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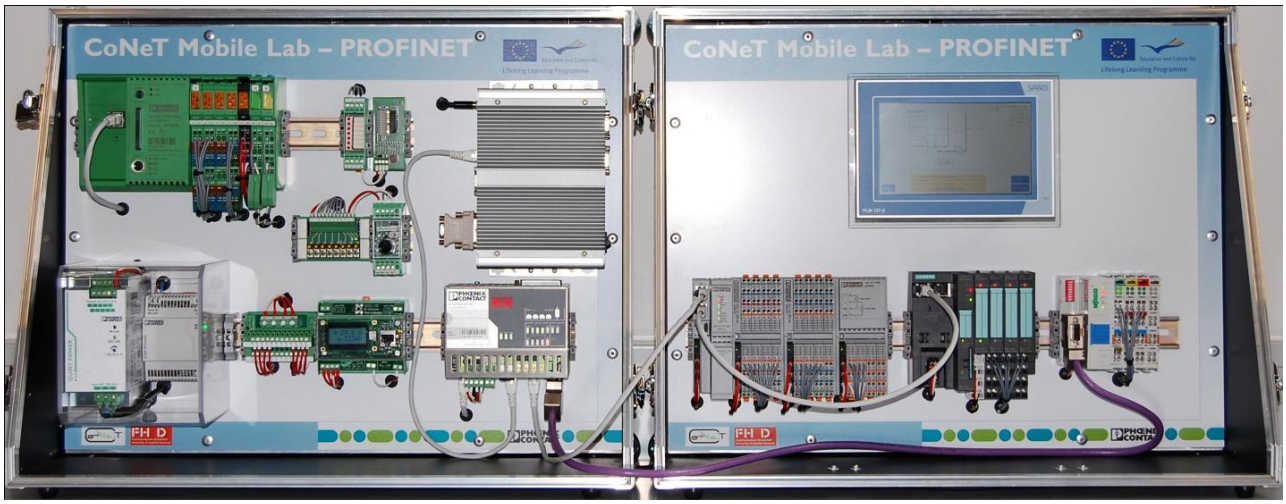
CoNeT Mobile Lab 3

PROFINET ON PHOENIX CONTACT PLATFORM



- PROFINET basics –

Revision 1.0

Co-operative Network Training

Education and Culture DG
Lifelong Learning Programme

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PROFINET Basics

What is PROFINET?

If we talk about industrial automation, you might think about fieldbus systems first, such as PROFIBUS, INTERBUS, DeviceNet or CANopen, etc. Indeed, the widespread usage of fieldbus technology has become established in industrial automation in the past few years. One of the important advantages of fieldbus systems is that you can migrate from your central automation systems to the decentralized ones.

If we talk about communication between computers, you may be familiar with intensive data-transferring networks such as Internet. The development of this kind of communication transfer systems has increased rapidly. Most Internet communications are based on the Ethernet standard that was given by IEEE 802.3 (**I**nstitute of **E**lectrical and **E**lectronics **E**ngineers). One of the significant properties of the Ethernet is its simple structure. It can be implemented easily and therefore is very popular.

Fig.1 PROFINET logo

PROFINET is the **open and innovative standard** for industrial automation **based** on the **industrial Ethernet**, i.e. you can exchange process data with your machines as before but instead of using a fieldbus system, you use the Ethernet as the medium of communication.

The concept of the PROFINET satisfies all the requirements for industrial automation technology. You can use PROFINET for your factory and process automations that require response time under 100 milliseconds. Other applications, like drive technology applications or clock-synchronized Motion Control, can be served with response time up to less than 1 millisecond. For the purpose of running safety applications, you can use PROFIsafe, which is part of PROFINET.

PROFINET technology is developed and published by PROFIBUS/PROFINET International e.V. (PI). It supplements the approved PROFIBUS technology, especially in terms of speed of data transmission and the use of **I**nformation **T**echnology (IT). PROFINET uses IT standards such as TCP/IP and XML to communicate, configure and diagnose the machines or field devices.

Function classes of PROFINET

In PROFINET, we can distinguish two function classes that are independent of each other, the PROFINET IO and the PROFINET CBA (**C**omponent **B**ased **A**utomation). PROFINET IO is concerned with distributed I/O (**I**nput/**O**utput) and PROFINET CBA is concerned with distributed automation. Fig. 2 illustrates the function classes.

- **PROFINET IO**: The distributed field devices are connected through the PROFINET IO. If you are familiar with PROFIBUS, you will find considerable similarity between these two systems; for example, process data from the field devices is transmitted into the control system periodically.
  PROFINET IO uses three different communication channels to exchange data with the control systems and other devices. The standard TCP/IP channel is used for parameterization, configuration and acyclic read/write operations. NRT (**N**on-**R**eal **T**ime)

is used for non-time-critical processes. The RT channel (**R**eal **T**ime) is used for standard cyclic data transfer and alarms. The third channel, IRT (**I**sochronous **R**eal **T**ime) is the high-speed channel used for Motion Control applications. The technical characteristics of the field devices are described by the so-called GSD file (**G**eneral **S**tation **D**escription) which is based on XML (e**X**tensible **M**arkup **L**anguage).

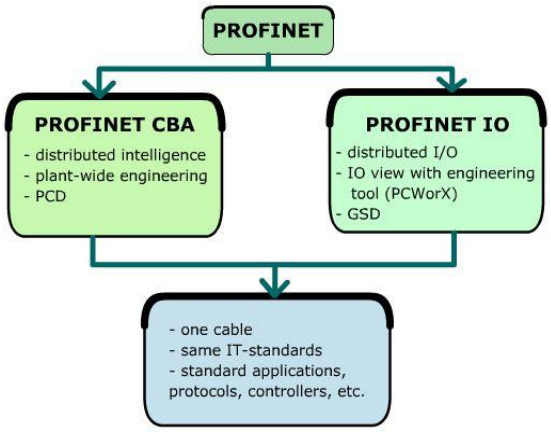


Fig. 2 Function classes of PROFINET

- **PROFINET CBA**: This concept is designed for distributed industrial automation applications. The PROFINET CBA is built on the standard DCOM (**D**istributed **C**omponent **O**bject **M**odel) and RPC (**R**emote **P**rocedure **C**all) technologies. DCOM is an object oriented mechanism that structures how a Client can locate, request and receive data from a Server. DCOM was originally developed by Microsoft. The DCOM objects, which are disconnected from the PROFINET CBA, are called **technological components**. These components act independently and coordinate their activities among themselves autonomously. The encapsulated technological components are called **PROFINET components**, which are described by PCD (**PROFINET C**omponent **D**escription). You can imagine them as a black box with the interfaces on the outside. They communicate with each other over these uniformly defined interfaces. This also allows us to connect them as we wish.

The PROFINET IO devices can be combined and considered as a PROFINET component by using the appropriate engineering tool. With the PROFINET CBA concept, you can interconnect the PROFINET components into machine-to-machine communication. Thus, we will have distributed automation interconnecting over PROFINET (Fig. 3).

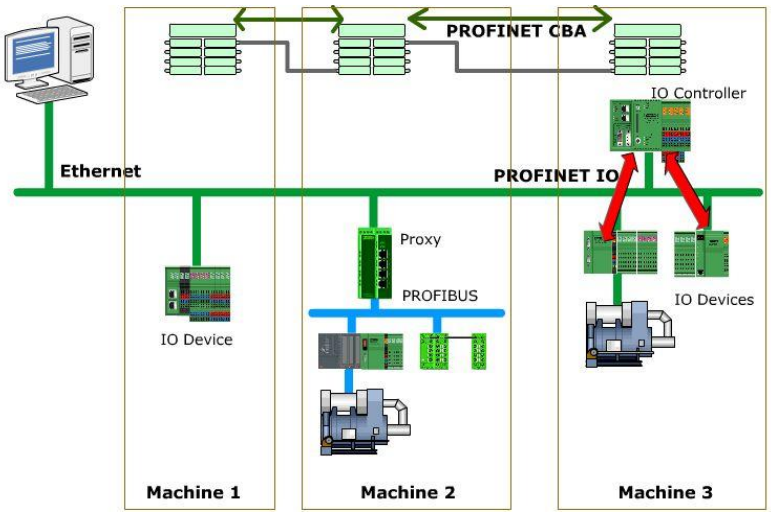


Fig. 3 Distributed automation system with PROFINET IO and CBA

Communication and Security

All kinds of data transfer over the Internet can be intercepted and recorded. In this chapter, we discuss how the PROFINET implements communication using Ethernet and how the connection can be made secure.

PROFINET Communication Concept

PROFINET uses Ethernet as a communication medium. For it to be possible to use Ethernet, you must implement a bunch of protocols that are defined in the IEEE 803.2 standard (more details in the sections below). For transporting the data, the TCP or UDP and IP protocols are implemented. However, they are not enough to process the data. Therefore, you must implement more protocols, so-called application protocols, such as HTTP, SNMP, SMTP, FTP, etc.

To repeat; PROFINET uses three channels for communication with different performance classes according to the use envisaged (Fig. 4):

- NRT (Non-Real Time) for non-time-critical processes: PROFINET uses standard TCP/IP and UDP/IP to transmit data packets.
- RT (Real Time) for optimized data exchange performance: The read-write operation for industrial automation requires mostly high-speed data transfer, while standard TCP/IP or UDP/IP cannot satisfy this requirement.
- IRT (Isochronous Real Time) for clock-synchronized communication: Drive applications, such as Motion Control, need to be satisfied immediately. The IRT can do this with a response time of less than 1 millisecond.

