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COMPARATIVE ANALYSIS OF INDUSTRIAL ETHERNET NETWORKS: PROFINET, ETHERNET/IP AND HSE

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Abstract. *Industrial Ethernet has appeared in order to support the industrial communication for distributed applications in easy and reliable way to field devices. The Ethernet network used in offices and other places does not provide the requirements demanded for industrial environment, real-time, flexibility, scalability and maintainability without dangerous changes on the network topology. This article shows the comparative analysis of three industrial Ethernet networks spreadly employed in the market for industrial automation. It will be showed communication characteristic, configurations and applications considering standard as PROFINET, Ethernet/IP and HSE networks. It is accomplished with a comprehensive analysis among these networks showing common characteristics to these standards. After this approach, it will be explained a case study with simulations that will be done using the information obtained to analyze the performance and possible improvements in the system previously studied.*
Keywords: Industrial Ethernet, PROFINET, Ethernet/IP and High Speed Ethernet

1. Introduction.

In the 40s, the process instrumentation was operated considering pressure signals (i.e., range of 3-15 psi) to monitor and control devices on the factory floor. The industrial system has had the conception of the application of hydraulic and pneumatic systems. Already in the 60s, electrical technology has maturity inducing a changing for analog signal of 4-20mA, bringing to industry the benefits of electrical components being able to measure, monitor and control field devices.

With the development of semiconductors devices in the 70s, the idea of using computers to monitor, control and diagnose processes in industry in digital way has brought also the motivation in providing implementation of new and more efficient control strategies, taking the industry for a new era with optimization of the industries of process and manufacturing.

In the 80s, begin the development of the first intelligent sensors, actuators and digital controllers associated, with digital components, which has as requirements the digital integration between them. So was born the idea of a network that would unite all devices and dispose all process signals in the same physical environment. Thereafter, the need for a network (fieldbus) to interconnect devices was clear, and a standard to provide benefits for user and developers in order that different devices from several suppliers could be integrated in seamlessly.

Fieldbuses, in turn, are digital networks that arose with the intention of replacing the standard 4-20mA. Before their existence to local information exchange was performed using many cables with point-to-poiny connection that interconnected elements sensors or actuators directly to controllers, the field devices were passive with one half-duplex communication flow without services of calibration and diagnostic.

The first fieldbuses have emerged as something new in the process industry and manufacturing, during the 80s. The "war between fieldbuses", the episode known attempts to standardize a single industrial protocol, creating a unique standard proposed by the ISA, called the SP-50. However, they created multiple protocols, different associations and institutions around the world. They promised to do away with the complexity of existing cables, besides offering other functions to diagnose possible network failures and perform system upgrades control [5].

In this initial period of setting networks fieldbuses, Ethernet network was present in the office and in homes, but showed signs that could also reach the industrial plant level. This came to the fore in the 90s, when the first solutions for industrial Ethernet were developed using the standard PROFINET, Ethernet/IP and HSE.

At first, Ethernet solutions for industrial environment, they presented several problems that have been detected for direct application on the factory floor, but after a period of improvement and new developments, Ethernet could be considered reliable for this harsh environment, due to the robustness of the equipment and the staggering determinism of messages used in the network design [4,5].

Considering the pyramid of integration of various levels of communication devices in process and manufacturing industry, we can classify from bottom to top the communication bus to connect them. Fieldbus network connects field devices providing signals acquisition and actuation. The control network provides real time control, safety and interface and the plant network being able to do supervision, commands, planning and database management.

However, the Ethernet technology can be employed in various levels of communication systems for an industry automation, considering that the requirements need to be defined as preliminary for each layers according to environment specification.

We present a comparative analysis considering the characteristics and properties of different Ethernet standards well done that are PROFINET, Ethernet/IP and HSE. A computer tool is provided for conception and preliminary analysis, with a real case study to verification and validation of experimental setting of the project with industrial Ethernet.

This work provides a good support for future works on industrial Ethernet that can consider the other standards available as Modbus/TCP, EPA, EPL, EtherCAT, IEC 61850, JetSync, P-Net, Sercos III, SynqNet, TCnet and Vnet/IP.

The paper is structured as follows. Section 2 presents an overview over industrial Ethernet technology. Section 3 describes the main characteristics and properties of technologies PROFINET, Ethernet/IP and HSE. Section 4 shows a case study that should be a background for experimental tests in Section 5 and in the last Section 6 an overall conclusion is presented.

2. **Industrial Ethernet.**

Several developers have created their own standards of industrial Ethernet networks, each differing from the other in terms of application project and the use or not of certain layers of the TCP/IP standard. Some of developers have dedicated to hardware manufacturing, which makes it uncompetitive for industrial application. Nowadays, there are around fourteen standard protocols (standardized by IEC 61784 and IEC 61158), and some by their own associations, for industrial Ethernet are:

PROFINET, Ethernet/IP, HSE, Modbus/TCP, EPA, EPL, EtherCAT, IEC 61850, Jet-Sync, P-Net, Sercos III, SynqNet, TCnet and Vnet/IP. Among these protocols, we highlight the PROFINET, Ethernet/IP and HSE that are broadly used in process automation and manufacture systems and have greater emphasis in this work [5].

Industrial Ethernet systems need to satisfy some requirements defined for industry environment in which the equipment must operate. Plant-floor equipment must tolerate a wider range of temperature, vibration, and electrical noise than equipment installed dedicated information-technology areas. Since closed-loop process control may rely on an Ethernet link, economic cost of interruptions may be high and availability is therefore an essential criterion. Industrial Ethernet networks must interoperate with both current and legacy systems, and must provide predictable performance and maintainability. In addition to physical compatibility and low-level transport protocols, a practical industrial Ethernet system must also provide interoperability of higher levels of the OSI model. An industrial network must provide security both from intrusions from outside of the plant, and from inadvertent or unauthorized use within the plant.

Industrial networks often use network switches to segment a large system into logical sub-networks, divided by address, protocol, or application. Using network switches allows the network to be broken up into many small collision domains. This reduces the risk of a faulty or misconfigured device generating excess network traffic. When an industrial network must connect to an office network or external networks, a firewall system can be inserted to control exchange of data between the networks. To preserve the performance and reliability of the industrial network, general office automation systems are separated from the network used for control or I/O devices.

