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A STUDY ON SOME INDUSTRY 4.0 KEY TECHNOLOGIES

Alexandre Baratella Lugli[1], Antônio Marcos Alberti[1]
Tales Cleber Pimenta[2] and Thiago Bueno da Silva[1]

[1]Department of Industrial Automation
National Institute of Telecommunications (INATEL)
CEP 37.540-000, Santa Rita do Sapucaí, MG, Brazil
{ baratella; alberti }@inatel.br; thiagobueno@gea.inatel.br

[2]Institute of Engineering System and Information Technology
Federal University of Itajubá (UNIFEI)
CEP 37.500-903, Itajubá, MG, Brazil
tales@unifei.edu.br

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Abstract. *Industry 4.0 is a trend that aims to revitalize the industries in a global scale. In order to achieve this ambition, it considers encompassing several disruptive concepts and technologies in factories, transforming an outdated environment into a smart factory capable of dealing with the current demands of an ever-changing world. In this scope, this article aims to present some relevant technologies that foster this vision, focusing on Industrial Internet of Things, Cloud Computing, and Industrial Ethernet Networks that are Industry 4.0 driven. In addition, this paper shows a comparative analysis among some real time Ethernet protocols, applied to the Industry 4.0 concept.*
Keywords: Industry 4.0, Industrial Internet of Things, Industrial Ethernet Networks, Protocols, Smart factories

1. **Introduction.** The Industry 4.0 (I4.0) is nothing more than a trend that represents the upcoming fourth industrial revolution. This new revolution is taking place in the current days and it aims to encompass Information and Communication Technologies (ICT), such as Cloud Computing (CC), additive manufacturing, and Cyber-Physical Systems (CPS), in the industrial factories, making these environments more autonomous, competitive and efficient. Therefore, I4.0 will achieve a factory that does not require too much human influence, a place where the own devices will be performing the processes and combining the efforts mostly by themselves. Finally, these same systems will also be able to optimize their own results by the combination of machine learning, artificial intelligence and decentralized controls.

Will this be a major step towards an era in which robots fully replace humans in the industrial workforce? Well, this is out of the scope of this paper and it lies more in the field of philosophy and futurism. Nonetheless, one thing is certain: the I4.0 will lead to huge changes in the society for sure. When this concept is implemented, the role of humans in the industrial environments will be even more related to higher-level tasks, such as supervision and management of the processes, than related to directly interacting with them, dealing with the raw materials or performing basic tasks. In fact, this shift has already been seen during the past industrial revolutions, yet none of them represented such social and cultural disruptions as this upcoming one, once one of I4.0 pillars is also to establish an efficient and continuous communication among machines. Moreover, I4.0 will even affect in the tasks related to the maintenance of industrial plants of the future, when the concept of "self-healing" devices is truly and effectively achieved and implemented.

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This paper presents a review focused on a set of I4.0 technologies, composed by the Industrial Internet of Things (IIoT), Cloud Computing and the Industrial Ethernet Networks that are qualified to be employed in the I4.0 context. In addition, this paper presents a comparison about the main market industrial real time Ethernet protocols, about each technical characteristics, an overview of the main IIoT protocols and the industrial development. Therefore, Section 2 focuses on the I4.0 paradigm and it discusses the selected technologies of I4.0, characterizing each trend and deepening on some concepts related to its topic. Section 3 gives discussion and future industrial challenges. Finally, Section 4 concludes this paper.

2. **Industry 4.0.** The first grasp of the so called "Industry 4.0" was developed as a German governmental initiative in 2011 [1]. This proposal is a German response to deal with the ever-growing aggressiveness of global competitiveness and the ever-shrinking cycle time in markets requests by incorporating new technologies that allow more customizable, connected and autonomous processes. Some other contemporaries' initiatives to boost industries could be seen in other countries, such as the French "*Industrie du Futur*", the Chinese "*Made in China 2025*", and the Japanese "*Industrial Value Chain*" [1,2]. Even though they come from other countries, most of these plans are inspired or based on German I4.0, so they share the same beliefs, even they may diverge on the approach.

