Intelligent distributed systems

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2022/2023

Outline

1. Communication Systems
   - Basic pillars of communication systems
   - Open System Model
   - Industrial automation standards
   - Final comments
   - Examples
2. Industrial Networks
   - Interconnection Systems
3. Take home message

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Communication systems

The *communication systems* can be seen as an *infrastructure that provides services to applications*.

In our case, the applications are mainly *estimation* and *control* applications.

In general, the applications are said to be *distributed applications* when they involve *multiple components* that exchange data with each other.

Communication module

Basically, the *communication systems* are used to transfer *information* from one source, i.e., the *transmitter*, to a destination, i.e., the *receiver*. The *transmitter* and the *receiver* are generically denoted as *hosts* or *end systems*.

The term *host* is because it *hosts* programs and applications.

Communication module

Hosts are connected together using *communication links*.
Communication links use the *communication modules* to interface the transmitter/receiver with the *physical medium* upon which the signals are transmitted.

Definition

In communications, *physical media* (singular is *medium*) refers to the physical components used to transmit information.

Physical media

Definition

A *communication channel*, or *channel*, may refer to the physical medium or to the logical connection over a multiplexed medium.

Definition

Multiplexing is the technique by which multiple analog or digital signals are combined into one signal over a shared medium.

Examples: *time-division* (TDM), *frequency-division* (FDM) or *space-division* (SDM) multiplexing.

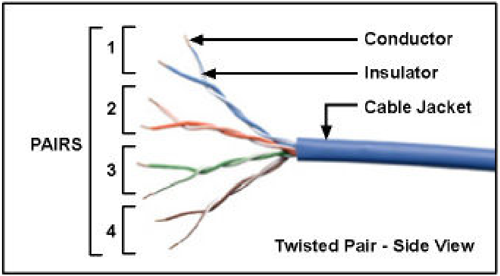
Communication systems

Telecommunication engineers view-point

- The *transmission quality* is determined by the selected *medium* and the *bandwidth*.
- There are *guided media* in which the transmission is directed by the medium, i.e. the wire. In this case, the medium determine the transmission quality.
- For *unguided media* the transmission is in the air (*wireless communication*). In this case the bandwidth of the signal produced by the *transmitting antenna* is more important than the medium for the transmission quality.

Physical media

Popular guided media



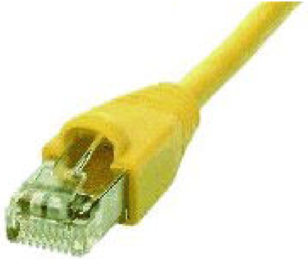


Figure: Pair of twisted wires UTP with the popular RJ-45 Jack (courtesy of www.infocellar.com).

Physical media

Popular guided media

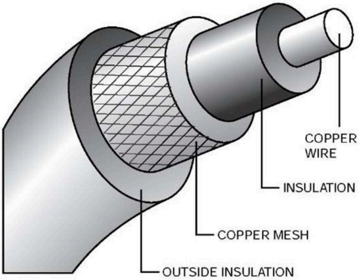
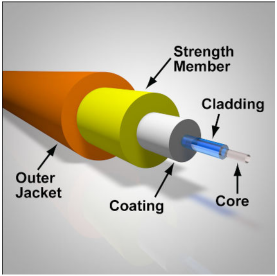
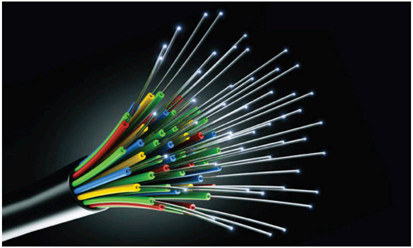


Figure: Coaxial cables.

Physical media

Popular guided media





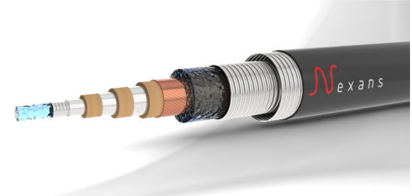


Figure: Optical fibre.

Communication systems

Transmission rate

Different *transmission links* can transmit data at different rates. The *transmission rate* specifies the *information-per-second* that can be transmitted.
This is influenced by:

- *Bandwidth* ([Hz]) refers to the range of frequencies that a medium can pass without a loss of one-half of the power (- 3 dB) contained in the signal. Each channel has a certain capacity for transmitting information, i.e. the *bandwidth*, which is quite relevant for FDM approaches.
- The more is the *noise* in the transmission line, the less is the transmission rate.

Communication systems

Analog vs. Digital transmission

Analog transmission takes place whenever a medium carries a *carrier*, i.e. a sinusoidal wave, and it is modulated.

Digital transmission uses *digital signals* representing a limited set of values that can be *coded* (in *bits*, usually using the *American Standard Code for Information Interchange* or ASCII).