Ethernet based networks [12] and, in turn, are responsible for the interconnection of local networks, having in their content features that allow this operation. This is detailed by the headers present in its frame shown in Figure 1 and explained in Table 1 [13].

Talking about Ethernet without mentioning the TCP/IP (Transmission Control Protocol/Internet Protocol), is not usual, because they are related. The TCP/IP suite was created in the 70s by V. G. Cerf and R. E. Khan, and [1] is one of the most widely used standards for communication between computers nowadays which can be compared with the OSI (Open Systems Interconnection) seven layers. Therefore, differ from it because it does not have a mapping layer five and six and functions present in these layers are implicit within its architecture [2]. His rise is justified by the high interconnectivity and patterning is provided as well as to provide communication regardless of the distance.

The Ethernet link present in the TCP/IP [3] protocol layer, is responsible for interconnecting local area networks, also called LAN (Local Area Network). Its creation is attributed to R. M. Metcalfe.

Through the need for the exchange of information between the factory floor and the highest levels in a Supply Chain, provide a more efficient and expansive production, and the idea arose of industrial Ethernet. Through it, it would be possible to communicate between fieldbuses and administrative levels.

After the initiative to create a standard that interconnects different levels of internal hierarchy of an industry, different associations backed the development of industrial Ethernet. As a result, a pattern differs from one another and is incommunicable with each

PRE	DFS	DA	SA	T/L	DATA	CRC
7	1	6	6	2	46-1500	4

FIGURE 1. Structure of an Ethernet frame

TABLE 1. Field description of an Ethernet frame

Description of Ethernet Frame	
Field	**Description**
PRE (Preamble)	Its function is to warn other network elements when the start of transmission.
DFS (Delimiter of frame start)	Delimit the beginning of the frame. His last two bits are always one.
DA (Destination address)	MAC (*Medium Access Control*) address of destination
SA (Source address)	MAC (*Medium Access Control*) address of source
T/L (Type or length)	FF High Speed Ethernet
DATA (Information)	From 46 to 1500 bytes are data to be transmitted
CRC (Check of Redudancy Cyclic)	Consist of a CRC (Cyclic Redundancy Check) error checking to the transmitted frame

other. They differ in the use of layers of the TCP/IP and application developed for the user, resulting in a lack of interoperability between networks. Some even have private standards hardware, dedicated, only, the infrastructure of a specific network [1].

3. **Ethernet Technologies: PROFINET, Ethernet/IP and HSE.** Among the fourteen available protocols for industrial Ethernet, three stand out largely used in industry. They are protocols developed by private associations that had experience in the networking industry – mostly are associations dealing with fieldbuses.

3.1. **PROFINET.** PROFINET is a standard that aims to improve the processes where it is applied, suggesting to provide a better performance, reliability and flexibility. These characteristics made it the most widely used standard in industrial.

This pattern is based on industrial Ethernet, following the rules of PROFIBUS organization [6] and regulated for the standards IEC 61158-5 and IEC 61158-6, being the tenth standard protocol, as shown in Table 2 [11].

TABLE 2. The protocols suite specified according to IEC 61158 standard

Protocols Type According to IEC 61158	
Type	**Protocols**
Type 1	Foundation Fieldbus (FF)
Type 2	ControlNet
Type 3	PROFIBUS
Type 4	P-Net
Type 5	FF High Speed Ethermet
Type 6	SwiftNet
Type 7	WorldFIP
Type 8	Imterbus
Type 9	Foundation Fieldbus (FF), FMS
Type 10	PROFINET

Table 3. Main differences between Profibus and PROFINET

Parameter	Profibus	PROFINET
Nodes	126	255
Bytes	244	1440
Baudrate	12Mbps	100Mbps

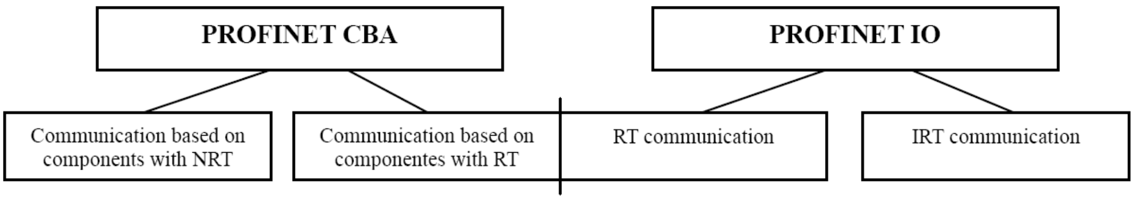

Figure 2. Basic structure of the PROFINET

The PROFINET standard is an evolution of PROFIBUS original, with significative changes in its architecture which can be verified the improvements in properties as number of nodes, amount bytes and baudrate that they have direct impact over the performance from the target industrial application.

Table 3 presents a comparative analysis in number of these mentioned properties.

We note that the evolution between fieldbus and Ethernet aimed at providing greater dynamism in applications, meeting the present needs of the industrial market [11].

Figure 2 illustrates the basic structure of the PROFINET, which is composed of two types of networks: PROFINET CBA (Component Based Automation) and PROFINET IO (Input/Output).

The PROFINET CBA system consists of various automation components where one component covers all mechanical, electrical and IT variables and can be generated using the standard programming tools. A component is described using a PROFINET component description (PCD) file in XML format and a planning tool loads these descriptions and enables the logical interconnections between the individual components to be generated for implementing a plant. This model was largely inspired by the IEC 61499 standard.

The basic idea of CBA is that an entire automation system can be divided into autonomously operating subsystems with design and the functions can end up in identical or slightly modified form in several systems. Each component is usually controlled by manageable number of input signals and within the component, and a control program executes the function and passes the corresponding output signals to another controller. The engineering that is associated with it is manufacturer-neutral and the communication of a component-based system is only configured, instead of being programmed. The communication with PROFINET CBA (without real time) is suitable for bus cycle times of approx. 50 to 100ms. The parallel running RT channel allows for data cycles similar to PROFINET IO (a few ms).