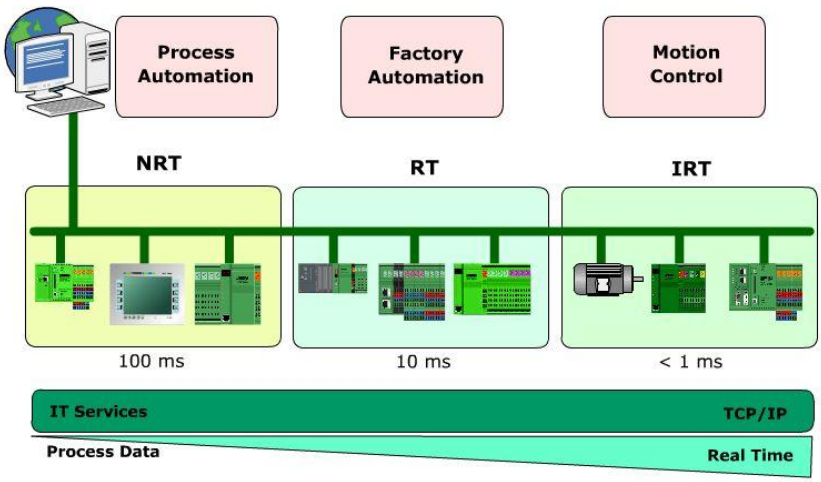


Fig. 4 PROFINET communication concept

PROFINET Security Concept

The core of the PROFINET Security Concept focuses on securing networks in the separated security zones, the so-called **cells** (Fig. 5). Different cells may be interconnected by a

backbone network. Each cell can be connected to the backbone through an entry point and is protected by using special security network components, such as switches or other security devices. These components check the data being transmitted for their authorization and integrity. If you want to access the secure automation devices, you can use special security client software.

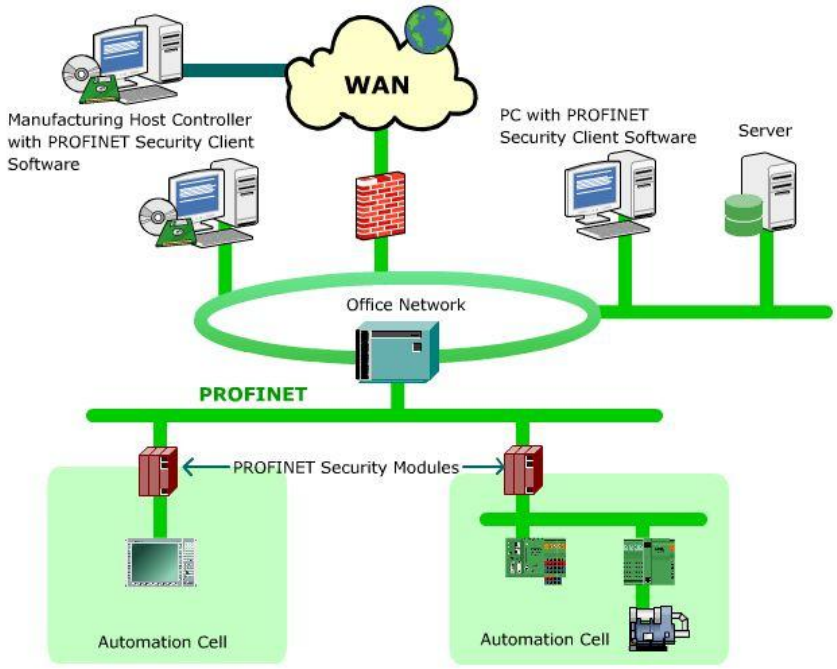


Fig. 5 PROFINET security concept

The data traffic between secure cells or between client software and the cell can also be encrypted using conventional encrypting algorithms. This secured connection can protect the data from being manipulated or spied on. This is necessary, especially if you want to access your secure automation devices over an insecure network, such as Internet.

Questions

What kind of network does PROFINET use?

1. Industrial fieldbus communication
2. Industrial Ethernet
3. Industrial Internet
4. Asynchronous Transfer Mode (ATM)

What kinds of PROFINET are there?

1. TCP and IP
2. UDP and XML
3. TCP, UDP and IP
4. IO and CBA

If you want to use a drive application, what kind of PROFINET protocol has to be implemented?

1. NRT, because I want to access process automation.
2. RT, because I want to receive optimized data exchange transfer rate.
3. IRT, because I want to receive an immediate response.
4. TCP/IP, because it is the connection-oriented protocol.

How can you secure your data if you want to transmit them over an insecure network?

1. With an encrypting algorithm.
2. With a decrypting algorithm.
3. With a special cell.
4. With a backbone network.

The separated security zones are called “cells”.

1. True
2. False

PROFINET vs. PROFIBUS

For those who are already familiar with PROFIBUS, you can see PROFINET as a further development of the PROFIBUS DP. However, in comparison to PROFIBUS, PROFINET has many more advantages (Table 1). In this chapter, we examine some of the advantages of PROFINET. At the end you will be able to judge whether you should use PROFINET or not.

Advantages of PROFINET

The PROFINET offers several advantages from different points of view. As a user, you can have more flexibility, e.g., controlling your automation devices. As a PROFIBUS device manufacturer, you still can manufacture the good old PROFIBUS field devices while planning for PROFINET devices production. So, let's take a look at the following list.

- **High-speed operation**: The real time communication channel provides high-speed process data exchange by bypassing the time required to process the TCP/IP stack. The time-critical process data can then be exchanged by using RT or IRT protocols. Time-critical alarm signals or time-uncritical diagnostic data can be set up by one installation on one medium.
- **Simple network structure**: The construction of Ethernet standard is very simple and easy to implement. Furthermore, this standard is widely used in the office sector. Therefore, it is possible to ensure compatible connections to administration departments and offices.
- **Cost-effective technology**: If we compare the set up cost and performance of Ethernet with other network systems, such as ATM (**A**synchronous **T**ransfer **M**ode) or Frame Relay, you will see that Ethernet is much more cost-effective than the others. Moreover, Ethernet will give each user the same speed regardless of where the application is actually hosted.
- **One line data transfer**: Using Ethernet means that you can use just one cable to transmit all kinds of data. This, of course, results in a reduction of cable costs. By using switches, you can then access your desired devices.
- **IT Software:** For accessing process data or diagnostic purposes, you can use the conventional software of the IT world, such as web browsers like Internet Explorer, Firefox, Opera, etc., or office applications, like Microsoft Office.
- **Simple extensible network**: In PROFINET IO for example, you can add new field devices by using the device library which allows easy extensibility. This kind of approach lets you extend your network however you wish.
- **Individual settings**: The field devices can be set individually, e.g., you can set up different field devices with different cycle times on the same network. This lets you have cyclic data at different times depending on your needs.
- **Seamless integration with fieldbus systems**: For those who already have a fieldbus system, e.g., PROFIBUS, DeviceNet, INTERBUS, etc., installed in their factory, PROFINET offers the so-called **proxy** which has been designed to connect PROFINET and PROFIBUS. In this way the investment made in already installed fieldbuses is protected.

Comparison PROFIBUS with PROFINET

Table 1 Comparison PROFIBUS vs. PROFINET

Features	PROFIBUS DP	PROFINET IO
	Master class 1	IO controller
	Master class 2	IO supervisor
	Slave	IO device
Wired transmission technology	PROFIBUS over copper or fiber-optic cable	Industrial Ethernet over copper or fiber-optic cable
Wireless transmission technology	Infrared transmission is possible	Industrial WLAN (Wireless Local Area Network) is possible
Data exchange	By requesting	Once an IO device is parameterized, it can work by itself. Data can be exchanged cyclically or acyclically (by requesting)
Data channels	One exactly defined data channel between Master and Slave.	Several data channels between Controller/Supervisor and Device
Number of devices	126 devices maximum	Arbitrary, depends on network.
IT services	Not possible	Can be integrated
Device description	Keyword based	XML based with schema definition
Data priority	Same priority	Different priorities can be set
Access of a field device	Read only from several users.	Read and write from several users possible.
Address assignment	Coding of the PROFIBUS address over a DIP-switch or Engineering tool	• Assignment of IP addresses to IO controller with Engineering tool • Assignment of IP addresses to IO devices by IO controller • Assignment of device name to IO device with Engineering tool • Assignment of IP addresses by using web page which is integrated in some switches
Data transfer rate	Max. 12 Mbit/s	100 Mbit/s with full duplex
Topology	Standard: star and tree Possible: bus and ring	Standard: line Possible: tree and ring

Integration with PROFIBUS

The concept of PROFINET allows you to use a so-called **proxy** in case you want to integrate an existing fieldbus system, such as PROFIBUS, INTERBUS, ASI, etc., to the PROFINET system. With this architecture, you will have a hybrid system consisting of fieldbus and Ethernet-based subsystems. A seamlessly continuous technological transition from a fieldbus system to PROFINET is therefore possible.

Figure 6 depicts the integration of a PROFINET and a fieldbus system; PROFIBUS. As you can see, a proxy is in between these two systems and connects them together. This allows you to integrate existing PROFIBUS configurations in PROFINET.

