Industrial Ethernet Takes Off - Switching and 100 Mbps in Industrial Communication

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SIMATIC NET

White Paper

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1. Introduction

In 1980 a consortium of companies (Xerox, Intel and Digital Equipment) released Ethernet version 1.0. After various improvements version 2.0 was adopted almost unchanged in 1983 as the IEEE 802.3 standard.

Initially, however, local networks were not very popular. They were used mainly in universities and in large companies.
XT personal computers from IBM had been on the market since 1981. Available applications were, however, not suitable for operation on local area networks. There was also a lack of suitable network operating systems.

Rapid progress in the hardware sector in turn led to the continuous development of increasingly powerful software applications. The number of users rose dramatically. Growing interest in common utilization of existing resources, uniform data management and software maintenance finally brought about the breakthrough for local networks.

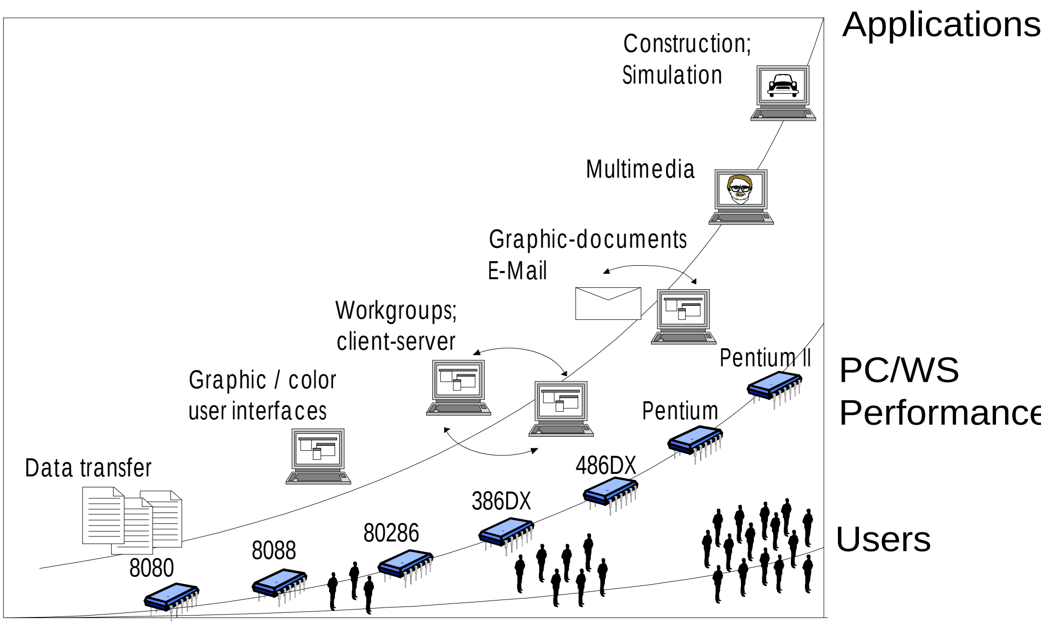


Figure 1: Driving Factors in the Development of Local Area Networks

New concepts in automation accompanied by growing rationalization demanded network solutions in industry that would meet special requirements in terms of reliability and ruggedness.

As early as 1985, Ethernet technology took its place in industrial communication with the Siemens SINEC H1 bus based on a special screened bus cable and rugged network components designed for an industrial environment. In the years following (since 1996 under the name **Industrial Ethernet**) SIMATIC NET has brought numerous innovative Ethernet solutions for industrial communication onto the market.

Today, Industrial Ethernet is the de-facto standard for Ethernet networks in industry, for example in the automotive or process industry and in the industrial plant sector where ruggedness, availability and reliability are particularly important requirements for communication.

If the eighties were the decade of the personal computer, the nineties are the era of local area networks.
With an increasing number of network users and ever-growing bandwidth requirements of software applications, the conventional 10 Mbps Ethernet was no longer adequate.
Various 100 Mbps solutions were discussed and specifications formulated (for example Fast Ethernet, FDDI, 100BaseVG).

The Fast Ethernet story started in June 1993 when more than 50 manufacturers formed the Fast Ethernet Alliance, with the objective of producing a specification for 100 Mbps Ethernet. This group included manufacturers of all important network components such as adapter cards, repeaters/hubs, switches, routers and management tools. The objective was to define a standard as quickly as possible and at the same time ensure the interoperability of products from different vendors. This undertaking profited from the fact that Fast Ethernet was understood as a logical further development of the stable and proven Ethernet technology. In June 1995, the Fast Ethernet Standard IEEE 802.3u (100BaseT) was at last finalized.

Fast Ethernet provides the opportunity of step-by-step migration to 100 Mbps technology. The user does not need to change over an entire network all at once. This is one major reason why Fast Ethernet is the most frequently used 100 Mbps network today and will remain so in the future.

2. Technical Basis of Fast Ethernet

2.1. Ethernet and Fast Ethernet Compared

One important reason for the wide acceptance of Fast Ethernet is its great similarity to the familiar, original Ethernet.
The Fast Ethernet standard is based essentially on the classic Ethernet standard for twisted pair cable (10BaseT) with a transmission rate increased by a factor of 10 to 100 Mbps.
The advantage for the user is obvious; existing technological know-how can continue to be used. Personnel do not need to start all over again learning about completely new technology. The new fast technology can be put into operation immediately and efficiently.

Factors Common to both Ethernet and Fast Ethernet Networks:

- The data format
  Shortest packet: 64 bytes
  Longest packet: 1518 bytes
  Address field length: 48 bytes
- Medium access: CSMA/CD
- The same cables (with the exception of coaxial cables)
- Use of repeaters to implement the network

The difference between the two networks is the increased speed of Fast Ethernet:

- **The network span of Fast Ethernet networks is significantly smaller than 10 Mbps Ethernet networks:**
  To ensure that the CSMA/CD collision access procedure works correctly, the propagation time of a data packet from one node to another is restricted.
  This propagation time, depending on the data rate, results in a restriction in the span of the network, the so-called collision domain. With 10 Mbps Ethernet this is 4520 m, and for Fast Ethernet 412 m.

  The largest span of a Fast Ethernet network when using twisted pair cables is 205 meters. With exclusive use of fiber optic cabling, the maximum span of a network is 320 meters. As a comparison, simple 10BaseT networks can achieve spans up to 500 meters.

- **There is no Fast Ethernet specification for coaxial cable:**
  Fast Ethernet is specified as follows:
  ➢ 100BaseT4 4 twisted pairs of the twisted pair cable categories 3, 4, 5
  ➢ 100BaseTX 2 twisted pairs of the twisted pair cable category 5
  ➢ 100BaseFX Fiber optic cable 62.5/125 µm (2 fibers)

  Ethernet, on the other hand, is specified both for twisted pair cables (10BaseT) and fiber-optic cables (10BaseFL) as well as for different coaxial cable types (10Base5, 10Base2).

- **The design rules for Fast Ethernet networks differ essentially from the Ethernet configuration rules:**
  Fast Ethernet networks may contain a maximum of 2 repeaters. Two classes of repeaters are specified:

Class 1 repeater: In addition to 100BaseFX this repeater category supports both 100BaseT4 and 100BaseTX (two different types of twisted pair cable can be used).
In one network (collision domain) only one class 1 repeater may be used.

Class 2 repeater: This repeater category only supports 100BaseTX in addition to 100BaseFX (only one type of twisted pair cable can be used).
In one network (collision domain) 2 repeaters of class 2 may be used.
The interconnecting cable between the two repeaters can be up to 5 meters.

In classical Ethernet more or less any number of repeaters may be used, as long as no more than 4 repeaters are located between two nodes (nodes are in this sense any connected components such as DTEs, bridges/switches, routers, but not another repeater).

- **Signaling Methods**
  Whereas 10BaseT uses the same signaling for all three cable categories 3,4 and 5, Fast Ethernet uses different signaling for 100BaseT4 and 100BaseTX and these methods differ in turn from 10BaseT signaling. This means 10BaseT, 100BaseT4 and 100BaseTX are incompatible with each other.
  When selecting Fast Ethernet components with twisted pair technology, it is important to ensure that network components and DTE interfacing meet the same specification.
  The signaling methods of Ethernet and Fast Ethernet also differ when using fiber-optic cables.

