19 Comparison of Ethernet Systems

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Ever since the end of the 90's, the usage of industrial Ethernet in automation has been a pursued target. Along with this, the desire emerged to have a universal and standard communication infrastructure from the business management level down to the sensor/actuator bus. The wish for uniformity has actually turned into the opposite: The number of Ethernet solutions developed so far currently exceeds the number of fieldbuses, and a comparison of the systems, from the user's perspective, is hard to achieve.

19.1 Performance Indicators

In the Standard IEC 61784 Part 2, the performance indicators for the comparison of Real-Time Ethernet (RTE) solutions are discussed first.

The performance indicators, according to IEC 61784, include the following topology and timing features that characterize the data throughput. The performance parameters can be divided into three groups:

- Information on performance and capacity such as update rate (delivery time), real-time data throughput (throughput RTE), and non real-time data bandwidth (Non-RTE bandwidth);
- Information on the timing characteristics such as time synchronization accuracy, non-time-based synchronization accuracy, or the redundancy recovery time;
- Information on the supported topology such as the number of end-stations, the allowed topologies (basic network topology), or the number of switches between end-stations.

For the assessment it is important to consider that the unique parameters are not independent of each other. For instance, the update rate (delivery time) depends on the number of number of end-devices. In addition the dependence of the performance parameters is technology-specific. In IEC 61784 this is represented in terms of an inter-dependency matrix.

The information on the individual performance parameters and the dependencies are included in the standard with very different qualities. For this reason, although they may serve as a guide, they can not be strictly used for a comparison.

A comparison of the systems becomes even more complicated due to the fact that the individual solutions were conceived for different application fields, which is an aspect that is not completely covered by the performance parameters.

The experience shows that on the selection of an Ethernet solution, apart from the pure technical performance parameters, there are other criteria whose roles frequently are more important. Before a detailed discussion on these criteria can be held, it is necessary to consider the different requirements and solution concepts.

Dependent PI	Influencing PI						
	Delivery time	Number of endstations	Basic network topology	Number of switches between endstations	Throughput RTE	NON-RTE bandwith	Time synchronization accuracy
Delivery time		NO	NO	YES	NO	NO	NO
Number of endstations	NO		YES	YES	NO	NO	YES
Basic network topology	NO	NO		NO	NO	NO	NO
Number of switches between endstations	YES	YES	YES		NO	NO	YES
Throughput RTE	NO	NO	NO	NO		YES	NO
NON-RTE bandwith	NO	NO	NO	NO	YES		NO
Time synchronization accuracy	NO	NO	YES	YES	NO	NO	

Figure 19.1: Example of a Performance Indicator (PI) Dependency Matrix according to IEC 61784 Part 2

19.2 Requirements

Ethernet is used in automation, not only because of its real-time capabilities. When compared to fieldbus systems, Ethernet provides a crucial contribution to the integration concept. While the communication of fieldbus-based solutions is limited to islands of communication, Ethernet based solutions enable a common communication infrastructure that provides the direct data exchange between all layers in the automation pyramid and the IT world (MES, ERP) thus enabling vertical integration.

In order to achieve this objective, the following prerequisites have to be fulfilled by the implemented Ethernet solution.

- Support for standard communications protocol and services of the IT world.
- Support for real-time requirements in automation (real-time process data exchange).

However, depending on concept and main application field, these two aspects are covered differently by solutions already found on the market.

The requirements for the standard communications services mentioned in [1] are currently implemented by the use of TCP/IP-based technologies. With the introduction of Ethernet, these technologies are taken for granted in the world of automation. TCP/IP-based solutions are basically found at all levels of the automation pyramid up to the field devices. Control panels that communicate via IP protocol with controllers, or integrated web servers that provide web pages for the configuration or diagnosis are typical examples and common practice.

In contrast to the rather uniform demand on the communication features of IT services, the requirements on the real-time capabilities mentioned in [2] are strongly dependent on the respective field of use and application.

Generally, three categories of requirements can be distinguished , that can be described by the typical update rates of the process data :

- **Category A:** Applications with low real-time capability requirements and typical update rates of up to 100 ms.
- **Category B:** Applications with high requirements on real-time capabilities and typical refresh rates of up to 10 ms. Most of the Ethernet-based communication systems applications in automation engineering can be found in this category. A typical field of application is the manufacturing automation.
- **Category C:** Applications with the highest requirements on the real-time capabilities where the typical update rate is less than 1 ms. Motion Control applications fall into this category.

Within the industrial Ethernet context, the employment of IP-based communication is usually implicit. The real-time capabilities of Ethernet relying solely on IP-based communication are limited, though, and thus different solution alternatives have been developed to work without IP-based communication.