Communication systems

ASCII table

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	
0	00 0000 0000 NUL	01 0000 0001 SOH	02 0000 0010 STX	03 0000 0011 ETX	04 0000 0100 EOT	05 0000 0101 ENQ	06 0000 0110 ACK	07 0000 0111 BEL	08 0000 1000 BS	09 0000 1001 HT	10 0000 1010 LF	11 0000 1011 VT	12 0000 1100 FF	13 0000 1101 CR	14 0000 1110 SO	15 0000 1111 SI	8
1	16 0001 0000 DLE	17 0001 0001 DC1	18 0001 0010 DC2	19 0001 0011 DC3	20 0001 0100 DC4	21 0001 0101 NAK	22 0001 0110 SYN	23 0001 0111 ETB	24 0001 1000 CAN	25 0001 1001 EM	26 0001 1010 SUB	27 0001 1011 ESC	28 0001 1100 FS	29 0001 1101 GS	30 0001 1110 RS	31 0001 1111 US	9
2	32 0010 0000 SP	33 0010 0001 !	34 0010 0010 "	35 0010 0011 #	36 0010 0100 $	37 0010 0101 %	38 0010 0110 &	39 0010 0111 '	40 0010 1000 (	41 0010 1001)	42 0010 1010 *	43 0010 1011 +	44 0010 1100 ,	45 0010 1101 -	46 0010 1110 .	47 0010 1111 /	A
3	48 0011 0000 0	49 0011 0001 1	50 0011 0010 2	51 0011 0011 3	52 0011 0100 4	53 0011 0101 5	54 0011 0110 6	55 0011 0111 7	56 0011 1000 8	57 0011 1001 9	58 0011 1010 :	59 0011 1011 ;	60 0011 1100 <	61 0011 1101 =	62 0011 1110 >	63 0011 1111 ?	B
4	64 0100 0000 @	65 0100 0001 A	66 0100 0010 B	67 0100 0011 C	68 0100 0100 D	69 0100 0101 E	70 0100 0110 F	71 0100 0111 G	72 0100 1000 H	73 0100 1001 I	74 0100 1010 J	75 0100 1011 K	76 0100 1100 L	77 0100 1101 M	78 0100 1110 N	79 0100 1111 O	C
5	80 0101 0000 P	81 0101 0001 Q	82 0101 0010 R	83 0101 0011 S	84 0101 0100 T	85 0101 0101 U	86 0101 0110 V	87 0101 0111 W	88 0101 1000 X	89 0101 1001 Y	90 0101 1010 Z	91 0101 1011 [	92 0101 1100 \	93 0101 1101]	94 0101 1110 ^	95 0101 1111 _	D
6	96 0110 0000 `	97 0110 0001 a	98 0110 0010 b	99 0110 0011 c	100 0110 0100 d	101 0110 0101 e	102 0110 0110 f	103 0110 0111 g	104 0110 1000 h	105 0110 1001 i	106 0110 1010 j	107 0110 1011 k	108 0110 1100 l	109 0110 1101 m	110 0110 1110 n	111 0110 1111 o	E
7	112 0111 0000 p	113 0111 0001 q	114 0111 0010 r	115 0111 0011 s	116 0111 0100 t	117 0111 0101 u	118 0111 0110 v	119 0111 0111 w	120 0111 1000 x	121 0111 1001 y	122 0111 1010 z	123 0111 1011 {	124 0111 1100 |	125 0111 1101 }	126 0111 1110 ~	127 0111 1111 DEL	F

Communication systems

Analog vs digital

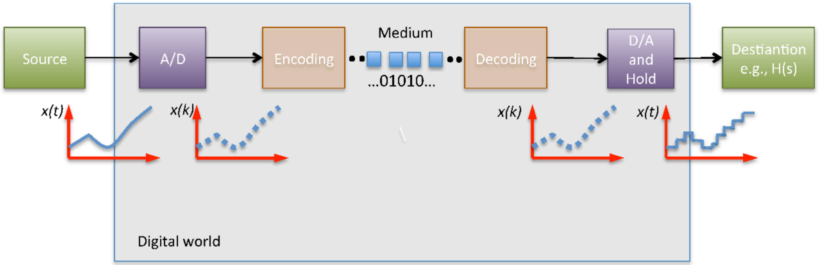


Figure: Connections between the digital and the analog world.

Communication systems

Digital encoding

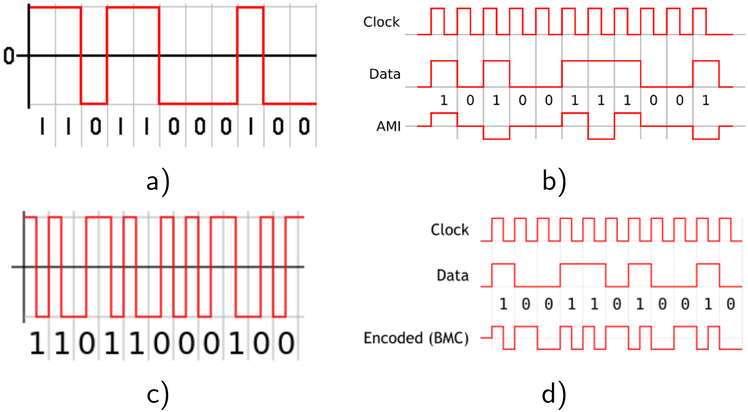


Figure: a) Polar Non-Return-to-Zero (NRZ). b) Bipolar (AMI). c) Manchester. d) Biphase Mark Code (BMC).

Communication systems

Telecommunication engineers view-point: digital communications

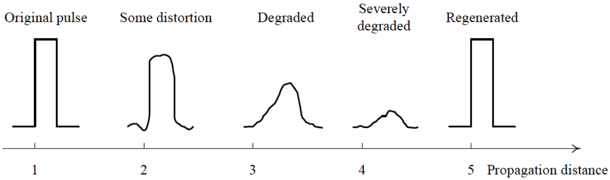


Figure: Courtesy of Ha H. Nguyen and E. Shwedyk, "A First Course in Digital Communications", Cambridge University Press

Digital communications show robustness towards noise, since only a finite set of known waveforms are transmitted.
In *analog communications* instead the shapes of the transmitted waveforms can be very widespread, virtually infinite.

Communication systems

Digital vs Analog

Digital	*Analog*
Can be regenerated	Difficult to be regenerated
Encoded	Modulated
Use digital circuits	Use analog circuitry
Large low-pass bandwidth	Band-pass bandwidth
Need synchronisation	Self synchronised
Need decoding algorithms	Message is auto-encoded
"All or nothing"	Degraded communication is possible

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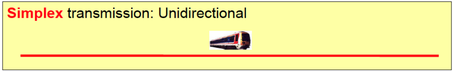
Transmission types

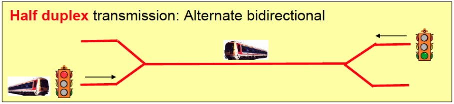
Basically, digital transmission relies on the exchange of a flow of bits. The transmission can take place using different *modalities*.
For example:

- *Direction of the information flow*: radio stations broadcasting their messages are different from a telephone call;
- *Data per message*: the information is sent in a sequence or all together?
- *Synchronism between sender and receiver*: you need to know the schedule to see your favourite match on TV but not to receive a phone call.
- *Data encoding*: is it nice to see the content of a video podcast by looking at its Fourier transform?