  These differences mean that only Fast Ethernet components with an autosensing function can communicate with classic Ethernet components.

SIMATIC NET components conform to the following specifications:
- 100BaseTX for Industrial Twisted Pair links
- 100BaseFX for fiber-optic links

	Ethernet	**Fast Ethernet**
IEEE Standard	802.3	802.3u
Data rate	10 Mbps	100 Mbps
Time duration of a bit	100 ns	10 ns
Access procedure	CSMA / CD	CSMA / CD
Largest data packet	1518 bytes	1518 bytes
Smallest data packet	64 bytes	64 bytes
Address field length	48 bytes	48 bytes
Topology	Bus, star, tree	Star, tree
Supported media	coax, twisted pair, fiber-optic	twisted pair, fiber optic
Max. network span (collision domain)[1)]	4520 m	412 m
Max. TP cable length	100 m	100 m
Max. FO cable length HDX	2000 m	412 m (direct point-to-point)
Max. FO cable length FDX	2000 m	2000 m

1) The maximum network span depends on the signal propagation time. It is reduced depending on the number and type of active network components used.

Table 1: Ethernet / Fast Ethernet Compared

2.2. Cabling and Network Attachments

The 100BaseTX specification describes transmission of 100 Mbps on 2 twisted pairs of category 5 twisted pair cables.
Category 5 cables are suitable for data transmission up to 100 MHz. The attachment components used (male and female connectors, patch panels, patch cords) must also correspond to category 5.
The RJ-45 connector familiar from 10BaseT as well as the sub D 9-pin connector for STP cables are specified.
A cabling system meets the requirements of a link class if a complete link from the active component to the DTE (patch cord, patch panel, installation cable, telecommunications outlet, connecting cable) is within the specified limits. If components of different manufacturers are used, this is not always the case.
Link class D describes the link specified for data transmission of up to 100 MHz.

The SIMATIC NET industrial twisted pair cable and attachment components far exceed the requirements of category 5.
The SIMATIC NET Industrial Twisted Pair cable, successfully in use since 1995, already conforms to tomorrow's data rates!

The 100BaseT4 specification describes transmission of 100 Mbps on 4-pairs of category 3, 4 and 5 twisted pair cables.
The 3 signal pairs are used for data transmission. The 4th pair is used to signal collisions.
Category 3 cables were specified for transmission up to 16 MHz in 10BaseT networks. Compared with cables of category 5, category 3 cables are somewhat less expensive but have not been successful in Europe due to their restrictions. Category 4 cables are familiar from token ring networks and are specified for transmission of data up to 20 MHz.

By far the largest proportion of twisted pair Fast Ethernet networks are designed in compliance with 100BaseTX. One reason for this is that full duplex mode is not possible in 100BaseT4 networks.

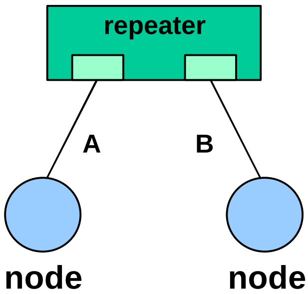
The 100BaseFX specification defines 100 Mbps transmission on two 62.5/125 µm fiber optic cables. The MIC, ST, and SC connector types familiar from 10BaseFL or FDDI are used.

Fiber-optic technology is suitable to cover large distances. In half duplex mode, the maximum fiber optic cable length is 412 meters (point–to-point coupling of two network nodes). Of particular interest for connection of switches or routers is the distance of up to 2000 meters with full duplex.

2.3. Rules for Network Design

The design regulations for Fast Ethernet networks can be summarized in the following four rules for network configuration:

1. **Twisted pair connections**
   Twisted pair connections may be a maximum of 100 meters long
   (e.g. DTE/repeater or repeater/switch).
2. **Use of repeaters**:
   Between two nodes only one class 1 repeater may be used.
   Between two nodes a maximum of two class 2 repeaters may be used. The connecting cable between repeaters may not exceed 5 meters.
3. **Full duplex links**
   Full duplex connections (e.g. switch/switch link) may be a maximum of 2000 meters long.
4. **Fiber optic links**
   The maximum possible length depends on the repeaters used and their topology.

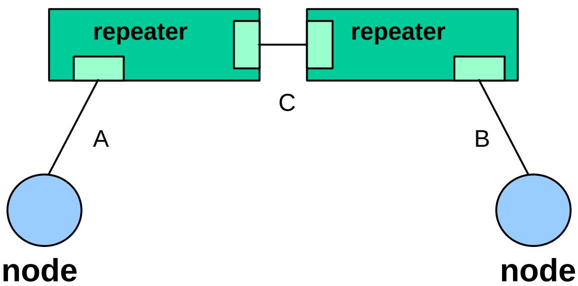


Nodes in this sense means any connected components such as DTEs, bridge/switch or router, but not repeaters.

Figure 2: Configuration with One Repeater

Medium link A	Medium link B	Repeater	Max. length A	Max. length B
Cat. 5	Cat. 5	Class 1 / 2	100	100
Cat. 5	Fiber optic	Class 1	100	160.8
Fiber optic	Fiber optic	Class 1	136	136
Cat. 5	Fiber optic	Class 2	100	208.8
Fiber optic	Fiber optic	Class 2	160	160

Table 2: Max. Cable Length for Configurations with One Repeater (class 1 or class 2)



Nodes in this sense means any connected components such as DTEs, bridge/switch or router, but not repeaters.

Link C is a twisted pair cable with maximum length of 5 meters.

Figure 3: Configuration with Two Repeaters (class 2)

Medium link A	Medium link B	Repeater	Max. length A	Max. length B
Cat. 5	Cat. 5	Class 1 / 2	100	100
Cat. 5	Fiber optic	Class 2	100	116.2
Fiber optic	Fiber optic	Class 2	114	114

Table 3: Max. Cable Length for Configurations with two Class 2 Repeaters

2.4. Full Duplex / Half Duplex

Full duplex (FDX) and half duplex (HDX) are network modes. In half duplex, nodes send and receive data alternatively, whereas in full duplex, nodes can send and receive at the same time. When using FDX, collision detection of the participants involved is automatically deactivated.

The two terms full duplex and half duplex originate from serial data communication. They describe how data are exchanged on a point-to-point link.
During the course of time these terms have also been incorporated in data communications.

Full duplex is not a network topology, but is also a method of exchanging data between two nodes on a point-to-point link in Ethernet and Fast Ethernet.
Full duplex need not be used uniformly over the entire network. It is indeed possible and often useful to operate only some links between particular nodes in full duplex mode, for example to implement a full duplex link between a server and a repeater/switch or a full duplex link between switches.

A requirement for FDX is the use of transmission media with separate reception and transmission channels, since in each case different paths are used for transmission and reception of data.
On the one hand, the nodes involved must support full duplex mode.
On the other hand, the medium must be capable of separating transmission and reception channels. This is the case with fiber-optic cables and ITP.
With fiber optic cables this is implemented using two different fibers for transmission and reception.
With twisted pair cables this is achieved in a similar manner using different wire pairs for transmission and reception.

In the half duplex mode, the transmitter and receiver use the same physical medium (wire pair). At any one time only one partner can transmit while the other receives. The communication partners use the medium alternately to transmit.
The classical coaxial cable is a typical example of a half duplex medium. Twisted pair and fiber-optic cables, however, are also used predominantly in half duplex mode.

Whereas with classical Ethernet different proprietary full duplex (FDX) solutions exist, the Fast Ethernet standard explicitly specifies full duplex links.
Full duplex is not, however, possible with 100BaseT4, since here all four pairs are used for one-way data transmission.

For coaxial cables, there is no full duplex specification in either Ethernet or Fast Ethernet.

