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A Novel CPPS Architecture Integrated with Centralized OPC UA server for 5G-based Smart Manufacturing

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Abstract

The deployment of a Cyber Physical Product System (CPPS) is an important system that must be accompanied in order to build a smart factory. Based on 5G network, it is true that Smart Factories move physical factories to a digital-based cyber world through CPPS and monitor and control them intelligently and autonomously. However, the existing architectures of CPPS present only abstract modeling forms of architecture, and there was a lack of research into applying the OPC UA Framework (Open Platform Communication Unified Architecture), an international standard for data collection and exchange at smart plants, as the basic framework of CPPS. Architecture Configuration This enables the implementation of CPPS, which can include both cloud and IoT, only when field data distributed under a CPPS architecture is collected and centralized on a centralized server. In this study, a CPPS architecture was implemented through a central OPC UA server that applied the technology system to the OPC UA Framework compliant with the Central Processing UA Framework based on the 5G network, and a CPPS architecture, including how the OPC UA modeling process automatically generated CPPS logic and data processing processes, were actually implemented to study its performance and availability.

Keywords: Industry 4.0; Smart Factory; CPPS Architecture; 5G Network; OPC UA TSN

1. Introduction

In the Industrial 4.0, CPS refers to the same implementation of the physical world on a cyber basis using IT technologies such as IoT and ICT, and real-time delivery of realistic actions or phenomena of the physical world to the cyber world and feedback to the physical world through logical process processing. In smart factory, CPS is implemented through data collection and exchange of actual factory machines, actuators, sensors, etc. called Cyber Physical Production System (CPPS). Thus, the CPPS concept increases autonomy and flexibility in the industrial environment, ensuring high levels of integration and interoperability between manufacturing applications and systems.

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CPPS is composed of various IT technologies such as IoT, Cloud, TSN and others, along with OT (Operating Technology), which operates process operation and equipment and facilities related to production process. In these diverse environments, connectivity between systems and equipment is essential. However, this is not a simple task because of this variant model, such as various installations and devices, and should incorporate a very wide range of systems and concepts. Interoperability of devices, equipment, and systems requires an integrated architecture that enables possible exchange of information. In an integrated environment, the promising OPC UA (IEC 62541) standard provides interesting features such as service-oriented architecture, data security, and reliable information models. In this study, CPPS helps to achieve two main objectives of vertical integration among various objectives: (1) data collection related to plant site processing [1] and (2) command transmission to control devices [2].

OPC UA is trying to combine with various technologies to meet the needs of vendors such as real-time and QoS. To implement real-time communication of OPC UA, OPC Foundation wants to apply Time Sensitive Networking (TSN) technology. Based on TSN technology, the correct transmission time of data can be ensured to implement deterministic networks and meet the communication requirements of various Industry 4.0 fields.

In addition to TSN, 5G networks used in various network IoT environments are also one of the most important requirements for realizing manufacturing scenarios. The future manufacturing industry will have complex manufacturing scenarios, including real-time health monitoring of all manufacturing equipment, operational and management modes based on service-oriented technologies, design processes and assembly maintenance. 5G is the foundation for building CPPS through high communication speeds compared to conventional radio communication technologies in complex manufacturing scenarios.

Some of the OPC UA architectures previously presented introduce existing technologies that can be applied to CPPS automation with OPC UA servers. In this sense, the relevant tasks, paradigms, and implementation technologies, i.e. service-oriented architectures and CPPS architectures, provide an overview of the 5G network.

The composition of this paper is explained in Section 1, Introduction, in Industry 4.0, the definition of CPPS and the need for 5G network, as well as the need for this study. Section 2 related sections describe the 5G network and OPC UA TSN required for smart manufacturing before describing the system proposed in this paper. Section 3 The Proposals section of this paper proposes a CPPS architecture utilizing a centralized OPC UA server and discusses the architecture's construction and role. Section 4 Implementation defines a sample factory and implements the resulting OPC UA Modeling in line with the architecture proposed in this study to automatically add to the OPC UA server / client and demonstrate its implementation process and results. Section 5 describes the limitations of the system proposed in this paper in the results and the direction of the study after its orientation.