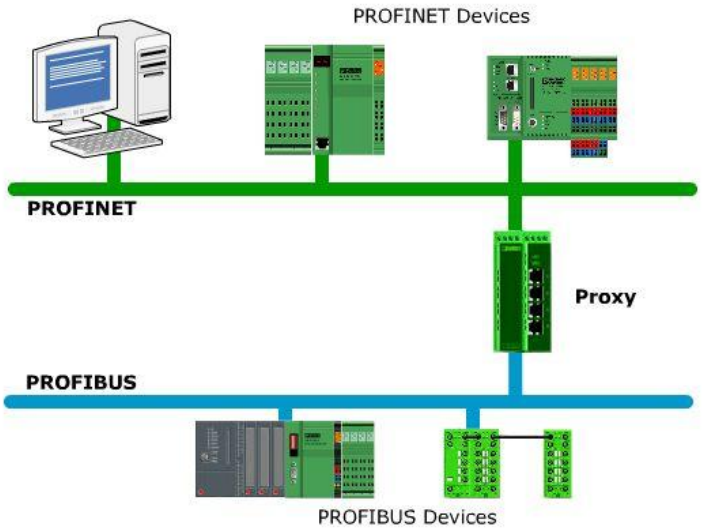


Fig. 6 Integration of a PROFINET and a PROFIBUS system

The main reasons for developing the new technology are to reduce the cost and improve the existing techniques and/or the cost/performance relationship. The PROFINET accomplishes this kind of demand in every way. It uses standard technology which is simple to implement and cost-effective, and the handling of industrial automation solutions is easier than before.

Questions

Which of the following statements is **correct**?

1. PROFINET uses RT or IRT protocols for time-critical processes.
2. PROFINET has no special protocols for time-critical processes.
3. PROFINET has no advantages for time-critical processes.
4. PROFINET uses TCP/IP for time-critical processes.

Which of the following statements is **incorrect**?

1. You can use IT software to access process data on PROFINET.
2. PROFINET uses the simple network structure of Ethernet.
3. PROFINET uses the simple protocols of ATM.
4. You can integrate PROFIBUS field devices into PROFINET.

Cost reduction is one of the goals for developing new technology.

1. True
2. False

Can one set up the cycle time individually in PROFINET?

1. Yes
2. No

Can PROFINET IO devices be accessed from the Internet?

1. Yes
2. No

ISO/OSI Reference Model

The ISO/OSI reference model is denoted as a layer model which one can refer to as a reference for data communication. These two acronyms stand for International Standardization Organization and Open System Interconnection. According to the ISO/OSI reference model, also called **layer model**, you can divide the communication operation into **seven** layers. Every layer has a specified assignment, which can be passed to the layer above or below, according to the task, as a **service**. Communication between two layers can be made by using the specific interface called SAP (**S**ervice **A**ccess **P**oint).

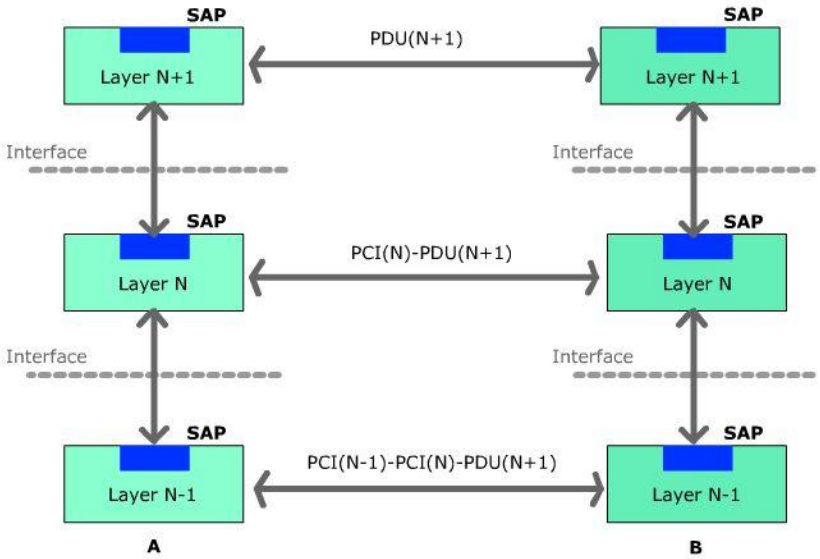


Fig. 7 Data communication in the ISO/OSI reference model

As you can see in Fig. 7, the physical data communication within one user is made in the vertical direction. From the **N** layer point of view, you can see a data flow on this layer. The data flow contains the services that can be exchanged at the SAP interface.

The logical data communication between two users is made apparently in the horizontal direction. The information will be exchanged by using the standardized protocols. These standardized protocols are PDU (**P**rotocol **D**ata **U**nit) and PCI (**P**rotocol **C**ontrol **I**nformation).

Table 2 Seven layers of the ISO/OSI reference model (see also Fig. 8)

ISO/OSI Layer	Integration on PROFINET
Layer 1: Physical Layer On this layer, the single bits will be transmitted over the cable. The electrical and mechanical properties of the transmitting medium are controlled to make sure that all the bits arrive at the receiver completely. Electrical properties are, for example, how much volt is "1" and how long is a bit. Mechanical properties are, for example, cable types, pin assignment for the connectors, direction of the transmission (uni- or bidirectional).	When transmitting data, PROFINET uses the Fast Ethernet with 100 Mbit/s according to the Ethernet standard from IEEE 802.3. The Fast Ethernet works in the full-duplex mode, i.e., the user can send and receive the data simultaneously (bidirectional). Cable types are: 10BaseTX: 10 Mbit/s in copper cable (Twisted Pair). 10BaseFX: 10 Mbit/s in fiber optic cable. 100BaseTX: 100 Mbit/s in copper cable (Twisted Pair). 100BaseFX: 100 Mbit/s in fiber optic cable.

Layer 2: Data Link Layer This layer delivers error-free data transmission between two users to layer 3. The incoming data are split up into **frames.** The receiver can check whether the transmission was correct or not. If not, the frame concerned will be requested again. Furthermore, this layer manages collision-free access of the transmission medium. The MAC (**M**edium **A**ccess **C**ontrol) defines the unique identification of the device. This MAC address is given by the device manufacturer. A MAC address consists of two parts, the manufacturer identifier and the consecutive numbering.	The PROFIBUS Nutzerorganisation e. V. (PI) offers the device manufacturers the manufacturer identifier part of the MAC address. This part is also called OUI (**O**rganizationally **U**nique **I**dentifier). The device manufacturers can purchase this part from the PI and then add their own consecutive numbering part.
Layer 3: Network Layer This layer enables communication between users over great distances and different network types. The Network Layer transmits the data packets by using their IP address (**I**nternet **P**rotocol). Suitable **routing** is selected. The packets are temporarily saved on the subnodes. The subnodes will look at the current routing table, find the most suitable route and then forward the packets along the route.	In the case of plant extension it is necessary to use the engineering tool in order to give the PROFINET devices the network addresses. Within one network, an IP address must be unique. We can access the appropriate PROFINET device by using its IP address. And the packets can be transmitted to this device correctly.
Layer 4: Transport Layer This task of this layer is to ensure connection. The data packets may be split into small pieces (fragmentation) and assembled again on the receiver's side (defragmentation). If there are possible errors, they will be corrected here. Possible errors are, e.g. lost data, erroneous data, false order of the fragmentation, etc. These errors will be corrected by using, for example, receipts or repeated requests. The most well-known protocol for data flow control is TCP (**T**ransmission **C**ontrol **P**rotocol). Another protocol is UDP (**U**ser **D**atagram **P**rotocol).	In PROFINET IO, UDP is implemented for the process data exchange. The PROFINET applications use the port 34962 to 34964 for the communication.[POP00]
Layer 5: Session Layer In this layer, services like dialog control for supervision of data flow direction or recovery points are actualized. If a connection is interrupted, it can be recovered at the last point, without the need to repeat from the beginning.	No usage
Layer 6: Presentation Layer The data is translated into the common format on this layer. On the sender's side, the data is coded and compressed. On the receiver's side, the data is then decoded and decompressed. It is then transmitted to the appropriate application.	No usage
Layer 7: Application Layer	The following scenario is conceivable:

The specific interfaces are defined on this layer. These interfaces enable communication between applications. Communication between different protocols is actualized by using the so-called gateways or proxies.	You already have the bus system installed, e.g., PROFIBUS. You want to have PROFINET and then integrate PROFIBUS devices to the PROFINET. Thanks to the defined interface in layer 7 and the use of a proxy, we can actualize this relatively easily. Data exchange between PROFIBUS and PROFINET devices is therefore possible seamlessly.

