbit/s

[a]: At least one of the specified data rates must be supported.

The CCs only define minimum requirements for the devices. Devices can support additional functions that are not defined by the conformance class.

2.3.2 Defining the conformance classes

Now define the conformance class of all devices. The selection of the CC depends on the time requirements, the available devices and the other functions required.

High time requirements

In areas with high time requirements, the choice of CC is partly determined by the real-time channel, as IRT is only available in CC-C and TSN only in CC-D. Often, however, either IRT or TSN can be used to enable the high time requirement. In this case, follow the instructions below to decide between CC-C and CC-D:

- The CC-C and CC-D cannot be mixed within a functional group. They are not compatible with each other.
- Check whether a required device is only available in the CC-C or only in the CC-D. In this case, the device determines the CC.
- The CC-D offers the advantage of Gigabit Ethernet compared to the CC-C.

Please note that clock synchronization is an **optional** function in the CC-C and CC-D.

If you want to use a clock-synchronous application, you must ensure that the devices support clock synchronization when selecting them.

Information on whether a device supports clock synchronization can be found in the data sheet, by contacting the manufacturer or in the GSD file (ApplicationClass = “Isochronous”).

No high time requirements

In areas without high time requirements, RT or TSN can be used as the real-time channel. CC-A, CC-B and CC-D can therefore be considered.

CC-A should only be used if other CCs cannot be used. This is the case, for example, if a device is only available in CC-A or non-certified switches are used.

In most systems, this leaves the choice between CC-B with RT and CC-D with TSN. The differences between these two CCs are briefly explained here to make it easier for you to decide.

2.3.3 Advantages of TSN compared to RT

Time Sensitive Networking (TSN) is used in the CC-D. This involves several Ethernet standards that lead to an improvement in the properties of the network. The CC-D offers a number of advantages over the CC-B:

- **Isolation of real-time traffic**: When using RT in the CC-B, real-time traffic is prioritized over other traffic. If the network is overloaded by non-real-time traffic or large packets are transmitted, this still has a negative impact on real-time communication. These problems are solved by TSN. The use of TSN ensures that the transmission of process data cannot be influenced by other data in the network. This makes it easier to implement convergent networks in which PROFINET and other services use the same network.
- **Clock-synchronous application**: TSN enables a clock-synchronous application. However, implementation in CC-D devices is optional.
- **Bumpless media redundancy**: Bumpless media redundancy is optionally possible with FRER.

The differences between CC-B and CC-D therefore mainly concern the network properties. As the network has not yet been planned at this time, it may be necessary to adapt the CCs in the further course of planning.

Conformance Class D devices are not yet available on the market at the time of publication of this document (July 2024), as CC-D has only recently been defined. If you wish to use CC-D functions, you have two options:

- Find out from the manufacturer whether they offer devices that meet your requirements without using TSN.
- Ask the manufacturer about the market launch of CC-D devices.

Conformance Class D devices are currently (July 2024) not available on the market.

Now define the conformance class of each device. This ensures that the desired range of functions is available in the PROFINET devices.

The CC-A should only be used if other CCs cannot be used.

The CC-B is suitable for typical applications and is used most of the time.

The CC-C is suitable for applications with high time requirements.

The CC-D is suitable for typical applications as well as for applications with high time requirements and offers a number of advantages over the CC-B and CC-C through the use of TSN.

Document the defined conformance classes.

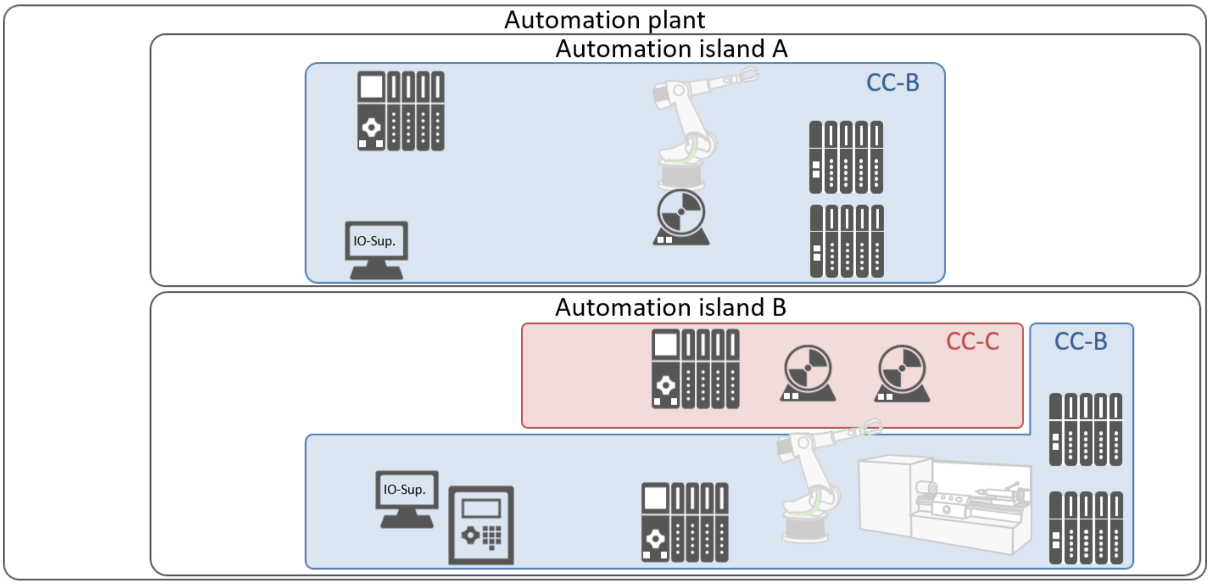


Figure 2-5: Plant example with conformance classes

Figure 2-5 shows the plant example after the conformance classes have been defined. As IRT is used in one part of island B, CC-C is used there. CC-B is used for the other components.

2.4 Further criteria for device selection

In addition to the functional scope of the conformance classes, further criteria must be considered when selecting devices. In this chapter, you will find information and planning tips on the following criteria:

- PROFINET application profiles
- Functional safety with PROFIsafe
- Specifications of the end customer
- Environmental requirements
- Type of connection of the device
- Other specifications

In addition, check the manufacturer's specifications for the devices you have selected for restrictions and boundary conditions.

2.4.1 Application profiles

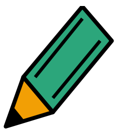
PROFINET defines application profiles that can optionally be implemented by devices. Application profiles define a series of manufacturer-independent properties that are supported by the devices. This ensures that devices from different manufacturers behave identically. The use of application profiles results in the following advantages:

- Manufacturer-independent device selection
- Simple device replacement even when changing manufacturers
- Simplified configuration

Table 2-4: Overview of selected application profiles

Profile	Zweck des Profils	Quelle
PROFIsafe	Transmission of security-relevant data	[PRS2023]
PROFIdrive	Interface to drives	[PRD2015]
PROFIenergy	Energy management	[PRE2021]
PROFIprocess	Profile for the process industry	[PRP2022]
SRCI	Programming robots	[PRR2024]

Table 2-4 shows some application profiles and their areas of application. In addition to the profiles listed, there are many more. An overview can be found at https://www.profibus.com/download/profiles.



Check whether you want to use one or more application profiles. When selecting the devices, make sure that the required profiles are supported.

2.4.2 Functional safety with PROFIsafe

PROFIsafe is a PROFINET application profile for safety-related communication. It ensures that people and machines will not suffer any damage during the operation of an automation plant. PROFIsafe devices can be operated in parallel with standard PROFINET devices on a PROFINET network. Figure 2-6 shows an example of the use of PROFIsafe devices in a PROFINET network.

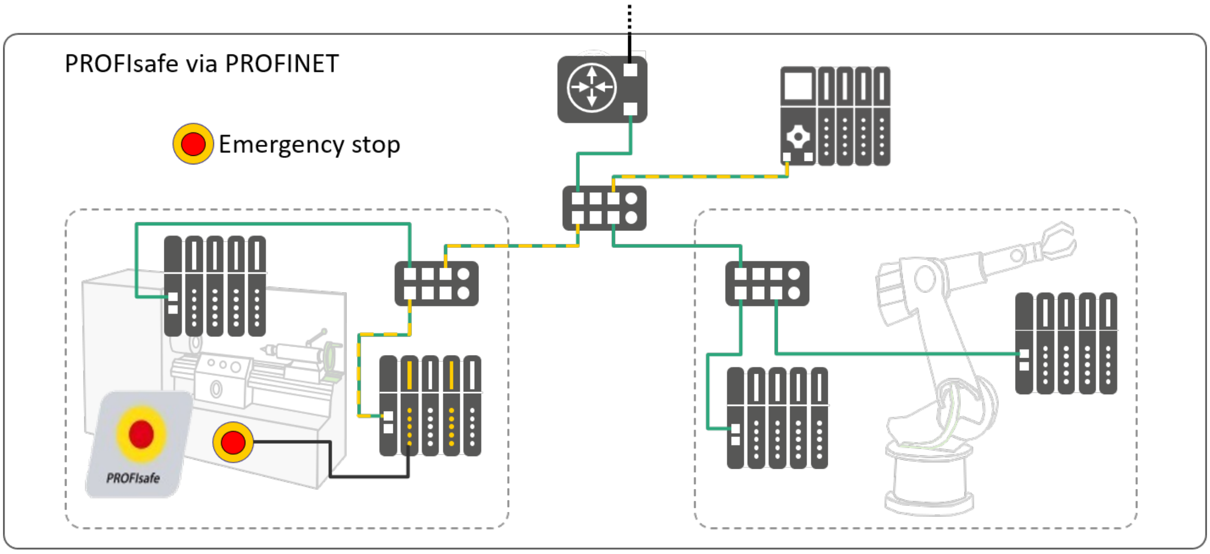
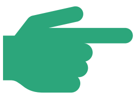


Figure 2-6: Use of PROFIsafe via PROFINET

The safety-related PROFIsafe communication (yellow), as well as the PROFINET communication, is transmitted via the shared network. All nodes in the safety-related communication must have IEC 61010 certification (CE mark in the EU).

When selecting devices, take safety-related aspects into account if potential damage to people and machines must be avoided during operation. PROFIsafe devices must have PROFIsafe certification in addition to PROFINET certification.



Further information on PROFIsafe can be found in IEC 61784-3-3.

2.4.3 Specifications of the end customer regarding device selection

In many cases, the requirement profile of an automation system is already predetermined. In these cases, it is common for so-called approval lists provided by the end customer to be used when designing or selecting devices. These lists contain components approved by the end customer. The purpose of an approval list is to

To reduce the time and effort involved in the selection process.

To use similar components throughout the entire system.

To always have the same requirements profile available.

Specifications from your end customer must always be observed when selecting devices. Of course, the release lists should also comply with your conformance class specifications.

Check whether the current status of the release lists is available to you.

2.4.4 Environmental requirements for the PROFINET device

Environmental aspects must also be considered for the selection of devices when planning an automation plant. With reference to the location of the devices, we basically differentiate between the installation in a cabinet and the unprotected installation in the plant environment.

Both environments imply certain requirements for the nodes of the PROFINET network.

- Penetration of foreign objects and liquids (IP protection class).
- Mechanical requirements, e.g. vibration, shock
- Temperature influences
- Electromagnetic influences

In order to optimize your device selection, mark those areas of the plant that generate special requirements for the device to be installed.

For the device selection, consider potential external influences. Adjust your device selection according to the manufacturer’s information.

2.4.5 Type of connection at the PROFINET device

PROFINET supports many different types of connections to the network. Copper cabling is normally used for the connection of PROFINET devices. Optical fiber and wireless communication can also be used.

Several connection technologies are available when using wired transmission media. These connection technologies can be categorized according to their transmission medium, as shown in Table 2-5.

Table 2-5: Connection types for PROFINET devices

Copper cable connections	Optical fiber connections
M12 RJ45 (IP20) Push-Pull-RJ45 (IP65)	M12 SCRJ (IP20) SCRJ Push-Pull (IP65)

The connection technology is determined by the selected device. In a later design step, additional media converters may be necessary due to certain topology or environmental requirements.

All connectors and cables are PROFINET components that require a manufacturer declaration concerning the compliance with PROFINET standards.

2.5 Defining the devices

Now make your device selection based on the information available to you. Consider the requirements of the automation task, the conformance class, the ambient conditions and other requirements for the devices.

The selection of devices may need to be adjusted at a later time, in order to adapt the connection technology and the transmission medium to the requirements.

Please check again whether all requirements for the placement and properties of the devices have been considered.

2.6 Documentation of results

After completion of the device selection, you should have all the information about the selected devices. This includes device information such as:

- The real-time channel used (RT, IRT or TSN)
- The Conformance Class
- The device connection or transmission medium (copper, fiber optic or wireless)
- The support of additional functions

You should not carry out any detailed planning of device parameters at this time. These will be part of later chapters.

Document your selection of PROFINET devices and collect all relevant information. Create lists of the selected devices and their properties.

3 Determine the Network topology

This chapter is preceded by the analysis of the automation project. The first step was to determine which devices will be used in the plant. As part of the progressing more detailed planning, the next step is to create the network topology for the plant. Network components such as switches and routers are planned and the transmission media are defined.

Some general topology examples are discussed, followed by an overview of the transmission media that can be used and their most important properties.

The network topology is defined in two steps. In the first step, the topology is defined within the functional groups. This ensures that all devices can communicate with their controllers. In the second step, the remaining communication tasks between functional groups or to other networks are solved. The automation system is also integrated into the architecture of the company network.

Once the topology and the transmission media to be used have been defined, a check is made to see whether the devices selected in Chapter 2 permit the connection of the selected transmission media.

Finally, the topology planning is documented.

The information on transmission media and connectors considered here is only a brief outline of the most important information.

Please consult the appropriate source (e.g. the manufacturer) for more detailed information.

3.1 Basics of network technology

This chapter describes the basics of network technology that are relevant for planning the topology. First, the terms port, interface, switch and router are defined:

- A **port** is a physical socket on a network participant to which an Ethernet cable can be connected.
- An **interface** is a logical access point on a network participant. An interface can comprise one or more ports. Each interface has a MAC address and an IP address via which the interface can be addressed.
- **Switches** are used to create a network in which all nodes can communicate with each other as required. A switch has several ports to which the nodes are connected. Single devices or integrated switches can be used as switches. A switch forwards incoming date to one or more outgoing ports.
- **Routers** are used to connect several networks with each other. A router has several interfaces. For communication across a router to be possible, communication must be IP-based. Examples of IP-based protocols are SNMP and HTTP.

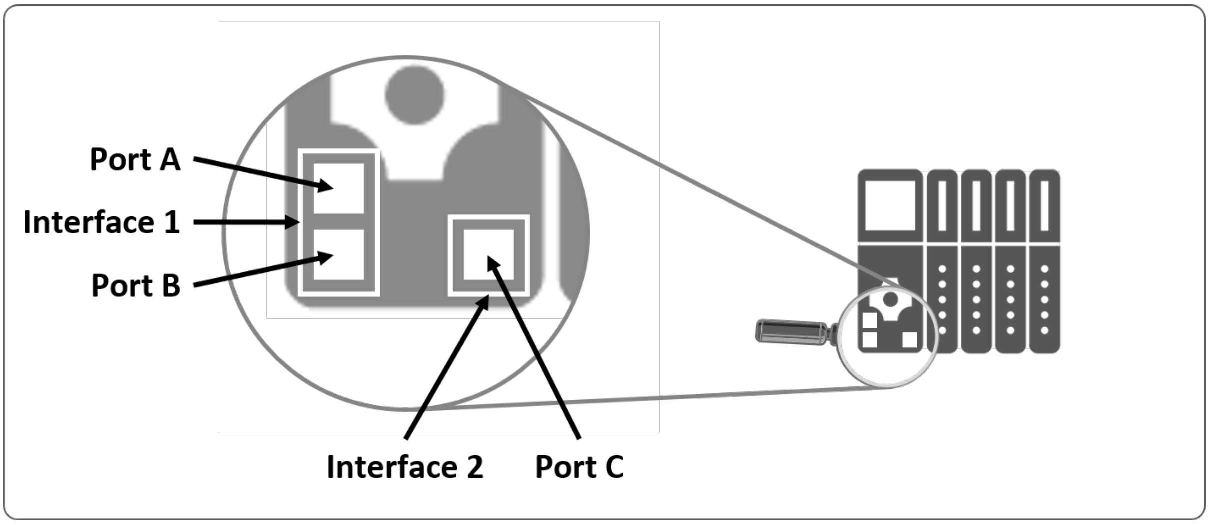


Figure 3-1: Difference between the terms port and interface

Figure 3-1 shows a PROFINET device with two interfaces. Interface 1 has two ports (port A and port B), interface 2 has one port (port C).

If a PROFINET device has several interfaces, it can be connected to several different networks. This is used, among other things, to connect the device to two separate networks simultaneously, e. g. for redundancy purposes.

If an interface has several ports, these are connected to each other via an integrated switch. This enables the connection of devices in a line topology. Alternatively, switches can be used as separate switches. Figure 3-2 shows the difference between the connection via an integrated switch or a switch as a separate switch.

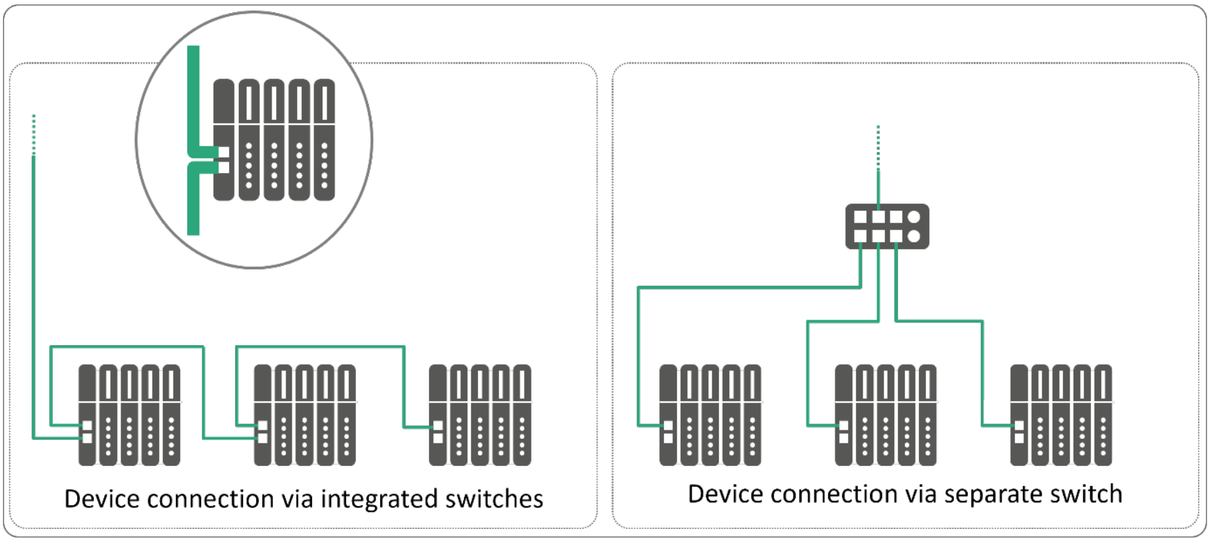


Figure 3-2: Difference integrated switch and separate switch

Table 3-1 lists the advantages of the two switch variants.

Table 3-1: Benefits of both switch connection options

Benefits of integrated switches	Benefits of separate switches
Cost reduction since no additional switch is required. Replacement of defective network nodes without interruption of the remaining communication is possible for line topology with ring redundancy.	Replacement of defective network nodes is possible without interruption of the remaining communication for star and tree topologies.

From Conformance Class B on, the use of managed switches is mandatory for PROFINET. However, such switches also offer advantages for plants designed in Conformance Class A, such as better diagnostics, which is why the use of managed switches is recommended in any case.

The selection criteria for the nodes in the PROFINET network with regard to device properties and environmental requirements must also be defined for switches as individual devices. A guide to selecting switches as separate devices can be found in the annex of this document (see chapter 10.9).

Because PROFINET communication of process data is not IP-based, it cannot take place across routers. Figure 3-3 shows two PROFINET networks that are connected to each other via routers. Within network 1, all devices can exchange process data with each other via PROFINET and also communicate using IP-based protocols. The same applies within network 2, although a device from network 1 cannot exchange process data with a device from network 2 via PROFINET. Only IP-based communication is possible in this case.

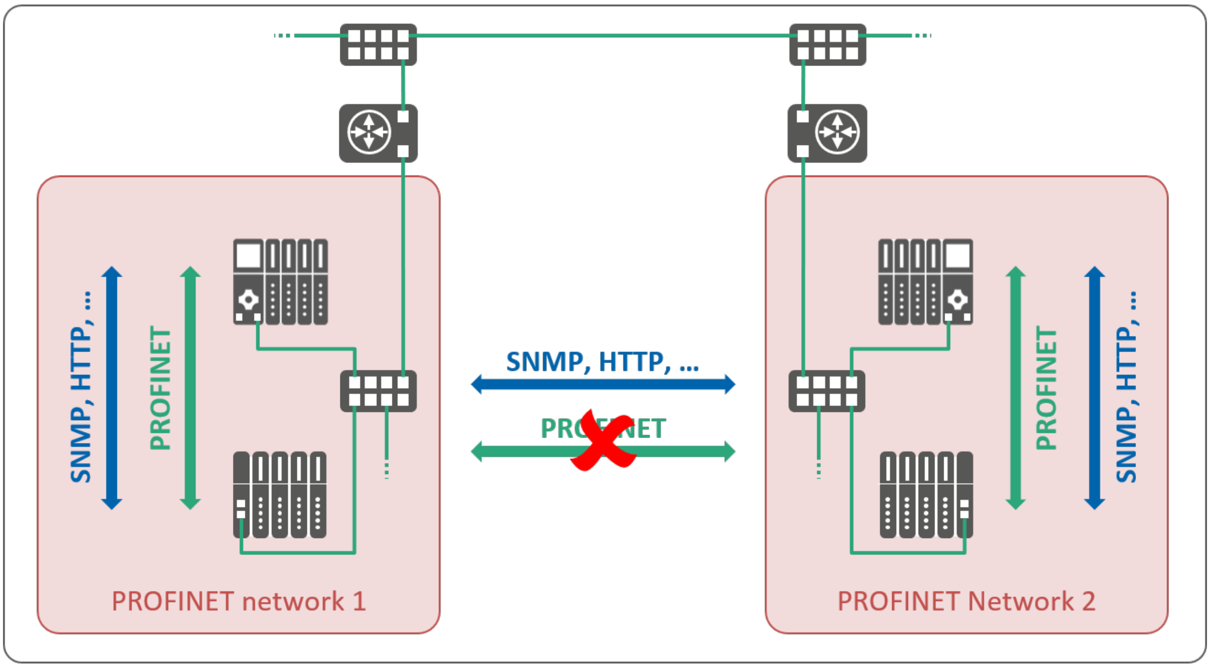


Figure 3-3:Using a router in PROFINET networks

Process data is communicated with each other within the functional groups that you have marked in the layout plan. Therefore, all devices in a functional group must be networked with each other using switches. Networking can take place using various topologies and transmission media, which are explained below.

3.2 Possible PROFINET Topologies

The following pages of this chapter will introduce the different basic PROFINET topologies.

Flexibility in network design and layout is a key feature of PROFINET. Since all standard Ethernet topologies are used, PROFINET supports an almost unlimited number of combination options.

Star topology

The star topology is suitable for areas with limited geographical extension. A star-topology is automatically created if several communication nodes are connected to a common switch.

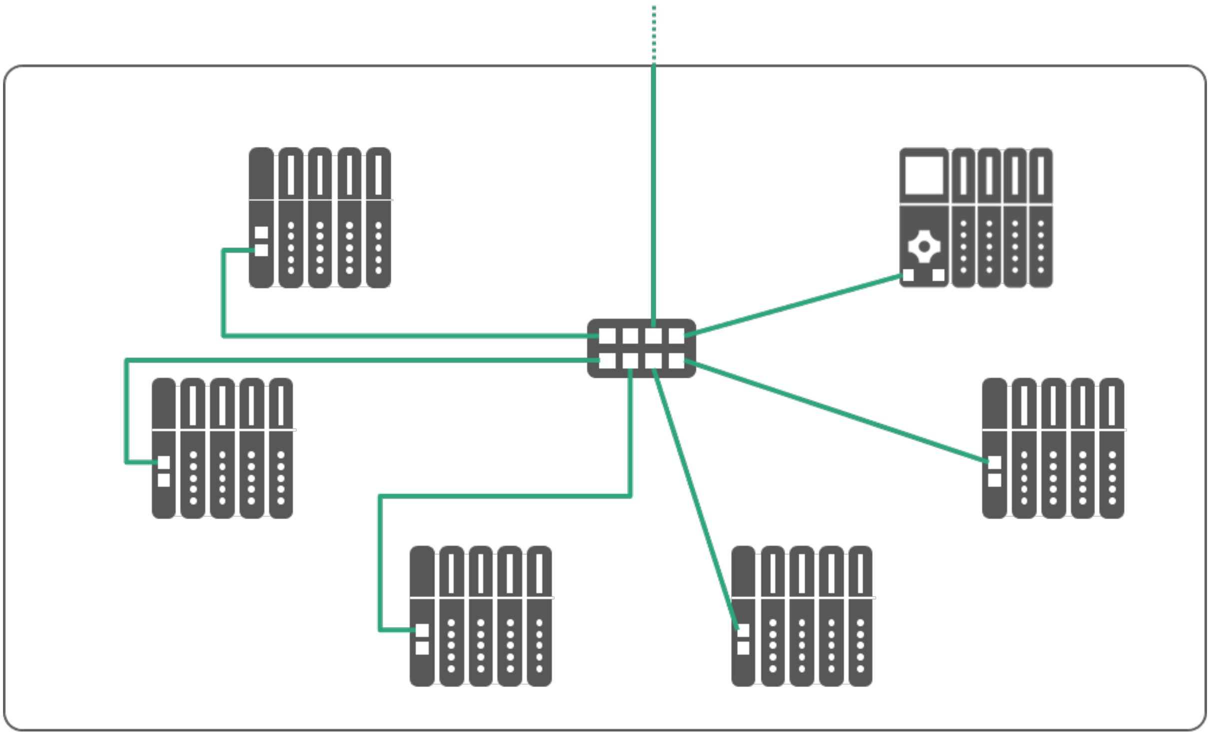


Figure 3-4: Star topology

If a single PROFINET node fails or is removed, the other PROFINET nodes will continue to operate. However, if the central switch fails, communication to all the connected nodes will be interrupted.

Tree topology

A tree topology is created by combining several star-shaped networks to one network. Plant parts forming a functional unit are combined to star points. These are inter-networked via neighboring switches.

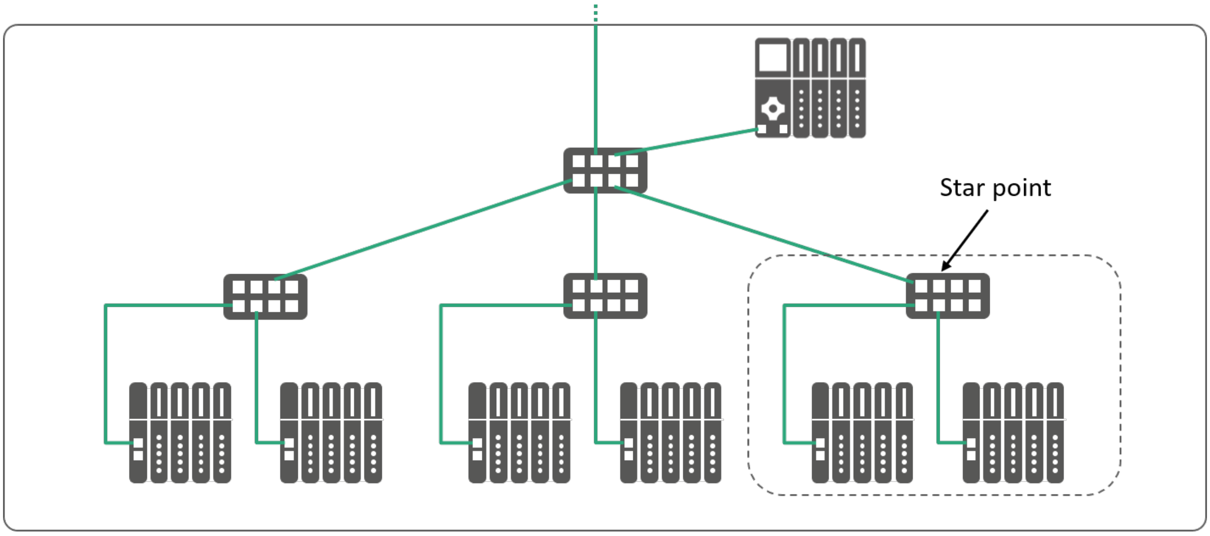


Figure 3-5: Tree topology

One switch operates as a signal distributor in the star point. Since the switch routes messages based on an address, only those messages will get to a neighboring distributor which are really required at this distributor.

The tree topology is a typical example for an automation plant being grouped into different manufacturing islands.

Line topology

The line is a well-known topology used in automation. It is used for applications in extensive automation plants such as conveyor belts, but also for small machine applications. PROFINET devices equipped with an integrated switch facilitate the realization of line topologies.

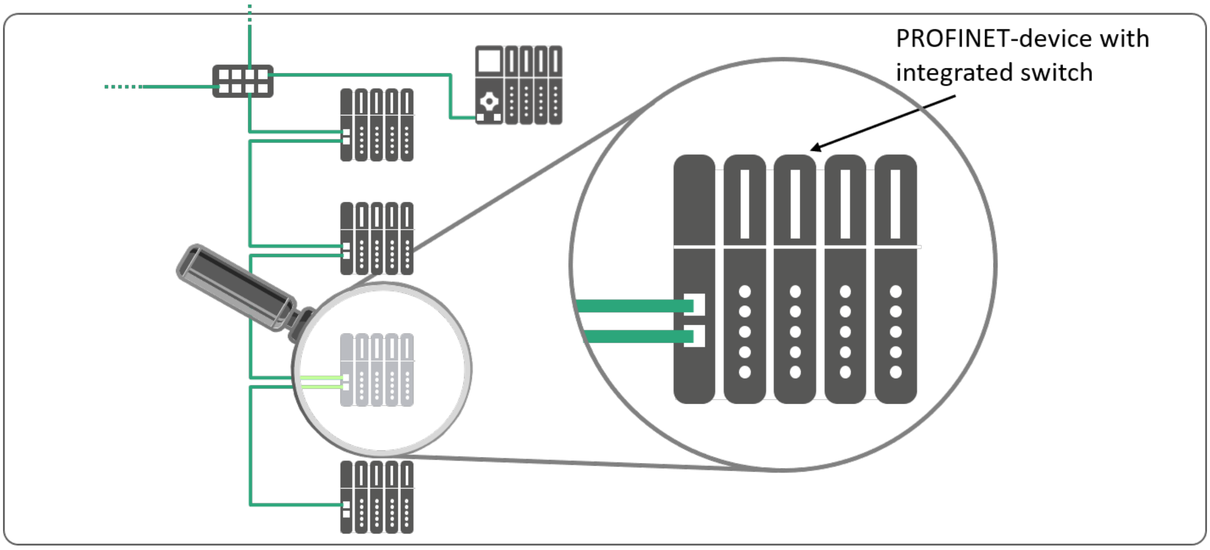


Figure 3-6: Line topology

The line is a well-known topology used in automation. It is used for applications in extensive automation plants such as conveyor belts, but also for small machine applications. PROFINET devices equipped with an integrated switch facilitate the realization of line topologies.

When using line topologies, bear in mind that in case of a line interruption (e.g. outage of a device), the devices located behind the failed device can no longer be contacted. This can be prevented by extending the line to a ring structure using a redundancy protocol.

Ring topology

The creation of a ring is not allowed in standard Ethernet. By using a redundancy protocol, rings are nevertheless possible with PROFINET.

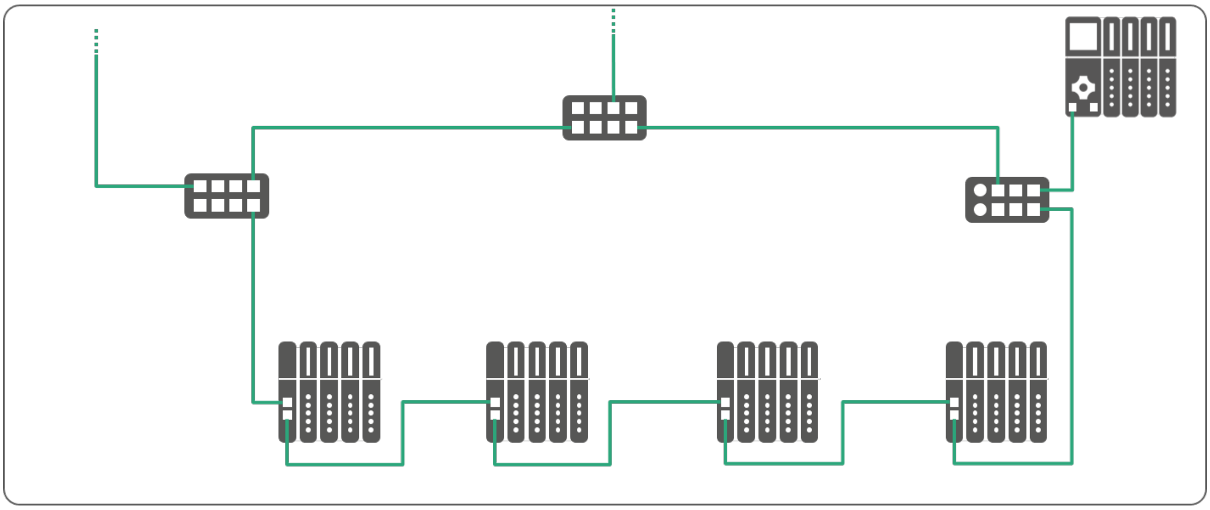


Figure 3-7: Ring topology

Using a ring increases the availability of the system. If a participant or a connection fails, the ring is split into a line. All nodes are still connected to each other.

A ring topology requires the use of a redundancy protocol.

Read chapter 4.2 and the PROFINET planning guideline Redundancy (Order No.: 8.131) if you want to use a ring topology.

3.3 Selection of the data rate

Different data rates can be used in a PROFINET network. Table 3-2 shows the data rates generally permitted for PROFINET in the various CCs. However, please note that most devices only implement a small part of the permitted data rates. The most frequently used data rates are 100 Mbit/s and 1 Gbit/s.

Table 3-2: Permitted data rates depending of the conformance class

Non-real-time channel	CC-A	CC-B	CC-C	CC-D
Permitted data rate	10 Mbit/s to 10 Gbit/s	10 Mbit/s to 10 Gbit/s	100 Mbit/s	10 Mbit/s to 1 Tbit/s

The 100 Mbit/s data rate is also known as “Fast Ethernet”. The data rates from 1 Gbit/s to 100 Gbit/s are referred to as “Gigabit Ethernet” in this document.

The selection of the data rate has an influence on:

- The devices that can be used: The devices must support the data rate.
- The performance: A higher data rate leads to more available bandwidth and less congestion and delays in the switches. In addition, the transfer of large amounts of data is completed more quickly.

Several different data rates can be used in a PROFINET network, this is referred to as **Mixed Link Speeds**. In this case, special requirements must be observed to avoid congestion at the boundary between two data rates.

Read chapter 7.4 if you want to use mixed link speeds. .

3.4 Primary infrastructure

Compared to cyclic real-time communication, data exchange in a PROFINET network mainly occurs between the controllers and the devices. As a result, PROFINET-certified switches should be used for the communication link with the major load.

Generally, a link can be established by using a line structure with arbitrary PROFINET devices and integrated switches. However, depending on the application, it is recommended to define a primary communication link to which sub networks or line topologies can be connected. This will also simplify later plant extensions.

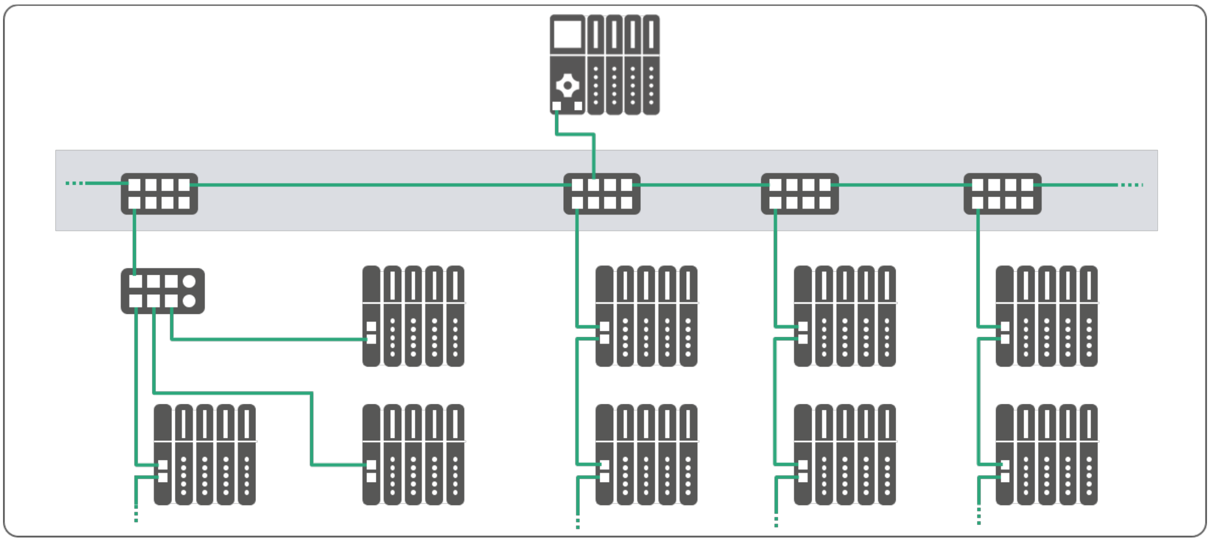


Figure 3-8: Topology example

Figure 3-8 shows an example of a primary communication link (grey box). This link can also be implemented as a redundant configuration, to increase the availability.

In a PROFINET network, it is possible to use Gigabit-Ethernet between the switches, even though the PROFINET devices are only designed for 100 Mbit/s. The Ethernet connection is made between the switches. To use 1 Gigabit-Ethernet, a CAT 6 cable must be used.

A primary communication link is particularly recommended if the network has many nodes. If possible, use PROFINET-certified managed switches for the primary communication link.

3.5 Applicable transmission media

Copper cables and optical fibers are available for a wired connection of network nodes. The cable used must meet the requirements of the planned automation project. For this purpose, cable manufacturers offer a range of PROFINET cables that are differentiated by their applications and special properties.

If wired connection is not possible, wireless transmission technologies such as WLAN, Bluetooth or 5G can be used. The use of wireless communication is only possible in CC-A and CC-D.

Wireless communication should only be used when necessary. Wireless communication has a number of disadvantages compared to wired communication.

The use of wireless communication requires special planning. Further information can be found in chapter 4.4.

The following chapters describe the main considerations when selecting the PROFINET copper and optical fiber cabling. Compared to copper cabling, the optical fiber cabling has additional typical parameters such as attenuation and used wavelength which primarily restrict the length of the transmission link. Additionally, the minimum distances between data cables and power cables must be observed when planning the correct installation (see chapter 3.5.3).

In the Annex to this document, in addition to an overview of typical cable properties you will find a description of the transmission media as well as their application ranges and versions.

When selecting the transmission medium, you should bear in mind the possible influences in the application area (e.g. chemical, electrical or mechanical).

A PROFINET connection between two devices is named “end-to-end link” if the two connectors at the end of the cable are considered. A channel is a connection that excludes the two connectors at the end of the cable.

At this the channel can consist of different transmission mediums like copper or fiber optical cables.

Some examples are provided in the annex to illustrate the selection of cabling components. Pre-assembled and field-assembled cables are also described.

The correct installation of the PROFINET cabling must be considered in the design. Make sure the allowed distance between power cables and data cables will not be undercut. For more information, please see the PROFINET Assembling Guideline Order No.: 8.072.

3.5.1 PROFINET copper cabling (4-core, 8 core)

A typical PROFINET copper cable is a 4-core, shielded copper cable (star quad). For high transmission rates (1000 Mbit/s) an 8-core cable is specified. The different types of cables vary in.

- the structure of the wires (solid core / stranded for fixed / flexible applications)
- and / or the jacket material and construction.

The cores are color-coded. In a 4-core cable, wire pair 1 is yellow and orange, wire pair 2 is white and blue. The cores in each pair are arranged to be diametrically opposite within the cable. 8-core PROFINET copper cables consist of 4 wire pairs, with green, blue, orange and brown wires and the corresponding white wire.

As in standard Ethernet applications, the maximum distance between the end points of communication is limited to 100 m when using copper cabling. This transmission link has been defined as PROFINET end-to-end link.

For automation plants you may only use PROFINET cables.

The corresponding manufacturer's declaration is available for PROFINET cables.

Application-neutral cabling (e.g. based on existing building cables) may only be used in network areas that correspond to Conformance Class A (e. g. to interconnect automation islands).

However, it is recommended to use PROFINET cabling for this application (e. g. in order to cover higher Conformance Class requirements).

The common installation of power cables and copper cables for communication is subject to regulations in order to minimize the electromagnetic influence of power cables on the communication lines. Optical fibers, however, are not subject to these electromagnetic influences.

Regulations for the common installation of power cables and PROFINET copper cables must be observed for the design of cable routing.

Follow the instructions provided in the PROFINET Installation Guideline Order No.: 8.072 and in chapter 3.5.3.

Cable types

PROFINET copper cables are categorized in different types which are mainly differentiated by the relevant applications:

Type A cables are designed for fixed installations. This cable type is not subject to any motion after being installed.

Type B cables are designed for flexible installations. This cable type allows for occasional motion or vibrations. When vibrations occur, use this type of cable because it is less susceptible to vibrations.

Type C cables are designed for special applications (e.g. for continuous movement of the cable after being installed). This includes e.g. applications such as trailing chains or festoons.

Type R cable is intended for robotic applications with combined torsional and bending loads.

Special properties of some copper cables, such as flexibility for use in trailing chains or construction using flame retardant materials, can reduce the maximum length of a copper cable to less than 100 m.

Observe the manufacturer data for cables and connectors.

In addition to the special properties of PROFINET copper cables, the Annex of this document provides detailed data concerning the individual cable types. Please check also [PCI2023] for further information about cabling and interconnection technology.

Types of PROFINET copper cables

A number of special cable types are available for PROFINET. The most commonly used PROFINET cable types as well as their applications are listed below:

- **PE cables:** PE cables are suitable for installation in areas where constant humidity must be expected.
- **Buried cables**

- **Flame retardant non-corrosive cables (FRNC cables):** Suitable for installation in areas where special fire protection regulations must be observed, e.g. halls with public access.
- **Trailing cable** for installation on moving machine parts.
- **Festoon cable**
- **Ship wiring cable (with approval for shipbuilding):** For installation on board ships and offshore units.

You should only use cables that have been specified as PROFINET cables by the manufacturer. Only such cables will ensure trouble-free operation of the network.

Observe the information material provided by the cable manufacturer.

You will find further information about the installation and grounding of copper cabling in the PROFINET Installation Guideline Order No.: 8.072.

Information on the installation and structure of the earthing and equipotential bonding in a PROFINET network can be found in the PROFINET Assembling Guideline Order No.: 8.072 and in the guideline Functional Bonding and Shielding of PROFIBUS and PROFINET, Order No.: 8.102.

3.5.2 Ethernet-APL Cables

Ethernet-APL defines a two-wire cable to connect sensors and actuators to PROFINET. The connection provides a data rate of10 Mbit/s and delivers energy to the field devices.

Please check the Ethernet-APL Engineering Guideline [APL2021] for further details on Ethernet-APL cabling.

3.5.3 Separation distances between cables

When laying PROFINET copper cables, observe the minimum required separation distances specified in Table 3-3. The values have been taken from the EN 50174-2 standard. The **minimum distance** A between power cable (s) and PROFINET cable is calculated by multiplying the minimum separation distance S to be taken from Table 3-3 by the factor for the power supply wiring P from Table 3-4. According to section 11.5.2 of the standard the recommended distance should be the double of the minimum distance.

Table 3-3: Minimum required separation distances for PROFINET cables according EN 50174-2:2018

	Conduits used for information technology cables and mains power cables		
Separation without electromagnetic barriers	**Open metallic conduits a**	**Perforated metallic conduits b, c**	**Solid metallic conduits d**
10 mm	8 mm	5 mm	0 mm

[a] Shielding effect (0 MHz to 100 MHz) equivalent to welded meshed steel basket with mesh size 50 mm × 100 mm. The same shielding effect can be achieved using steel cable trays (cable bundles, without cover) with a wall thickness of less than 1.0 mm and/or an evenly perforated surface of more than 20%.

[b] Shielding effect (0 MHz to 100 MHz) equivalent to a steel cable tray (cable bundles, without cover) with a minimum wall thickness of 1.0 mm and an evenly perforated surface of not more than 20%. This shielding effect can also be achieved with shielded power cables which do not provide the features specified in footnote d.

[c] The top surface of the installed cables must be at least 10 mm below the top surface of the barrier.

[d] Shielding effect (0 MHz to 100 MHz) equivalent to a steel installation pipe with a wall thickness of 1.5 mm. The specified separation distance must be taken into account in addition to the separation distance required by dividers/barriers.

Table 3-4: Factor *P* for power cabling

Type of electrical circuit [a, b, c]	Number of circuits	Factor for the power supply cabling P
20 A, 230 V, single-phase	1 to 3	0,2
	4 to 6	0,4
	7 to 9	0,6
	10 to 12	0,8
	13 to 15	1,0
	16 to 30	2
	31 to 45	3
	46 to 60	4
	61 to 75	6
	>75	6

[a] Three phase cable must be treated as 3 single-phase cables.

[b] More than 20 A must be treated as a multiple of 20 A.

[c] Power cables for lower AC or DC power must be treated based on their rating, i.e. H. a 100 A/50 V-DC cable is equivalent 5 of the 20-A-cables (P = 0,4).

As a next step we will look at a calculation example for the recommend distances.

Assumptions:

- Open metallic conduit: according Table 3-3 Minimum distance S = 8 mm
- 20 Power circuits with 20 A each according Table 3-4: Factor P = 2
- Recommended distance is twice the minimum distance according sections 11.5.2 of the standard.

This results in:

$$Recommended\_distance = 2 \cdot Minimum\_Distance$$

$$Minimum\_Distance = S \cdot P$$

$$Recommended\_distance = 2 \cdot S \cdot P$$

$$Recommended\_distance = 2 \cdot 8 \text{ mm} \cdot 2 = 32 \text{ mm}$$

Disclaimer:

The information regarding the minimum cable distances refers to installations in which PROFINET / PROFIBUS cables run parallel to unshielded power lines over longer distances. The values given here provide an orientation framework. For shorter parallel cable runs, e.g. inside machines, with shielded power cables or when using hybrid cables, it is permissible to stay below the minimum distances.

The application-specific reduced distances must be specified by the manufacturer of the system cables. This procedure is provided for in EN 50174-2.

For more details about minimum separation distances please refer to the IEC 61784-5-3 or EN 50174-2 standard, respectively.

3.5.4 PROFINET optical fiber cabling

In areas where electromagnetic interference may be present or significant earth potential differences are expected it is recommended that fiber optic (FO) connection is used. Fiber optic connection can completely remove problems caused by electromagnetic interference (EMI) and/or ground equalization currents flowing in copper cable screens.

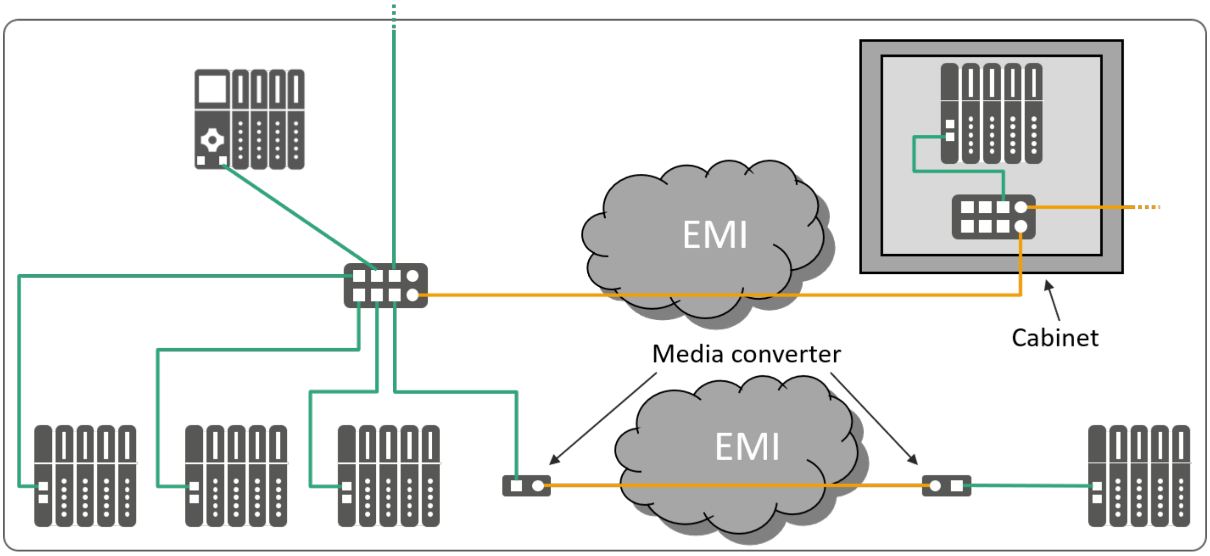


Figure 3-9: Application of optical fiber technology for EMI

Figure 3-9 shows the application of optical fiber technology for the connection of network nodes and / or switch cabinets in areas subject to electromagnetic interference. The benefits of optical fibers over copper cables are:

- Optical fiber cables usually cover longer distances as compared to copper cables.
- FO cables provide total electrical isolation between plant areas.
- FO cables are totally immune to electromagnetic interference (EMI).

