Communication Networks

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Technical Information

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Communication networks based on serial data transmission are the platform of up-to-date automation systems. Whether this is office automation or automation of manufacturing or process plants, the task remains always the same, exchanging data between different devices or participants within a system. Communication networks provide a number of advantages over systems in which a point-to-point line enables only two participants to communicate with each other.

Classification of communication networks

Depending on the application, i.e. manufacturing, process, office or building automation, the communication tasks to be performed vary in complexity and are sometimes even contradictory. The use of only one communication network would therefore not yield optimum results. So the market offers very different networks and bus systems that are more or less tailored to a specific application.

optimum performance features enable optimum solutions

A quite general classification criterion is the distance over which communication takes place. There are local networks, LANs (Local Area Networks), as well as widely distributed networks, WANs (Wide Area Networks) (Fig. 1). With LAN, emphasis is put on fast and powerful data exchange within a locally restricted area, whereas WAN must be able to transmit data on very different data media and over several thousand kilometers.

LANs and WANs differ in their radius of action

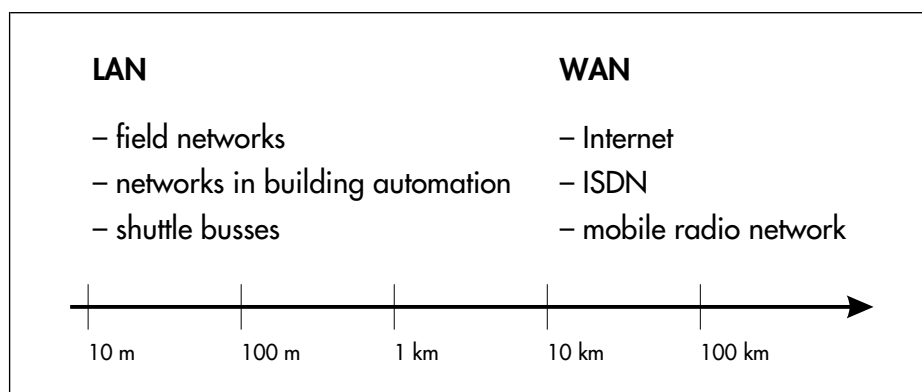| LAN	WAN
– field networks	– Internet
– networks in building automation	– ISDN
– shuttle busses	– mobile radio network

| 10 m | 100 m | 1 km | 10 km | 100 km |

Fig. 1:   Radius of action of communication networks

access to LAN data over the Internet

The Internet is an example for a wide area network. This network is a world wide group of greatly varying communication networks which in turn can comprise many subnetworks. Due to the increasing connection of LANs to the Internet, data which was only locally available is now available at any place in the world. Latest developments enable plants using field bus communication to be remotely monitored and operated via commercially available Internet browsers.

Demands on communication networks differ not only in the varying distance to be covered. Depending on the application, they also vary as to

▸ the required data rate,

▸ the number of data bytes per communication cycle,

▸ the renewal rate of the data,

▸ the required real-time capability, and others.

communication on different hierarchical levels

To obtain a practice-oriented classification, the communication networks are assigned to different hierarchical or application levels (Fig. 2) which form a communication pyramid with three, sometimes four, levels.

At the bottom level, the number of participants, the required real-time capability as well as the message renewal rate is high. The higher the hierarchical level, the lower the number of participants. Requirements concerning real time and sampling rate are also lower. However, the complexity and the length of the message telegrams are increasing.

requirements on the factory level

The factory level supervises the higher-level management. What is important in this case is not the response time, but the safe transmission of even very long messages (file transmission). As these networks also control the lower levels, they are considered the backbone of the system and are thus frequently called backbone networks. Typical protocols used in this field are for example:

▸ MMS (Management Message Specification),

▸ PROFIBUS-FMS and

▸ TCP/IP (Transmission Control Protocol / Internet Protocol)
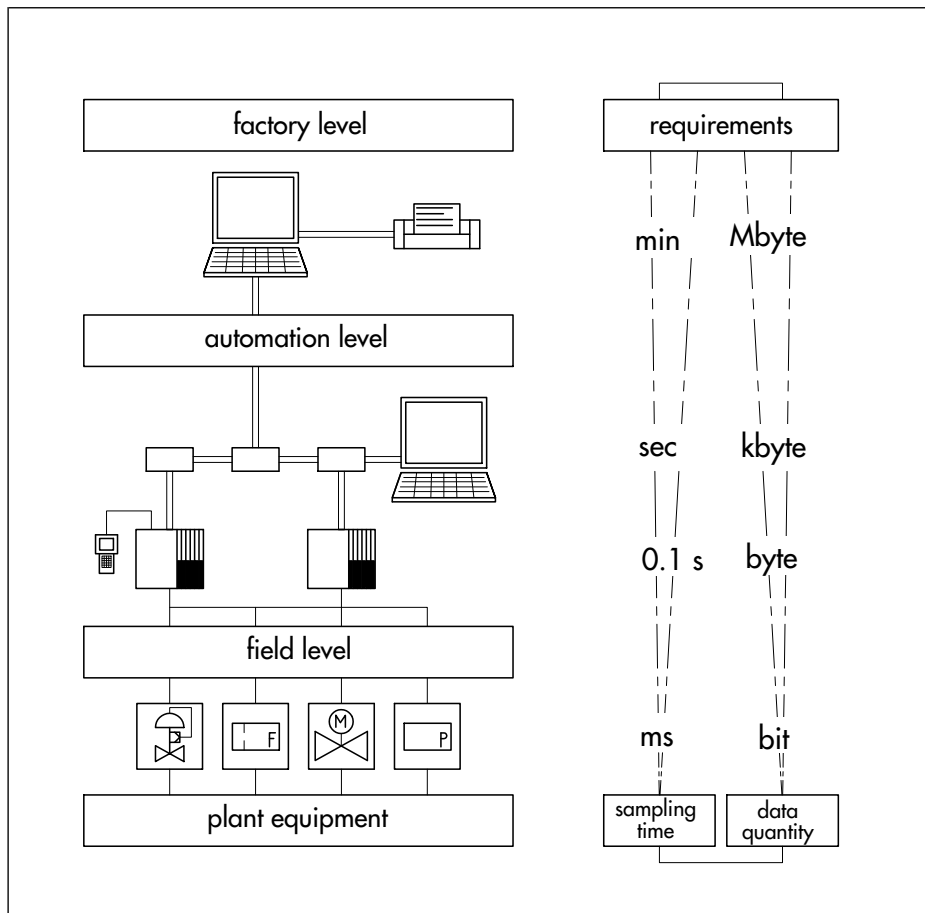
Fig. 2: Hierarchical levels in communication systems

On the factory and the automation level, messages just have an average length (10 to 500 bytes), while response times of 5 to 20 ms must be reached. These requirements are fulfilled by the so-called automation networks which include the following:

requirements on the automation level

▸ Bitbus,

▸ FF (FOUNDATION Fieldbus),

▸ FIP (Factory Information Protocol),

▸ LON (Local Operating Network),

▸ Modbus,

▸ and, depending on the application, PROFIBUS-FMS and -DP.