It is the complexity of these communication alternatives that makes it difficult, from the user's perspective, to distinguish between the different concepts of the individual real-time Ethernet solutions.

To be able to classify the individual solution concepts, it is helpful to know the underlying base mechanisms. These can be described by the following three communication elements:

- The actual transportation mechanism based on Ethernet packets. This mechanism is specified at layer 1 and 2 of the ISO/OSI Communication Model. At layer 2, the characteristics of the data packets are defined (e.g. the MAC addressing or the maximum size of the data packet) as well as the mechanism for the access to the transmission medium (Media Access Control CSMA/CD).
- The so-called TCP/IP-Stack (Layer 3 and 4), that allows hardware-independent addressing of network devices by means of IP addressing, and also enables the communication beyond and between local area networks.
- The application protocol that interprets the content of the data packets and determines the data update rate among other characteristics.

19.3 Implementation Concept

The solution concepts of the market and the products for real-time Ethernet are divided into three different categories. They differ in their performance capabilities (as in the above described requirement categories) and in the degree of compliance with Ethernet standard.

Category A: TCP / IP-based solutions

The Ethernet solutions of this category utilize TCP/IP-based automation protocols for the process data communication. They rely on the TCP/IP software stacks and utilize standard Ethernet hardware. The real-time capability is limited and mainly defined by the response time behavior of the hardware. The addressing of participant devices is IP-based and makes communication possible also beyond local area networks. Since the IT services are built on the same communication standards (Fig. 19.2), the design of homogeneous infrastructures to ease the integration in corporate networks is enabled.

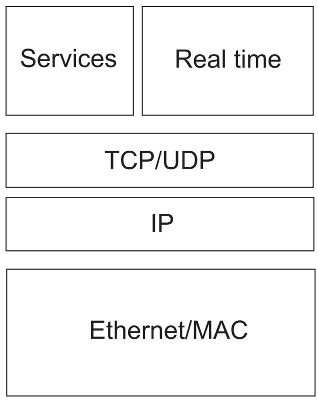

Figure 19.2: Ethernet communication with standard TCP/IP

This category includes solutions such as, for example, MODBUS TCP.

Category B: Ethernet MAC

In this category, the employment of the IP protocol and thus the TCP/IP Stack for the communication of process data is omitted. The automation protocol is fully based on the Ethernet frame and works with standard Ethernet hardware. The addressing of the networked devices occurs by means of the MAC addresses of the network controllers. The short protocol overhead leads to an improved time response with higher determinism and lower jitter. From the perspective of the communication participants, there are two communication channels available: IP-based services and MAC-based real-time communication. Both communication channels can be set up in the same infrastructure (cable infrastructure). Based on this concept, on the one hand, the real-time communication can be used within network segments (broadcast domain), yet on the other hand, the IT services can be utilized and the integration of the network devices into the company network can take place.

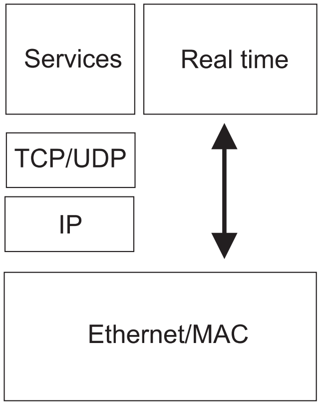

Figure 19.3: Protocol with IP-based services and MAC-based real-time communication

A typical representative of this category is PROFINET RT, which, as an additional feature, performs the prioritization of the real-time data traffic through the utilization of Ethernet VLAN-tags.

Category C: Ethernet with modified bus access process and timing

The third category describes solutions, where the automation protocol is incorporated in the Ethernet frame. In contrast to category B, the Ethernet bus access control (Layer 2) or the timing is modified and the use of specific Ethernet hardware is required.

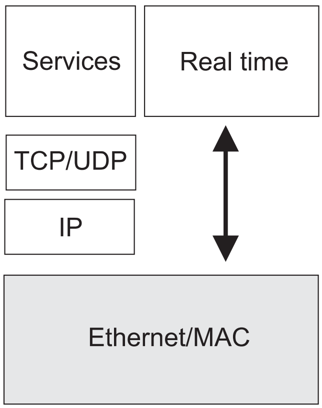

Figure 19.4: Industrial Ethernet with specific hardware requirements

The solutions offered by category C fulfill the highest demands as to the time response of real-time Ethernet (update interval < 1 ms, jitter < 1 μs). Nevertheless, this category represents the biggest deviation when compared to standard Ethernet. At the same time, the differences between various solutions within this category are also the largest.

For instance, EtherCAT is based on the summation frame protocol and requires special slave hardware. On the other hand, PROFINET IRT uses a time slot method and requires appropriate hardware support in the infrastructure components (switch).