2. Related Work

2.1. 5G Network

The mobile communications technology has experienced three important periods, namely 2G voice digitization, 3G multimedia and 4G wireless broadband, respectively. With the continued growth of new mobile devices, telecommunications services and network traffic, existing mobile communication technologies can no longer meet growing demand. 5G is a technology that has much better data transmission speed, latency, and capacity of terminals on network than previous LTE. For data transmission speeds, the company aims to achieve a maximum speed of 20Gbps (2.5GB per second), which is 20 times faster than LTE with a maximum of 1Gbps and a minimum of 1ms for latency. It can accommodate up to 1 million units for handset capacity. Many scholars carried out various research tasks on 5G wireless communication technology prior to the large-scale deployment of 4G LTE. Fig. 1 represents the RAN Architecture of 5G.

For example, the architecture of the 5G communication network, the air interface, antennas, and heterogeneous network interconnections were investigated by [3]. The literature [4] conducted studies of communication channels, beamforming, large-scale MIMO, and full-duplex technologies for the physical layer of 5G wireless communications. Changes in the physical layer will inevitably lead to changes in the media access control layer. Thus, related technologies at the MAC layer, such as multi-access, multiplexing, and frame structures, also attracted research attempts [5]. To ensure a good user experience, [6] studied QoS of 5G wireless networks, quality of experience (QoE), and self-organizing networks (SON). In addition, integrating green and sustainable technologies into future 5G wireless

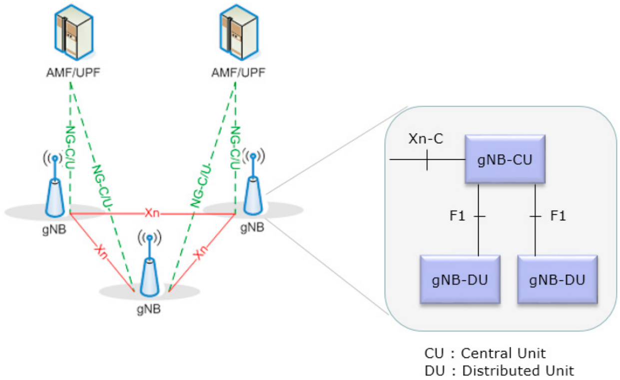

Fig. 1. 5G/NR - RAN Architecture

networks has become even more important to achieving significant energy savings. As a result, the literature [7] conducted a preliminary study of the energy consumption of the 5G network.

2.2. *OPC UA TSN*

Within the IEEE 802.1 standards series, enhancements of Ethernet for realtime communication have been developed first under the name of Audio Video Bridging (AVB) and in recent years as Time-Sensitive Networking (TSN). Some standards that are part of TSN have already been adopted, such as clock synchronization of the participants in IEEE 802.1AS [8] and the reservation of transfer capacity via time slots in IEEE 802.1 Qbv. The authors of [9] describe traffic types for common use cases in industrial communication and their relation to the TSN standards. See also [10] for the computation of the potential performance of Ethernet-based realtime protocols. Fig. 2 represents the TSN standard projects.

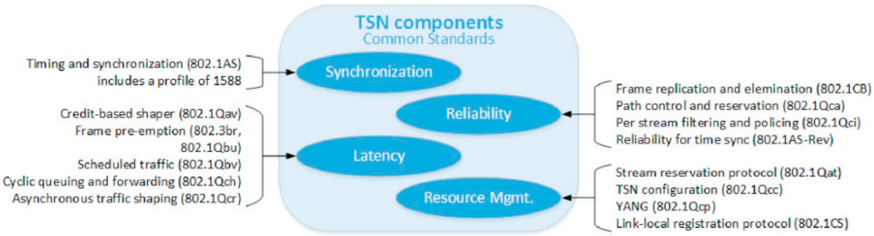

Fig. 2. Important TSN standard projects according to the TSN TG.

The advantage of TSN compared to classical fieldbuses is the vendor neutrality without licensing fees, potentially higher throughput [11], the possibility to flexibly add connections with assured quality-of-service properties over multiple hops in a bridged network [12] and the economies of scale of a widespread technology that is intended for both industrial use-cases and consumer devices.

3. 5G-based CPPS Architecture using Centralized OPC UA Server

This section describes the architecture of the CAC Architecture using Centralized OPC UA Server (CAC OPC) system proposed in this paper. Presentation of the architecture of smart factory CPPS (Manufactured Cyber Physics System) using the architecture and ideas of OPC UA Framework, the international smart factory standard, and the structure and methods of systems that can construct CPPS models dynamically with OPC UA modeling alone, including each of the architecture's configuration modules and services, interworking methods, automation methods, flow and sequence, and OPC Server methods.