The interfacing to peripherals is implemented by PROFINET IO. It defines the communication with field connected peripheral devices. Its basis is a cascading real-time concept. PROFINET IO defines the entire data exchange between controllers (devices with "master functionality") and the devices (devices with "slave functionality"), as well as parameter setting and diagnosis. PROFINET IO is designed for the fast data exchange between Ethernet-based field devices and follows the provider-consumer model [1]. Field devices in a subordinate PROFIBUS line can be integrated in the PROFINET IO system without any effort and seamlessly via an IO-Proxy (representative of a subordinate bus system). A device developer can implement PROFINET IO with any commercially available Ethernet controller. It is well-suited for the data exchange with bus cycle times of a few ms. The configuration of an IO-System has been kept similar to PROFIBUS. PROFINET IO always contains the real-time concept.

A PROFINET IO system consists of the following devices:

a) IO Controller – controls the automation task;
b) IO Device – is a field device, monitored and controlled by an IO Controller which consists of several modules and sub-modules;
c) IO Supervisor – consists at software based on a PC for setting parameters and diagnosing individual IO Devices.

The Application Relation (AR) is established between an IO Controller and an IO Device. These ARs are used to define Communication Relations (CR) with different characteristics for the transfer of parameters, cyclic exchange of data and handling of alarms and refer to PROFINET IO connection life-cycle for a more detailed description.

The characteristics of an IO Device are described by the device manufacturer in a General Station Description (GSD) file. The language used for this purpose is the GSDML (GSD Markup Language) – an XML based language. The GSD file provides the supervision software with a basis for planning the configuration of a PROFINET IO system.

This approach is outcome of the application requirements.

PROFINET has three operation modes denoted as:

a) NRT – non-real time (Controller and HMI);
b) SRT – soft real time (Field Devices);
c) IRT – isochronous real-time (Motion Control).

The first mode, NRT is based on TCP/IP standard, and it has that name by having a longer processing time approaching with 100ms. Its application is for network configuration or communication with Proxies (Gateways). Proxies are in turn responsible for network elements interconnection between a PROFIBUS fieldbus with the PROFINET standard. They consist of two main parts, one part acts as a PROFIBUS DP master and the other part acts as a PROFINET CBA. The information is allocated in a shared memory which can be accessed by both parties performing this interconnection. The ACCO (Active Control Connection Object) ensures that the transfer of the information to its destination is performed, working as a manager of interconnections [11].

The second mode, named by SRT eliminates several layers of the TCP/IP protocol, the Ethernet interconnect layer to the application. With this reduction in layers, the length of the messages to be transmitted is reduced, so the transmission of data occurs at a speed of approximately 10ms.

Finally, the operation mode called TAI is used in applications that require a rapid response of the system smaller than 1ms time. Example application is assigned to robot motion control (motion control) [7,10,11].

PROFINET CBA communication uses mode non-real time (NRT) or via real-time (RT) and PROFINET IO uses modes real-time communication and isochronous real-time (IRT) [11].

Figure 3 illustrates the operation where the forms are applied.

The PROFINET introduced the first Ethernet controllers with integrated functionality switches. These drivers help to reduce considerably the cost in an automated system, since in many cases it is not necessary to use external switches, so reduce the amount of cabling. The main drivers used in the design of field instruments in PROFINET (masters, slaves

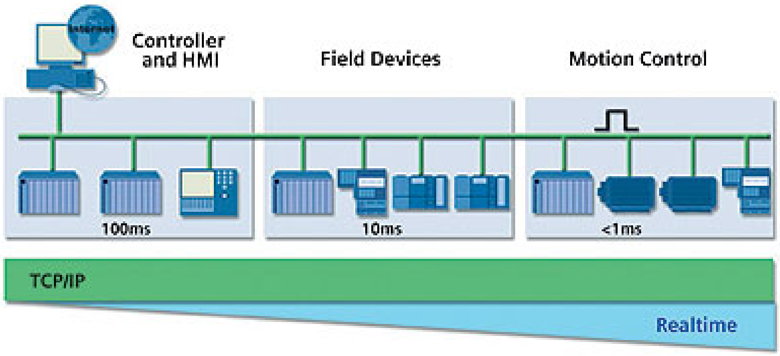

Figure 3. Response time from operation ways at the PROFINET

Table 4. The comparative analysis from controllers ERTEC 400 and ERTEC 200

Parameter	**ERTEC 400**	**ERTEC 200**
SRAM Memory	192Kbytes	64Kbytes
PCI Interface	32bits	16/32bits
Timer	Yes	No
Operating Temperature	–40 up +85°C	–40 up +85°C
Operating Voltage	3,3V	3,3V
Switch Ports	4	2
Consumption	450mW para 1.5V 200mW para 3.3V	–

or proxies) are: ERTEC (Enhanced Real-Time Ethernet Controller) 400 and ERTEC 200. Table 4 shows some specifications and comparisons of these drivers [11].

All the components are based on the PROFINET industrial Ethernet, thus requiring an IP address so that they can carry out their operations. Each IP is characterized by eight octets, being subdivided into network number and host number (field element). PIs addresses are assigned to each element by the master controller present on the network. Thus, subordinate to this controller device shares the same subnet mask [11].

For the IP address occurs, it must be given a name for each component. After the appointment of these elements PROFINET controller performs a singular quest for assigning names to each different device an IP address. In comparative terms, assigning a name to a PROFINET component is set as an address of DP slave (Decentralized Peripherals), in a PROFIBUS network. The IP address is assigned automatically, ascending and beginning of this in PROFINET master controller IP address [11].

The PROFINET devices can be configured by their basic functions, via GSD (Generic Station Description) to meet the desired needs. The GSD determines some basic information like options present in communication and some diagnostic mechanisms available in the system [11,16].

Components can display these files out of the factory and if not present, the GSD file can be acquired by the user and inserted in the device configuration.

There is a different version of the GSD named GSDML. This version is an (Extensible Markup Language) XML file, where the same data configuration is willing, but following the standards of this language. Both types of files can be created or edited using ordinary text editors or in the case of GSDML also in XML editors. Figures 4 and 5 show portions of GSDML and GSD files respectively.

