Intelligent Network Services enabling Industrial IoT Systems for Flexible Smart Manufacturing

Daniel Behnke, Marcel Müller, Patrick-Benjamin Bök
Weidmüller Group, Detmold, Germany
daniel.behnke@weidmueller.com
marcel.mueller@weidmueller.com
patrick-benjamin.boek@weidmueller.com

José Bonnet
Altice Labs, Aveiro, Portugal
jbonnet@alticelabs.com

***Abstract*—In recent years developments of Industrial IoT components and data analysis paved the way for optimization of manufacturing processes. Additional sensors provide manifold data of machine parks and individual machines. Due to the huge amount of data, communication and storage systems get into focus of research. In this work, we are introducing a concept for the usage of Network Services in smart manufacturing, creating the missing link between the closed machine architecture and flexible 5G services.**

I. Introduction

The Internet of things is a hype topic for nearly a decade now. Extensively growing, millions of devices get direct access to the Internet providing a plethora of application, e.g. smart homes or mobile health management. This trend can also be found in industry where IoT components hardened for these environments are introduced, called Industrial IoT (IIoT) devices which can be either sensors or actors, as well as mobile equipment such as smartphones, tablets, and smart glasses [1]. Hence, mobile communication becomes ubiquitous in smart factories. IIoT devices provide massive data on temperature, pressure, machine states etc. like demonstrated in Fig. 1. In comparison to conventional data acquisition in machines, the amount of data will increase significantly and the interaction between machines on the edge as well as between distributed machines and cloud services [2] will rise.

Digitalization, Industry 4.0 or Advanced Manufacturing are programs which are pushing the progress described before. Additionally, they are bringing the flexibility of production sites and systems in the digital era onto a new level which leads to new constraints and requirements regarding the communication networks [3]. Although the basic concepts are used for many decades now, production sites and systems are optimized using methods like the Toyota Production System, the Lean concept and many other techniques. These require a continuous improvement of the whole setup of manufacturers, meaning that machines and components are physically moved around the site to increase the flow of produced parts and products [4]. Additionally, the demand for individual personalized products is increasing, not only for consumer products, but also for professional products. Although the programs mentioned before go into the direction of increasing flexibility in production sites, the impact of physical flexibility

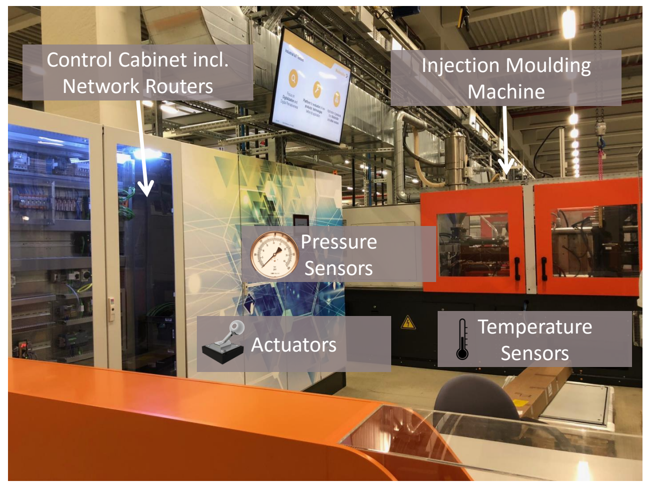

Fig. 1. IIoT components in modern factories

on communication networks is neglected and will lead to huge issues for network architecture, network performance engineering and IT security. This causes flexible requirements on autonomous configuration of the network and its elements from the component at the edge through the backbone to the source or sink of communication [5].

Network slices are often used in the backbone parts of a network to allow for a differentiation of the various types of communication and data streams, especially in the context of 5G technology [6]. This concept solely is neither able to cope with physical flexibility at the edge, nor with the demand of production systems that require end-to-end guarantees [7] which have been known in the past for performance engineering based on integrated services. This concepts were just focusing on performance, but not on flexible architecture or IT security which are also required for flexible production systems beginning at the edge [8].