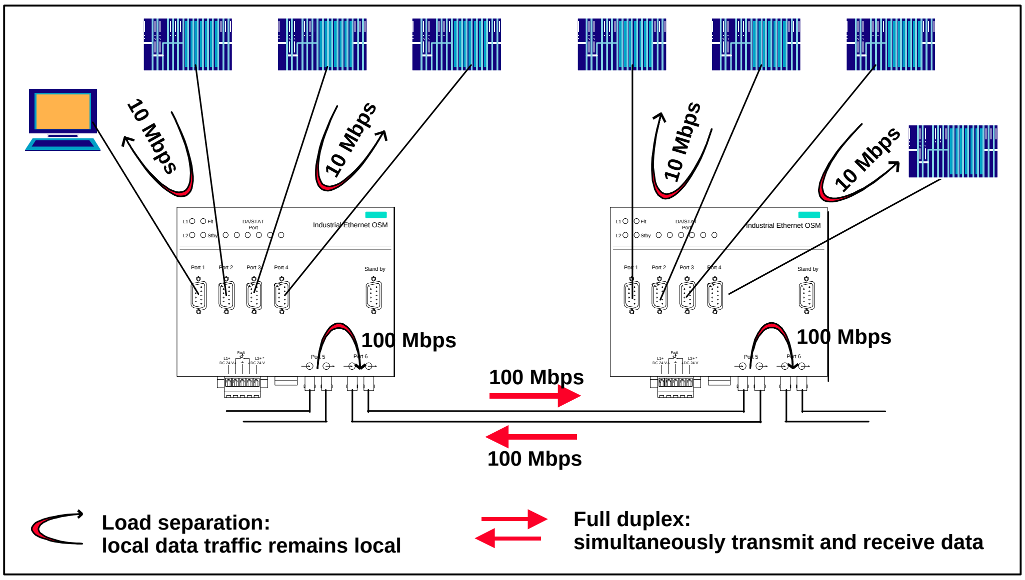


Figure 4: Full Duplex and Parallel Communication

Full duplex mode has two decisive advantages:

- Since with FDX no collisions occur, the data throughput increases to double the nominal data rate of the network, 20 Mbps with classical Ethernet and 200 Mbps with Fast Ethernet.
- FDX allows an increase in the network span up to the power and sensitivity limits of the transmission and reception components used. This is particularly important in conjunction with fiber optic cables.
  In the 100BaseFX standard the maximum length for 62.5/125 µm fiber optic cables is specified as 2000 m.

  Since in an industrial environment, in particular in large plants, this distance is somewhat restrictive, special high-performance transmission and reception elements were selected for SIMATIC NET OSM/ORM, allowing distances of up to 3000 meters between components.

2.5. Switching

Switches forward data packets directly from the input port to the output port based on the address information in the data packet. Switches allow, as it were, a direct interconnection.

The switch is a further development of the bridge, but in contrast to bridges, switches can process several data packets simultaneously.

A switch has essentially the following functions:

- Connection of collision domains / subnets
  Since repeaters/hubs function at the physical layer, their use is restricted to a collision domain (see maximum network span, Table 1).

Switches interconnect collision domains. Their use therefore is not restricted to the maximum span of a repeater network. Switches actually permit very large networks to be implemented up with spans of up to 150 km and more.
The maximum span is only restricted by the propagation delay of data packets.

- Load management:
  By filtering the data traffic based on the Ethernet (MAC) addresses, local data traffic remains local. In contrast to repeaters, which distribute data unfiltered to all ports / network nodes, switches operate selectively. Only data intended for nodes in other subnetworks are switched from the input port to the appropriate output port.
  To make this possible, a table of Ethernet (MAC) addresses is created by the switch for each port in a “self-learning” mode.
  In the Ethernet environment, the term "frame switching" is often used to denote the switching of complete data packets of different lengths.
  In contrast to this, there is a method known as cell switching, in which cells of fixed length are transported (for example ATM).

- Limiting the effects of errors to the subnet involved:
  By checking the validity of a data packet on the basis of the checksum which each data packet contains, the switch ensures that bad data packets are not transported further. Collisions in one network segment are not passed on to other segments.
- A larger number of connectable terminals in comparison with a classical Ethernet.
- Parallel communication:
  Switches have the capability of handling multiple data packets between different network segments or nodes simultaneously. Depending on the number of ports the switch has, it establishes several temporary and dynamic links between different pairs of network segments/terminals.
  The result is an enormous increase in the network's data throughput, and a considerable increase in network efficiency.

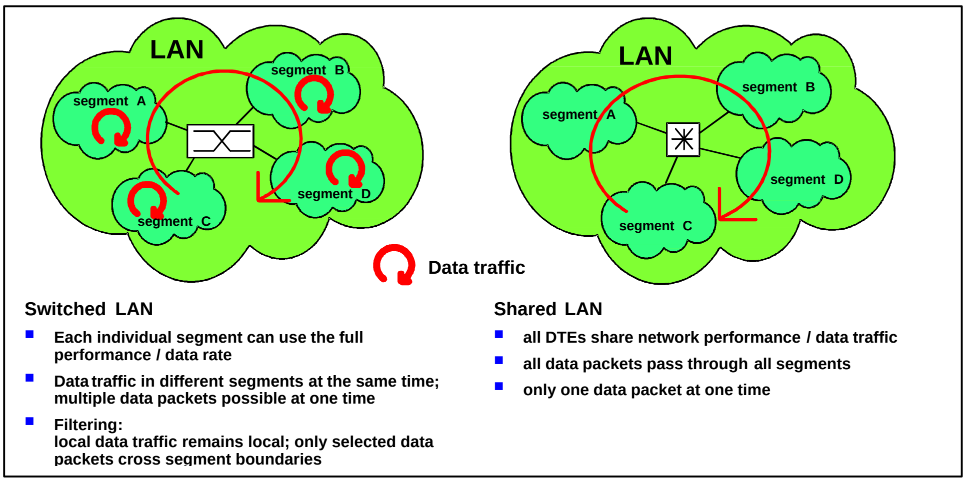


Figure 5: Switched LAN / Shared LAN Compared

2.6. Autonegotiation

Autonegotiation is the configuration protocol in Fast Ethernet. It allows the nodes involved to negotiate and agree on a compatible mode for data transmission to one another before transmission of the first data packets. As soon as two nodes are connected, the highest priority mode for data transmission is selected. This selection is made according to the following priority list:

1. 100BaseTX or 100BaseFX full duplex
2. 100BaseT4 (half duplex)
3. 100BaseTX half duplex
4. 10BaseT full duplex
5. 10BaseT half duplex

To achieve a specific configuration, it is also possible to deactivate autonegotiation.

The great advantage of autonegotiation is the trouble-free interoperability of all Ethernet components. Classical Ethernet components which do not support autonegotiation can operate without problems in conjunction with new Fast Ethernet components, which do support autonegotiation.

2.7. Autosensing

Autosensing describes the property of network nodes (terminals and network components) to automatically detect the data rate of a signal (10 Mbps or 100 Mbps) and support autonegotiation.
So-called dual speed NICs (Network Interface Cards) are capable of processing both data rates 10 Mbps and 100 Mbps.
The autosensing functionality is contained in all new SIMATIC NET CPs.
The first CP of this new series, the CP 1613 PC adapter, will be available at the end of 1998. In early 1999 the S7-400 adapters CP443-1 and CP443-1 IT will follow, in summer of 1999 the CP343-1 and CP343-1 IT adapters for S7-300.

2.8. Spanning Tree Algorithm

The IEEE 802.1d standard describes the spanning tree algorithm which is used in the organization of Ethernet structures with any mesh of bridges/switches. To prevent data packets circulating in the network, various links of closed meshes are switched to standby, so that an open tree structure is derived from the meshed structure. To achieve this, the bridges/switches communicate with one another using the spanning tree protocol.
Since this protocol must cover all possible structures, it is very complex. Depending on the topology and the number of switches, the organization of network structures with the spanning tree protocol requires time (seldom less than 30 seconds). During this time productive communication for reliable visualization or process control in a network is not possible.

These delay times may be acceptable in an office environment, but with the cumbersome and time-consuming spanning tree protocol, the demands of industrial communication for a fast reaction time from the network infrastructure in the event of a fault cannot be met. To achieve the required very fast reaction times, SIMATIC NET uses specially developed procedures for controlling redundancy guaranteeing the re-establishment of a functional network infrastructure within less than 0.5 seconds.