**requirements on
the field level**

On the field level, i.e. the level of sensors and actuators, short messages (several bytes) must be transmitted at high speed (10 to 100 s). This area is covered by the large group of field networks. Due to the very special and varied requirements, a great number of networks are used:

▶ ASI (Actuator-Sensor Interface),

▶ CAN (Controller Area Network),

▶ FF (FOUNDATION Fieldbus),

▶ InterBus-S,

▶ PROFIBUS-DP and -PA

▶ and others.

**many differences but
yet more similarities**

The structures as well as the software and hardware components of the different communication systems are similar in many respects. This can be explained by the fact that the essential task is always the same, i.e. trouble-free communication between all connected participants. Also, all communication systems must equally comply with the standards relevant in their field of application. The following descriptions therefore apply largely to more than one or partly even to all communication systems listed in this paper.

Network topologies

The network topology describes the physical arrangement of the participants in relation to each other within a network. The term also describes the logical arrangement of the participants in relation to each other during communication, which is not necessarily the same as the physical arrangement. For the

a) mesh topology
b) bus topology
c) tree topology
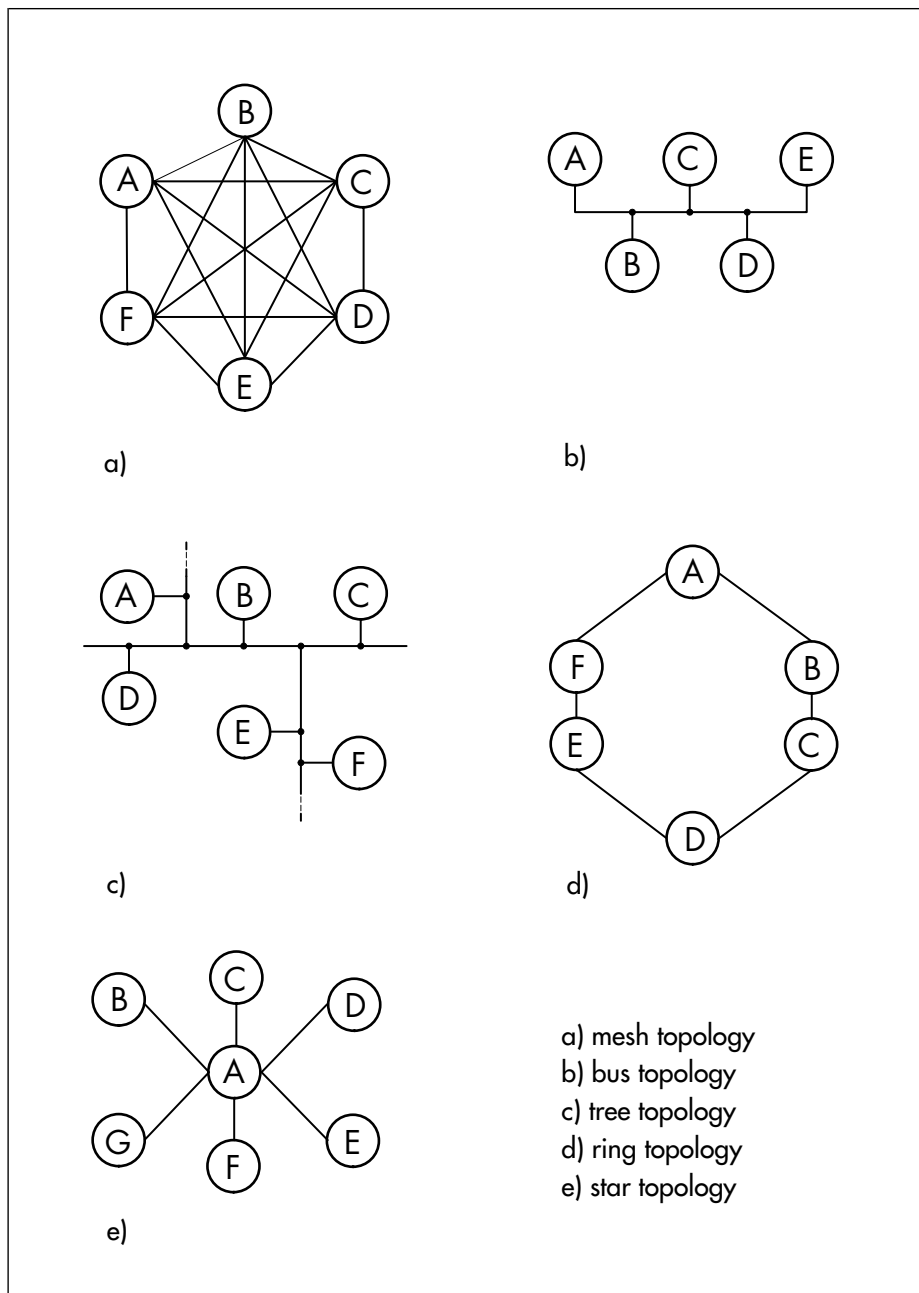d) ring topology
e) star topology

Fig. 3:   Network topologies

connection of more than two participants, very different networking structures are possible:

mesh topology

The most complex method is to create a mesh connecting all the participants with each other via separate communication lines (Fig. 3a). When it comes to network extensions, the flexibility is very low and the amount of hardware required is so high that this topology is rarely used in practice.

line or bus

A much clearer and simpler structure is the line or bus topology. In this case, all participants communicate over the same line (Fig. 3b) and are connected via short stub lines so that each participant requires only one interface to the bus. Since a transmitted message can be 'seen' by all participants, broadcasting or multicasting of messages can be easily done. The common transmission medium is controlled by a special bus access control unit which is usually able to maintain the functions of the bus-operated system even if one station happens to fail.