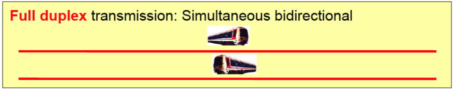
Transmission types



(a)



(b)



(c)

Figure: (a) Simplex, (b) half-duplex and (c) full duplex communication methods (Courtesy of Schneider Electric).

Transmission types

Serial vs. parallel

Serial	*Parallel*
Low throughput	High throughput
(sequential transmission)	(simultaneous transmission)
Long distance	Short distance
Robust to interference	High interference
Reduced number of wires	Multiple wires

Transmission types

The frame

Encoded data are transmitted by means of *frames*.

Definition

A *frame* is a digital data transmission unit.

Hence, the frame contains a sequence of bits with various meaning, some of them adopted for *synchronisation* between transmitter and receiver.

Transmission types

Asynchronous vs Synchronous

Synchronous	*Asynchronous*
Faster	Slower (wait to retransmit)
Clocks synchronised	Clocks synthonised
Wait for transmission slot	Transmit immediately
Costly	Cheap (no synchro)
For large regular data	For sporadic short data

Transmission types

Current industrial choice

Historically, due to cost, durability, reliability and simplicity, most of the communication network adopted in the industrial domain is the *half duplex asynchronous serial digital communication*.
However, more efficient and powerful buses are gaining market shares in these days.

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Open System Interconnection model

In digital data communications, wiring together two or more devices is *one of the first steps* in establishing a network.

As well as this hardware requirement, *software* must also be addressed.

The *Open System Interconnection* (OSI) model proposed by the *International Organisation for Standardisation* (ISO) is a standard way to structure communication software that is applicable to any network.

The ISO OSI, or simply OSI, model was developed by Pouzin and Zimmermann in the '70 to structure telecommunication *protocols*.

What is a protocol?

Protocols

Example

Imagine you want to connect to a Web-page on Internet.
First, you send a *request* for a TCP connection.
Then, the webserver may or may not reply with a TCP connection reply.
If so, you make a request on the specific page you were searching for.
Finally, the webserver replies with the requested file.

Definition

A *protocol* defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other event.

Protocols are formally or informally defined in everyday life: for example, when you are asking information to another human being.

Protocols

Definition

The *protocols* define the rules for communication. When data is exchanged through a computer network, the system rules are called a *network protocol*.

A protocol must define the *syntax*, *semantics*, and *timing* of communication (i.e. *how*, *what* and *when*); the specified behaviour is typically independent of how it is to be implemented.
Syntax: refers to the structure or the format of the data.
Semantics: the way in which the bit patterns are interpreted.
Timing: specify when the data can be sent and how fast it will be. Another term is *synchronisation*.

Protocols

A protocol can be implemented as *hardware, software, or both*.
To address heterogeneity in networks, instead of using a single universal protocol to handle all transmission tasks, a set of cooperating protocols fitting the *layering scheme* has been adopted.
Again, this *layering scheme* is probably the first approach you may think of if you have to describe the *airlines complexity*, from buying the ticket to in case complain with the airline company after arrival.

Layered Protocols

A closer look

The *layering scheme*:

- Protocols are structured into *layers*;
- Each layer deals with a *specific aspect* of communication;
- Each layer *uses the services of the layer below it*. An interface specifies the services provided by the lower layers to the upper layers;
- The upper layer sees the lower layer as a *black box*, implementing a specific *protocol*.

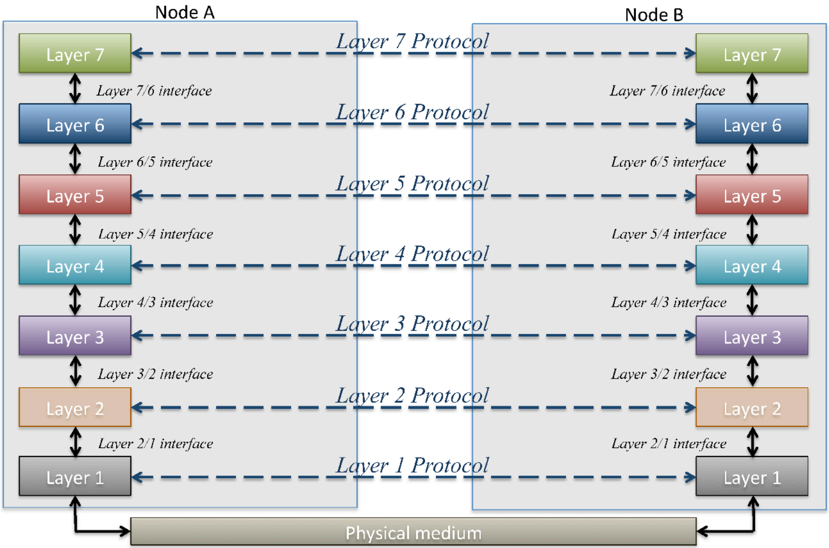
Layered Protocols

Protocol stack

- The n–th layer in the sender node *logically speaks* with the n–th layer in the receiver node;
- The protocols for each layer are organised in a *protocol stack*;
- Each protocol adds a *header* to the message to be sent.

Layered Protocols

Protocol stack



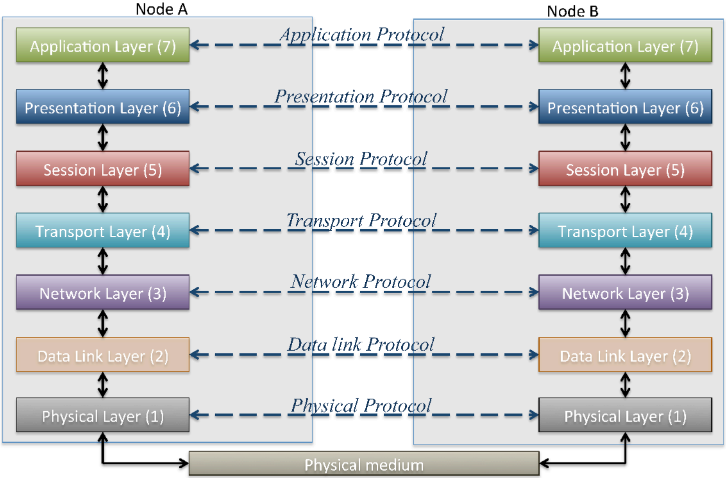
Open System Interconnection

More in depth

- Almost all communication protocols can be mapped to the OSI model;
- The OSI is a *model not* a *protocol*;
- A *protocol* is a *particular instantiation* of the OSI *model*, i.e., it specifies all the details of each layer;
- The OSI can be mapped to *industrial communication systems*, since it is specifically designed to allow *open systems* to communicate.