3. Industrial Ethernet - Industrial Communication You Can Rely On!

The requirements for communications in an industrial environment differ significantly from those for a conventional office environment. This applies to almost all aspects of communications such as active and passive network components, connected DTEs, network designs and topologies, availability, data throughput, and environmental conditions – to mention only a few. Network protocols specially optimized for industrial communications are also available, although recent developments have seen TCP/IP - a classical protocol from the office sector – take hold in the production and process control field.
The basic idea of Industrial Ethernet is to make use of existing standards and to extend them specifically for industrial communication purposes. This results in products developed for the special conditions of production or process environments: Industrial Ethernet - Designed for Industry.

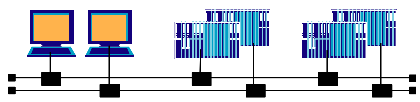
3.1. Milestones in Industrial Communications

More than 10 years ago SIMATIC NET, then known as SINEC, introduced Ethernet Technology for industrial communication and laid the foundation stone of Industrial Ethernet. More than 250,000 Industrial Ethernet nodes are currently in use worldwide making Industrial Ethernet the de-facto standard in industry.

A short overview of Industrial Ethernet History:

1985 SINEC H1 bus cable: Standard yellow cable
featuring solid aluminum shield;
plant-wide grounding concept

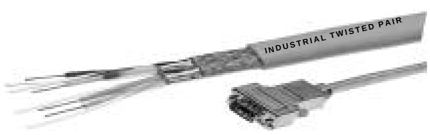
1989 Redundancy for the bus structure:
Increased availability of the network by virtue of
double-bus structures;
Control of access via special software
in the automation system



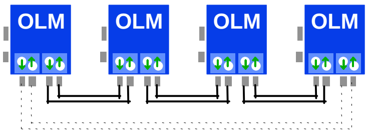
1992 Fiber optic networks for highly reliable data transfer
in EMC-polluted areas:
modular star coupler and
robust fiber optic cables for industrial use

1994 Redundancy with optical rings:
High availability using optical rings with
star couplers;
Ring structure reduces costs for
media redundancy in the network

1995 Industrial twisted pair:
Twisted pair cables with double extra thick
shield: connectors in sub D design



1996 Optimization of the optical components:
OLM - Optical Link Module, a standard rail star coupler/hub brings with it cost advantages at with comparable redundancy functionality



Uniform signaling principle:
For OLM and star couplers digital signaling contacts are provided, through which network statuses can be incorporated into an existing HMI system (e.g. WinCC). Expensive network management is no longer necessary.

1998 Industrial Ethernet takes off - Switching and 100 Mbps in industrial communication:
Proven Industrial Ethernet designs are now also available for Fast Ethernet.
Network interface cards offer both options:
10 Mbps and 100 Mbps (autosensing).
With the OSM - Optical Switch Module and ORM - Optical Redundancy Manager network components, optical 100 Mbps rings can be structured with fast media redundancy.
Information technology is introduced into industrial communications (CP 443-1 IT for the SIMATIC S7-400).

SIMATIC NET will continue to adopt new communication technology or develop innovations for automation carrying on this success story!

3.2. What is so Special about Industrial Ethernet ?

3.2.1. Standards

Industrial Ethernet means compliance with recognized standards along with numerous useful extra features! Industrial Ethernet is based on the relevant international standards (for example IEEE 802.3, ISO/IEC 11801, EN 50173). Trouble-free interaction between Industrial Ethernet and conventional Ethernet components is always guaranteed. Only where standards do not take into consideration the harsh requirements demanded by production or process environments, does Industrial Ethernet differ from the standard (for example, attachment technology for industrial twisted pair; requirements for redundant networks).
In addition to the details required by the standards, Industrial Ethernet offers a wide range of useful functions and features for industrial use. This allows solutions that cannot be implemented with conventional Ethernet components.

3.2.2. Designed for Industry

This motto encompasses all the useful extra functions and features of Industrial Ethernet.

3.2.2.1. Environmental Conditions

The environmental conditions in an industrial environment differ greatly from those of the office.

This is also taken into account in the EMC standard, where a distinction is made between industrial and domestic/residential environments.
Differences in the following areas are particularly important:

- EMC immunity and emission
- Temperature
- Vibration
- Humidity
- Contaminated environment (oil, grease, cooling and cleaning agents)

Industrial Ethernet - Designed for Industry – ensures a high degree of immunity against electromagnetic disturbances and therefore reliable data transfer, even in the hostile environmental conditions found in industry.

3.2.2.2. Housing

Only rugged all-metal housings are used with Industrial Ethernet. As a rule this means compact module housings for standard rail mounting, with minimum space requirements for cubicle installation.
The vibration-proof characteristics of the components are a major design priority.

3.2.2.3. Temperature Range

Conventional network components are generally specified for a temperature range from 0^0C to 40^0C . For use in manufacturing buildings, therefore, cooling is often necessary in cubicles, since the ambient temperature here often exceeds 50^0C.
Industrial Ethernet components are designed for operation in a temperature range between 0^0C and 60^0C.

3.2.2.4. Sub D Connectors

The sub D connector had already been used successfully for many years in industry, also with the leading fieldbus PROFIBUS, when this connector was selected for Industrial Ethernet.

For data communication in industry, the sub D connector has significant advantages compared with the usual RJ-45 design used in the office sector:

	Sub D Connector	RJ-45 Connector
Contacts	Enclosing pin, socket	Touching contact, jack strip
Long-term contact quality	++	o
Connector housing material	All metal	Plastic (with metal shield)
Shielding	++	o/+
Suitability for vibration	++	-
Suitability for contaminated environment	+	-
Attachment density	o	++
Achievable distance	100 m [1)]	10 m [1)]

1) The achievable length depends on the dimensions and attenuation of the cables that can be directly inserted into the connector (see 'Industrial Twisted Pair' section).

3.2.2.5. Twisted Pair / Industrial Twisted Pair

Twisted pair cabling in accordance with ISO/IEC 11801 and EN 50173 is described first. This standard for structured cabling defines how a link is implemented from the active network component (star coupler/hub) to the DTE (for example PC). The permitted lengths for twisted pair cables are also specified.

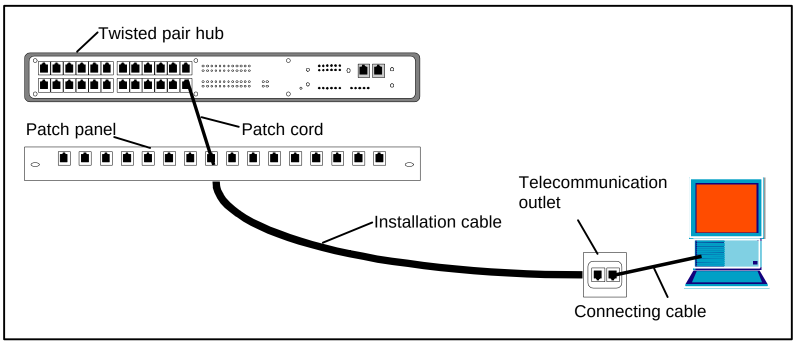


Figure 6: Node Attachment with Structured Cabling

The length prescribed in the standard for patch cord, installation cable and connecting cable depends on the physical characteristics of this cabling.

The RJ-45 connector has very narrow contacts, so that only conductors with a very small copper cross-section can be inserted into the plug (patch cord, connecting cable). These thin conductors have high signal attenuation and frequently have only simple shielding.

The installation cable has a far better shield. The larger cross-section of the copper conductors results in significantly lower signal attenuation, but prevents direct assembly with the RJ-45 connector. For this reason, the patch technique using patch panels and telecommunication outlets was introduced.

The standard prescribes a maximum length of 100 meters for the link between star coupler/hub and DTE. The patch cord and connecting cable may have a total length of 10 meters. The installation cable, with its far better shielding characteristics compared with other cables, can be up to 90 meters long.

The advantages of RJ-45 design are the high attachment density in active components and the simple patching of network connections in an office environment when people and their PCs are moved to different location (as is often the case).