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2005 rel. 3 U (http://www.altova.com) by Andreas Macher (Siemens AG) -->
<xsd:schema xmlns:ds="http://www.w3.org/2000/09/xmldsig#" xmlns:gsdml="http://www.profibus.com/GSDML/2003/11/DeviceP
	<xsd:import namespace="http://www.w3.org/XML/1998/namespace" schemaLocation="xml.xsd"/>
	<xsd:import namespace="http://www.profibus.com/GSDML/2003/11/Primitives" schemaLocation="GSDML-Primitives-v2
	<xsd:import namespace="http://www.w3.org/2000/09/xmldsig#" schemaLocation="xmldsig-core-schema.xsd"/>
	<!--________________________________________________-->
	<!-- *** ISO 15745 Profile definition ***-->
	<xsd:element name="ISO15745Profile">
		<xsd:complexType>
			<xsd:sequence>
				<xsd:element name="ProfileHeader" type="gsdml:ProfileHeaderT"/>
				<xsd:element name="ProfileBody" type="gsdml:ProfileBodyT"/>
				<xsd:element ref="ds:Signature" minOccurs="0"/>
			</xsd:sequence>
		</xsd:complexType>
		<!-- Unique Keys - not referenced -->
		<xsd:unique name="DeviceAccessPointItem_ID">
			<xsd:selector xpath=".//*/gsdml:DeviceAccessPointItem"/>
			<xsd:field xpath="@ID"/>
		</xsd:unique>
		<xsd:unique name="SubModuleItem_ID">
			<xsd:selector xpath=".//*/gsdml:VirtualSubmoduleItem"/>
			<xsd:field xpath="@ID"/>
		</xsd:unique>
		<xsd:unique name="SubslotNumber">
			<xsd:selector xpath=".//*/gsdml:Subslot"/>
			<xsd:field xpath="@SubslotNumber"/>
		</xsd:unique>
		<!-- Key Definitions -->
		<xsd:key name="ExternalText-ID">
			<xsd:selector xpath=".//*/gsdml:PrimaryLanguage/gsdml:Text"/>
			<xsd:field xpath="@TextId"/>
		</xsd:key>
		<xsd:key name="ModuleItem-ID">
			<xsd:selector xpath=".//*/gsdml:ModuleItem"/>
			<xsd:field xpath="@ID"/>
```

Figure 4. Data structure of the GSDML file

```
; Baratella / Humberto
; SENSE ELETRÔNICA LTDA
; Rua Francisco Moreira Carneiro,600
; Santa Rita do Sapucaí - MG
; 0(xx)35-3471-0866
;**********************************************************

#Profibus_DP

Vendor_Name          = "SENSE ELETRONICA LTDA"
Model_Name           = "DP-MON-2EH-2ST"
Revision             = "1.0"
Ident_Number         = 0x065F
Protocol_Ident       = 0          ; PROFIBUS-DP
Station_Type         = 0          ; DP-Slave
FMS_supp             = 0   ; Somente DP
Hardware_Release     = "V1.0"
Software_Release     = "V1.0"

9.6_supp             = 1
19.2_supp            = 1
93.75_supp           = 1
187.5_supp           = 1
500_supp             = 1
1.5M_supp            = 1
3M_supp              = 1
6M_supp              = 1
12M_supp             = 1