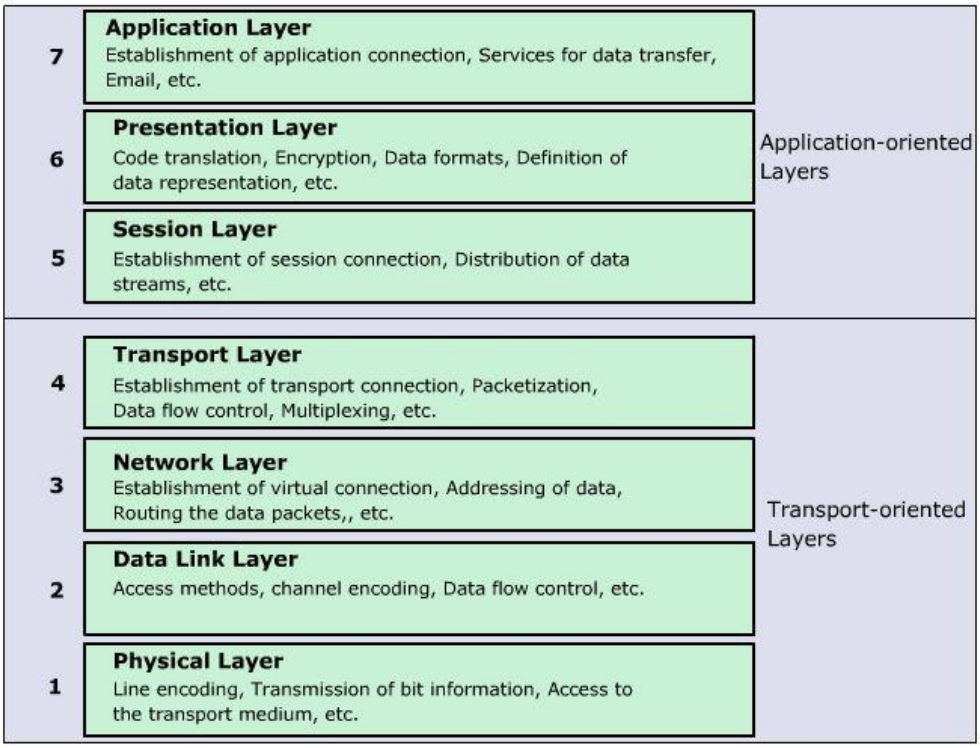


Fig. 8 Layer scheme of the ISO/OSI reference model

Communication Path

The communication process between two users is made in the **horizontal** direction. The single bits will be transmitted from user A to user B over the physical medium in layer 1 of the ISO/OSI reference model. However, communication within user **A**, in the case of sending, happens in the **vertical** direction. On layer 7, a layer 7-header is added to the data packets before they are passed to layer 6. On layer 6, a layer 6-header is added. They are then passed to layer 5, and so on. On layer 1, the data packets are transmitted. On the receiver's side, the previous procedure works in the reverse way. At the end of the path, you get the transmitted data packets.

Note that only the essential layers participate in the communication process. If there is no use for a specific layer, the header of that layer is not added.

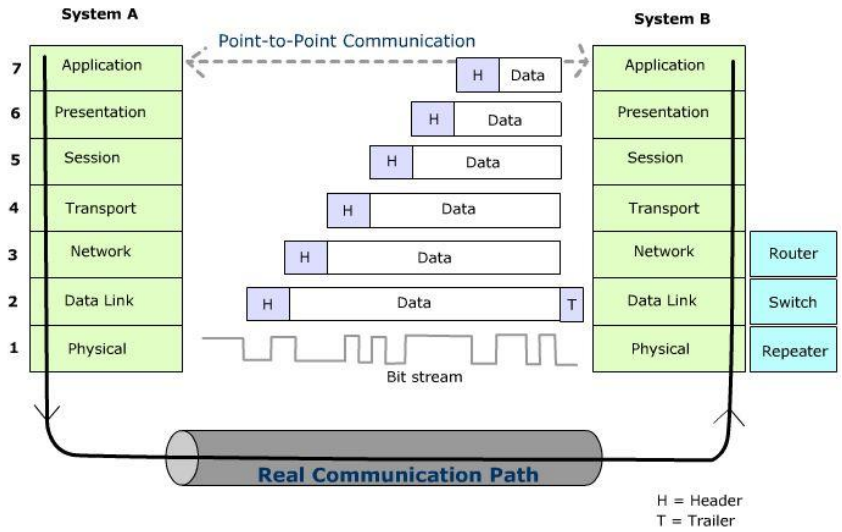


Fig. 9 Communication path in the ISO/OSI reference model

Questions

How many layers are there in the ISO/OSI reference model?

1. 4 layers
2. 5 layers
3. 6 layers
4. 7 layers

Which of the following characteristics belong to TCP?

1. Connectionless
2. Connection-oriented
3. The connection of TCP can not be observed
4. TCP is important for time-critical applications

On which layer will proxies be implemented?

1. Transport Layer
2. Session Layer
3. Presentation Layer
4. Application Layer

What will be added if the data packets travel from one layer to the one below?

1. Data type
2. User name
3. Header
4. Attachment

Communication between two users happens in a vertical direction.

1. True
2. False

Ethernet Basics

Short History

Ethernet is a kind of computer network that is part of the most commonly installed local networks in the world. The most well known examples are LAN (Local Area Network) and WLAN (Wireless Local Area Network).

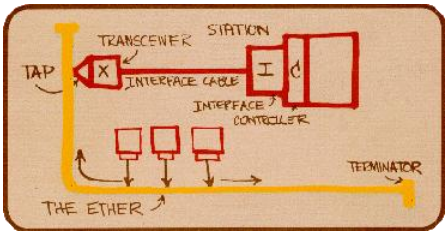


Fig. 10 First scheme of Ethernet system

The history of the Ethernet began at the beginning of the seventies. The US Company XEROX introduced the innovative concept of the Ethernet. With Ethernet, computers can communicate among themselves without prior knowledge of one another.

On February 1980, the working group 802 of the American IEEE (Institute of Electrical and Electronics Engineers) officially defined the first standard for LAN communication. The transmission rate was set at 10 Mbps (Megabits per second). At the time of writing (January 2011) and thanks to the further development of transmission techniques, the standard transmission rate of the Ethernet is now 100 Mbps. This kind of transmission rate is also called **Fast Ethernet**. In the near future, we can expect a transmission rate of 1 Gbps (Gigabits per second) to become the new standard. This transmission rate is also called **Gigabit Ethernet**.

The Ethernet standard is made up of the following components:

- MAC (Media Access Control);
- PLS (Physical Layer Signaling);
- AUI (Attachment Unit Interface);
- MAU (Medium Attachment Unit);
- PMA (Physical Medium Attachment);
- MDI (Medium Dependent Interface).

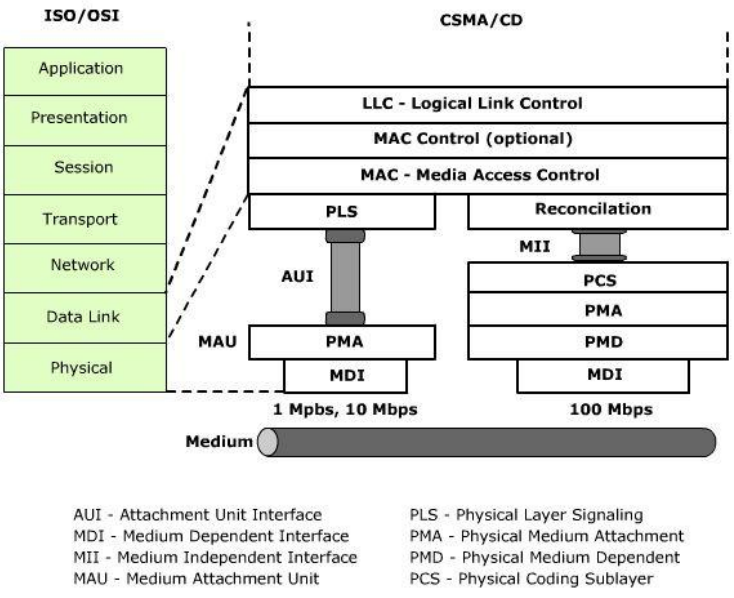


Fig. 11 Physical and data link layers in the Ethernet system

Access Method

Ethernet uses the CSMA/CD network access method to control access to the network. The devices attached to the network cable listen to the transmission medium and begin to transmit data as soon as the medium is available. If the medium is in use, the devices wait before transmitting. There is no central station monitoring or controlling access to the network.

CS (**C**arrier **S**ense): The devices check whether the medium is available.

MA (**M**ultiple **A**ccess): MA indicates that many devices can connect to or share the same network. If the medium is available, each device can begin to transmit data.

CD (**C**ollision **D**etection): If two or more devices sense a clear channel and start to transmit data at the same time, this causes a so-called data collision. If a collision occurs, the devices abort their transmission attempts, wait for a random length of time and then retransmit the data. This approach is called a **truncated binary exponential backoff** algorithm and works as follows (Fig. 12):

- Initially: **n**=0, **k**=0, **r**=0
- Incrementing **n**, the Transmit Counter, which counts the number of sequential collisions experienced by a node
- If **n** > 16, also 16 unsuccessful successive transmission attempts, transmission fails and the higher layers should be informed
- If **n** <= 16, select a number from the set **k** = min(**n**, 10), called truncation
- A random number **r**, is selected from the set (0, 1, 2, 4...2 ^{k}), also exponential and binary
- The node then waits (**r** x **slot_time)** before recommencing a transmission attempt.