These advantages are, however, lost in a manufacturing and process environment. Typically, there is a low attachment density with nodes often widely distributed. Permanent and reliable connections are the order of the day here.

Industrial Twisted Pair is based essentially on two important components:

- Installation cable (S/STP screened/shielded twisted pair) with specially designed shield
- Sub D connectors

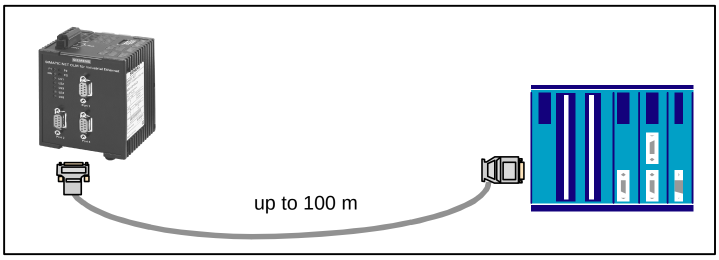


Figure 7: Node Attachment with Industrial Twisted Pair

Since the installation cable can be inserted directly into the sub D connector, important advantages result:

- Optimum suitability even in an EMC-polluted environment
- Permanent and reliable links
- Direct 100 meter links with double shielded cable
- Patch panels and telecommunications outlets are unnecessary
- Cables supplied in cut lengths (including connector for customer assembly) or prefabricated
- Fault reduction due to factory-prefabricated and tested cable
- Prefabricated cable saves time and effort on site (fitting and grounding connectors, measurements, etc.)
- Prefabricated cable supports plug and play

The industrial twisted pair installation cable and the all-metal sub D connector complement each other and together result in an exceptionally well-shielded cable connection. This is verified by the results of measurements in which different systems were compared.

Over a fixed time (in the example below 5 minutes) the cabling systems were subjected to defined interference voltage pulses at a constant bus load. The objective was to establish the number of the corrupted data packets, which are shown in the following table.

Disturbance voltage	Standard S/STP twisted pair cable	Industrial Twisted Pair cable
- 2 kV	119	0
+ 2 kV	2	0
- 4 kV	617	12
+ 4 kV	247	0

Table 4: Comparative Measurement Results

With increasing numbers of bad data packets, the efficiency of the network decreases. Because of the CSMA/CD access procedure, communication can still take place in this network under certain circumstances (quote: 'It still works!'). However, this communication is fairly sluggish. Required reaction times for example for alarm signals cannot always be guaranteed.
Added to this is the unpredictability of such a constellation for network expansion. Even if a network 'still works' under the above conditions, it might break down on connection of one further node (the straw that broke the camel’s back!).

3.2.2.6. Distances

The above section already covered twisted pair technology in detail. Industrial Twisted Pair permits direct links up to 100 meters using the well-shielded installation cable, whereas with conventional twisted pair technology, only 10 meters can be achieved with less well-shielded patch cords.

Using optical components and depending on the fiber type and the active components used, the following distances can be achieved:

Components	Fiber optic	Distance
OLM standard rail star coupler/hub	Multimode 62.5/125 µm	3100m
OSM standard rail switch	Multimode 62.5/125 µm; 50/125 µm	3000m
ORM redundancy manager	Multimode 62.5/125 µm; 50/125 µm	3000m

3.2.2.7. Optical Ring Redundancy

Redundant network infrastructures ensure continuity of communication in spite of faults in the network.
By structuring the network with an optical ring topology, an efficient media redundancy can be achieved very economically. If an active component fails or a fiber-optic cable is disconnected, the network reconfigures itself as a functional bus within a few milliseconds. Expensive production downtimes caused by network failure are thus avoided. Including redundant DTEs in the redundant optical ring has even greater advantages. In some cases, two faults occurring simultaneously in the network can be tolerated.
This optical ring redundancy is available for both Industrial Ethernet rates (10 Mbps and 100 Mbps).

3.2.2.8. High Availability

Communication is an integral part of automation. In manufacturing and process control, it is essential to guarantee trouble-free communication. Faults on the network or problems in communication cannot be allowed to cause production failures. Interruptions of a process cannot be tolerated due to the immense costs that may be involved. The breakdown of a network is tantamount to a disaster and must be avoided at all costs.

This requirement is met by SIMATIC NET Industrial Ethernet thanks to the following characteristics:

- Fulfillment of the more exacting immunity requirements for industry according to EN 50082-2
- Redundant 24 V DC power supply of network components
- Signaling contacts for signaling fault states
- Network components are designed for use in hostile industrial conditions (EMC, construction, all-metal housing)
- Redundant network structures with fast-reaction media redundancy

3.2.2.9. Signaling Concept

The signaling concept allows simple and very economical monitoring of the network. This is particularly important in redundant networks. Due to the medium redundancy, communication continues even if a fault occurs on a transmission path and as a result the fault could easily remain unnoticed. If a second fault then develops, the network would fail completely.

Since the introduction of the standard rail star coupler/hub OLM, all active Industrial Ethernet network components incorporate signaling contacts. The network components provide a 24 V DC group signal via a relay allowing various states of the components or the network to be indicated. With this simple mechanism, signals from the network infrastructure can be incorporated into an existing HMI system (for example, WinCC). Any faults occurring can then be eliminated before a network failure.

In addition to the signaling contacts, the network components have LEDs to display different states.

Expensive network management, which in many cases represents “overkill” when used simply to monitor network errors, is no longer necessary. The Industrial Ethernet signaling principle dispenses with the need for special network management software or a special network management station (separate PC or workstation). Personnel no longer need special training in network management.

4. Switching and 100 Mbps - Scenarios in Industrial Communication

With the backdrop of the Fast Ethernet standard, this chapter looks to the future of networking in an industrial environment with Fast Ethernet and switching.

4.1. Migration

One of the factors in the success of Fast Ethernet, as described above, is its great similarity to classic 10 Mbps Ethernet, which means that the new technology can be introduced step by step without needing to completely reconfigure the network all at once. Both the effort and outlay involved in introducing the 100 Mbps technology can therefore be tailored to individual requirements.

4.1.1. Stage 1: Switching

The performance of a network can be greatly improved simply by structuring it. The network can be divided into individual segments connected to a switch. Individual DTEs can also be connected directly to a switch if required.

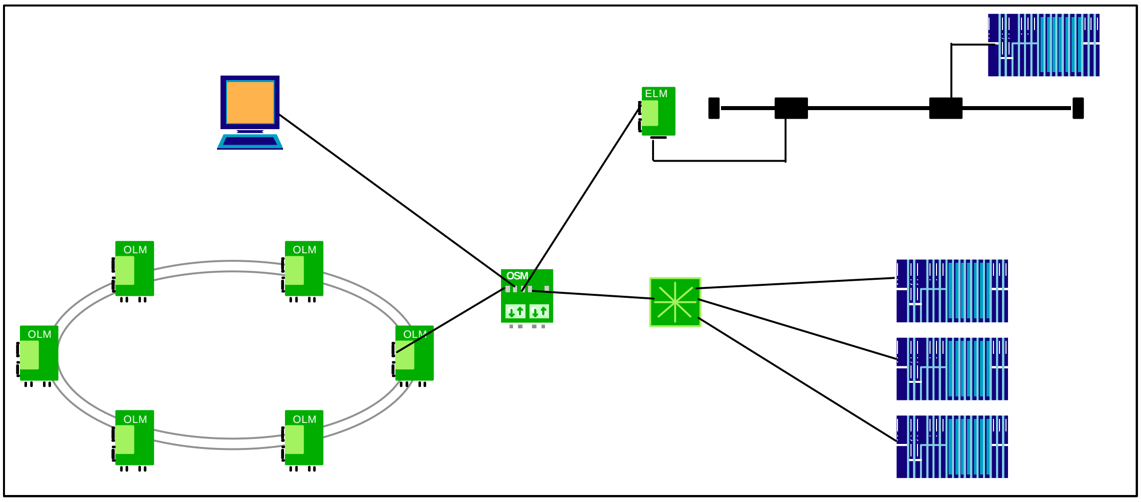


Figure 8: Load Management and Segmentation with a Switch

The improved performance is achieved by two effects:

- By load management – local data traffic remains local – each segment has the nominal data rate available.
- The switch can process multiple data packets simultaneously.