tree topology

The tree topology is in most respects similar to the bus topology, except that the tree structure enables several bus branches to be connected in so-called nodes (Fig. 3c). This topology makes it easier to network larger areas. As is the case for the bus structure, the maximum line lengths and the number of participants connected without line amplifiers (repeaters) are limited.

ring topology

When several two-point connections are used to create a physical ring, we speak of a ring topology (Fig. 3d). A transmitted message is forwarded from one participant to the next. As the signal can be amplified whenever it is forwarded, very long distances can be covered. Unfortunately, the transmission speed depends on the number and the processing speed of the participants. This means that the failure of a single participant can lead to network failure when no extra ring is provided.

star topology

In the star topology, all participants are connected to a center station via two-point lines (Fig. 3e). The center station may either be active, acting as a master for the network control, or passive and assume the task of a so-called star coupler which establishes the connection between the currently active transmitter and recipient. In both cases, failure of the center station causes the entire network communication to fail.
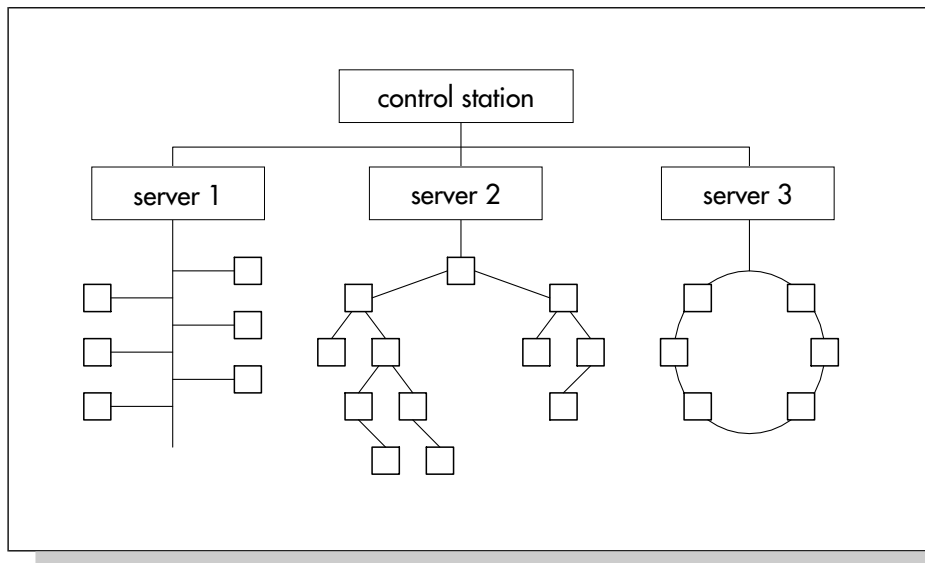
Fig. 4:   Complex network consisting of several subnetworks

The topologies described above form the basis of almost every serial communication network. However, a lot of network specifications allow the use of free topologies or mixed structures so that line and tree topologies or tree and star topologies can be combined. To ensure compliance with the electrical specifications of the transmission medium, a coupler, amplifier or distributor (repeater, hub, etc.), as required, must be provided at the connection node.

free topologies enable flexible network structures

Complex network structures often consist of several, partly autonomous, subnetworks. Each subnetwork can be based on a different topology and a different communications protocol (Fig. 4). In any case, each participant must be able to clearly identify any of his communication partners and address him directly. In addition to this, any of the communication participants must be able to access the transmission medium. The way in which the transmission lines are assigned to the various participants is determined by the protocol specification which defines the access method.

autonomous subnetworks are part of complex networks

Media access control

active and passive participants connected to one transmission line

'Active' participants are able to initiate information exchange while 'passive' participants only take part in communication on request of an active participant. When several active participants are connected to a network, it is necessary to coordinate their actions in order to avoid data collisions. This task is performed by the media access control.

- Real-time capability

Many automation tasks require that a message or an operating action be transmitted within a fixed time span, or even processed within a fixed equidistant time frame. If a communication system meets the time requirements of such an application, this system is referred to as being real-time capable.

real-time capability through deterministic media access methods

A prerequisite for real-time capability is that a communication participant is able to start his data transmission within a prescribed maximum time. This can only be guaranteed when access rights are granted in a definite order (Fig. 5). Communication systems operating on controlled media access are called deterministic (e.g. Master/Slave, Token Passing).

random access with stochastic methods

Apart from the controlled network assignment inherent in deterministic methods, there are also stochastic methods granting access to the network at random. As the time needed to transmit a message depends considerably on
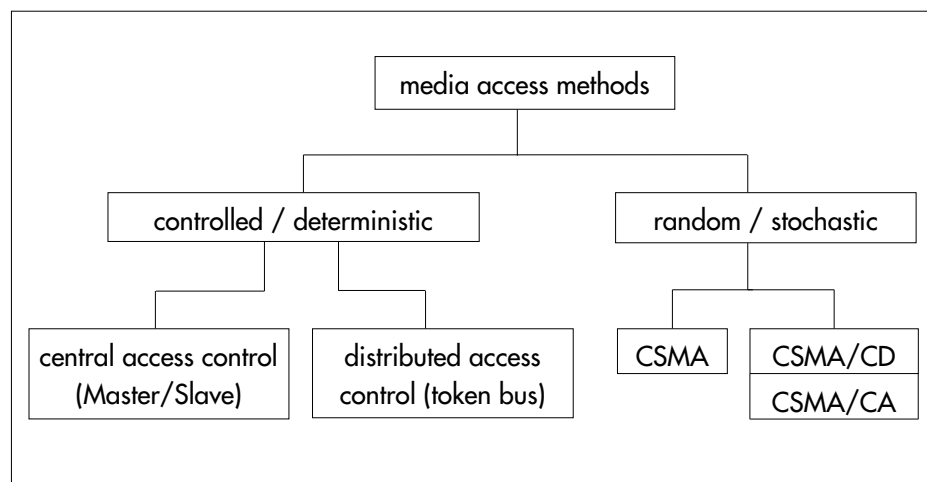

Fig. 5:   Classification of media access methods

the number of participants, such methods are not suitable, or only under certain conditions, for real-time applications.