Open System Interconnection

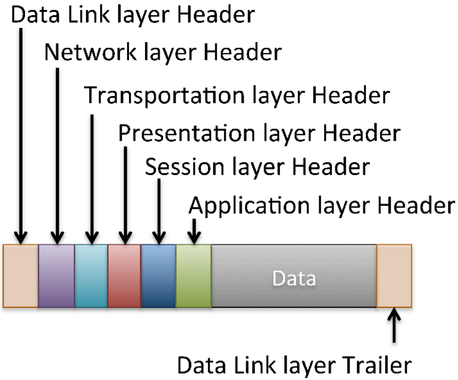
Graphical representation



The message to be sent in Node A moves downwards in the stack. The received message in Node B moves upwards.

Open System Interconnection

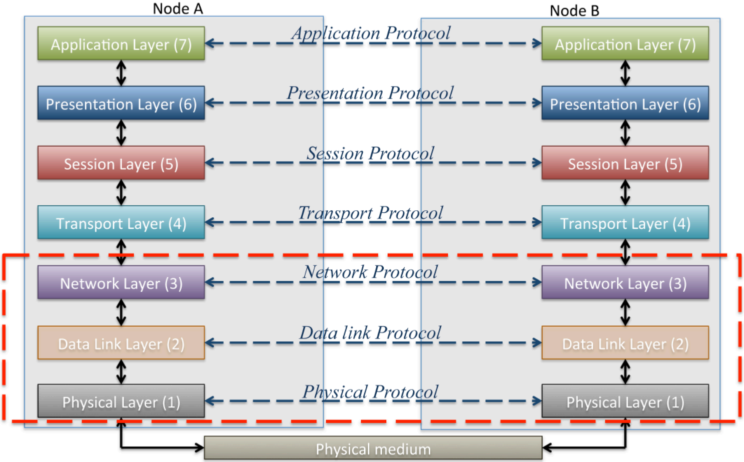
Message



- The information in the layer n-th header is used for the layer n-th protocol;
- Independence among headers.

Open System Interconnection

Low level layers



- These layers implement the basic functions of a computer network.

OSI: Low level layers

Low layer

Physical layer: electrical and mechanical definition of the system (e.g., RS485, Ethernet Physical Layer).

Data link layer: framing and error correction format of the data (e.g., network protocol *High-Level Data Link Control* (HDLC)).

Network layer: Optimum *routing* (i.e., choosing the best path minimising the delay) of messages and possibly message segmenting (e.g., *Internet Protocol* (IP)).

Remark

Frame*: physical layer representation of the message.* Packet *or* Datagram*: Network or transport layer representation of the message.*

OSI: Low level layers

Data link layer

One method implemented in the *Data-Link layer* to increase the number of system that can communicate on the same medium is to *virtually parallelise* the shared resource.

Definition

The *multiplexing* is the technique combining multiple analog or digital signals over a shared medium.

OSI: Low level layers

Data link layer

The data link layer comprises as sub-layers:

- *Logical Link Control* (LLC): provides multiplexing mechanisms for successful coexistence of several network protocols within a multipoint network. It can also provide flow control and automatic repeat request error management mechanisms;
- *Media Access Control* (MAC): provides *addressing and channel access control* mechanisms that make it possible for several terminals or network nodes to communicate within a multiple access network that incorporates a shared medium, e.g. Ethernet. The hardware that implements the MAC is referred to as a *Medium Access Controller*.

OSI: Low level layers

Logical Link Control (LLC): example

Medium access methods

Since there must be some method of determining which node can send a message, this is a critical area that determines the efficiency of the LAN. The *Media Access Method* refers to the manner a computer gain and controls access to the network's physical medium (e.g., defines how the network places data on the cable and how it takes it off).
One of the primary concern with media access is to prevent packets from *colliding*.

Definition

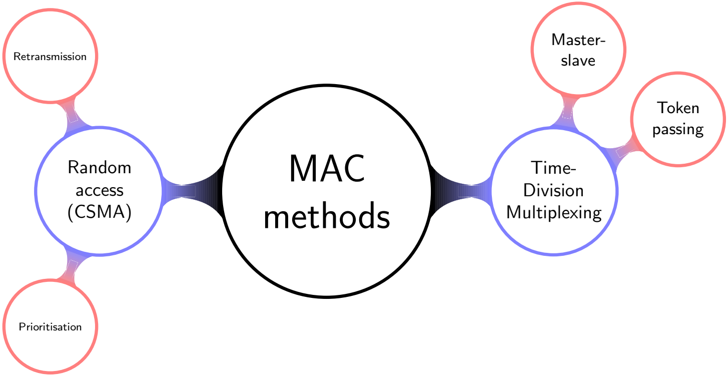
A *collision* occurs when two or more computers transmit signals at the same time.

Medium access methods
MAC

The MAC sublayer protocol within the data link layer describes the protocol for *obtaining access to the network*.
Hence, the data link layer is the primary differentiator for the industrial networks.
It is responsible for:

- Satisfying the *time-critical / real-time* response requirement over the network;
- The *quality* and *reliability* of the communication between network nodes.

Medium access methods
MAC



Because each node gets its turn within a fixed period, deterministic access methods are more efficient on networks that have *heavy traffic*.

Medium access methods

CSMA/CD

Carrier Sense Multiple Access - Collision Detect: Destructive collision.

- Collision detection;
- Stop of the emitted frame;
- Scrambling frame emission;
- Wait a random time;
- Frame re-emission.

Example: Ethernet.