In summary, the I4.0 is a movement to incorporate new ICT technologies in industries, changing its own paradigms of production, supply chain and management to achieve a "Smart Factory" environment [3]. Through this shift, it will be possible to achieve a flexible mass production, regarding products and quantity, shortening production cycles and lowering overall costs [4]. Moreover, I4.0 can be the solution to handle the ever-growing production complexity of processes [5], once it also aims to provide some self-everything or self-* properties (e.g., self-configuring, and self-optimization) to the factories' systems. Thus, the devices will be able to reconfigure their own internal and external resources to produce a customizable item in a reasonable time, while maintaining the factory's competitiveness upon some random request [6].

Concerning these new technologies to be adopted in industrial environment, each country proposal has its own favorites and gambles in which they believe that are going to be essential in the future. Nonetheless, most of these modernization approaches agree on Cyber-Physical Systems (CPS), Cloud Computing (CC), Industrial Internet of Things (IIoT), and decentralized control [6].

2.1. **Industry 4.0 key technologies.** The concept of I4.0 is boosted by several disruptive technologies. Nonetheless, this paper will focus on IIoT, CPS and Industrial Ethernet Networks, which the authors believe to be the current key advancements on the industrial fields, largely investigated on the academia or private initiatives. These trends combined provide the virtualization of resources, the intertwining of the physical with the virtual world and the extreme connectivity between devices, systems and stakeholders, which achieves an optimal management and usage.

2.1.1. *Industrial Internet of Things.* IIoT is nothing more than a branch of the broader technology trend called Internet of Things (IoT). Above all, the main distinction lies on the fact that IIoT is mainly designed and applied for industrial automation applications. Thus, these specific devices must be compatible to work in such environment, which is more hostile than the ones that conventional IoT devices are projected to work in. Then, IIoT must meet high levels of robustness, reliability and security parameters to be suitably deployed in an industrial environment [7].

Comparing these two technologies, IIoT will suffer a slower acceptance than IoT. To illustrate this, Gaj et al. [6] and Schneider [7] argue that IIoT will not only be completely accepted without meeting the industrial requirements (robustness, reliability and security), but also they must encompass and guarantee a fully real-time communication in any context and promote to create an interoperable environment, once the current factories are a highly heterogeneous environment, with several vendor-specific solutions.

Industrial Internet of Things protocols. The IIoT protocols are used in communications between Operational Technologies (OT), which are the ones that impact or oversee an industrial process or asset, and Information Technology (IT), which are concerned with the overall industrial information processing. These protocols aim to convert the information between OT and IT, e.g., a temperature measurement from the OT spectrum to an IT application. Nowadays, the main protocols employed in the industry are the Message Queue Telemetry Transport (MQTT) and OPC Unified Architecture (OPC UA) [8].