A description of the different fiber types that can be used for the design of the PROFINET network is provided below

Optical fiber types

Four different fiber types can be employed when using optical fibers (FO) for PROFINET. The fiber types must be selected according to requirements given by the planned automation project.

The following fiber types are available:

- Plastic optical fiber (POF)
- Glass fiber (multi-mode)
- Glass fiber (single-mode)
- Glass fiber with plastic jacket (hard-cladded silica fiber (HCF) or plastic-cladded fiber (PCF))

The key parameters of optical fibers are listed below.

Specific attenuation of the fiber

The specific attenuation of the fiber depends on the operating wavelength and is indicated in dB/km. The maximum values for the different fiber types, based on IEC 61784-5-3, are shown in Table 3-5.

Table 3-5: Specific attenuation of fiber types

Fiber type	Maximum attenuation	Wavelength
POF	≤ 230 dB/km	650 nm (LED excitation)
Multi-mode	≤ 1.5 dB/km	1 300 nm
Single-mode	≤ 0.5 dB/km	1 310 nm
HCF / PCF	≤ 10 dB/km	650 nm

Maximum FO transmission path

The maximum FO cable length is limited due to the attenuation of the optical signal within the fiber. The optical wavelength that is used will also have an effect.

Table 3-6: Attainable transmission links of optical fiber types

Fiber type	**Core diameter**	**Sheath diameter**	**RT/IRT Operation**	**Transmission path (typ. values)**
POF	980 µm	1 000 µm	RT/IRT	up to 50 m
HCF / PCF	200 µm	230 µm	RT/IRT	up to 100 m
Multi-mode	50 µm or 62.5 µm	125 µm	IRT	100 Mbit/s: up to 2 000 m 1 Gbit/s: up to 2 000 m
			RT	100 Mbit/s: up to 5 000 m 1 Gbit/s: up to 2 000 m
Single-mode	9 µm to 10 µm	125 µm	IRT	100 Mbit/s: up to 4 000 m 1 Gbit/s: up to 4 000 m
			RT	100 Mbit/s: up to 26 km (200 km with Extreme Long Haul Transceiver) 1 Gbit/s: up to 40 km (120 km with Extreme Long Haul Transceiver)

The maximum transmission link is a criterion for the design of the optical fiber link. Please note that the information in Table 3-6 is for guidance only. The manufacturer's specifications are always decisive. The maximum PROFINET end-to-end link attenuation of optical fiber links applies as well.

Maximum permissible PROFINET end-to-end link attenuation

Table 3-7 summarizes the maximum admissible attenuation values, based on the IEC 61784-5-3 and IEC 61300-3-4 standard for optical transmission links.

Table 3-7: Maximum permissible PROFINET end-to-end link attenuation

Fiber type	Maximum PROFINET end-to-end link attenuation	Wavelength
POF	12.5 dB	650 nm (LED excitation)
Multi-mode optical fiber	62.5/125 µm: 11.3 dB 50/125 µm: 6.3 dB	1 300 nm
Single-mode optical fiber	10.3 dB	1 310 nm
HCF / PCF	4.75 dB	650 nm

When using optical fiber links, make sure that the maximum permissible PROFINET end-to-end link attenuation are observed as taken from IEC 61300-3-4.

These limit values already include attenuation reserves.

Additional junctions in optical cables

Additional junctions in the link (splices or plug connections) cause an additional attenuation of the transmitted optical signal. Plastic optical fiber (POF) and hard-cladded silica are often assembled in the field using simple tools. This practice has been accounted for by means of a higher attenuation for the junction. Typical values are shown in Table 3-8.

Table 3-8: Attenuation of splices and connector pairs

Fiber type ➔ Connection 🡻	Optical fiber	Plastic optical fiber / Hard-cladded silica / PCF
Per thermal splice connection	0.3 dB	Not possible
Per pair of connectors	0.75 dB	1.5 dB

Use of different fiver types

The use of different fiber types in one plant often produces costs due to additional materials or tools being required. Although it is possible to use various types of fiber in the same plant, this should only be done in exceptional cases.

Table 3-9: Use of different fiber types

The use of different types of fiber can be justified:	The use of different types of fiber should be avoided:
If, within one plant, numerous links can be realized using plastic fiber and only one link, due to its length, requires the use of glass fiber. In this case the overall costs would be higher if all links were realized using glass fiber.	If most of the links have to be configured as glass fiber and only a few links can be realized using plastic fiber. This could cause higher costs due to the additional treatment of the plastic fiber required (tools, material).

Attenuation of an optical fiber link

The secure operation of an optical fiber transmission system requires that optical signals reaching the receiver have sufficient signal strength. The PROFINET end-to-end link attenuation must not exceed the maximum permissible attenuation value.

The following parameters could have an influence:

- Specific attenuation of the fiber
- Additional junctions in optical cables

In order to achieve reliable communication over optical fibers, the following condition should be checked.

Transmit power - total attenuation ≥ receiver sensitivity

For short transmission links it may be necessary to check the max. permissible receiver sensitivity. If required, reduce the transmit power of the transmitter.

For the design of an optical fiber link, the specified limit values indicate the maximum transmission link length. You should also use a simple attenuation calculation to check the link.

You will find examples for the selection of cabling components for optical fiber links in the Annex of this document. In addition, you will find an example for the determination of the attenuation balance.

However, bear in mind that this is only a verification which by no means replaces potential acceptance measurements.

3.5.5 Selection of required connectors

PROFINET cables are equipped with connectors at both ends. The combination of connectors at the cable and at the socket is considered as a connector pair. The annex contains a description of the connectors currently used for PROFINET (see chapter 10.7). Please check also [PCI2023] for further information about cabling and interconnection technology.

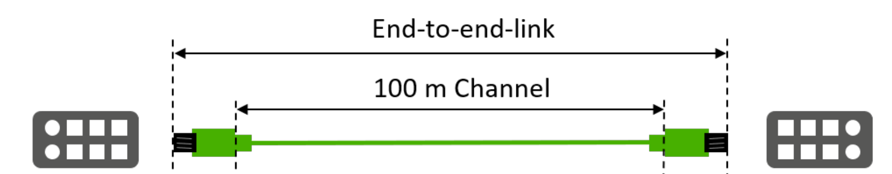
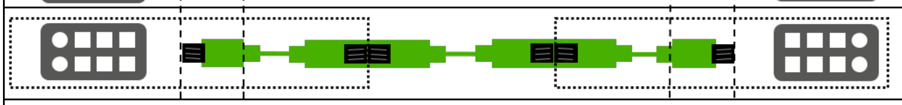
The connectors at both ends of the cable must also be included. Each of them forms a pair with the socket of the terminal device.

Detachable connections including bulkhead connectors and transition points are also part of the cable/connector system. The Annex provides a short description of such items.

Connectors of copper cabling

For the design of your PROFINET network you should bear in mind that the number of detachable links within an end-to-end link is limited.

Table 3-10: Transmission link length and connector pairs (copper)

Cabling example of two network components	Number of Connector pairs	Maximum distance
	2	100 m
	3	100 m
	4	100 m
IP20 environment · Connector · Coupler		

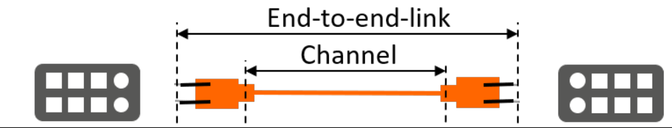
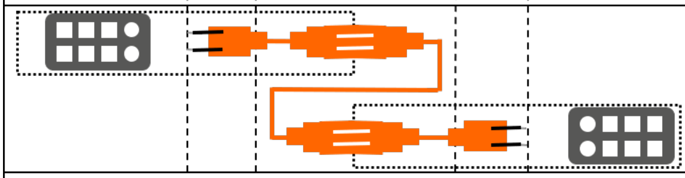
If the specified cables are used in combination with the specified connectors, a maximum cable length of 100 m can be achieved when using up to four connector pairs. You should try to use as few plug connections are possible since each plug connection represents a potential disturbance source.

In case more than four connector pairs are required for an application, you have to make sure that the attenuation values for the entire link are observed. (channel class-D values)

Connectors for optical fiber links

The maximum number of detachable connections for a channel based on optical fiber is limited, similar to a channel based on copper cabling.

Table 3-11: Transmission link length and connector pairs (FO)

Transmission example of two network components	Number of Connector pairs	Maximum distance		
		POF	HCF/ PCF	Optical fiber MM / SM
 End-to-end-link, Channel	2	50 m	100 m	2.000 m / 14.000 m
	3	42,5 m	100 m	2.000 m / 14.000 m
	4	37 m	100 m	2.000 m / 14.000 m
IP 20 environment	Connector	Coupler		

The comparably high attenuation of POF fibers, combined with the simultaneous use of several connectors, has a large impact on the maximum length of a POF connection. This should be considered in case you use POF fibers in a network.

3.6 Definition of the topology in functional groups

This chapter starts with networking. The topology is defined within each functional group to enable PROFINET communication. The topology of the network is primarily determined by criteria such as:

- Spatial arrangement of the components
- Distances to be bridged
- EMC requirements
- Requirements for electrical potential separation
- Requirements for the use of certain Conformance Classes
- Requirements for increased availability
- Consideration of network loads

Choosing the right topology is important for the further planning of the PROFINET automation plant. The topology may need to be adapted in a later planning step.

Additional switches may be required to create the topology.

Go through the following process for each functional group:

Step 1:

Check whether it is necessary to consider the performance of the network. Consideration of the performance is necessary if one of the following cases applies to the network:

- Number of nodes > 64
- Different data rates
- Devices with high data volume (e.g. camera)
- Use of wireless communication

In this case, read chapter 7 and follow the instructions given there during planning to ensure sufficient performance.

Step 2:

Plan the topology for CC-C or CC-D devices. These must form a consistent subnetwork that is not interrupted by devices of other CCs. If you are planning switches, these must also comply with CC-C or CC-D.

Step 3:

Plan the topology for the remaining devices (CC-A and CC-B) in the functional group. You can use the switches placed in step 2 for the connection or plan additional switches.

Step 4:

Specify the transmission medium for each connection. In this step, also define the exact route of the PROFINET cables. Note the length of the cable, the EMC requirements and the cable spacing.

Check for each network participant whether it supports the selected transmission medium. If necessary, install additional media converters in the transmission path.

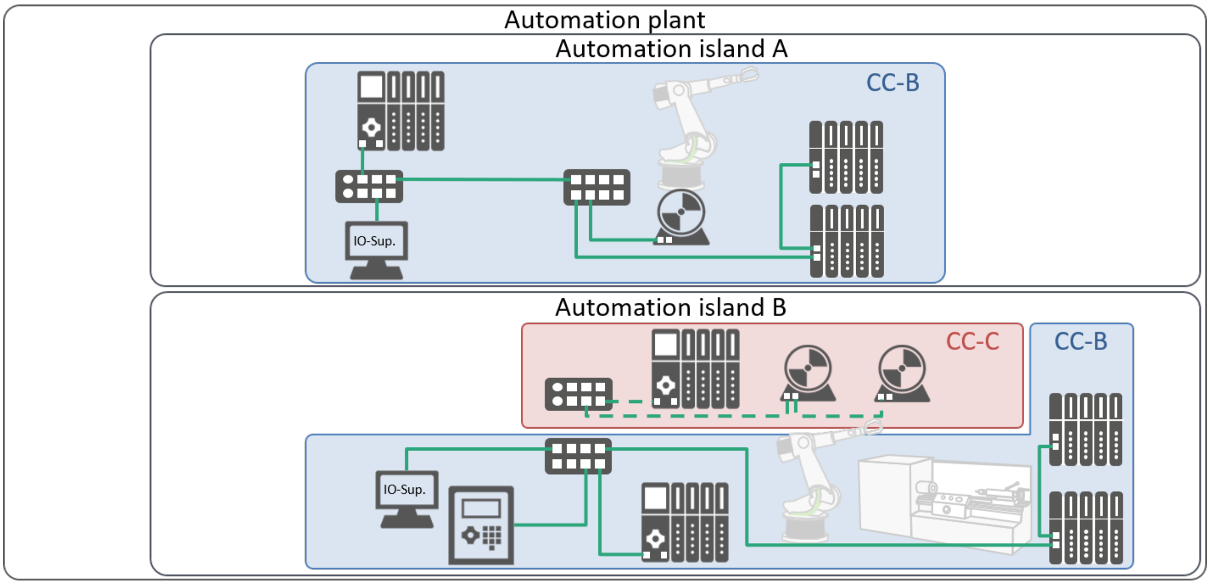


Figure 3-10: Plant example with interconnected functional units

Figure 3-10 shows the plant example after the four steps have been carried out for all functional groups. The components of the CC-C were connected to each other via a switch in tree topology. The switch fulfills the CC-C to enable IRT communication.

The CC-B components were connected partly with a star topology and partly with a line topology. The necessary CC-B switches were included in the planning.

At this point in the planning, PROFINET communication within the functional groups has been enabled.

3.7 Solving further communication tasks

The topology within the functional groups was defined in the previous chapter. In this chapter, the functional groups are connected to each other or to other networks in order to solve further communication tasks. This planning takes place in several steps:

1. integration of the plant into the network architecture
2. determination of the communication tasks and their requirements
3. information about different solution variants and their advantages and disadvantages
4. selection of solutions and definition of the topology

3.7.1 Integration into the network architecture

A classification of the PROFINET system in the company's network architecture helps you to identify the necessary communication tasks. Figure 3-11 shows an exemplary network architecture.

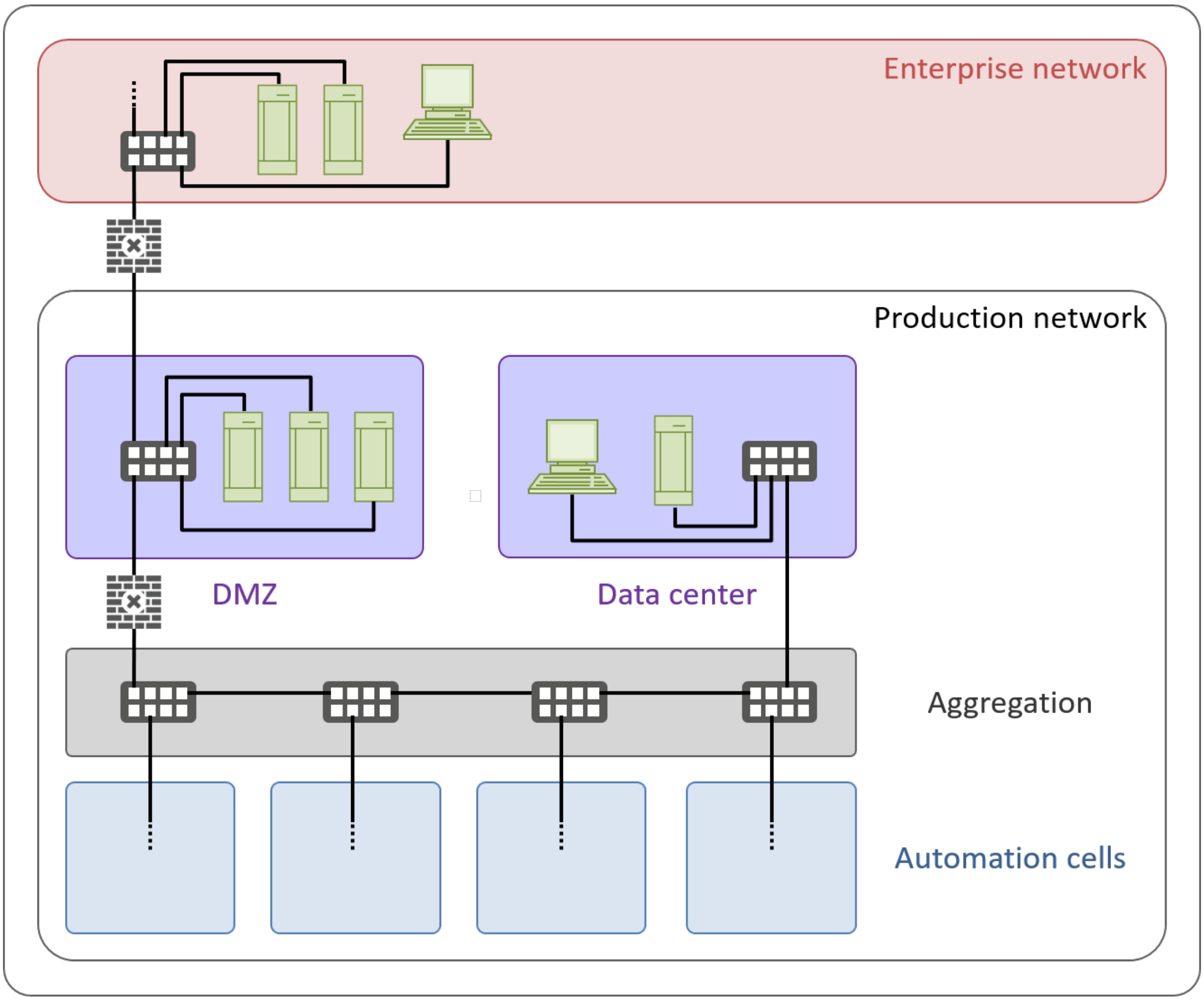


Figure 3-11: An example of a typical network architecture

The exemplary network architecture in Figure 3-11 contains various components, which are now described.

Enterprise network: The enterprise network contains the office-related devices and services, such as PCs, printers, network drives and an Internet connection.

Production network: The production network contains the devices and services required for the automation system to function. A firewall between the production network and the company network prevents the two networks from negatively influencing each other and ensures security.

Production network - Automation cells: The production network contains several automation cells. Each automation cell contains a PROFINET system with controllers, devices and other devices. An automation cell can contain one or more controllers. Within an automation cell, all devices are directly connected to each other via switches. This means that process data can be transferred within each automation cell using PROFINET.

Production network - Aggregation: The aggregation layer is used to connect the automation cells to the rest of the network. The connection can be made in various ways, which are explained later in the chapter. Communication in the aggregation is carried out with IP-based protocols and not with PROFINET.

Production network - Demilitarized zone (DMZ): The DMZ represents a buffer zone between the production network and the corporate network. Devices from the corporate network cannot access the production network directly, only the DMZ. Typical services in the DMZ are: Entry point for remote maintenance, update server or Active Directory.

Production network - Data center: In contrast to the DMZ, the data center contains services that do not require access from the corporate network. Typical services in the data center are PC with engineering tool, process control system or databases.

Different network architectures and different positioning of the services in the architecture are possible. The planning guideline can only provide a short introduction to planning the network architecture. In addition to the solutions shown, other solutions are possible that offer other advantages and disadvantages.

Now categorize your automation task in the network architecture available to you. For example, answer the following questions:

- Is there already existing network architecture? If so, how is it structured?
- Is the automation task related to one automation cell or several?
- Is communication necessary between a device in the automation cell and a service in the DMZ or data center?
- Is communication necessary between two devices from different automation cells?
- Are services from the DMZ or the data center required? If yes, are these services already available? What requirements do these services place on communication with the automation cells?

This classification serves as a guide. It is often not yet possible to answer the questions clearly at this point in the planning. For example, each functional group could become a separate automation cell, or several functional groups could be combined into one automation cell.

3.7.2 Specification of further communication tasks

Now determine communication tasks that exist beyond the boundaries of the functional groups. Take into account not only the PROFINET devices, but also other network nodes in the PROFINET network. Examples of such communication tasks are:

- Communication with an existing and subordinate field bus or sensor/actuator bus
- Communication between two controllers.
- Communication between a controller and a device from another functional group.
- Communication between a controller and a service in the data center or DMZ.
- Communication between a device and a server or the cloud.

Determine which requirements apply to the existing communication tasks. Answer the following questions, for example:

- Do real-time requirements exist?
- Which network load is generated by the communication?
- Is there an increased requirement for the availability of the communication?
- Should the communication occur with functional safety?

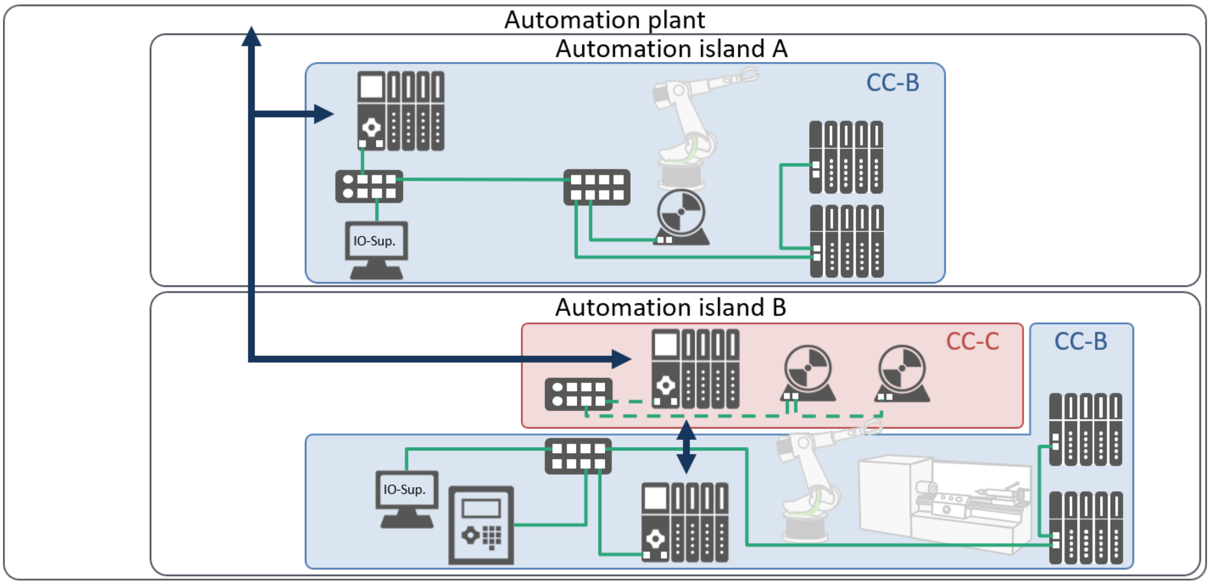


Figure 3-12: Plant example with additional communication tasks

Figure 3-12 shows the other communication tasks in the plant example. The communication tasks are marked with arrows.

In island B, communication between the two controllers is required. The analysis in the example has shown that there are real-time requirements for this communication.

Both controllers from island B must communicate with the controller in island A. There are no real-time requirements.

All three controllers should be connected to a higher-level process control system. This is indicated by the arrow pointing upwards.

3.7.3 The possible solutions for the other communication tasks

This chapter contains information about the various solutions for the other communication tasks.

Connection of fieldbus or sensor/actuator bus

It can happen that subordinate bus systems are connected to PROFINET networks. This usually concerns an existing field bus or sensor/actuator bus. In both cases, the connection to the PROFINET network is made via a gateway. A gateway has an interface for PROFINET and an interface for the bus. In relation to the PROFINET network, the gateway behaves as a PROFINET device. Figure 3-13 shows the use of a gateway in an example system.

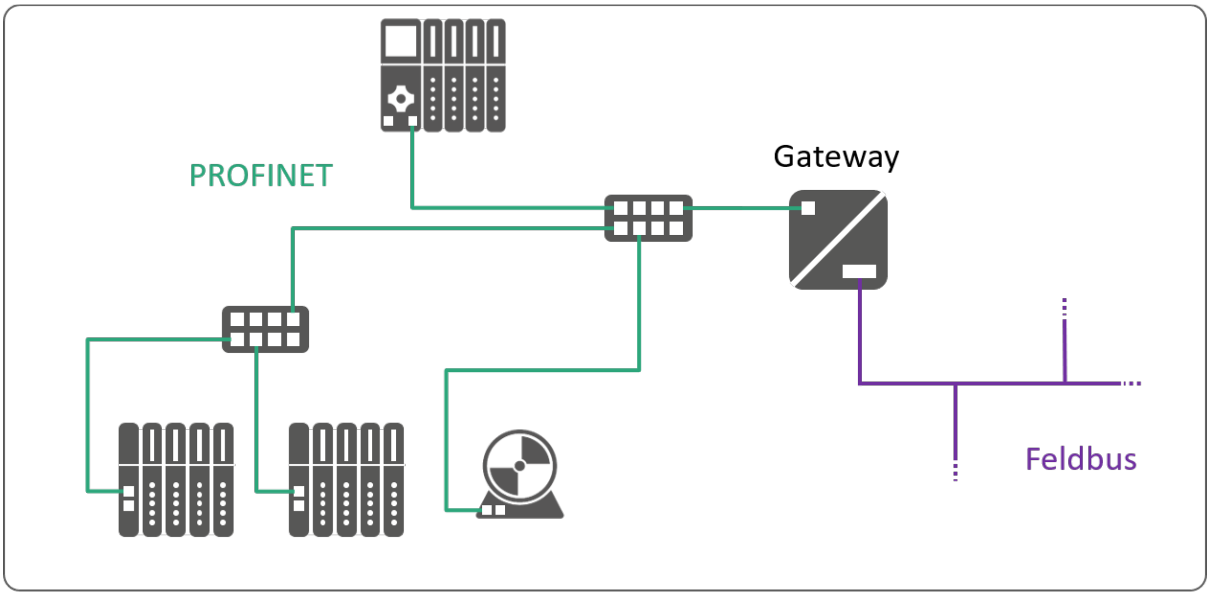


Figure 3-13: Use of a gateway to connect a fieldbus

Direct connection of several functional groups

Functional groups can be connected directly to each other. Together, they then form an automation cell with several controllers.

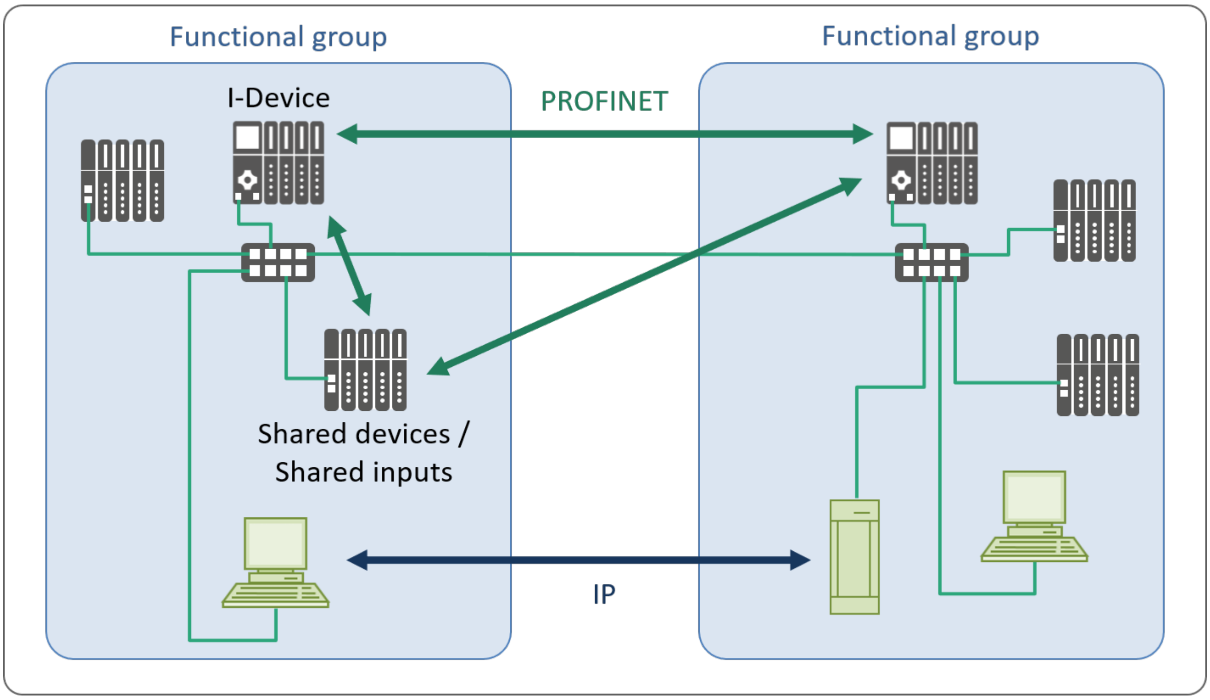


Figure 3-14: Direct connection of several functional groups

Figure 3-14 shows an example in which two functional groups are directly connected to each other. The connection can be used for PROFINET communication, for example. PROFINET defines the I-Device function for communication between controllers and the Shared Devices and Shared Inputs functions for multiple access to devices. Further information on these functions can be found in chapter 4.3.

IP-based communication (e.g. MQTT, OPC UA server client, ...) is also possible in such a network. This applies both to the PROFINET nodes and to other devices in the network.

Functions such as I-Device, Shared Devices and Shared Inputs are optional functions. They are not supported by all devices. Please bear this in mind when selecting a device.

Whether a combination of several functional groups makes sense is determined by the spatial proximity, the number of nodes and the performance of the network, as well as the advantages and disadvantages listed in Table 3-12

Table 3-12: Advantages and disadvantages of the direct connection of several functional groups

Advantages	**Disadvantages**
Both PROFINET communication and IP-based communication are possible between the functional groups. Both real-time communication and communication with functional safety via PROFIsafe are possible. Only one connection to the aggregation layer is necessary. Only a few additional components are required.	The network load in the automation cell increases as the number of nodes rises.

There is no fixed limit for the maximum number of nodes in an automation cell. The maximum number is determined by the data rate used, the topology, the communication and the time requirements. Please note the information on network performance in chapter 7 if the automation cell has a large number of nodes.

Connection of several functional groups with PN/PN couplers

Two functional groups can be connected to each other via a PN/PN coupler. Figure 3-15 shows the use of this solution.

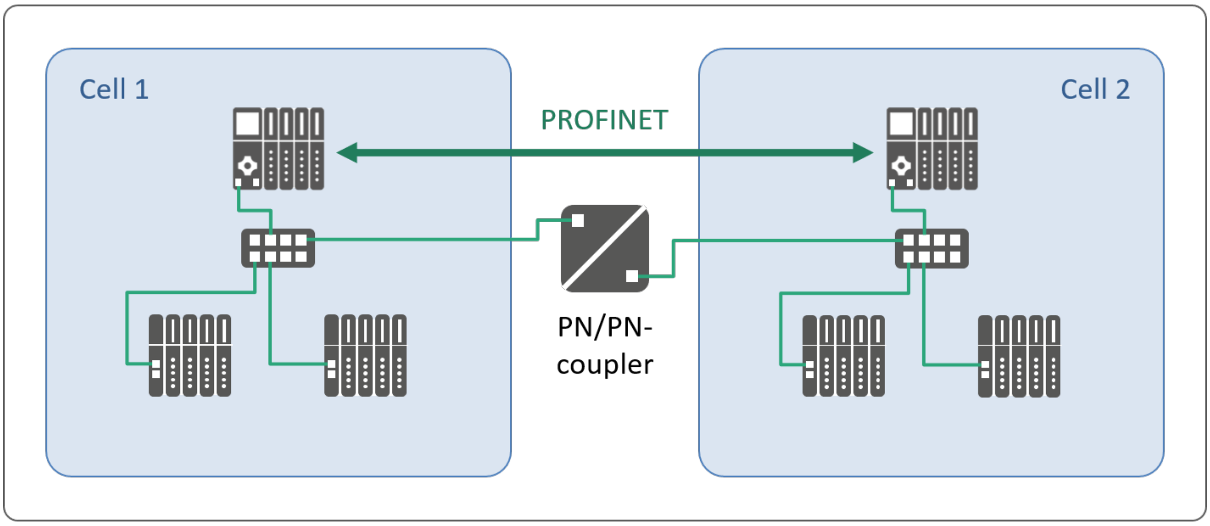


Figure 3-15: Connection of two functional units with PN/PN coupler

The PN/PN coupler appears in both networks as a PROFINET device. Input data received on one side is made available as output data on the other side. This enables communication between the two controllers. Table 3-13 shows the advantages and disadvantages of this solution.

Table 3-13:Advantages and disadvantages of connecting several functional groups with PN/PN couplers

Advantages	**Disadvantages**
PROFINET communication between the functional groups is enabled. Both real-time communication and communication with functional safety via PROFIsafe are possible if the PN/PN coupler supports this. The solution works with any controller.	P-based communication via the PN/PN coupler is not possible. Each cell requires a connection to the aggregation layer. If there are more than two functional groups, the number of PN/PN couplers required increases significantly. Four groups require six PN/PN couplers and five groups already require ten PN/PN couplers.

Connecting devices via the second Ethernet interface

If devices have several Ethernet interfaces, these can be used to generate connections.

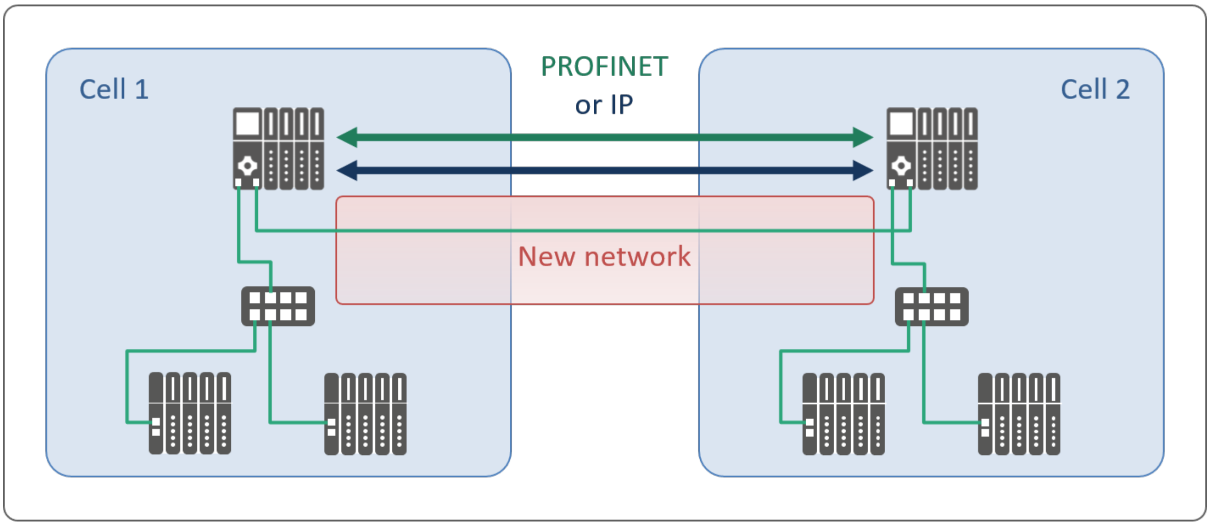


Figure 3-16: Connection of two controllers via the second Ethernet interface

Figure 3-16 shows an example application in which two controllers are directly connected to each other via their second interface. This creates a third network that only has two nodes. The controllers can communicate with each other without restriction, both via PROFINET and IP-based. However, they cannot communicate with the other nodes in the other network.

Table 3-14: Advantages and disadvantages of connecting multiple devices via the second interface

Advantages	Disadvantages
Both PROFINET communication and IP-based communication are possible. Both real-time communication and communication with functional safety via PROFIsafe are possible. The network load and communication in the functional groups are not affected.	Communication can only take place with the devices that are directly connected to each other via their second interface. Each cell requires a connection to the aggregation layer. Not all devices have more than one Ethernet interface. If a second interface is available, it is not always PROFINET-capable.

Connection to the aggregation layer with router

The automation cell can be connected to the aggregation layer by using a router. The router separates a network into several sub-networks and also handles the forwarding of authorized data to the connected sub-networks.

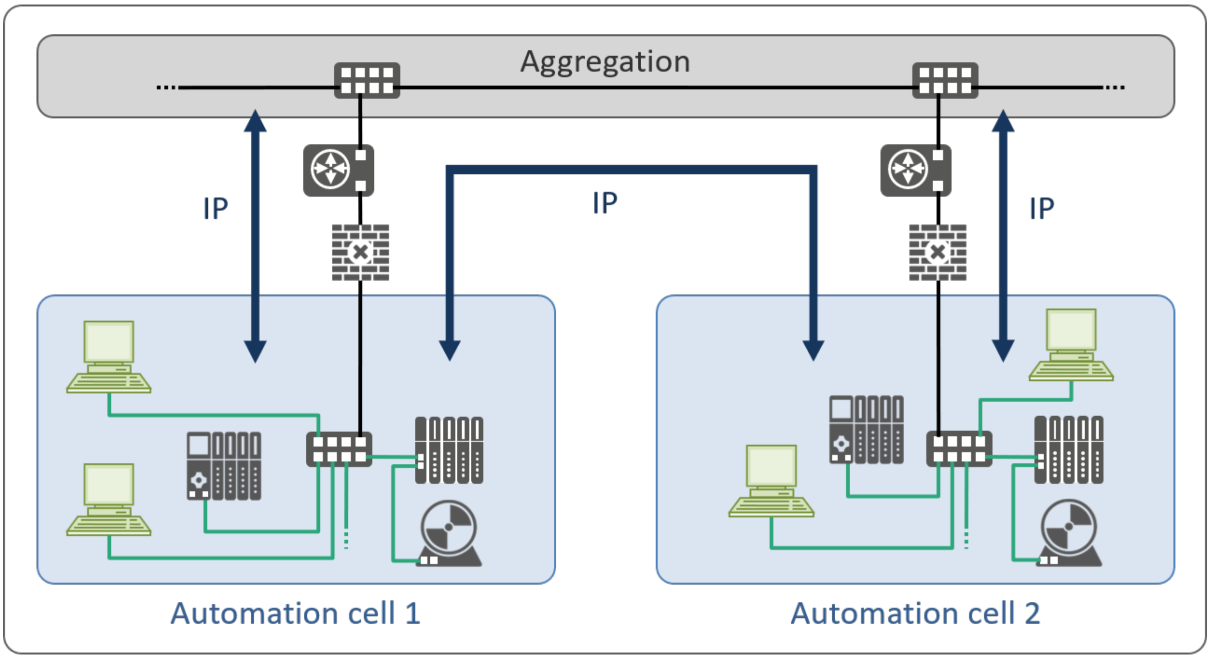


Figure 3-17: Connection to the aggregation layer with router

Figure 3-17 shows the use of routers using an example. Two cells are connected to the aggregation with routers. IP-based communication between the cells and with higher-level networks is possible.

Table 3-15: Advantages and disadvantages of connecting to aggregation with routers

Advantages	Disadvantages
All network devices in the automation cell can be reached from the higher-level network with IP-based communication. All network nodes from different automation cells can communicate with each other using IP-based communication.	From a security point of view, it can be a disadvantage if all network nodes are accessible. The transmission of process data across the router is not possible with PROFINET.

Connection of separate devices to the aggregation layer

It may make sense to connect individual devices from the automation cell to the aggregation layer via a second interface. With this solution, the other nodes in the automation cell cannot be reached from the higher-level network.

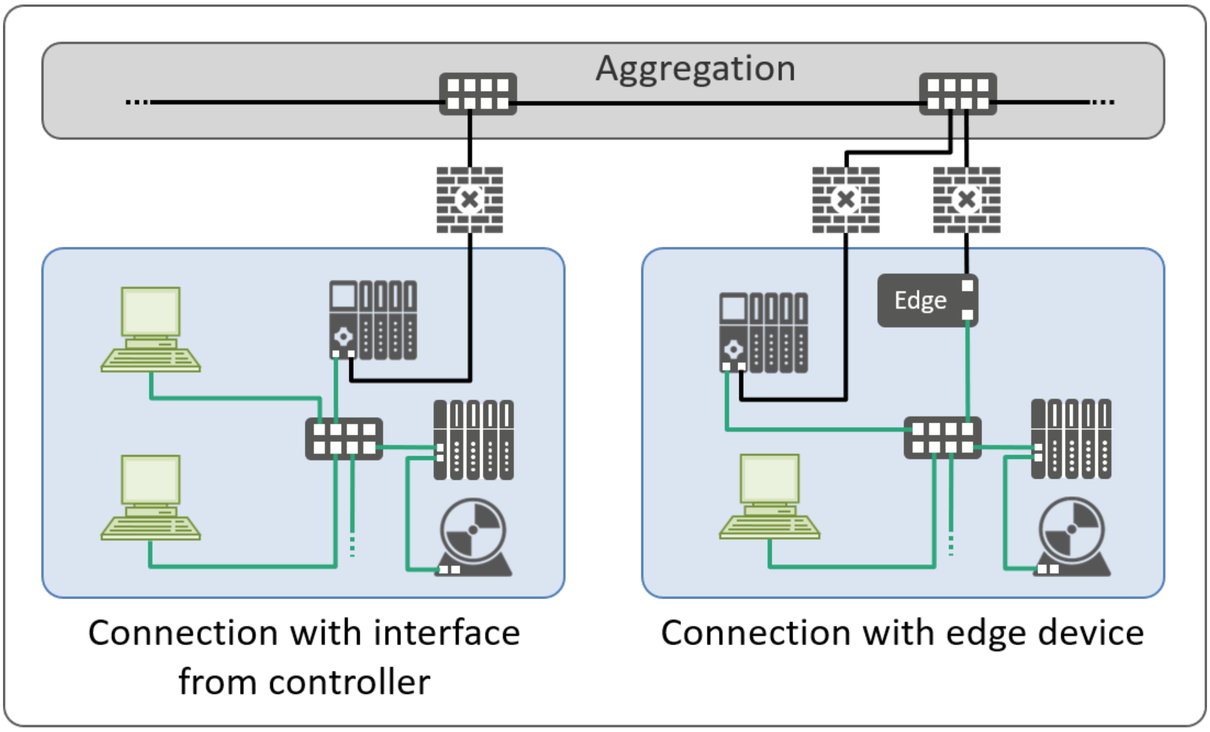


Figure 3-18: Examples for the connection of separate devices

Figure 3-18 shows two examples in which separate devices are connected to the aggregation. The controller is connected in both cells. This makes sense as the controller has the relevant process data. An edge device is also used in the cell on the right. The edge device collects process data and performs data pre-processing. This reduces the amount of data that is sent to the higher-level network.

Table 3-16: Advantages and disadvantages of connecting individual devices to the aggregation

Advantages	Disadvantages
From a security point of view, it can be an advantage if not all network nodes can be reached.	The other network nodes from the automation cell cannot be reached from the higher-level network.

In this chapter, various solutions were shown to enable communication across the boundaries of the functional groups. Please also note the following information:

Real-time requirements and communication with functional safety through PROFIsafe require special attention during planning if they take place across devices such as routers or firewalls.

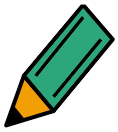
A firewall should be used when connecting to higher-level networks. Connection via a firewall protects against unauthorized access to your system from outside. In which cases the use of a firewall is necessary depends on the precise network architecture and the security concept.

When connecting your PROFINET solution to higher-level networks, follow the instructions in the PROFINET Security Guideline (Order No.: 7.002).

Only connect automation systems to the enterprise network and configure the router or firewall in consultation with the enterprise IT department.

3.7.4 Definition of the further topology

Decide now on solutions to solve the communication tasks. Define the network topology and plan the required components. Check which functions your devices require. Make sure that your selected devices support the necessary functions.



Document which communication tasks are present and how they are solved. Also document the extended topology of the network.

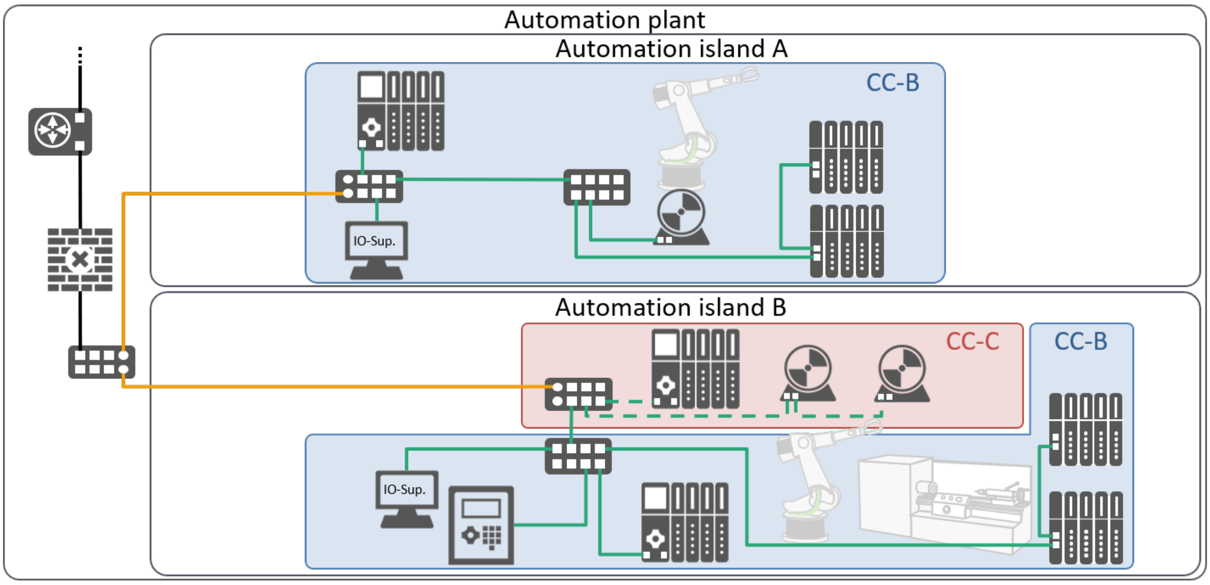


Figure 3-19: Plant example with complete topology

Figure 3-19 shows the system example after connecting to other networks.

The communication task between the controllers is solved by directly connecting the functional groups and using I-Device. The result is a common automation cell. The direct connection between islands A and B is realized with fiber optic cables, as the cable length is greater than 100 m.

The connection to the process control system requires a connection to the higher-level network. This is realized by a router with firewall.

In addition to the spatial view of the system in the site plan, it can also be useful at this point to highlight the network technology of the system in a plan. Figure 3-20 shows the same system example from the perspective of network technology and without spatial assignment.

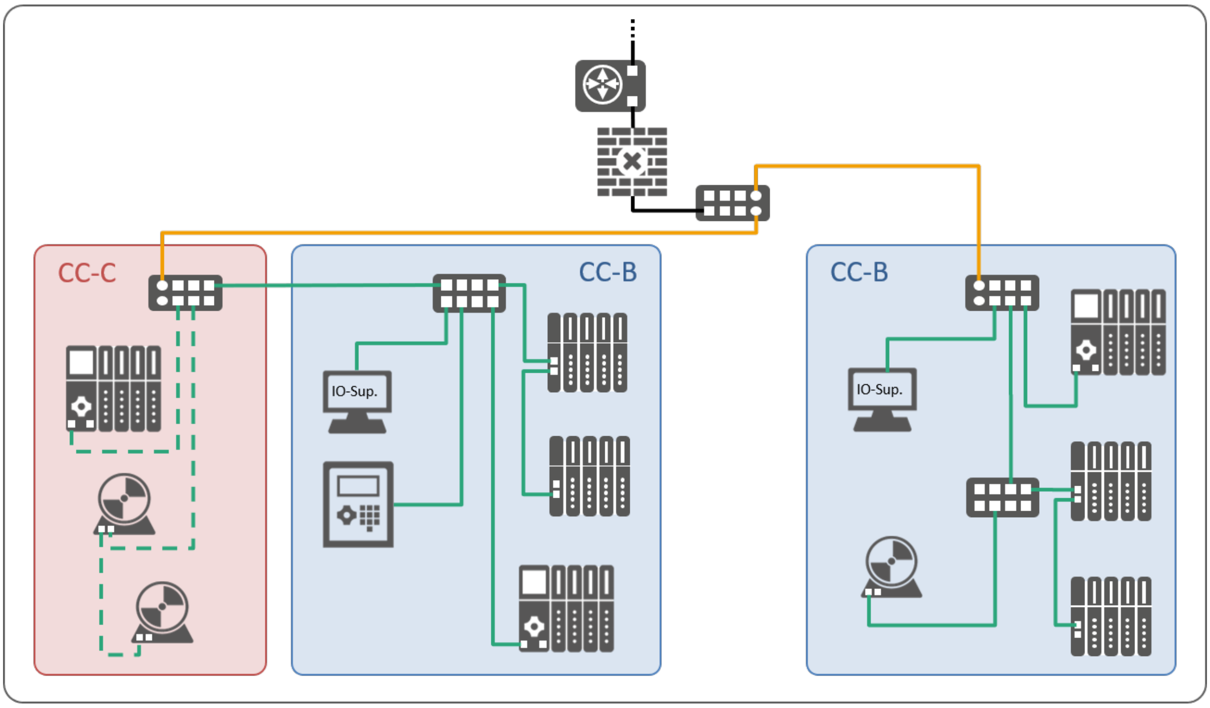


Figure 3-20: The plant example from network perspective

3.8 Topology check

After defining the topology and the transmission media deployed for the individual links you need to check whether the selected PROFINET devices support the corresponding chosen media.

Where possible, select devices that support the required transmission media. Where this is not possible, additional media converters or switches with support for different media may be required.