Medium access methods

CSMA/CA

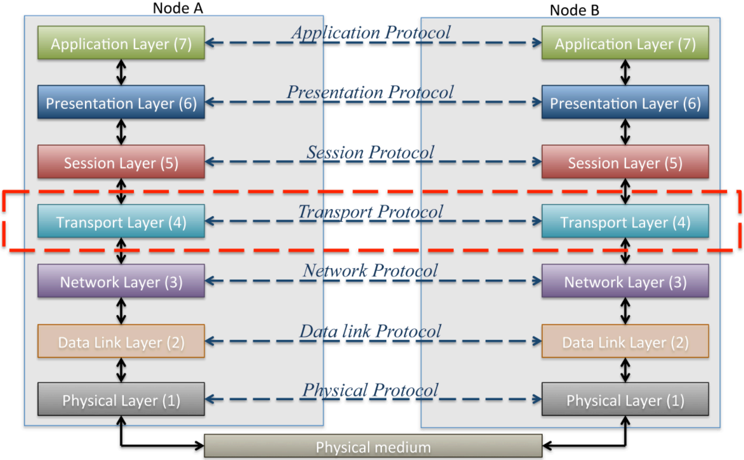
Carrier Sense Multiple Access - Collision Avoidance: Non destructive collision.

- Non destructive collision detection;
- The device with the lower priority stops its transmission;
- End of the high priority frame transmission;
- The device with lower priority can send its frame.

Example: CAN.

Open System Interconnection

Mid level layer

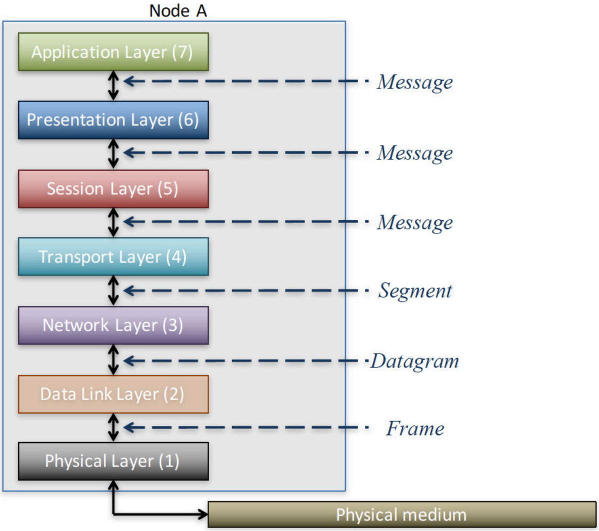


OSI: Mid level layer

Transport layer

Transport layer: end-to-end flow control and error recovery (e.g. *Transmission Control Protocol* (TCP) or *User Datagram Protocol* (UDP)). *Header content*: which packets have been sent, received, there is room for, need to be retransmitted.

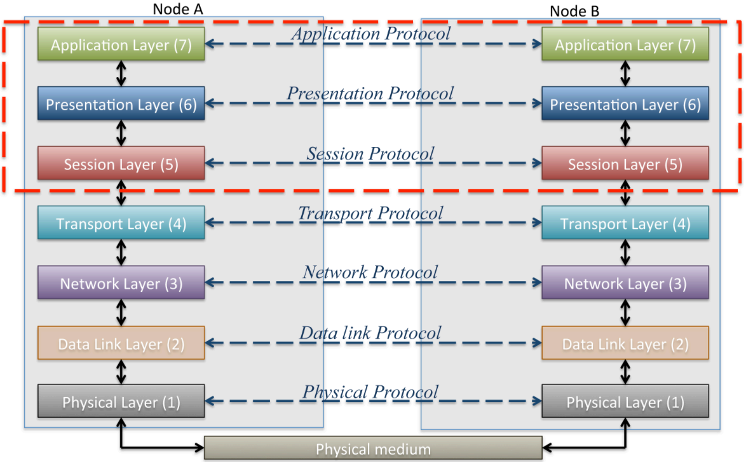
OSI: Internet Protocol Messages



The *packet* changes its name when it goes downwards the *protocol stack*.

Open System Interconnection

High level layers



In practice, only the application layer is used for industrial and robotic applications.

OSI: High level layers

Session layer

Session layer: organisation and synchronisation of the data exchange (e.g., ISO 8326).
Presentation layer: data format or representation (e.g., *Abstract Syntax Notation One* (ASN 1) used for notation, software description and encoding procedures).
Application layer: file Transfer, message exchange (e.g., *Simple Mail Transfer Protocol* (SMTP)).

Concepts used at the *application layer*

At the *Application Layer*, there are concepts defined for:

- *Standardisation of components*, to allow interchangeability. This is necessary for *open systems*.
- *Characteristics of the traffic*, in order to carry out optimal counteractions in the presence of (burst) heavy traffic:
  - *Cyclic data*: Data that is refreshed periodically according to a pre-determined time. Example: sampled data for a control loop (e.g. *time triggered*). In essence it is a *small amount* of information *refreshed frequently*;
  - *Acyclic data*: Data that is refreshed according to a request or to an event. This is used at start-up for configuration and setup, or for diagnostics in the event of a fault. Example: event based control (e.g. *event triggered*). In essence it is a *lot of information* without time constraints.

Concepts used at the *application layer*

Mechanism to access the service: Client-server

The services offered by the applications running on the network are ruled by mechanisms that establish *who is the recipient of a certain service*.
One the most used approaches is the *client-server*.
The *client* is an entity requesting a service on the network.
The *server* is the entity which responds to a request from a client.
Example: Modbus.

Concepts used at the *application layer*

Mechanism to access the service: Producer-consumer

Another approach is represented by the *producer-consumer*.
The *producer* is a single entity which produces information.
The *consumer* is an entity which uses it (several entities can use the same information).
Example: CAN bus.
Example: a sensor producing data according to events or time periods.

Concepts used at the *application layer*

Mechanism to access the service: Publisher-subscriber

Finally, it is also available the *publisher-subscriber*.
It is the same as the *producer-consumer*. The difference is that *producer-consumer* delivers the massages using a *broadcast* communication, while the *publisher-subscriber* uses a *multicast* communication.

Definition

Unicast: from one source to one destination, i.e. one to one. *Broadcast*: from one source to all possible destinations, i.e. one to all. *Multicast*: from one source to multiple destinations stating an interest in receiving the traffic, i.e. one to many or many to many.