One solution to overcome these challenges are Software Defined Networks (SDN), allowing for an agile and flexible network configuration. Virtual Network Functions (VNFs) are dividing the issue in small and manageable elements. The Network Service, assembling the services of multiple VNFs, enables the machine park operator to connect existing machines to the cloud-based services such as data analytics. Subsequent, the data is processed to provide additional knowledge and services. Data analytics is supporting machine park operators to identify maintenance intervals, incidents with machines or potential increase in performance. Software Defined Networks will offer the flexibility for production systems as they are required [9].

The EU-funded 5G-PPP research project *5GTANGO* addresses the emerging challenges associated with both the development and the validation of vertical services and applications based on SDN.

The following technologies are envisioned:

1) A modular, dependable service platform with a modular orchestration framework that will support vertical sector needs. A key evolution is a more profound separation of concerns by factoring out the verification and validation (V&V) steps to the V&V store role.
2) A store for Verification and Validation expertise [10]. The V&V component is key to 5GTANGO and not present in existing NFV architectures.
3) A NFV specialized Software Development Kit (SDK) to support the development of NFV services.
4) An adapted DevOps methodology and associated tools that will help connect stakeholders to a modern, agile workflow that supports the rapid development cycles of software-driven networks, and helps tackle the inter-organizational challenges.

In this work, the authors provide a concept for intelligent network services for flexible smart manufacturing based on identified needs [12]. Therefore, the paper is structured as follows:

- State-of-the-art as well as future machine data acquisition principles are described in Section II.
- Based upon, requirements, use-cases and the concept for flexible network services are described in Section III.
- Finally, we conclude our contribution and give an outlook on future developments in Section IV.

II. Machine Data Acquisition

As described in Section I, data analytics can be used to support machine park operators, but for data analytics machine data is required. Therefore, in this section the focus is on machine data acquisition in factories.

Machines generate constantly data such as operational data, machine data, and process data (O/M/P data). Often, most of the data is only used within the machine, but due to topics such as big data and data analytics the interest in using these data and further data is growing. As a result, the requirements to factory networks increase dramatically.

Fig. 2 shows an injection moulding machine which produces plastic components, e.g. for terminal blocks. The machine is controlled by a programmable logic controller (PLC) which reads sensor input data (S1 ... Sn) and generates output data for actuators (A1 ... An) across analogue and digital input and output (I/O) modules. A machine computer (MPC) and its human-machine interface (HMI), which visualizes process parameter sets and the actual process data, and makes process data modification possible, extends the machines communication capabilities. The machine's MPC provides data directly via standardized high-level interfaces for data acquisition by central computers or manufacturing execution systems (MES).

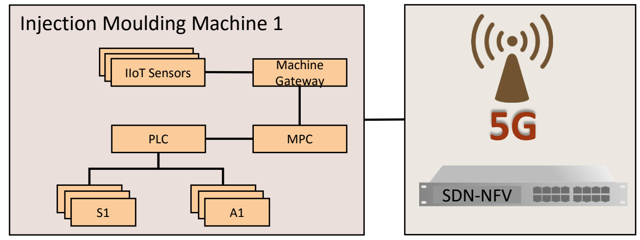

Fig. 2. Combined wired and wireless machine data acquisition

The standard that describes the interface between injection moulding machines and MES for data exchange is called Euromap 77. Euromap 77 is based on OPC UA and replaces Euromap 63, which is an obsolete text file based data transfer standard, but due to the longevity of machine tools, Euromap 63 will still be of interest for the next few years. Therefore, both standards Euromap 63 and Euromap 77 must be considered for acquisition of injection moulding machine data. The longevity of machine tools is a fundamental challenge for the digitalization of factories because new standards and old standards have to be considered and those data has to be harmonized.