OPC UA Modeling is modelled in eight node types. The types of nodes include Object, Object type, Variable, Variable type, Data Type, Method, Reference, and View, which is a standard configuration of the OPC UA Framework. OPC UA is a structure in which all components have different hierarchical structures in the form of nodes, and can model everything accurately, such as the hierarchy, attribute structure, data type and length of all objects in the real world. This is the same as hierarchical modeling of plant topologies (mechanics and facilities) in CPPS. In addition, the OPC UA modeling itself can be a CPPS modeling because data communication through OPC UA is essential for CPPS to move the real world into the cyber world and to monitor and control in real time, and CPPS modeling without data communication is practically meaningless.

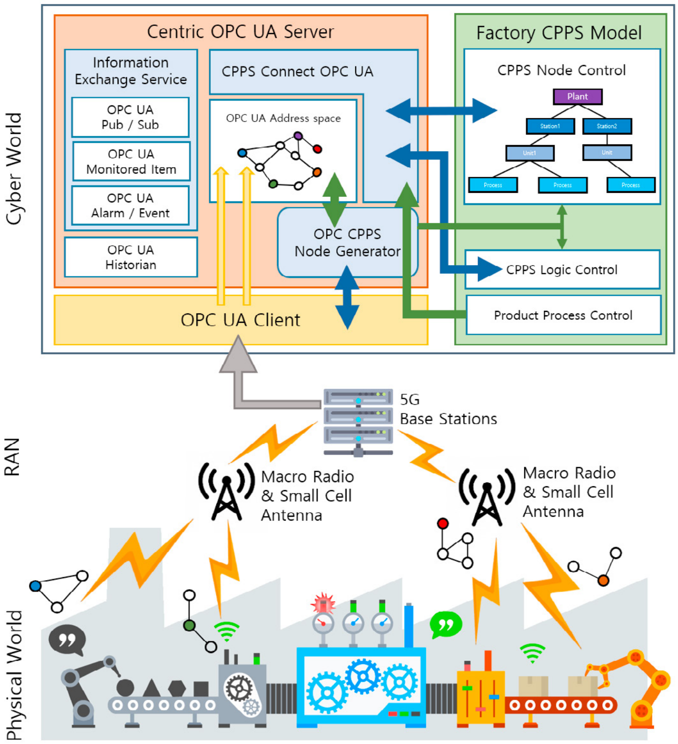

Fig. 3. 5G-based Centralized OPC UA CPPS Architecture

Fig. 3 presents the architecture of the manufacturing cyber physics system (CPPS) in the cloud using the architecture and ideas of the OPC UA Framework, and includes the architecture and methods of the system that can construct the CPPS model dynamically through OPC UA modeling alone, including each of the architecture's components and services, interworking methods, automation generation methods, flow and sequence, and NPC Server/ Server client methods. The architecture of CPPS consists largely of a centralised OPC UA Server and a factory CPPS model.

- Centralized OPC UA Server focuses on OPC UA Address Space, which follows OPC UA standards, with Information Exchange Service for data exchange with CPPS and Factory CPPS Model and OPC UA Client, which automatically generates system-driven connections to the OPC User Shop.
- OPC UA Address Space is a variable system that changes the value of the modelled total object node in real time. The OPC UA specification manages and communicates all values through Address Space. Within the Centralized OPC UA Server, the standard modules of OPC UA Specs, OPC UA Pub/Sub, OPC UA Monitored Item, Alarm/Event, and Historian, all data is communicated and updated through OPC UA Address Space.
- Information Exchange Service is responsible for exchanging and communicating data with external systems. It consists of existing OPC UA standard specifications and distributes data asynchronously to the broker and cloud via the OPC UA Pub/Sub.

- OPC UA monitored item registers and periodically sends data to systems and applications that want to exchange data periodically. When registering with OPC UA monitored item, the OPC UA monitored item registers the index value of the node you want to obtain along with the attributes such as the transmission period and data transmission filtering, and thus the OPC UA monitored item sends the data for each session accordingly.
- OPC UA Alarm/Event distributes event data by generating the alarm/Event both internally and externally at the same time as the event occurs, in line with the properties of the Alarm/Event defined in OPC UA Node Modeling.
- CPPS Connect OPC UA is responsible for updating and altering all data that occurs in the OPC UA Address space and for communicating data to CPPS Node Control, CPPS Logic Control, and Product Process Control inside the Factory CPPS Model.
- The OPC CPPS Node Generator is a key function of this study that parses OPC UA Modeling to automatically generate the attributes and codes required for CPPS Node Control, CPPS Logic Control, and Product Process Control, which are registered with OPC UA Address Space and OPC UA Client.
- OPC UA Historian records all information updated in Address Space The recording method can be used by selecting relational databases, NoSQL databases, XML, binary files, etc.