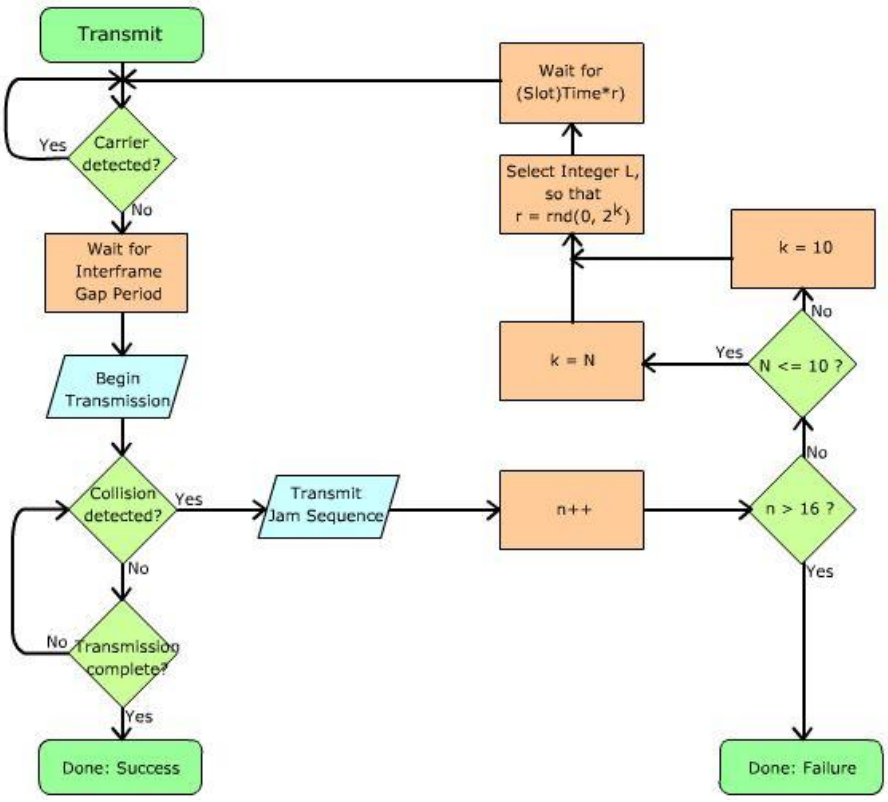


Fig. 12 CSMA/CD with truncated binary exponential back off algorithm

Standard Ethernet Frames

What are frames?

We define "**frames**" as the format of data packets which are transmitted from A to B on the wire or wirelessly. A frame usually begins with a so-called **preamble**, which would show on the actual physical hardware as start bits. At the end of a frame, there is a so-called Frame Check Sequence (FCS). FCS is required by all physical hardware for data integrity checking purpose.

A standard IEEE 802.3 frame has a seven-byte preamble followed by a single byte Start Frame Delimiter (SFD). Then a fourteen-byte MAC header follows, then the actual data and at the end is a four-byte FCS (Fig. 13).

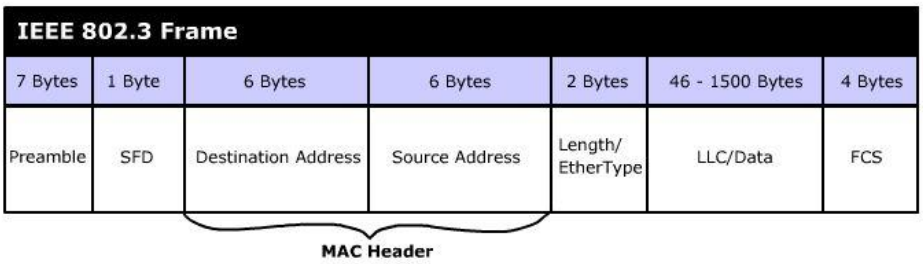


Fig. 13 Structure of a MAC frame

- **Preamble**: The preamble consists of 7 bytes of alternating 1 and 0, also 1010101010, and so on.
- **Start Frame Delimiter** (SFD): The SFD consists of 10101011. The last two "1s" indicate that a valid frame is about to begin.
- **Destination Address**: The Destination Address consists of the MAC address of the receiver. The first bit indicates whether the address is a multicast address (1) or a unicast address (0).
- **Source Address**: The source address consists of the MAC address of the sender.
- **Length/EtherType**: This field consists of the length or the EtherType of the following data field, according to the IEEE 802.3.
- **Data**: The data filed consists of the user data that can be up to 1500 bytes long but not less than 46 bytes.
- **Frame Check Sequence** (FCS): This field consists of the checksum of the transmitting data, including Destination Address, Source Address, Length and Data.

From Fig. 13, you can easily calculate the legal frame length excluding the preamble. It is from 64 to 1518 bytes long.

MAC Address

If you want to send a letter to a specified person, you have to know his/her address in order that he/she receives your letter. In the Ethernet world, too, each active Ethernet component must have a unique address in order to be identified.

The MAC (**M**edia **A**ccess **C**ontrol) address is the hardware address of the devices that participate in the network. There are many names for MAC addresses, such as Ethernet address, physical address, station address or adapter card address. The MAC address is assigned by the device manufacturer and is 6 bytes long.

A MAC address consists of two parts, each 3 bytes long, the manufacturer-specific one and the consecutive numbering one. The manufacturer-specific part of a MAC address can be obtained from the IEEE for an administration fee and is called OUI (**O**rganizationally **U**nique **I**dentifier). The consecutive part can be obtained from the manufacturer. Each manufacture can register up to 16,777,214 devices.

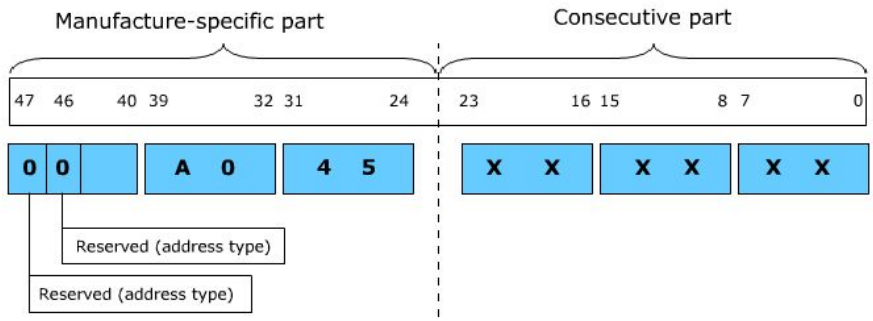


Fig. 14 MAC address

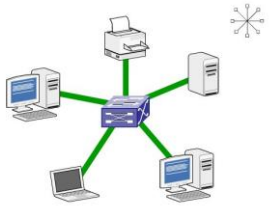
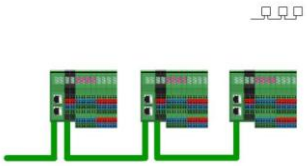
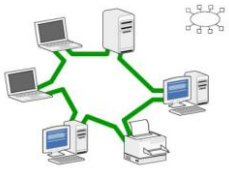
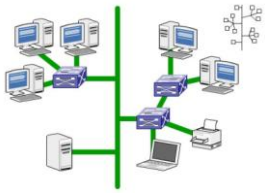
Fig. 14 shows a MAC address 00.A0.45.XX.XX.XX where 00.A0.45 is the manufacturer-specific part and in this case represents the company "Phoenix Contact". The XX.XX.XX is the consecutive numbering part where XX are the hexadecimal numbers, from 0 to F.

Small device manufacturers who do not want to apply the OUI from IEEE themselves, can purchase the OUI part from PI, which is 00.0E.CF.XX.XX.XX.

Network Topologies

You can interconnect the Ethernet devices to a network according to the so-called network topology. There are many network topologies, including Star, Line, Tree and Ring. Which network topology should be used depends on what we want to do. The assignment of the network affects the requirements of the network topology. In practice, you have a mixed system consisting of several types of network topologies. An overview of the network topologies is given in Table. 3.

Tab. 3 Network topologies

Description	Structure
Star: The characteristic of the star topology is that a **switch** is involved. That means, we have a central signal distributor and the devices of the network connect to this distributor individually. If an individual device fails, it does not lead to the failure of the entire network. Nevertheless, if a switch fails, the connection in this network will fail as well. Star topology is used in areas with high devices density and short distances, e.g., in small manufacturing cells or a single production machine.	
Line: All the network devices are connected in series as a bus. For the connection between network devices there is either a link device (switch) connecting to the network device or the link device is integrated into the network device. If a link device fails, the connection after this link device will fail, too. This kind of topology requires the least wiring. Line topology is used preferentially to connect distant systems, such as conveyor systems or for connecting manufacturing cells.	
Ring: If you connect the two ends of a line topology, you will have a ring topology. Ring topologies are redundant, i.e., this kind of topology increases the breakdown safety of the network. If the wire in the network breaks or any of the network components fails, the entire network still functions.	
Tree: If you connect several star topologies together, you will have a tree topology. In the tree topology it is possible to combine fiber optic and copper (twisted pair) cables together. This topology is used when a complex system is divided into several system segments and they need to be interconnected.	

Some Network Components

Switches

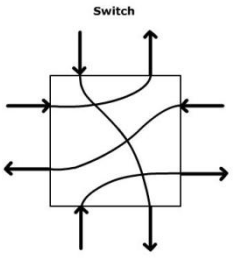


Fig. 15 Pictorial schematic of a switch

In PROFINET, industrial Ethernet switches are used to create a simple gateway between network devices (Fig. 15). A network in which every device is assigned specifically to one port of a switch is called "**Switched Ethernet**". By using switches, the devices or network infrastructure components can be located. This leads to an avoidance of the collision of the domains with dedicated point-to-point connection. The network is therefore more robust during temporary high traffic. Furthermore, switches can actualize the full-duplex connection for every point-to-point connection. Switches work at the layer 2 (data link layer) of the ISO/OSI reference model.