MaxTsdr_9.6          = 60
MaxTsdr_19.2         = 60
MaxTsdr_93.75        = 60
MaxTsdr_187.5        = 60
MaxTsdr_500          = 100
MaxTsdr_1.5M         = 150
MaxTsdr_3M           = 250
```

Figure 5. Data structure of the GSD file

3.2. **Ethernet/IP.** The Ethernet/IP standard was developed and standardized by OD VA (Open DeviceNet Vendors Association), and as well as PROFINET is based on the TCP/IP architecture. The IP term is not referenced as Internet Protocol at TCP/IP, and represents Industrial Protocol [1]. It is based on physical and data link layers from standard network protocol IEEE 802.3 [6].

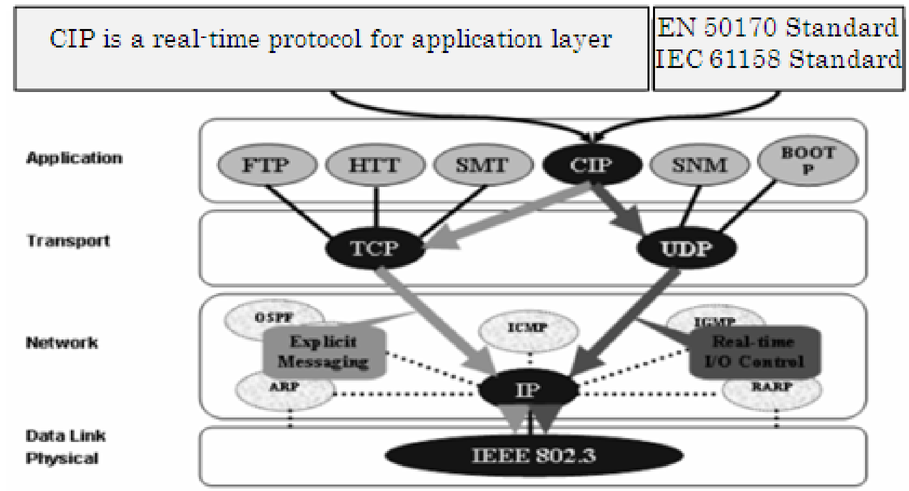

FIGURE 6. Ethernet/IP architecture

The Ethernet/IP network consists in exchange of information that is carried over TCP (Transmission Control Protocol) or UDP (User Datagram Protocol). TCP is a transport protocol where communication is reliable with acknowledgment with overheads and UDP does not provide warranty information delivery but is faster and requiring that low layers offer a reliable communication. While TCP has a cycle time of around 100ms and is used for configuring the network elements, UDP has its time reduced to 10ms cycle and is used to exchange information in real time [1].

The application layer of the Ethernet/IP is represented by CIP (Common Industrial Protocol). The CIP provides standards and services for device control via network messages. Is it responsible for presenting the information generated by the system architecture as shown in Figure 6. The CIP is encapsulated in TCP and UDP protocols, and is transmitted following the concepts of sending and receiving messages presented earlier [1,6].

The CIP is a protocol that is not compatible with the application layer of the PROFI NET, which makes the incommunicable networks among each other, but is presented in other networks such as ControlNet, DeviceNet and Ethernet/IP [6]. As it has also been developed by DeviceNet ODVA, some interfaces can be replaced according to need, Ethernet/IP interfaces [1].

There are three extensions to CIP protocol, which are: CIP Safety – which enables the use of secure devices to the same network CIP, CIP Sync and CIP Motion – extensions used for applications that require short response time, and high synchronization control rate of information transfer [21].

As the Ethernet/IP is based on standard Ethernet with TCP/IP and UDP/IP, in CIP all messages are sent based on the Ethernet frame. The frame has IP header and its structure is shown in Figure 7 [21].

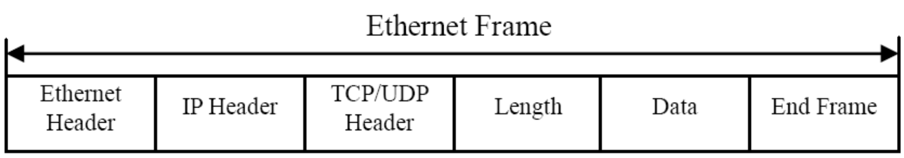

FIGURE 7. Ethernet frame for common industrial protocol

3.3. **HSE (High Speed Ethernet).** The HSE (High Speed Ethernet) network is applied to other industrial Ethernet and was developed by the International Association Fieldbus Foundation. HSE is employed as a backbone for industrial automation with distributed architecture.

However, HSE works in conjunction with H1 technology (IEC 61158-2 – 31,25Kbps), and that is possible integrate different devices linked on H1 Fieldbus. The H1 Devices communicate via link (DL) by HSE, as well as LD's can connect an H1 network with an HSE network, only performing data conversion. The communication scheme is shown in Figure 8 [1,6].

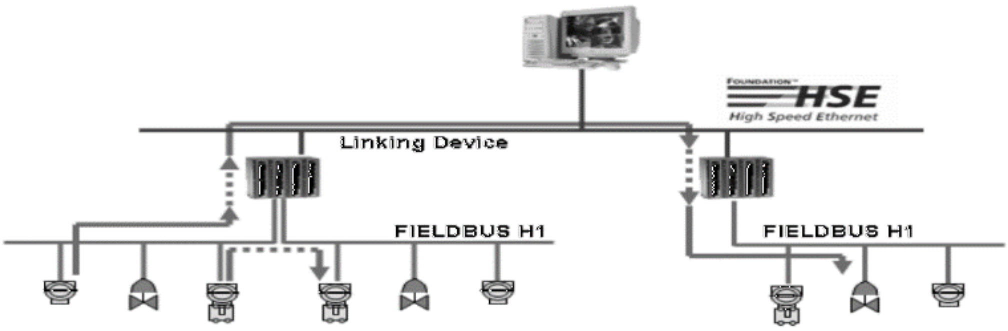

Figure 8. Industrial communication with networks H1 and HSE

It is interesting to mention that both the Fieldbus Foundation and the Profibus User Organization almost at the same time were setting up standards for fieldbus physical layers including the requirement to have intrinsic safety as an option and later on both decided to use the IEC Standard 61158-2 as their lowest level for both, Foundation Fieldbus H1 and Profibus PA.

The H1 is based on the IEC 61158-2 that has its background from the 4-20mA current interface feeding a transmitter or similar devices with up to 4mA and putting the analog information on top of this base current. For digital information the IEC 61158-2 uses a base current of at least 10mA. A logical "1" subtracts 9mA of this by cutting down the input current momentarily and logical "0" adds another 9mA. The data transmission speed depends on the capacitive and inductive load of the fieldbus derived from the cable as such and from the devices. The IEC 1158-2 uses a lowest frequency of 31,25Kbps which creates almost no restriction on the impedance of cable and devices.

The reason for definition of 31,25Kbps, is in first approach that they considered 1Mbpswas a very popular often easily obtained. Therefore, the 31,25Kbps is a sub-integer multiple of 1Mbps, i.e., 1Mbps $\div$ 32 = 31,25Kbps. Moreover, at the time of definition, the guys wanted a rate that is higher than that of competitors (Hart and Modbus) and still had great commitment to low power for instrument connection.

HSE network uses UDP/IP over the data link layer [1], and the application layer guarantees delivery of data unlike other networks where confirmation is performed at the transport layer [6].

The speed is determined by the rate of transmission of the Ethernet network, and reached its maximum 100Mbps. The physical limitation is due to the type of cable used and its length must not exceed 100 meters. The greater the length of the cable is, the greater the chance of losing information during transmission is, making the delivery of messages.

High Speed Ethernet (HSE) is ideally suited for use as a control backbone running at 100Mbit/s, and the technology is designed for device, subsystem and enterprise integration. It supports the entire range of fieldbus capabilities, including standard function blocks and Device Descriptions (DDs), as well as application-specific Flexible Function Blocks (FFBs) for advanced process and discrete/hybrid/batch applications.

HSE supports complex logic functions, such as those performed by Programmable Logic Controllers (PLCs), or data-intensive process devices, such as analyzers and gateways to other networks. HSE enhances access to H1 fieldbus technology via linking devices, while providing expanded capabilities for high-speed automation devices and hybrid/batch applications.

HSE enables tight integration and a free exchange of information needed for the plant enterprise. HSE is a superior solution to proprietary, Ethernet-based technologies since it provides end users with interoperable devices from multiple suppliers. And like H1, HSE is an international standard (IEC 61158).

HSE provides the same benefits as H1, but at the subsystem integration level instead of the field device level. It supports interoperability between disparate controllers and gateways in the same way that H1 supports interoperability between transmitters and actuators from different suppliers. FFBs in HSE devices can be set up using programming languages such as those found in the international standard IEC 61131-3.