In addition to Euromap 63 and Euromap 77, a machine can be equipped with further data sources. For example, when a machine does not provide energy data via Euromap standard, an energy measurement device such as an energy meter can be integrated in the machine as an additional data source which assists in assembling a power management system. In this context, further protocols become interesting, e.g. Modbus.

Furthermore, additional Industrial IoT sensors are becoming increasingly important; e.g., for measuring specific temperatures and pressures inside a machine, or for considering ambient conditions such as temperature and humidity. With these retrofit procedures existing older machines can be integrated into novel data analysis systems as well. Upcoming 5G technology for mobile radio edge communication will pave the way for this. These general conditions indicate that flexible SDN/NFV-based network components are useful for the digitalization of factories.

III. Machine Interconnection Network Service

Network Services for smart manufacturing must fulfill manifold requirements and use cases as flexible and agile networks become mandatory in the future.

1) Seamless integration of wired and wireless IIoT components
2) Enabling quality-of-service guarantees for flexible applications

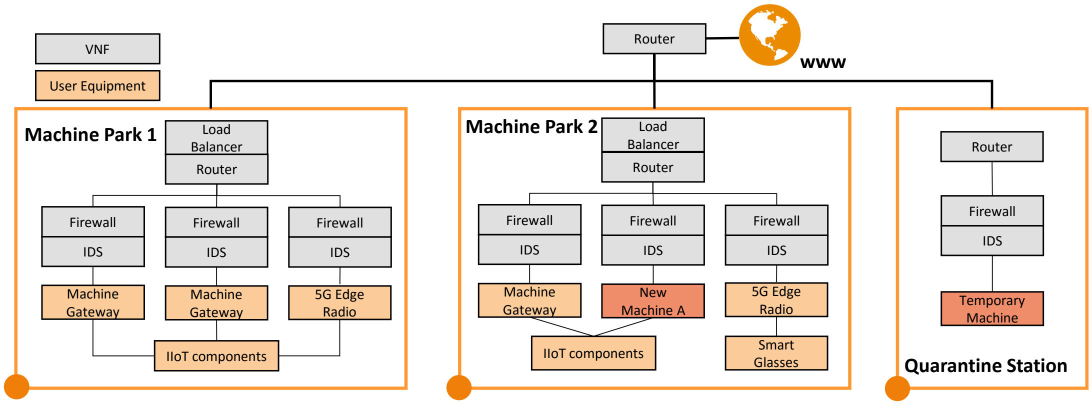

Fig. 3. Machine Interconnection Network Service

3) Automated configuration of new machines and components such as smart glasses
4) Isolation of infected machines or if remote manufacturer support is needed

A. Overview of the Network Service

The aim is to connect multiple machine parks at different geographical locations to a common company network. Applications, e.g., cloud analytics and remote support/maintenance, require flexible configuration and security measures which cannot be provided easily nowadays.

This Machine Interconnection Network Service (*MINS*) (cf. Fig. 3) is the basis for the connection of machines. It comprises the firewall and IDS close to the machine and the router as well as load balancer for interconnection with further machines and the company network.

In Machine Park 1 and 2 several machines and additional user-equipment such as AR/VR glasses are used. These parks must be interconnected and usually have access to the Internet through the Company IT network. This component bridges internal and external networks. Hence, based on the use-case, a high traffic load may appear.

B. Overview of needed VNFs

In the following sections, the Virtual Network Functions (*VNFs*) are introduced in more detail.

1) VNF1 - Router: This VNF connects different network segments but keeps a logical separation. The router should connect the machines in a machine park, creating different subnets for each machine because in this scenario a machine is a logical representation for sensors and other IIoT devices embedded in a machine. Additionally, edge mobile radio systems will be included as well in the network.

2) VNF2 - Firewall: Firewalls will be used at different locations in the network. First, each machine should be separated behind an individual firewall to minimize the risk of spreading attack software across the manufacturing site. Second, the whole traffic, incoming and outgoing, should be analysed regarding predefined rules. In case of a high traffic load additional or more powerful (in terms of computing resources) instances should be activated.

