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Prototyping and Demonstrating 5G Verticals: The Smart Manufacturing Case

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***Abstract*—5G together with software defined networking (SDN) and network function virtualisation (NFV) will enable a wide variety of vertical use cases. One of them is the smart manufacturing case which utilises 5G networks to interconnect production machines, machine parks, and factory sites to enable new possibilities in terms of flexibility, automation, and novel applications (industry 4.0). However, the availability of realistic and practical proof-of-concepts for those smart manufacturing scenarios is still limited.**

This demo fills this gap by not only showing a real-world smart manufacturing application entirely implemented using NFV concepts, but also a lightweight prototyping framework that simplifies the realisation of vertical NFV proof-of-concepts. During the demo, we show how an NFV-based smart manufacturing scenario can be specified, on-boarded, and instantiated before we demonstrate how the presented NFV services simplify machine data collection, aggregation, and analysis.

I. Introduction

Verticals are considered to be the main drivers for the wide adoption of 5G technologies, such as software defined networking (SDN) and network function virtualisation (NFV). One reason for this are the demanding, sometimes even contradicting, requirements imposed by the different vertical use cases. Some of them require ultra-low latency whereas others have ultra-high data rate demands, which makes it complicated to implement these verticals in legacy, general-purpose networks [1]. Examples for vertical use cases are immersive media applications, connected vehicles, public protection and disaster relief, remote surgery, or smart manufacturing (industry 4.0).

However, proof-of-concept implementations or deployment trails that show these 5G verticals in action are still limited. To change this, a series of research projects, like 5GCAR [2], 5GTANGO [3], 5G-TRANSFORMER [4], or Global5G [5] are working towards pilot implementations of different verticals. One of the first is 5GTANGO's smart manufacturing pilot which will be based on concepts and scenarios shown in this demo. Other existing work on 5G in the smart manufacturing domain [6], including our own previous work [7], mostly focuses on requirement elicitation and architectural discussions rather than on practical trail implementations which distinguishes them from the work presented in this paper.

One challenge for these trail deployments is the fact that many use cases deal with distributed scenarios in which vertical services are deployed across multiple points of presence (PoP), each typically realised with its own NFV in-

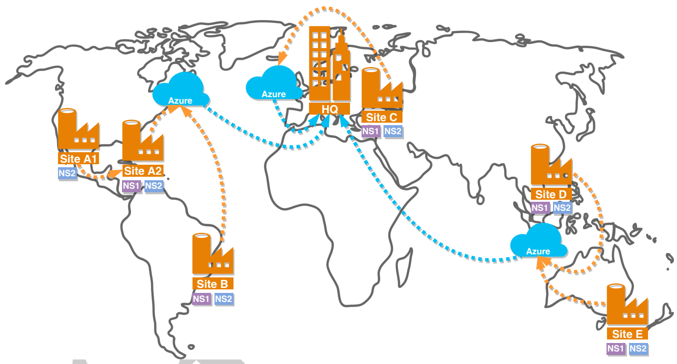

Fig. 1: Globally-distributed smart manufacturing scenario in which machine data is aggregated at each production site and sent to the enterprise-wide cloud backend to be analysed.

frastructure (NFVI) installation. Due to the limited availability of globally distributed testbeds, like *5GINFIRE* [8] or *5GTONIC* [9], NFV infrastructure emulators, like *vim-emu* [10] or *NIEP* [11], have been invented and serve as rapid prototyping platforms for different 5G scenarios.

In this demo, we focus on the smart manufacturing use case and make use of the expertise of the Weidmüller Group [12], a globally acting manufacturer for electronic connectivity solutions and factory automation. The contributions of our demo are three fold. First, we show how a distributed end-to-end smart manufacturing scenario, including multiple factory sites and machine parks, looks like. In this scenario, multiple network services are used to interconnect machines and collect sensor data from them. The data is then aggregated at each factory site and sent to the enterprise-wide cloud backend as shown in Fig. 1. The presented network services make use of standardised protocols and interfaces, such as Euromap63 [13] and MQTT [14], so that they can be used in real-world factory installations. Second, we use the concept of a *injection molding machine simulator (IMMS)* to simulate multiple molding machines using standardised interfaces commonly used in industry. Third, we present a rapid prototyping platform introduced by the 5GTANGO project, which extends our work initially presented in [10]. We use this platform to deploy the involved network services in a large multi-PoP scenario using realistic link delays between the factory sites.