• Random bus access

Random, i.e. stochastic media access means that the transmitter stations are waiting with their own transmission until the transmission medium is free. If two transmitter stations happen to begin with transmission at the same time, the data is superimposed and destroyed. The transmitter stations recognize a data collision, because the recipients do not return an acknowledgement for reception. They repeat transmission after a short, varying period of time. The random access method provides the advantages of flexibility and fast response times when the network load is low, however, high network load causes repeated blocking of the lines. Evidently, the response behavior is not deterministic since it is not possible to determine when a message will finally reach the recipient. This kind of access is termed CSMA (Carrier Sense Multiple Access) and illustrated in Fig. 6.

**CSMA method: Carrier Sense Multiple Access**

An improved variant of this access method makes use of the widespread Ethernet. Here, the transmitters recognize a data collision by monitoring the level of the line during transmission. When a collision occurs, the transmitters immediately abort the transmission and attempt to repeat the transmission after a waiting time chosen at random. This extended CSMA access method is called CSMA/CD (Carrier Sense Multiple Access – Collision Detection).

collision detection with CSMA/CD

Even better results can be achieved when collisions are avoided (CSMA/CA – Collision Avoidance). The level, e.g. the low level, of one transmitter is gi-

collision avoidance through CSMA/CA
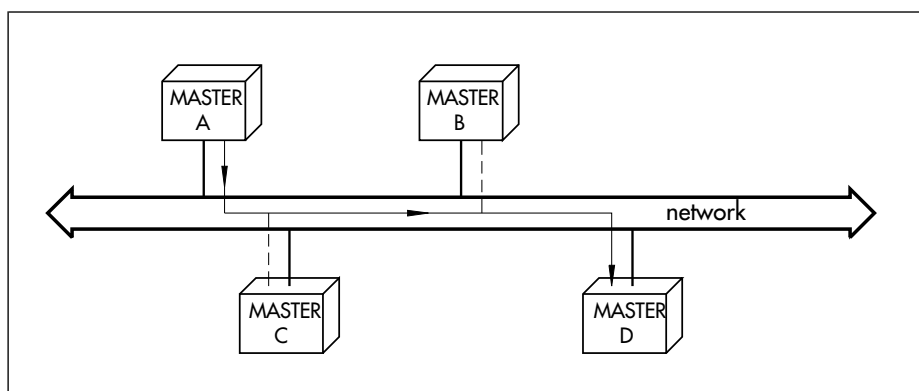
participants B and C wait until communication between A and D is finished

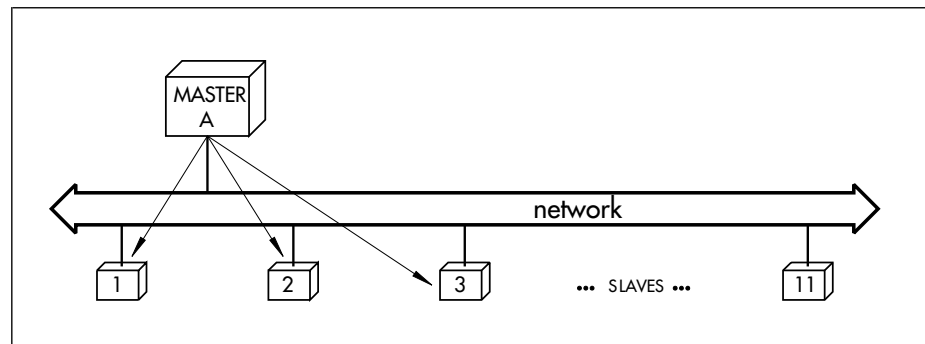*Fig. 6: Random access with the CSMA method*

Fig. 7:   Controlled media access with the Master/Slave method

ven priority over the level of the other transmitter, and the data of the lower-priority transmitter is simply overwritten. When two participants start transmission at the same time, the transmitter with the higher priority will be able to send its data. While sending its address, the dominant transmitter overwrites the non-dominant address bits of the other participant. The transmitter with the lower priority immediately stops transmission and repeats the procedure after a short, varying period of time. This kind of access method is also used, among others, by the CAN protocol (Controller Area Network).

• Controlled bus access

The controlled, deterministic media access methods are subdivided depending on the type of participants. When only one participant is active, we speak of a central access assignment, whereas a distributed access right is assigned when several active participants are present.

master/slave control   When using the central access assignment, only one device, the master, has the right to initiate a communication cycle. This ensures that two devices can never access the network at the same time. All other devices, the slaves, transmit only when requested by the master (Fig. 7). Usually, the master **polling the slaves** employs the polling method, servicing the slaves one after the other in a cyclic manner. Messages with high priority are polled repeatedly within a cycle.

Slave devices are frequently low-maintenance field devices, such as sensors, control valves and transducers. Normally, the slaves cannot communicate directly with each other. The data is read by the master and forwarded as
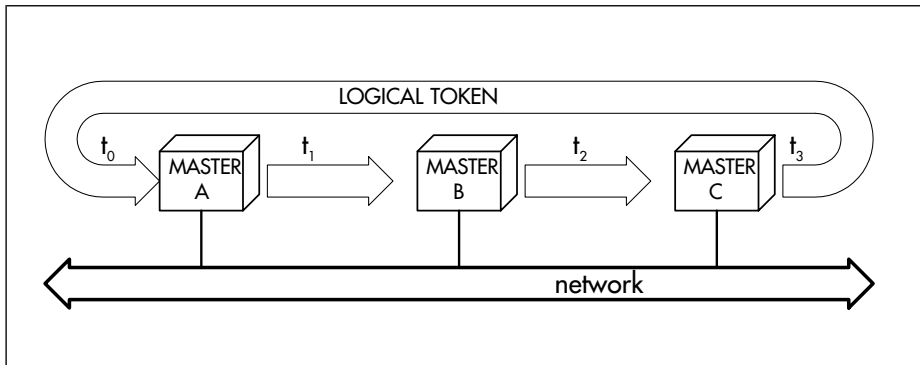
Fig. 8:   Controlled media access using the token passing method

required. However, it is possible to address a transmitter and a recipient slave at the same time, thereby initiating direct data exchange.