- **MQTT:**
  Andy Stanford-Clark (IBM) and Arlen Nipper (Eurotech) developed the protocol in 1999. This is a Machine-to-Machine (M2M) application-oriented messaging protocol, based on the publish/subscribe communication model. Its purpose is to operate in environments with insecure networks, low bandwidth and high latency, as well as embedded devices with limited memory and processing resources. MQTT protocol is currently in version 3.1 and it adopts the TCP/IP protocol and the publish/subscribe message standard. Through this arrangement, all data is sent to an intermediary, or broker, who is responsible for sending the information to the correct recipients. This structure allows to decouple the customer from the producer and to enable one-to-one, one-to-many, or many-to-many communication, wherein the only requirement lies on the knowledge of the broker address to forward the data. Concerning the protocol, each of the MQTT command messages has a fixed header composed of two bytes. From these, the first byte contains the field that identifies the message type in addition to the marker fields, while the second is used to represent the number of bytes remaining in the message, including the variable header and the payload data. In fact, the variable header is a component present in some MQTT message types and it is located between the fixed header and the payload, composed by two fields destined to identify the protocol name and version, besides of a series of markers that will define some directives for the publisher-subscriber connection [8].
- **OPC UA:**
  The protocol defines a series of communication interface specifications introduced in 1996 by the OPC Foundation. This was initially designed to address weaknesses inherent in proprietary protocols at the time, besides of fostering the reliable data exchange and the inter operability between different devices in the industrial automation sector. In this environment, the fieldbuses establish a physical layer that is common to all field devices of a given standard and each manufacturer has its own interface at the software level. Meanwhile, the manufacturers of Supervisory Control and Data Acquisition (SCADA) and Human Machine Interface (HMI) systems have to create specific drivers for each device to communicate. Therefore, the OPC standard aims to provide a standard interface for different devices on a system to communicate without having to understand how they work at the hardware level. The protocol establishes the operations that every device should implement, the standard of how a given data should be treated and it employs an object-oriented concept in its approach. Each OPC UA server has an *AdressSpace* associated with it, which defines a set of information that customers can access and provides objects that offer a complete model with metadata along with the variables. For instance, a pressure sensor operating with OPC UA can return data beyond its pressure reading: its model, reading unit, tolerance and a multitude of other information that

can be customized to suit a given application. Therefore, the metadata enhances the application of machine learning tools and analytics in an industry facility. Suppose, for example, that the sensor begins to give erroneous readings. Through the metadata provided by a device, control algorithms can detect the failure and draw a behavioral profile of this device over time. If another sensor in the future begins to behave similarly to the defective component, the algorithms may request full automatic maintenance, reducing operating costs and downtime. In terms of the object-oriented approach, techniques such as inheritance and classes allow objects to explore parallel programming techniques, speeding up the process of implementing a system [8].

2.1.2. *Cloud Computing.* The broader concept of Cloud Computing (CC) exists since 1960. Nonetheless, the modern idea was first introduced in 2006 by the Google's CEO Eric Schmidt, which defined the term "cloud" as a "business model of providing computational resources through the Internet" [9].

Since its modern definition, CC paradigm provides some key advantages that attract businesses to contract its services, since it reduces considerably up-front investment, fixing costs related to operations and variable costs related mainly to maintenance of the computational infrastructure [9]. Moreover, CC enables the dynamic allocation of computational resources, turning this asset scalable and the easy management of data, since it is transparent to users [9,10].

Nonetheless, CC presents some challenges that still need to be addressed overall. Some of these issues can be associated to energy efficiency, traffic management and data security [9]. These topics are continuously developed by private enterprises, such as Google, Amazon, and Microsoft, and by the academia. Through these advancements, CC will be fully exploited in several contexts, from start-ups to more complex areas, such as health and industry.

One interesting outcome of these enhancements on CC field was the development of two distinct branches of this service, which led to improvements of its Quality of Service (QoS) in accordance with the target application. In brief, CC is currently divided in Cloud Computing and Edge Computing (EC). Furthermore, EC can be subdivided in three major approaches: Fog Computing (FC), which is a distinct EC that works jointly with the Cloud, Multi-Access Edge Computing (MEC), applied to mission-critical environments [11], and Cloudlet, used to mobile computer-intensive and latency-sensitive applications [11]. The generic CC service is the first introduced branch concerning the cloud services and it encompasses public, private, and hybrid clouds [9]. Each of these approaches has its own perks, but they are often deeply affected by reliability, connectedness, and security [10]. This branch presents a higher latency to the application, being aggravated by several factors, but mainly by the Cloud owner's network performance and by the distance between the cloud data center and the target application [11]. In an industrial context, this is a serious issue.

FC is an EC approach proposed to handle the connectivity limitation between the cloud and the end-user or end-device [10]. Thus, FC handles this restraint by placing the cloud service closer to the target application, or "at the edge of it". Through this approach, EC is suitable to perform latency-sensitive tasks, improving the service's spectral efficiency [12], providing a superior support to machine communication, and enabling power and location awareness [13]. In this context, the cloud handles the delay-tolerant applications [14]. For instance, the Fog could manage an alarm to avoid an accident in a reasonable time, while the Cloud could apply machine learning and big data algorithms to historical data [15].