II. Prototyping Smart Manufacturing Services

The following sections describe the architecture, components, and platforms used to implement the proposed demo.

A. NFV-based Smart Manufacturing

The presented smart manufacturing scenario consists of two different network services, each instantiated multiple times, as shown in Fig. 2. The first network service, is called *NS1: Factory Edge Service* and is instantiated once per production site. This service consists of four VNFs and is responsible to collect and aggregate machine data of the entire production site before sending it to the enterprise cloud backend. The first three VNFs implement the *cloud connector (CC)* functionality, including an MQTT broker, a data processor, as well as a time-series database for local data backup. The fourth VNF of the service is the *edge analytics engine (EAE)* and allows on-site analysis of machine data.

The second network service, shown in our demo, is called *NS2: Machine Interconnection Service* and is instantiated once per physical machine (or once per machine simulator). After the service is instantiated, the corresponding machine connects to the *machine data connector (MDC)* VNF using the Euromap63 [13] protocol. The MDC is then able to control the machine and collect data, e.g., sensor values, from the machine. It then translates the data into a standardised MQTT format and sends it to NS1. The interconnection to NS1 is established using a *router (RTR)* VNF which is also part of NS2. The router VNF allows to use dedicated network segments for each machine, a typical setup in real-world factory networks [7].

Both demonstrated network services are described using 5GTANGO's ETSI-aligned NFV descriptor format and are packaged using the 5GTANGO network service and VNF package format, also compatible to the ETSI specifications [15]. All involved VNFs are realised as lightweight containers (Docker) which can be quickly instantiated. Some of them rely on open-source software, e.g., the CC broker runs the Mosquitto[1] MQTT broker. Other VNFs, like the MDC, run custom code that was specifically developed for the presented scenario and published under Apache 2.0 license.

B. Simulating Machines

One of the main challenges for many 5G vertical proof-of-concepts is the limited availability of special-purpose (hardware) components. For example, molding machines in the smart manufacturing scenario. Even if those components are available in-principle, they are usually embedded into production setups and cannot be used for proof-of-concepts or experimentation. Moreover the number of such components is often limited making large-scale experiments, e.g., with many molding machines, infeasible.

We solve this challenge by using our injection molding machine simulator (IMMS). The IMMS is a lightweight software component which can be easily configured and deployed. It mimics the behaviour of a real-world machine using standard-compliant interfaces, e.g., Euromap63 [13]. Thus, it looks like a real machine from the perspective of the factory network.

[1]Eclipse Mosquitto MQTT broker: https://mosquitto.org/

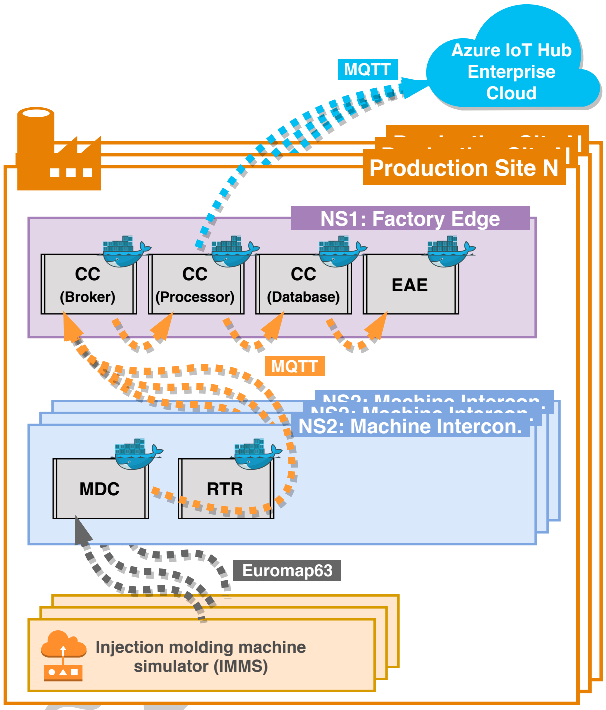

Fig. 2: Demo scenario with multiple production sites, each running multiple network services and injection molding machine simulators. The arrows indicate the data flow and used protocols.