The master/slave control is a simple and cost-effective method as only one station must assume the complex task of controlling the network. As far as the slave participants are concerned, only part of the protocol needs to be implemented. However, a defective master causes the entire network to fail. This can be avoided when a slave is configured to assume the functions of the master.

simple and cost-effective implementation

The distributed access assignment according to the token passing method (Fig. 8) does not require a single participant to be so reliable and available. All the network participants are able to assume the functions of a master.

token passing method

The master functions are assigned to the communication participants in a prescribed order. This is done by passing a special message, the token, from one active participant to the next within a logical ring. The participant which presently has the token is the network master having sole control over the network. When a time span defined by the token rotation cycle is over, the token must be passed on to the next active participant. When the token passing method is used with mesh topology, forming a physical ring, we speak of a token ring; analogous to that, we speak of a token bus when a bus topology is used.

token marks the currently active master

The combination of the master/slave method and the token passing method is called hybrid access method (e.g. PROFIBUS). It is used when active (master functions) as well as passive participants (no network control functions) are connected to one network.
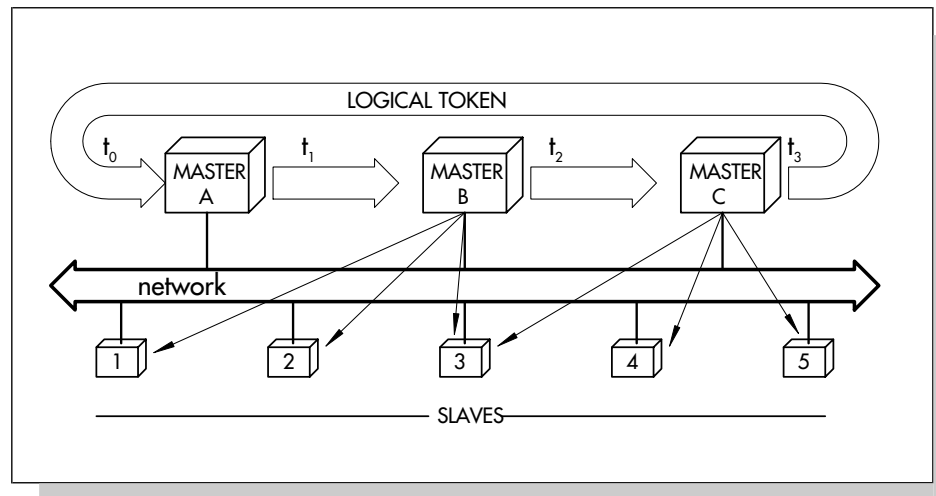
hybrid access method

*Fig. 9: Controlled media access with the hybrid access method:
token passing and master-slave*

**subordinate master/
slave communication**

The master selected by the token can communicate with the passive participants through the master/slave functions, while communication with the active participants is performed using the token passing method (Fig. 9). To enable the token carrier to distinguish whether its communication partners are active or passive, this information must be provided to all active participants in advance upon configuration of the network.

**deterministic media
access**

Calculation of the maximum transmission time of a message is possible for all types of controlled media access. Real-time automation tasks require calculable, i.e. deterministic media access, since the cycle time and the frequency of the data transmission must be guaranteed for a lot of control functions.

Protocols and telegrams

Communications protocols are required to exchange the data between two or more devices/participants reliably. When we send a letter, we need to indicate the sender's address as well as the destination address. This is also true when sending "digital letters". Protocols help distinguish between the control data and the proper message. This is achieved by defining a certain format for the data telegram, which specifies the beginning and the end of the telegram as well as the control data and the proper messages. Usually, telegrams consist of the basic components as illustrated in Fig. 10.

protocols define the data exchange

messages are packed into telegrams

The data field containing the proper message is preceded by the header information. In multi-point connections (networks), the header generally contains the source and destination address of the message or indicates its contents. Additionally, the message control data, such as message length (e.g. number of bits), is included here.

The data field is succeeded by the data security section. This component provides the error checking information generated by the transmitter, helping the recipient to check whether the message is correct (see section: Error detection).

access to telegram fields

The header, data field and data security section can be delimited by

▶ inserting special control characters or

▶ counting the received characters (applies only to fixed lengths).

In bit-oriented data transmission, too, the message is framed by control data. Fig. 11 shows a typical telegram for bit-serial data transmission within a network. Each data telegram uses a transmission frame which is divided into several fields.
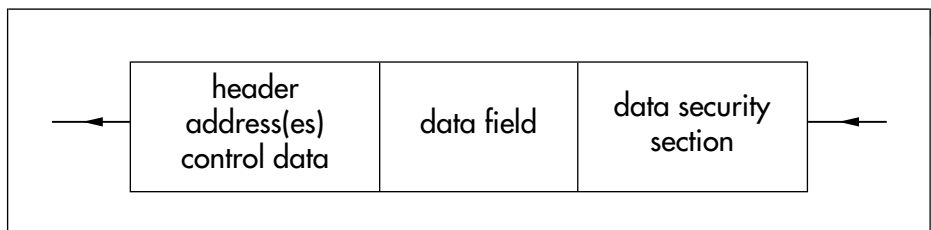
bit-oriented data transmission

| header address(es) control data | data field | data security section |

Fig. 10: Basic structure of a transmission telegram

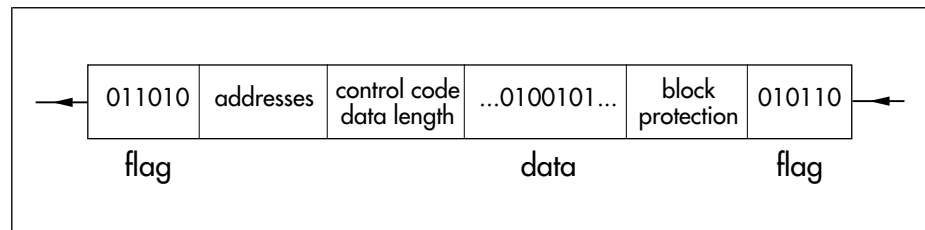| 011010	addresses	control code data length	...0100101...	block protection	010110
flag			data		flag

Fig. 11: Telegram in bit-serial transmission

header and trailer are the frame of the telegram

The beginning and the end of the telegram are marked by a bit sequence. The header can also be used for synchronization in the case of asynchronous transmission. Analogous to the start bit of the UART character, the recipient synchronizes with the frequency of the transmitter.

fixed bit sequence and number ensures clarity

Every single field of the telegram contains a prescribed number of bits. This allows the recipient to distinguish message data from control data simply by counting the bits in the individual fields. If the transmission protocol specifies also telegrams with variable message lengths, the transmitter enters the number of data bits in a special control field (e.g. the field data length). The recipient then analyzes this information before reading the variable data field.

user data rate allows for additionally required protocol data

When digital data is transmitted, the transmission speed of a message cannot be determined by the bit rate alone. To be able to estimate the user data rate, the ratio between the control and the user data must be taken into account while at the same time considering the type of transmission protocol used. With character-controlled, asynchronous transmission, the single bytes are sent as UART characters (11 bits for one data byte) which reduces the user data rate to 73 per cent.