There are two operating modes of switches:

- **Cut-Through Switches**: A cut-through switch or "on the fly" switch forwards a data packet immediately after receiving the 6 bytes long destination address. This way, the delay time between sender and receiver is reduced and the data packets will not be buffered completely. The delay time of a current cut-through switch is between 5 to 60 microseconds.
- **Store-and-Forward Switches**: A store-and-forward switch examines every data packet. The data packets will be buffered briefly, checked for correctness or validity, and then either rejected or forwarded. This way causes an increase in the delay time for forwarding data packets. On the other hand, no faulty data packets will be transmitted. The delay time of a data packet depends on its frame length. A short frame length has a delay time between 8-100 microseconds, and a long one has delay time up to 1.5 milliseconds.

Furthermore, switches can have the following properties:

- **Blocking or Wire speed (non-blocking)**: If a switch can serve all services at the same time, then it is non-blocking. However, if it only has restricted capacity, then it is a blocking switch.
- **Managed or Unmanaged**: If a switch just uses the address table for transmitting the data packets, it is called "unmanaged". However, if we can insert some additional criteria for the data transmission, such as, the priority of the packet, the priority of the single IP address, etc., it is called "managed". Please note that the connection between networks with different transferring rates can only be done with store-and-forward switches.

In PROFINET, a switch should forward a data packet in less than 10 microseconds after receiving it and support at least 4 priority classes. Since switches are active network components, and they will lead to the failure of the entire network if they fail, the **Rapid Spanning Tree Protocol (RSTP)** is used to detect this. The idea behind this protocol is that when the topology changes are indicated, the network structure will not be deleted immediately. The alternative routes will be calculated and a new tree will be created. This method can reduce the network downtime from 30 seconds to less than one second.

Hubs

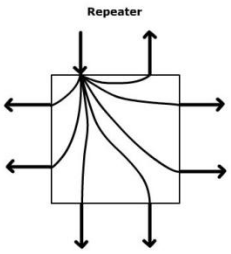


Fig. 16 Pictorial schematic of a hub

An **Ethernet hub** is a device that is used to connect two or more networks or devices together (Fig 16). A multiple twisted pair or fiber optic Ethernet devices can also be connected together. This lets them act as a single segment. Hubs work at the layer 1 (physical layer) of the ISO/OSI reference model. Ethernet hubs work as a repeater for the network, too. Meaning that the signal will be amplified and regenerated for a long distance. They are also responsible for forwarding a jam signal to all ports if they detect a collision.

With hubs, you can pass just one data packet at a time with a speed of up to 10/100 Mbps for a dual-speed hub. Furthermore, the hubs do not know which station is connected to which port, and cannot learn this information. The advantages of hubs are, e.g., ease of use because they do not need to be configured, and they are cheaper than switches. Hubs are not used in PROFINET networks.

Routers

A **router** is a computer-networking device that is used to interconnect two or more separate subnets together (Fig. 17). A router consists of hardware and software, which are usually tailored to the tasks of routing and forwarding the data packets.

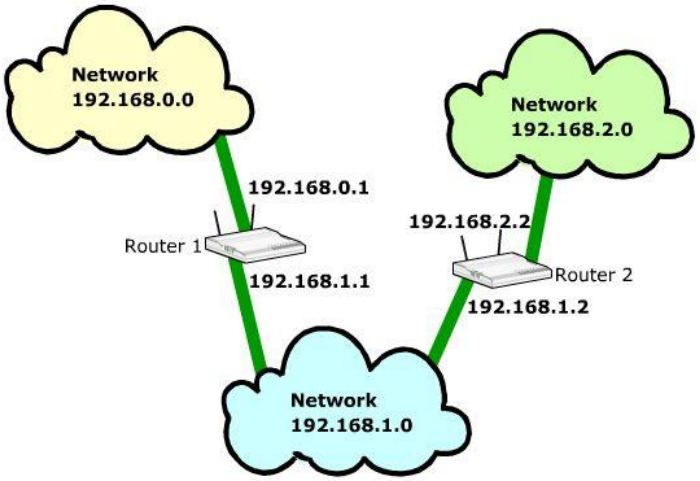


Fig. 17 Network with routers

A router will look at the IP address of the data packet and determine, with the help of a subnetwork, whether it is within the same network or not. If not, it will forward the data packet to the appropriate network.

Another advantage of routers is the possibility of increasing the security of the network. An automation network can be protected by strict and individually adapted access rules. The device for the network security is also called "**firewall**" which can be integrated in routers or separated as a single device.

Please note; real time communication in PROFINET does not function beyond the network boundaries. It is also only possible to communicate with PROFINET devices within a network.

Signal Coding

Which signal coding for an Ethernet will be used, depends on the transfer rate of that Ethernet. In the 10 Mbps Ethernet Standard from IEEE 802.3, the Manchester Coding will be used. In the Fast Ethernet, the FDDI technique is used. Information of 5 bits in length will be gathered into a "symbol". The symbols will then be transmitted. In Gigabit Ethernet, information 10 bits long will be gathered into a symbol.

VLAN

VLAN stands for **Virtual Local Area Network**. VLAN is a method of creating a closed network. This logical network can independently exist within a physical network, i.e., you can separate the logical and the physical network structure. A VLAN creates its own broadcast domain according to the specified logical criteria.

The network components, which connect to the same VLAN may actually be physically connected to different segments of a LAN. If you move a network component physically from A to B, you do not have to reconfigure the hardware. Following are some properties of VLANs:

- Reduction of network traffic and an increase in network security;

- Reduction of management effort for creating subnetworks;
- Reduction of hardware requirement and cost;
- The network components can be classified into function groups, e.g., servers, IPCs, etc.;
- Physical distance does not affect the distribution of the tasks for devices;
- Easy mapping of function units to the network structure.

Questions

Which of the following is the current Ethernet standard?

1. 10 Mbps standard
2. 100 Mbps, Fast Ethernet
3. 1000 Mbps, Gigabit Ethernet
4. 10000 Mbps, 10 Gigabit Ethernet

How long is the MAC Header?

1. 10 bytes
2. 12 bytes
3. 14 bytes
4. 16 bytes

What kind of network topology is used mostly often in practice?

1. Star
2. Line
3. Ring
4. Tree

If you want to have point-to-point communication, which device will you use?

1. Hub
2. Repeater
3. Network card
4. Switch
5.

Which is true?

1. VLAN creates a logical network within a physical network.
2. VLAN creates a virtual network within a logical network.

PROFINET Cabling and Cable-jack Systems

Network Installation

The network components for use in industrial automation must be designed to support the extreme conditions in the production area. The extreme conditions are, e.g., dust, EMC (Electromagnetic Compatibility), temperature, moisture, vibration, etc. The definitions and descriptions of the industry-standard for Fast Ethernet can be found at "PROFINET Installation Guidelines" from PI that are based on IEC 11801. Table 4 compares some of the characteristics of office and automation areas.

Table 4 Comparison: Office and automation area

Office Area	Automation Area
Fixed basic installation in a building	Largely system-related cabling
Laid under raised floor	System-related cable routing
Variable device connection at workplace	Connection points are seldom changed
Pre-fabricated device connection cable	Field-preparable device connection
Tree network topology	Quit often: line and ring network topology
Large data packets (e.g. images)	Small data packets (e.g. process data)
Medium network availability	Very high network availability
Moderate temperature (0 to +50 °C)	Extreme temperature (-20 to +70 °C)
No moisture	Moisture possible
Minimal vibrations	Vibrating machines
Low EMC	High EMC
Low mechanical danger	High mechanical danger
Low chemical danger	High chemical danger, e.g. oil or aggressive atmospheres

Basically, we distinguish the installation of a network in the industrial area between **inside** and **outside** the control cabinet. Table 5 shows the corresponding environmental conditions.

Table 5 Environmental conditions inside and outside a control cabinet

	Inside of the control cabinet	Outside of the control cabinet
Protection class	IP20	IP65 and IP67
Intrusion	12.5 mm	50 micrometers
liquids	none	Water jet (12.5 l/min from 2.5 m) water resistant (1 m for 30 minutes)
climate	0°C to +60°C	-20°C to +70°C

Cables

Like other network components described above, the industry-standard cables have to withstand extreme mechanical stress in the production area. Therefore, they have special properties that are described in the "PROFINET Installation Guide".

Basically, you have 2 cable types, cables with copper and cables with fiber optic. Furthermore, you have a so-called **hybrid cable** that transmits not only process data but also the power as well. It is also possible to transmit process data wirelessly.

Twisted pair cables (from copper):

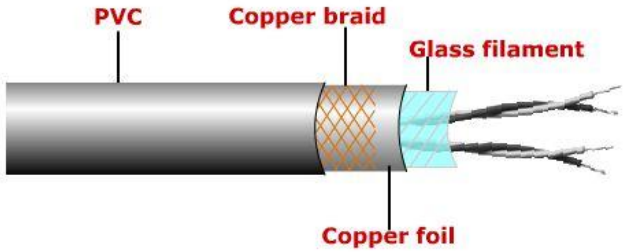


Fig. 18 Twisted pair cable

Nowadays, a so-called **balanced cable** is used. This is also called **symmetrical cable** because the potential difference to the reference ground is 0 V in an ideal case. To transmit a signal, two wires are **twisted together as a pair**. For a full duplex, you need four wires. Therefore, an industrial network cable has at least 4 wires (quad cable). Fig. 18 shows a twisted pair cable which uses copper.

In practice, 100BASE-TX cable for Fast Ethernet with 4 wires is used (Fig. 19). The cable is defined as **STP** (**S**hielded **T**wisted **P**air) meaning that two shielded copper wires are twisted into a pair. The cables fulfill the requirements of **CAT5** with **cable class D** of IEC 11801.