The 5G-based CPPS can be used in a structure suitable for smart factory environments, such as data analysis and real-time processing of various types of data through a central control method.

4. Implementation and Modeling

4.1. Preferences

In the implementation of this paper, we implemented the Centralized OPC UA Server using the C# library provided by OPC UA Foundation, and the CPPS related program used C#. Shop Field's OPC UA Server uses UVC's commercial OPC UA Server product did.

4.2. Physical Factory Configuration and CPPS Architecture

D-Piston, an auto parts maker based in Ansan, South Korea, has 50 automatic machines and 50 automatic robots. Physical plants were modeled with two mechanical tools, two robots, one conveyor belt and one sensor. The physical plant configuration in Fig. 4 consisted of one CNC mechanical tool in Star HS-20VLG-R and one KUKA robot. They access the central OPC UA server via TCP/IP Wi-Fi. The conveyor system that supplies these products receives IO signals from Siemens PLC connected to the CNC and robots and controls optical sensors and stops. OPC UA modeling is created to build CPPS nodes in the above factory, and configurations for OPC UA communication, such as address space in the cloud's central OPC UA Server and OPC UA Client are created.

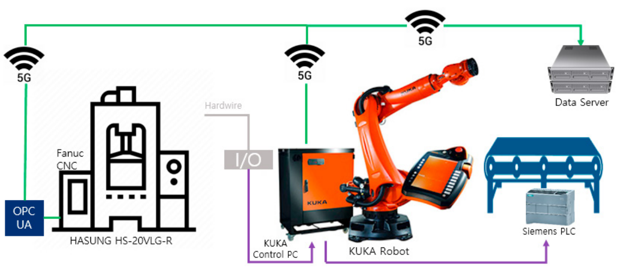

Fig. 4. 5G based Physical Plant Structure

The hierarchical structure of the CPPS Node and the centered OPC UA Server is the same, and it is the same as the OPC UA Server modeling because the physical facilities of the CPPS and the machine of the factory at the remote site can be expressed in one factory in cyber.

4.3. Centralized OPC UA Server Implementation

OPC UA is intended to replace previous standards such as OPC DA, OPC A&E and OPC HDA. OPC UA has developed this standard by providing vendors with an independent open architecture [13]. As with previous versions, OPC UA follows the client/server paradigm. When it comes to portability, the main difference is that servers use a portable communications stack that can be used directly in an automated system. OPC UA provides reliable, robust and high-performance communication tools suitable for devices such as industrial automation applications and CPPS-enabled devices.

Classical OPCs cannot adequately represent the essential problems of today's connected world, such as data types, information, and the relationship between data items and systems. Unlike traditional OPCs, OPC UA provides modelling liquor to support the plant floor model by providing more than a means of transport.

In the manufacturing sector, information technology should be integrated with process control engineering. This requires interoperability that requires exchange of information. In this sense, the concept of address space in OPC UA servers is very important. In particular, this concept involves a set of objects that enable clients to use the server. These objects represent basic real-time system data. Concepts of address space in general Can represent real-world process environment and real-time process behavior in unique ways that can be understood by various systems [14].

OPC UA servers can be represented as model-based systems. This approach introduces a model concept to better adapt to the needs of modern industrial applications. Profiles are typically designed for vertical integration of automation systems. The OPC UA architecture provides a complete description of all system data, regardless of its complexity. All of the above options may not be required to implement most CPPS. In this sense, the information described in the address space of the OPC UA server may be sufficient for most industrial systems.

4.4. Implementation of Automatic Generation of CPPS through Modeling

A centralized OPC UA server in the cloud can access factory site data through an internal OPC UA client. The Shop Filed OPC UA server is the CNC's intelligent external device, and the robot is the software built into the control computer. The PLC accesses I/O directly to the central robot and the CNC through the Profibus. The cloud's centralized OPC UA Server controls each system that integrates a distributed Shop Field OPC UA server. This CPPS connection feature provides access to process data for monitoring and control of OPC UA clients, such as surveillance stations and clouds. OPC UA server and client functions integrate with OPC UA Foundation-provided libraries built using the C stack and self-built libraries. The OPC UA library is integrated at the automated runtime. As such, server and client functions can be included at the same run-time. The OPC CPPS node generator is automatically added to the CPPS node and CPPS logic control by analyzing CPPS-related properties in OPC UA modeling. Perform real-time data collection and addition at the same time to ensure that the CPPS node and OPC UA address space can be added nondisruptively.Measure the results added to the centralized OPC UA server and the time automatically generated by the client's address space display.