Concepts used at the *application level*

Standardisation of components: Open systems

An *open system* comprises *interoperable* (i.e., the ability to communicate intelligibly with other devices) and *interchangeable* (i.e., the ability to replace one device with another, possibly supplied by a different manufacturer) components.

Interoperability is achieved by means of strict adherence to *protocol specifications*.

Interchangeability is achieved by means of adherence to *profile specifications*.

All manufacturers reserve the right to define whether or not they wish to offer manufacturer-specific functions in addition to those which are part of the minimum profile or core.

Concepts used at the *application layer*

Standardisation of components: Profile

The profile settings and types are expressed in the available industrial standards.
Two popular industrial standards are:

- *IEC61499*: It is mainly related to *abstraction* of network devices building up the Distributed Control System by means of *function blocks*. We will see that this concept is in spirit quite close to the *object oriented software*;
- *IEC61131*: It is mainly related to the design of *control software* in the industrial domain and has a tight relation with *Programmable Logic Devices*.

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Concepts used at the application level

Standardisation of components: IEC61499

The major advantages of *standardisation* are: *improved software productivity* through the re-use of standard solutions and *improved design flexibility* by being able to plug-and-play software and devices from different vendors.

In the past, standards have focused mainly on enabling *technical integration* of distributed components.

Recently, the major hurdle of *semantic integration* has been addressed, i.e., *making the data exchange between software in a remote industrial controller and a control algorithm running in a PC be meaningful*.

The software modules subject of this new proposal are called *function blocks*: they describe the data flow as well as its structure.

Concepts used at the application level

Standardisation of components: IEC61499

The concept underlying the FBs is the same that have pushed towards *object oriented programming* in computer science.

To deal with the complexity of the object oriented programming, new methodologies, such as the *Universal Modeling Language* (UML), have been proposed.

The standard IEC 61499 deals directly with such a complexity and provides a methodology for modeling DCSs.

Main message: The standard defines concepts and models so that software in the form of FBs can be interconnected to define the behaviour of a DCS.

It is now very difficult to define where the main intelligence of any control system really resides!

Concepts used at the application level

Standardisation of components: IEC61499

FB execution is controlled by *events*, with very fast responses, i.e. *event-driven execution*. Hence the FB *remains idle* unless an event is sent to one of its *event inputs*.

Nonetheless, the execution can also be *cyclical*. This is important for many control programs in modern devices.

Concepts used at the application level

Standardisation of components: IEC61499 - FB

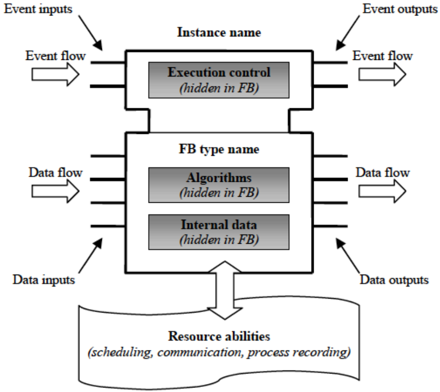

Figure: Function block model (courtesy of Tomás Bezák, "Usage of IEC 61131 and IEC 61499 Standards for Creating Distributed Control Systems").

Concepts used at the application level

Standardisation of components: IEC61499 - Example of a PID

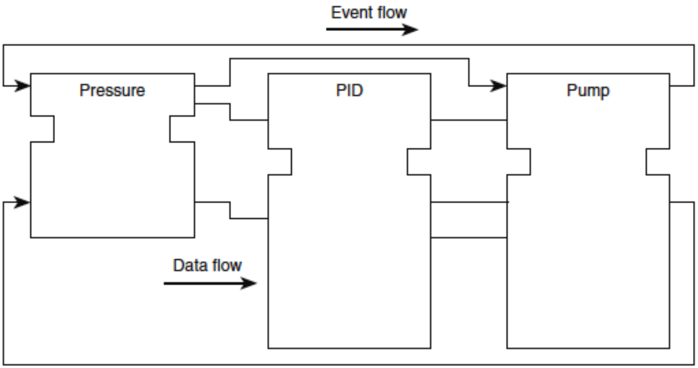

Figure: PID control of a pump (courtesy of R. W. Lewis, “Modelling Control Systems Using IEC 61499”, IEE Control Series, 2001).

Concepts used at the application level

Standardisation of components: IEC61131

While IEC 61499 was developed especially as a methodology for *distributed control system modelling*, the standard IEC 61131 is *not* conceived for large automation systems.
The IEC 61131 deals with the *software development description* *Programmable Logic Controllers* (PLCs), comprising the *function blocks* (FB).

Concepts used at the application level

Standardisation of components: IEC61131

Originally developed in the late 60's to serve the automation needs of the *automobile industry* in USA, PLCs have grown much beyond this sector and today it is *difficult to name an industry segment that does not use a PLC*.
The initial purpose was to replace *hardwired relay* based interlocking circuits by a more flexible device.

Definition

Relay logic is a method for controlling industrial electronic circuits by using relays and contacts.

Concepts used at the application level

Standardisation of components: IEC61131 - Relay logic

Definition

A relay is an electrically operated switch.

In practice, a *relay* consists of a coil of wire wrapped around a soft iron core, a movable iron armature and one or more sets of contacts.

Concepts used at the application level

Standardisation of components: IEC61131 - Relay scheme

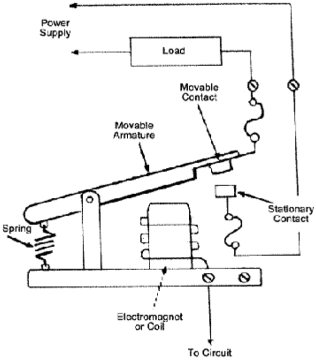

Figure: Electric scheme of a relay (courtesy of Galco Industrial Electronics).

Concepts used at the application level

Standardisation of components: IEC61131 - Relay logic

The schematic diagrams for *relay logic circuits* are often called *line diagrams*, because the inputs and outputs are essentially drawn in a *series of lines*.

A relay logic circuit is an electrical network consisting of lines, or *rungs*, in which each line must have continuity to enable the output device.

Concepts used at the application level

Standardisation of components: IEC61131 - Relay logic

A typical circuit consists of a number of rungs, with each *rung controlling an output*.