It was designed from the ground-up to support fault-tolerant networks and devices used in mission-critical monitoring and control applications. All or part of the HSE network and devices can be made redundant to achieve the level of fault tolerance required for a particular application. Best of all, redundancy is supported using standard Ethernet equipment, thus eliminating the cost of special network equipment.

It also supports standard Ethernet wiring, including a fiber optic media option to provide cost-effective electrical isolation between plant areas or immunity from distortion through noisy environments.

3.4. **Comparative analysis of PROFINET, Ethernet/IP and HSE.** Ethernet networks have singularities which hinder interoperability of automated systems together. Parameters, as can be seen in Table 5 illustrate the comparison between the protocols in study.

The PROFINET is according to the PROFIBUS standard having as background the PROFIBUS and Interbus networks with support for real-time and good timing and cyclic communication properties satisfied. It uses in application level a suite of protocols of TCP/IP and can operate in process and factory automation.

The Ethernet/IP is managed by ODVA having nearly the DeviceNet and ControlNet networks, with owner application protocol named CIP and with low performance in real-time and timing. HSE is managed by Fieldbus Foundation and used to network interconnection and management with low performance in real time and timing. It has owner HSE application protocol.

However, the three presented protocols based on Ethernet standard can be used in differences levels of the automation pyramid according to the design requirements.

4. **Case Study.** The company PETROM (Petrochemical Mogi das Cruzes SA) conducted in 2004 a case study in a company located on Highway Mogi – Bertioga in Mogi das Cruzes, currently presenting a production area of 21.000 m^2 [22]. Its main objectives were: to increase the production of phthalic anhydride and improve the performance of reactors. For the realization of the project was established partnership between PETROM

Table 5. Comparative analysis of PROFINET, Ethernet/IP and HSE

Parameter	PROFINET	Ethernet/IP	HSE
Previous network	PROFIBUS or Interbus	DeviceNet or ControlNet	Foundation Fieldbus
Real time	Yes	No	No
Repetitor distance	100m	100m	100m
Timing performance	High	Low	Low
Application protocols	HTTP, SNMP, DHCP and other	CIP	HSE Application Protocol
Function	Interconnection of networks, motion control of robots and cyclic communication	Interconnection of networks, communication management and cyclic	Network interconnection and management
Baudrate	< 1Gbps	< 1Gbps	< 100Mbps
Topology	Star, tree and bus	Every Ethernet topologies	The major is in ring
Power	24Vdc	24Vdc	24/48Vdc

and CBTA (Brazilian Center for Automation Technology LTDA), Smar and Siemens companies. At the end of the project annual expected production capacity was 80 tons of phthalic anhydride, 90.000 tonnes of plasticisers and 3600 of fumaric acid [23]. With investments to meet the demand of its raw materials, production in the year 2013 proves to be greater: 82.000 tones of phthalic anhydride, 108 thousand tonnes of plasticisers, 4000 tons of fumaric acid and 18 tons of isoamyl alcohol [22].

The solution was to invest in automation to process control and safety which were improved. The PROFIBUS network technology based on fieldbus, to be known internationally and provide a wide range of instruments and suppliers was chosen as it is a robust and reliable protocol. In the project the PROFIBUS PA network was also used to control the existing heat exchangers. The exchange of data in this type of network is slower and is used for communication of analog with digital sensors networks [23].

The AS-Interface network was applied to some control points system. This network has the advantage of digital communication. It is a fast network and its physical assembly is simplified, streamlining possible maintenance and increasing reliability of the plant [23].

After choosing the network to be used, the number of required field for the first stage was complete automation equipment which was set. The equipment are: 130 PROFIBUS PAinstruments, 68 instruments in AS-Interface, 30 control valves for PROFIBUS PA, 3 frequency inverters on PROFIBUS DP and 13 motor drives on PROFIBUS DP [23].

According to this case study, the network architecture consists of two CPU's (Central Processing Unit) that are interconnected by Ethernet. Each CPU has an output for PROFIBUS DP, where ETM200M, PA/PA Coupler gateway equipment and a DP/AS-Interface are connected as shown in Figure 9.

The amount of U.S.$ 520.000,00 was invested in the first phase of the project and was responsible for process control and field mount system. The PROFIBUS system replaced the 4-20mA, generating savings of 40% over the cost of this old standard. This savings is due mainly to the reduction of cables. Before 15.000 feet of cable would be needed and the deployment of PROFIBUS was used approximately 6000 meters. For PETROM

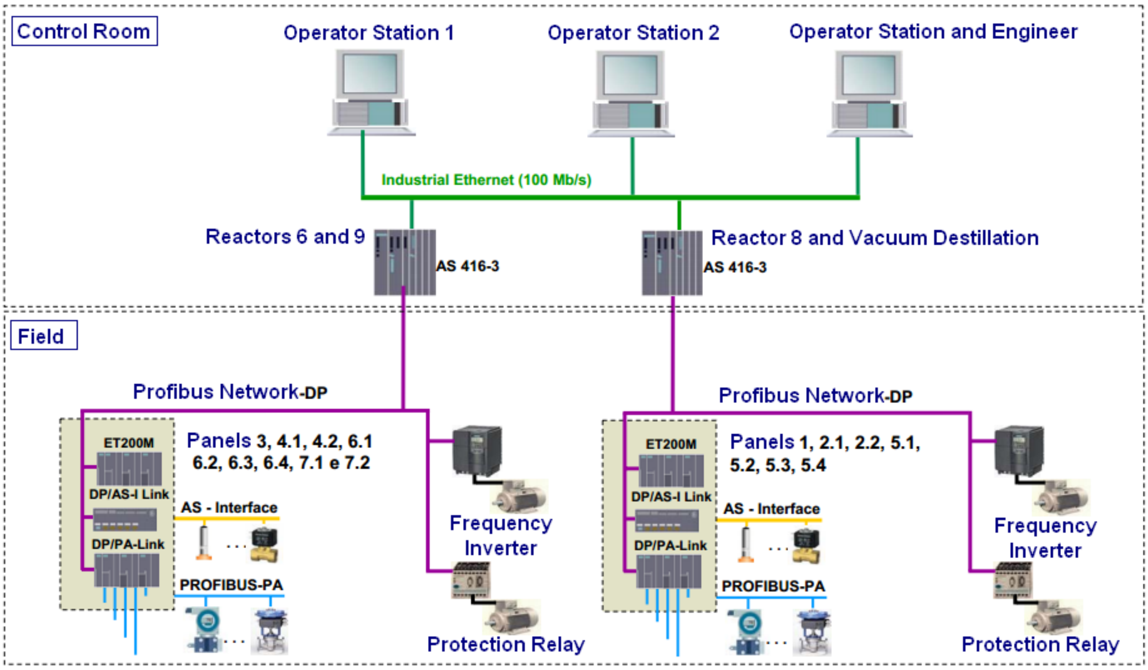

Figure 9. Case study of PETROM

its largest economy was on deployment time, physical space, training and starting up the plant. With the PROFIBUS, you can have input and output close to the sites of application interfaces, allowing a large reduction in the cost of installation of pipelines, ducts and wires [23].

5. **Target Application.** The case study was conducted by PETROM based on fieldbus networks used at the application level, but the focus of this analysis is based on the Ethernet network used for communication between the area – floor factory and supervision.

For this study to be performed the following computational tools will be used: Ethernet Simulator [1] and a computer application developed in order to observe the occupation of the network. These computational tools are responsible for viewing and analyzing virtually control systems and automation, as well as generating graphs and reports on the functional characteristics of the networks.

The aim is to analyze, through these tools, the network shown in the case study conducted by PETROM which is overloaded or if there is the possibility of increased operating equipment. The network analysis is of high importance due to the risk in a production environment, such as PETROM. To prevent possible accidents that may occur due to the explosive atmosphere presented at the operational level, the transmission must be performed safely and reliably, while minimizing the probability of packet loss.

Thus, the analysis of the two computational tools is presented and the results are compared.