Addressing and communication services

When a communication system comprises more than two participants and a message must be passed to a particular participant, direct addressing of this participant must be made possible. For this purpose, a bit sequence (a character or a character string) is used to serve as the participant's address (see structures of a telegram in Figs. 10 and 11).

direct addressing for message transmission

The simplest way is to assign an address statically to each device. Static address assignment can be implemented on the hardware level via Dip switches or on the software level. Another possiblity is to assign the addresses dynamically. This can be done during the first parameterization and start-up phase of the system, or by the master during operation in special initialization phases.

address assignment via hardware or software

To enable the participants to perform their communication tasks, various services are available. The number of services provided is a criterion for assessing communication systems.

communication service ...

There are two different types of communication services. Connection-oriented services transmit data over a communication channel which links the transmitter and the recipient directly by using their addresses.

.. connection-oriented

Whereas connectionless communication services do not provide a direct connection between the transmitter and the recipient. Typical examples for connectionless services are the following:

... or connectionless

▸ multicasting: message directed to a group of participants

▸ broadcasting: message directed to all participants.

multicast and broadcast messages

Such message types are used to identify and parameterize all the participants upon system initialization, or when procedures or actions must be executed with several participants at the same time.

Addresses can be organized hierarchically so that all participants of one group, e.g. with the same address beginning, can be addressed simultaneously.

Communication of open systems: ISO/OSI layer model

communication via standardized interfaces

Effective and unambiguous communication between different participants and through the various hierarchical network stages requires generally applicable rules. Whenever devices and systems of different manufacturers and system operators are supposed to communicate with each other, standardized interfaces are needed.

ISO/OSI layer model ...

The International Standardization Organization (ISO) developed a definition for such a standardized interface, specifying the tasks for computer communication, and proposed this definition in the ISO standard 7498 under the title "Basic Reference Model for Open Systems Interconnection – OSI". This definition describes the communication of an open system in which any number of components and subsystems can be integrated, provided that the defaults of the reference model are maintained.

... divided into seven layers ...

The so-called ISO/OSI model specifies all elements, structures and tasks required for communication and assigns them to seven layers, each forming the basis of the next (Fig. 12). The different layers perform precisely defined tasks or services within a communication procedure, each layer providing its services to the next higher level via defined interfaces, the Service Access Points (SAP's).

... for data transmission and application

The four bottom layers provided in the hierarchical structure are responsible for data transmission between the devices (transmission layers), while the layers 5 to 7 coordinate interaction with the application program or the operating system (application layer).

physical layer

Layer 1 defines how the data is transmitted physically, i.e. electrically and mechanically. This includes, for example the type of coding (e.g. NRZ) and the transmission standard used (e.g. RS 485).

connection or security layer

The task of layer 2 is to provide error-free information. It must detect errors that probably occured in layer 1 and eliminate them by utilizing appropriate error routines. Layer 2 also controls the data flow when the transmitter and the recipient process the data at different speeds, and is responsible for the media access control (MAC: Media Access Control) in local networks.

Layer 3 establishes and cancels connections in the network and performs routing, i.e. defining the way the data has to take within the network. Also, the number of data packets on their way in the network is supervised to avoid possible congestions.

network layer

Layer 4 assumes total control of a data transmission requested by layer 5. A permanent connection is established between the participants, lasting as long as the transmission. The transmission is supervised with respect to possible transport errors, the data packets of the next higher level are divided into transportable units and the proper order of the exchanged data units is restored on the recipient side.
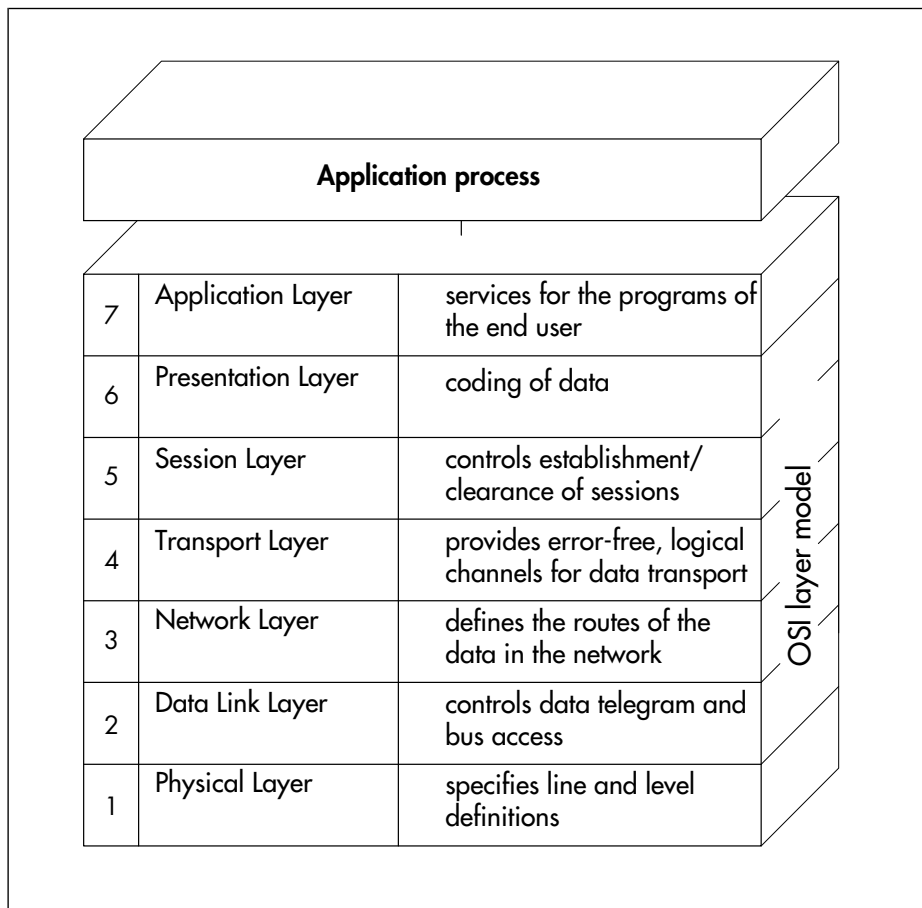
transport layer