This output is controlled by a combination of input or output conditions (*IF-THEN statements*), such as *input switches and control relays*.

The conditions that represent the inputs are connected in *series* (logic *AND*), *parallel* (logic *OR*) or a combination thereof.

The relay logic circuit forms an *electrical schematic diagram* for the control of input and output devices and represents the *physical interconnection of devices*.

Concepts used at the application level

Standardisation of components: IEC61131 - Example

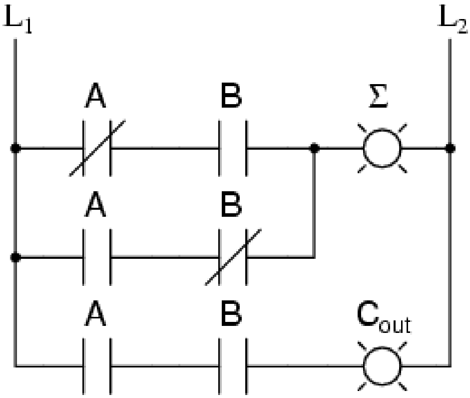

Figure: Graphical representation of the relay logic.

Concepts used at the application level

Standardisation of components: IEC61131

With respect to the relay logic, PLCs add *flexibility*.
Flexibility in PLCs comes through the programmability of the device, which made it possible to use the *same basic hardware* for any application as well as the ability to *quickly change the program* and modify the behaviour of a circuit.
In particular, *portability of code* and *interoperability* pushes the definition of the standard IEC 61131-3 and makes the PLC the standard for industrial automation.

Concepts used at the application level

Standardisation of components: IEC61131

Figure: A modern PLC.

Outline

1. Communication Systems
   - Basic pillars of communication systems
   - Open System Model
   - Industrial automation standards
   - Final comments
   - Examples
2. Industrial Networks
   - Interconnection Systems
3. Take home message

OSI Model

Final comments

- In practice, the lower three layers, *Physical*, *Data-link* and *Network* layers are the responsibility of the *network*.
- The upper four layers, *Transport*, *Session*, *Presentation* and *Application* layers are the responsibility of the *host*, i.e. the computer.

The *layering scheme* has been also adversed by many researchers, since it may happens that many functionalities are *duplicated*. Moreover, some layer may need a service (e.g. a timestamp) that *can only* be provided by another layer, thus violating the idea of separation between layers.

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OSI Model: examples

The CAN bus

The *Controller Area Network* (CAN bus) is a bus standard defined to let micro-controllers and devices to communicate with each other *without the presence of a host computer*.

The CAN bus is a *message-based protocol* originally used in the Automotive industry.

It comprises the *Physical layer* (with the definition of the *dominant and recessive states*), the *Data link layer* (with message *arbitration* and *error detection*) and the *Application layer*.

OSI Model: examples

IEEE 802.11

The *IEEE 802.11* is a set of *Media Access Control* (MAC) and *Physical layer* specifications, released in 1997, for implementing *wireless local area network*.

- The bandwidth is usually in the 900 MHz and 2.4, 3.6, 5, and 60 GHz frequency bands.
- The standard defines the basis for the Wi-Fi network products.

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Industrial Networks

LAN and topologies

The objective of the industrial network, aka *Local Area Networks* (LAN), is to share information and resources.
To share information among the network nodes, they must be connected by some transmission medium organised in a *network topology*.

Definition

The *topology* specifies the way the nodes are connected to form a network.

Basically, a physical topology defines the wiring layout for a network. This specifies how the elements in the network are connected to each other electrically.

Industrial LAN

Topologies

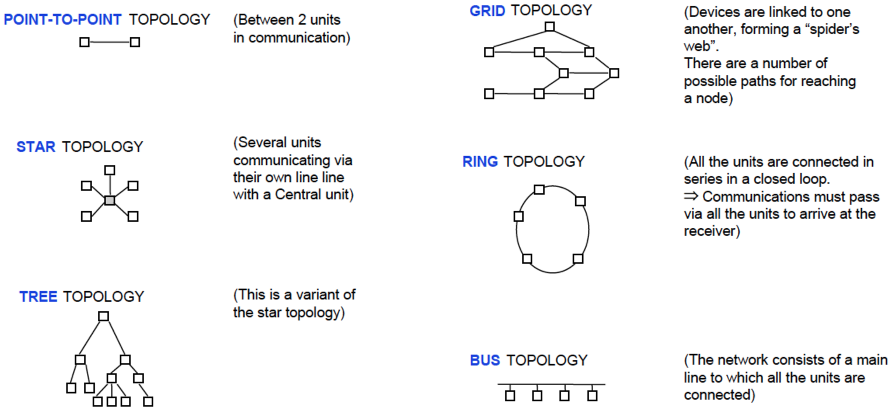

Figure: Most common topologies (Courtesy of Schneider Electric).

LAN topologies

Bus

One of the most common industrial connection is the *bus*, in which each node is connected to a common single communication channel.

In a bus, sometimes called a *backbone* as it provides the "spine" for the network, every node can hear each transmitted message packet.

Each node checks the *destination address* that is included in the message packet to determine whether that packet is intended for the specific node.

When the signal reaches the end of the bus, an electrical terminator absorbs the packet energy to keep it from reflecting back again along the bus cable, hence avoiding interference. Therefore, each end of a bus cable must be terminated.

In a long bus topology, the signal strength is boosted up by some form of amplification, or *repeater*.

LAN topologies

Bus topology

Bus topology

Pros	*Cons*
Simplest wiring	Security
Scalability	Fault isolation
Flexibility	No handshake
Data broadcasting	Low throughput (due to traffic)

LAN topologies

Star topology

A *star topology* is a physical topology in which multiple nodes are connected to a central component, generally known as a *hub*.

The hub may be a wiring centre or may actually be a file server.

All signals, instructions, and data going to and from each node *must pass through the hub* to which the node is connected, e.g., telephone lines.

There are *not so many* industrial LAN implementations that use a logical star topology.