5.1. **Ethernet simulator.** To analyze the simulator tool Ethernet, it uses a transmission rate of 100Mbps and scan time is equal to 10ms. Since, the goal is not to verify the network of fieldbus (PROFIBUS and AS-Interface), but only the network supervision and control of information (Industrial Ethernet). It is considered as input and output bytes of the maximum number bytes each instrument connected to these networks. The Gateway ET200M and DP/AS-Interface supply, each, 16 bytes of information to the PROFIBUS

DP. The DP/PA Coupler provides 244 bytes. Therefore, the maximum available for all devices in the PROFINET network is 276 bytes input and 276 bytes output.

In Figure 10, which also illustrates the arrangement of the instruments in the network, the cable length between each machine is the maximum allowed for an industrial Ethernet network distance used, which is 100 meters.

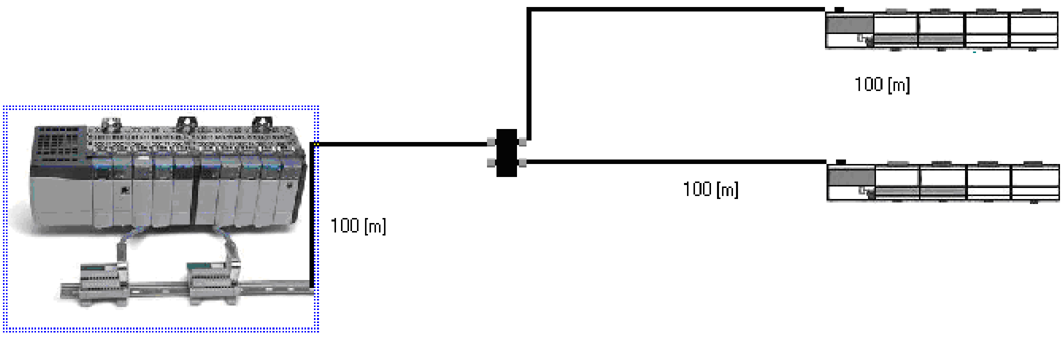

Figure 10. Network topology in simulation tool

After mounting the tool topology and setting its parameters, using 1.25% of the capacity of this industrial Ethernet, with the remainder available for the addition of other components or acyclic network message traffic is observed. Figure 11 illustrates graphically the results presented by the computational tool.

The occupation of each device within the percentage used is equally divided. This occurs because the number of bytes of input and output available to each device is equal, so the distribution of information will be the same on each device. If there are differences between the bytes of input and output, the percentage of occupancy will not be equal, being directly proportional to the amount of information provided. Figure 12 shows the occupancy of each module in the network.

Through computational analysis tool Ethernet Simulator low network utilization is observed, with the addition of possible instruments on the Ethernet bus. This network enables high scalability to the enterprise, providing the additional equipment, and checking that there is no information overload if necessarily expanding the productive system.

5.2. **Real communication – socket simulation.** The purpose of this application is to perform the actual communication between two devices on an Ethernet network in order to analyze the time required to conduct a full scan cycle. The computational analysis was based on a common Ethernet network. In the simulation socket, perform the analysis on PETROM Ethernet network, if two computers are interconnected so that each plays the role of a device on the Ethernet bus. A computer has a computer application "client" whose function is to send a message using UDP protocol, with the number of bytes in the fixed package 552. This number only represents the bytes of useful information (excluding the bytes for header, IP and Ethernet encapsulation, among others reserved to perform communication). The other computer has a computer application "server", whose purpose is to receive the message sent by the client and respond with a message of the same size. This process is responsible for simulating the traffic case study of PETROM industrial Ethernet network.

Figure 13 illustrates the interconnection of computers used to perform the simulation.

The "client" computer was installed a computational tool called *Wireshark* [24] that passively analyzes information trafficked by the network card. This analysis was based on

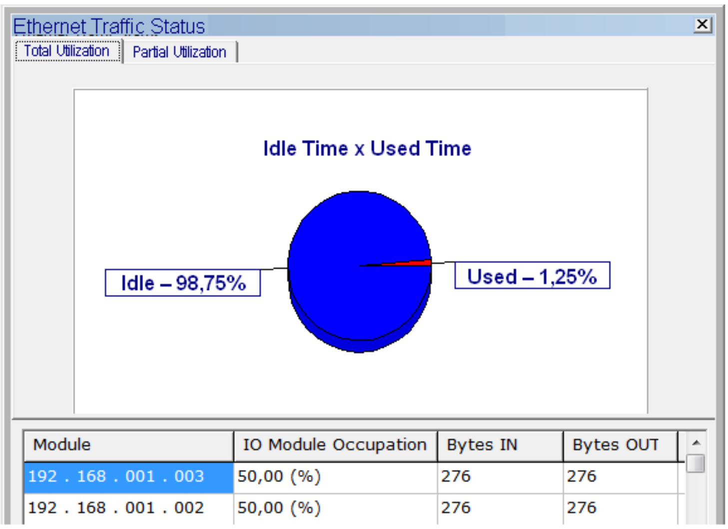

FIGURE 11. Bus load graphic

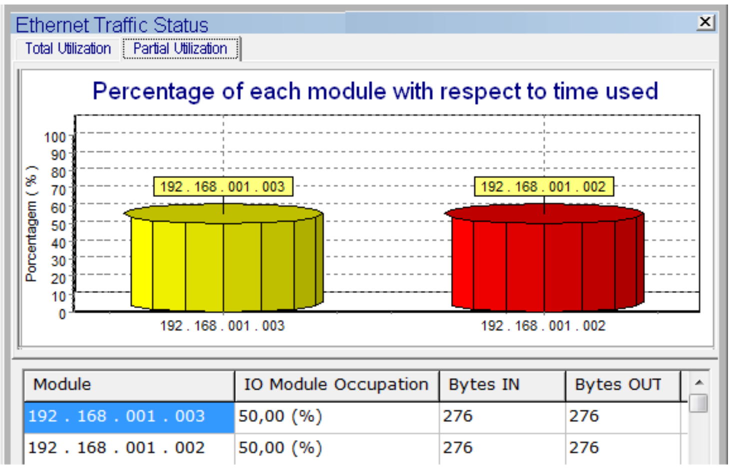

FIGURE 12. The partial utilization graphic from each UCP

FIGURE 13. The hardware platform for experimental tests

three different simulations. For the first simulation, the "client" application and "server" are on the same computer, so the packets would not be routed externally being processed

Time	Source	Destination	Protocol	Length
102.566276000	127.0.0.1	127.0.0.1	UDP	594
102.566404000	127.0.0.1	127.0.0.1	UDP	594

FIGURE 14. Screen of the analyzer for use in loopback

Time	Source	Destination	Protocol	Length
93.622960000	10.0.0.1	10.0.0.2	UDP	594
93.623437000	10.0.0.2	10.0.0.1	UDP	594

FIGURE 15. Screen of the analyzer for the application with the computers connected directly with a network cable

Time	Source	Destination	Protocol	Length
6.075679000	10.0.0.1	10.0.0.2	UDP	594
6.076345000	10.0.0.2	10.0.0.1	UDP	594

FIGURE 16. Screen of the analyzer to the application with the connected computers through a switch

and only loopback has been installed. Thus, the time delay obtained was conditioned by the private network equipment and operating systems involved. The result was 128ms, the time required for the packet out of a computer and receiving the response "server" on the same port, as shown in Figure 14.

In the second simulation, the "client" application and "server" were installed and run on different computers. Their results were obtained by linking these computers directly via a conventional network cable. After establishing a stable connection between the two PCs (Personal Computers), and isolating them from other connections of this network, it was possible to perform communication. In this simulation, it is possible to observe the presence of communication delays. These delays are related to the computational processing and the delay of the network card to send information. As illustrated in Figure 15, one can observe that the time increased to 477ms, due to the delays mentioned.

The third simulation is performed similar to the second, but the interconnection of computers is made indirectly through a switch. The communication by means of a switch generates, besides the computational processing delays and delays relating to network cards, a delay caused by the switch itself. According to LUGLI [1,9], for an industrial switch, the typical delay is 9.6μs. The switch requires internal processing to identify the MAC address (Media Access Control) to determine the source and destination of the packet, thus generating significant delays. The time found for this case was 666ms, as shown in Figure 16.

5.3. **Results analysis.** The time of network utilization found by computational tools should only be compared when the application runs in loopback, because the computational application Simulator Ethernet was developed disregarding any form of delay in reporting by the network or operating system.

The computational application Simulator Ethernet occupation showed 1.25% of the network. As the scan time of 10ms, to perform the calculation of use of this time, the value is 125ms. Running the application in loopback found a time of 128ms. When performing the same calculation, the occupancy rate of the net is 1.28%, and a value close to that is proposed by Ethernet Simulator application to a communication without delays of operating system and network traffic.