Bear in mind that the installation of a switch or media converter requires additional space.

3.9 Documentation of topology

To conclude the definition of the network topology, document all information about the selection of:

- Switches
- Topology
- Transmission media
- Connectors
- Data rates
- Further network components

If necessary, document changes to the device selection and check whether the network topology needs to be adjusted again.

The topics covered in the following chapters, i.e. consideration of network performance and integration of additional network nodes, could lead to an adjustment of the network topology.

4 Planning of additional functions

Many functions can be added to PROFINET automation plants. These special aspects of planning are described below. This chapter provides information about:

- Time synchronization
- Increased availability
- Networks with multiple controllers
- Wireless transmission technology
- Power over Ethernet (PoE)
- Fast Startup (FSU)
- Utilization of existing cable infrastructure
- Planning access points for network diagnostics
- Determination of firmware revision levels and asset management

The special design aspects may require an adjustment of decisions already taken for the device selection and design of topology.

4.1 Time synchronization

This chapter describes the synchronization of times in PROFINET networks. The following questions are answered in this chapter:

- When is time synchronization useful and when is it necessary?
- Which times are available?
- How is time synchronization achieved?
- What needs to be considered during planning?

The details of PROFINET time synchronization are not described here. Further information can be found in the PROFINET Guideline Time Synchronization (Order No.: 7.232).

PROFINET differentiates between two types of times:

- **Working Clock**: A relative time is used. Synchronization only takes place within the local network. The time source is usually the controller.
- **Global clock**: The absolute time is received by a time server, by satellite or by radio. The devices in the network are synchronized with this.

These times can be synchronized using various protocols:

- **NTP** [RFC_5905] is commonly used in the office sector and achieves an accuracy of around 1 s.
- **gPTP** [IEEE802.1AS] is used for time synchronization in PROFINET and achieves the following accuracies:
  - Working Clock: **1 µs**
  - Global Clock: **1 ms**

Planning the working clock

The working clock is used for the clock-synchronous application, among other things. The working clock has already been considered in the planning process by selecting the appropriate Conformance Class in section 2.3.2 and planning the topology in section 3.6.

Please note that the maximum line depth between the time source and the devices to be synchronized is 64.

Applications of the Global Clock

The Global Clock is used to synchronize the PROFINET devices with the absolute time. Occurring events can be provided with a globally valid time stamp and saved. This enables the following applications, among others:

- **Sequence of Events**: After failures or accidents, the cause of the malfunction should be determined. This is only possible if the sequence of events can be determined retrospectively.
- **Security Event Logging**: When logging of security-related events is planned, the use of time stamps is useful.
- **Data analysis**: Process data can be collected to be analyzed for various purposes. Accurate time stamps are necessary to perform the analysis.

In principle, these applications are also possible without time synchronization of the devices if the time stamps are generated in another device (e.g. controller or process control system). However, the following applies:

The closer to the cause of an event the time stamps are generated, the more accurate the time stamps are.

Planning the Global Clock

When planning the time synchronization of the Global Clock, you must consider the following aspects:

- The devices to be synchronized must support the desired application (e.g. time stamping for Sequence of Events, ...).
- A suitable time source must be used. For example, satellite systems (GNSS such as GPS) or radio-based time transmitters such as DCF77 can be used as a time source. Another option is to use an existing time server in the network. It should be noted that the synchronization of the global clock can only ever be as accurate as the time source.
- The time source, the devices to be synchronized and all bridges between them must support clock synchronization according to gPTP / IEEE 802.1AS with two time domains.
- The maximum line depth between the time source and the devices to be synchronized is 64.

gPTP makes no requirements on the topology of the network. Time synchronization with gPTP can take place across routers, firewalls and gateways if these devices support gPTP.

The time synchronization of the global clock is optional in all CCs. It must be checked for each device whether it supports gPTP / IEEE 802.1AS with two time domains.

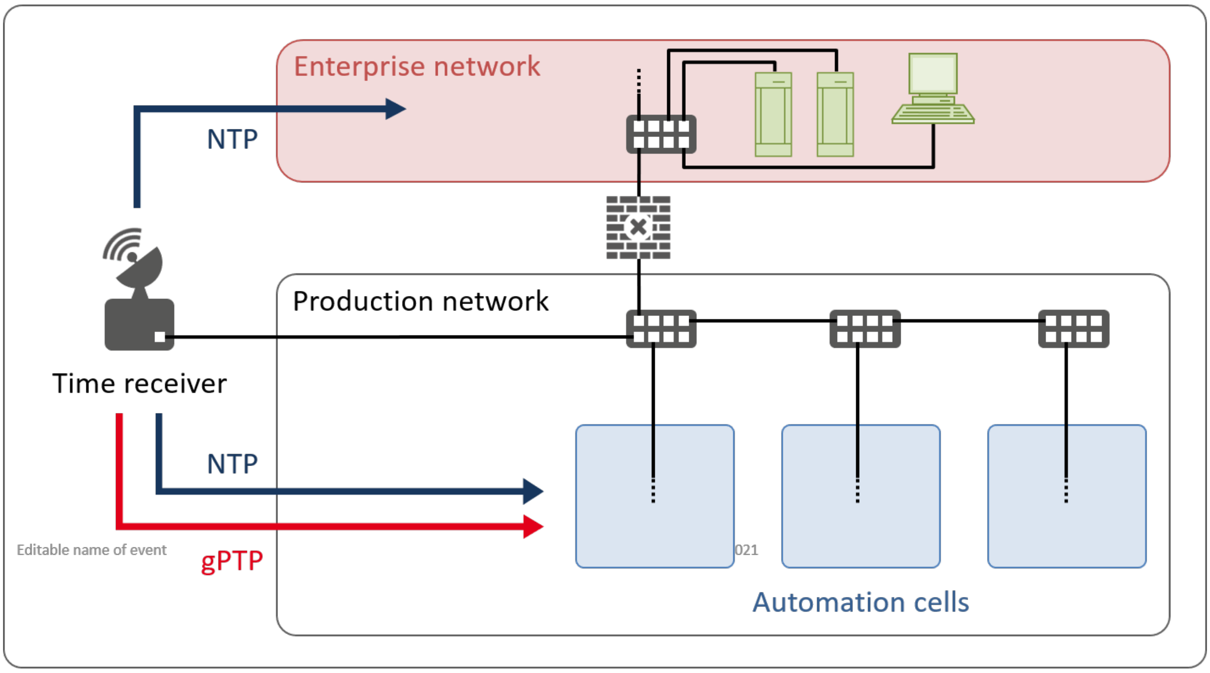


Figure 4-1: Possible architecture for the distribution of time information

Figure 4-1 shows an exemplary architecture in which both the enterprise network and the production network are synchronized with the time source. A time receiver gets the absolute time via satellite or radio.

The production network is synchronized with both gPTP and NTP. This has the advantage that components that only support NTP can also be synchronized, even if only with a lower accuracy.

The enterprise network is synchronized with NTP, as the lower accuracy is sufficient in the IT sector and most devices only support NTP.

4.2 Increased availability

In some cases, automation technology requires higher plant availability. There are three approaches to increasing the availability of PROFINET systems:

- Adjustment of the network topology
- Media redundancy
- System redundancy

By adjusting the network topology, it is possible to influence how many devices are affected by a failure or device replacement.

The basis for media redundancy is the use of a ring topology. The basic idea here is that the failure of a single device or a single cable only splits the ring at one point. A line topology is then formed in which every subscriber is still connected to every other subscriber.

System redundancy describes the duplication of the controller, the devices and the connection between them. System redundancy can be implemented in different levels, with reliability increasing from level to level. By using system redundancy, a highly available plant network can be built.

If you want to use media redundancy or system redundancy, read the PROFINET planning guideline Redundancy (Order No.: 8.132).

Check the availability requirements of your automation task. If required, plan for media or system redundancy.

Media and system redundancy are optional functions. Make sure that the selected devices support the required functions.

4.3 Networks with multiple controllers

Multiple controllers can be used in a PROFINET network. In networks with only one controller, cyclic communication of process data only takes place between the controller and device. In networks with multiple controllers, there are two other possible communication relationships:

- Communication between controller and controller
- Communication from one device with several controllers

Three functions that enable these communication relationships are explained below.

4.3.1 I-Device

I-Device enables communication between controller and controller.

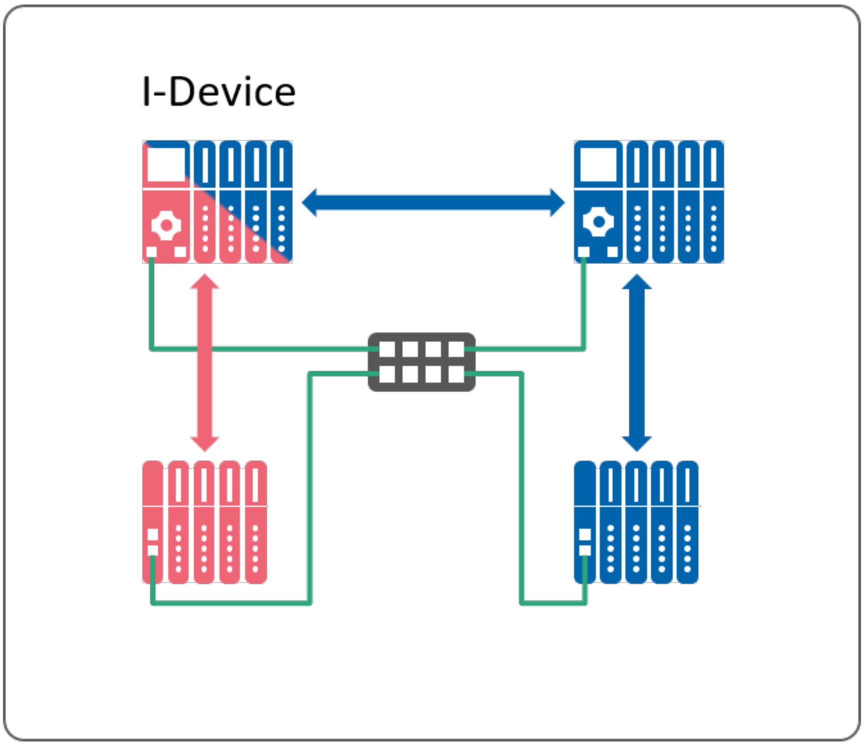


Figure 4-2: Use of I-Device

The I-Device is a function that a controller can optionally support. If I-Device is activated, the controller behaves both like a PROFINET controller and like a PROFINET device. The controller can build up a communication relationship with both devices and other controllers.

Figure 4-2 shows the use of I-Device. The left controller uses I-Device and communicates with a device as well as with the right controller.

4.3.2 Shared Devices

The function shared device enables the communication between one device and multiple controllers. Figure 4-3 shows two controllers that access a shared device in parallel.

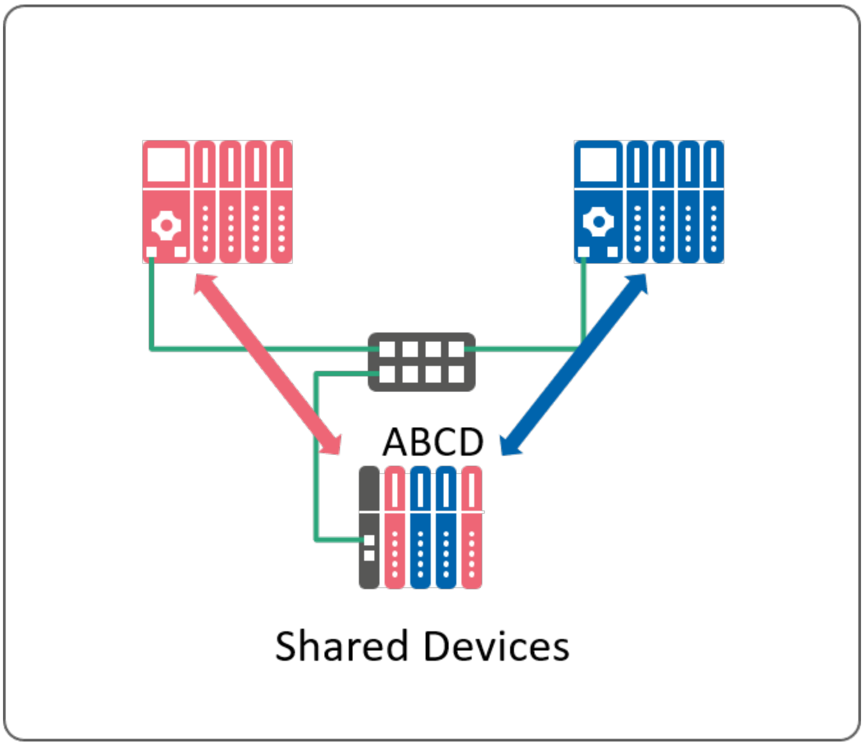


Figure 4-3: Use of shared devices

A shared device is a function that a device can optionally support. The device must be composed of several modules. Each module is permanently assigned to exactly one controller. The controllers can communicate independently of each other and in parallel with the modules assigned to them.

Figure 4-3 shows the use of shared devices. The device has four modules. Modules A and D are assigned to the left controller. Modules B and C are assigned to the right controller.

4.3.3 Shared Inputs

The function shared input enables communication between a device and multiple controllers.

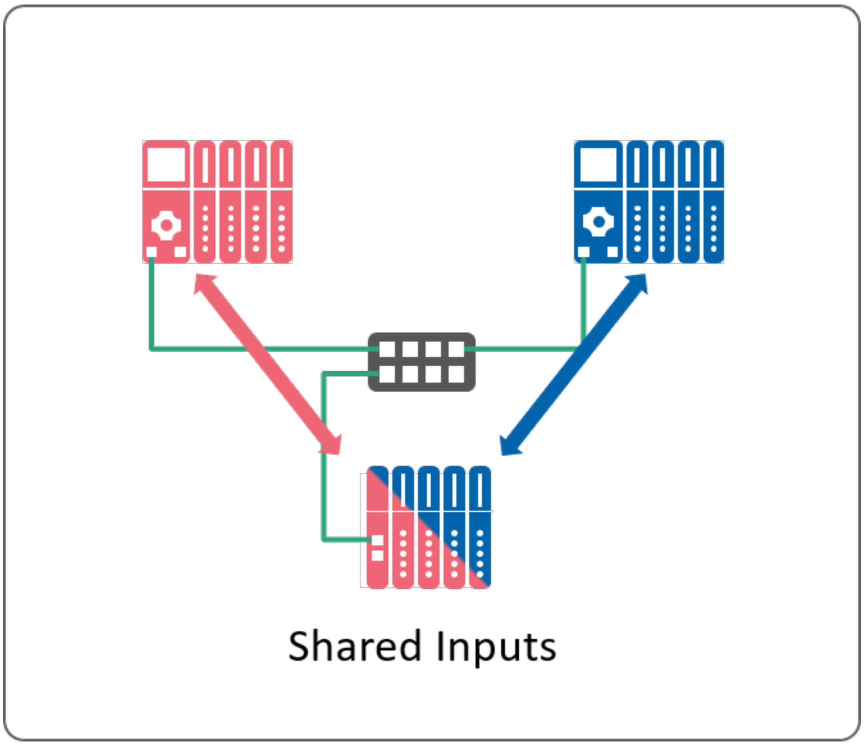


Figure 4-4: Use of shared inputs

Shared input is a function that a device can optionally support. A shared Input is an input that can be read by several controllers at the same time. The outputs can still only be controlled by one controller.

Figure 4-4 shows the use of shared inputs. The inputs of the device are sent cyclically to both controllers.

The functions for I-Device, Shared Devices and Shared Inputs are not supported by all PROFINET devices.

If you want to use one of the functions, select your device accordingly.

4.4 Wireless transmission technology

PROFINET allows for the use of wireless transmission systems. In contrast to the use of cable-based links, wireless technology uses free space as transmission medium. In automation technology, this commonly used medium is usually designed as an infrastructure network with a central access point. Spontaneous networks without any central access point are rarely used.

The usage of wireless technology requires consideration of certain factors that do not occur in connection with wired transmission technology. This includes terms such as:

- Attenuation in the free field upon visual contact (free-field attenuation),
- Reflection of radio waves from obstacles,
- Interference of mutually impairing signal sources with identical frequency
- Interference from other signal sources or
- Scattering, diffraction and absorption of signals at surfaces and barriers,

All of which have an impact on the signal strength and quality of the wireless system. Figure 4-5 shows the different influences on wireless transmission technology.

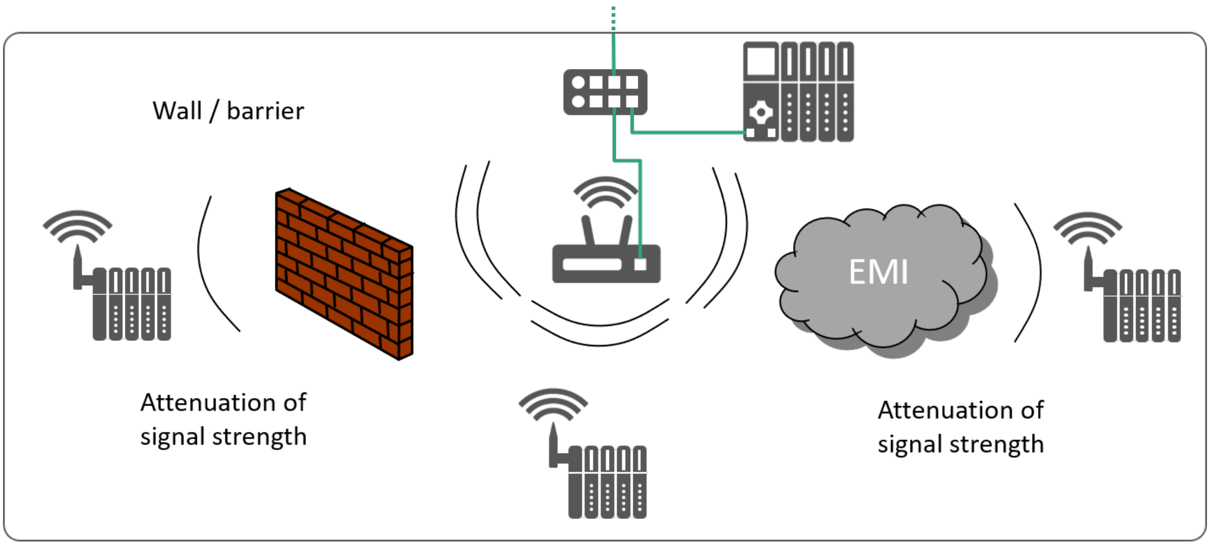


Figure 4-5: Use of wireless transmission technology

To ensure full coverage of the supply area, an appropriate transmission field planning and site survey must be carried out. The transmission field planning is used to determine the impact on the propagation and the behavior of radio waves. It considers points such as special conditions, i.e. factors such as room dimensions, wall thickness, wall materials and metal objects etc. (see also Figure 4-5).

These factors can e.g. be determined by means of on-site measurements or by means of checking the building and plant plans. Similarly, it is possible to use simulation tools to model the transmission field allowing prediction and better planning of the signal propagation from building plans.

After completion of the installation, you should also measure the signal quality in the plant. For further information see PROFINET Commissioning Guideline Order No.: 8.082.

Note that a wireless access point will require a free switch port.

The fact that wireless systems support different data rates has an impact on the number of wireless PROFINET network nodes or their update rate. You should therefore select a suitable update time for the wireless network nodes.

Find out the gross or net data rate supported by your wireless access point and use the network load calculation tool to design the wireless transmission system.

The usually lower transmission rate of wireless networks, when compared to a wired infrastructure, reduces the update rate in a wireless PROFINET network.

This also reduces the maximum number of clients per access point.

The use of wireless transmission makes sense if a wired system cannot be used or can only be used with difficulties, or if the use of wireless transmission technology provides the required mobility and flexibility.

Good candidates for wireless transmission include autonomous guided vehicles and extensive conveying systems. Wireless can however also be used for short range sensor networks.

Wireless networks must be protected against unauthorized access from outside. You have to take appropriate precautions for safeguarding your wireless network.

This chapter can only give a first introduction to the topic. When using wireless transmission technology, a more comprehensive design phase is required (e.g. regarding the geographical coverage, frequency planning, etc.). This work is beyond the scope of this design guideline.

4.5 Power over Ethernet

Power over Ethernet (PoE, IEEE802.3 Clause 33) allows low consumption devices to be powered directly over the PROFINET cable. No separate power supply is therefore required. This may save installation costs. Typical devices which can be powered over Ethernet are:

- Access points (wireless)
- IP cameras
- HMIs and control stations
- Barcode readers

The PoE functionality must be supported by both the supplying device (e.g. a switch or separate injector) and the powered device.
Using PoE is recommended if the installation of a power cable in parallel to the PROFINET cable shall be avoided.

Please note that the utilization of Power over Ethernet implies limitations regarding the network topology. A direct link must be provided between the supplying device and the powered device (see Figure 4-6).

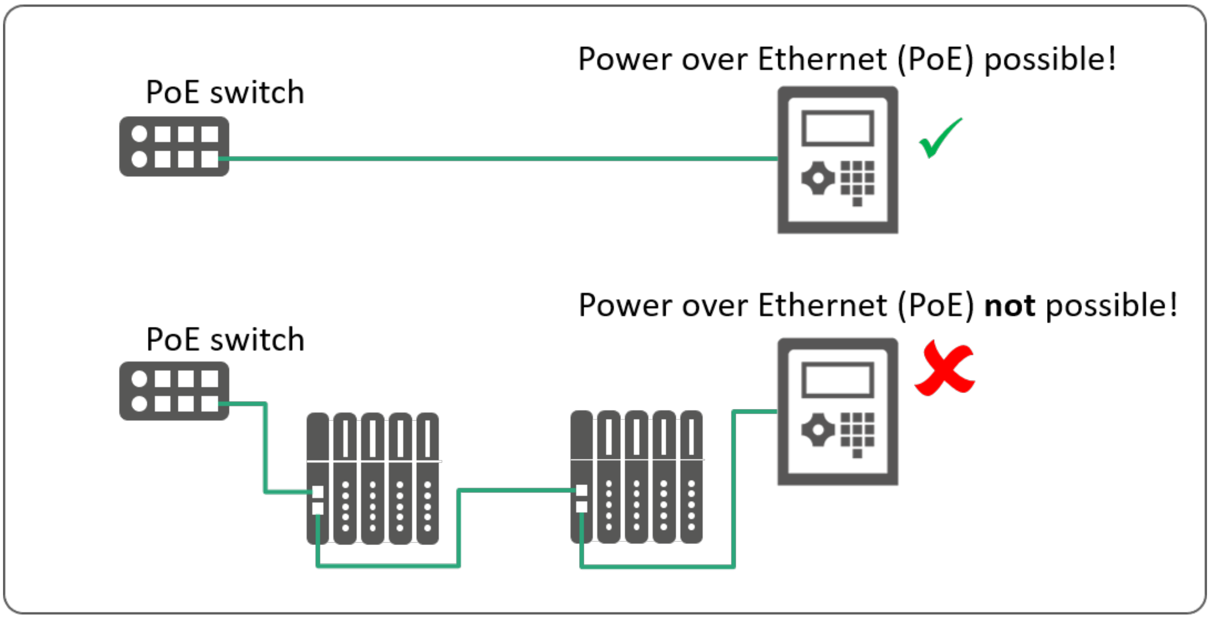


Figure 4-6: Topology limitations with Power over Ethernet

Ethernet-APL (see chapter 5) also provides power via the network cable. It should be noted that the power delivery of APL is different to the power delivery of Power over Ethernet (PoE). The two power concepts must not be mixed in a system. It is not possible to connect device powered via PoE to an APL network and it is not possible to connect an APL field device to e network with PoE.

4.6 Use of "Fast Startup"

In some applications it is necessary for PROFINET devices to be operational within a very short time. For example, after a tool change on a robot. In order to minimize the startup time, PROFINET offers the "Fast Startup"(FSU) protocol function. This function can be activated when configuring the devices that support fast start-up.

To be able to realize start-up times below 500 ms, it must be possible to deactivate the auto negotiation and auto crossover function at the relevant switch of the network node. Without auto crossover activated a crossover cable or a switch with internal cross connection is required. Figure 4-7 shows the implementation using a crossover cable.

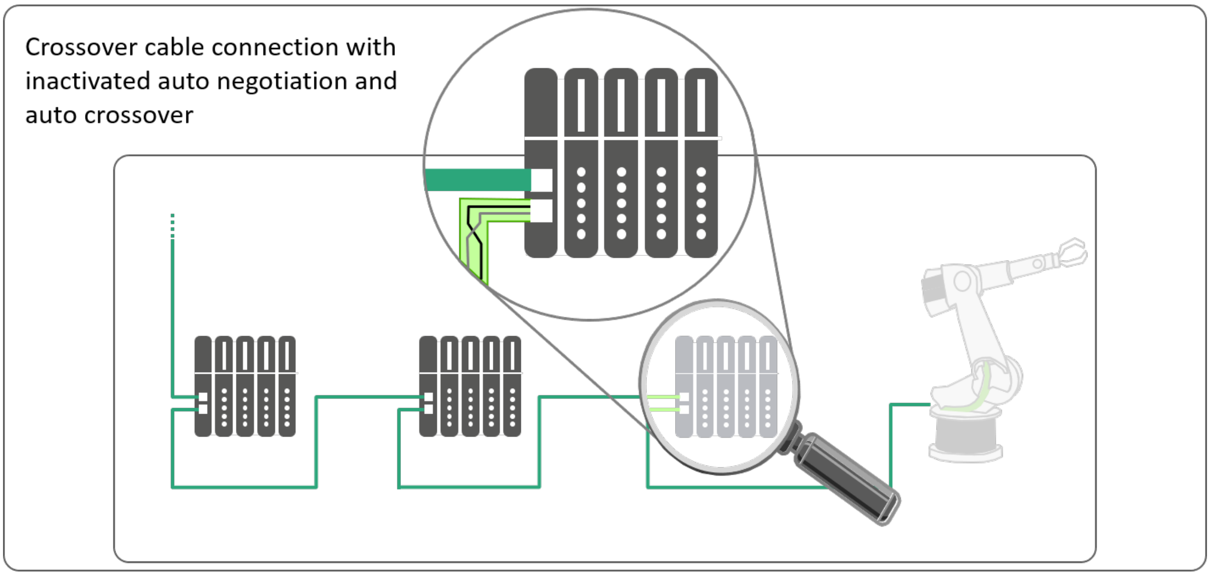


Figure 4-7: Implementation of "Fast Startup" with PROFINET

Please see the manufacturers' documents for details about FSU functionality and the connection of the relevant network nodes.

4.7 Utilization of existing network infrastructure

Cabling

Existing cable infrastructure can be used for the use of PROFINET. This is, however, possible only in case the cable infrastructure is suited for PROFINET transmission. The cables are suited for PROFINET if the cabling is a 4-core or 8-core, symmetrical, twisted and shielded copper cable for the transmission of standard Ethernet.

The application-neutral cabling often used for standard Ethernet in the industrial environment falls under the scope of application of Conformance Class A when using PROFINET and should only be used there.

If you plan to use existing cabling for the PROFINET plant to be designed, you will find relevant information in the Conformance Class A Cabling Guideline [CCA2008]. Please check also [PCI2023] for further information about cabling and interconnection technology.

When using existing cabling, the design should be based on the existing infrastructure. The existing cable infrastructure must be extended by the required transmission links.

Switches

When using standard switches in an existing infrastructure, ensure that they support the following functions required by PROFINET:

- VLAN prioritization according to IEEE 802.1Q with at least two queues
- Handling of LLDP packets according to IEEE 802.1AB

Switches are not certified in the CC-A. However, the manufacturers can declare support for PROFINET. Look either for the functions just mentioned or for a manufacturer's declaration to determine whether the switches can be used.

4.8 Planning of access points for network diagnoses

In the commissioning phase and for maintenance you will need network access points, e.g. for analyzing network traffic or reading device data. Such access points are also helpful for trouble-shooting or long-time diagnosis of the network condition.

In order to be able to connect diagnostic devices without interrupting normal plant operation, network access points should be available.

For diagnostic purposes, reserve easily accessible ports distributed over the entire plant.

In any case switches with diagnostic port should be provided at the communication nodes, e.g. directly at the controller.

Free ports can be used for a first rough analysis of the network traffic, if the corresponding switch supports port mirroring.

A TAP (Test Access Point) can be used to analyze data streams for an exact data traffic diagnosis. A TAP is directly implemented in the communication link, as shown in Figure 4-8.

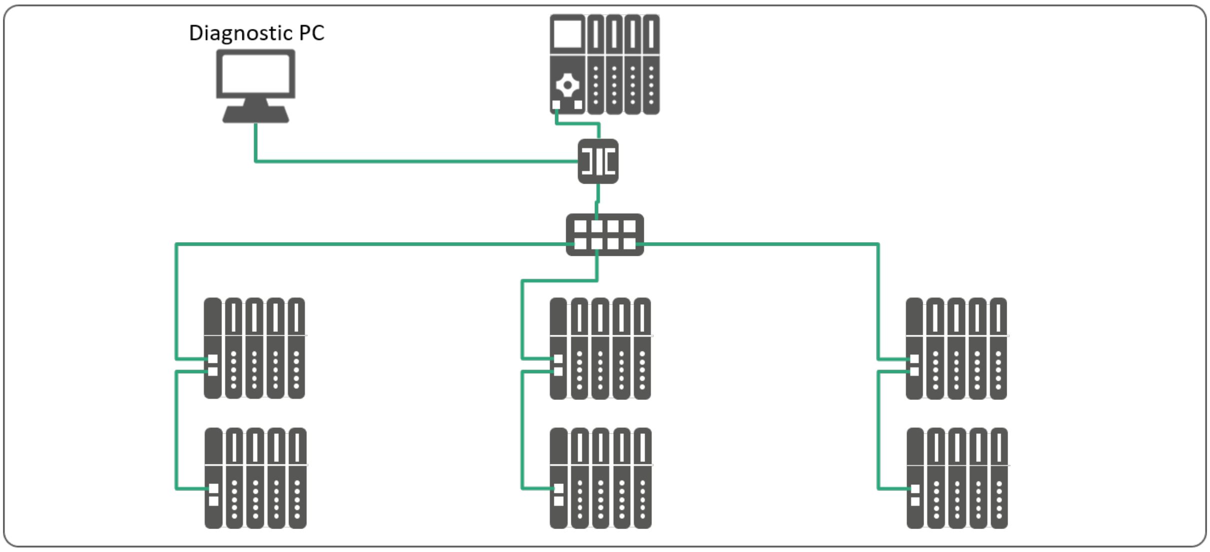


Figure 4-8: Reading data streams via TAP

A PC can be used for evaluating the data stream. Diagnostic devices with integrated TAP are also available on the market.

In order to be able to install or remove a TAP, you have to open the communication link. It may be useful to permanently install TAPs at important points in your plant design.

TAPs are additional network components which may affect the network availability. However, this effect is negligible when using passive, non-reactive TAPs. See also [PNC2022].

Providing TAPs at important points, e.g. directly at the controller, may be advisable.

It is recommended to exclusively use passive TAPs without any reaction on the PROFINET communication.

4.9 Determination of firmware revisions and asset management

Frequently, different firmware revisions are used for PROFINET devices, e.g. if functions have been extended in the software.

It is nevertheless useful to determine a corporate firmware revision level in the design phase of the plant and to make sure – prior to commissioning – that all PROFINET devices have the same firmware revision level. This ensures consistent device behavior and project planning. Please contact your device vendor for the latest firmware revision level and determine this level as a standard for each device type used. Different firmware revision levels for the same device type should be avoided.

Determine a common firmware revision level for each device type.

It may also be useful to determine a common hardware revision level.

Prior to commissioning, update all PROFINET devices with an older firmware version to the defined firmware revision level.

4.10 Documentation of modified network topology

You should update your documentation with the results that you have gathered while considering the special aspects. In the Appendix a proposal for a network documentation is given in section 10.11.

Some engineering tools, company-internal documentation tools or design software provide additional functions that can generate design documentation.

4.11 Security

The aspect of security (OT security) is only dealt with in this document in individual aspects e.g. within the scope of system documentation. Detailed information on the topic of PROFINET security can be found in the following documents:

- [PSA2013] PROFINET Security Guideline
- [PSB2023] Security Class 1 for PROFINET-Security - Guideline for PROFINET
- [PSC202X] PROFINET Planning Guideline Security (not yet published, in preparation)

5 Ethernet-APL

This chapter describes the basics of Ethernet-APL, which is a 2-wire-physical layer used to connect field devices to an Ethernet network. Detailed information about the planning process of Ethernet-APL can be found in the Ethernet-APL Engineering Guideline [APL2021].

5.1 What is Ethernet-APL

The increasing use of Industrial Ethernet yields benefits with respect to network diagnosis, training of staff and the use of single converged technology, in case Ethernet technology is used throughout the plant. The basic requirements for such a network are:

- Communication considering the requirements of the process industry (harsh environment, specific topology specifications)
- Operation in areas with explosive atmosphere shall be possible
- Handling by maintenance personnel shall be possible
- Robust and simple connection technology
- Cycle time for the transmission is between 10 ms and 2 000 ms, depending on the task
- All field devices shall support the same defined and standardized physical layer.
- The protocols shall be supported by all bus components (e.g. field devices, process control systems, infrastructure components, ...).
- All protocols used shall be interoperable with each other, i.e. simultaneous operation shall be possible.

With the Ethernet-APL physical layer, the cooperating standards development organizations (SDOs) cooperating in the APL project defined a communication solution to meet the demand of the process industry for a converging network architecture in the automation domain having the following features:

- Ethernet based communication
- Two-wire connection to the sensor
- Power supply of the devices via two-wire connection
- Re-use of existing cable installations shall be possible (depends on cable type)
- Operation of field devices and switches in the areas with explosive atmosphere is possible
- Replacement of failing devices during operation in areas with explosive atmosphere is possible.

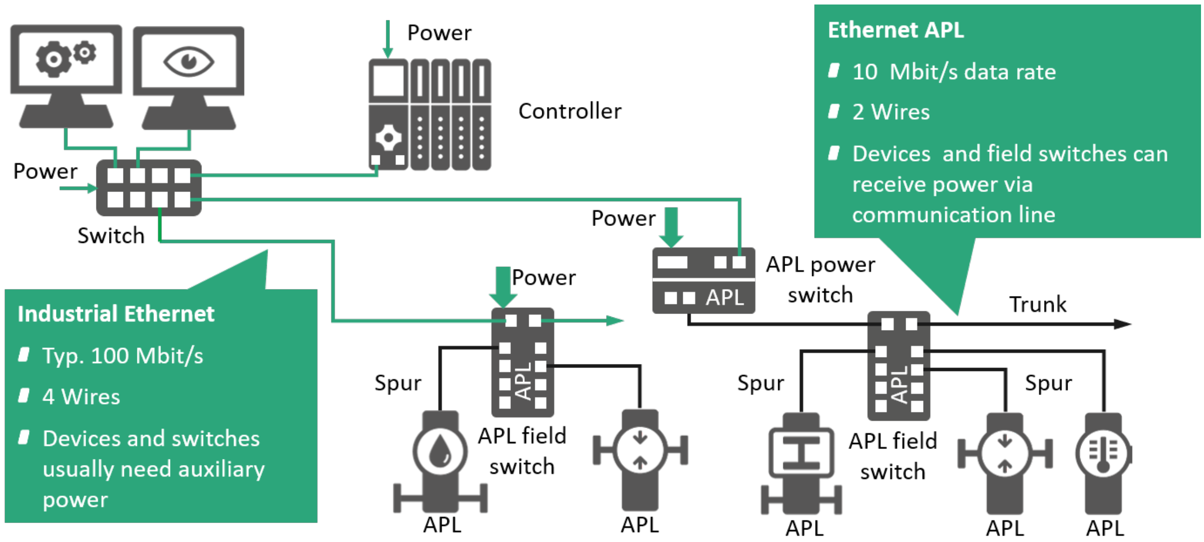


Figure 5-1: Differences between Fast Ethernet and APL

Figure 5-1 shows the differences between an Industrial Ethernet (typ. 100 Mbit/s) and Ethernet-APL. In the top left corner, a controller is shown in combination with an engineering- and operator station. The two devices are connected e. g. via a 100 Mbit/s Industrial Ethernet. Both devices need auxiliary power. The Ethernet cable uses 4 wires, the communication usually runs in full duplex mode at a maximum length of 100 m when using copper media. The center of Figure 5-1 shows an APL power switch. The APL power switch connects on the one side to the fast Ethernet and receives auxiliary power. The APL power switch converts the 100 Mbit/s fast Ethernet to the 10 Mbit/s Ethernet-APL. The Ethernet-APL uses two wires (single pair) and provides full duplex communication. The APL trunk connects the APL power switch with the APL field switches. The length of an APL trunk segment can be up to 1 000 m. The APL power switch provides in parallel electrical energy for the devices, connected to the APL network. In this case the APL field switch and the APL field devices. The APL field devices are connected via APL spurs to the APL field switches. In addition, Figure 5-1 also shows a field switch that is directly connected to the 100 Mbit/s Industrial Ethernet.

It can be seen that Ethernet-APL is just another physical Layer for PROFINET. The user now has the choice to use 100 Mbit/s Ethernet physical layer, higher data rates or the 10 Mbit/s Ethernet-APL-Physical Layer.

5.2 Possible topologies for an APL system

Ethernet-APL offers three different topologies that are compared in Table 5-1 with respect to their features.

Table 5-1: Features of different APL network structures

Feature	Field switches with Industrial Ethernet	Powered APL trunk
Maximum spur length	≤ 200 m for cable category IV[1]	≤ 200 m for cable category IV[3]
Maximum trunk length / Industrial Ethernet length	Fiber optic: Depends on type of fiber. Typically, ≤ 2 000 m for multimode fibers. Copper cable: ≤ 100 m	≤ 1 000 m for cable category IV. Depends on power load of the field switches and the devices and the cable used.
Voltage drop on the trunk cable to be considered	No	Yes
Data rate on trunk / Industrial Ethernet	Typ. 100 Mbit/s	10 Mbit/s
Network load (communication load) on trunk / Industrial Ethernet to be observed	Yes, but at 100 Mbit/s data rate impact will be negligible	Yes
Auxiliary power needed in the field	Yes, to power the field switches	No, field switches are powered via trunk
Equipotential bonding	In case fiber optic is used to connect the field switches, equipotential bonding is uncritical	To be observed, especially when long trunk connections are used

The next chapters will deal with the three topology alternatives in detail.

5.2.1 Alternative 1: APL field switches with Industrial Ethernet connection

This alternative uses standard Industrial Ethernet to connect the APL field switches to the control network. In this case the control network is routed to the APL field switches via a fiber optic. Copper cable is possible as well, but length limitation has to be observed. A power switch is not necessary. The APL field switches need to be powered by an auxiliary power source.

[1] See [APS2021] for Cable specification details

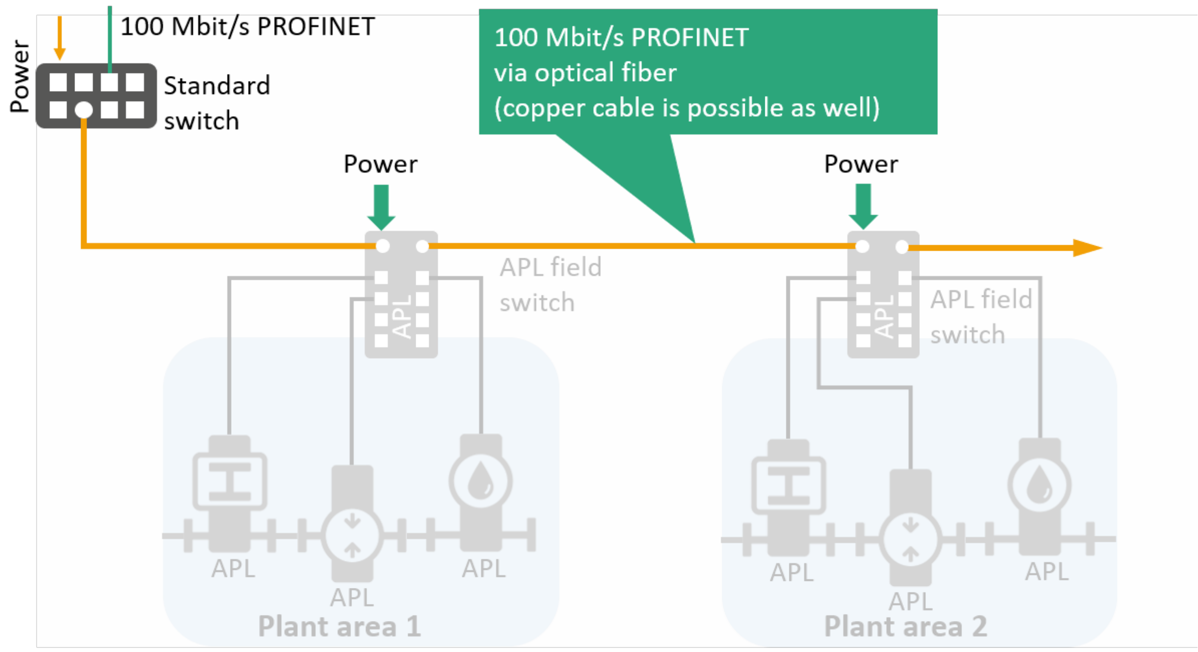


Figure 5-2: Field switches with Industrial Ethernet connection

Figure 5-2 shows the network structure using Industrial Ethernet cable. Copper cables allow distances up to 100 m. Multimode optical fibers typically allow distances between the APL field switches of up to 2 000 m.

When creating APL networks with large cable lengths, the functional bonding and shielding needs to be observed. See APL Engineering Guideline [APL2021] for further details. In plants with an unclear situation with respect to functional bonding and shielding, the use of fiber optic Industrial Ethernet (FO) is an alternative.

Check the Ethernet-APL Engineering [APL2021] Guideline for further details.

5.2.2 Alternative 2: Powered APL Trunk

This chapter deals with the powered APL trunk.

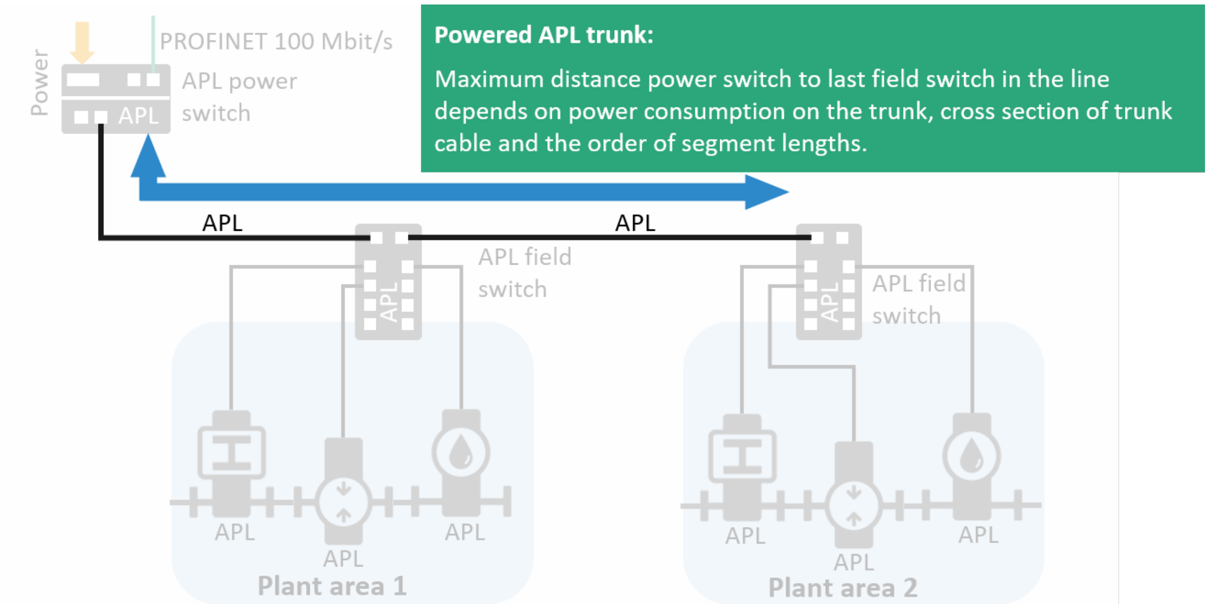


Figure 5-3: Powered APL trunk

Figure 5-3 defines the last limitation for the placement of the APL field switches in case a powered trunk is used. The maximum distance for each segment in the line can be up to 1000 m, but depends on the following parameters:

- Output voltage of the APL power switch.
- Number of the APL field switches connected to the powered APL trunk.
- Number of the APL field devices connected to the field switches and their power consumption.
- Cross section (wire gauge) of the trunk cable.
- Temperature of the trunk cable, as resistance depends on ambient temperature.

The location of the APL field devices is defined by the technical process and is input for the APL planning process. APL field switches to be placed in a way that maximum spur length is 200 m, maximum distance between the power switch and the last field switch in the line has to be calculated. These cable lengths depend on the cable type

Check the Ethernet-APL Engineering Guideline [APL2021] for further details.

6 Plant examples

You have now considered all the PROFINET functions described in this document in the planning process. This chapter presents some examples of automation tasks and describes how they can be solved with PROFINET.

First, typical plants from the following industries are shown:

- Manufacturing industry
- Mechanical engineering
- Process industry

Three examples are then shown in which the new functions of TSN are used in the CC-D:

- Integration of a camera into the process
- Time synchronization for data analysis and Sequence of Events
- Converged networks

6.1 Factory automation

The topology for an automation plant, designed for factory automation, could have following structure.

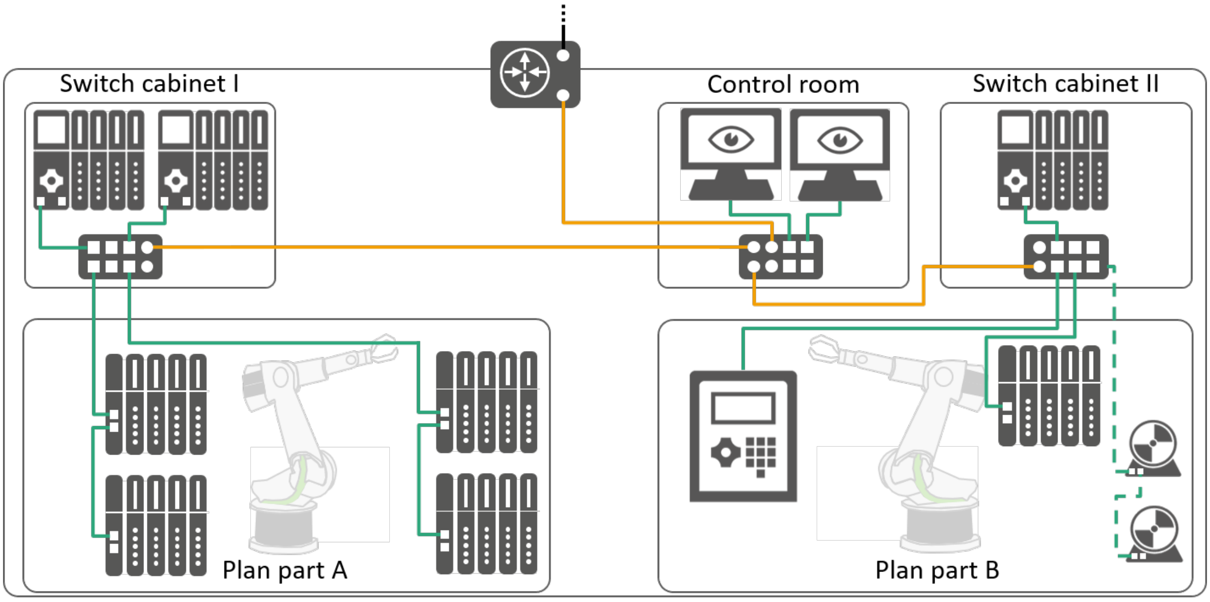


Figure 6-1: Example of a factory automation

In this example, the controllers and switches are installed in separate switch cabinets next to the production line. All controllers are able to communicate with each other without limitation. Due to the large distance between the plant areas, the links between the switches are implemented by means of optical fiber.

In plant area A, the devices are located near the manufacturing process and are connected via a line structure while plant area B, in addition to a synchronous connection of drives, foresees additional PROFINET devices with cyclic communication such as devices and panels.

This example clearly shows the combination of different topologies.

6.2 Automation of a machine

The following example shows the automation of a machine. Here, the plant is subdivided into several areas, which assume different functions. The response times of the plant typically are very short.