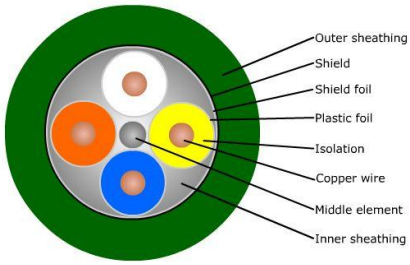


Fig. 19 Twisted pair cable

CAT5 is for data transmission up to 100 MHz, attenuation 24 dB and NEXT (Near End Crosstalk) 27 dB. Cable class D means that the transmission bandwidth is up to 100 MHz. Each wire has a cross section of AWG 22 (American Wire Gauge) meaning that the diameter is not greater than 0.64 millimeter. This specification minimizes the attenuation and enables the complex wiring structure. The maximum cable segment length is 100 meters. The plug RJ45 or M12 is used as a connector.

Fiber optic cables

A glass fiber optic cable comprises a core and a shield. The core is a highly sterile, extremely thin silica or quartz glass thread which is shielded by glass with low optical density.

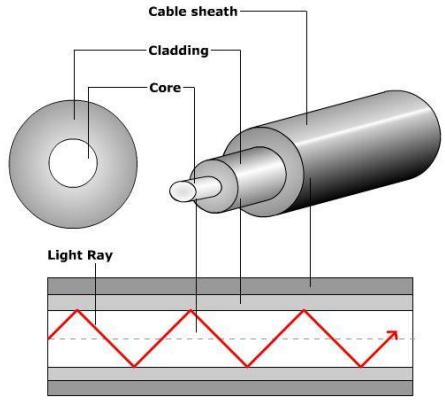


Fig. 20 Fiber optic cable

The light pulses are reflected totally and forwarded along the core. In order to enable the sending of data, the data signals are converted into light pulses by using LEDs or laser diodes. Fig. 20 illustrates a fiber optic cable.

There are two modes of fiber optic cables, single mode and multimode. PROFINET can be operated with both of them. Please note that to operate correctly the optical fiber and optical interface must have the same mode.

For the Fast Ethernet 100BASE-FX, two fiber optic cables are used. The optical interfaces conform to the specifications of ISO/IEC 9314-3 (multimode) and ISO/IEC 9314-4 (single mode). For multimode, the maximum segment length is 2 kilometers, and for single mode, 14 kilometers. For installation outside of the control cabinet, the properties of the shield, which encloses the core, must meet the requirements, e.g., mechanical, chemical, thermal, etc., for the installation location.

There are many advantages of optical cables compared with copper-based cables:

- Optical cables are insensitive to electromagnetic influences;
- Low cable weight per meter;
- No electromagnetic radiation;
- Can be used for a maximum distance;
- Resistant to tapping;
- Large bandwidth.

The disadvantages compared to the copper-based cables are the higher price and the assembly of the connection is more complicated.

Hybrid cables

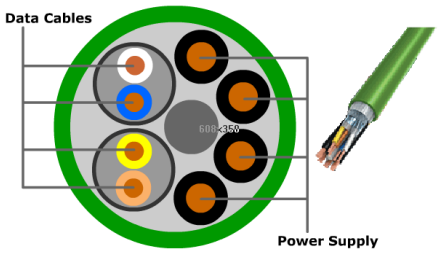


Fig. 21 Hybrid cable

In the production area, some of the devices will need to be connected to the power supply. A hybrid cabling structure is therefore very useful (Fig. 21). The voltage is 24 V. Hybrid cables contain wires (optical or copper-based) for both data signal and the transmission of energy. For optical cables, you need 2 optical wires for data transmission and 4 copper wires for energy transmission. For copper-based cables, you need 4 copper wires for data transmission and 4 copper wires for energy transmission.

Connectors

Connectors for copper-based cables

There are two connector types for copper-based cables used in PROFINET: RJ45 and M12 connectors (Fig. 22).

Fig. 22 RJ45 and M12 connectors

For installation inside a control cabinet, you can use the RJ45 connector with IP20 variant that is compliant with the connectors used in the office area. For installation outside the control cabinet, the connectors must satisfy the requirements for the extreme conditions in the installation area. Here, the RJ45 connector with IP65 or IP67 variant, or M12 is used.

The RJ45 connectors specified for PROFINET are the variants 14 and 5 in the IEC 61076-3-106. The shield for M12 connectors is designed according to D-coded variant from IEC 61076-2-101. Table 6 shows the contact description of the connectors

The hybrid connectors are RJ45 connectors with IP67 variant. The entire plug is fully touch-protected.

Table 6 Contact description

Signal	Name	Wire color (quad cable)	Wire color (EN 50173 T568B)	Contact Assignment	
				RJ45	M12
TD+	Transmission Data +	Yellow	Orange/White	1	1
TD-	Transmission Data -	Orange	Orange	2	3
RD+	Receive Data +	White	Green/White	3	2
RD-	Receive Data -	Blue	Green	6	4

Connectors for fiber optic cables

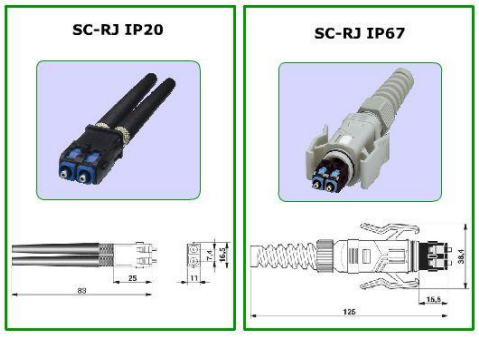


Fig. 23 Fiber optic connectors

For connecting fiber optic cables in PROFINET, SC-RJ connector technology is used (Fig. 23). The SC meets EN recommendations (EN 50377-6). The key features of this connector type are; small dimension, high packing density and high reproducible connection quality. For installation inside a control cabinet, SC-RJ connector with IP20 variant, and IP65/IP67 variant for installation outside a control cabinet are used. This connector is suitable for both multimode and single mode fibers. In the near future, the M12 connectors will be used, too.

Wireless system

If you take a look at the connecting systems currently used in industrial automation, you will see that the wireless system is becoming more and more common. The biggest advantages are savings in cabling costs and installation expenditure. Due to its mobility and flexibility, we can install devices where electrical power lines can only be used with limitations.

Fig. 24 Industrial wireless access point

PROFINET communications is also possible on these wireless communications networks. You can operate PROFINET field devices with different radio technologies for different application areas, with specific parameters regarding transfer rates, range, number of nodes, and so on. Thus, the profiles are specified for each technology. They specify how to integrate into PROFINET, which topologies and performance values can be achieved, and the conditions for security requirements.

PROFINET supports WLAN (Wireless Local Area Network) standard IEEE 802.11b/g, Bluetooth standard IEEE 802.15.1 and ZigBee standard IEEE 802.15.4. They use the 2.4 GHz frequency band in the ISM (Industrial, Scientific, and Medical Band) frequency range that can be used free of charge and without license.

Questions

Which of the following properties are you most likely to find in an office area?

1. Fixed cabling in a building
2. Related cabling according to the system
3. High EMC
4. High mechanical damage

What kind of copper-based cables are used in PROFINET?

1. Unbalanced cables
2. balanced cables
3. symmetrical cables
4. 2. and 3. are correct

You have to connect 2 devices which are 5 kilometers apart. What kind of cable will you use, if you have just one cable?

1. Glass fiber optic cable with multimode
2. Glass fiber optic cable with single mode
3. Copper-based cable
4. Hybrid cable

For installation outside a control cabinet, what kind of connector will you use?

1. M12 and RJ45 IP65
2. M12 and RJ45 IP20
3. M12
4. RJ45 IP20 and RJ45 IP65

Which of the following statements is true?

1. Wireless systems cause more cabling costs.
2. Wireless systems cannot be used in industrial automation.
3. Wireless systems are mobile and flexible
4. Wireless systems charge for the license.

Internet Protocol Family

When you want to communicate with people you all have to use the same language. Likewise, in the information technology (IT) world, where **protocols** are used as a common language that IT devices use to communicate with each other. There are many protocols used in IT. Some are vendor-independent, but some are proprietary. Let's take a look at some of the required protocols in industrial automation using Ethernet.

Internet Protocol (IP)

The Internet Protocol is probably the most used protocol in the IT world. The current version of this protocol is version 4 (IPv4), but version 6 (IPv6) will be used fully in the near future because one can assign much more addresses. IP provides a connectionless transport service transmitting and receiving datagrams. As shown in Fig. 25 a datagram consists of a header and a data portion (payload).

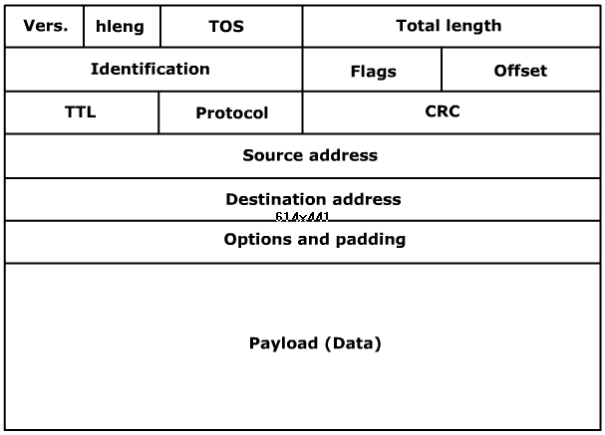


Fig. 25 IP header

The term **datagram** or **packet** is used to describe a chunk of IP data. Each IP datagram contains a specific set of fields in a specific order so that the reader knows how to decode and read the stream of data received.