4.1.2. Stage 2: 100 Mbps Backbone

Initially, 100 Mbps technology is used in the network to set up a fast backbone. The existing 10 Mbps DTEs and network components can still be used without modification so that previous investment in equipment is by no means lost.

With OSMs (Optical Switch Module), SIMATIC NET provides the necessary components. An OSM is a network component with two 100 Mbps FO ports and four 10 Mbps ITP ports.
The 100 Mbps backbone is configured using the fiber-optic ports. DTEs or existing network segments (consisting, for example, of Industrial Ethernet OLMs) are connected to the 10 Mbps ITP ports.

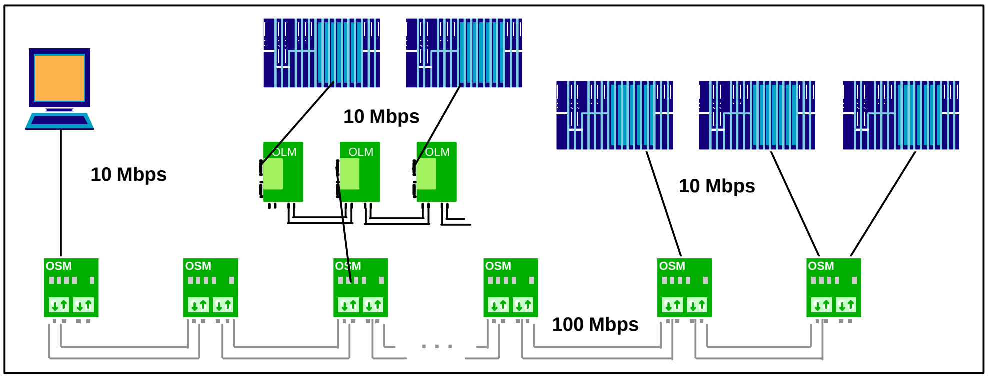


Figure 9: Switched Network with a 100 Mbps Backbone in a Bus Structure

4.1.3. Stage 3: 100 Mbps DTE Connections

More and more new DTEs are being equipped with dual speed NICs (interfaces with autosensing functionality, which can handle the 10Mbps and 100 Mbps data rates).
Initially these DTEs can be connected to a 10 Mbps network. When performance requirements increase, connection to a 100 Mbps network is possible without complex modifications.

For applications working with large amounts of data or where fast reaction times are required, a 100 Mbps connection from the server PC or HMI stations to increase network performance may be appropriate.
These stations are connected with the SIMATIC NET CP 1613 adapter directly to a 100Mbps port of the network component.

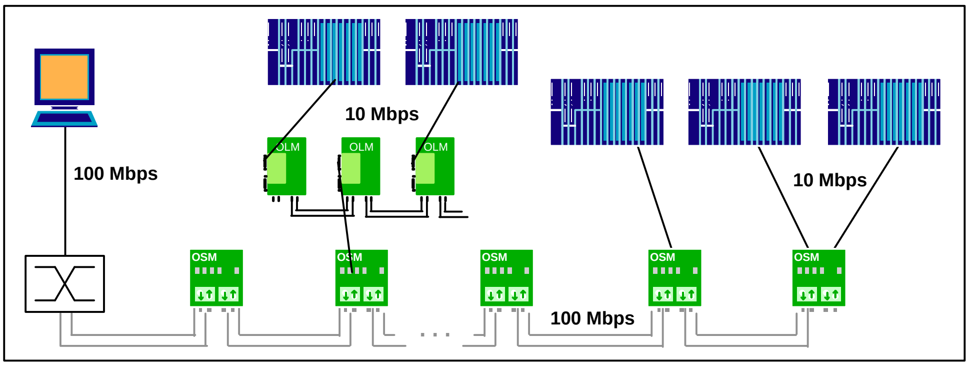


Figure 10: Connection of 100 Mbps DTEs to a Switched Network

4.1.4. Stage 4: The 100 Mbps Network

In the last step, a 100 Mbps network finally takes shape. DTEs are connected as required to the 100 Mbps network. The attachment of existing 10 Mbps network segments or DTEs still remains possible assuming that the adapters have autosensing and autonegotiation functionality, which all new SIMATIC NET CPs incorporate as described in Stage 3.

With SIMATIC NET OSM V2, which will be available at the end of 1999, SIMATIC NET also has the ideal network components for this network. In addition to the two 100 Mbps fiber-optic ports, OSM V2 will also have 10/100 Mbps autosensing/autonegotiation ITP ports.

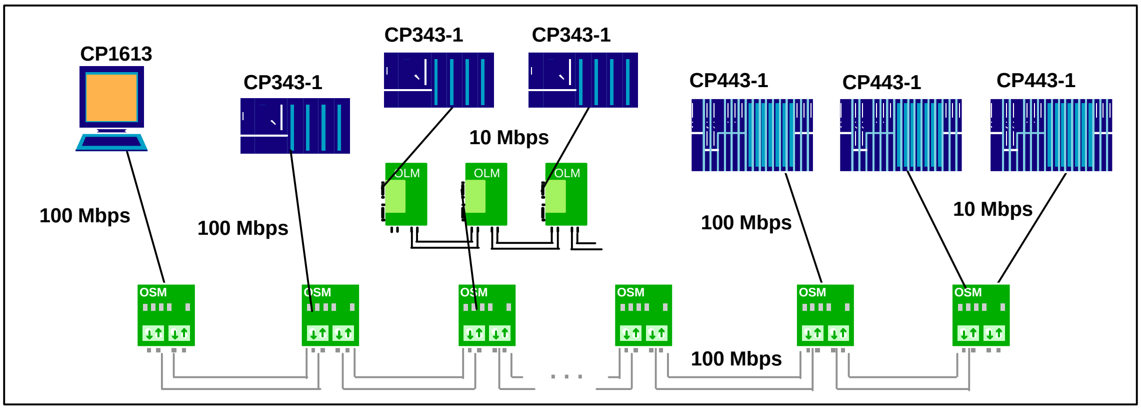


Figure 11: Switched 100 Mbps Network

4.2. Design of New Network Topologies

Conventional network structures such as bus or star are not always suitable to meet the requirements of communication in an industrial environment.
High-reliability and fail-safe network topologies must ensure that the production or the process is not interrupted at any time. Production downtimes can cause immense costs. A redundant network capable of handling faults in the network and increasing the availability of communication is required in many cases.

The SIMATIC NET network components OSM (Optical Switch Module) and (ORM) Optical Redundancy Manager were especially developed to meet these requirements and provide various options for configuring redundant network topologies.

4.2.1. The Redundant Optical Ring with Switches

In the past, due to the absence of alternatives, redundant networks were generally implemented as double busses. For several years now, however, OLMs have been used to configure redundant optical rings in Industrial Ethernet.

Optical rings have numerous advantages. In addition to the general advantages of fiber optic technology with regards to EMC, it enables the ring structure to achieve redundancy economically using only one additional cable (from the end to the beginning of the line). In contrast to double bus structures, ring structures can even tolerate two simultaneous faults in some cases.
For these reasons, the optical ring was selected for switched networks as the basic topology for a redundant network.

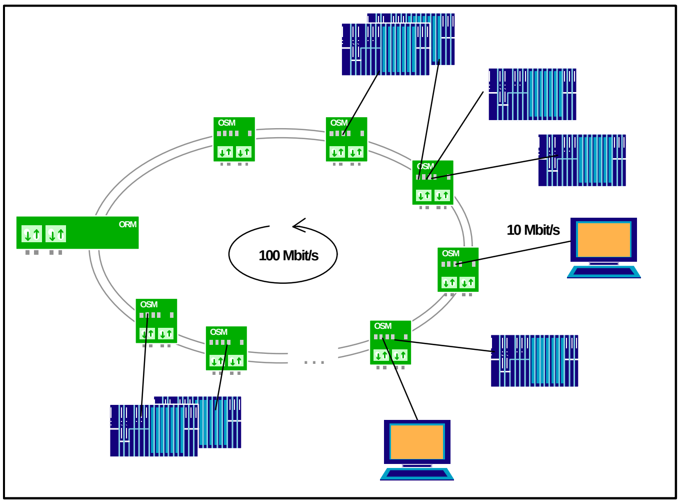


Figure 12: Switched Network in Redundant Optical Ring Structure.