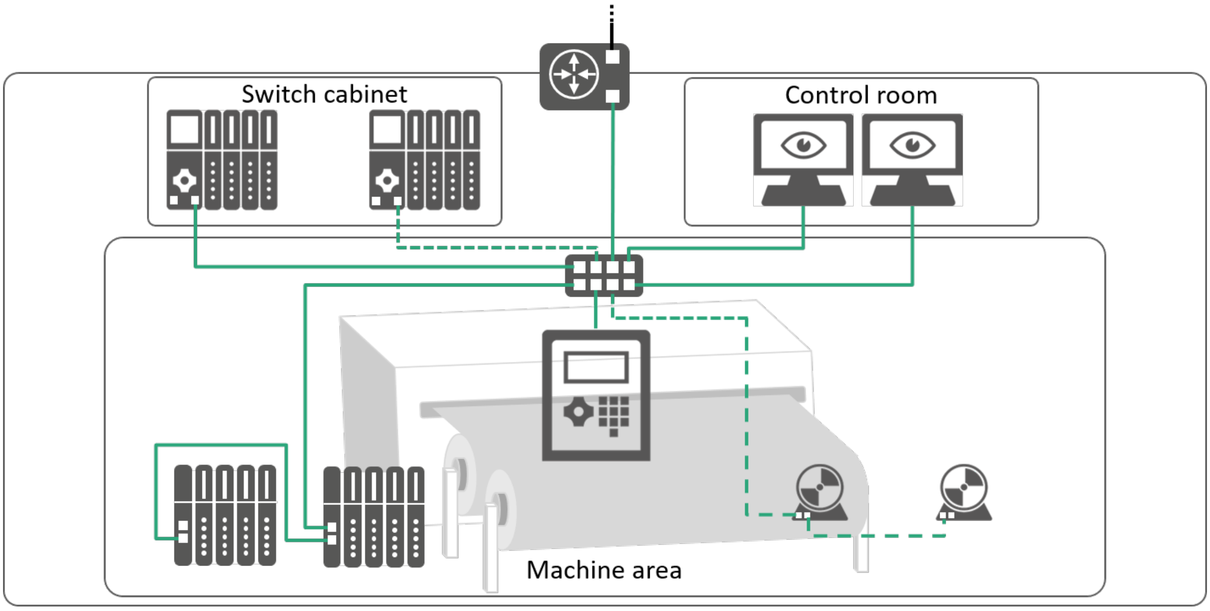


Figure 6-2: Example of a machine automation

While the operator panel is installed in the control room and the controllers outside the machine area are in a switch cabinet, the devices and an panel are located in the machine area.

The PROFINET devices, which do not require a synchronous connection are positioned first and connected to the switch. The special requirement in terms of determinism (e.g. position-controlled axes) also implies the drives to be synchronously connected to a switch supporting IRT. Non-IRT PROFINET devices can also be routed via the IRT switches jointly with the IRT traffic.

6.3 Process automation

Process automation amongst others covers chemical industry applications. Here, the network structure is typically used to link:

- chemical reactors,
- power plants or
- chemical plants.

The requirements in terms of response times are typically lower in process automation than they are in manufacturing or machine automation.

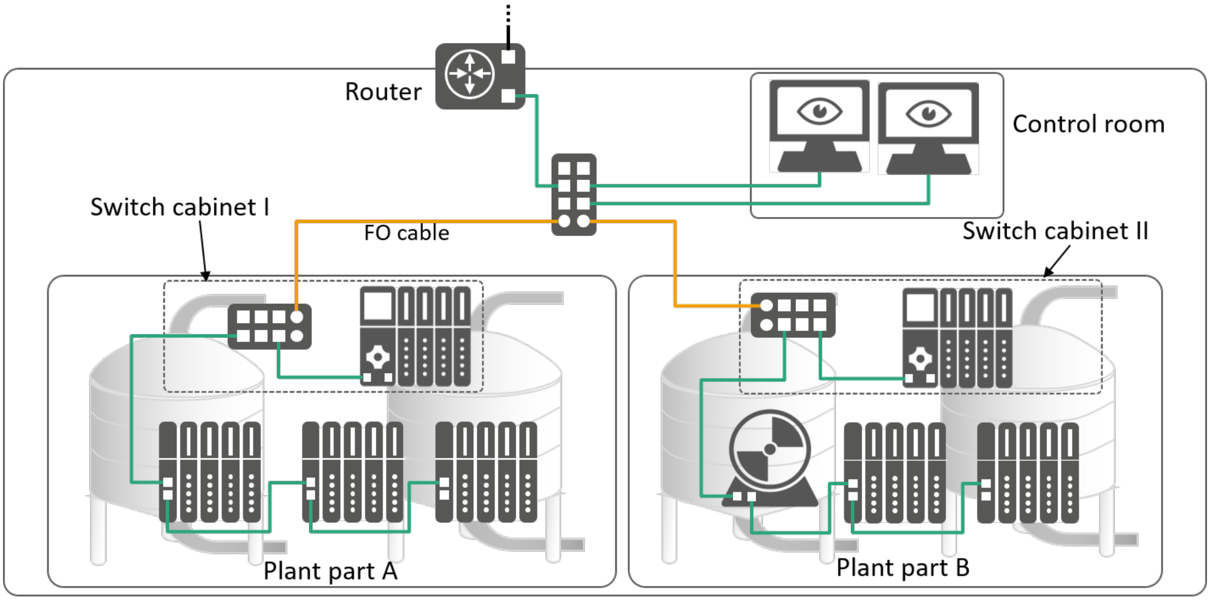


Figure 6-3: Example plant process automation with remote IO

The control room monitors both processes, which are divided into plant part A and B. Both plant parts have a local switch cabinet, which is equipped with a switch and a controller.

Due to the extensive distances involved in the plant, the network nodes are linked via a star topology from the control room to the switch cabinets with FO cable and a line structure inside the plant parts A and B. This reduces the amount of cabling required. The sensors and actuators are connected to the remote IOs, e. g. via 4 … 20 mA and HART.

.

6.4 Process automation with Ethernet-APL

Ethernet-APL is a two wire 10 Mbit/s Ethernet that is intended to connect sensors and actuators directly to PROFINET. See chapter 5 and the Ethernet-APL Engineering Guideline [APL2021] for further details.

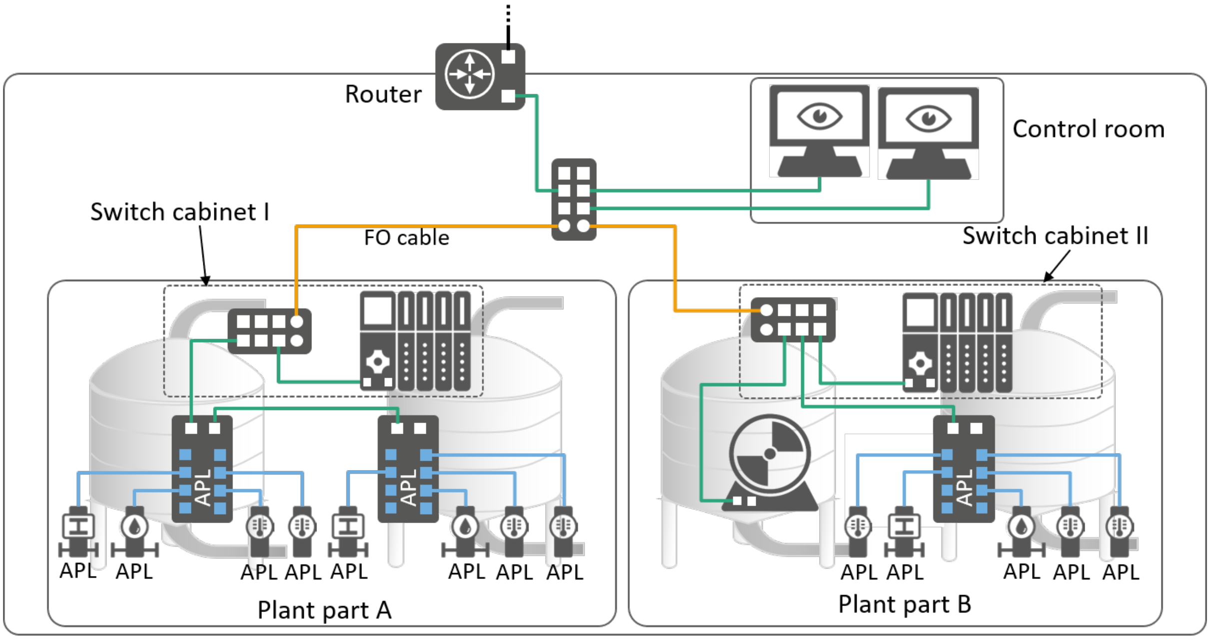


Figure 6-4: Example Plant Process Automation with Ethernet APL

Figure 6-4 shows an example plant in the process industry equipped with Ethernet-APL sensors. The plant layout in the upper part is similar to the previous example shown in Figure 6-3, but instead of the remote IO, APL field switches convert the 100 Mbit/s PROFINET to the 10 Mbit/s Ethernet-APL signals. The APL field devices are connected to the field switches via 10 Mbit/s APL spurs. These spurs convey data as well as energy to the sensors. The use of a remote IO is not any longer necessary.

For further information refer to chapter 5 and the Ethernet-APL Engineering Guideline.

6.5 Camera as sensor with TSN

The following example shows a sorting plant. A video camera is integrated into the process. The camera can therefore be regarded as a sensor for real-time process.

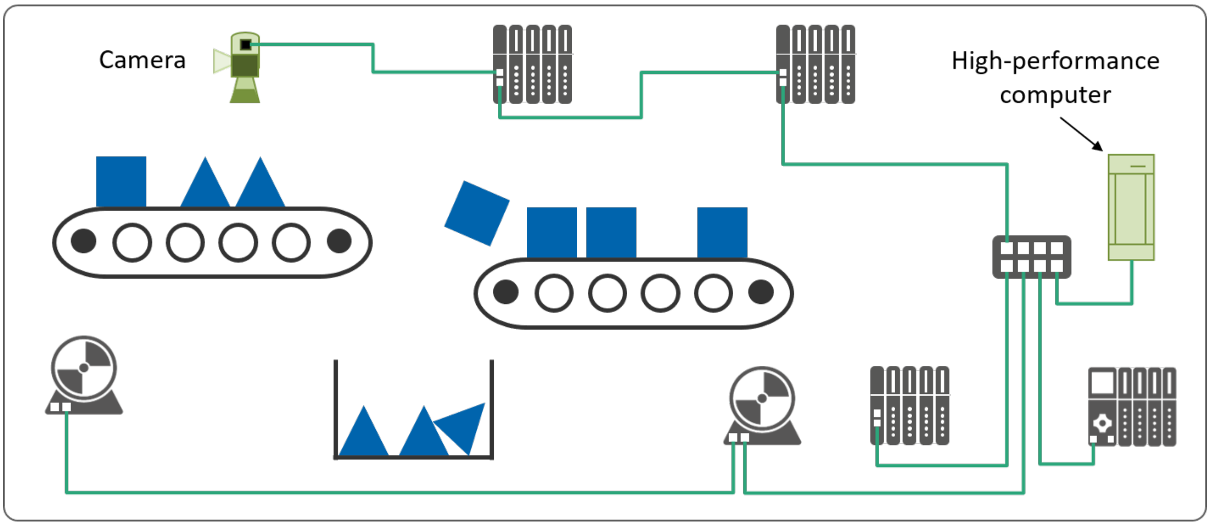


Figure 6-5: Plant example for camera as sensor

In a sorting plant, there are two types of objects on a conveyor belt. The objects can be recognized by their appearance.

A camera with a high resolution and frame rate is used to record a video of the conveyor belt. The images are time-stamped and sent to a computer with high processing performance. This carries out object recognition. Using the time stamps, it can calculate exactly when the valves need to be opened in order to sort out the objects with a blast of air. The calculated time stamps are sent via the controller to the remote I/O, which activates the valves at the correct time.

The following technologies are used to enable the system example:

- Gigabit Ethernet is used, as the camera requires a data rate of 150 Mbit/s.
- Time synchronization with gPTP is used. The time stamps are generated using the working clock of the devices.
- CC-D is used as the Conformance Class. The video stream and the process data are transmitted via the same network. The TSN technologies used in CC-D ensure that the video stream has no negative impact on the transmission of the process data.

6.6 Data analysis and Sequence of Events with TSN

The following example shows two pump stations. Globally valid time stamps are used to enable multiple technologies.

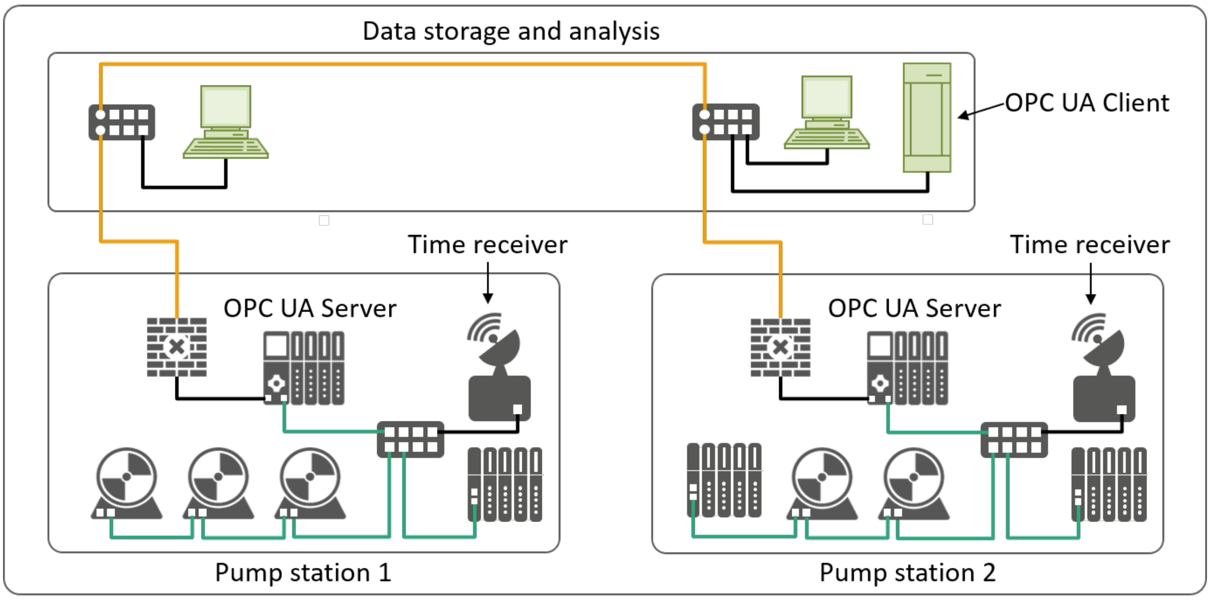


Figure 6-6: Plant example of data analysis and Sequence of Events

In this plant, two pump stations are used to control the pressure in a shared water network. In the event of a fault, it should be possible to determine the cause and course of the failure. For this reason, certain signals and events are provided with time stamps and temporarily stored in the controllers. An OPC UA server runs on each of the controllers and provides the values. A database uses an OPC UA client to receive and permanently store the controller data. In the event of an error, this data can be used to determine the cause of the error. This is also known as a **Sequence of Events**.

The system also generates data that is not required to control the process but is nevertheless valuable. This includes data from the frequency converters and sensors. In this system, for example, vibration sensors are attached to the pump housings. This data is also time-stamped and sent from the controller to a database. Data analysts can use the data to determine changes in pump behavior and the need for maintenance. This is also known as **Predictive Maintenance**.

The devices in the plant must support the time synchronization of the Global Clock:

- The time is synchronized using gPTP. This can then be used to provide data with exact time stamps. As the pumps are located in different networks, the global clock must be used. This requires a local time receiver. A GPS receiver is used in the example.

6.7 Converged networks with TSN

The following example shows a typical plant in the manufacturing industry. The plant is connected to a higher-level network. A number of IP-based protocols are used to communicate with network nodes independently of the controller.

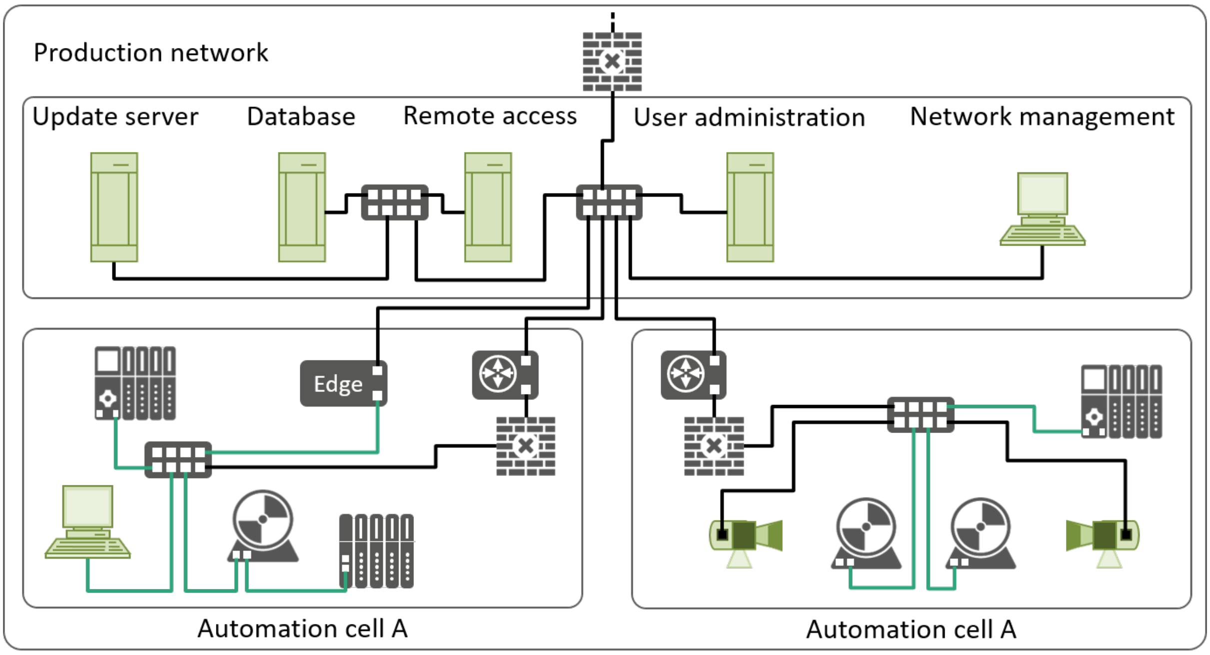


Figure 6-7: Plant example for converged networks

In addition to the PROFINET devices, a number of other devices are connected to the network in this plant, including a standard PC and a video camera. In addition, all network nodes should be reachable from the higher-level network. The PROFINET networks are therefore connected to the higher-level network using routers and firewalls. The higher-level network contains servers and PCs for the following services:

- **Update server**: The operating system and the programs of the standard PC obtain the current software version via the update server.
- **Database**: An MQTT broker collects data from PROFINET nodes and stores it long-term. It also receives the image from the surveillance camera as a UDP stream and saves this too.
- **Remote access**: A separate server is used for remote access. For remote maintenance jobs, the remote server must first be accessed from the Internet. This access requires authorization and authentication. Only then can the production network be accessed.
- **User administration**: Standardized user administration is used in the company, which is also used in the production network.

- **Central network management**: The company has a network that includes both the corporate network and the production network. Network management is therefore carried out centrally for the entire network.

In PROFINET networks, the CC-D is used together with Gigabit Ethernet. This is for the following reasons:

- The various protocols are transmitted in the same network as the process data. The TSN technologies used in the CC-D ensure that this communication has no negative impact on the real-time transmission of the process data. Real-time traffic is logically and temporally isolated from non-real-time traffic by the TSN mechanisms.
- The video camera creates a known and high non-real-time load. The update server creates an unpredictable, irregular and high non-real-time load.
  The use of Gigabit Ethernet enables the fast transmission of large amounts of data. The camera's video stream therefore takes up a smaller proportion of the total bandwidth. Updates take less time. More bandwidth remains for other applications, which also makes them faster.

The services and protocols shown are merely examples. Any services and protocols can be used as long as the devices support them and the communication is IP-based.

7 Performance considerations

It is necessary to next consider the performance of the network. This chapter will guide you through the analysis of your design plan in a step by step manner and show which points have to be considered primarily in terms of the network performance. The following section deals with:

- Description of the PROFINET cycle,
- Definition of the device parameters relevant for the performance of the network and
- PROFINET network topology with a special focus on the cyclic and non-cyclic load which is generated by PROFINET devices and standard Ethernet devices.

The topology of your network may have to be adjusted to ensure reliable and timely communication.

Isochronous real-time communication (IRT) and the effect of safety and security concepts are beyond the scope of this chapter.

The following chapter 7.1 provides a short overview of general Ethernet functions and of the PROFINET functions relevant for performance. If you are already familiar with these topics, you can skip this chapter and continue with chapter 7.2.

7.1 PROFINET transmission cycle

This chapter describes the PROFINET functions relevant for the performance. It provides a good basis for the analysis of the design planning you have made so far.

7.1.1 Prioritization of PROFINET packets and switching technologies

Two types of communication may be used within a PROFINET network: real-time communication (RT) and non-real-time communication (NRT).

Real-time communication is prioritized. The standard Ethernet prioritization mechanism in the VLAN Tag, illustrated in the example in Figure 7-1, is used. It can be seen that the RT packet get higher priority compared to the NRT packets.

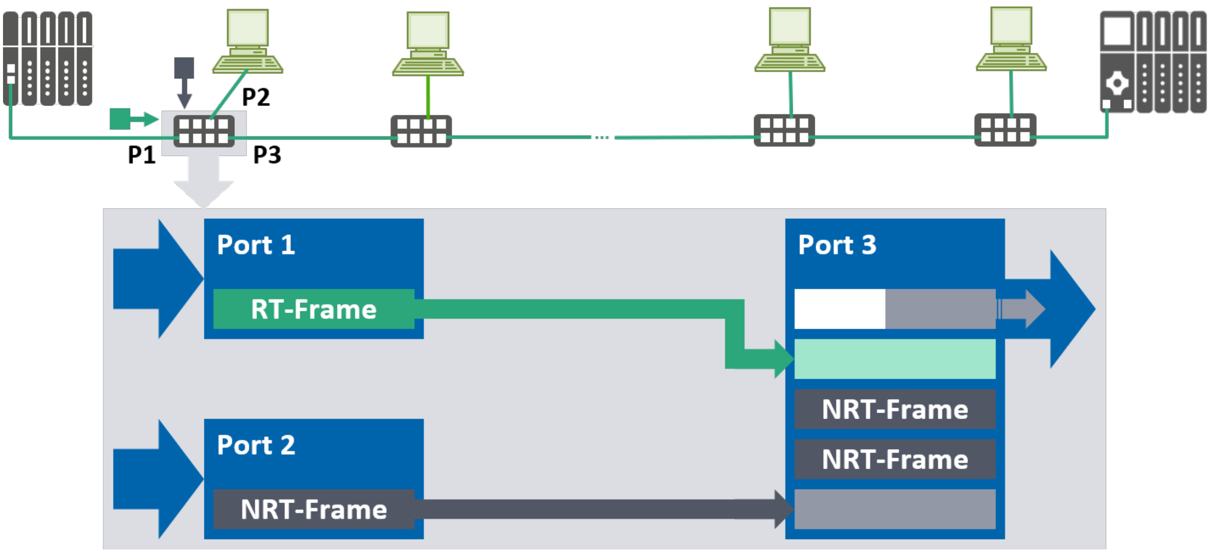


Figure 7-1: Prioritization of real-time communication with PROFINET

As a result, NRT communication is only executed in time periods when no RT communication occurs. Usually, the following switching technologies are applied:

- **"Store and Forward" Switches**: The packet is received in its entity, checked for errors and then forwarded or – in case of an invalid packet – dropped.
- **"Cut Through" Switches**: Only the packet parts that are essential to the forwarding process (i.e. the address information) are read and then the packet is directly forwarded without further delay.

The switching technology used is of major importance to your topology design plan, especially regarding the line depth (i.e. number of switches between the controller and the device). For more details about this topic, please see chapter 7.3.1.

7.1.2 Update time

PROFINET devices can be updated at different intervals depending on the process requirements and the hardware used. The update time may vary for different PROFINET devices within the same plant. The length of the transmission cycle, in which all PROFINET devices receive or transmit their data at least once, is determined by the PROFINET device with the slowest update time, see Figure 7-2.

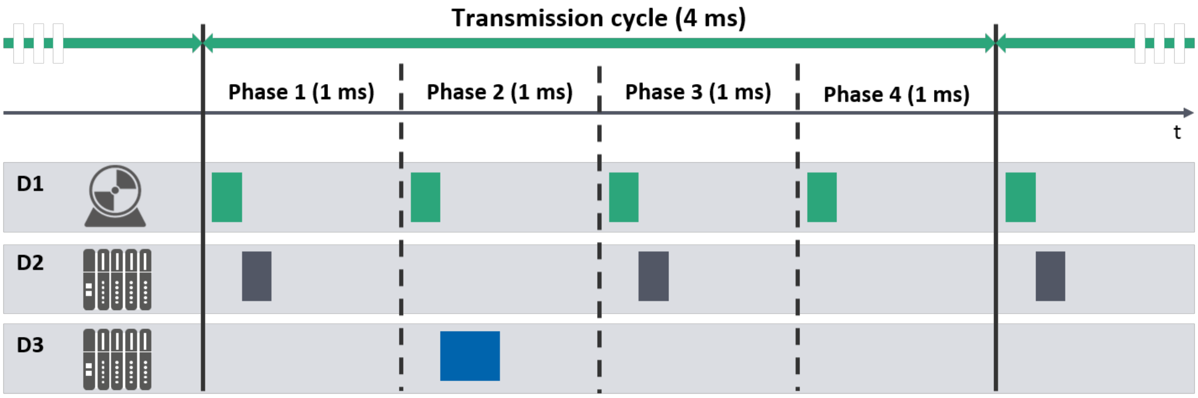


Figure 7-2: PROFINET transmission cycle

For fast update times the transmission cycle is subdivided into several phases. The phase time T_p is always an integer multiple of the PROFINET base clock of 31.25 µs, as given by the formula (7-1). This integer multiple is the *SendClockFactor*.

$$T_p = SendClockFactor \cdot 31.25\ \mu s \quad \textbf{(7-1)}$$

Update times, T_a, other than the minimum transmission clock, are achieved by using *a ReductionRatio* as given by the formula (7-2).

$$T_a = ReductionRation \cdot SendClockFactor \cdot 31.25\ \mu s \quad \textbf{(7-2)}$$

In the example in Figure 7-2 the minimum transmission clock resulting in an update time of 1 ms is required by the device D1. A *ReductionRatio* of 2 would be assigned to the device D2, and a *ReductionRatio* of 4 to the device D3, giving a transmission cycle of 4 ms.

The transmission clock, which defines the minimum clock for the transmission of packets, can be set in the controller. You can additionally set the transmission clock that defines the minimum clock for the transmission of packets. The chosen controller transmission clock will generally correspond to the fastest update time assigned to a device.

The following example illustrates the choice of timing for a typical application. Note that the values in this example have been chosen arbitrarily to illustrate the principle.

Example Controller data is to be transmitted to 4 devices with an update time of 4 ms.

If the controller transmission clock is chosen as 1 ms, a data packet will be transmitted every millisecond.

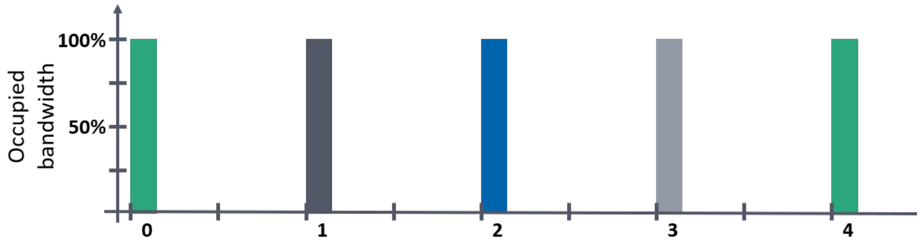


Figure 7-3: Network load, transmission cycle 4 ms, controller transmission clock 1 ms

However, if the controller transmission clock is chosen as 4 ms, the data packets will also be transmitted every 4 milliseconds.

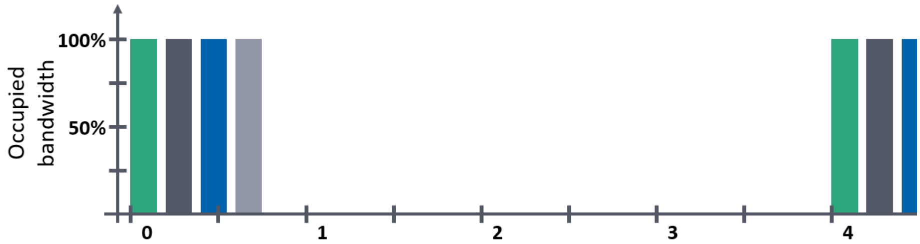


Figure 7-4: Network load, transmission cycle 4 ms, controller transmission clock 4 ms

In the first case, the load is evenly distributed within the transmission cycle, whereas in the second case the transmitted packets are bunched together giving an uneven load on the bus.

As shown in the example, it is recommended to keep the controller transmission clock short even with slower update times of the devices. This is done to achieve a better distribution of the generated network load. As a result, you should modify the *ReductionRatio* rather than the controller transmission clock when changing the update time of the devices.

Usually, these calculations are made by the engineering tool. Only the update time has to be preset by the user.

Once the update time has been defined, the PROFINET device will automatically transmit its data at the intervals given by the update time. With PROFINET RT-communication only this time interval, at which the data packets are to be sent and not the exact time, is defined.

The preset update time has a major impact on the transmitted data volume and, thus, the network load. This aspect will be detailed in the following chapter.

7.1.3 Network load

The ratio of the used bandwidth and the maximum available bandwidth is called the network load. The load distribution of the load over the considered time period is can be considered as random.

The period under consideration is important to the definition of the network load, because 100% of the entire network bandwidth is occupied for specific time periods during a transmission process, as shown in Figure 7-5, using a transmission cycle as an example. Packets of different length – 108 bytes (green, gray) and 300 bytes (blue) in the example – use the full bandwidth while being transmitted.

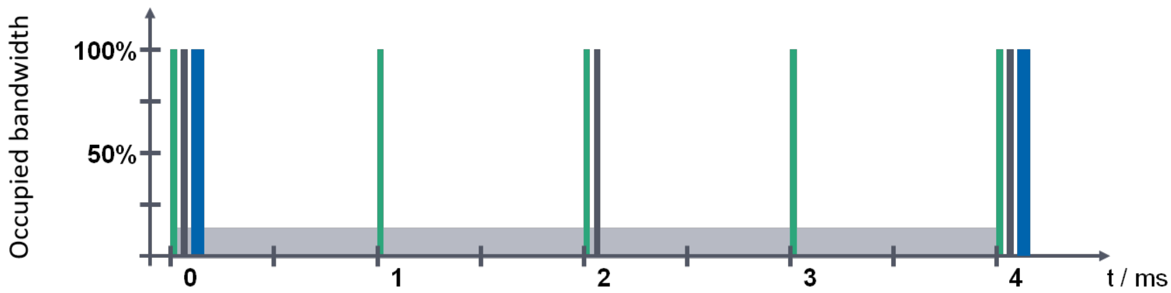


Figure 7-5: Example of the network load development during a transmission cycle

The distribution of the network load over the time period under consideration cannot be determined directly, as the values are always averaged. The longer the period under consideration, the more the averaging effect takes effect, i.e. short network load peaks are simply “blurred”. In the example shown in Figure 7-5 the network load is 2% related to 4 ms.

With PROFINET the data is usually transmitted in full-duplex mode, i.e. data is simultaneously transmitted and received. As a result, you can individually consider each communication direction.

The ratio of the used bandwidth and the maximum available bandwidth is called the network load.

Depending on the data volume to be transmitted and the preset update time the bandwidth required for the RT communication varies. The bandwidth available for NRT communication changes accordingly. Please note that Ethernet APL (see chapter 5) runs at a data rate of 10 Mbit/s. The mix of different link speeds in a network can lead to congestion issues in switches. Check chapter 7.4 for further information.

7.1.4 Response time of processing chains

Every PROFINET device sequentially executes its program within a specific cycle time. The inputs are read at the beginning and the outputs are set at the end of each cycle. The relative timing of these cycles to each other (see Figure 7-6) has an impact on the response time in a processing chain.

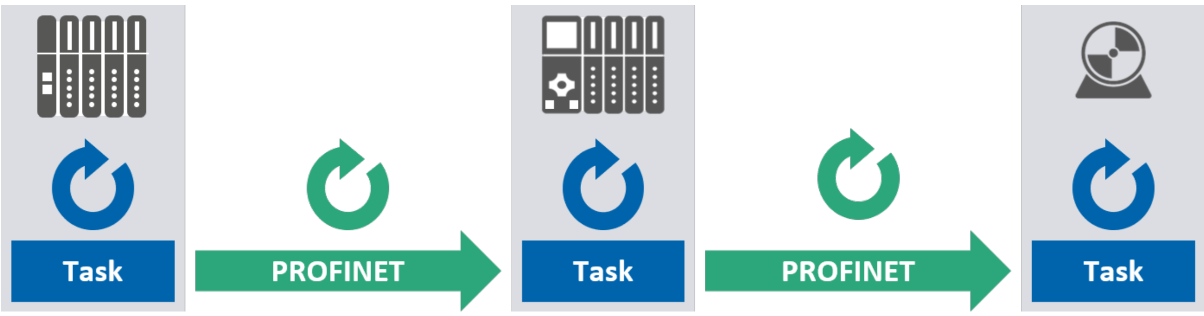


Figure 7-6: Cycles in the processing chain

Figure 7-7 shows an example for processing an event. This event could be, for example, the entry of a stop command for a motor.

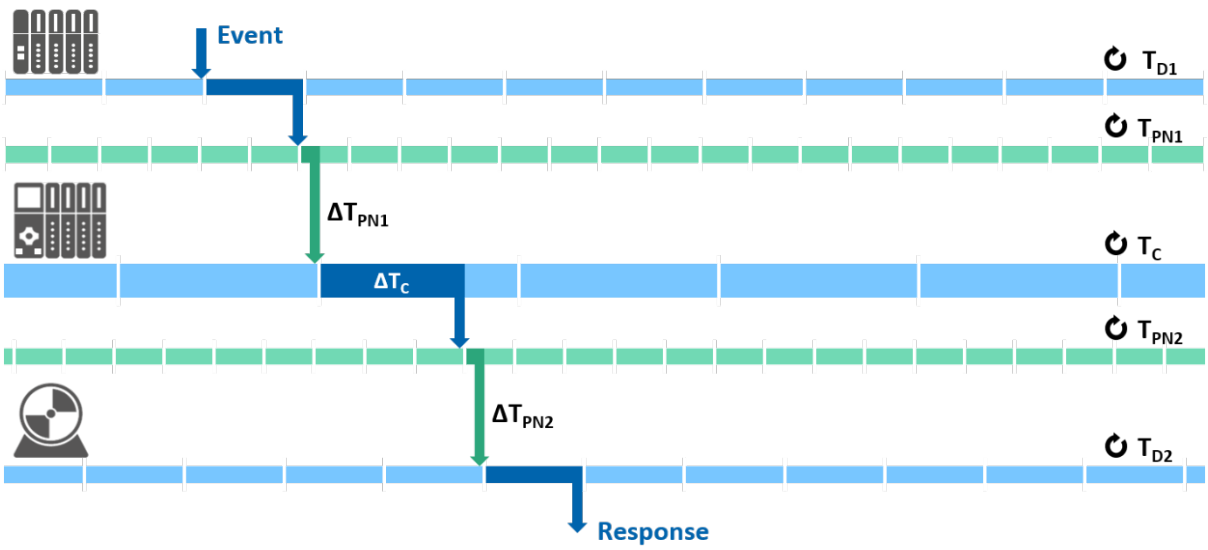


Figure 7-7: Examples of cycles in the processing chain, shortest response time

The execution time is determined by:

- The cycle time of the controller T_C.
- The processing time in the controller ΔT_C.
- The cycle times of the devices T_{D1} and T_{D2}.
- The cycle times / update times of the devices T_{PN1} and T_{PN2}.
- The transmission times of the data through the network ΔT_{PN1} and ΔT_{PN2}.

In this example it is assumed that the PLC tasks are cyclically executed in the controller, e.g. with IEC 61131-3-systems. It is assumed that the processing time of the PLC task ΔT_C is faster than the cycle time T_C of the task. If the tasks are executed in the controller cyclically ("PLC mode"), the cycle time of the controller T_C corresponds to the processing time in the controller ΔT_C.

In the best case, the data are received "just in time" right before the start of the next cycle and can be directly processed. No additional delay occurs.

In the worst case the execution must wait for an entire cycle in each processing step until evaluation and response will be possible again, see Figure 7-8. This consideration is based on the assumption that with cyclic processing the event has "just been missed" and processing will not be possible before the next cycle starts.

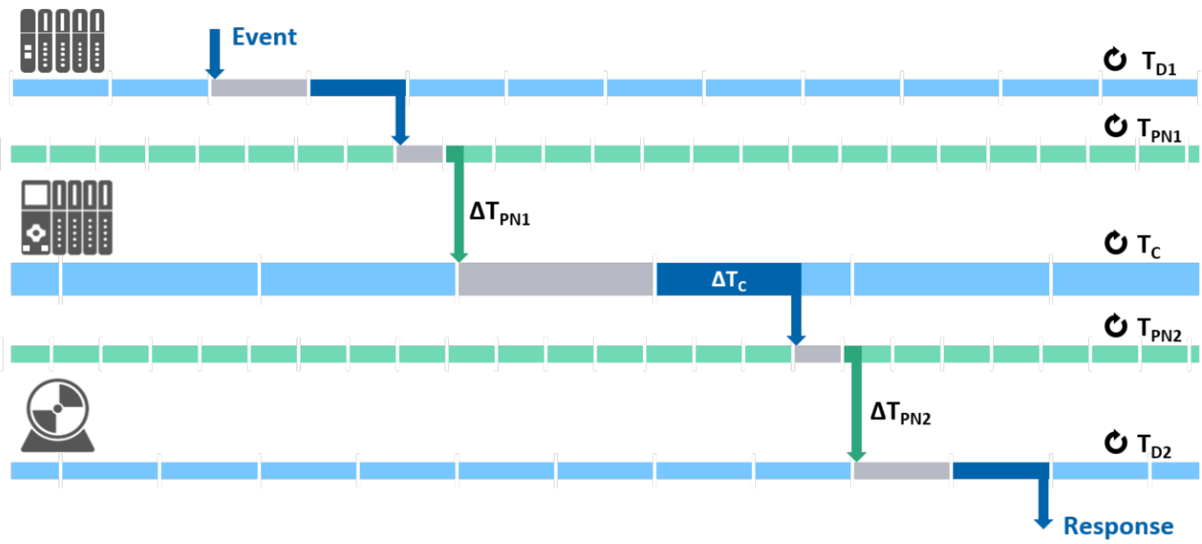


Figure 7-8: Examples of cycles in the processing chain, longest response time

As the cycles of the components in a system are not synchronized with each other, variations of the response time must be expected.

In the worst case the response time in the processing chain may be twice the time required in the best case, as shown in the following example:

Example Assuming

- T_C = 15 ms
- ΔT_C = 10 ms
- T_{D1} = T_{D2} = 3 ms
- T_{PN1} = T_{PN2} = 2 ms
- $\Delta T_{PN1} = \Delta T_{PN2}$ = 100 µs

gives a response time of

- min.
- $T_{D1}+\Delta T_{PN1}+\Delta T_C+\Delta T_{PN2}+T_{D2}$ = **16,2 ms**
- max.
- $2\cdot T_{D1}+T_{PN1}+\Delta T_{PN1}+T_C+\Delta T_C+T_{PN2}+\Delta T_{PN2}+2\cdot T_{D2}$ = **41,2 ms**

In the example described above, the impact of the PROFINET update time is rather low, as shown in the example below:

Example Reducing the response time T_{PN1} and T_{PN2} from 2 ms to 1 ms while maintaining the assumptions specified in the previous example will result in a minimum response time of 16.2 ms and a maximum response time of 39.2 ms.

In this case, the ratio of the update time and the controller cycle time is 1:15.

In the above example the reduction of the controller's cycle time has a considerably higher impact on the response time:

Example Reducing the controller cycle time T_C from 15 ms to 10 ms with a controller processing time ΔT_C of 5 ms while maintaining the other assumptions of the first example gives a minimum response time of 11.2 ms and a maximum response time of 31.2 ms.

In this case, the ratio of the update time and the controller cycle time is 1:5.

A change of the ratio of the update time and the controller cycle time will result in a change of the response time.

Make sure that the response time of your control system is sufficiently fast for your application, but only as fast as needed.

7.2 Planning of the IO cycle

The following section deals with the definition of the device configuration. In this context, the PROFINET update times and monitoring functions are discussed.

7.2.1 Planning of update times

Controllers operate cyclically with a specified update time. The update time of all other PROFINET devices must be defined as a function of the controller cycle time. For multi-controller applications the devices assigned to the corresponding controller must be considered.

With fast update times the data will be updated at shorter intervals. As a result, they will be available for processing more quickly. However, the data volume transmitted in a time period and, thus, the network load is increased.

Figure 7-9 illustrates how the network load increases as a function of the update time and the number of network nodes, using the typical PROFINET packet size 108 bytes (60 bytes payload data) as an example.

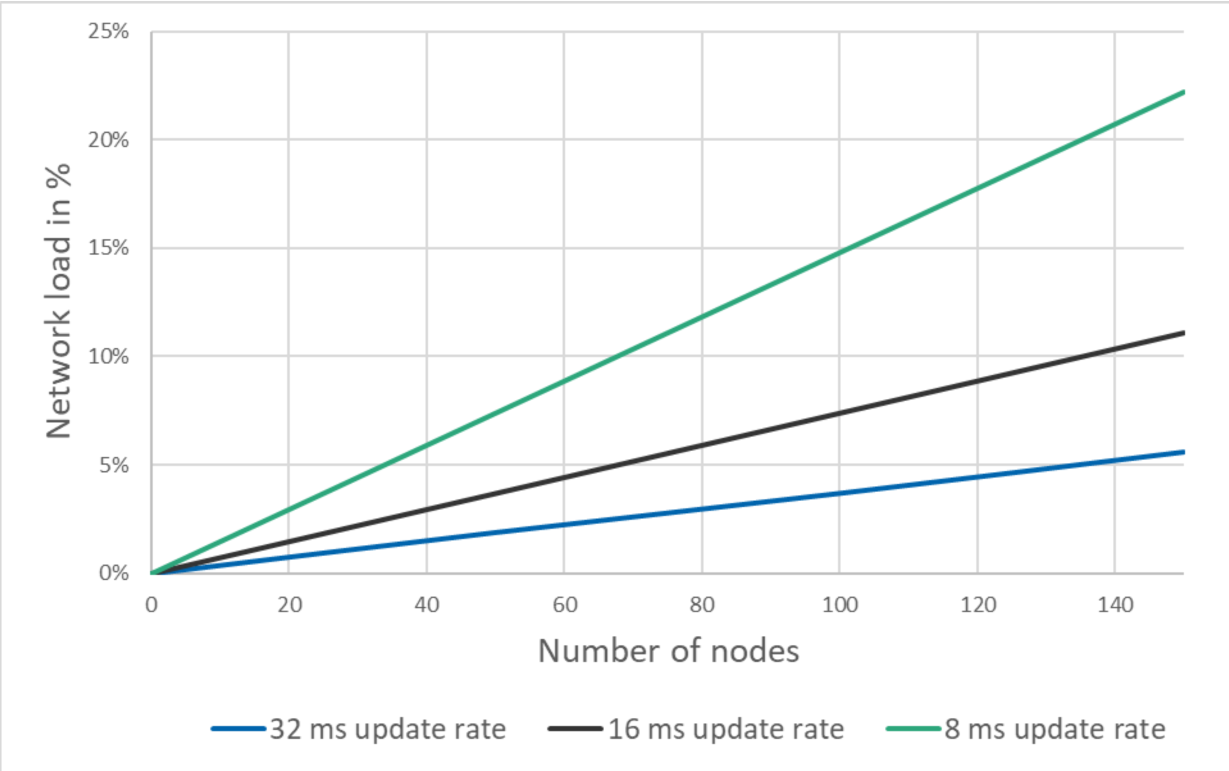


Figure 7-9: Cyclic PROFINET network load as a function of update time and number of network nodes (typ. PROFINET packets) at 100 Mbit/s data rate

When the network load is increased by cyclic real-time communication, the bandwidth available to other communications decreases. The network load topic is discussed in more detail in chapter 7.3.3.

Ethernet APL (see chapter 5) runs at a data rate of 10 Mbit/s and is intended to connect sensors and actuators to the PROFINET network. The typical network updated times in the process industry used for Ethernet APL field devices and are slow, compared to factory automation. Therefore, the network update rates for Ethernet-APL sensors should be set to values that fit the need of the process automation application (e. g. 128 ms). Detailed information about the calculation of the network load of Ethernet-APL segments can be found in [APL2021].

The faster the update time, the larger the bandwidth occupied by cyclic real-time communication.

The slower the update time, the slower the response time.

It is therefore recommended to choose the update time per PROFINET device as fast as required and as slow as possible.

Observe the line depth and update time specifications in chapter 7.3.1.

- Define the update time for all devices.
- Bear in mind that you have to adapt the update times accordingly when using wireless transmission technologies.
- Check the response time of the entire system resulting from this.
- Document these specifications.

7.2.2 Definition of PROFINET communication monitoring

Data transmission errors may occur in a network. As a result, communication monitoring must be fault-tolerant to a certain extent. However, it must be possible to detect an error as early as possible to be able to react accordingly in the event of communication failure, e.g. by setting outputs to a defined state. The goal is to check and, if required, adapt communication monitoring.

The communication monitoring function in a PROFINET network checks if valid data are received. If no valid data are received within a preset time or number of communication cycles, it is assumed that an error has occurred.

In the following description, the number of communication cycles without valid data after which an error is assumed is called the threshold.

The designation of the communication monitoring setting depends on the manufacturer. Examples include:

- “Number of accepted update cycles with missing IO data”
- “Number of update cycles without IO data”
- “Number of faulty telegrams before communication is terminated”

Figure 7-10 illustrates the process of setting the standard threshold to 3.

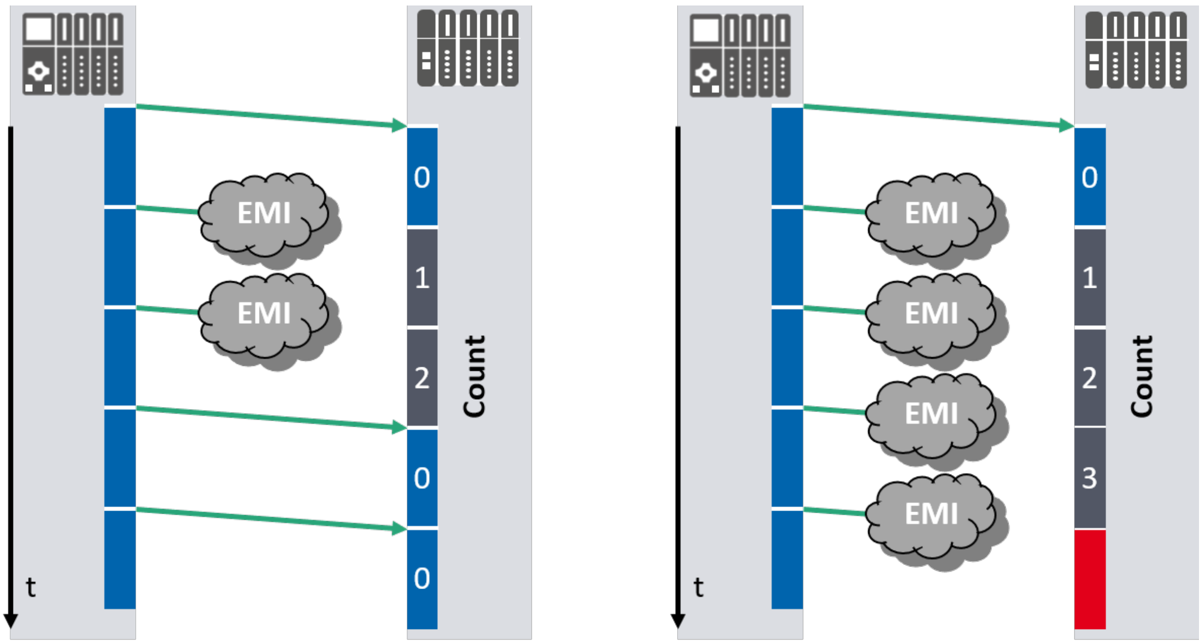


Figure 7-10: Communication problems with error threshold 3

In the first case (left part of the figure) the communication is disturbed for two cycles, for example by electromagnetic interference (EMI). As the threshold is not reached, the counter is reset at the restoration of the communication, and normal communication continues.
If the problem persists for a longer time (right part of the figure) a communication error is assumed and the communication is terminated.

The threshold value determines the time from which on the absence of data will be considered as an error.
The higher the threshold, the later a communication error will be recognized. Figure 7-11 shows the situation of a persistent communication error, using the standard threshold of 3 and a threshold of 10 as an example.