4.5. 5G Smart Factory

As a next-generation wireless communication technology, the 5G network offers a wealth of service capabilities with significant increases in throughput, speed, latency, coverage, reliability and security (a 10-100-fold increase) over the previous generation of communication technologies. In Fig. 5, 5G Smart Factory requires advanced mobile communication technology with high transfer rates, low latency, high reliability, high coverage, large node capacity and high security to meet the communication needs of transport layers and applications. Facilitates the application of advanced manufacturing technologies such as the smart workshop layer and machine vision. They include virtual reality, augmented reality, digital twin, human-machine collaboration, machine-to-machine collaboration.

Fig. 5 shows the strategic business and detailed tasks of Smart Factory that converges 5G platforms. Production process innovation technology: share production information through 3D image information, develop wearable device and system technology, production process monitoring and condition analysis solution. Industrial Network Service: Develop 5G-based ultra-precision integrated check management solution and 5G cloud edge-based smart factory virtualization technology for facility management at industrial sites. Smart Factory 5G platform-based application service:

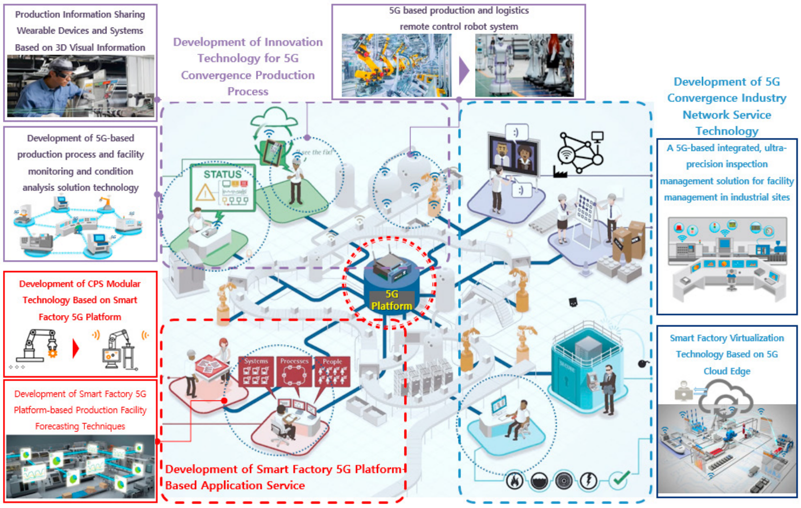

Fig. 5. 5G based Physical Plant Structure

Through the development of CPS modular technology based on smart factory 5G platform, automation facilities are actively judged through data on their own and facility prediction maintenance technology is developed.

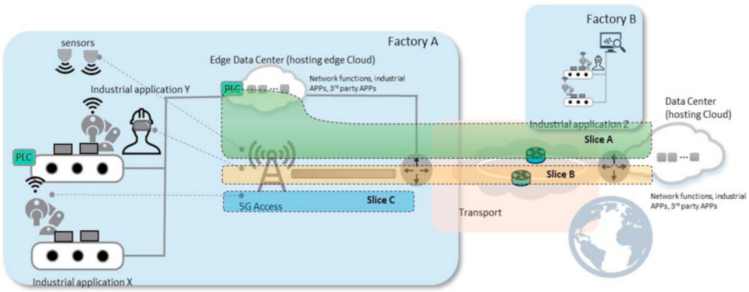

Fig. 6. 5G based Physical Plant Structure

Fig. 6 shows the type of 5G network and as a solution for cooperation with PLMN/MNO, the network slice is a complete logical network including RAN and CN. Type A is a factory network with PLMN/MNO roaming function that supports internal logistic and mobility. Type B automates real-time control and processes with a complete personal network owned by Simens without interworking with PLMN. Type A and Type B may be owned by the factory or operated by the new plant operator, data shall not be leaked out of the plant and all communication termination shall be subject to the constraints imposed within the plant's firewall.