The spanning tree algorithm is not suitable to control redundancy in industrial networks due to the unacceptable times involved when faults occur.
A special new procedure had to be developed for the SIMATIC NET switches to ensure extremely fast redundancy.

4.2.2. Fast Redundancy with OSMs and ORM

The redundancy in an OSM ring is controlled alone by one ORM in the ring. It ensures that in a ring of 50 OSMs, reconfiguration of the network after a fault (cable open circuit or failure of a switch) is completed in less than 0.5 seconds.
This ensures that existing software applications remain unaffected by the change in the network.

4.2.3. Large Network Spans

Distances of up to 3000 meters are possible between two OSM/OSM or OSM/ORM components. This means that a redundant optical ring with 50 OSMs can achieve a span of up to 150 km.

4.2.4. Hierarchical Ring Structures

In certain applications, it is not desirable to implement the entire network in a single ring. It is often preferable or necessary to structure the network by breaking it down into smaller subnets.

Using the OSM, ORM and OLM Industrial Ethernet components, different structures can be implemented to meet these requirements.
To connect two network segments with a fast redundant link, two OSMs are inserted in between. With this configuration, one link is active, and the other is on standby. The two linking OSMs are connected to each other and exchange status data via the standby ports. If a fault occurs on the active link, the changeover to the standby link takes less than 0.5 seconds.

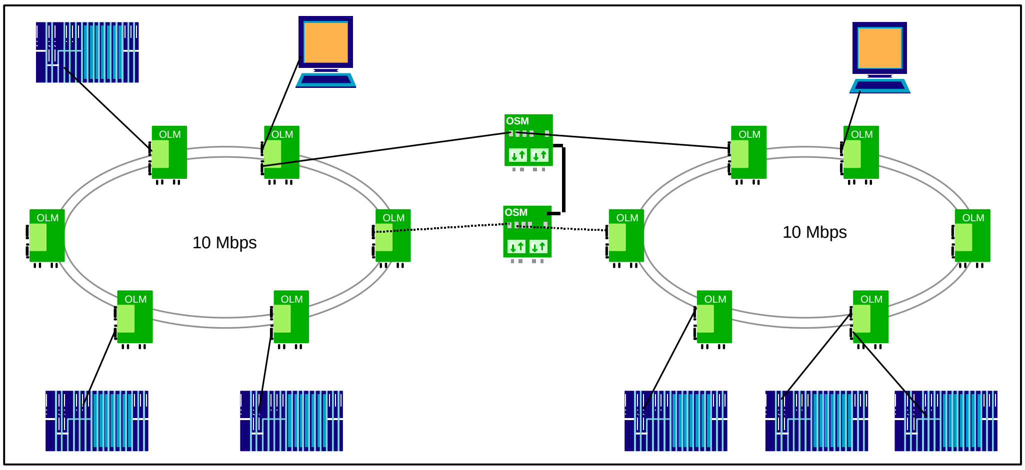


Figure 13: Interconnecting Industrial Ethernet Optical Rings

Another option that is used especially with a subprocess-orientated network topology, is to connect subrings to a second, wider-ranging ring to allow cross communication. Once again, each redundant subring is connected via two coupling OSMs to the wider ring.

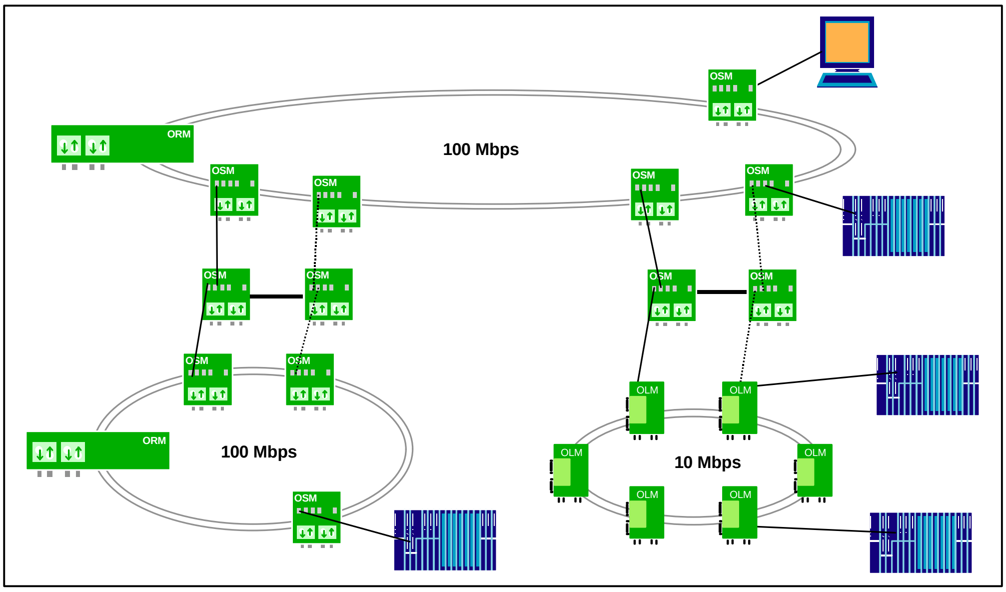


Figure 14: Switched Network with Hierarchical Ring Structure

5. Industrial Ethernet - Universal Basis for Industrial Communications

In addition to the classical applications such as process control, Industrial Ethernet is being used increasingly in new applications.

The TCP/IP communications protocol which has now become the de-facto standard, allows open and worldwide communication.
The automation network can be connected to a higher-level company network without using gateways. Standard routers are used as the connectivity devices.

Due to the tremendous improvement in performance, switching and 100 Mbps are opening up the process automation market, where Ethernet was not used in the past due to its non-deterministic response.

A further highly interesting sector for new applications is Information Technology (IT) in automation, for which Industrial Ethernet represents an ideal basis.
New communications processors will have web server functionality. Using standard web browsers (for example Netscape or Internet Explorer) the user has no difficulty getting information about the automation systems.

Multimedia applications on the basis of the switched 100 Mbps Industrial Ethernet are also possible.
Cameras directly connected to a 10 Mbps port on the switch can supply information about the process itself or be used for quality assurance.
The ability to call up video sequences from a video server by the maintenance personnel can increase efficiency considerably.