2.2. **Industrial Ethernet Networks for Industry 4.0.** The TCP/IP model, formulated by Vinton G. Cerf and Robert E. Khan, is a union of two communication protocols between network computers: TCP (Transmission Control Protocol) and IP (Internet Protocol). This came in order to make the connection between different types of networks, providing services such as voice, data and image [16].

The Ethernet protocol, developed by Robert M. Metcalfe, operates at the data link layer of the TCP/IP model and it aims to implement the communication at local networks, also known as LAN (Local Area Network) [16,17].

As a consequence of the association of digital controls and smart sensors developed in the 80s, the idea of creating innovative digital networks, called fieldbuses, was boosted to replace the industrial 4-20mA standards. These new networks promised the simplification and flexibility of the systems, in which the exchange of information between the factory floor and administrative levels would be made by a single physical mean [18,19].

There are several fieldbuses in the industrial area, such as DeviceNet, PROFIBUS, and Foundation Fieldbus. Over time, communication and interaction between these different fieldbuses became necessary, so they had to be adapted to the Ethernet technology. However, each manufacturer developed its own standard for Industrial Ethernet, each of which (and each one of them) differed in the use of the TCP/IP layers and the network applications. These differences did not meet or answer the interconnectivity between the various standards [18,19].

In fact, there are fourteen protocols that are applied as Industrial Ethernet that are PROFINET, Ethernet/IP, HSE (High Speed Ethernet), Modbus/TCP, EPA, EPL, EtherCAT, IEC 61850, JetSync, PNET, Sercos III, SynqNet, TCnet and Vnet/IP [16,19]. From these, the protocols PROFINET, Ethernet/IP and HSE are more used in industrial environments [16,19]. Table 1 shows a comparison between similar features of Industrial Ethernet Networks discussed here, contrasting the main protocols employed in the industry.

3. **Discussion and Future Industrial Challenges on Industry 4.0.** Through the concept of Industry 4.0, the current barriers of industrial plants might be broken. In other words, these areas of economical production will be connected worldly due to the several concepts being incorporated in the Industry 4.0 proposal. Some technological examples were presented in the previous section, grasping the connectivity within a factory through the introduction of IIoT and the Industrial Ethernet Networks (IEN), while CC and IEN grant the external communication, being these to a specific industrial device from another industry or to a stakeholder desiring to check a productivity data.

Considering the advantages of Industry 4.0, it can be cited the real-time assessment of resources, which can be seen in Saez et al.'s work [20] that combines robots, CNC machinery, Ethernet/IP protocol and Cyber-Physical System concept. In addition, an increase of efficiency can be expected due to this shift of concepts. For instance, the logistics within a production process encompasses 95% of the whole execution time [21]. This can be optimized through the concepts of Artificial Intelligence, which can be seen in Zhong et al.'s work [22] that combines Big Data, Cloud Manufacturing and an RFID-enabled shop floor.

On the other hand, Industry 4.0 presents several challenges to be fully implemented and exploited. The first one that can be pointed lies in the reliability of these future systems and their interconnection, which is severe considering an industrial environment. In addition, there are several concerns about the latency of Industry 4.0 connectivity, as shown in Dai et al.'s work [23] that a delay derived from the Cloud impacted their results in the proposal of a Cloud-based decision support system for self-healing in distributed automation systems. Moreover, security, privacy and sensitiveness of data require an extra care, as seen in the Triton's case [24], a malware that targeted specifically the safety instrumented systems designed by Schneider Electric SE in 2017.