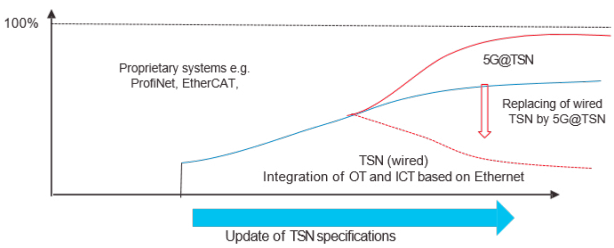

Fig. 7. 5G based Physical Plant Structure

5G is the correct solution to connect the device (industrial sensors / actuators) to the TSN network wirelessly. In particular, the new 5G features in the Wireless Access Network (RAN) offer significantly better reliability and transfer latency than in 4G, and the new 5G system architecture allows for flexible deployment. As a result, 5G can extend the TSN network to avoid the limitations of cable installation. To support TSN services on a 5G system, the main challenge is to enable interworking of the TSN and the 5G network. Fig.7 shows the 5G network extending the TSN wired network.

5. Conclusion

The use of OPC UA CPPS architecture in this paper makes it possible to configure CPPS and operate the system continuously by OPC UA Modeling alone, without any system redesign or program changes or downtime. In addition, by managing the distributed OPC UA Server information in Shop Field in real time through an integrated address space in the cloud's OPC UA Server, the efficiency of horizontal data distribution and exchange operations is increased, the time and cost is greatly reduced, the problem of data loss, system performance degradation, real-time processing delays, and the ability to accommodate a number of machines and a number of single protocol products. This enables transparent and standard systems to be built by selecting facilities and selecting systems that comply with OP UA Specs without any additional changes to existing systems, even in the face of various plant changes such as continuous expansion.

Acknowledgements

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References

[1] N. Jazdi. (2014) " Cyber physical systems in the context of Industry 4.0" *IEEE International Conference on Automation, Quality and Testing, Robotics.*

[2] Constantin Scheuermann, Stephan Verclas, Bernd Bruegge. (2011) "Agile Factory - An Example of an Industry 4.0 Manufacturing Process" *IEEE 3rd International Conference on Cyber-Physical Systems, Networks, and Applications.*

[3] F. Boccardi, R.W. Heath, A. Lozano, T.L. Marzetta, P. Popovski. (2014) "Five disruptive technology directions for 5G." *IEEE Commun. Mag. 52.* **2.** :74-80.

[4] C.X. Wang, F. Haider, X. Gao, X.H. You, Y. Yang, D. Yuan. (2014) "Cellular architecture and key technologies for 5G wireless communication networks." *IEEE Commun. Mag. 52.* **2** :122-130.

[5] B. Bangerter, S. Talwar, R. Arefi, K. Stewart. (2014) "Intel networks and devices for the 5G era." *IEEE Commun. Mag. 52.* **2** :90-96.

[6] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, et al. (2014) "Network densification: the dominant theme for wireless evolution into 5G." *IEEE Commun. Mag. 52.* **2** :82-89.

[7] I. Chih-Lin, C. Rowell, S. Han, Z. Xu, G. Li, Z. Pan. (2014) "Toward green and soft: a 5G perspective." *IEEE Commun. Mag. 52.* **52** :66-73.

[8] S. Schriegel, J. Jasperneite. (2007) "Investigation of industrial environmental influences on clock sources and their effect on the synchronization accuracy of ieee 1588." *ISPCS . IEEE International Symposium on.*

[9] Industrial Internet Consortium. (2018) "Time Sensitive Networks for Flexible Manufacturing Testbed - Description of Converged Traffic Types." *Tech. Rep*.

[10] J. Jasperneite, M. Schumacher, and K. Weber. (2007) "Limits of increasing the performance of industrial ethernet protocols." *Emerging Technologies and Factory Automation. IEEE Conference on.*

[11] Shaper Group. (2018) "OPC UA TSN: A new Solution for Industrial Communication." *Tech. Rep*.

[12] M. Gutiérrez, A. Ademaj, W. Steiner, R. Dobrin, and S.Punnekkat. (2017) "Self-configuration of ieee 802.1 tsn networks." *Emerging Technologies and Factory Automation (ETFA). IEEE International Conference on.* **22**:1-8.

[13] D. Van Der Linden, H. Mannaert, W. Kastner, V. Vanderputten, H. Peremans, and J. Verelst. (2011) " OPC UA interface for an evolvable ISA88 controlmodule" *IEEE Int. Conf. Emerg. Technol. Fact. Autom. ETFA.*

[14] Arno Claassen, Sebastian Rohjans, Sebastian Lehnhoff Member. (2011) " Application of the OPC UA for the Smart Grid" *IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies.*