LAN topologies

Star topology

Star topology

Pros	*Cons*
Fault isolation	Centralisation
Scalability	Cabling
Flexibility	
Monitoring	

LAN topologies

Ring topology

A *ring topology* is distinguished by the fact that message packets are transmitted sequentially from node to node, e.g., point-to-point system, in a predefined order. Hence, each node is connected to exactly two other nodes.

Nodes are arranged in a *closed loop*, so that the initiating node is the last one to receive a packet. Hence, *simplex communication*.

Equivalence of physical and logical description.

In a ring topology, *each node can act as a repeater*, boosting the signal before sending it on.

The node packets have an address, so *each node checks* whether the message packet's destination node matches its address. When the packet reaches its destination, the destination node accepts the message, then sends it back to the sender, to *acknowledge receipt*.

Ring topologies use *token passing* to control access to the network.

LAN topologies

Ring topology

Ring topology

Pros	*Cons*
Cabling	Fault tolerance
No centralisation	Fault isolation
Automatic acknowledgment	No scalability
Regeneration	No Flexibility

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Interconnection systems

In each and every network presented, the nodes are interconnected to form different topologies.
We will now consider the *interconnecting components* among the different branches of the network.

Interconnection systems

Repeater

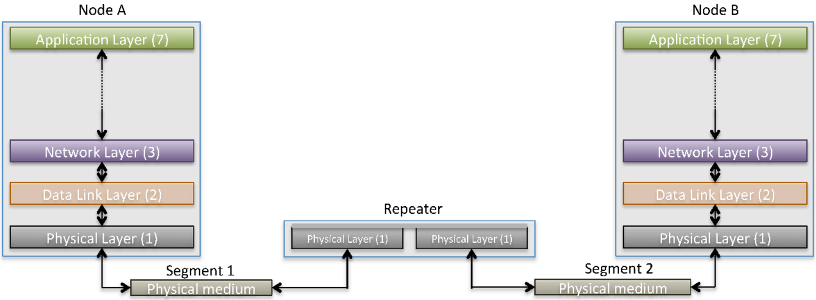

Figure: Repeater.

The *repeater* is used to add *segments* to a network. The repeater amplifies and restores the signal.

All traffic that appears on one side of the repeater appears on both sides.

Repeaters handle *only* the electrical and physical characteristics of the signal.

Interconnection systems

Hub

A basic *hub*, also known as *multi-port repeater* or *concentrators*, is merely a collection of repeaters, so no intelligence and microprocessors on board. Some hubs are instead intelligent, hence can perform basic diagnostics and test the nodes to see if they are operating correctly.
The hub amplifies and restores the same type of signal on *all* ports, therefore *does not* reduces the number of collisions.
They are usually used to extend star topologies.

Interconnection systems

Switch

A *switch*, also known as *switched hub*, amplifies and restores the same type of signal on a *single* port.

They are usually used to reduce the number of collisions in the network.

They are usually used to extend star topologies.

Interconnection systems

Bridge

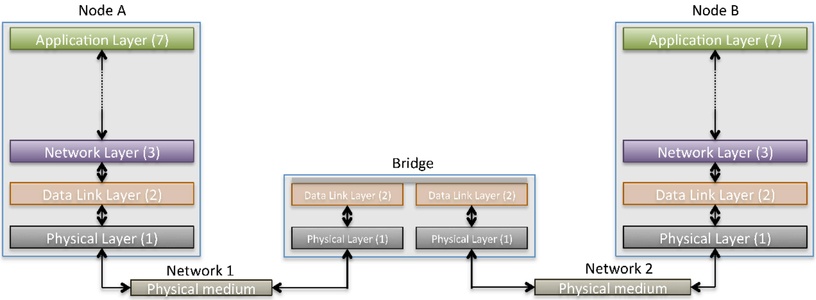

Figure: Bridge.

The *bridge* is used to connect two networks using the same protocol but different lower layers.
Example: Modbus RS485/Ethernet TCP-IP bridge.

Interconnection systems

Router

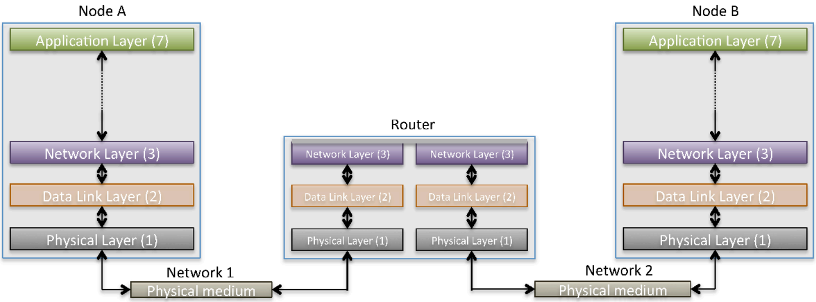

Figure: Router.

The *router* is used to connect two networks of the same type.
Example: Ethernet TCP-IP router.

Interconnection systems

Gateway

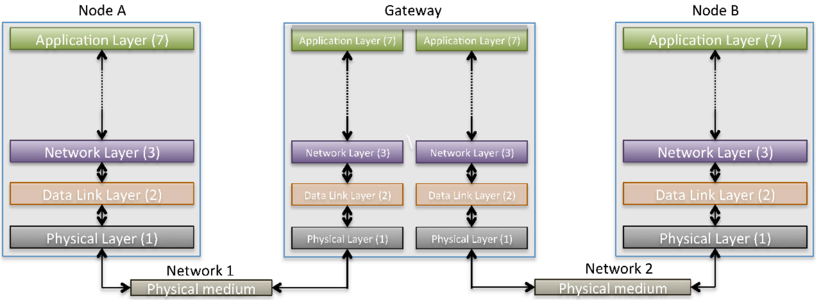

Figure: Gateway.

The *gateway* is used to connect two networks of different types.

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Communication systems

Digital communication takes place in different *modalities*.

Communication is possible when the different actors speak the same language, i.e. *the protocol*.

The *Open System Interconnection* (OSI) model defines a standard for digital communication.

The *MAC* sublayer is the one that probably affects the most a communication network in terms of reliability and latency.

Interoperability and *interchangeability* are ensured by the adherence to *standards*.

Modern *LAN* comes with different topologies. At the industrial level, the *bus* is the most adopted.

A network is expanded by means of *Interconnection systems*.