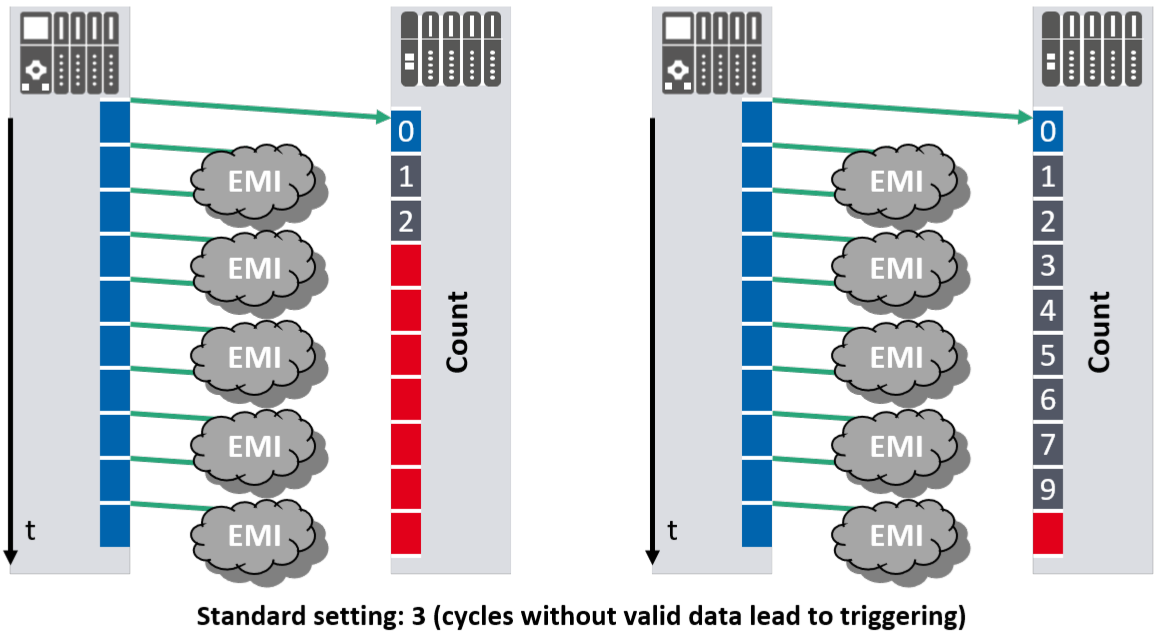


Figure 7-11: Comparison of low (3, left) and high (10, right) threshold

The time until an error is recognized is given by the communication cycle time and the threshold. This means that with a standard threshold of 3 and an update time of 2 ms an error would be detected after 6 ms, whereas an update time of 4 ms would result in an error detection time of 12 ms, etc.

A higher threshold increases the fault tolerance in case of problems, but also delays the detection of an error.

It is recommended to keep the standard threshold setting of 3. If you should choose another threshold value, you have to check if the response time in the event of an error is sufficiently short.

Define the thresholds for the monitoring function and document your settings.

7.3 Checking the performance of the planned network topology

Having defined the update times and the monitoring functions, the designer should check the expected performance of the planned topology.

7.3.1 Checking the line depth for 100 Mbit/s network

Each switch that is placed between a device and its controller introduces a delay in the data transfer. The number if switches between a controller and a device is called the line depth. The designer must take account of the line depth in the proposed topology. A line topology will exhibit a significant line depth because of the integrated switches in the devices. A large line depth will introduce delay which must be considered when planning the topology. Figure 7-12 shows an example with a line depth of 9.

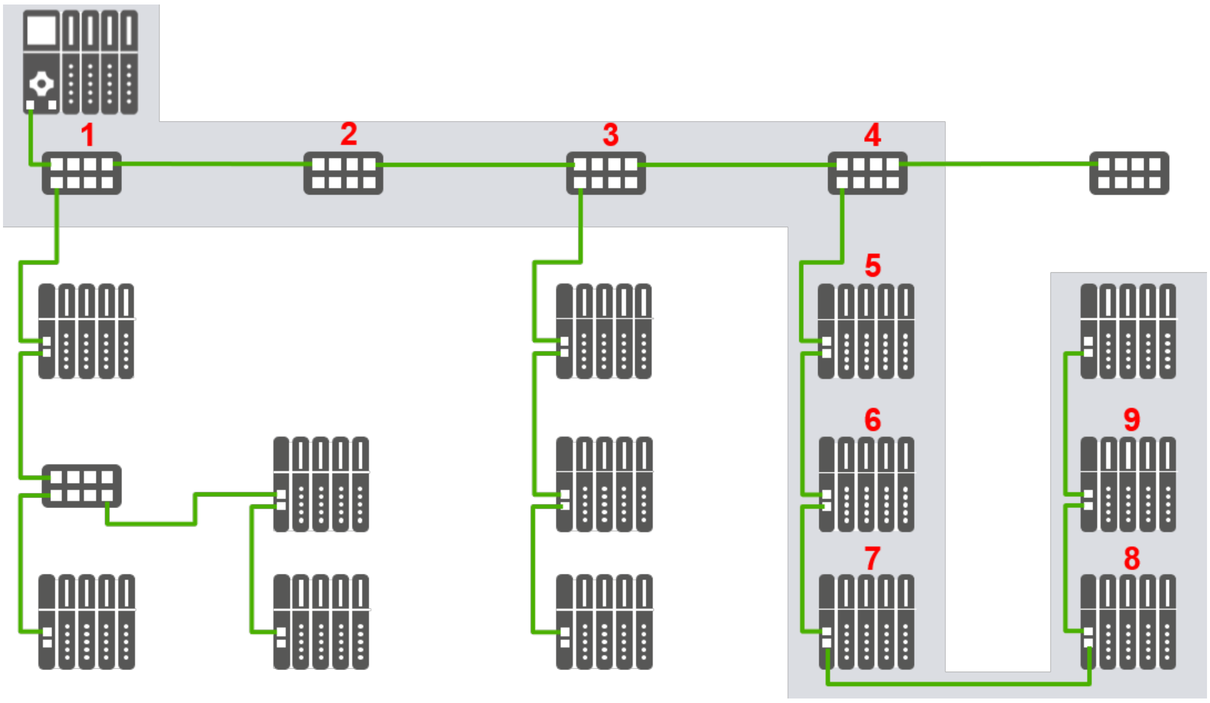


Figure 7-12: Line depth example

Usually, critical communication relations occur between devices and controllers. If more than one controller is involved, the devices assigned to each controller must be considered.

The larger the line depth, the larger the delay of data transmission. As a result, the data will have a certain age when it arrives at the destination. Excessive line depth should be avoided for time-critical applications.

A large line depth may affect the response time.

Check which type of switches ("Store and Forward" or "Cut Through") are to be used in your network. Store and Forward switches give more delay than Cut Through switches. If you do not know the type of switches used, assume "Store and Forward" switches, to be on the safe side.

The maximum line depths listed in Table 7-1 are valid for "Store and Forward" switches.

Table 7-1: Maximum line depths with "Store and Forward" switches

Update rate	1 ms	2 ms	4 ms	8 ms
Maximum line depth	7	14	28	58

In a worst-case scenario, the processing time for these line depths in a line topology is as large as the update time.

The maximum line depths listed in Table 7-2 are valid for "Cut Through" switches.

Table 7-2: Maximum line depth with "Cut Through" switches

Update rate	1 ms	2 ms	4 ms	8 ms
Maximum line depth	64	100	100	100

It is recommended to plan a maximum line depth of 45, for the benefit of higher availability and easier diagnosis.

This also allows future extensions using media redundancy (MRP).

A mixed setup of “Store and Forward” and “Cut Through” switches can be used. In this case it is recommended to assume the limit values for “Store and Forward” switches or explicitly calculate the processing time.

If it should not be possible to observe the values specified in Table 7-1 resp. Table 7-2. You should re-design the structure of your network. It is, for example, possible to segment line topologies to achieve several short lines, as shown in Figure 7-13.

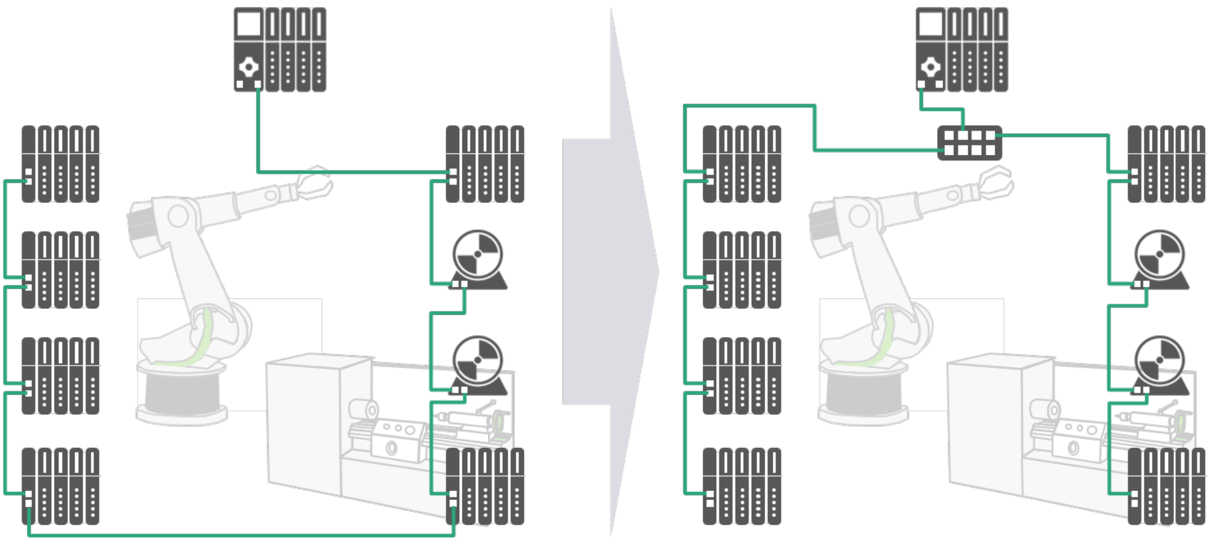


Figure 7-13: Example of reduced line depth

The re-structuring options depend on the structure of your individual plant. Possible additional expenditure for supplementary switches or cabling is compensated by a higher plant availability and shorter plant response time.

Check the line depth of your plant. If required change the topology. Take into account the specifications in Table 7-1 resp. Table 7-2.

7.3.2 Checking the line depth for Ethernet-APL networks

Ethernet-APL allows to connect APL field devices directly to a PROFINET network by using the 10Mbit/s Ethernet Advanced Physical Layer (Ethernet-APL). Possible network structures can be found in chapter 5. Figure 5-2 shows a topology, that connects the APL field devices via a field switch directly to the 100 Mbit/s PROFINET network.

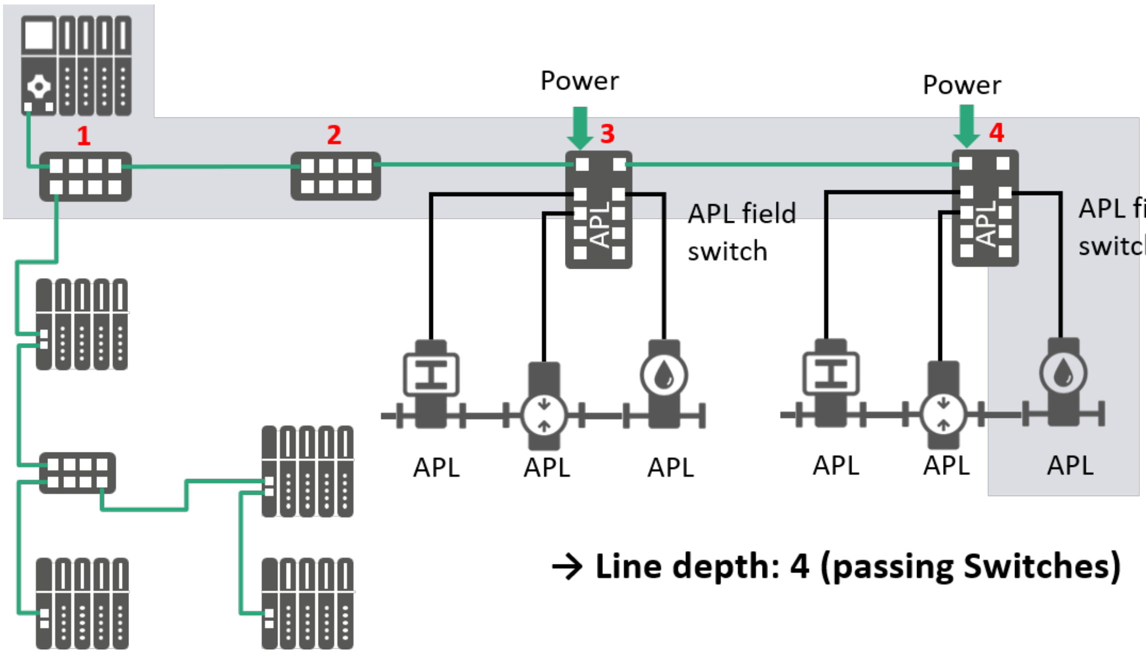
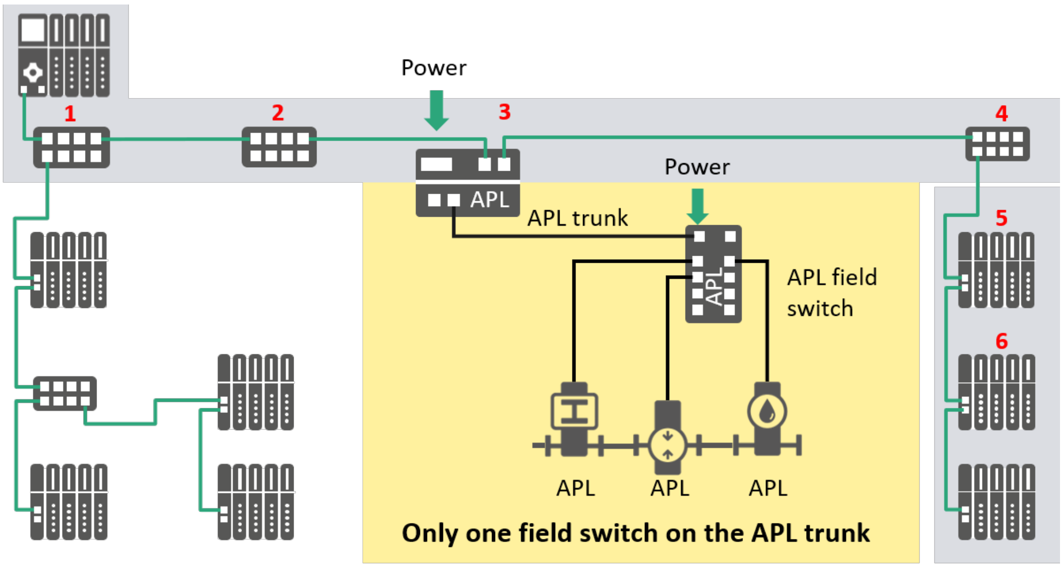


Figure 7-14: Line depth with APL Field-switches connected to 100 Mbit/s network

Figure 7-14 shows the calculation of the line depth for network with Ethernet-APL field switches that are directly connected to the 100 Mbit/s PROFINET. The calculation principle is the same as described in chapter 7.3.1.

For an APL topology with a powered trunk, as shown in Figure 5-3, the line depth of the trunk has to be considered in addition to line depth known up to now.



Editable name of event

Figure 7-15: Line depth with APL trunk

Figure 7-15 shows a system with an APL trunk. Up to now, only one APL field switch is allowed to be connected to a trunk

The limitation to one field switch per trunk is a preliminary value due to PROFINET as conformance testing is ongoing. This limitation is not related to Ethernet-APL and is assumed to be changed in future.

7.3.3 Checking the cyclic real-time network load

You should have defined update times of the PROFINET devices in a previous step.

As already mentioned in chapter 7.2.1, every PROFINET device generates a specific cyclic network load with a given update time. In this chapter, the cyclic real-time network load (RT network load) is analyzed and evaluated.

Figure 7-16 shows a PROFINET network with one controller and several devices as an example. For illustration purposes, it is assumed that each device in the example generates a cyclic real-time network load of 1%. This value is used for illustration, only. In a real plant it is usually smaller. In the example only the direction from the device to the controller is investigated, although the data are actually transmitted in both directions.

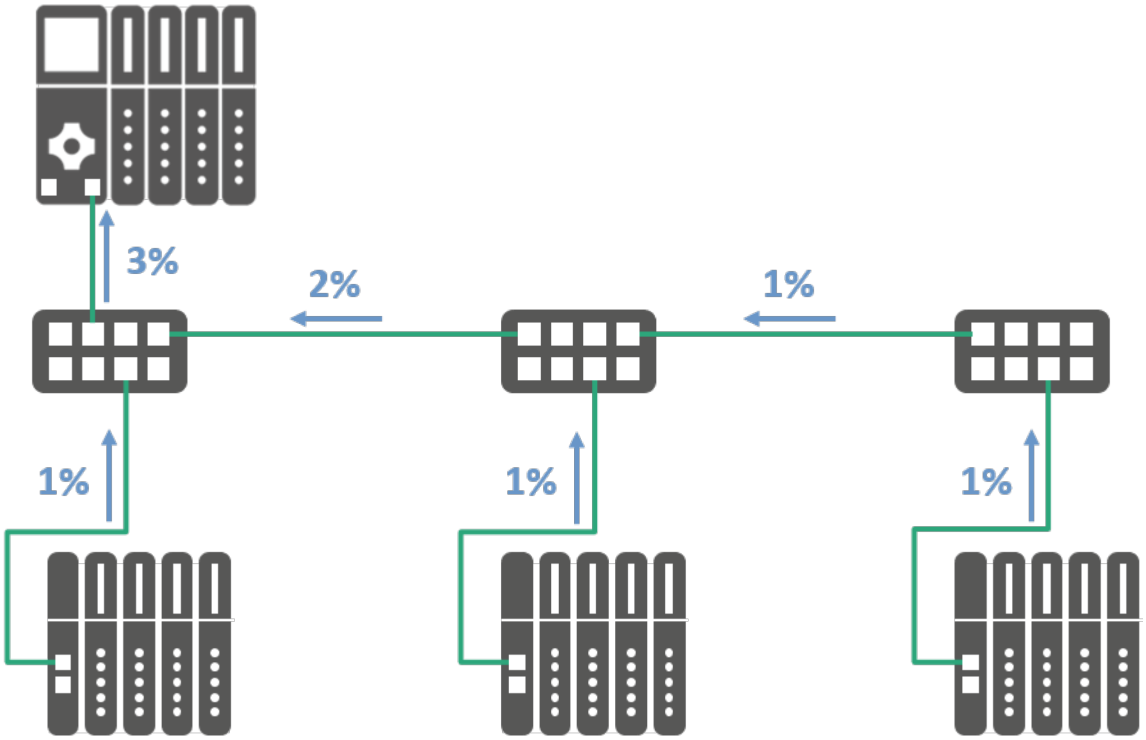


Figure 7-16: Example of network load distribution in a single controller application

As shown in the example, the data streams in the same direction add up. The highest network load, i.e. the total of all network loads generated, occurs in the link between the switch and the controller.

This applies also to applications with multiple controllers. As an example, the given configuration is extended by another controller and three assigned devices, as shown in Figure 7-17. At the locations highlighted red the network loads of the different controllers add up.

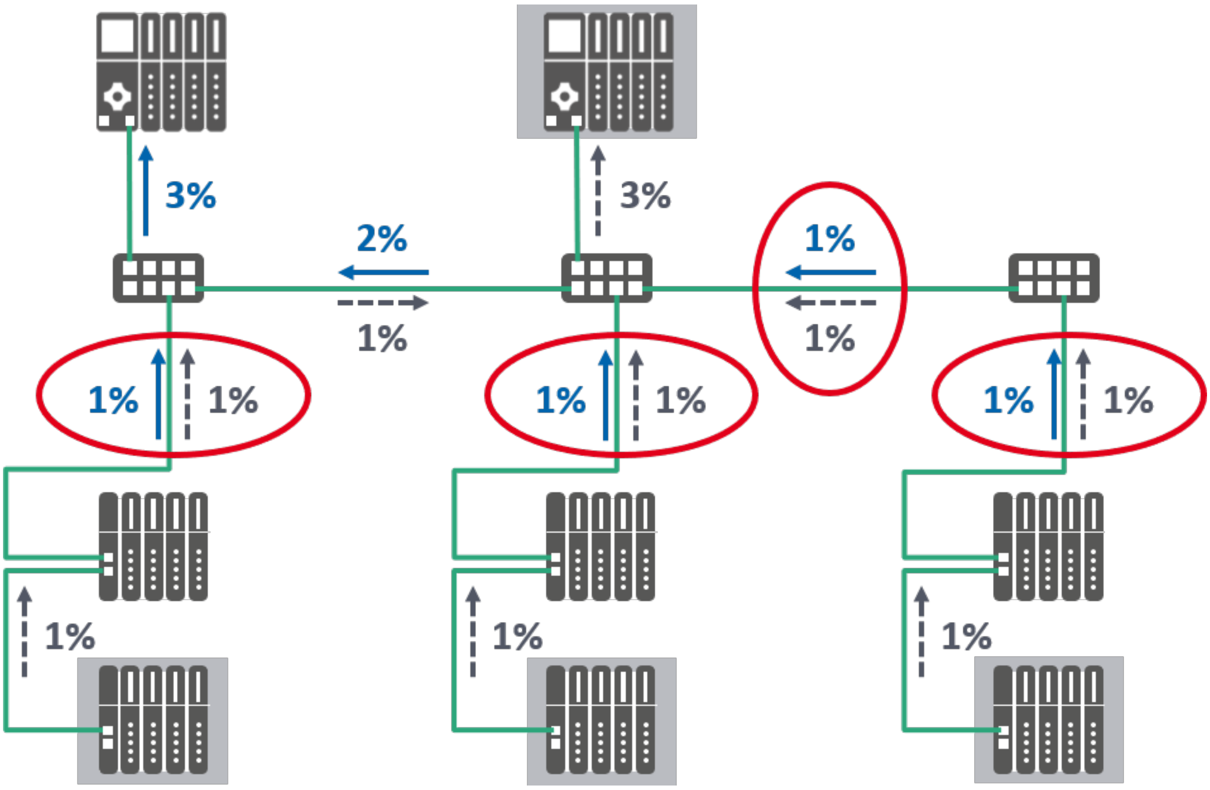


Figure 7-17: Example of network load distribution in a multi-controller application

It is important for your planning to identify the critical locations in your topology, i.e. the locations of maximum network load. In the given example these are the links to both of the controllers.

The critical locations are those of maximum network load.

The communication runs simultaneously in transmit and receive direction. In practice it is sufficient to analyze only the direction with the higher load.

In order to be able to identify the critical locations, you have to know the cyclic real-time network load generated by each PROFINET device, which depends on the update time and data volume.

Table 7-3 is an example of the cyclic real-time network load generated by PROFINET devices at different update times and assuming a network bandwidth of 100 Mbit/s. A typical PROFINET packet of 108 bytes (60 bytes payload data) is considered. As the data volume depends on the application, this table is only intended to give you a first idea. It is recommended to calculate the generated network load for your individual application.

Table 7-3: Generated cyclic real-time network load (typ. PROFINET packet size 60 byte of PROFINET payload data, 100 Mbit/s)

Update time	Generated cyclic real-time network load per PROFINET device
1 ms	0.86 %
2 ms	0.43 %
4 ms	0.22 %
8 ms	0.11 %

The specified values include Preamble, StartFrameDelimiter and InterFrameGap.

Determine the network load of your plant and identify critical locations.

The network load calculation tool is available free of charge for download at:

www.profinet.com
under "Download > Installation Guide > PROFINET Installation Guide"

An overview of the user interface as well as a short user manual is provided in the Annex.

Programs for network load calculation are also offered by various vendors. Usually, the engineering tool also provides this option.

Refer to Table 7-3 an introduction.

In order to provide sufficient reserve for future extensions and especially for NRT communication, it is recommended to observe the limit values specified in Table 7-4 when designing your PROFINET network.

Table 7-4: Limit values for the network load of cyclic real-time communication

Network load	Recommendation
<20%:	No action required.
20…50%:	Check of planned network load recommended.
>50%:	Take the appropriate measures to reduce the network load.

There are various options, of which the following should be considered first:

Increasing the update time (see chapter 7.2.1).

- **For multi-controller applications: Separating PROFINET devices assigned to the corresponding controller to different network paths**, thus reducing the load of links with parallel data traffic as shown in Figure 7-17.
- **Connecting subnets via additional network adapters in the controller**
- **Using additional controllers for load distribution:** The controllers should be connected to the network via separate paths to actually reduce the network load in critical sections.

Change the topology as required and document the changes.

Ethernet-APL networks require the same considerations with respect to network load, as described in this chapter, but adapted to the 10 Mbit/s data rate of the Ethernet-APL network. A detailed description of the network load calculation for Ethernet-APL networks can be found in the Ethernet-APL Engineering Guideline [APL2021].

7.3.4 Checking the non-real-time network load

PROFINET allows standard Ethernet nodes such as video cameras, PCs or control panel to be directly integrated into the plant network.

Consideration must be given to the effect of such devices on the performance of real-time communication. The PROFINET data traffic and the standard Ethernet data traffic may interfere. Standard Ethernet nodes may under certain circumstances exchange large data volumes.

The following scenarios are possible:

Regular NRT communication: For example, a video stream from a camera to an evaluation PC. Additional network load is permanently generated.

Temporary NRT communication: Data streams that occur only occasionally, for example during a data backup on an archive server, or during call up of process graphics at an operator station.

Figure 7-18 shows an example topology with an archive server (temporary NRT communication) and a video camera and an operator station representing standard Ethernet nodes that regularly generate NRT communication (video stream).

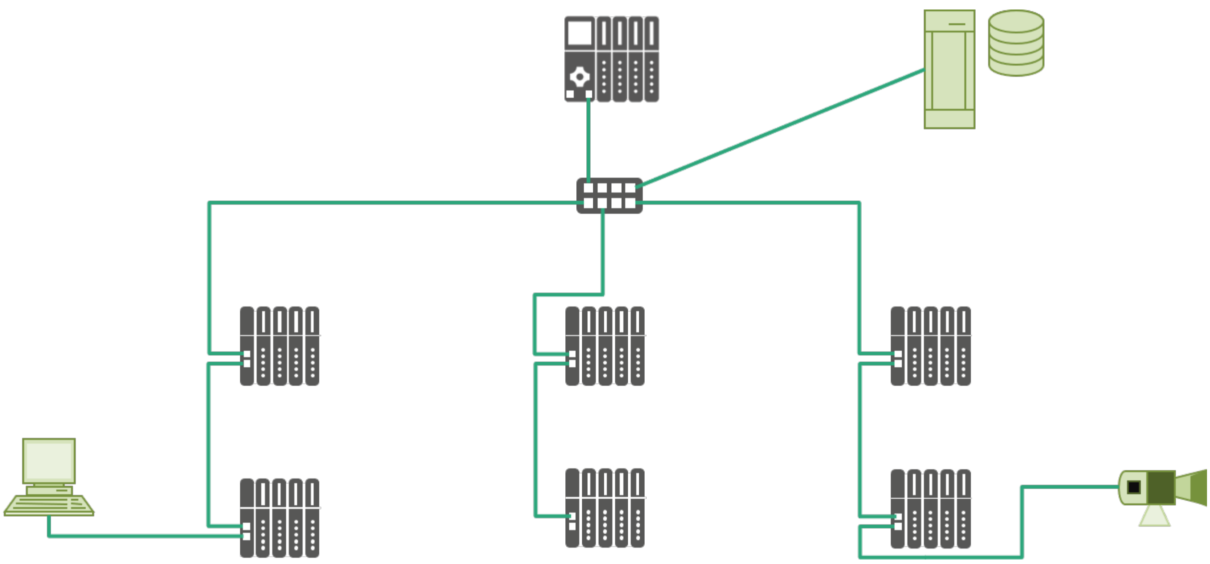


Figure 7-18: Example topology with standard Ethernet nodes

It is often very difficult or even impossible to exactly determine the additionally generated network load. If it can be determined, this information is useful for evaluating the total network load.

If possible, determine the **regular** NRT network load.

This load adds up to the cyclic real-time network load described in chapter 7.3.3. If required, identify the critical locations of your topology again and check if the network load limits specified in chapter 7.3.3 are complied with.

For temporary NRT communication it is often not possible to determine when communication actually occurs.

Some standard Ethernet nodes also prioritize their data packets. This may cause priority conflicts with PROFINET packets, which are consequently no longer getting higher priority compared to other prioritized packets.

This applies especially to image (camera) and voice (VoIP) data streams.

All network nodes that generate image or voice data streams should there for be checked for possible message prioritization. Where present the prioritization should be disabled if possible. If, however, this prioritization cannot be disabled or you cannot reliably determine whether these devices conduct prioritized data transmission or not, it is recommended to separate these data streams.

If required separate network nodes that prioritize their messages.

Change the topology if required and document these changes.

Communication relations not only exist between controllers and devices. Devices can also communicate with each other. This type of communication often occurs between standard Ethernet nodes.

Figure 7-19 shows a typical example of this type of communication between standard Ethernet nodes. A large data volume is transmitted from a camera to an operator station.

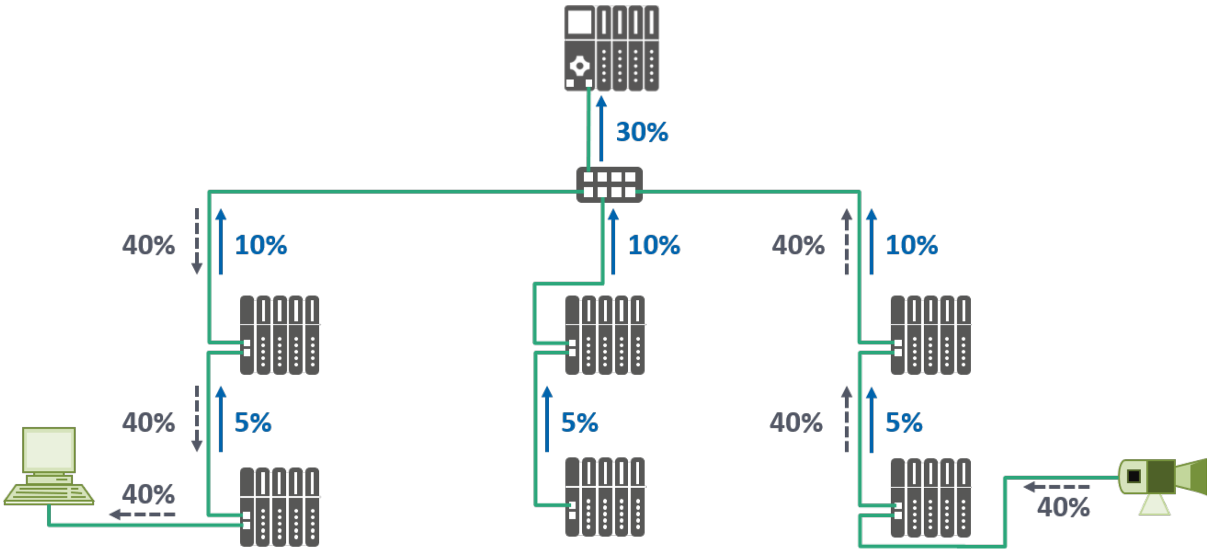


Figure 7-19: Integration of standard Ethernet nodes

Disadvantageous topologies as shown in the example in Figure 7-19 imply that the data stream runs throughout the entire plant network, generating additional load on the parts that convey cyclic real-time communication. In the example the additional communication volume would cause a network load of 50% in some locations (Figure 7-19, red circle).

To solve this problem the topology should be changed. In the example, the camera and the PC could be directly connected to the switch. As a result, the large data stream would no longer represent a considerable load for the other sections of the network, see Figure 7-20.

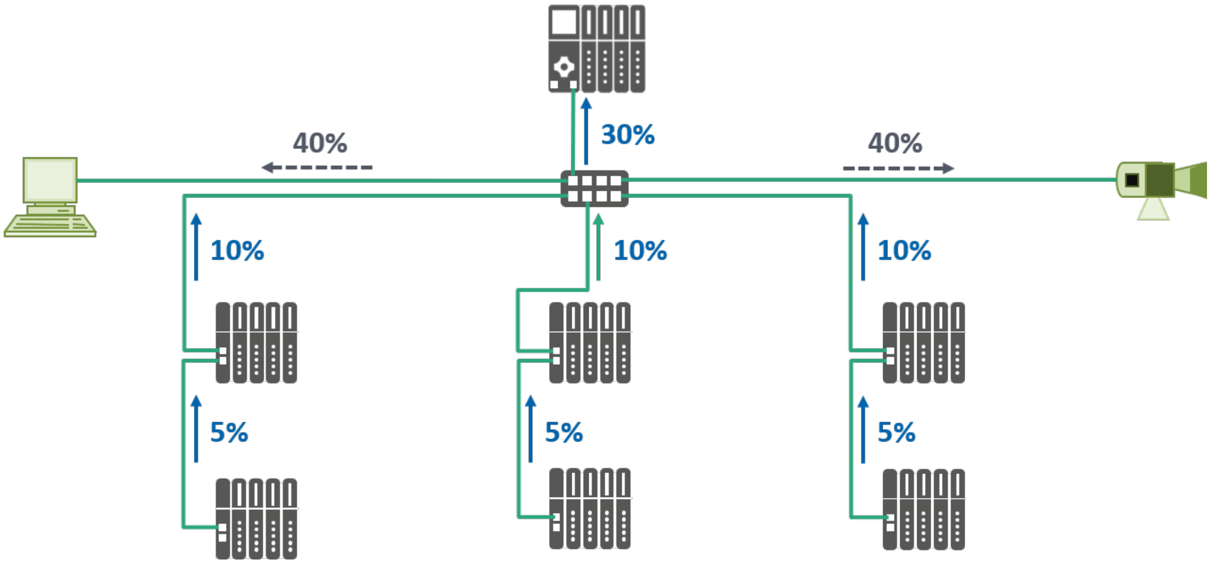


Figure 7-20: Optimized topology with reduced network load

Usually, switches have a sufficient internal bandwidth, so “crossing” data streams usually do not affect each other.

Check if it is necessary to separate data streams.

Change the topology, if required, and document these changes.

7.4 Mixed link speeds and star topology

This chapter deals with networks that use different data rates (link speeds) in different parts of the network. In addition to that the impact of topologies with a star structure will be covered. These two items are discussed here together, as they both may lead to the loss of data in switches, called congestion loss, if not observed during the planning process.

7.4.1 Problem Description mixed link speeds and star topology

Mixed Link speeds: The previous chapters of this document assumed a data rate of 100 Mbit/s throughout a PROFINET network. Due to technical progress, higher data rates like 10 Gbit/s, 1 Gbit/s are now applicable for PROFINET [PNO2024]. At the same time lower data rates of 10 Mbit/s will be used to directly connect sensors and actuators to PROFINET, e. g. by using the Ethernet-APL physical layer [APL2021] or a network connection according to Single Pair Ethernet [IEEE P802.3cg]. This leads to a situation where a mix of different data rates, called mixed link speeds are used in a single network. Mixed link speeds put additional requirements on a switch, as the amount of data coming into the switch on a high-speed link, needs to be forwarded to one or more links with a lower speed. If these data streams are not balanced properly, a data loss might occur in a switch. This data loss is called congestion loss.

Star topology: Field devices build as end stations are connected to a switch. Switches with higher port counts are typically used in this case. In star topology, congestion loss is possible, if the buffer size on the uplink port is not sufficiently large. APL field switches, that connect a larger number of field devices in a star manner to an uplink, are an example for this case. The Ethernet APL Physical Layer allows connecting Ethernet APL Field devices to PROFINET [APL2021].

7.4.2 Example System

Figure 7-21 shows a sample system that illustrates the mixed link speed as well as the star topology issue. Please note that this is a simplified example only. Typical systems that use such high data rates consist of far more components than are shown here.

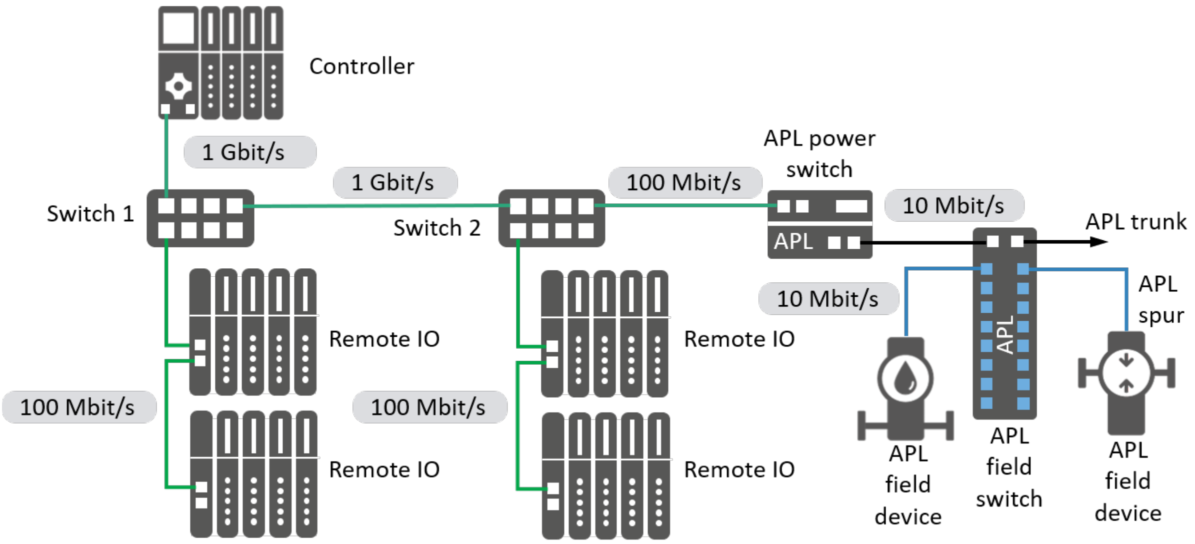


Figure 7-21: Mixed Link speeds and star topology in a PROFINET system

The connection between the Controller and Switch 1 as well as the connection between Switch 1 and Switch 2 operate at a link speed of 1 Gbit/s. The connection between Switch 2 and the APL power switch runs at 100 Mbit/s, as well as the connection to the Remote IOs. The Ethernet-APL connection between the APL power switch and the APL field switch, called APL trunk, as well as the connection between the APL field switch and the APL field devices runs at 10 Mbit/s.

In this example the controller serves as the central processing point that receives and send all data from and to the devices. The link speed data rates are increasing from the sensors to the controller according to the data volume to be transferred. The use of mixed link speeds is a good measure, to adapt the bandwidth of the links to the needs of the application. At the same time, mixed link speeds need special attention with respect to congestion loss.

In parallel the example in Figure 7-21 shows on the right side a star topology with an Ethernet-APL field switch. The field switch is able to connect 16 devices to a single uplink, the Ethernet-APL trunk.

In parallel to the described real time communication via PROFINET additional communication relations like OPC-UA or http-connections to web servers in the devices can exist.

7.4.3 Prioritized queues in network switches

This chapter will explain different scenarios that lead to congestion loss. In order to understand the issue of congestion loss in general, a closer look at the function principle of a switch has to be taken.

PROFINET uses prioritized network traffic according to [IEE802.1Q]. This standard defines eight priorities from 0 (low) to 7 (high). In order to simplify the following example, only two out of the eight priorities are considered. The examples differentiate between non-real-time traffic (NRT) with a low priority and real-time traffic (RT) with a high priority.

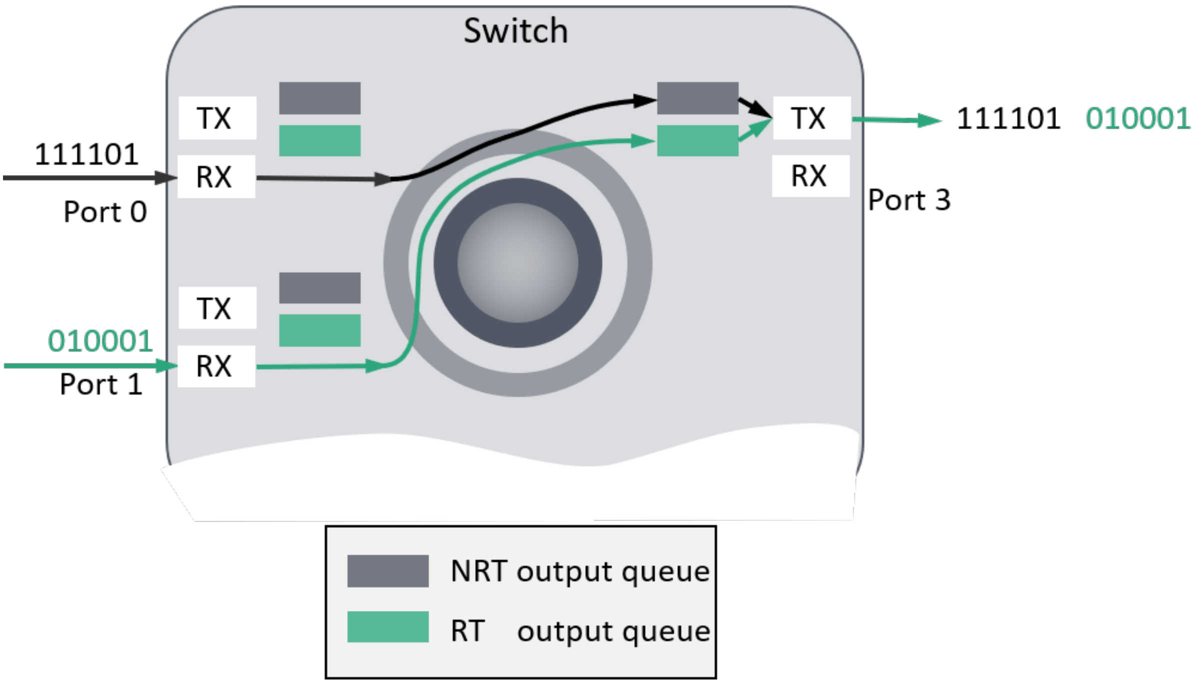


Figure 7-22: Switch principle with queues

Figure 7-22 shows the simplified structure of a switch. A switch is a device that receives an Ethernet data packet on an ingress port (RX) and forwards the data package to an egress port (TX), depending on the address information in the data packet. Every port of a switch (white squares with TX and RX) connects to a cable, also called link. Every link can receive and transmit data, usually in full duplex mode. Switches used for PROFINET usually support the prioritization of traffic according to IEEE 802.1Q. This allows us to assign a priority between 0 and 7 to each data packet. The switch provides different queues for the outgoing data of each port, assigned to the different priorities. As already described, Figure 7-22 will only show two out of the eight queues for the priorities. Outgoing data is sent according to its priority.

When working with mixed link speeds, it is helpful to limit the amount of data on the incoming section of the port with the high data rate, in order to ensure propagation of data to the ports with the lower data rate. For this purpose, ingress rate limiters are used. [PNO2022] describes ingress rate limiters in switches in Figure 7-22. The rate limiting is based on [IEE802.1Q] chapter 8.6.5.

7.4.4 Congestion loss due to prioritization of messages

Figure 7-22 shows the prioritized buffers in a simplified manner. For each port the output buffers for high priority data packets (named RT, green box) and the output buffers for low priority packets (named NRT, grey box) are shown. If a prioritized RT packet (green line) comes in at port 1, the packet is received, the destination address in the packet is read and the switch electronics forwards the packet to the respective destination port. In this case port 2. There the RT packet is stored in the output queue for RT packets (green box) and afterwards the packet gets sent via port 2. If at the same time, a low priority (NRT) packet (black line) enters the switch at port 0 and if the packet has the same destination port, the switch electronic will forward the package also to port 2, but will store it in the NRT output queue. The priority scheme at the output now ensures that the data in the RT queue will be sent first, afterwards, if the RT queue is empty, the switch will send the NRT packet. Due to hardware constraints the size of the output queues (i. e. the number of packages that can be stored in a queue) is limited. If more packages enter the queue as the packages leave the switch through the port, the queue gets overloaded and, in this case, typically the NRT data packages are dropped, due to the limited size of the output queue. In case that there is a high amount of outgoing RT packets, the buffer for the NRT packages might get full, resulting in the drop of NRT packages. We will refer later to this as **Case 1: Priority Congestion loss**.

In many cases the NRT communication (e. g. http or https) operates connection oriented. This means that the TCP/IP protocol detects the loss of data packets and repeats them. Therefore, priority congestion loss will lead to a degradation of the connection speed but not to a real loss of the NRT data, if the used protocol supports adaptation to the available bandwidth and retransmission.

7.4.5 Congestion loss due to input / output unbalance port count wise

As the priority impact has been considered in the previous chapter, this chapter will focus on data packages with the same priority.

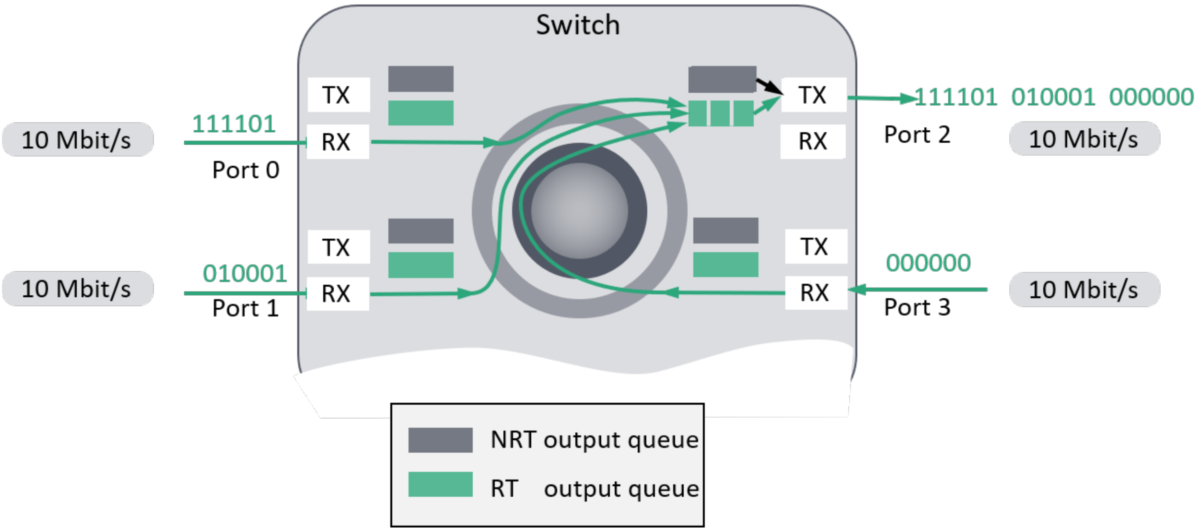


Figure 7-23: Congestion loss due to input/output unbalance port wise

Figure 7-23 shows an example, where three incoming data packets on port 0, 1 and 3 shall be forwarded to port 2. If the size of the output buffer of port 3 allows to store all three packets, the transmission of the data will be o.k. In case the buffer is smaller, one or more of the data packets are dropped and congestion loss occurs.

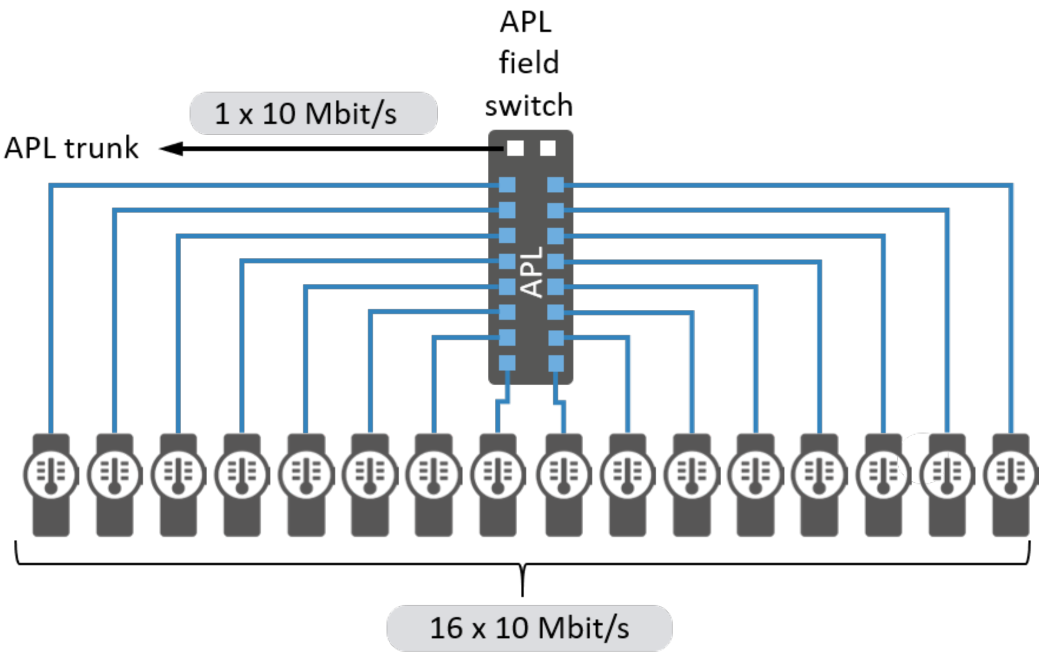


Figure 7-24: Example for input/output unbalance port count wise

An example for such an imbalance is shown in Figure 7-24. In this example, the Ethernet-APL field switch is shown. In this case, the APL field switch has 16 spur connections to connect the APL field devices with 10 Mbit/s each and one 10 Mbit/s connects the field switch to the power switch (see also overview in Figure 7-21). It can be seen that in an unfavorable situation (e. g. all devices randomly send data packets at the same time) a congestion loss could possibly happen. In case the APL field switch operates as a PROFINET device itself, the number of nodes will even go up from 16 to 17. This issue will be further referenced as **Case 2: Congestion loss input / output unbalance port count wise.** Chapter 7.4.9 will dig into a differentiation between permanent and spurious congestion.

7.4.6 Congestion loss due to input / output unbalanced link speed wise

The previous two chapters covered congestion loss examples, where all links operated at the same link speed. The next example will now provide an example with mixed link speeds.