Table 1. Comparison between the PROFINET, Ethernet/IP and HSE networks [16,18,19]

	PROFINET	**Ethernet/IP**	**HSE**
Physical environment	- twisted pair; - fiber.	- twisted pair; - fiber.	- twisted pair; - fiber.
Distance	- up to 100 meters of the twisted pair without a repeater; - up to 2000 meters of fiber without a repeater.	- up to 100 meters of the twisted pair without a repeater; - up to 2000 meters of fiber without a repeater.	- up to 100 meters of the twisted pair without a repeater; - up to 2000 meters of fiber without a repeater.
Maximum number of nodes	256.	256.	256.
Voltage applied to the nodes	24 V_{DC}.	24 V_{DC}.	24/48 V_{DC}.
Types of communication	- NRT (*Non Real Time*); - SRT (*Soft Real Time*); - IRT (*Isochronous Real Time*).	Follows exactly the model TCP IP, with two modes of operation.	Based on protocols Ethernet, IP and TCP/UDP.
Interoperability	Full interoperability between network elements is certified through the transposition of the existing application profiles.	Full interoperability with other Ethernet/IP products, certified by the ODVA.	Interoperability is performed from the link device, which makes the communication between various segments Fieldbus H1 with HSE.
Interconnectivity	From Proxies, PROFINET offers a transparent communication with PROFIBUS, Interbus, ASI, and other protocols based on Industrial Ethernet.	From a transparent routing with DeviceNet and ControlNet.	From the GD device (gateway device), communication is made from an HSE network with the network H1.
Network topology	- star; - ring; - tree; - bus.	- star; - ring; - tree; - bus.	- star; - ring; - tree; - bus.
Rate of transmission	Up to 1 Gbps.	Up to 1 Gbps.	Up to 1 Gbps.
Redundancy	Yes, with a ring topology to the physical medium with MRP (Media Redundancy Protocol) technologies and MRPD (Media Redundancy with Planned Duplication). It has the possibility of another kind of redundancy, the system with two controllers (PN I/O controllers) synchronized.	Yes, one built-in switch technology in ring topology.	Yes, several levels of redundancy, such as field sources, signal conditioners, controllers and interface cards, communication master (LAS) and Ethernet networks.
Distributed intelligence	Yes, smart devices allows the direct communication between Controller and Controller, in the IRT (Isochronous) mode.	Yes, smart devices allow the distributed control through an exchange of messages, such as producer/consumer.	Yes, it is performed by means of functional blocks, providing a uniform configuration throughout the system.

4. **Conclusion.** In a world of ever-changing processes and ever shrinking timespan between evolutions, the industry and automation practices must break their own paradigms and adapt themselves into this new reality. Nonetheless, new advancements must consider the past technologies and integrate them into new approaches, once some of these mature

systems can still be exploited on factories and internationally all of them are evaluated in more than 50 billion dollars [25]. Therefore, the new technologies take a pivotal role in migrating these aged structures into a new infrastructure and diminishing the industrial stakeholders' bias towards investing into new technologies.

Allied to this objective, the I4.0 is an attempt to increase the current factory's competitiveness and take care of the increasing complexity of the industrial systems. Moreover, new technologies will still be suggested and incorporated in this context as they also mature. For instance, there are studies already considering and evaluating the application of 5G and future mobile networks in the I4.0 scope.

The Industry 4.0 is a current worldwide hot topic of research, where some new approaches are being proposed often in congresses and in journals. Consequently, it seems that a complete or a set of architectures for this environment is still far to be adhered comprehensively, since every new approach tries to solve a problem in a different manner and does not address all the industrial concerns regarding the adoption of Cloud Computing, Cyber-Physical Systems and so on.

Currently, a European *Reference Architectural Model Industrie 4.0* has been proposed [26] and some other related projects are being sponsored by many initiatives. For instance, the European private-public partnerships under the European economic recovery plan sponsored about 150 projects under the factories of the future call under FP7 program and it continues under the Horizon 2020 program [27].

Finally, this article focused on a study of Industrial Internet of Things, Cloud Computing and Industrial Ethernet Networks, which are concepts related to boosting the Industry 4.0.

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