		Application process	
7	Application Layer	services for the programs of the end user	
6	Presentation Layer	coding of data	
5	Session Layer	controls establishment/ clearance of sessions	OSI layer model
4	Transport Layer	provides error-free, logical channels for data transport	
3	Network Layer	defines the routes of the data in the network	
2	Data Link Layer	controls data telegram and bus access	
1	Physical Layer	specifies line and level definitions	

Fig. 12: Definition of the OSI model layers

session layer   Layer 5 controls the establishment and clearance of temporary connections (sessions), in which one or several tasks can access the transport system. Tasks communicating with each other can be synchronized as needed. Layer 5 also manages and assigns the logical names to the physical addresses.

representation layer   Layer 6 encodes the data (representation), preparing them for analysis and interpretation by the higher layers.

application layer   Layer 7 is the interface to the application program and contains all the functions the user, generally a PC program, needs to access the communication functions.

data transmission between the OSI layers   To transmit a message from one application to another, the message is passed on the transmitter side from layer 7 down to layer 1, each layer appending its layer-specific control data as well as a protocol header (see Fig. 13). This data is used for communication with the corresponding layer on the recipient side. Apart from the original message, an accordingly large amount of control data is transmitted over the physical medium to the recipient. On the recipient side, the message is passed from layer 1 up to layer 7, each layer removing its specific control data and providing the requested services so that the message is finally available to the application process in its original state.
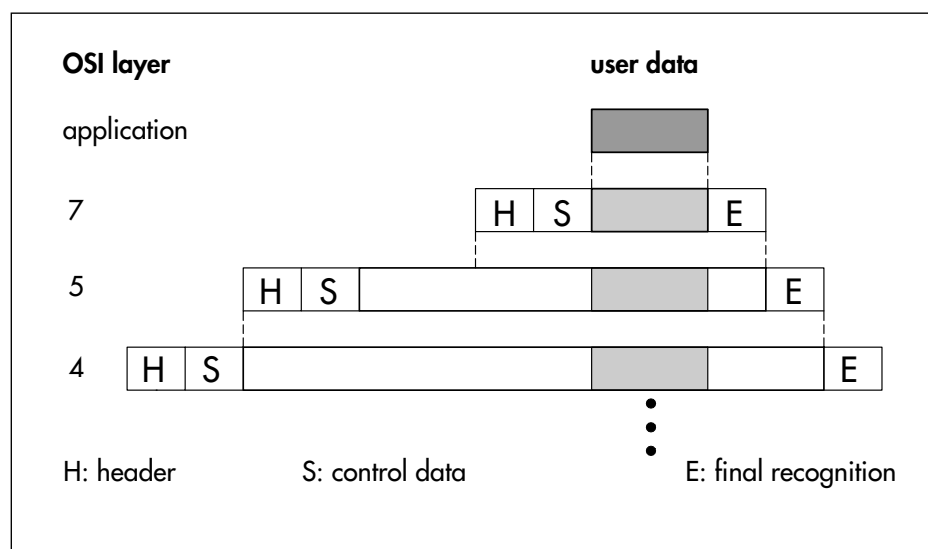

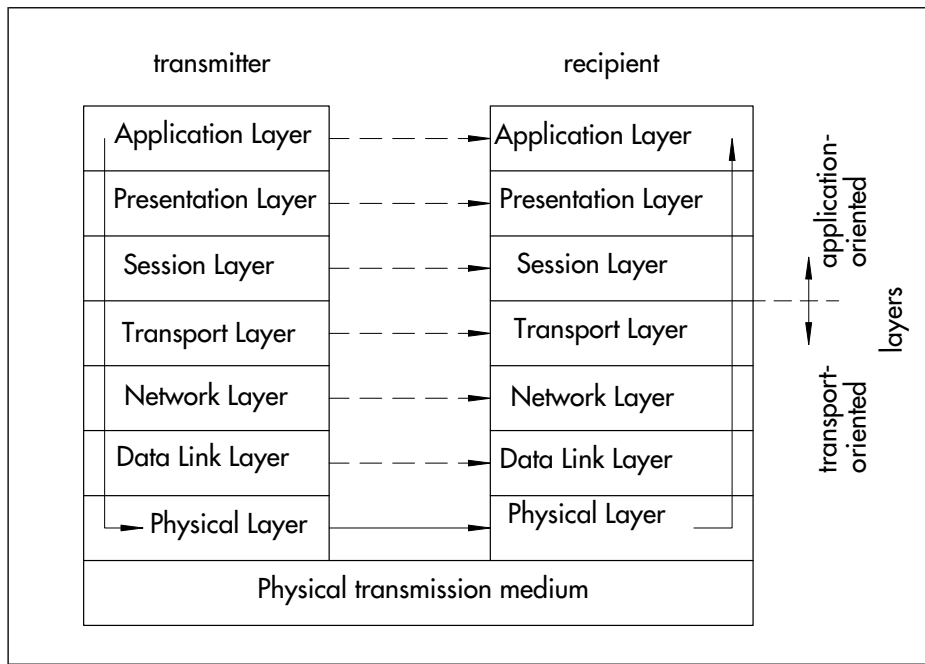*Fig. 13: Encapsulation of the message within the OSI layers*

Fig. 14: Layer-specific communication with the OSI model

This working principle allows only equal layers of the participants to communicate with each other (see Fig. 14). The physical layer of station A only communicates directly with the physical layer of station B. Of course, all other layers of station A exchange data with their corresponding layers of station B as well. Since each layer communicates only with its corresponding layer, it is not aware of the other layers.