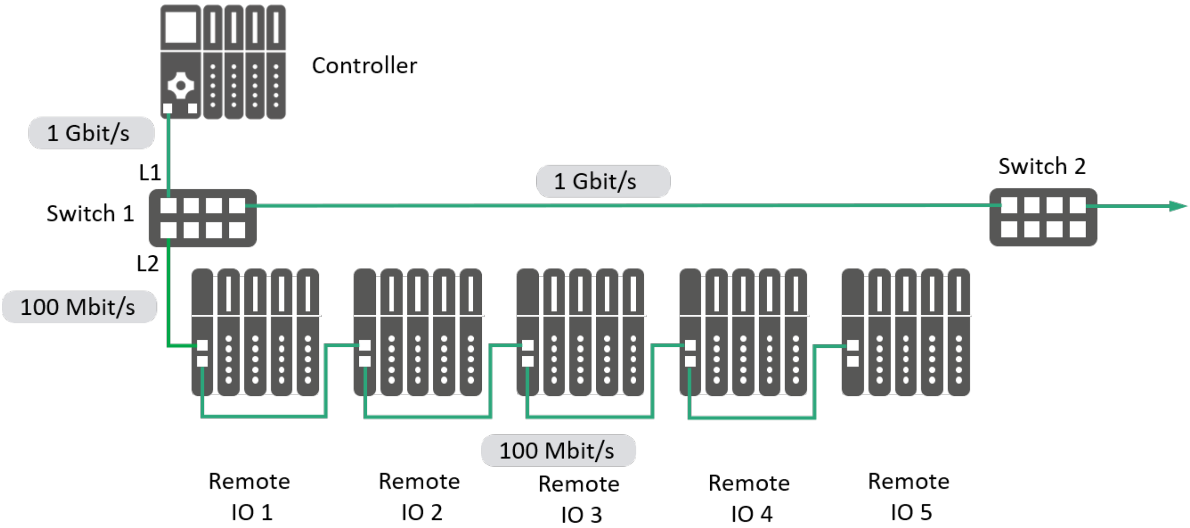


Figure 7-25: Example for input/output unbalanced link speed wise

Figure 7-25 shows an example where the controller connects to switch 1 via a link with 1 Gbit/s (L1). At the same time the Remote IOs 1 to 5 are connected to the same switch with a 100 Mbit/s connection via a line topology (L2). If we assume now that the controller sends out the output data to the remote IOs in a burst, a congestion issue could arise at the outgoing port of switch 1 that connects the Remote IOs via the link L2. This high rate of incoming data packets at Link L1 might cause an overflow of the output port that forwards the data to L2. This issue is referenced as **Case 3: Congestion loss input / output unbalance link speed-wise**.

The congestion loss described is also relevant in case there is a higher number of broadcast or multicast packages present in the network. As a switch forwards broad- or multicast packages to all ports, the ports with the lower speed might experience an overload condition due to a higher number of broad- or multicast messages.

Chapter 7.4.9 will dig into a differentiation between permanent and spurious congestion. The next chapter will now summarize the three cases described.

7.4.7 Congestion loss in Ethernet-APL Systems

The next chapter focusses on Ethernet-APL systems and possible congestion loss situations in such systems. Figure 7-26 shows an APL System with a trunk and spur topology.

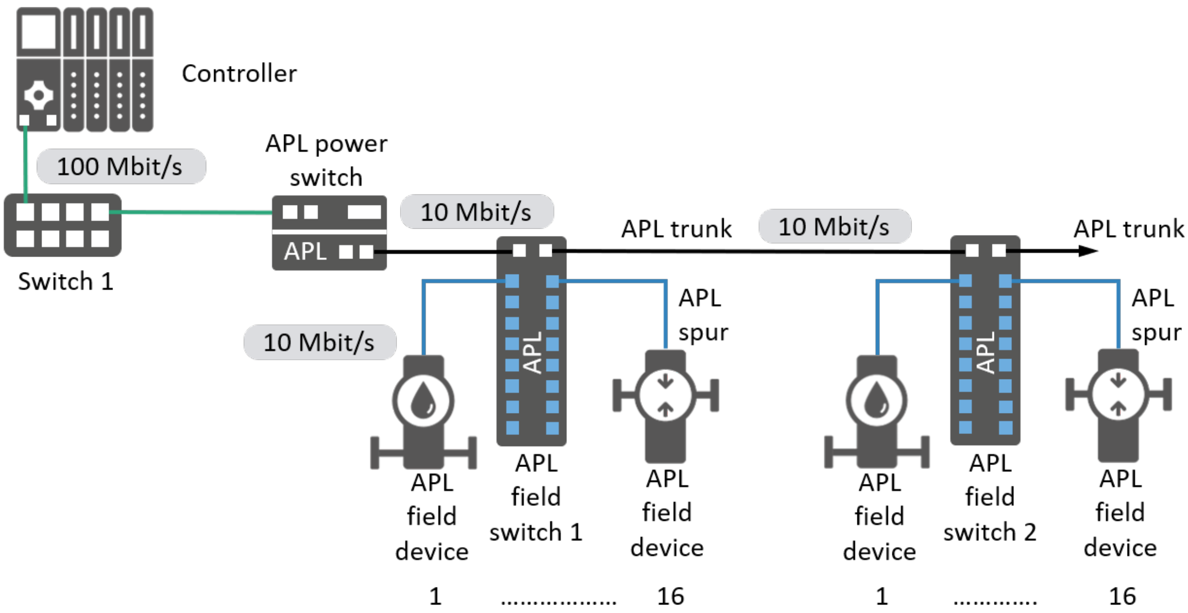


Figure 7-26: System Structure of an APL System with trunk and spur topology

In this example, the controller is connected via a 100 Mbit/s PROFINET connection to switch. An APL power switch converts the 100 Mbit/s physical layer to the 10 Mbit/s Ethernet-APL physical layer. It can be seen that the congestion loss issues described in chapter 7.4.6 apply for the APL Power switch. At the same time, the APL field switches 1 and 2 have to be considered with respect to the congestion loss issues described in chapter 7.4.5. It can be seen in Figure 7-26, that the APL field switch 1 needs to handle the incoming data from the 16 spurs as well as the incoming data coming from the APL trunk on the right side.

Figure 7-27 shows an alternative topology, that uses industrial Ethernet with a data rate of 100 Mbit/s to connect the field switches with the controller.

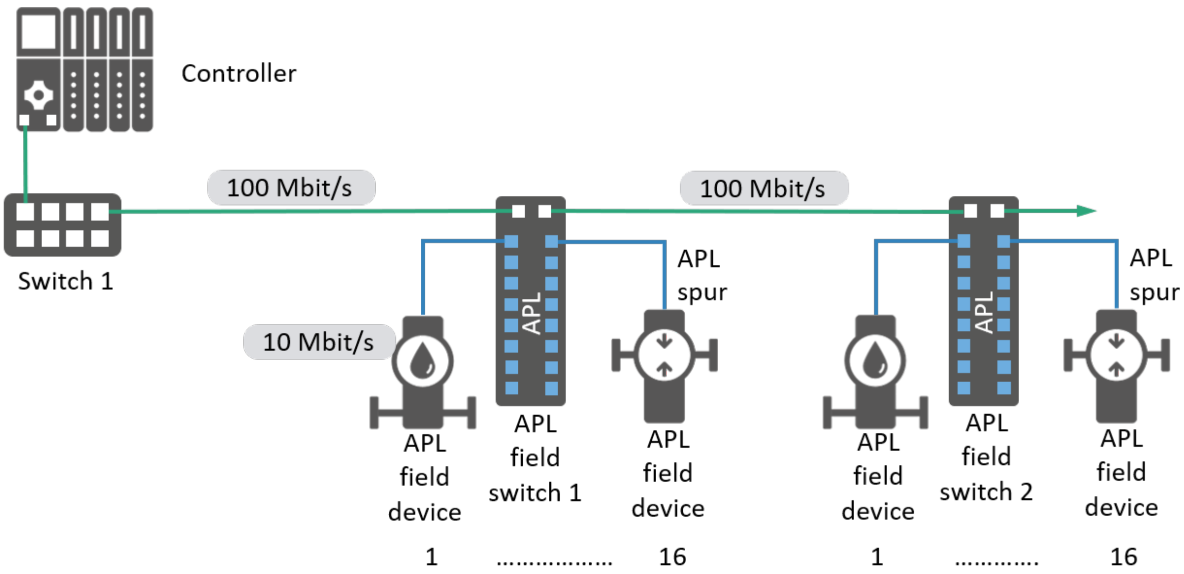


Figure 7-27: Ethernet-APL system with 100 Mbit/s industrial Ethernet to the field switches

In this case, the APL field switches 1 and 2 have to be considered with respect to the congestion loss issues described in chapter 7.4.5. Compared to the example with the trunk and spur topology, the congestion loss issue is less relevant, as the connection to the controller runs at a data rate of 100 Mbit/s compared to 10 Mbit/s shown in Figure 7-26.

Further details about possible Ethernet APL topologies can be found in [APL2021].

7.4.8 Summary congestion loss

This chapter summarizes the congestion problems discussed in the previous chapters. Table 7-5 sums up the categories discussed and the respective root causes.

Table 7-5: Categories of congestion loss

Case Nr.	Description	Root cause
1: Priority congestion loss (Chapter 7.4.4)	Output queue for low priority packets (NRT) gets overloaded due to the preferred transmission of high priority traffic (RT). Usually uncritical if aligned with the retransmission strategy as the NRT traffic is connection oriented and lost data packets will be repeated.	RT traffic outgoing on the same port in parallel to NRT traffic
2: Congestion loss input / output unbalance port wise. (Chapter 7.4.5)	A switch connects a number of devices and all devices sent their data to a single (outgoing) port.	Unsynchronized sending of a high number of devices connected to a switch simultaneously sending information to a single outgoing port
Case 3: Congestion loss input / output unbalance link speed wise (Chapter 7.4.6)	A switch connects a link with high data rate (e. g. 1 Gbit/s) to a link with a lower data rate (e. g. 100 Mbit/s). A burst of data packages comes in at the link with the high data rate and all packets need to be forwarded to a single port with a lower data rate.	Link speed conversion in a switch with a burst of data packets or a high number of broadcast and/or multicast packages to be forwarded to a port with a lower data rate.

Cyclic transmitted real-time traffic does not use retransmission. Thus, frame dropping due to congestion loss may lead to connection loss.

Other traffic, for example connection establishment or diagnosis and events, supports retransmission. Thus, frame dropping due to congestion loss leads to retransmission and, if the congestion loss occurs aligned with the retransmission, to connection loss.

After having discussed the congestion problems in general, the next chapter will evaluate, if these issues arise during normal operation.

7.4.9 Permanent or spurious congestion loss

When looking back at the described scenarios, it has to be questioned how likely such a congestion loss is in practice. In order to find this out, two issues have to be considered:

- Network load due to permanent, cyclic traffic.
- Burst network load due to a larger number of data packets sent out in a very short time frame.

In order to evaluate the permanent network load, the example in Figure 7-24 shall be looked at in more detail. The example shows an APL field switch with sixteen 10 Mbit/s spurs feeding data into a single 10 Mbit/s trunk link. In [APL2021] an equation is given to calculate the netload that is generated by a single APL field device. The following assumptions apply in for this calculation:

- Network update rate 64 ms
- Payload for one data frame: 46 Bytes (minimum frame size)
- Data rate 10 Mbit/s
- Number of APL field devices connected to the switch: 16

According to the calculation in [APL2021], this setup leads to an overall netload of 2.2% on the APL trunk. It is obvious, that the setup will not suffer from any congestion loss due to permanent cyclic traffic, but the sustained network load should be calculated and the maximum values, recommended in [APL2021] shall be observed and a reserve for other cyclic or non-cyclic traffic shall be considered. Please note that the low network update rate and the small payload size is process industry related. Other applications might require larger payloads and higher data rates. Nevertheless, the calculation principle described in [APL2021] allows the calculation of any network update rate in combination with any data size within the limitations of the Ethernet protocol.

So, if the sustained network load in the previous example is quite low, why does this document discuss the issue of congestion loss at all? This is due to the fact that the devices send out their data cyclically, but the point in time, when they send, is not synchronized. This could lead to the situation where all the sixteen APL field devices in Figure 7-24 send out their data simultaneously. In this (possibly unlikely) event, a congestion loss is likely to occur. Due to the fact that PROFINET RT does not provide a synchronization of the sending points in time, the problem is present, even though not very likely. Nevertheless, the planning process can help to reduce the impact of a possible congestion loss. The needed precautions will be described in the next chapter.

7.4.10 Planning measures to avoid loss of congestion

This chapter covers measures to avoid congestion loss in the network or at least to reduce the likelihood of a congestion loss. For this purpose, the planning measures described in Table 7-6 shall be observed.

Table 7-6: Planning steps to avoid / reduce congestion loss

Measure	Description	Document Reference
1	Calculate the cyclic network load and keep the load below the recommended limits. This measure keeps sufficient bandwidth also for non-real time traffic. Keep the update rates as fast as needed, but as low as possible.	APL: See [APL2021] chapter 4.8.2. PROFINET in general: See this document chapter 7.1.3.
2	Observe that switches with a high number of ports, like shown in Figure 7-24, might cause a congestion loss due to the unsynchronized operation of the field devices. Make sure that the switch provides a sufficient buffer size for the data to be transmitted to the trunk	Check the manufacturer's specification and/or contact the manufacturer of the switch used.
3	Make sure, that the controller does not send out IO data in bursts, when using mixed speed networks as described in chapter 7.4.6.	[PNO2022] describes a limiter for output data (Traffic shaper for output data) to avoid bursts that could cause congestion loss. Check the manufacturer's specification and/or contact the manufacturer of the controller used.
4	Use a rate limiter in a switch in order to limit the amount of traffic (esp. bursts) that runs from a network with higher speed (e.g. 100 Mbit/s) to a network with lower speed (e.g. 10 Mbit/s). The rate limiter can be placed for example	[PNO2022] describes rate limiters in switches on the domain boundary in Figure 124. The rate limiting is based on [IEE802.1Q] chapter 8.6.5.

	in Switch 1 or the APL Power switch in Figure 7-26.	

Besides these planning steps the PROFINET Commissioning Guideline [PNC2022] should be observed, especially chapter 5.4.3 (Network load) and 5.4.4 (Broadcasts and multicasts).

7.5 Documenting your settings

Once all the settings described in the above-listed steps have been incorporated, they should be incorporated into the documentation. The settings to be documented include:

- Changes of the network topology
- Update time settings
- Monitoring function settings

It is important to ensure that all settings and changes are incorporated in your documentation and are up to date. If required, add missing items.

8 Definition of device parameters

After completing the planning for network nodes and network infrastructure, appropriate parameters have to be assigned to the individual network nodes. These include:

- Device name
- IP address.

This chapter describes a systematic approach to the assignment of names and IP addresses. All PROFINET devices need to have a unique device name and unique IP address. For other network components such as switches this depends on their Conformance Class.

All PROFINET network devices of Conformance Class B must have a device name and an IP address. Switches of Conformance Class B can therefore also be considered as PROFINET devices with device names and IP addresses.

Both address parameters can usually be assigned during the planning of PROFINET devices, if they are supported by the network node.

Document the required address parameters of the devices unless this has already been done during the device selection.

To clarify the topic, an example of ordered name and IP address assignment is shown after the explanations. This is based on the already familiar system example from the previous chapters.

8.1 Assignment of names

Before a PROFINET device can communicate with a PROFINET controller, a device name must be assigned to both communication partners.

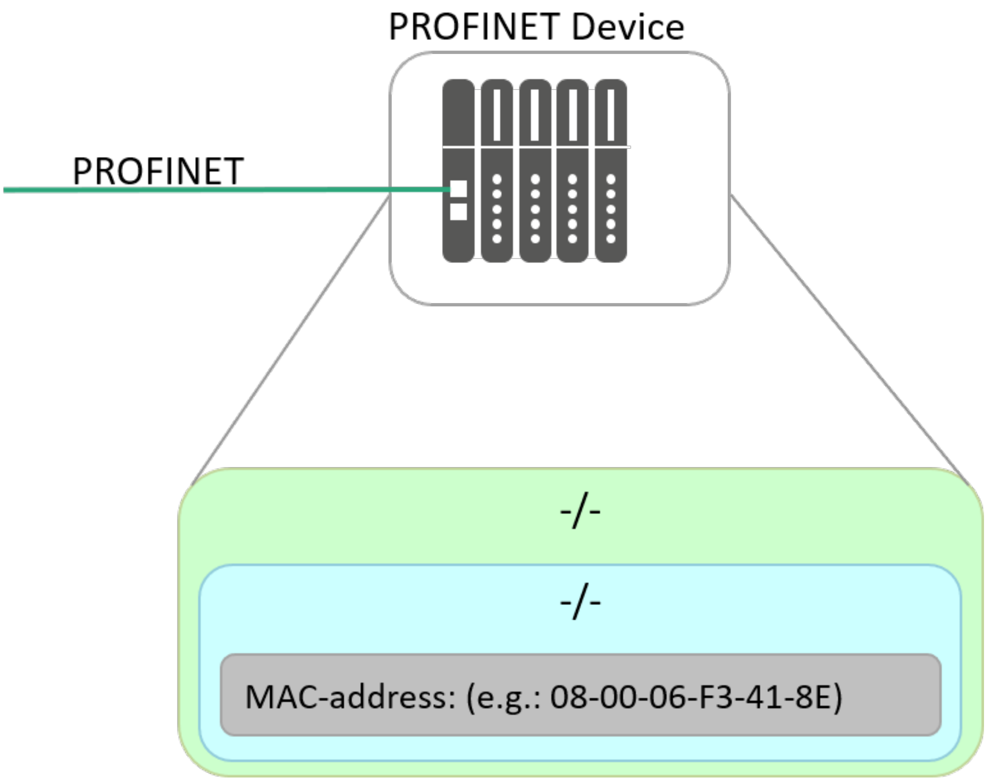


Figure 8-1: PROFINET device (delivery status)

For PROFINET, this procedure has been selected since self-explanatory names are easier to handle than IP addresses. In their original delivery status PROFINET devices do not have a device name, but only a MAC address. This is stored in the PROFINET device, it is globally unique and can usually not be modified. Many PROFINET devices have the MAC address printed on the housing or on the rating plate.

PROFINET devices can be accessed by a PROFINET controller only after its device name has been assigned. The device name must be stored by the device. If supported by the PROFINET device, it can alternatively be directly written to a storage medium (for example an SD card). The storage medium can then be inserted into the PROFINET device so that the device name is read by the PROFINET device.

It is advisable to use the device name used in the electrical diagram as the device name. With today's standard engineering tools, there are no restrictions on the device name, as the engineering tool automatically translates the visible name into a PROFINET- conforming device name.

If your engineering tool does not support this automatic conversion of the name, you must observe the detailed requirements for PROFINET device names. These can be found in the appendix in chapter 10.4.

It is well worth considering using a device naming convention that gives useful information to the maintenance engineer as to the location and function of the unit.

8.2 Planning of IP addresses

Automatic address configuration

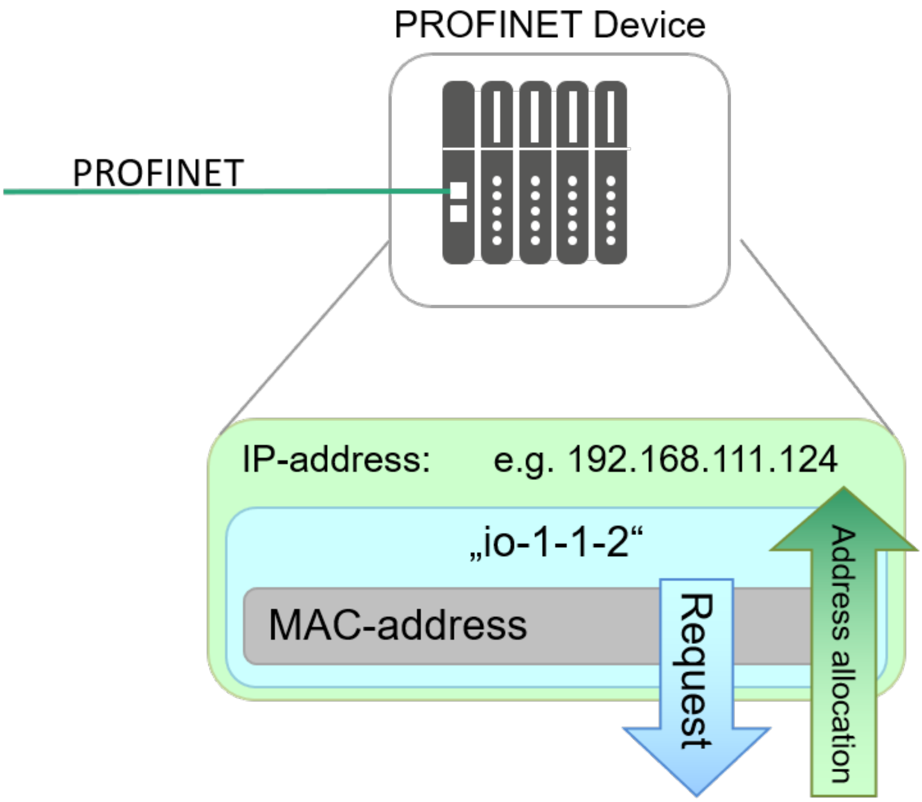


Figure 8-2: PROFINET device (address allocation)

The IP address is entered in the configuration of the PROFINET project. This is usually done automatically. The address thus allocated will be transferred to the PROFINET device when starting PROFINET controller. There is usually a fixed assignment of IP addresses to device names. In addition, this can also be stored permanently. Addressing of a PROFINET device therefore in total includes:

MAC address, which is predefined in the PROFINET device and can usually not be modified.

Device name, which can be flexibly selected, but which should be selected according to the relevant plant part to facilitate the overview.

IP address, for which, just as for the name, a firm plan should be defined for the assignment of addresses. You will thus facilitate the reference to the device types.

Information on address configuration

The notation of the IPv4 address used in PROFINET networks consists of four decimal numbers, each in the range between 0 and 255 and separated by a point, as e.g. 192.168.2.10.

In addition to the device name and the unchangeable MAC address, the IP address is required to clearly identify a network node. In addition to the IP addresses used in public networks such as the Internet, reserved address ranges have been allocated for private or non-public areas. Table 8-1 shows the various private address ranges. The bold-faced figure indicates the network, while the area behind it is uniquely assigned and thus clearly identifies the network node.

Table 8-1: Private IPv4 address ranges

No. of networks	Class	Address range	Network mask	Number of nodes per network
1	Class A	**10**.0.0.0 to **10**.255.255.255	255.0.0.0	16.8 million
16	Class B	**172.16**.0.0 to **172.31**.255.255	255.255.0.0	65534
256	Class C	**192.168.0**.0 to **192.168.255**.255	255.255.255.0	254

A network mask (sometimes called subnet mask) is assigned in parallel to the IP address. IP address and net mask form a firm pair. The net mask notation corresponds to the IP address.

We recommend the use of private IP addresses. The use of public IP addresses is under the responsibility of the plant operator.

For the assignment, the following points should basically be observed:

- From the previous considerations, given the **number of nodes** in a network, select an **address range of appropriate size**.
- **Define an address table.** Divide the PROFINET network nodes into classes. Define a separate address range for each class.
- **Any duplicate use of IP addresses is not permitted.** Any use of identical IP addresses will inevitably cause communication problems for the affected network nodes.

In most cases, addressing using the private class C address range is sufficient. For special cases where a larger address range with more than 254 addresses (Class C) is required, you can switch to a private class B or class A network.

Remember that in large companies, IP addresses are usually assigned by the department responsible for corporate networks.

Document the assignment of IP addresses and device names.

8.3 PROFINET plant example

The assignment of IP addresses for a PROFINET automation plant will now be described as an example, using the example plant previously used in this document.

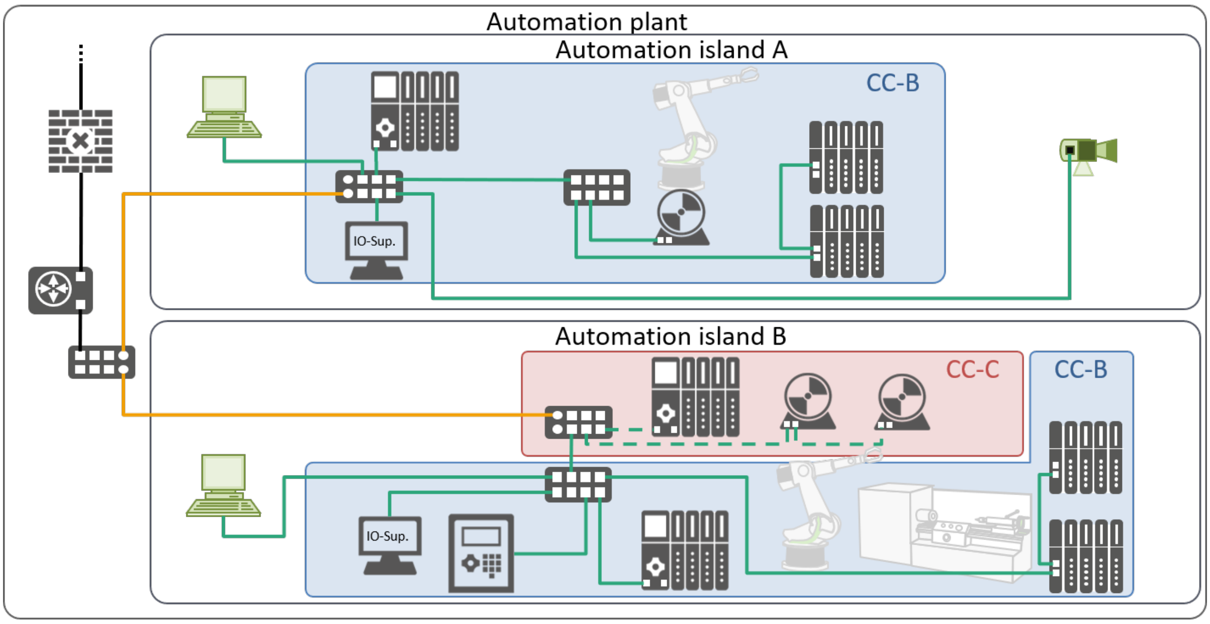


Figure 8-3: Overall structure of example plant

Plant overview

The topology and the number of PROFINET devices for the plant have been defined during the design. The result of this design has been as follows:

Automation island A

- Number of PROFINET devices: 3
- Tree topology with connected line topology
- 2 switches, 1 controller
- Supervisor, operating station, camera

Automation island B

- Number of PROFINET devices: 5
- Tree topology with connected line topology
- 2 switches (IRT function in one switch), 2 controllers
- IO supervisor, operating station

Higher level connection / control station

- Star or tree topology
- Optical fiber connection
- 1 switch, 1 router and 1 firewall

The summary of requirements results in the following number of IP addresses for the example plant.

Table 8-2: Overview of number of PROFINET network nodes

Process automation plant							
Automation island A							
Number switches	2	Number devices	3	Controller / IO Supervisor	1 / 1	Other	2
Automation island B							
Number switches	2	Number devices	5	Controller / IO Supervisor	2 / 1	Other	1
Higher level connection / control station							
Number switches	1 (+ 1 Router)	Number devices	0	Controller / IO Supervisor	0 / 0	Other	0

Address selection

When commissioning a large plant, you should create an address table where the most important information about the PROFINET nodes can be entered. This will allow you at a later stage to easily retrieve faulty PROFINET nodes or PROFINET nodes to be replaced.

Individual plant parts can be addressed using these addresses. It is a good idea to allocate addresses in blocks for each plant area. An alternative scheme is to allocate address ranges for different device types, such as switches, drives, remote IO etc. Some addresses should be reserved in each block for future expansion.

A possible scheme for address allocation for our example plant might be as follows.

Selection of IP Addresses

1. Different address ranges are assigned to the individual device types in the plant: (see example)

Example	Controller/Router:	192.168.2.1 to 192.168.2.19
	Switches:	192.168.2.20 to 192.168.2.49
	PN devices:	192.168.2.50 to 192.168.2.199
		I/O: 192.168.2.50 to 192.168.2.99
		Drives: 192.168.2.100 to 192.168.2.149
		Panels: 192.168.2.150 to 192.168.2.199
	Additional functions/ Reserve:	192.168.2.200 to 192.168.2.254

The net mask here corresponds to the standard class C address range (sub net mask “255.255.255.0”).

In case the selected address range is too small, a similar structure can also be applied to the other private IPv4 address ranges (class A / class B).

2. Each automation plant receives an address range

Example	Higher-level connection:	192.168.1.xxx
	Automation plant 1:	192.168.2.xxx
	Automation plant 2:	192.168.3.xxx etc.

Only a Class C network is normally used for automation plants. For the communication between the individual automation plants with different address ranges a router may be used for connection (IP-based communication, only).

Selection of device names:

According to the structure as per chapter 8.1, the name for a PROFINET device e.g. looks like:

1. The device name includes the designation of the type.

e.g.:	Idevice	"io"	Switch	"swi"
	drive	"drv"	IO panel	“hmi"

2. In addition to the device type, a consecutive numbering and / or a position identifier should be included in the device name to describe the position of the device in the plant.

   e.g.: The second device of automation plant 1 in automation island 2 is named

   "io.1.2.2"

In the selected example, "swi.1.0.1" includes the figure "0", indicating that this switch is assigned to automation plant 1, but it is not assigned to a certain island in this plant. This switch interconnects the islands and connects them to the higher-level router.

Address selection

Using this notation, the following address assignment can be used for the plant example

Table 8-3: Address selection in automation plant 1

Type	Name according to planning	Device name	IP address:
Router	ROUT_V1	-/-	192.168.2.1
-/-	-/-	-/-	-/-
PN controller	CPU-123-AB	cpu.1.1.1	192.168.2.2
PN controller	CPU-345-CD	cpu.1.2.1	192.168.2.3
PN controller	CPU-678-EF	cpu.1.2.2	192.168.2.4
Switch	Switch-AB1	swi.1.0.1	192.168.2.20
Switch	Switch-CD2	swi.1.1.1	192.168.2.21
Switch	Switch-EF3	swi.1.1.2	192.168.2.22
Switch	Switch-GH3	swi.1.2.3	192.168.2.23
Switch	Switch-IJ4	swi.1.2.4	192.168.2.24
PN device	I/O device V3	io.1.1.1	192.168.2.50
PN device	I/O device V2	io.1.1.2	192.168.2.51
PN device	I/O device V6	io.1.2.1	192.168.2.52
PN device	I/O device-98	io.1.2.2	192.168.2.53
PN device	DRIVE _IRT	drv.1.1.1	192.168.2.100
PN device	DRIVE _V2	drv.1.1.2	192.168.2.101
PN device	DRIVE _V4	drv.1.2.1	192.168.2.102
PN device	IO_PANEL_1	hmi.1.2.1	192.168.2.150

Video camera	CAM_V1	-/-	192.168.2.200
Control station	STAT_1	-/-	192.168.2.201
Control station	STAT_2	-/-	192.168.2.202
PN IO Supervisor	IO_SUP_1	-/-	192.168.2.203
PN IO Supervisor	IO_SUP_2	-/-	192.168.2.204

A table provides better overview of the plant, reducing the required work and saving time.

In this example, the switches receive a device name and an IP address. These are required for switches as of Conformance Class B and have therefore been selected in this example.

9 Summary

After completion of the PROFINET design, all information about your entire PROFINET automation plant should be available to you. This includes information such as:

Component selection, such as the PROFINET devices, switches, transmission media and connectors. This also includes their necessary requirements, properties, conformance class and additional functions.

Communication relations with the data volumes to be transmitted and the geographical as well as functional grouping of all PROFINET devices.

Network topology of the automation plant under consideration of the data volumes to be transmitted and communication relations of the plant parts. Extensions such as standard Ethernet devices and potential network loads have been integrated in the topology structure.

A **performance consideration** reflecting common network loads of standard Ethernet devices and PROFINET devices as well as their update times.

Device parameters, such as IP address and device names.

In this context you should check whether all design information of your PROFINET automation plant is available to you.

10 Annex

10.1 Addresses

PROFINET Competence Center

The PROFINET Competence Centers can be contacted in case of any problems with PROFINET. The PROFINET Competence Centers have specialists who are able to help in case of problems. The PROFINET Competence Centers also provide training.

You can find the current contact data of the PROFINET Competence Centers online at

www.profinet.com

in the Support area.

10.2 Glossary

You will find important definitions about PROFINET in the PI Glossary on page

www.profinet.com

under the search term "Glossary".

10.3 GSD files

Each PROFINET device is described by a General Station Description (GSD). This is a file that contains information about the device in machine-readable form. The XML-based GSDML language is used for this purpose.

The engineering tool requires the GSD files for all PROFINET nodes so that project planning can take place. You can obtain the GSD file for a device from the manufacturer. Some engineering tools have a database with which GSD files can be obtained using the article number.

In most cases, you will not met GSD files during the planning process.

They are only integrated into the engineering tool during project configuration.

As part of security enhancements to PROFINET, GSD files will be digitally signed in future. A new file format, the so-called GSDX format, is being introduced for this purpose. Further information on this file format can be found in [GSX2024].

10.4 Conformity of the PROFINET device name

Common engineering tools convert the visible PROFINET device name internally into an internal, PROFINET-compliant device name using PunyCode [RFC_3492]. If your engineering tool does not support this automatic conversion, you must observe the following requirements for the device name:

The device name must fulfill the following conditions:

- A name consists of one or more designations separated by [.].
- The label length is 1 to 63 octets
- The total length of the name is 1 to 240 octets
- Labels consist of [a-z, 0-9 or -]
- Labels do not begin and end with [-]
- The first label shall not have the form “port-xyz” or “port-xyz-abcde” with a, b, c, d, e, x, y, z = 0...9 to avoid a false similarity with the field AliasNameValue.

- Device names do not have the form a.b.c.d with a, b, c, d = 0...999 in order to avoid a false similarity with IPv4 addresses.

10.5 Details about PROFINET copper cables

This section of the Annex provides detailed information about PROFINET copper cables.. Please check also [PCI2023] for further information about cabling and interconnection technology.

Properties of PROFINET copper cables

Parameters of cable types

Table 10-1: Cable parameters PROFINET Type A copper cable

Parameter	Specified limits
Impedance	100 Ω ± 15 Ω
Loop resistance	<115 Ω/km
Transmission rate	100 Mbit/s
Max. cable length	100 m
Number of wires	4
Wire diameter	0.64 mm
Wire CSA	0.32 mm^2 (AWG 22/1)
Sheath color	green
Color of insulation	white, blue, yellow, orange

Table 10-2: Cable parameters PROFINET Type B copper cable

Parameter	Specified limits
Impedance	100 Ω ± 15 Ω
Loop resistance	<115 Ω/km
Transmission rate	100 Mbit/s
Max. cable length	100 m
Number of wires	4
Wire diameter	0.75 mm
Wire CSA	0.36 mm^2 (AWG 22/7)
Sheath color	green
Color of insulation	white, blue, yellow, orange

Table 10-3: Cable parameters PROFINET Type C copper cable

Parameter	Specified limits
Impedance	100 Ω ± 15 Ω
Loop resistance	<115 Ω/km
Transmission rate	100 Mbit/s
Max. cable length	100 m
Number of wires	4
Wire diameter	0.13 mm
Wire CSA	AWG 22/7 or 22/19
Sheath color	green
Color of insulation	white, blue, yellow, orange

Table 10-4: Cable parameters PROFINET 8-core Type A copper cable

Parameter	Specified limits
Impedance	100 Ω ± 15 Ω
Loop resistance	<85 Ω/km (AWG 23/1)
Transmission rate	1000 Mbit/s
Max. cable length	100 m
Number of wires	8
Wire diameter	≥0.546 mm (AWG 23/1)
Sheath color	green
Color of insulation	white / orange, white / green, white / blue, white / brown

Table 10-5: Cable parameters PROFINET 8-core Type B copper cable

Parameter	Specified limits
Impedance	100 Ω ± 15 Ω
Loop resistance	<85 Ω/km (AWG 23/7)
Transmission rate	1000 Mbit/s
Max. cable length	100 m
Number of wires	8
Wire CSA	≥0.254 mm^2 (AWG 23/7)
Sheath color	green
Color of insulation	white / orange, white / green, white / blue, white / brown

Table 10-6: Cable parameters PROFINET 8-core Type C copper cable

Parameter	Specified limits
Impedance	100 Ω ± 15 Ω
Loop resistance	<95 Ω/km (AWG 24)
Transmission rate	1000 Mbit/s
Max. cable length	100 m
Number of wires	8
Wire diameter	Application-specific
Wire CSA	Application-specific
Sheath color	Application-specific
Color of insulation	white / orange, white / green, white / blue, white / brown

Mechanical properties

In addition to the physical data (e.g. diameter and conductor material), the cable manufacturers specify additional mechanical properties of the cable which provide information about the application ranges and installation options of the cables. Typical manufacturer specifications are:

- Bending radius
- Bending frequency
- Tensile strength

While the bending radius and the bending frequency mainly depend on the wire design (fixed / flexible), additional elements such as aramid fibers are added to the cable to achieve a higher tensile strength.

The limit values listed in Table 10-7 have been taken from the IEC 61784-5-3 standard.

Table 10-7: Mechanical properties of PROFINET copper cables

Parameter	**Specified limits**
Minimum bending radius, single bent	20…65 mm
Bending radius, multi-bent	50…100 mm
Tensile force	<150 N
Permanent tensile load	< 50 N
Maximum shear force	--
Temperature range during installation	-20…+60 °C

The limit specifications depend on the cable type. For more detailed information, please see the manufacturer specifications.

Chemical properties

PROFINET copper cables are available with different sheath materials to protect them against environmental influences.

Cable manufacturers specify the properties or the existence of a certain material (e.g. halogen / silicone) in the cable datasheets. Typical manufacturer specifications are:

- UV resistance
- Freedom from silicone
- Resistance against mineral oils and greases
- Permissible temperature ranges

Special attention must be paid to the flammability of the cables. The relevant data are usually provided separately by the cable manufacturers, with reference to the following properties:

- Freedom from halogen
- Flame retardance
- Smoke density

The smoke density is closely related to the freedom from halogen and is not specified by all manufacturers. Therefore, also pay special attention to additional specifications like FRNC (Flame-Retardant-Non-Corrosive). The acronym FRNC indicates that a cable is halogen-free and flame-retardant.

Only halogen-free and flame-retardant cables may be used in areas where, in case of fire, human life is endangered by toxic gas and smoke gas.

Types of copper cables

PROFINET cable

This section describes PROFINET cables with 2 wire pairs. The specifications for 4-pair cables are similar.

The most usual material for the PROFINET cable sheath is PVC (PolyVinylChloride). PVC is generally UV resistant & chemically non-reactive. It is resistant to water, salt solutions, alcohol and light caustic/acid/oil. However, PVC is not suitable for hydrocarbons or organic solvents and has a restricted temperature range (-30 °C to +70 °C).

Type A PROFINET cables usually meet most requirements of automation projects and therefore they are the most frequently used type of cable. As a round cable they have four wires and are radially symmetric. The wires are stranded to form a so-called star quad.

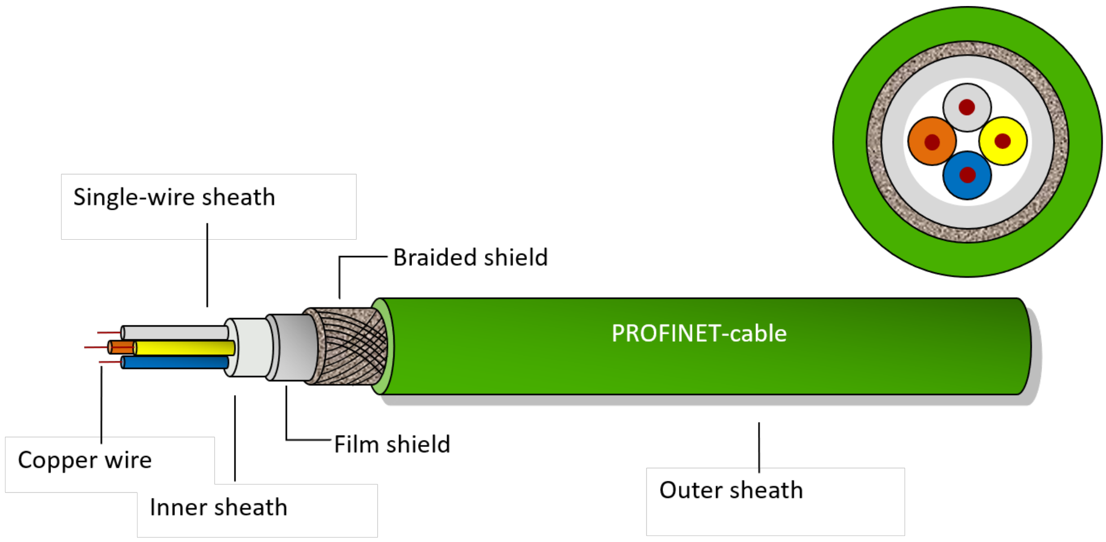


Figure 10-1: PROFINET cable type A

The PROFINET cable type A has been designed for static installation, e.g. in cable trays.

PROFINET PE cable

A PE (PolyEthylene) sheath has better electrical properties than PVC. Excellent moisture resistance makes PE cables suitable for direct burial and damp environments. PE cables with black sheath are in addition UV resistant. The only difference to type A copper cables is the different sheath color and the sheath material.

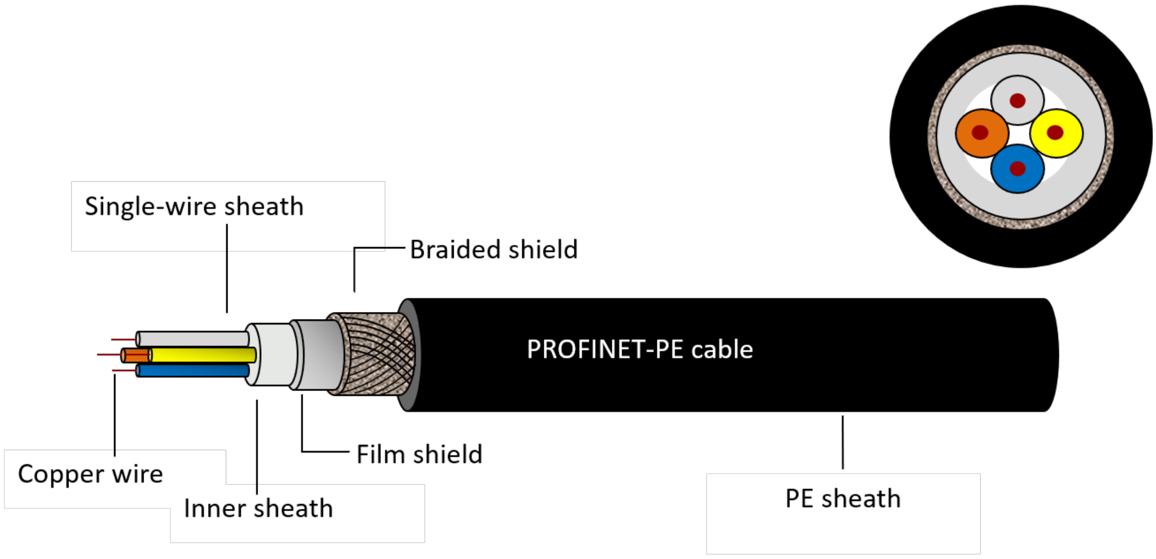


Figure 10-2: PROFINET PE cable

PE cables are suitable for installation in areas where constant humidity must be expected. Due to the PE sheath, the cable, without any flame-resistant additive, is flammable.

PROFINET ground cable

PROFINET ground cables have robust, black outer sheaths made of PE. In many cases, this is applied to the PROFINET cable as an additional sheath. After removing the outer sheath, the uncovered PROFINET cable can be used and assembled as usual.

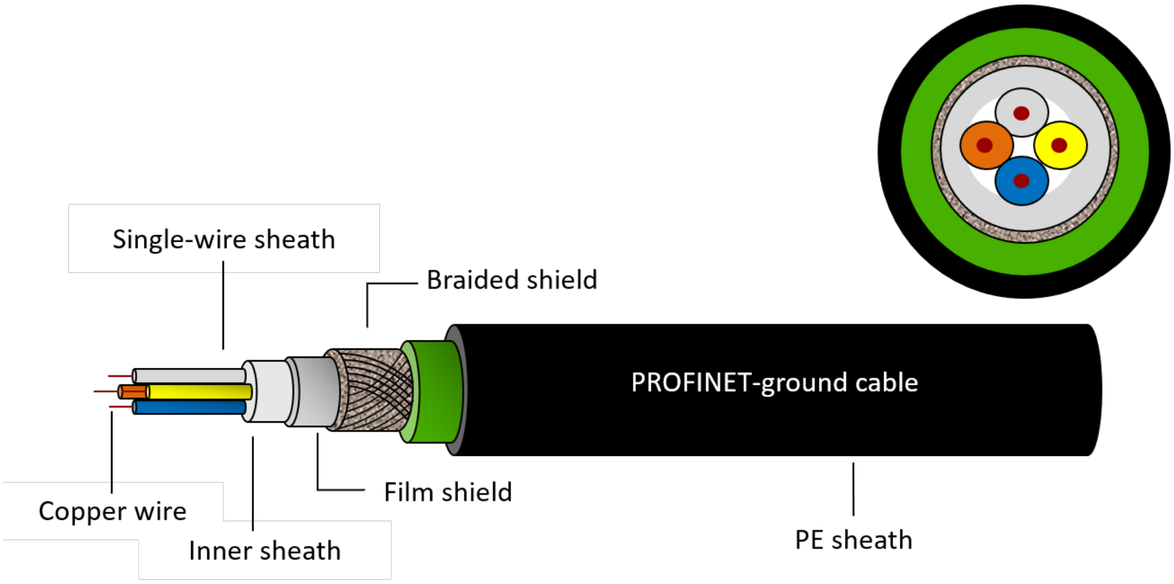


Figure 10-3: PROFINET ground cable

Suitable for outdoor installation or installation in the ground.

Cables with additional protection against rodents are also available. This protection is ensured by means of additional, metal or fiber-based mesh. Observe the manufacturer information about this.

Trailing cable

The wires of this type of cable consist of thin-wired braid, enabling the cable to be used at flexible machine parts. The quad star four-wire structure increases the crush and tread resistance. The sheath of this cable type is usually halogen-free and resistant against mineral oil and grease.

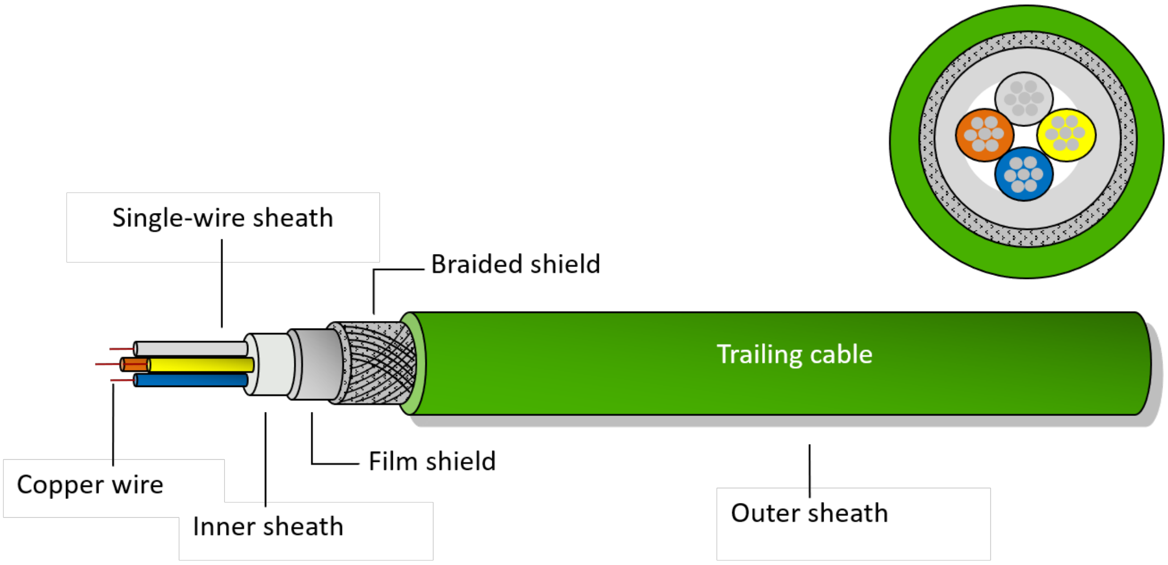


Figure 10-4: Trailing cable

Specially designed cables should be used in cases where the cable will be subject to frequent flexing or bending, such as with mobile machine parts for example. Special cables are also available for trailing chains.

Festoon cable

The wires of this type of cable (similar to trailing cables) consist of thin-wire braid, enabling the cable to be used for festoon applications. The quad star four-wire structure increases the crush and tread resistance. The sheath of this cable version is usually halogen-free and resistant against mineral oil and grease.