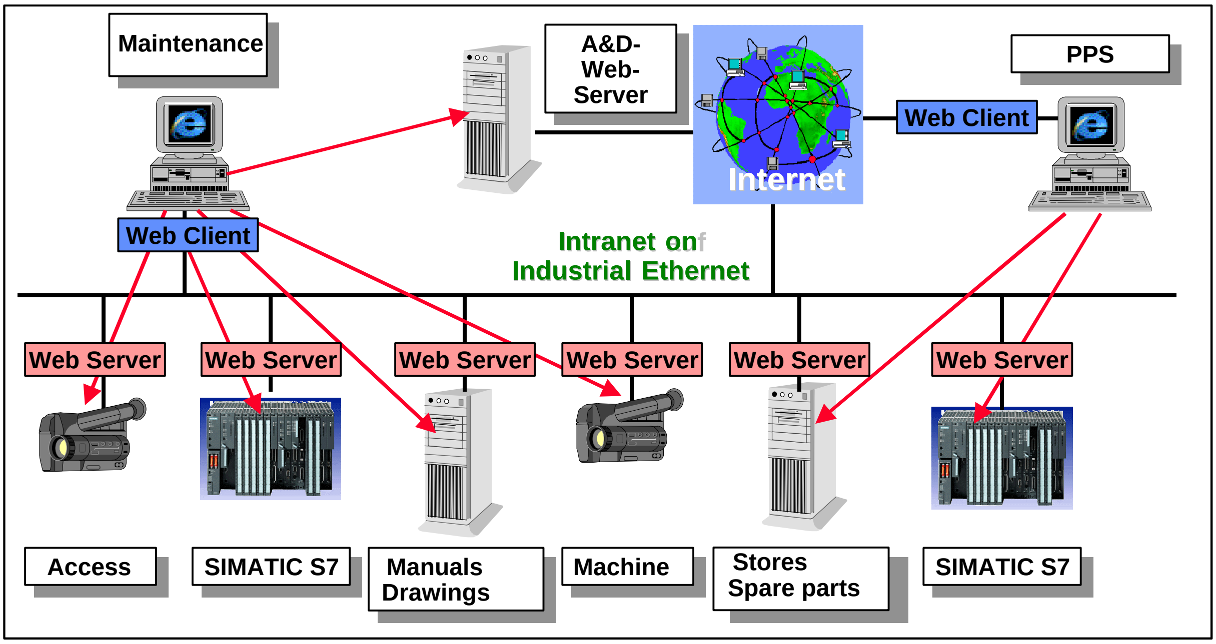


Figure 15: Information Technology in automation

6. Fast Ethernet in Field Communication

At the Fieldbus Foundation, the use of Ethernet or Fast Ethernet in the field environment is currently being discussed.
Existing field bus segments, known as H1 segments with a data rate of 31.25 Kbps, will be connected to Fast Ethernet, and the direct connection of field devices to Fast Ethernet is also being planned.
For communication of individual devices with one another, the existing H1 field bus profile will be mapped onto Ethernet, with Fast Ethernet serving as a transparent transport network.

SIMATIC NET, the trendsetter in industrial communication, is actively involved in this work and after completion of specifications will also offer suitable products in this market segment - products designed for industry!

7. Conclusions and Outlook for the Future

SIMATIC NET Industrial Ethernet is a standard-based network optimized for the needs of industrial communication. For more than 10 years, Industrial Ethernet has been setting the trends in industrial data communications.
In the future, Industrial Ethernet will continue to lead the way in industrial communication. Switching, 100 Mbps technology and Information Technology for automation are the next milestones.
In the more distant future, a further trend is already foreseeable:
Use of Ethernet technology in the field area.

Today, Industrial Ethernet users can implement cost-effective networks tailored to the requirements of an industrial environment and with the required availability and reliability secure in the knowledge that their investment will pay dividends in the future.

8. Glossary

10Base2	Standard for transmission of 10 Mbps Ethernet on thin coaxial cables; segment length 185 meters.
10Base5	Standard for transmission of 10 Mbps Ethernet on coaxial cables (yellow cable); segment length 500 meters.
10BaseFL	Standard for transmission of 10 Mbps Ethernet on glass fiber-optic cables (fiber link).
10BaseT	Standard for transmission of 10 Mbps Ethernet on twisted pair cables.
100BaseT	Fast Ethernet Standard.
100BaseFX	Fast Ethernet Standard for data transmission on glass fiber-optic cables.
100BaseVG	A specification for 100 Mbps networks. The basis is the Demand Priority access method, which is completely incompatible with CSMA/CD. 100BaseVG is also specified for telephone cables (voice grade).
Autonegotiation	Configuration protocol in Fast Ethernet. Devices on the network negotiate a transmission mode suitable for every device prior to transmission (100 Mbps or 10 Mbps; full duplex or half duplex).
Autosensing	Capability of a device to automatically detect the data rate, (10 Mbps or 100 Mbps) and transmit/receive at this rate.
Bridge	A network component that connects network segments. It ensures that local data traffic remains local, i.e. only data packets to a node on the other segment are passed through the bridge. Faults in a network segment remain limited to the particular network segment. Bridges can handle only one data flow at a time in contrast to switches.
Burst	Temporarily increased network load due to data burst or sudden flurry of signals.
Category x components	Cabling components are divided into different categories depending on their transmission characteristics. Different physical limit values are stipulated for each category (e.g. maximum signal attenuation for a defined transmission frequency). Category 3: Data transmission up to 16 MHz Category 4: Data transmission up to 20 MHz Category 5: Data transmission up to 100 MHz Category 6: Data transmission up to 200 MHz
Collision domain	To ensure the functionality of the CSMA/CD collision access procedure, the propagation time of a data packet from one node to another is restricted. Depending on the data rate, this propagation time results in a restricted network span known as the collision domain. With 10 Mbps Ethernet this is 4520m, with Fast Ethernet, it is 412m. Multiple collision domains can be connected via bridges/switches. Full duplex enables extensions beyond one collision domain.
CSMA/CD	Carrier Sense Multiple Access / Collision Detection. Network access procedure in the Ethernet.
FO	Fiber optics

Filtering	A switch filters data traffic based on source and destination addresses in a data packet. A data packet is passed on by the switch only to the port to which the addressee is connected.
FDX	Full duplex.
Full duplex	Capability of device to transmit and receive data simultaneously. In full duplex mode, collision detection is deactivated.
Half duplex	The device can either receive or transmit data at any one time.
HDX	Half duplex.
Hub	Active network component with repeater functionality, synonym for star coupler.
IEEE 802	Institute of Electrical and Electronics Engineers. LAN/MAN Standards Committee.
IEEE 802.3	Institute of Electrical and Electronics Engineers. Ethernet workgroup.
IEEE 802.3u	Institute of Electrical and Electronics Engineers. Fast Ethernet workgroup.
ITP	Industrial Twisted Pair; particularly efficient screened twisted pair cable for industrial use.
Link class	The link class describes the quality of a complete link from the active component to the terminal (patch cord, patch panel, installation cable, telecommunication outlet, connecting cable). This link must meet the values specified in the structured cabling standard ISO/IEC 1180. In contrast to this, there is also the specification regarding 'categories', where only requirements on products are defined, for example, cable according to category 5. The suitable interaction of components of a link is ignored.
Load management	By filtering, the switch ensures that local data traffic remains local; the local network load on a segment is “isolated” from the remaining part of the network.
MAN	Metropolitan Area Network. Data network with the geographic extension of a city.
Media redundancy	Redundancy in the network infrastructure (cable and active components such as OLM or OSM/ORM).
NIC	Network Interface Card (for example SIMATIC NET CPs - communications processors)
OLM	Optical Link Module. Industrial Ethernet network component with repeater functionality.
ORM	Optical Redundancy Manager. Industrial Ethernet network component; Controls medium redundancy in an OSM ring.
OSM	Optical Switch Module. Industrial Ethernet network component with switch functionality.
RJ-45	Symmetrical connector for data cables. Also called Western connector or Western plug. Widely used in telephone, ISDN technology and office LAN installations.
Router	Active network component which controls the data traffic based on the IP address. Routers have extensive filter functions.
Signal propagation time	Time which a data packet requires on its way through the network.

Shared LAN	All components in a shared LAN share the nominal data rate. Shared LANs are set up using repeaters/hubs or fan-outs.
Spanning tree protocol	Configuration protocol for bridges specified in the IEEE 802.1d standard. Different ports in the bridges are switched to standby in meshed bridge structures to prevent data packets from circulating in the network. This results in a functioning network with tree structure. The standby ports/links are available as redundant links in the event of a fault. Reconfiguration of the network using the spanning tree protocol takes several seconds (up to 60 sec.) and is thus not suitable for industrial purposes.
S/STP	Screened Shielded Twisted Pair. With this cable design, the individual twisted pairs are surrounded with a foil screen. Both individually screened pairs are also screened with a common copper braiding.
Switch, switching	A switch is a network component which has in principle the same characteristics as a bridge. In contrast to the bridge however the switch can establish multiple links simultaneously between the ports. These links are established dynamically and temporarily, depending on data traffic. Each link has the full nominal bandwidth.
Triaxial cable	The SIMATIC NET 727-0 bus cable is based on the coaxial cable specified in the 10Base5 standard (IEEE 802.3), but enhanced with a solid aluminum sheath for use in industry.
Twisted pair	Data cable with twisted pairs. The twisted pairs ensure favorable transmission characteristics and prevent electromagnetic disturbances. Twisted pair cables are available in various grades for different transmission rates.