```
if ((numbytes = sendto(sockfd, argv[2], strlen(argv[2]),
                 p->ai_addr, p->ai_addrlen)) == -1) {
        perror("talker: sendto");
        exit(1);
}
```

FIGURE 17. Function responsible for sending data packets over a socket

```
if ((numbytes = recvfrom(sockfd, buf, MAXBUFLEN-1 , 0,
        (struct sockaddr *)&their_addr, &addr_len)) == -1) {
        perror("recvfrom");
        exit(1);
}
```

FIGURE 18. Function responsible for receiving data packets over a socket

The two computational applications used were accurate results, revealing a large symmetry in the measurement of the proposed values. The difference of 0.03% is acceptable to know that even in loopback communication is not ideal, with delays, but less significant.

In Figures 17 and 18, you can see part of the program made to realize the communication between the network elements.

Figures 17 and 18 show part of the code developed to realize the communication between the network elements. Figure 17 shows the function responsible for sending data packets over a socket, and in Figure 18, the code is responsible for receiving data packets over a socket.

6. **Conclusion.** Industrial Ethernet shows to be a very well developed technology to ally IP in communication within the industry standard TCP. Using a standard such as TCP/IP is possible to provide network technologies that can satisfy the requirements of distributed applications as flexibility, scalability and determinism.

Several devices enable scalability and change the topology of the networks already deployed in industries. As an example, you can enter the network, gateways that perform the connection between a network and a PROFINET fieldbus AS-Interface and are one more reason to use an industrial Ethernet network as solver on expansionary measures.

The results obtained by practical application show that the industrial Ethernet network is a network PETROM little used – only 1.25% is occupied with field information (sensors and actuators). Excluding delays generated in practice it is possible to use the same network configuration, supporting 80 plants equal to PETROM on the same Ethernet network proposal. The equipment arranged in the way that was disclosed allows a major expansion in their production without any traffic loading on the Ethernet network.

When considering the result obtained using a switch (generating the longest delay between simulations), the occupancy rate remains relatively small, being 6.66%. PETROM still has in its network, a large clearance, should be paid attention to only when connecting new equipment so that the rate did not grow excessively.

Other factors such as cable connections, and switches using connector types are also important for achieving good communication of each instruments in the network. The physical part is very important as well as network utilization. The computational applications are of vital use to design and architect new networks in an industrial context. There are cases, arranged in the industrial community, where poor implementation of a network took serious damage to property. The simulation should be performed, proving to be extremely valuable in preventing damage, and selecting the best equipment for use in specific applications.

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