In general, firewalls close to the machines are very restrictive regarding allowed traffic. Most ports and source IP addresses will be blocked but adapting a rule for a certain machine is a common requirement.

3) VNF3 - Intrusion Detection System (IDS): If an attack is occurring, it is important to detect this attack to isolate the infected area and prevent further distribution and damage. Hence, the IDS VNF is instantiated at the same locations in the networks as the firewalls.

4) VNF4 - Load Balancer: Network traffic is expected to increase in future applications integrating analytics or augmented reality (AR) in manufacturing sites. This VNF must distribute the traffic keeping into account different Quality of Service (QoS) requirements of the applications. Additionally, it might be necessary to transmit all available data of a machine in real-time because an issue has to be analysed and fixed and therefore, the network capacity must be shifted automatically to match this requirement.

C. Deployment & Use-Cases

With the deployment of this network service, the interconnection of multiple machines in a machine park is enabled; i.e. one network service per machine and hundreds of machines per park. Using several subnets the machines are separated and secured by an individual firewall and IDS. The machines create different kinds of traffic, starting with low traffic, rising up to HD video streams.

A very important aspect of this use case is the management of this Network Service and the included devices. Machines are moved from one site to another like Machine A and mobile devices like smart glasses are switched on. In this case the network has to adapt itself automatically, switching on new instances of needed firewalls and IDS as well as establishing a new subnet for this machine/device and re-configure routes. Additionally, this network service has to deal with up to 100 machines per park, thus scalability is very important.

A further aspect is the isolation of a machine/device. If a remote support or maintenance is needed, Internet connection is temporarily needed for the end device itself. This should be done in a separate network segment, avoiding to open ports for the rest of the machine park. Also, if an attack is recognised the device should be isolated to stop the infection of the rest of the network.

For the network service itself it is not necessary to provide continuous Internet connectivity. That is of importance as the availability of Internet access cannot be guaranteed all the time due to work on connecting cables etc. Nevertheless, it is a 'must' to connect to the 5GTANGO service platform to monitor and control the network service in an appropriate manner. Hence, the assumption is that Internet is available.

We will deploy this network service on our NFVI-PoP on Weidmüller premises to execute performance measurements and test the usability of the 5GTANGO system.

IV. Conclusion & Outlook

In this work, we are providing a concept for flexible smart manufacturing using the technologies of network services and 5G. Additionally, requirements and use cases are introduced which allow for performance measurements of the 5GTANGO system and SDN in general. In future publications, we will depict the high value of SDN for industrial analytics and first results of our implementations.

Acknowledgment

This work has been partially supported by the 5GTANGO project, funded by the European Commission under Grant number H2020- ICT-2016-2 761493 through the Horizon 2020 and 5G-PPP programs (http://5gtango.eu).

References

[1] M. Simsek, A. Aijaz, M. Dohler, J. Sachs, and G. Fettweis, "The 5G-Enabled Tactile Internet: Applications, requirements, and architecture," in *2016 IEEE Wireless Communications and Networking Conference*, Apr. 2016, pp. 1–6. DOI: 10 . 1109 / WCNC . 2016 . 7564647.

[2] R. Munoz, J. Mangues-Bafalluy, R. Vilalta, C. Verikoukis, J. Alonso-Zarate, N. Bartzoudis, A. Georgiadis, M. Payaro, A. Perez-Neira, R. Casellas, R. Martinez, J. Nunez-Martinez, M. R. Esteso, D. Pubill, O. Font-Bach, P. Henarejos, J. Serra, and F. Vazquez-Gallego, "The CTTC 5G End-to-End Experimental Platform : Integrating Heterogeneous Wireless/Optical Networks, Distributed Cloud, and IoT Devices," *IEEE Vehicular Technology Magazine*, vol. 11, no. 1, pp. 50–63, Mar. 2016, ISSN: 1556-6072. DOI: 10 . 1109 / MVT . 2015 . 2508320.