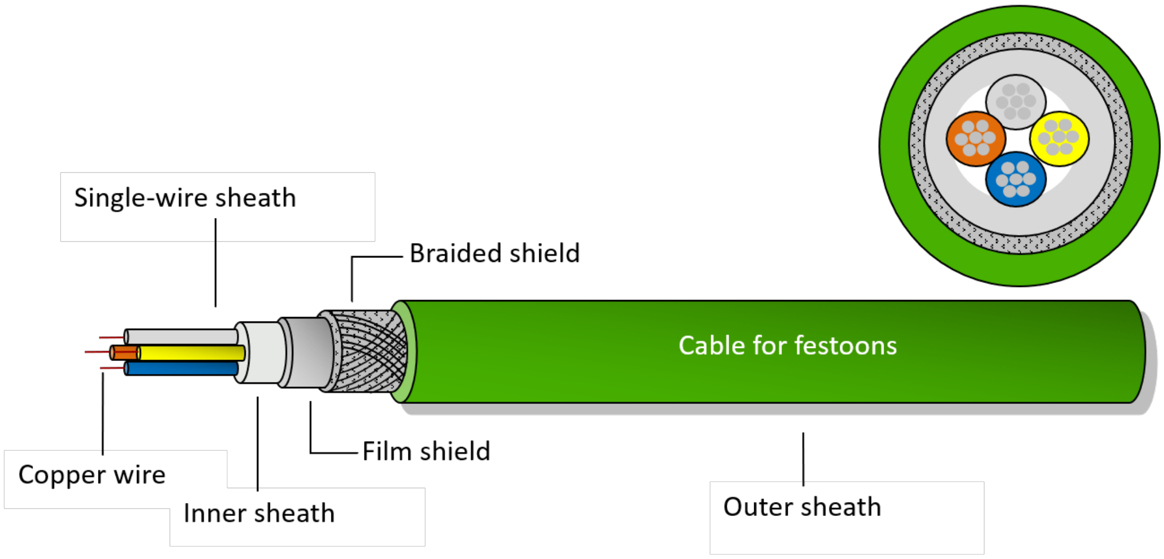


Figure 10-5: Cables for festoons

Specially designed festoon cables should be used in cases where the cable will be subject to permanent movement, such as with mobile machine parts, hoists and cranes. Special cables are also available for torsional movement.

Flame retardant non-corrosive cables (FRNC cable)

FRNC (Flame Retardant Non-Corrosive) cable is made with a sheath of halogen-free material for use where flammability is to be avoided. The sheath color of FRNC cable is normally green.

You should use a halogen-free cable for applications in areas where in case of fire there are more demanding requirements to the fire behavior of the cable. Possible places of application e.g. are residential buildings or hospitals.

Ethernet APL Cables

The supported Ethernet-APL cable is a balanced, shielded twisted-pair cable with a characteristic impedance in the range of 100 Ω ± 20 % in a frequency range of 100 kHz to 20 MHz as typically used for PROFIBUS PA and FOUNDATION Fieldbus H1. Wire diameters can be in the range of 26AWG (0.14 mm²) to 14AWG (2.5 mm²) either with solid or stranded wires. Cable parameters for Ethernet-APL cables can be found in the Ethernet-APL Engineering-Guideline [APL2021] as well as in the Ethernet APL Port Profile Specification [APS2021]. Figure 10-6 shows the structure of the Ethernet-APL cable.

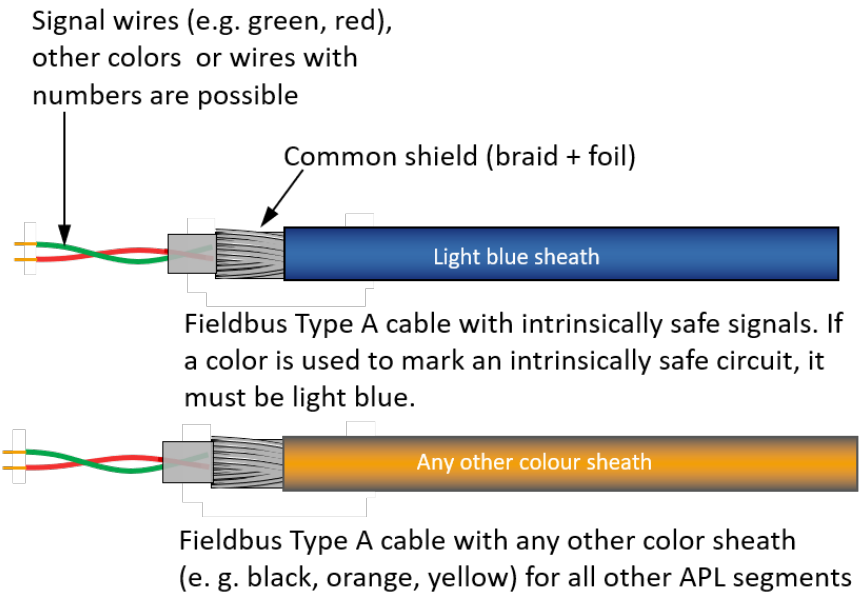


Figure 10-6: Ethernet-APL cable

For new Installations a special two-wire-Ethernet cable has been specified in [IEC 61156-13]. This cable should be used in all cases where the reuse of an existing cable is not required.

10.6 Details about PROFINET optical fibers

This section of the Annex provides detailed information about PROFINET optical fibers. Please check also [PCI2023] for further information about cabling and interconnection technology.

Properties of PROFINET optical fibers

Mechanical properties

The mechanical properties of cables give information about possible types of application and installation. In order to get an overview, the following tables show detailed values for typical mechanical properties of optical fibers. The tables differentiate between the fiber types used.

The limit values listed in Table 10-8 and Table 10-9 have been taken from the IEC 61784-5-3 standard.

Table 10-8: Mechanical properties of single / multimode FO

Parameter	Specified limits
Minimum bending radius, single bent minimum	50…200 mm
Bending radius, multi-bent minimum	30…200 mm
Tensile force maximum	500…800 N
Permanent tensile load maximum	500…800 N
Shear forces maximum	300...500 N/cm
Temperature range during installation	-5…+50 °C

Table 10-9: Mechanical properties of POF optical fibers

Parameter	Specified limits
Minimum bending radius, single bent minimum	30…100 N
Bending radius, multi-bent minimum	50…150 N
Tensile force maximum	50…100 N
Permanent tensile load maximum	not allowed
Shear forces maximum	35…100 N/cm
Temperature range during installation	0…+50 °C

The limit values listed in Table 10-10 have been taken from the IEC 61784-5-3 standard.

Table 10-10: Mechanical properties of PCF optical fibers

Parameter	Specified limits
Minimum bending radius, single bent minimum	75…200 mm
Bending radius, multi-bent minimum	75…200 mm
Tensile force maximum	100…800 N
Permanent tensile load maximum	< 100 N
Shear forces maximum	75…300 N/cm
Temperature range during installation	-5…+60 °C

The limit specifications depend on the cable type. For more detailed information, see the manufacturer specifications.

The cable properties in the tables above meet the requirements of common industrial applications. Special applications such as trailing cables, festoons or torsional movements require adjusted cable designs with extended properties.

Chemical properties

FO cables, just as the previously described copper cables, have different sheath materials, giving them certain properties.

- Typical manufacturer specifications are:
- UV resistance
- Freedom from silicone
- Resistance against mineral oils and greases
- Permitted temperatures

For FO cables as well, special attention must be paid to the fire behavior of the cable. Manufacturer data for this include:

- Freedom from halogen
- Flame retardance
- Smoke density

Only halogen-free and flame-retardant cables may be used in areas where, in case of fire, human life is endangered by toxic gas and smoke gas.

Types of FO cables

The cable types most commonly used for PROFINET, with their applications, are listed in Table 1-1. The cable types described can use all fiber types mentioned in section 3.5.4. Additional protection including rodent-protection or special cables for ground installation, are also available.

Table 10-11: Types of FO cables

Cable version	Applications
PROFINET FO cable	For simple point-to-point links between two PROFINET devices
PROFINET FO trailing cable	For installation at moving machine parts.

PROFINET FO cable

Figure 10-7 shows the general structure of a PROFINET FO cable. It consists of two parallel wires. The wires are suitable for direct assembly of connectors. The orange wire is printed with directional arrows to facilitate the assignment of wires to the transmit and receive connections.

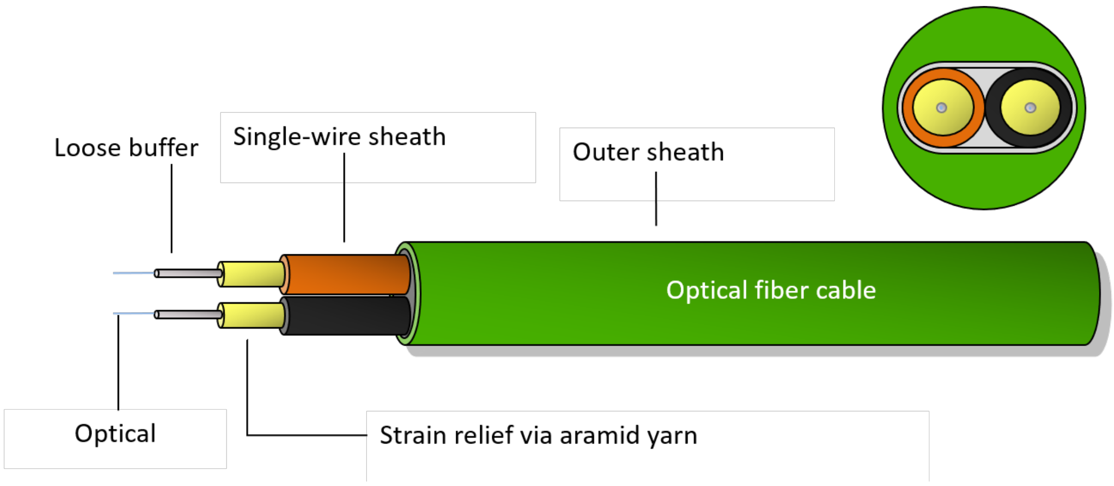


Figure 10-7: PROFINET optical fiber cable

PROFINET FO trailing cable

The FO trailing cable (Figure 10-8**)** has additional non-woven wrapping as well as strain relief elements and an additional support element. The sheath of this cable type is usually halogen-free and resistant against mineral oil and grease.

You should use specially designed cables in case the cable will be subject to frequent movement, such as e.g. the use at mobile machine parts. PROFINET FO trailing cables are available with all common fiber types.

Cables for use in trailing chains can normally not be used as festoons.

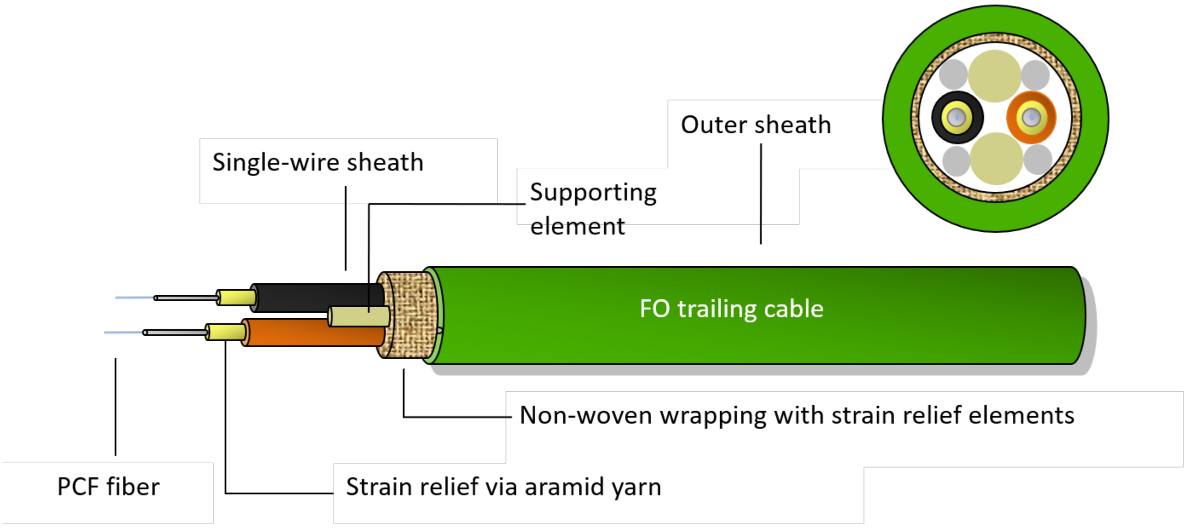


Figure 10-8: PROFINET FO trailing cable

10.7 Selection of connectors

This chapter will describe these requirements in more detail so that your previous planning can be completed with suitable connection technology as required for your application. Please check also [PCI2023] for further information about cabling and interconnection technology.

This chapter covers the following subjects:

- Explanation of differences between pre-assembled cables and cables for field-assembly
- Introduction of available connection systems
- Selection of required connectors

Differences between pre-assembled cables and cables for field-assembly

Pre-assembled cables

Pre-assembled cables are delivered with connectors fitted on both ends of the cable. Such pre-assembled cables can only be used if you know the exact distance between the individual network components (observe cable routing).

Advantages of pre-assembled cables:

- Reduction of installation time since no cable assembly is required.
- Potential assembly mistakes are avoided.
- The installation personnel does not need any training for the assembly of PROFINET cables.
- No special assembly tools required.
- Suitable in particular for wiring cabinets.

Disadvantages of pre-assembled cables:

- The assembled connectors could be obstructive or could be damaged when installing the cables.
- Cable lengths must be specified when ordering the cables.
- If pre-assembled cables are too long, the excessive cable length must be accommodated correctly.

Cables for field-assembly

Cables for field assembly are delivered by the manufacturer as bulk material without any connectors and have to be assembled on site by the installation personnel.

Advantages of cables for field-assembly:

- Cable lengths do not have to be specified when ordering the cables.
- Cables are easier to install without connectors attached.

Disadvantages of cables for field-assembly:

- Assembly on site requires additional time.
- Special tools are required.
- The installer needs to be trained for the assembly of PROFINET cables.
- Potential source of errors (acceptance measurement is recommended).

Please contact your cable manufacturer or the manufacturer of the connection system required for your installation to find out which assembly tools are required.

For more detailed information about the assembly of connectors and cables, please see the PROFINET Installation Guideline Order No.: 8.072.

Connection systems for copper cables

This chapter describes the connection systems for copper cables with different protection types, using various figures.

The connectors shown in the figures below (Figure 10-9 and Figure 10-10) are generic drawings based on models typically available on the market. The real design depends on each manufacturer.

Connectors

RJ45 connectors

RJ45 connectors are suitable for use with terminal devices and network components. A major criterion for the potential use of connectors is their manageability on site. Inside cabinets, RJ45 connectors are used in the IP20 version. Outside cabinets, the rugged environmental conditions must be accounted for. In such cases, an RJ45 push-pull connector in IP65 or IP67 version can be used. Another advantage of RJ45 connectors is that they are often used for connection of engineering tools or laptops etc allowing these to be easily and quickly connected for service purposes.

Figure 10-9 and Figure 10-10 show two versions of RJ45 connectors with different protection classes.

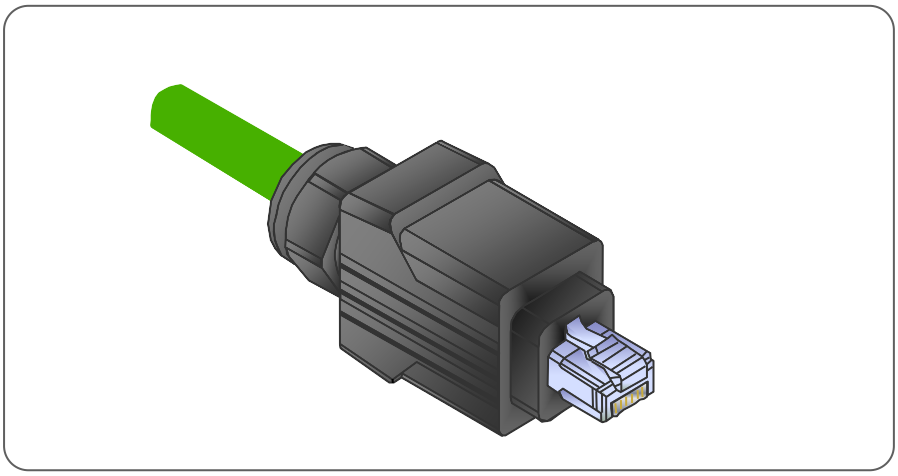


Figure 10-9: Typical RJ45 push-pull connector with IP65 rating

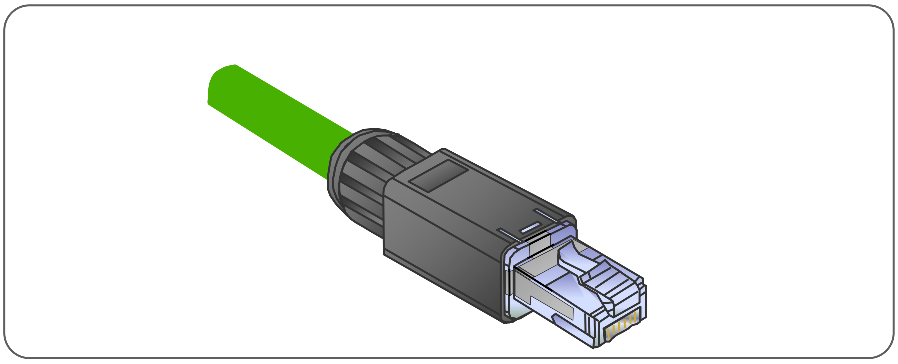


Figure 10-10: Typical RJ45 push-pull connector with IP20 rating

M12 D-coded connector

For applications in rugged industrial environments with IP67 protection class, the PNO has specified the M12 connector which allows for the safe connection of sensors / actors. The M12 D-coded connector has been standardized in IEC 61076-2-101.

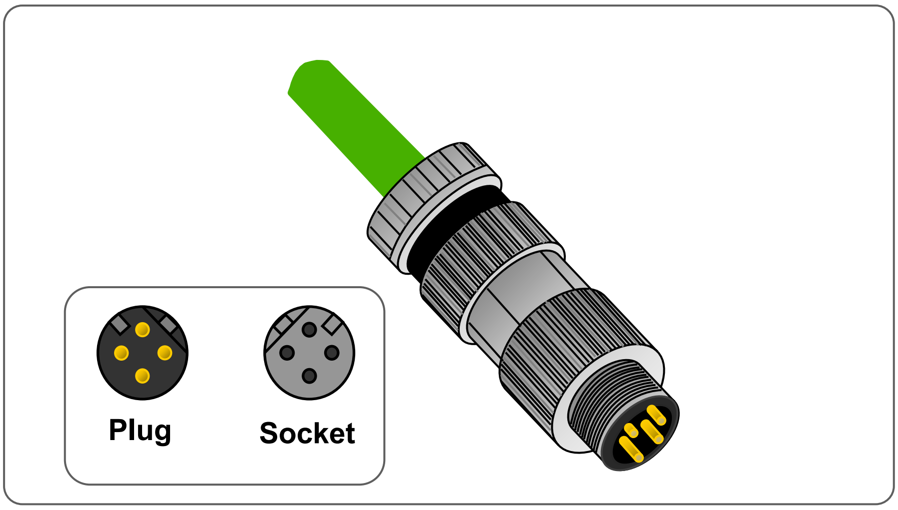


Figure 10-11: Typical D-coded M12 connector

M12 TypeX connector

The M12 TypeX connector is suited for applications in rugged industrial environments with high transmission rates. The M12 Type X has been standardized in IEC 61076-2-109.

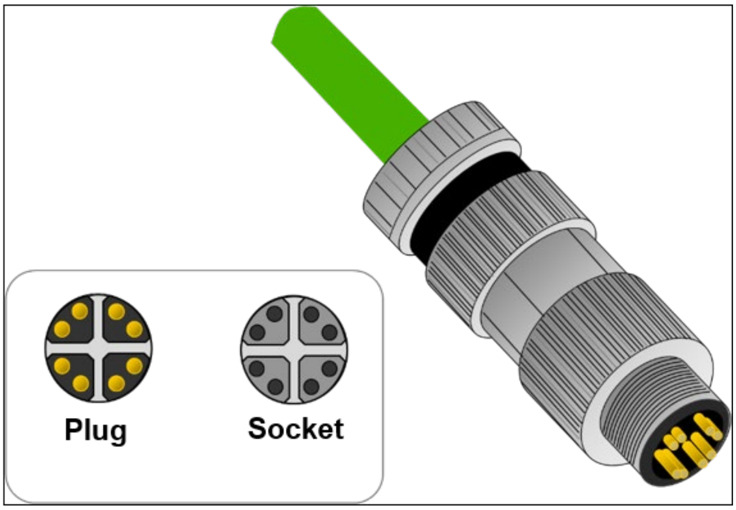


Figure 10-12: Typical M12 TypeX connector

Connection systems for optical fiber

The optical interfaces of PROFINET devices have to meet the specifications for multi-mode fibers (IEC 9314-3) and for single-mode fibers (IEC 9314-4). Non-permanent and permanent connections of PROFINET FO connectors are differentiated. These connectors should only be assembled by trained personnel using appropriate special tools.

For more detailed information about the assembly of FO connectors and cables, please see the PROFINET Installation Guideline Order No.: 8.072.

Please contact your cable manufacturer or the manufacturer of the ordered connection system required for your installation to find out which assembly tools are required.

Permanent FO connections are always implemented by means of so-called splicing. Splicing is mainly used in order to extend FO cables or to repair broken fiber.

Connectors

The connectors shown in the figures below (Figure 10-13 and Figure 10-14) are generic drawings based on models typically available on the market. The real design depends on each manufacturer.

SCRJ connectors

The SCRJ is used for PROFINET data transmission via FO. The basic version of this connector has been developed for use in switch cabinets (IP20 protection class). The SCRJ push-pull version (Figure 10-14) is used for rugged environments or IP65 / IP67 requirements.

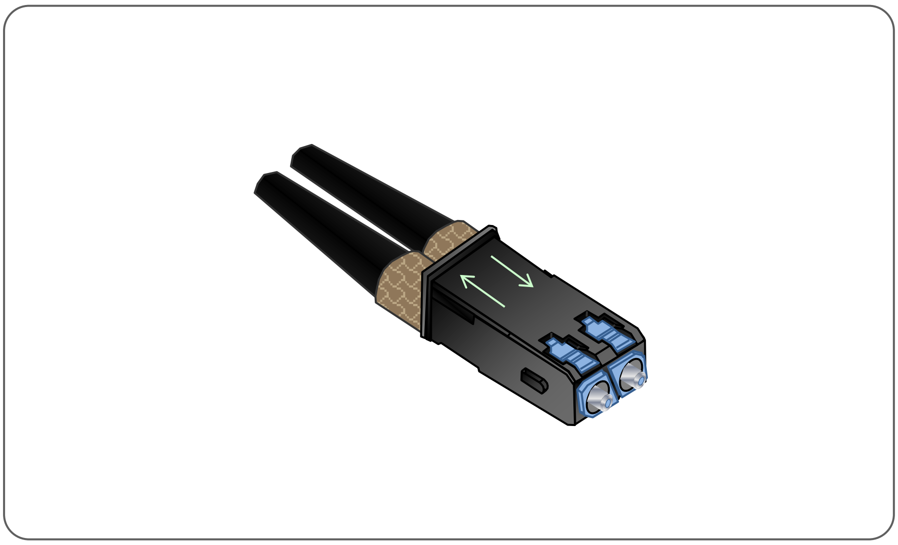


Figure 10-13: Typical SCRJ push-pull connector with IP20 rating

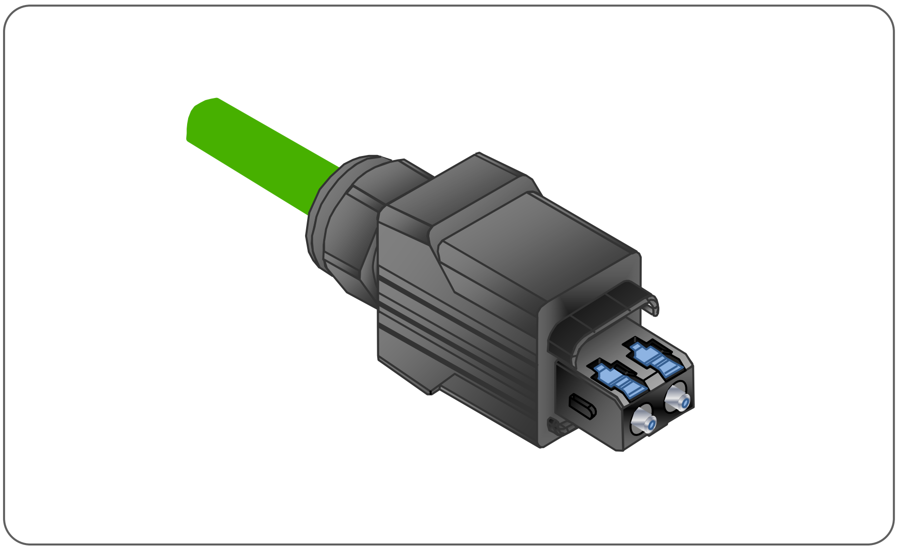


Figure 10-14: Typical SCRJ push-pull connector with IP65 rating

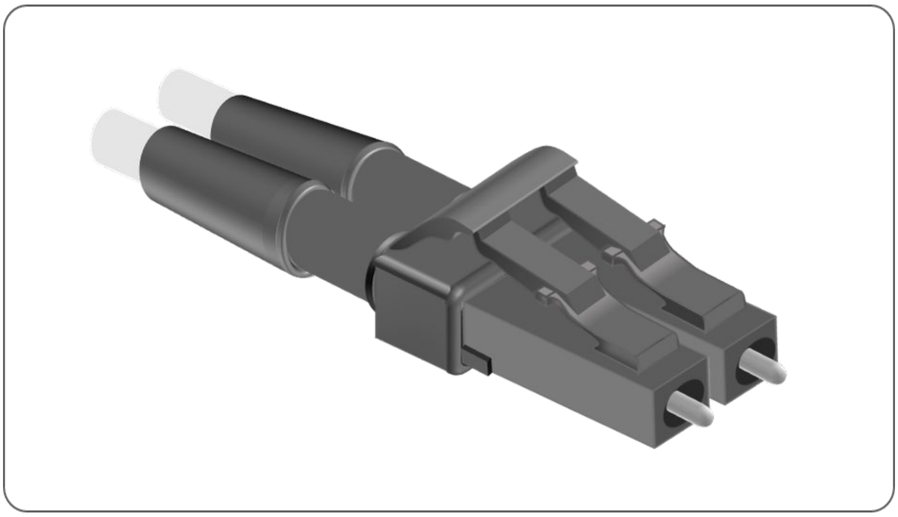


Figure 10-15: Typical LC-Connector with IP20 rating

Connector types BFOC and SC

The use of connector types BFOC / 2,5 (IEC 60874-10) and of the SC plug system (IEC 60874-14) is not recommended for new automation plants.

Transition points

Transition points are potential connection points for PROFINET cables for further distribution. Connectors with protection class IP65 / IP67 are available for use in rugged environments, while modules with protection class IP20 are available for use in switch or distribution cabinets.

The various distributors and sockets are also differentiated by:

- the number and type of ports (copper or FO),
- maximum number of plug cycles (insertions),
- the connection technology (special tools may be required) and
- the protection class.

Please see the manufacturer data for more detailed information concerning the technical properties of the required transition points.

Figure 10-16 and Figure 10-17 show two examples of RJ45 distributors with different protection classes which are based on the models available on the market.

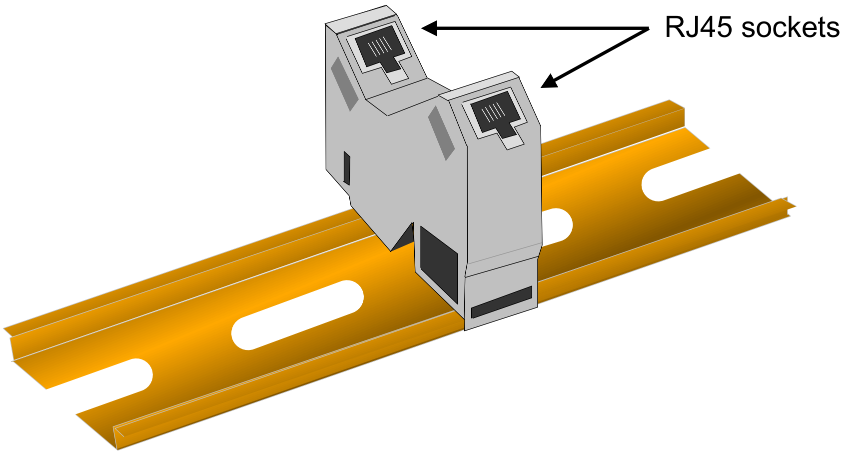


Figure 10-16: RJ45 distribution module for top hat rail mounting in IP20 environments

Distribution modules are available for IP20 environments for all commonly used FO and copper connectors with appropriate sockets.

Top hat rail mounted distribution modules should be used for the transition of the fixed cabling to the internal cabling of the cabinet with patch or adapter cables.

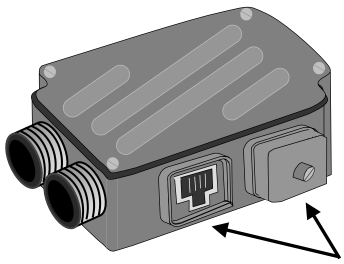


Figure 10-17: RJ45 connection socket for IP65 / IP67 environments

Connection sockets for all commonly used FO and copper connectors with appropriate ports and sockets are available from many different manufacturers.

Connection sockets should be used for the transition from fixed to flexible cabling in the field. Connections in trailing chains can thus be replaced easily.

Bulkhead Connectors

Bulkhead connectors can be used for securely passing external PROFINET copper cables or optical fibers into a cabinet. Such connectors provide transition from an IP65 / IP67 external environment to an IP20 internal environment.

Please see the manufacturer data for more detailed information concerning the technical properties of the required bulkhead connectors.

Figure 10-18 shows an RJ45 Push-Pull wall duct and Figure 10-19 shows an M12 wall duct. These wall ducts are generic drawings based on models currently available on the market.

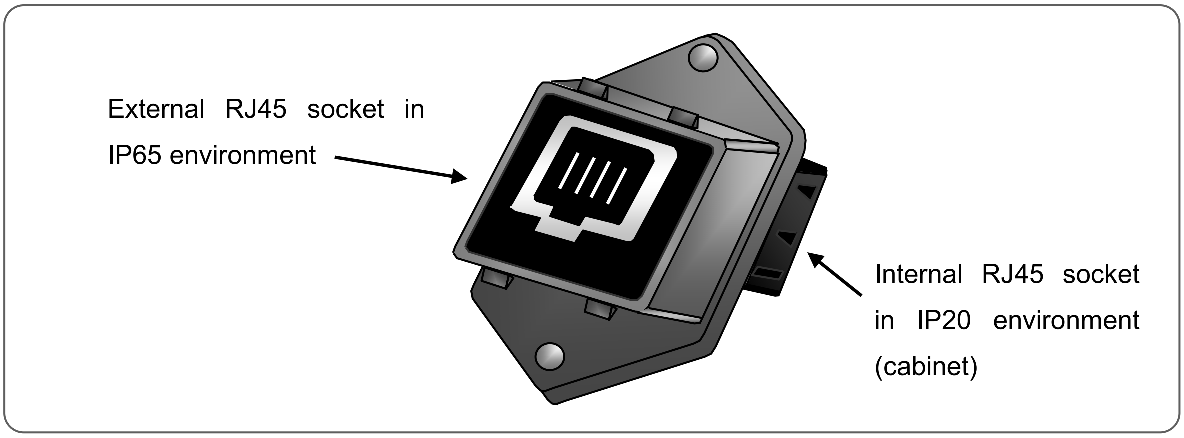


Figure 10-18: RJ45 Push-Pull bulkhead connector for use with cabinets

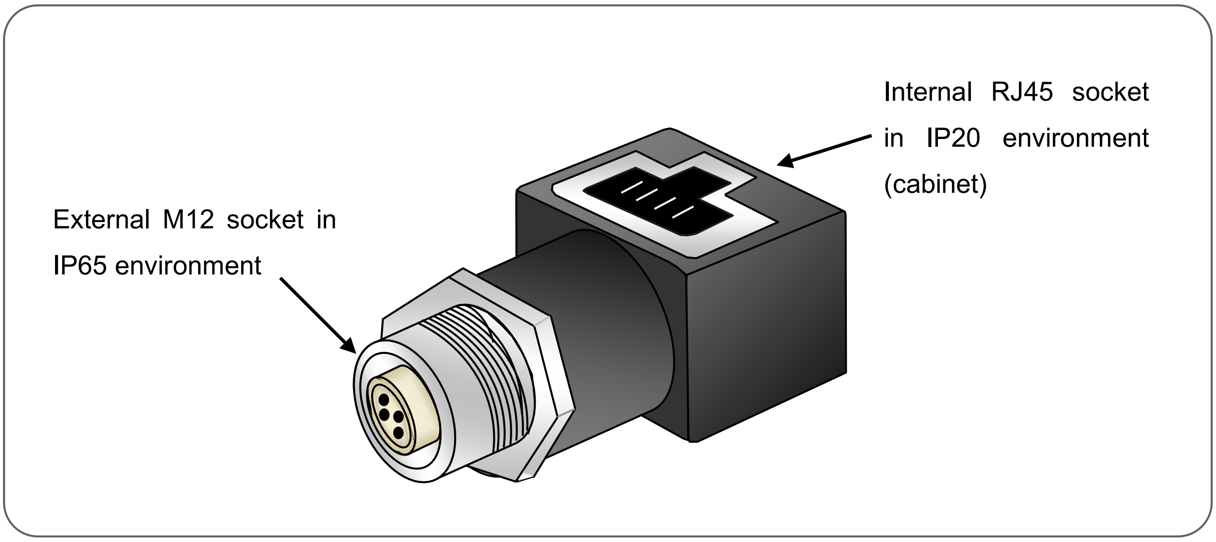


Figure 10-19: M12 bulkhead connector for use with cabinets

10.8 Cabling examples

Two examples for the component selection for FO and copper cabling are shown below. A sample calculation of the attenuation balance is also provided.

Example copper cables

The copper-based, star-topology cabling shown in Figure 10-20 illustrates how the required components could be selected.

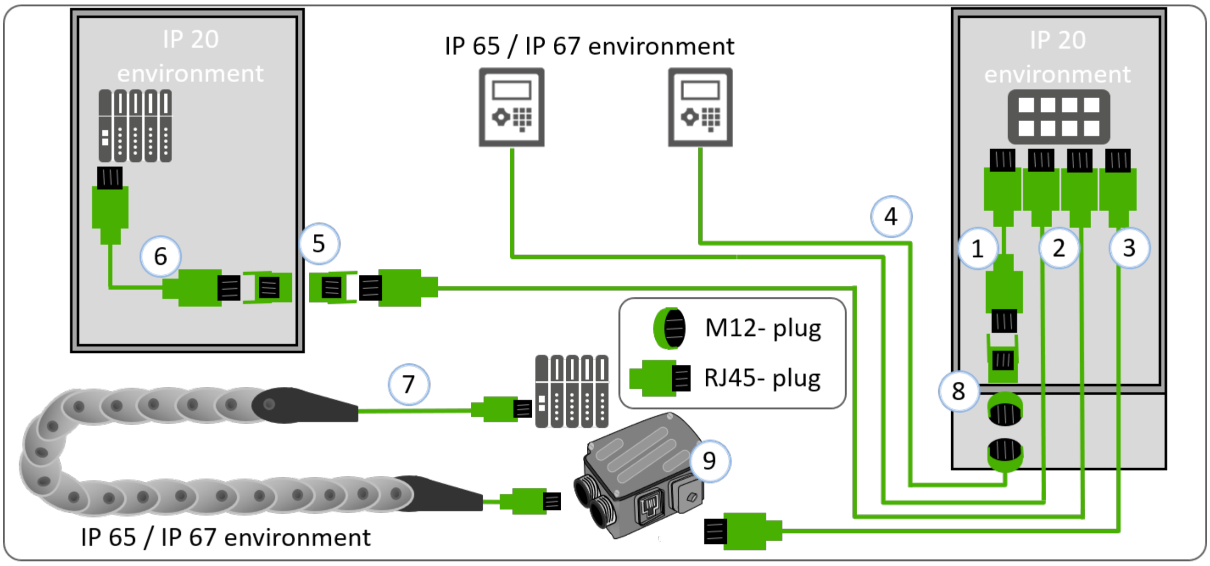


Figure 10-20: Examples of copper-based cabling

Table 10-12 shows the material list for the copper-based cabling described on the previous page.

Table 10-12: Material list copper-based cabling

Number	Name
1	Pre-assembled PROFINET cable with RJ45 connectors within an IP20 environment.
2	Pre-assembled PROFINET cable with RJ45 connectors in IP65 / IP67 environment.
3	PROFINET cable for field assembly, for static installation with RJ45 connectors in IP65 / IP67 environment and RJ45 connectors in an IP20 environment.
4	Pre-assembled PROFINET cable with M12 connectors for use in an IP65 / IP67 environment.
5	Bulkhead connector from RJ45 IP65 / IP67 to RJ45 IP20
6	Pre-assembled PROFINET cable, for fixed installation with RJ45 connectors in an IP20 environment.
7	PROFINET cable for assembly in the field, suited for trailing chain, with RJ45 connectors in an IP65 / IP67 environment.
8	Bulkhead connector from M12 IP65 / IP67 to RJ45 IP20
9	RJ45 connection socket for an IP65 / IP67 environment.

The FO-based, star-topology cabling shown in Figure 10-21 is supposed to illustrate how the required components could be selected.

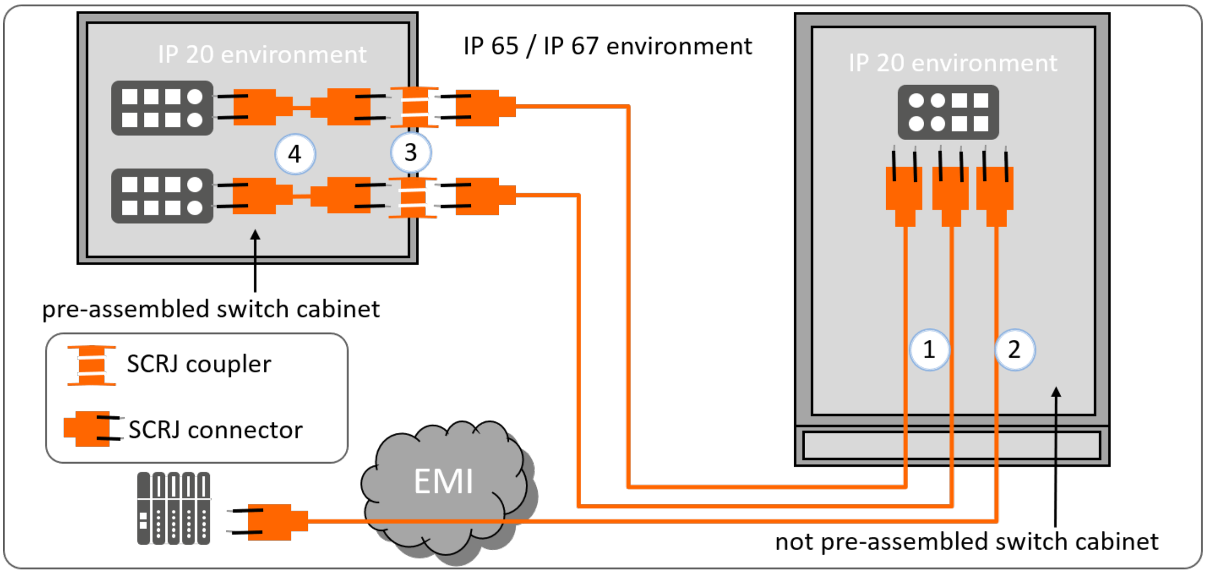


Figure 10-21: Example of FO cabling

Passive couplings such as bulkhead connectors or connection socket will increase the signal attenuation and thus reduce the available cable length.

For example, each passive coupling used in POF cables will reduce the maximum cable length by 6.5 m. Thus, two passive couplings will reduce the maximum POF cable length from 50 m to 50 m - 2 · 6.5 m = 37 m.

Table 10-13 shows the material list for the FO-based cabling described on the previous page.

Table 10-13: Material list FO cabling

Number	Name
1	Pre-assembled FO cable, with SCRJ connectors in IP65 / IP67 and IP20 environments at each end.
2	Pre-assembled POF cable, with SCRJ connectors in IP65 / IP67 and IP20 environments at each end.
3	SCRJ bulkhead connector from IP65 / IP67 to IP20 environment.
4	Pre-assembled adapter cable with SCRJ connectors in an IP20 environment.

Couplings and connectors are available from many different manufacturers, in multiple versions for different environments and applications. Consult manufacturers' information to select suitable connection technology for your application.

Document your selection of connection technology.

Calculation examples

Two examples will now be examined illustrating the calculation of attenuation and power budget.

Figure 10-22 shows a simple example based on a single-mode optical fiber cable.

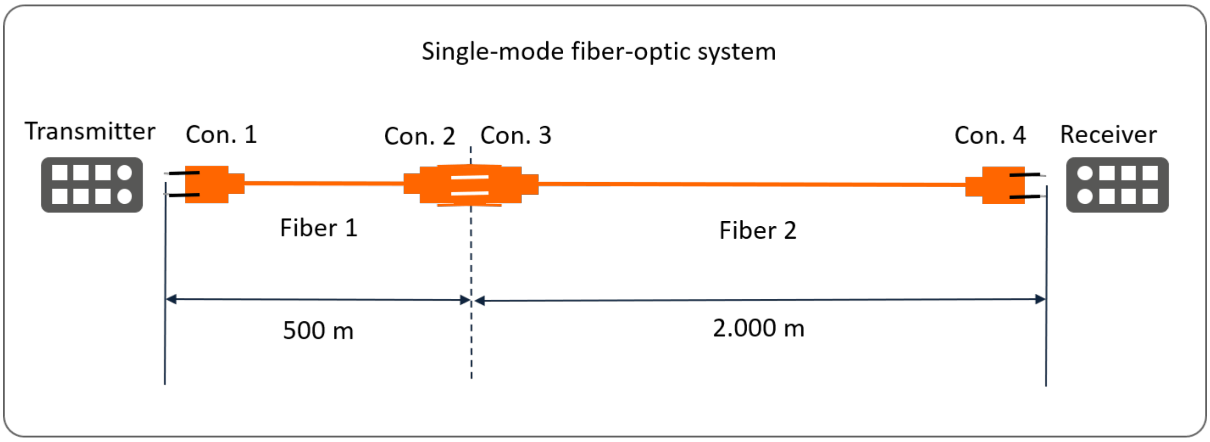


Figure 10-22: Representation of attenuation balance for single-mode optical fiber links

Note that it is important to account for the total number of connections used and not the number of connectors.

Table 10-14 shows the individual passive components, the attenuation caused by them and the total attenuation for the example in Figure 10-22. The attenuation of the fiber is based on 0.5 dB/km and the connections introduce 0.75 dB each. According to Table 3-6, the maximum permissible PROFINET end-to-end-link attenuation is 10.3 dB.

Attenuation balance:

Table 10-14: Calculation of end-to-end link attenuation for single-mode fibers

Fiber 1 500 m	Connections (Con. 1+2/3+4)	Fiber 2 2 000 m	Total attenuation ✓
0.25 dB	3 ·0.75 dB	1 dB	= 3.5 dB
maximum permissible attenuation is 10.3 dB			

Figure 10-23 shows the attenuation calculation based on a polymer fiber link (POF).

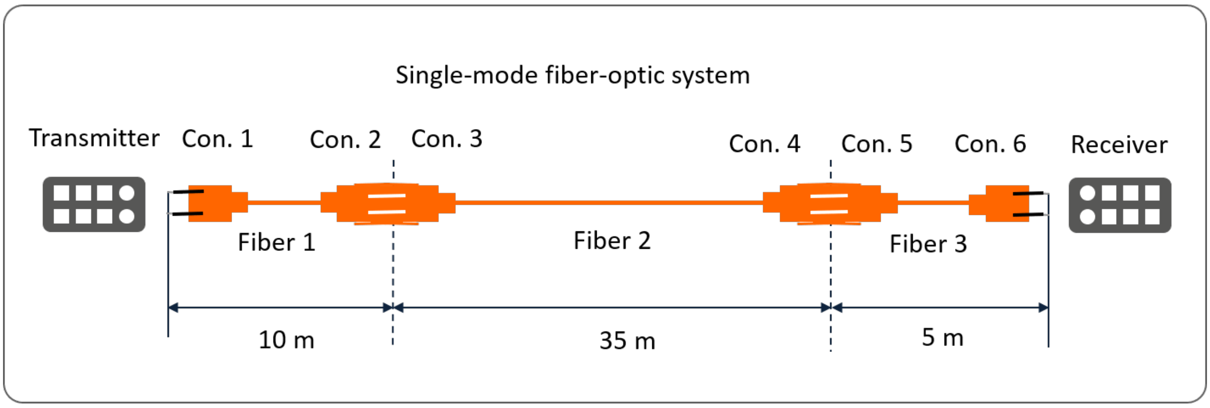


Figure 10-23: Representation of attenuation balance for POF FO link

Table 10-15 shows the individual passive components, the attenuation caused by them and the total attenuation for the example in Figure 10-23. Acc. to Table 3-6, the maximum permissible PROFINET end-to-end-link attenuation is 11.5 dB.

Attenuation balance:

Table 10-15: Calculation of end-to-end link attenuation for polymer fiber links

Fiber 1 **10 m**	**Connections** **(Conn 1+2/3+4/5+6)**	**Fiber 2** **35 m**	**Fiber 3** **5 m**	**Total attenuation** X
2.3 dB	4 ·1.5 dB	8.05 dB	1.15 dB	= 17.5 dB
maximum permissible attenuation is 11.5 dB				

As can be seen, the PROFINET end-to-end link attenuation in this example exceeds the maximum permissible value. To achieve a value of ≤ 11.5 dB, either the transmission link or the number of passive couplings would have to be reduced.

The calculation and, if applicable, the graphical representation of the attenuation balance shows whether the planned FO link meets the transmission requirements.

10.9 Selection of switches

Switches suited for PROFINET are designed for Fast Ethernet (100Mbit/s, IEEE 802.3u) and full duplex transmission. In full duplex operation a switch simultaneously transmits and receives data at the port. There are no collisions.

Switches are available in IP20 versions for top hat rail installation and in IP65/67 versions for field installation. The following section describes some functions of switches which are considered in the selection. The switches are first categorized in two types:

- Unmanaged switches
- Managed switches (with additional PROFINET functionality)

The advantage of PROFINET is the prioritization of the PROFINET data traffic. This feature however is only ensured if switches with „Quality of Service“ (QoS) support are being used (IEEE 802.1q / p).

Unmanaged switches

Unmanaged switches route the entire data traffic based on the address / port allocation table. Users are not able to intervene manually. This is a low-cost version of a switch.

Unmanaged switches do not offer a web interface and have no diagnostic functions.

This type of switch is used in conformance class A networks.

Managed switches

Managed switches offer several advantages over unmanaged switches. These include user option selection based on a web interface and diagnostics capability. The functionality of the management software is different among various switch types, including features ranging from redundancy control up to statistical analysis of network data traffic.

Managed switches support diagnosis functions. The offered switch functionality is controlled and read out either via a web-based interface or via a suitable engineering tool.

To make sure a switch can be identified as PROFINET device, the switch has to support the PROFINET services. The identification of a switch as PROFINET device is foreseen as of conformance class B networks.

Managed switches should be used in conformance class B and C networks

Switches can also be selected as “cut through” or “store and forward”.

Cut through switches

Cut through switches give less delay than store and forward switches. This is because the frame is forwarded directly once the destination address is determined. The switch will buffer only as many bytes of the data packet as are required for analysis of the address / port allocation table. Then all incoming bytes of the data packet are sent directly to the relevant port without any buffering. The routing delay thus does not depend on the frame size.

Store and Forward Switches

Store and Forward switches read and buffer the complete data packet on the incoming port. The switch checks the whole frame for errors and, if error free, sends it to the relevant port. This can cause longer delay times than for switches using the cut through technology. The delay depends on the telegram size of the data packet to be transmitted.

Auto-sensing / Auto-negotiation

Auto-sensing describes the ability of a device to automatically identify the transmission rate of a signal.

Auto-negotiation additionally allows the involved devices to jointly negotiate and agree upon the transmission rate before the first data transmission is started.

If Fast Start-up is used at one port, auto-negotiation should be disabled in order to further optimize the start-up time.

Auto Cross-Over

Auto Cross-Over provides automatic crossing of transmit and receive lines at a port interfaces. If this function is deactivated, a cross-over cable or a switch with port wiring for crossing of connections is sometimes required.

If Fast Start-up is used at one port, auto cross-over should be disabled in order to further optimize the start-up time.

Redundancy support

The redundancy support allows for bumpless or non-bumpless changeover of failed links to a redundant link.

The implementation of redundancy with PROFINET is only achieved by means of managed switches which support an appropriate Media Redundancy Protocol (MRP) and which are configured via an engineering tool or a web-based service.

Port mirroring

Port mirroring is a helpful function for diagnosis in a network. It provides a copy of all the inbound and outbound data from one port (the mirrored port) of a switch to another port (the mirror port) in order to analyze the data frames. Most switches with port mirroring allow the selection and configuration of the mirrored and mirror port from a web page in the switch.

Note that port mirroring is generally only available on managed switches. Also note that many managed switches do not support port mirroring. Always ensure that the selected switch supports port mirroring if required.

You will find further information about the diagnostics options in the PROFINET Commissioning Guideline Order No.: 8.081.

Power over Ethernet

Power over Ethernet (PoE) allows devices with this facility to be powered from the Ethernet cable. A switch with a PoE injector is required.

Switches with PoE functionality are available in various variants with different maximum power specifications. Select the appropriate type according to the number of components to be supplied.