A 32-bit IP address for addressing the field devices is used, denoted with decimal figures. An IP address consists of two parts, Host ID and Network ID. An IP address can be divided into 5 classes (A, B, C, D, and E), but only A, B and C are used in practical applications (Table 7) The first bits represent the network class followed by the network address and the user address. Take a look at the table below.

Table 7 The classes of IP addresses

	First bits	Network ID	Host ID	Address	Networks	Host
Class A	0	7 bits	24 bits	0.0.0.0 - 127.255.255.255	126	16777216
Class B	10	14 bits	16 bits	128.0.0.0 - 191.255.255.255	16384	65536
Class C	110	21 bits	8 bits	192.0.0.0 - 223.255.255.255	2097152	256
Class D	1110	28 bits, multicast identifier		224.0.0.0 - 239.255.255.255		
Class E	11110	27 bits, reserved		240.0.0.0 - 247.255.255.255		

The example in Table 8 shows a Class C IP address.

Table 8 Example of a Class C IP address

IP Address/Network	Address	Subnet Mask	Addresses in the network	Broadcast
192.168.0.1	192.168.0.1	255.255.255.0	192.168.0.1 to 192.168.0.254	192.168.0.255

Within an IP network, you can use a subnet mask to extend your network addresses. From the example, we use 255.255.255.0 as a subnet mask. Therefore, you can assign addresses from

192.168.0.0 to 192.168.0.255, where the last address 192.168.0.255 has a special function; namely broadcast function.

Subnet Mask

The subnet mask indicates how many network devices can connect to this IP address. In the binary form, the ones in the subnet mask indicate the subnet number part and the zeros indicate the host part. Table 9 shows the subnet mask 255.255.255.0 for the Class C IP address, 192.168.1.1.

Table 9 Subnet mask of a Class C IP address

	Network	Host
Decimal	255.255.255.	0
Binary	11111111.11111111.11111111.	00000000

From the example in Table 9, we can connect 256 network devices to this network, and they will have IP addresses from 192.168.1.0 to 192.168.1.255. But as before, the first (192.168.1.0) and last (192.168.1.255) addresses are reserved for special assignments.

User Datagram Protocol (UDP)

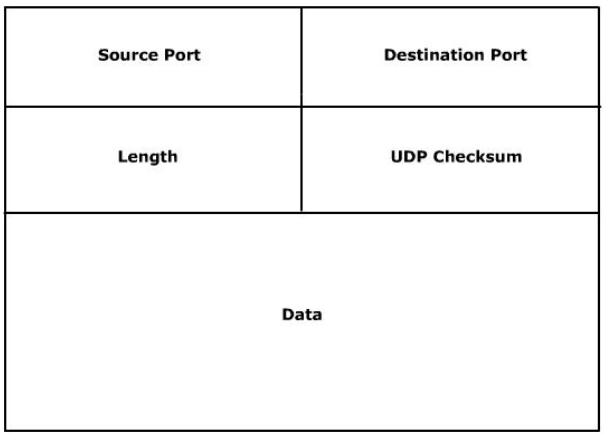


Fig. 26 Header in the UDP

UDP is used to provide a **connectionless** and unreliable data transport service. UDP will not inform the sender whether the data packet was received or lost. Using the UDP, you can have problems with data integrity because the data packet can be dropped, mis-sequenced or doubled. However, UDP has a short and simple header, only 8 bytes long. UDP introduces the concept of port numbers, which are used by the application layer that resides above UDP.

UDP provides faster data exchange because there is no acknowledgment to the sender. Therefore, this protocol is used for acyclic data exchange and system startup in PROFINET IO.

Transmission Control Protocol (TCP)

TCP is used to provide a connection-based and reliable data packet transporting service for processes. One can be sure that the data packet is delivered correctly. Besides reliable connections, TCP provides flow control to ensure stations are not flooded with data.

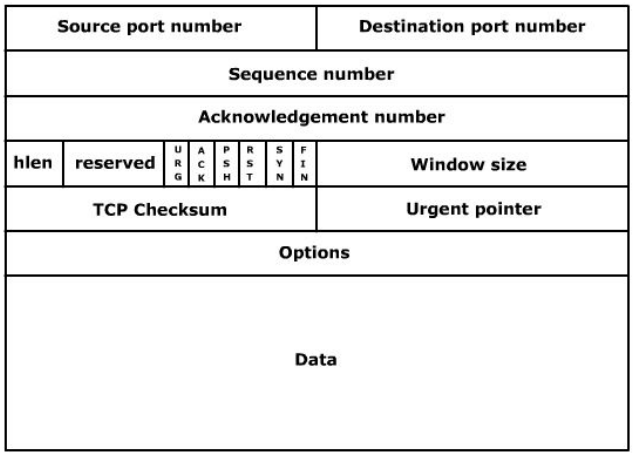


Fig. 27 Header in TCP

The header of TCP is larger than UDP (Fig. 27). In some cases, it can be up to 40 bytes in length. TCP uses the same port assignment scheme as UDP does.

Port Number Assignment

Port number is introduced in combination with transport protocol, such as UDP or TCP. It is 16-bits long. The Port number has significance since it identifies a particular application in the application layer. This property of the port number makes it possible that one station can support several different applications simultaneously. The use of a **port number** along with an **IP address** creates what is called a **socket** and looks like this: 192.168.0.1:8080.

There are three ways to classify port numbers.

- **Assigned**: The Internet Assigned Numbers Authority (IANA) defined the assigned port numbers in the range of zero to 1023 for various applications that are considered part of the TCP/IP protocol suite. These port numbers are **well-known**, meaning that they are used by common applications and cannot be used by other applications. These applications include TELNET, FTP, SMTP, WWW, POP3, etc.
- **Registered**: The port numbers in the range of 1024 to 49151 can be registered by firms or organizations for proprietary purposes. Other firms or organizations cannot use these port numbers anymore.
- **Dynamic**: The port numbers in the range of 49152 to 65535 are considered either private or dynamic, and can be used by anyone.

Address Resolution Protocol (ARP) and Reverse Address Resolution Protocol (RARP)

These two protocols are very important for the network access layer. With these protocols, one can resolve the logic addresses to the physical addresses and vice versa. ARP is used to resolve the Ethernet address from an IP address in order to construct an Ethernet packet around an IP data packet. This must happen in order to send any data across the network. If an IP host wants to call another IP host knowing only its IP address, an ARP request via LAN broadcast is sent to all local IP hosts. The called station (if active) will answer with an ARP reply telling its MAC address in return.

RARP is used to determine the IP address using the network. When a network device wants to know its IP address, it sends a RARP request to a RARP server. The RARP server will find

the corresponding IP address in its configuration file and send this IP address back with a RARP reply packet.

Other useful protocols

- **LLDP**: Low Level Discovery Protocol is used to **recognize its neighbor**. Each station sends its own information, such as MAC address, device name, etc. as a frame to the direct neighbor.
- **DHCP**: Dynamic Host Configuration Protocol is used for assignment of the IP addresses and related parameters, if the corresponding infrastructure is available.
- **DNS**: Domain Name Service is used in order to manage the logic names.
- **SNMP**: Simple Network Management Protocol is used in order to monitor the network. With this protocol, one can read out the status, statistical information and detect communication errors.
- **ICMP**: Internet Control Message Protocol is used to forward error information.

Questions

What do we use as a common language for network devices?

1. Proxy
2. Gateway
3. Protocol
4. Message

What does the term “packet” describe in this case?

1. A chunk of protocol message
2. A chunk of IP data
3. A small box or part of a system
4. A small piece of a signal

The IP address 192.168.1.1 is a part of network class C.

1. True.
2. False

Which of the following statements is correct?

1. UDP is connectionless.
2. TCP is connectionless.
3. UDP provides data exchange faster than TCP.
4. TCP provides data exchange faster than UDP
5. 1 and 3 are correct

Which protocol can be used to recognize its neighbor?

1. SNMP
2. LLDP
3. ARP
4. ICMP

Summary

PROFINET is an industrial communication system based on industrial Ethernet standard. It builds on the well-known and highly popular PROFIBUS system. The main advantages of PROFINET against PROFIBUS are high-speed data transfer, which is up to 100 Mbps, and the possibility of obtaining the process data from the field devices. A positive side effect is that you will have a continuous communication system from the office area to the automation area. This will facilitate monitoring, improve engineering productivity and make management easier. Please bear in mind that in the automation area the environmental conditions for the devices can be extreme (dust, temperature, EMC, etc.). Therefore, the network devices must be robust enough in order to function correctly.

PROFINET IO is designed for a data exchange system between controllers and field devices. PROFINET CBA is designed for a distributed automation system. Both concepts are based on using industrial Ethernet standard.

To understand the PROFINET, you took a look at the basics of Ethernet standard. We discussed the basic ideas behind the ISO/OSI reference model and the method of CSMA/CD Ethernet concept. Furthermore, we explained the installation techniques for Ethernet and PROFINET. The copper cables “twisted pair” are used widely now, but in the near future the fiber optic cable will be more significant.

To enable network devices to “speak” with each other, they must speak the same languages, the so-called protocols. We looked at several network protocols from the Internet protocol family and at some network protocols which are useful for the PROFINET. The most important protocols are IP, TCP, UDP, SNMP, etc.