More specifically, we developed a IMMS that is able to simulate a molding machine, react to control messages, and produce sensor data. Our IMMS follows a modular design so that it can be easily adapted to other interface standards, like Euromap77 based on OPC UA [16]. It can be deployed as a Docker container and offers a web-based configuration interface allowing a user to configure the simulated production processes. Sensor data can either be generated randomly or using pre-defined functions, e.g., a sine signal. Alternatively existing sensor data traces can be used and replayed. Like the demonstrated network services and VNFs, a prototype of the IMMS is published under Apache 2.0 license and can be used by the research community for further research in the smart manufacturing domain.

C. Prototype Deployment with 5GTANGO

We use the 5GTANGO NFV prototyping platform [10] to develop, deploy, and demonstrate the presented smart manufacturing scenario. There are multiple benefits in using a rapid prototyping platform. First, the development process can be accelerated, e.g., due to the use of lightweight container technologies that allow to quickly change VNF implementations and configurations. Second, the multi-PoP deployment is simplified since the platform removes the need of complex

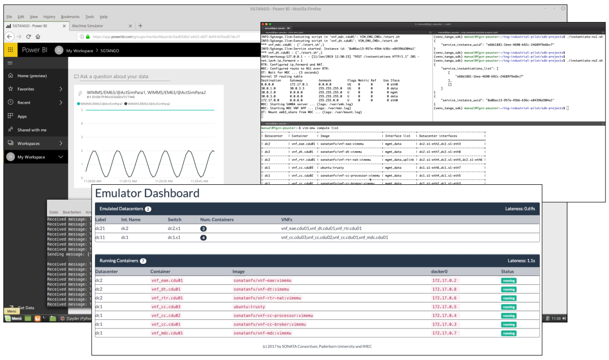

Fig. 3: Live demo with emulation platform dashboard, Azure Power BI dashboard, and multiple terminal windows showing the overall deployment state as well as the collected sensor data.

tunnel setups between distributed testbeds while still emulating realistic network conditions, e.g., inter-PoP latencies. Third, demonstrations are simplified due to the fact that the entire platform as well as the deployed network services can be executed on a single workstation.

III. Demonstration

During the demo, we will guide the audience through the composition, packaging, on-boarding and instantiation processes of the involved network services. The control interface of the IMMS, the collected machine data, as well as monitoring data of the deployed VNFs will be shown on various dashboards. Fig. 3 shows an example of that. The live demo includes the following steps:

Step 1: Present the ETSI-aligned descriptions of the involved VNFs and network services.

Step 2: Package and on-board the used network services and VNFs to 5GTANGO's prototyping platform.

Step 3: Instantiation and configuration of a complex scenario with multiple production sites and machine simulators on top of an emulated, large-scale network topology as shown in Fig 1.

Step 4: Activation of a simulated production process in the involved machine simulators.

Step 5: Analysis and verification of the collected sensor data arriving at the factory edge service as well as in the enterprise cloud backend.

IV. Conclusion

The presented demo shows one of the first NFV-based smart manufacturing proof-of-concepts which goes beyond a simple single-network-service scenario. Besides several network services, each consisting of multiple VNFs, we also present our IMMS as a reusable component for future smart manufacturing research. The components and workflows presented in this demo will be part of the official 5GTANGO smart manufacturing pilot [3]. The demo artefacts are open source and available online[2]. A video explaining the needs for NFV-based smart manufacturing solutions is available as well[3].

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[3]Smart manufacturing statement: https://youtu.be/ZLeBK14AFz4?t=163