Gigabit Ethernet

If the implementation of PROFINET networks with a transmission rate of 1 000 Mbit is intended, this must also be supported by the switches. Select the corresponding models with the required number of ports supporting Gbit transmission.

Support of the relevant conformance class

As mentioned before, a switch also has to meet the respective requirements to the conformance class.

The manufacturer must indicate the conformance class for which the switch is suitable. You should only use switches that have been certified by PI.

10.10 Functional equipotential bonding and shielding by PROFINET

Information about the functional equipotential bonding and shielding can be found in the guideline Functional Bonding and Shielding for PROFIBUS and PROFINET, Order No.: 8.102.

10.11 PROFINET Documentation

This chapter makes a proposal for the documentation of PROFINET networks. The notes are to be regarded as recommendations. Depending on the conditions in the system or in the company, it is possible to deviate from the specifications.

10.11.1 PROFINET information relevant for documentation

Prior to starting the documentation, the following aspects should be clarified:

- Responsibilities
  - For the creation of network documentation
  - For the management of the network documentation
  - Are there any people responsible for the plant? Are there any responsibilities for individual plant sections?
- How and where will the documentation be distributed?

The cover page should contain all relevant information needed for identifying the document:

- ID of the documentation
  - Document type (here: Network documentation)
  - ID number / name
  - Date of issue
  - Revision index or version
  - Revision date
  - Document status (is it a draft or final version?)
  - Specific data (customer name, plant name)
- Information on the creator
  - Company name
  - Company address
  - Responsible author

The network documentation should range from a network overview for the entire plant over detailed views of the networks of plant section up to device-specific information. A topology overview is a visual representation and, hence, provides a good introduction.

- For example, an R&I diagram, plant structure or the architecture of the premises.
- Enter the assets into the drawing
  - Automation devices
  - Network infrastructure
    - Cabling including patch fields
    - The cabling order must be represented correctly.
    - Ring topologies must be marked.
  - The people responsible of the plant must be noted.
- The identifiers/names of the devices must be included.

    - Device type (e.g. PLC, switch, repeater, etc.)
    - Make a clear allocation to the locality.
        - Specify the building (part).
        - Specify the room.
        - Make a note of the spot height to allow for easy device localization (e.g. in a high-bay storage).
        - Note the cabinet.
- The connection terminals (ports) of the devices must be designated.
- Segmentation plan
- Information on the cable
    - Cable length between two nodes
    - Used cable type (included in cable list?)
    - Note the medium (copper, FO).
        - Where are converters from copper media to optical media used?

For reasons of simplicity, further information should be documented in a separate Annex about topology.

- Information on the products
    - Manufacturer
    - Serial numbers of the devices
    - Model name / type designation
    - Spare parts
        - Serial number
        - Type number
        - Version number
        - Supplier (or alternative supplier)
        - Reference picture
    - Store data sheets.
    - Describe the device functionality.
    - Certificates
    - Document the used software or firmware revision levels.
- Document the reference measurements of the network.
    - Measure and document the network load in normal operation.
    - Mark any points where EMC disturbances have to be expected.
    - Validation report of the physical layer (what are the physical variables during commissioning?)
    - Validation report of the communication layer (what does data modulation look like?)
    - Validation report of the hazardous area (which devices are used in the hazardous area?) Are these devices certified?
    - Are there any delays? How long is the delay?

- Information for cases of faults
  - List for fault localization
  - Description of integrated diagnostic systems
  - Drawings and diagrams
  - Contact information for further help (hotline/support)
  - Who is responsible of the plant (parts)?

Further information needs to be documented for PROFINET networks.

- Document the device name in the topology plan.
- Note the IP address on the device in the topology plan.
- Note the subnet mask on the device in the topology plan.
- List the MAC addresses of the devices.
- Are the GSD saved? Which GSD are used?
- Which protocols are used? Which services are supported?
- Ring topology and corresponding switch-over times

The following special documentation items must be listed for an IT security audit:

- When firewalls are used
  - Is the firewall password protected?
  - Mark the (physical and logical) installation site.
  - Document the set of rules for the firewalls.
- Virus scanner
  - Does it exist?
  - How often is it updated?
  - How often is the segment scanned?
- Which ports/services are active?
- Does the current firmware revision levels feature any security gaps?
- Do VLANs exist?
- Passwords
  - Do they exist?
  - Was the default password, if any, changed?
  - Are access rights to the passwords defined?
- Are access rights to sensitive rooms defined? (R&D)
- Documentation of employee training
- Is an emergency manual available?

Which rules of conduct are to be followed in the event of a cyber-attack?

10.11.2 Proposal for a PROFINET forwards documentation

This section is intended to further explain the information in section 10.11.1. The individual steps of forwards documentation are discussed and the difficulties are described.

A network documentation often addresses more than one target group (persons in charge of the installation, revision, operation, troubleshooting or audit). In a simplified approach, however, it is possible to identify two fields of interest (see Figure 10-24).

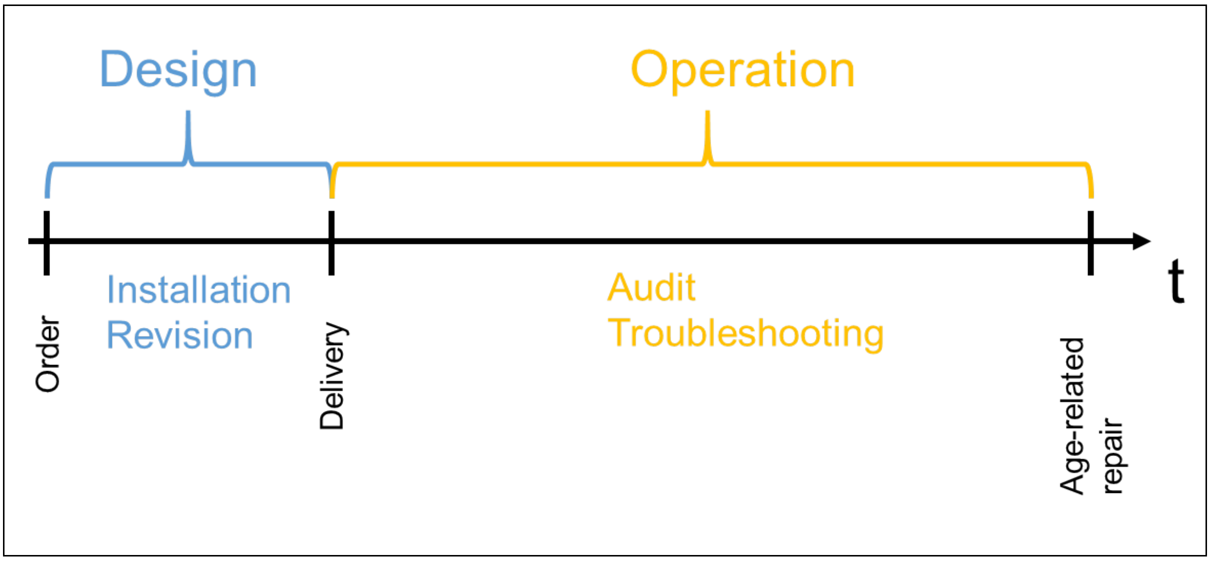


Figure 10-24: Fields of interest in a plant lifecycle

As the installation and revision departments normally use electrical wiring diagrams, the plant operators are the main target group of the network documentation.

The next step defines the format in which the network documentation is to be created. It must be clarified whether printed plans are to be published or digital documentation is to be used instead. Mind the fact that sensitive data must be access-protected. Digital plans must be saved in a file format which ensures (read and write) access and data readability and integrity. Also pay attention to the retention obligation. The documentation must be available for the retention period.

The persons responsible for the document creation and management during the operation phase must be defined. For large companies or plants, the persons responsible for the corresponding plant or plant sections must be contacted.

Every forward documentation begins with a cover page. The cover page should provide the information relevant for identification (plant, creator, responsibility). The document revision information (index, date) provides the revision level and allows you to clearly determine whether the document is up to date. It is also useful to indicate the status on the cover page. Moreover, it must be possible to clearly identify the creator for possible questions.

A table of contents must be included after the cover page. The more details the table of contents contains, the better, as you can directly access the information needed.

Begin with the topology plan. It is helpful to use the architecture, or an R&I diagram as a template. All necessary network nodes must be integrated and numbered consecutively. Assign unique device names. The name should indicate the type or function of a node and also its location (building or building part, room). The spot height can also be provided. Add the IP address and subnet mask of each device to the topology. The plan must allow for easy identification of the responsibility for the segments or building parts.

Document all cables and connectors in the correct order. The port of each node must be noted in the plan to allow for unique identification of the device connectors. Special attention must be paid to patch field. Ring topologies must be marked expressly. It is useful to assign a unique name to each connection (does a cable list exist?) and to note down the length of the laid cables. If different media (copper or FO cables, wireless) are to be used, these must be drawn differently.

Any further information and details should be moved to the Annex in order to keep the actual overview short and clear. It is recommended to list all further information in the Annex in a table and group the individual items by categories (product, cable).

Table 10-16 shows further information. Record the protocols and services of the individual devices used. All data sheets and certificates must also be stored. It is recommended to record in the documentation not only the information shown in Table 10-16, but also the type number, (alternative) suppliers and a picture of the node.

Add a network load calculation and measurement results of the network load in the individual segments to the documentation. Also record the data communication delays in the commissioning phase. Areas where EMC disturbances are likely to occur must also be marked. It is helpful to add a validation report for the physical layer and the communication layer. The reports should indicate whether and to which extent the physical (current, voltage) and communication-related (edge rise and fall times) PROFINET requirements were initially met by the plant.

Mark all integrated diagnostic systems and note the data of contact persons who may provide support (e.g. line manager, consultant engineer, hotline and support).

Table 10-16: Further information on the devices in the topology

No.	Device name	Manufacturer	Model/type	MAC address	HW revision level	Firmware revision level	Serial number
1	Sw.HA1.1	Manufacturer 1	Switch 12	12-34-56-78-9A-BC	1.3	1.3.1	ABC-12345
2	PLC.HA1.1	Manufacturer 2	PLC 5	13-24-56-11-90-01	2.0	2.2	1920-1812-8212-0

Additional information must be provided for an IT security audit. All places where firewalls are used must be marked in the topology to allow for the assessment of the IT security. Document the set of rules for each firewall. Also document whether default passwords were changed. In order to prevent any loss of knowledge or data in the event of illness, accident, death or job change of an employee, it is recommended to create and maintain a password list. Mind the access restriction and protection. Additionally, you should document all employee trainings related to IT security and have an emergency manual with rules of conduct to be followed in the event of a cyber-attack. When using a virus scanner, document the update intervals and the frequency of virus scans. Also document all existing VLANs.

10.11.3 Example of a PROFINET forwards documentation

Table 10-17 shows the preliminary considerations.

Table 10-17: Example of PROFINET forwards documentation, preliminary considerations

<table>
<tr><td>Target group</td><td colspan="2">Operator, special knowledge yes, special language yes</td></tr>
<tr><td>Target country/language</td><td colspan="2">Germany/German</td></tr>
<tr><td>Type of publication</td><td colspan="2">Printed documents, centrally managed plans, access only by counter-signature</td></tr>
<tr><td>Number of copies</td><td colspan="2">3 (1 design dpt, 1 operator, 1 external backup copy)</td></tr>
<tr><td>Retention period</td><td colspan="2">12 years, ensured by storage of printed plans in different locations</td></tr>
<tr><td rowspan="3">Responsibilities</td><td>Creation</td><td>Company A, Mr. Sample</td></tr>
<tr><td>Management</td><td>Company B, Ms. Example</td></tr>
<tr><td>Plant</td><td>Ms. Meyer (administration
Mr. Smith (hall 1)
Ms. Schulz (hall 2)</td></tr>
</table>

Figure 10-25 shows a cover page example.

Network Documentation PROFINET

Plant: Plant sections in hall 1
ID No.: 2508
Issue date: 25.08.2016
Status: Released

Revision:

Index	Date	Created by	Approved by
1			
2			
3			
4			

Customer: Customer Ltd.
Customer Road 2
56723 Customer City

Created by: Company Inc.
Example Road 12
123456 Example Town

Responsible author:
Mr. S. Sample

Figure 10-25: Cover page example for PROFINET forwards documentation

The information provided on the cover page should be repeated on all other pages. A title block on each page is a suitable means of achieving this. The title block must be placed in the bottom right corner of each page and contains all relevant information on the document. Table 10-18 lists the 15 most important items. Table 10-19 shows the structure of the title box in and Table 10-20; it also contains an example of the title box which will be represented on the following pages by a gray box for the purpose of simplification.

Table 10-18: Information in the title box in accordance with [ISO 7200]

Number	Data field
1	Legal owner of the document
2	Title
3	Supplementary title
4	Reference number
5	Change index
6	Date of issue of the initial version of the document
7	Language
8	Number of pages/sheets
9	Document type
10	Document status
11	Responsible department
12	Technical reference (contact person with required knowledge)
13	Name of the person who created the document
14	Name of the person who approved the document
15	Classification/key words

Table 10-19: Proposal for title box in accordance with [ISO 7200]

<table>
<tr><td>Responsible dept.
(11)</td><td>Technical reference
(12)</td><td>Created by
(13)</td><td colspan="4">Approved by
(14)</td><td>(15)</td></tr>
<tr><td colspan="2" rowspan="3">(1)</td><td colspan="2">Document type
(9)</td><td colspan="4">Document status
(10)</td></tr>
<tr><td colspan="2" rowspan="2">Title, Supplementary title
(3)</td><td colspan="4">(4)</td></tr>
<tr><td>Rev.
(5)</td><td>Date of Issue
(6)</td><td>Lang.
(7)</td><td>Sheet
(8)</td></tr>
</table>

Table 10-20: Table 1 9: Example of title box in accordance with [ISO 7200]

<table>
<tr><td>Responsible dept.
Design 2</td><td>Technical reference
Ms. N. Meyer</td><td>Created by
Mr. S. Sample</td><td colspan="4">Approved by
Mr. K. Smith</td><td></td></tr>
<tr><td colspan="2" rowspan="3">Company Inc.</td><td colspan="2">Document type
Network Documentation</td><td colspan="4">Document status
Released</td></tr>
<tr><td colspan="2" rowspan="2">Title, Supplementary title
PROFINET
Plant sections in hall 1</td><td colspan="4">2508</td></tr>
<tr><td>Rev.
A</td><td>Date of Issue
25.08.2016</td><td>Lang.
En</td><td>Sheet
1/5</td></tr>
</table>

Figure 10-26 shows the plant to be automated. It consists of three plant sections in hall 1 (responsible: Mr. Smith) of a company. A cabinet is already planned to be installed in the hall; therefore, it is represented by a dotted line.

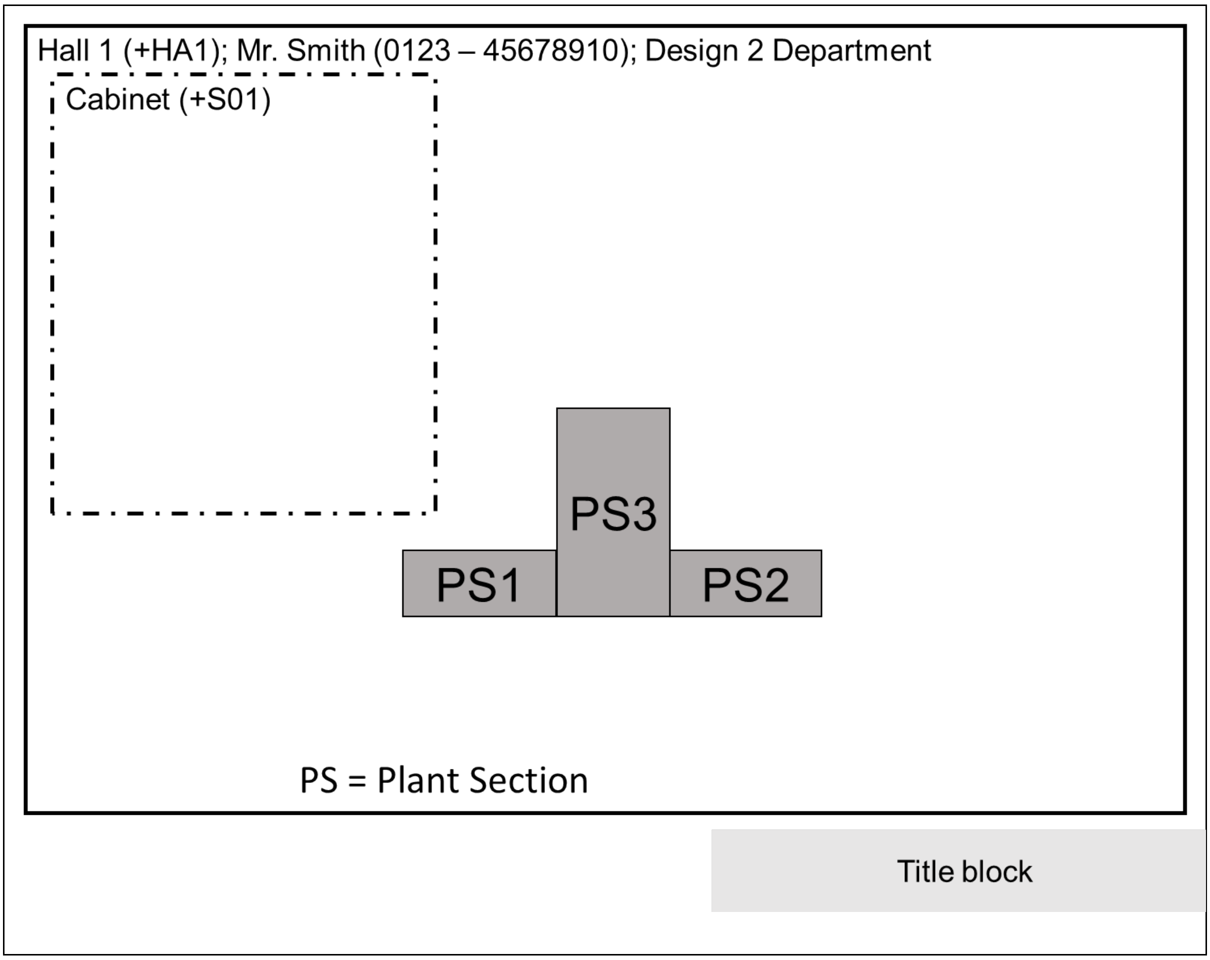


Figure 10-26: Example of forwards documentation for the automation of three plant sections

Figure 10-27 shows the configured automation devices and the required network infrastructure. In addition to a PLC and three remote IOs, there is a switch for connecting the network nodes and an HMI (Human Machine Interface) for visualizing the process. Figure 10-28 shows the logical topology plan.

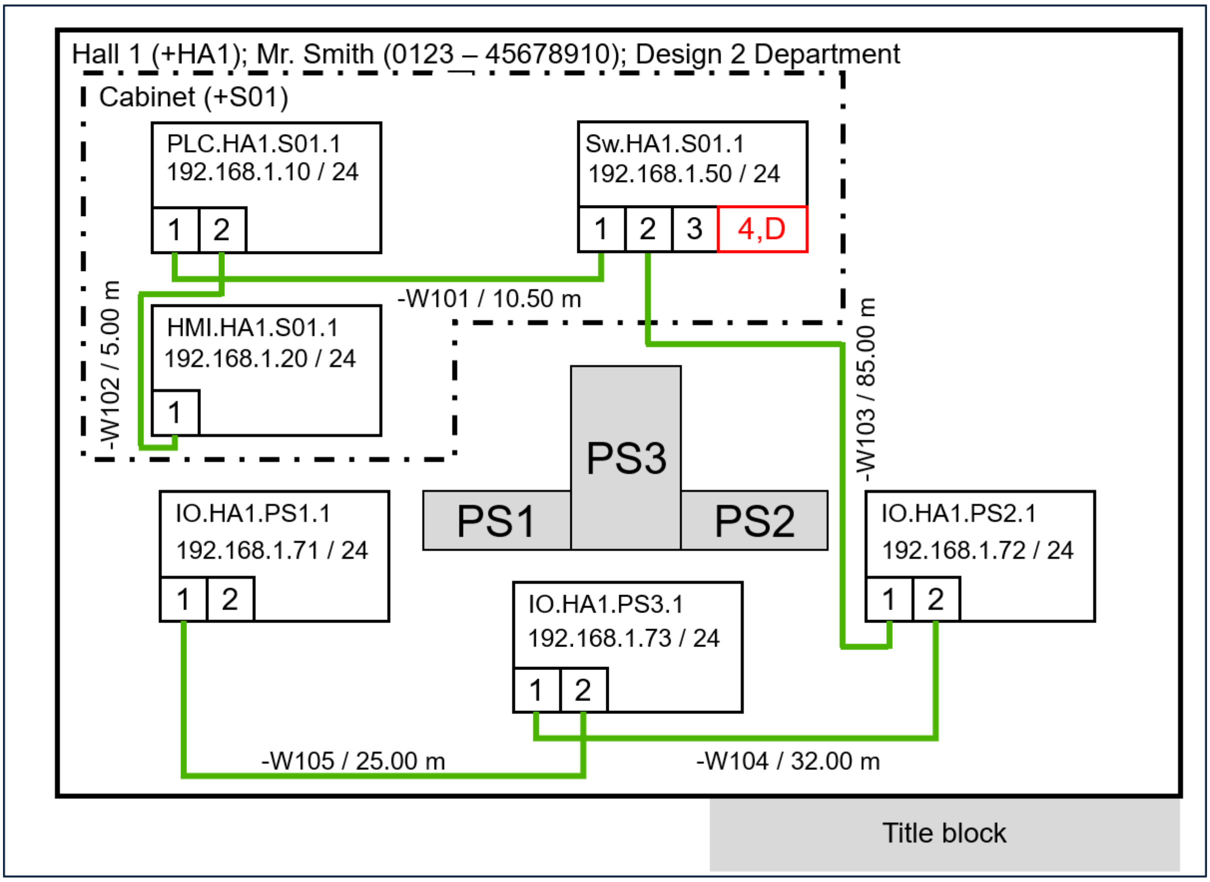


Figure 10-27: Example of PROFINET forwards documentation, physical topology plan

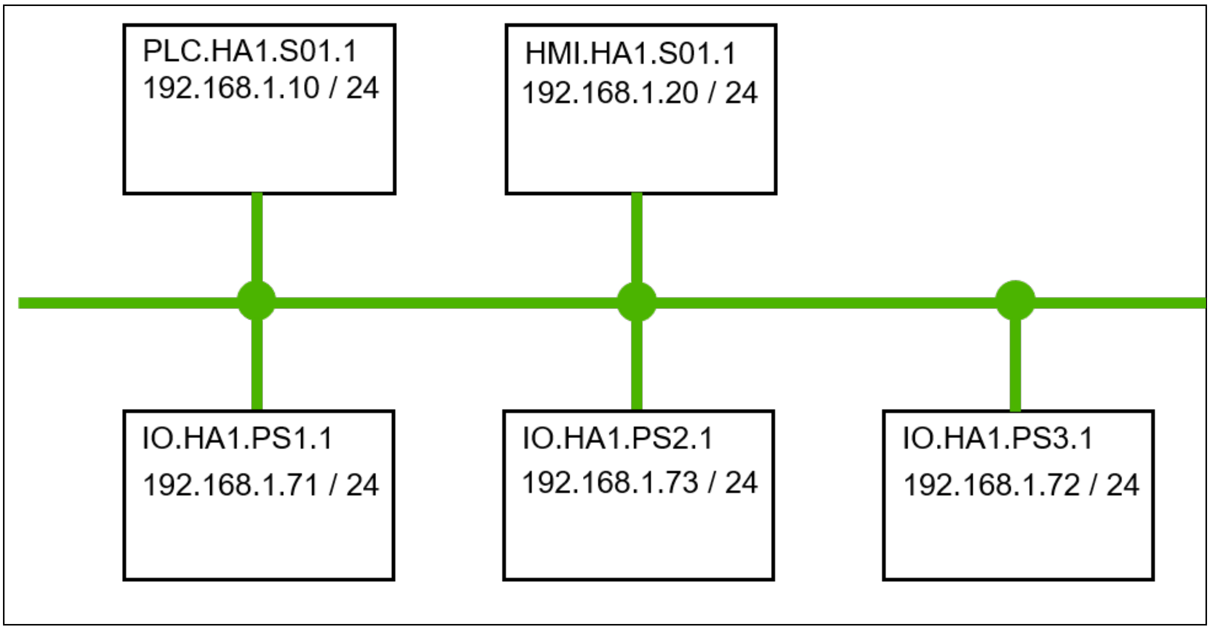


Figure 10-28: Example of PROFINET forwards documentation, logical topology plan

Figure 10-29 shows the topology plan of a ring topology. The switch (Sw+HA1+S01_1) is used to organize the ring. For this purpose, it's marked with a number (1) in a "ring". The ring is drawn exactly between the two ports that spread it out.

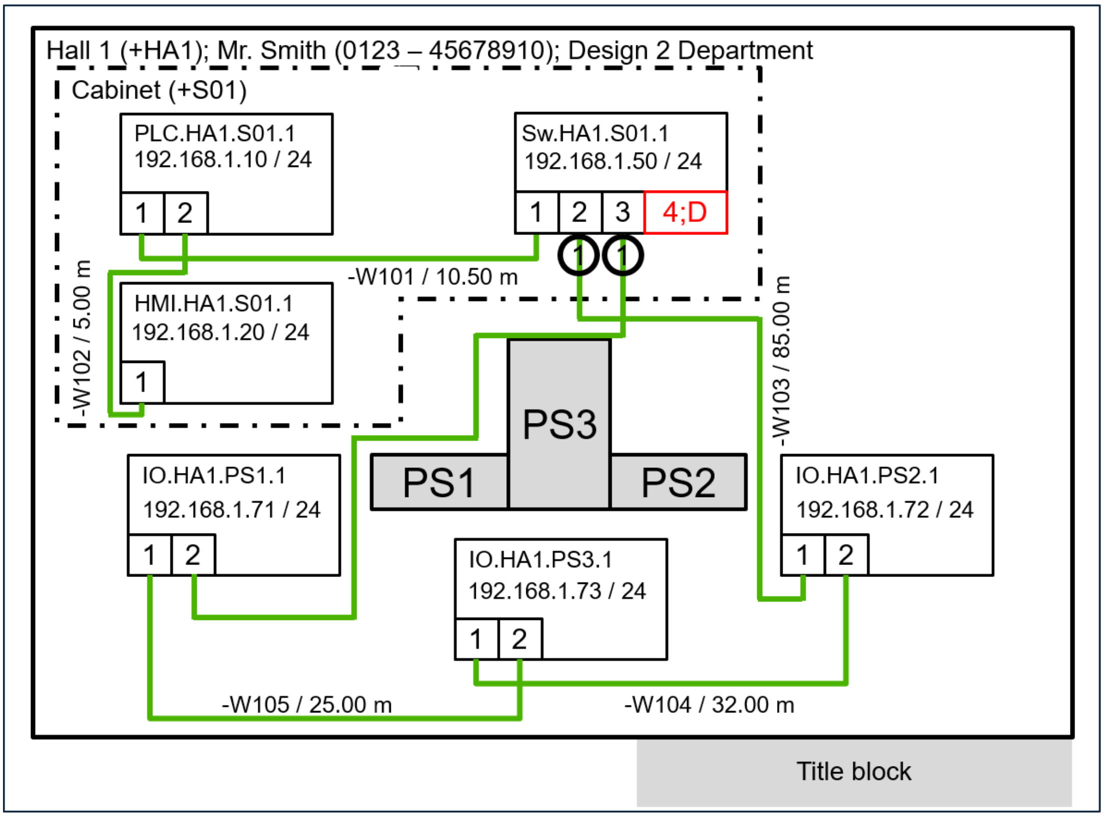


Figure 10-29: Example of PROFINET forwards documentation, ring topology

Table 10-21 enhances the topology plan (see Figure 10-29) with further information. The device in the first position manages the ring and, hence, has a different color.

Table 10-21: Example for PROFINET forwards documentation, information related to the ring topology

No.	Device name	Port	Next device		Port	Next device		Manager
			No.	Device name		No.	Device name	
1	Sw.HA1.S01.1	2	2	IO.HA1.PS2.1	3	4	IO.HA1.PS1.1	x
2	IO.HA1.PS2.1	1	1	Sw.HA1.S01.1	2	3	IO.HA1.PS3.1	
3	IO.HA1.PS3.1	1	2	IO.HA1.PS2.1	2	4	IO.HA1.PS1.1	
4	IO.HA1.PS1.1	1	3	IO.HA1.PS3.1	2	1	Sw.HA1.S01.1	

Table 10-22 contains further information on the automation devices and additional network nodes. Table 10-23 provides additional information for the replenishment.

Table 10-24 summarizes the most important information on cables as an addition to the topology plan.

Table 10-22: Example for PROFINET forwards documentation, additional device information

No.	Device name	IP address	Subnet mask	Protocols	Port: Service	PW changed		MAC address	Firmware revision level	GSD saved? (version and storage place)
						Yes	No			
1	PLC.HA.-S01.1	192.168.1.10	255.255.255.0	PNIO + TCP/IP	80: HTTP	x		13-24-56-11-90-01	2.2	10.5 Server on 2016-08-31
2	HMI.HA1.S01.1	192.168.1.20	255.255.255.0	PNIO + TCP/IP	80: HTTP		x	13-24-56-12-55-21	2.1	8.4 Server on 02.09.2016
3	Sw.HA1.S01.1	192.168.1.50	255.255.255.0	PNIO				12-34-56-78-9A-BC	1.3.1	1.1 Server on 02.09.2016

4	IO.HA1.PS1.1	192.168.1.71	255.255.255.0	PNIO				00-0E-8C-24-C5-51	2.5	1.3 Server on 02.09.2016
5	IO.HA1.PS2.1	192.168.1.72	255.255.255.0	PNIO				00-0E-8C-24-C5-4E	2.5	1.3 Server on 02.09.2016
6	IO.HA1.PS3.1	192.168.1.73	255.255.255.0	PNIO				00-0E-8C-24-C6-12	2.5	1.3 Server on 02.09.2016

Table 10-23: Example for PROFINET forwards documentation, enhanced device information

No.	Device name	Port	Cable	Device	Manufacturer	Model	HW/, FW revision level	Serial number	(Alternative) supplier Order No
1	PLC.HA1.S01.1	1	-W101	Sw.HA1.S01.1	Manufacturer 1	PLC 5	2.0 / 2.1.1	1920-1812-8212-0	Vendor X 7815182
		2	-W102	HMI.HA1.S01.1					
2	HMI.HA1.S01.1	1	-W102	PLC.HA1.S01.1	Manufacturer 1	HMI 17	2.5 / 2.6	1231-3017-0111-5	Vendor X 4825561
		-	-	-					
3	Sw.HA1.S01.1	1	-W101	PLC.HA1.S01.1	Manufacturer 2	Switch 12	1.3 / 1.3.2	ABC-12345	Vendor X 1541527
		2	-W103	IO.HA1.PS2.1					
		3	-	-					
		4	-	-					
4	IO.HA1.PS1.1	1	-W105	IO.HA1.PS3.1	Manufacturer 3	IO S2	2.0 / 2.2	14-93-15	Vendor X 4510965
		2	-	-					

5	IO.HA1.PS2.1	1	-W103	Sw.HA1.S01.1	Manufacturer 3	IO S2	2.0 / 2.2	14-93-15	Vendor X 4510965
		2	-W104	IO.HA1.PS3.1					
6	IO.HA1.PS3.1	1	-W104	IO.HA1.PS2.1	Manufacturer 3	IO S2	2.0 / 2.2	14-93-15	Vendor X 4510965
		2	-W105	IO.HA1.PS1.1					

Table 10-24: Example of PROFINET forwards documentation, cable list

Name	Connector 1			Connector 2			Actual length in meters (m)	Medium	Type / Nature
	Device	Port	Connection	Device	Port	Connection			
-W101	PLC.HA1.S01.1	1	RJ45	Sw.HA1.S01.1	1	RJ45	10.50	Cu	A
-W102	PLC.HA1.S01.1	2	RJ45	HMI.HA1.S01.1	1	RJ45	5.00	Cu	A
-W103	Sw.HA1.S01.1	2	RJ45	IO.HA1.PS2.1	1	M12	85.00	Cu	A
-W104	IO.HA1.PS2.1	2	M12	IO.HA1.PS3.1	1	M12	32.00	Cu	A
-W105	IO.HA1.PS3.1	2	M12	IO.HA1.PS1.1	1	M12	25.00	Cu	A

Describe normal plant operation in a clear manner (see Figure 10-30). For further checklists for visual inspection, cable acceptance checks and the two-part acceptance protocol refer to the Annex of the PROFINET Commissioning Guideline [PNI2014].

Figure 10-30 shows how the diagnostic port can be marked.

Segment: 192.168.1.0 – 192.168.1.255 / 24

Tag ____________________

Network load ______________ % (< 20 % all right; 20 .. 50 % review recommended; > 50 % need for action!)

No. of ARP broadcasts ______ (0 all right; > 0 review recommended)

No. of DCP multicasts ______ (0 all right; 1 .. 10 if cause is known and inevitable; 11 .. 20 consult design dept.; > 20 review recommended)

No. of MRP multicasts ______ (0 all right; > 0 review recommended)

EMC disturbances expected? ☐ No ☐ Yes, where: ____________

FO available? ☐ No ☐ Yes, attenuation: _____dB

Delay in communication? ☐ No ☐ Yes:

Title block

Figure 10-30: Example of PROFINET forwards documentation, information in cases of faults

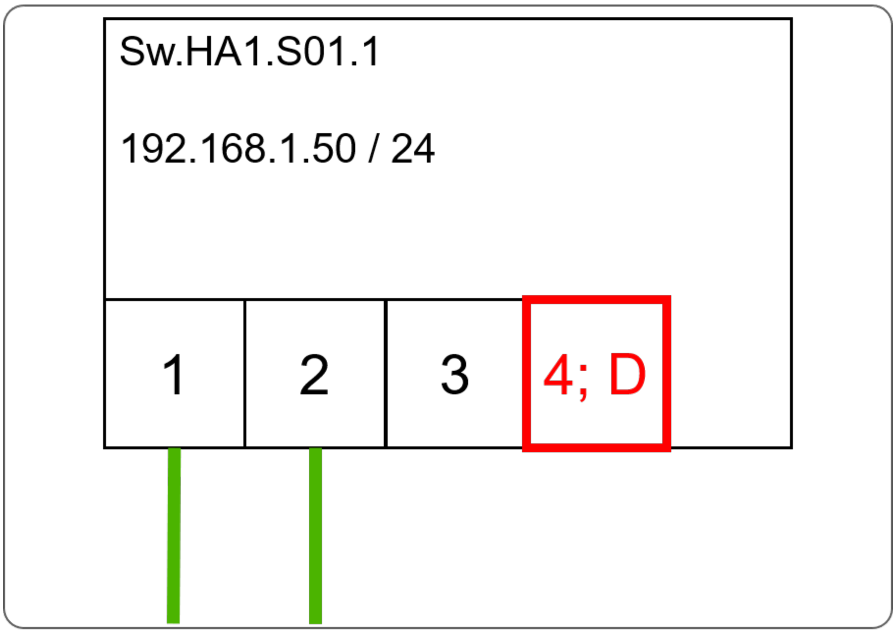


Figure 10-31: Example of PROFINET forwards documentation, diagnostic port example

The use of firewalls should be shown clearly in the topology. Further information related to the access and the default settings must be recorded in a separate list. Figure 10-32 shows an IT security assessment.

IT Security Assessment for Plant: Plant sections in hall 1 (ID No. 2508)

Security officer: Mr. Sam Sample

IT Security employee training
First execution: 16.09.2016 Execution interval: Annually (every 12 months)

Next IT Security audit: 16.03.2017
Connection to other networks?: ☒ No ☐ Yes, where:

Virus scanner used? ☒ No ☐ Yes, where:
Scan interval: __________ Update interval: __________

Emergency manual available? ☒ No ☐ Yes, where:

Access control to sensitive data? ☐ No ☒ Yes, how: Access through person transponder

Free device ports:

Device name	Port	Free?
Sw+HA1+S01_1	1 2 3 4	No No Yes Yes, diagnostics

Are there WLAN access points? ☒ No ☐ Yes, where:

Title block

Figure 10-32: Example of PROFINET forwards documentation, IT security assessment

Keep all data sheets and the manuals of the devices used. Add a functional description of the plant to your documentation.

10.11.4 Problems of forwards documentation in the product lifecycle

Deviations frequently occur in the installation or commissioning phase already. They should be eliminated in a revision. However, the large number of manual user interactions by different employees results in a high risk of faults. Once the system has been delivered to the plant operator, the designers are no longer responsible, and the knowledge recorded in good network documentation is no longer available. In cases of faults, the employees of the plant operator normally attempt to eliminate the faults themselves. Minor changes of the plant are often not recorded as they must be made under some time pressure.

A forward documentation often contains many items throughout the entire lifecycle of the plant. These reduce the quality of the network documentation. The documentation of the network becomes unclear, difficult to understand or faulty. Often the network documentation is not up to date, the access is denied, or the documents are missing.

Due to these disadvantages, it is not recommended to use the forwards documentation in the operational phase of the lifecycle. Writing an up-to-date network documentation on site is more suitable for troubleshooting. A standardized backwards documentation helps reduce the time required for documentation.

10.11.5 Proposal for a PROFINET backwards documentation

The requirements on the backwards documentation must be reduced to a minimum as the documentation is generated automatically. The backwards documentation should also begin with an overview and then provide details. The cover page contains all relevant information needed for identification:

- ID of the documentation
  - Document type (here: Network documentation)
  - ID number / name
  - Date of Issue
  - Revision index or version
  - Revision date
  - Document status (is it a draft or final version?)
  - Specific data (customer name, plant name)
- Information on the creator
  - Company name
  - Company address
  - Responsible author

The topology must be clearly designed and contain all additional information (device name, IP address, subnet mask, port assignment, cable length). Further information (cable type, cable medium) can be provided in tables. From the ports assignment you can derive free access ports of the plant. Additionally, the firewalls should be shown. Information about an existing password-protection can be written in the topology on the firewall or can be color-coded (green = password-protected, red = no password-protection)

Reading out the used network nodes is supposed to provide information on possible spare parts. This information includes:

- Manufacturer
- Model name/type designation
- MAC address
- Used protocols
  - Used ports and services
- Serial number
- Version number
- Reference picture
- Used software or firmware revision levels
- Contact information of the hotline or technical support
- Password security: Are standardized passwords used?

Any information that cannot be determined through backwards documentation must be provided by the employees.

Tools for analyzing PROFINET networks are already available. Various vendors offer tools for backwards documentation. Nearly all criteria can be met.

However, the information determined by commercial tools does not comply with the requirements of an IT security audit.

10.11.6 Difficulties of backwards documentation

A topology can only be read and visualized by the tools if all nodes are capable of handling the LLDP (Link Layer Discovery Protocol). This is an obstacle to using backwards documentation, as low-cost alternatives that do not support LLDP are often used in networks.

Moreover, passive network nodes require different measurement mechanisms and often result in incomplete network documentation, since passive network nodes cannot be recognized correctly.

10.11.7 Requirements for future backward documentations

A backwards documentation should begin with a topology plan. Additional information must be visualized on the devices. This information includes the device, name, IP address, subnet mask, port assignment, device function (if not clearly indicated by the device name) and a reference picture of the device. Further information should be listed in tables. You can find an overview of all information in section 10.11.1.

The general network documentation can be used as the basis for information on IT security. All services must be disclosed for this. As a result, the device vendors should reveal the standard ports/services of their devices.

In order to allow for successful backward documentation, the plant manufacturers and operators must select the appropriate components. Additionally, the product manufacturers must provide more data for their products. The conversions process is ongoing.

10.12 Network load calculation tool

Figure 10-33 shows the user interface of the network load calculation tool in Microsoft Excel. The purpose of the network load calculation tool is to facilitate the network load calculation for users.

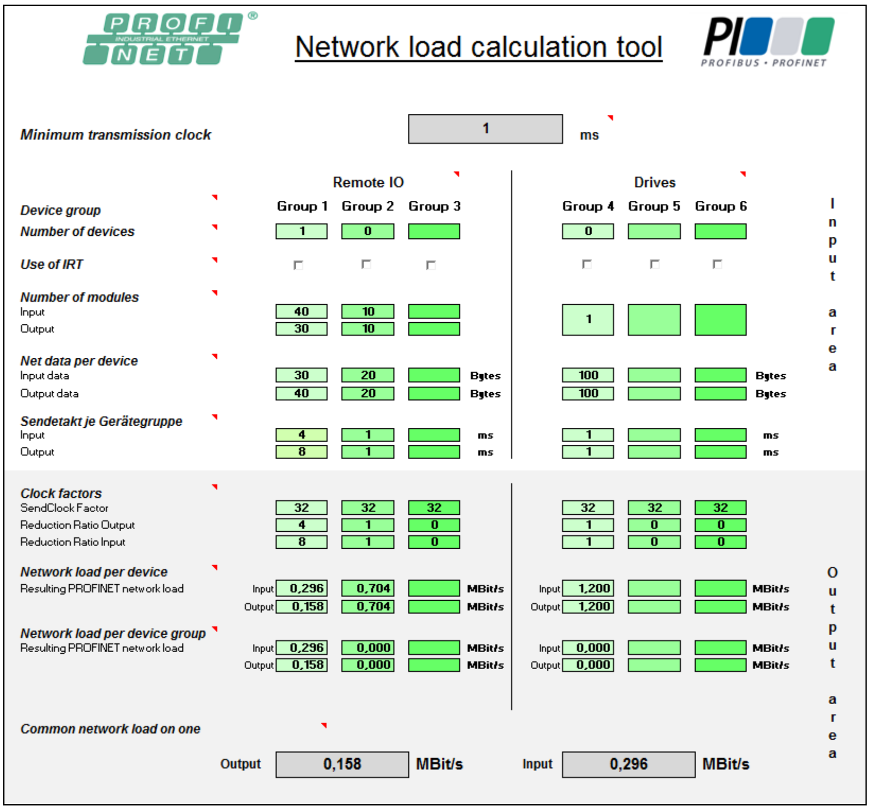


Figure 10-33: User interface of the network load calculation tool

The upper area, highlighted in white in Figure 10-33, has been defined as entry area. Here, users can define possible device configurations by entering values. The output area, highlighted in dark gray, displays the calculation results.

The “percentage network load“, with reference to the available bandwidth of a link, must be calculated by the user (*see separate example provided later on*). Make sure to consider the network load separately for the input and the output direction.

The network load calculation tool uses simple Excel formulae which are hidden when using the tool. You can however edit these formulae after inactivating the Excel worksheet protection and making the hidden areas of these formulae visible.

A detailed description of the network load calculation is included in the additional Excel worksheets “Description” and “Program flowchart” of the network load calculation tool. The user manual shown on the following pages can also be found in the calculation tool in the worksheet “User manual”.

All entries are checked for consistency. In addition, error messages are displayed in case of incorrect entries. Entries are possible only in the entry fields. The other fields are blocked for entries.

User manual

Figure 10-34 shows the different sections for entry of the calculation basics and the output fields grouped according to the device groups.

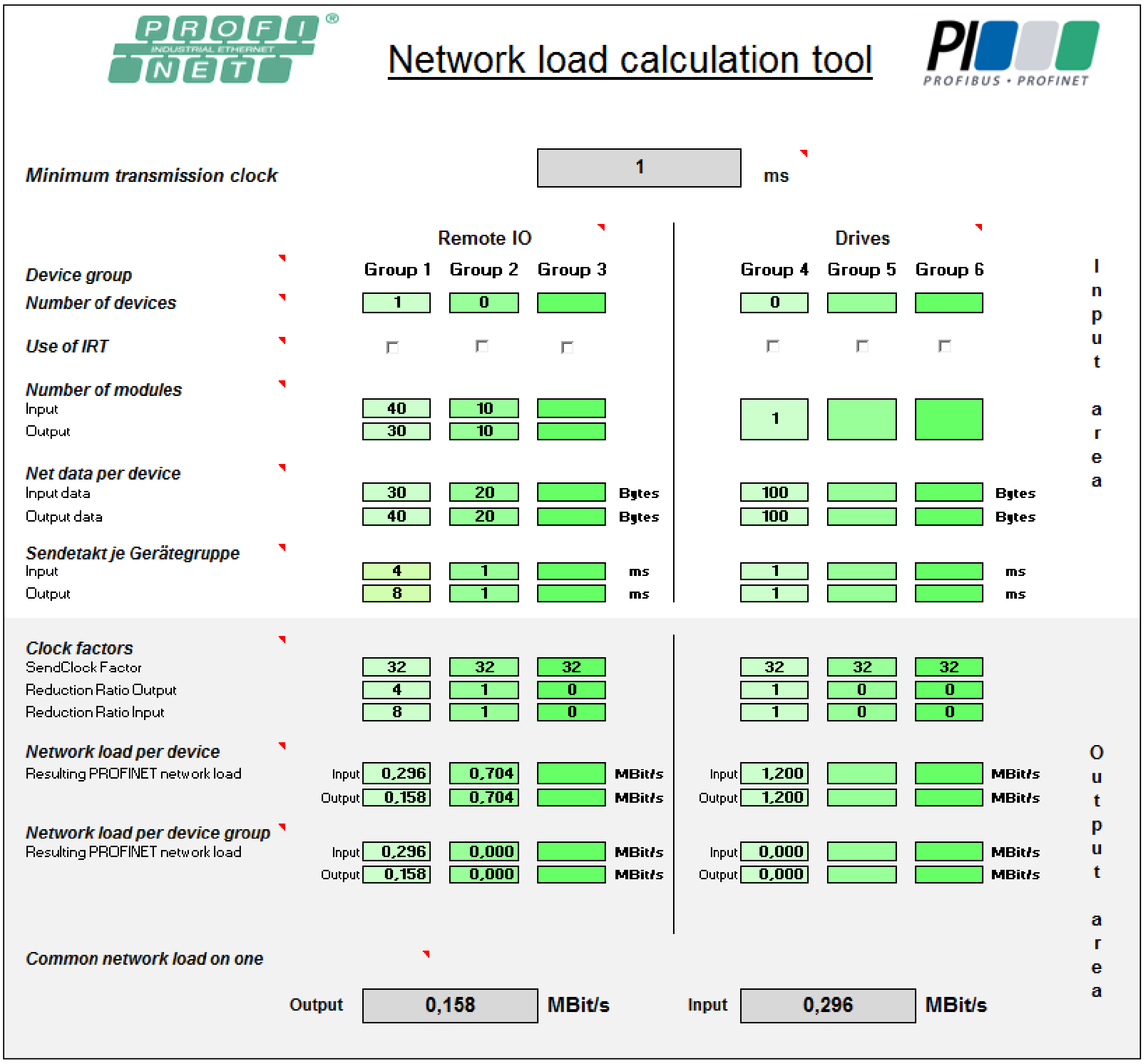


Figure 10-34: Network load calculation using average values

The upper red frame is used to select the minimum transmission clock via a dropdown menu. A manual entry is possible, but the entered value will be checked for usefulness when applied in a PROFINET transmission system. The minimum transmission clock is usually pre-determined by a fast PROFINET device. This information primarily helps to determine the clock factors of a PROFINET transmission system.

On the left side of the entry mask, device data are entered with separate number of modules for input and output, such as for remote IOs. On the right side of the entry mask, device data are entered with identical number of modules for input and output (e.g. drives).

For each side, entry values for three device groups can be specified, with entries made underneath each device group. The entry is checked for consistency. **Integers are permitted only.** Some entry fields also provide dropdown selection options.

PROFINET uses full duplex technology. Data are therefore entered separately for each transmit direction. The individual entry and display areas are used for:

1. Entry of the number of PROFINET devices per group and selection whether this group has an isochronous connection (IRT: Isochronous Realtime).
2. Entry of the number of modules per PROFINET device. This is done separately for each transmit direction, except for device groups 4 to 6.
3. Entry of user data (net data) of the PROFINET device in byte, separately for each transmit direction.
4. Entry of transmit clock in ms, separately for each transmit direction. The transmit clock may be different for both directions.
5. Display of required clock factors for configuration of transmission. Clock factors are usually determined via the engineering tool so that his data is only provided here for information purposes.
6. In addition to the network load generated by a device group, the network load of individual PROFINET devices is also shown here. The value of the device group results from the multiplication of a single device with the number of PROFINET devices in the group.

The network load of all PROFINET device groups added up is provided as a result (orange frame). The result is provided separately for both transmit directions. The determined network load can now be used in order to determine the percentage network load on a PROFINET network.

The following example shows how the percentage network load is evaluated:

Example: The network load calculation tool, after entering the device configuration and the update times, has determined a total network load of:

3.086 Mbit/s in output direction and

7.538 Mbit/s in input direction.

If in the network a:

100 Mbit/s transmission link is used, this results in a percentage network load of :

3,086 % in output direction and

7,538 % in input direction.

As explained in previous chapters, the total network load only occurs at communication nodes where several data streams meet. The network load generated by PROFINET should not exceed the 50% limit at these nodes. Based on the individual device groups in the entry mask, the group creating a high network load can be analyzed.

Some of the device groups have been left empty in this example. As shown in this example, they can be individually configured per transmission direction.

The network load depends on several influencing factors. The network load calculation tool provides an estimate of these influencing factors.

Based on the individual device groups and their device types in the entry mask, the group creating a high network load can be analyzed. It is then possible to modify if necessary.

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