...communication

...over corresponding layers

Communication between two participants is only possible when both participating parties service the same layers and apply the same definition. If particular services within a communication system are not required, the individual layers can be empty, consequently, the message telegram does not include the information associated with these empty layers.

only required layers are defined

Since the OSI layer model was developed for communication in open systems, the communication process is described only on an abstract level. No details are given on how to implement the individual layers. The OSI model only defines the services needed for communication and their integration in the communication sequence. Whereas it does not detail which physical lines and signal levels, which data format, error detection method and addressing of the participants to use and how to establish and clear the connections as well as provide the data to the application process.

implementation of OSI layers not defined

SAP: interface to the service of a layer

The individual layers can therefore be implemented in varying ways. Nevertheless, the uniformness of the services and service access points (SAPs) ensure exchangeability. Thus, a communication protocol imitating the OSI structure can be transferred layer by layer to another OSI-compatible protocol without restricting the functionality or the performance. This is made possible by gateways. They couple different communication systems which vary in all layers.

OSI as standard representation

The OSI model has established itself as quasi-standard as regards the implementation of communication services, though, many systems implement only part of the model definitions. Naturally, only those services and functions are implemented that are required for the respective application. Simple applications, such as field networks, do not need comprehensive services for organizational tasks as they are required for complex network topologies. This is why specifications for field networks usually define only the layers 1 and 2 completely, whereas all remaining services are performed by the application process itself or the layer 7.

field networks usually use only layers 1, 2 and 7

Selection criteria for communication systems

The communication ability of a device says nothing about its performance and versatility. It is only an indicator for the exchange of information between of two devices minimum. To exactly describe the performance and estimate the usability of a communication system, many more aspects must be taken into consideration.

Technical and functional aspects alone are still not sufficient to select an appropriate communication system. Availability and exchangeability of the components as well as economic aspects need to be considered.
The following criteria are essential when selecting a communication system:

▸ physical properties (e.g. transmission speed),

▸ functional aspects (e.g. noise immunity, exchangeability),

▸ application range (e.g. hazardous environments),

▸ popularity on the market (e.g. price, acceptance) and

▸ state of standardization (e.g. exchangeability).

**selecting a
communication system**

Depending on the respective application, each selection criterion must be analyzed and evaluated individually. The examples in the following list show how single requirements determine the necessary properties of the communication system:

▸ Depending on the application, bidirectional (in both directions) or uni-directional (in one direction) data exchange could be necessary.

uni- or bidirectional

▸ Processes with high dynamics require sufficiently high data rates.

▸ To implement real-time capable process control units, appropriately short response times must be guaranteed (deterministic system).

**guaranteed response
times**

▸ Optimum use of the network can only be achieved when the size of the data telegrams matches the actual length of the message.

**short or long data
packets**

▸ The processing of messages of varying importance can be simplified by using prioritized data transmission.

priorities required

is error detection important?

▶ Control units providing interference resistance and/or transmission error correction make optimum use of the interface. If one or several devices fail, the remaining devices should still be able to communicate and a failure of the transmission medium should be detected reliably.

Finally, user- and development-specific characteristics must be considered from an economic point of view:

optimum adaptation to devices

▶ a protocol tailored to the application, e.g. having a specially adapted application layer and predefined device descriptions, can reduce engineering costs and start-up times considerably,

independent, long-term device selection

▶ component interchangeability and interoperability of devices from different manufacturers expand the application range and, hence, the acceptance.

Additional conditions, such as

long distances

▶ data transmission over long distances and

for hazardous areas

▶ application in hazardous environments,

can influence the technical design of a communication system.

The multitude of applications and the sometimes contradictory requirement profiles, and company policy as well, are responsible for the fact that to date there is still no internationally approved and uniform communications standard. Therefore, each case must be analyzed individually to find out which communication system suits the application best.

no uniform standard due to numerous requirements

Terminology of communications technology

For a better understanding of the numerous technical and abstract terms used in the field of digital communication, the terms are compared to those used in everyday language. Even when the comparison cannot stand up to a detailed analysis, the assignment of terms will help understand the tasks and services.

In general language usage, the term 'communication' means 'talk' and describes 'information exchange between individuals'. 'Digital communication' pursues the same goal, information exchange between, this time, devices.

terminological comparison of everyday and technical language

In both cases, information is exchanged over a suitable medium and via appropriate interfaces.

air (acoustic medium)	channels (electric lines)
ears, mouth	hardware interface, e.g. transmission standard (RS 485)

General rules are the basis for mutual understanding.

letter, word	bit, byte, data formats
grammar, language	transmission protocols OSI/ISO model

Whoever participates in communication must fulfill specific tasks.

host	master
other participants	slave
orators, talkers	transmitter (talker)
auditors	recipient (listener)

It is important to define who may speak when and how long,

dialog control	network assignment assignment of talker function

because all participants talking (transmitting) at the same time would disturb the communication.

all talking at the same time	data collision

Equal participants can speak one after the other in a predetermined order

list of orators	token procedure

or try to get heard during breaks.

unsolicited participation in the dialog	CSMA method

Others have to wait until they are requested by the host.

teacher/student dialog	master/slave control

This coordination of communication is performed by an individual

host	single-master system

or a group of equal hosts.

group of hosts	multi-master system

Information is provided by a participant (orator/talker) and addressed to

all participants	all listeners (broadcasting)
addressed participants	previously addressed participants

Communication takes place as

tête-à-tête conversation	point-to-point connection
within the group	network connection of several partici-pants

The physical – local – arrangement of the participants

seating plan	network topology

can, but need not have an effect on the communication sequence because it is not only possible to address visible participants, but all other participants as well via the

names	participants addresses

The numerous corresponding terms in this list of comparison, which is certainly not complete, demonstrate that 'Digital communication', despite its many new terms, is a comprehensible and transparent field. When taking a closer look, you will see that here a commonly known method is utilized with similar means and for new technical applications.

However, the classification provided in this paper is not sufficient for an exact selection since even within the hierarchical stages the requirement profiles vary depending on the application. Especially on the field level, where the communication system communicates directly with the field devices and, hence, is immediately integrated in the process environment, a multitude of requirements exists.

Appendix A1:
Additional Literature

[1]   Digital Signals
        Technical Information L150EN; SAMSON AG

[2]   Serial Data Transmission
        Technical Information L153EN; SAMSON AG

[3]   Communication in the Field
        Technical Information L450EN; SAMSON AG

[4]   HART-Communication
        Technical Information L452EN; SAMSON AG

[5]   PROFIBUS PA
        Technical Information L453EN; SAMSON AG

[6]   FOUNDATION Fieldbus
        Technical Information L454EN; SAMSON AG

APPENDIX

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Figures