[3] B. Chen, J. Wan, L. Shu, P. Li, M. Mukherjee, and B. Yin, "Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges," *IEEE Access*, vol. 6, pp. 6505–6519, 2018, ISSN: 2169-3536. DOI: 10.1109/ACCESS.2017.2783682.

[4] P. Burggräf, M. Dannapfel, H. Voet, P.-B. Bök, J. Uelpenich, and J. Hoppe, "Digital Transformation of Lean Production: Systematic Approach for the Determination of Digitally Pervasive Value Chains," *IInternational Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, vol. 11, no. 10, pp. 7373–7380, 2017, ISSN: 2352-2361.

[5] Y. Ma, Y. Chen, and J. Chen, "SDN-enabled network virtualization for industry 4.0 based on IoTs and cloud computing," in *2017 19th International Conference on Advanced Communication Technology (ICACT)*, Feb. 2017, pp. 199–202. DOI: 10 . 23919 / ICACT . 2017 . 7890083.

[6] P. Rost, C. Mannweiler, D. S. Michalopoulos, C. Sartori, V. Sciancalepore, N. Sastry, O. Holland, S. Tayade, B. Han, D. Bega, D. Aziz, and H. Bakker, "Network Slicing to Enable Scalability and Flexibility in 5G Mobile Networks," *IEEE Communications Magazine*, vol. 55, no. 5, pp. 72–79, May 2017, ISSN: 0163-6804. DOI: 10.1109/MCOM.2017.1600920.

[7] Q. Li, G. Wu, A. Papathanassiou, and M. Udayan, "An end-to-end network slicing framework for 5G wireless communication systems," *CoRR*, vol. abs/1608.00572, 2016. arXiv: 1608.00572. [Online]. Available: http://arxiv.org/abs/1608.00572.

[8] R. Vilalta, A. Mayoral, D. Pubill, R. Casellas, R. Martínez, J. Serra, C. Verikoukis, and R. Muñoz, "End-to-End SDN Orchestration of IoT Services Using an SDN/NFV-enabled Edge Node," in *Optical Fiber Communication Conference*, Optical Society of America, 2016, W2A.42. DOI: 10 . 1364 / OFC . 2016 . W2A . 42. [Online]. Available: http://www.osapublishing.org/abstract.cfm?URI=OFC-2016-W2A.42.

[9] J. Wan, S. Tang, Z. Shu, D. Li, S. Wang, M. Imran, and A. V. Vasilakos, "Software-Defined Industrial Internet of Things in the Context of Industry 4.0," *IEEE Sensors Journal*, vol. 16, no. 20, pp. 7373–7380, Oct. 2016, ISSN: 1530-437X. DOI: 10.1109/JSEN.2016.2565621.

[10] P. Twamley, M. Müller, P. Bök, G. K. Xilouris, C. Sakkas, M. A. Kourtis, M. Peuster, S. Schneider, P. Stavrianos, and D. Kyriazis, "5GTANGO: An Approach for Testing NFV Deployments," in *2018 European Conference on Networks and Communications (EuCNC)*, Jun. 2018, pp. 1–218. DOI: 10 . 1109 / EuCNC . 2018 . 8442844.

[11] C. Parada, J. Bonnet, E. Fotopoulou, A. Zafeiropoulos, E. Kapassa, M. Touloupou, D. Kyriazis, R. Vilalta, R. Muñoz, R. Casellas, R. Martínez, and G. Xilouris, "5GTANGO: A Beyond-Mano Service Platform," in *2018 European Conference on Networks and Communications (EuCNC)*, Jun. 2018, pp. 26–30. DOI: 10.1109/EuCNC.2018.8443232.

[12] 5GTANGO Project, *D2.1 Pilot Definition and Requirements*, R. Muñoz and R. Vilalta, Eds., Website, Sep. 2017. [Online]. Available: http://5gtango.eu/documents/D21_v1.pdf (visited on 08/31/2018).