"Producing Cloud-Native": Smart Manufacturing Use Cases on Kubernetes

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***Abstract*—Building on 5G and network function virtualization (NFV), smart manufacturing has the potential to drastically increase productivity, reduce cost, and introduce novel, flexible manufacturing services. Current work mostly focuses on high-level scenarios or emulation-based prototype deployments.**

Extending our previous work, we showcase one of the first cloud-native 5G verticals focusing on the deployment of smart manufacturing use cases on production infrastructure. In particular, we use the 5GTANGO service platform to deploy our developed network services on Kubernetes. For this demo, we implemented a series of cloud-native virtualized network functions (VNFs) and created suitable service descriptors. Their light-weight, stateless deployment on Kubernetes enables quick instantiation, scalability, and robustness.

I. Introduction

Smart manufacturing is a recent trend that promises new levels of automation, flexibility, and productivity as well as completely new manufacturing-related services. To achieve this vision, 5G and network function virtualization (NFV) count as key enablers [1]. With NFV, smart manufacturing scenarios can be softwarized and implemented as flexible network services consisting of interconnected virtual network functions (VNFs), which can run on commodity servers.

As smart manufacturing is still an emerging trend, research focusing on smart manufacturing and its realization through 5G and NFV is still very limited. Existing work in the area mostly focuses on high-level scenarios, outlining technical trends, potential benefits, and challenges [2], [3]. Leveraging the experience of Weidmüller Group, a large-scale manufacturer, we previously designed an NFV-based architecture for smart manufacturing with multiple use cases [4], [5]. To quickly and efficiently validate our proposed use cases, we implemented the involved VNFs using light-weight containers and deployed the resulting network services on 5GTANGO's emulation-based prototyping platform. We further demonstrated the scalability of our architecture by emulating several interconnected and globally distributed factories that use our developed network services simultaneously [6].

A remaining challenge to further mature these smart manufacturing use cases is to move from the current emulation-based prototyping infrastructure to deployment on real production infrastructure. Traditionally, production deployment required building the involved VNFs as heavy-weight virtual machines (VMs), e.g., to run on top of OpenStack [7]. The focus has recently shifted towards so-called cloud-native VNFs, facilitated by tools like Docker [8] and Kubernetes [9]. Rather than using VMs, these VNFs are implemented in light-weight, stateless containers, which can be started and stopped in seconds. This enables quick recovery from failures as well as flexible scaling and migration, which are crucial for NFV [10]. While Kubernetes provides production-grade container orchestration, it still needs to be integrated with current, established workflows in NFV, e.g., supporting deployment and chaining of NFV network services based on their descriptors.

Our contribution is a demonstration of the first Kubernetes-based, cloud-native smart manufacturing use cases, addressing the aforementioned challenges. To this end, we evolved our existing container-based network service implementation for deployment on Kubernetes. We further created suitable NFV descriptors and packages of our smart manufacturing network services to on-board them to the 5GTANGO service platform, which integrates with Kubernetes. The service platform supports deployment of the developed VNFs and handles their interconnection by automatically starting and configuring the involved containers accordingly.

II. Cloud-Native Smart Manufacturing

A. Smart Manufacturing Scenario

We consider a smart manufacturing scenario in which manufacturing machines inside a machine park of a factory need to be interconnected in order to collect and analyze their data (e.g., parameter settings or sensor values) [4], [5]. Furthermore, the machine data is monitored to automatically detect potentially malicious traffic or attacks and react automatically. To support these use cases, we developed two network services, NS1 and NS2, consisting of multiple VNFs, where each VNF is implemented in one or more containers [4].

Fig. 1 illustrates the logical data flow through these services and their VNFs and containers. The data flow starts at a manufacturing machine or a digital twin, here called injection molding machine simulator (IMMS), which is connected to an instance of NS2. At NS2, the machine data collector (MDC) handles the data retrieval (here, using Euromap 63 [11]) and sends it to NS1 using MQTT messages.

At NS1, the data is pushed to the factory cloud for long-term storage and analysis. At the same time, it is temporarily stored in a local Prometheus database. The edge analytics engine (EAE) accesses this database to provide visualization

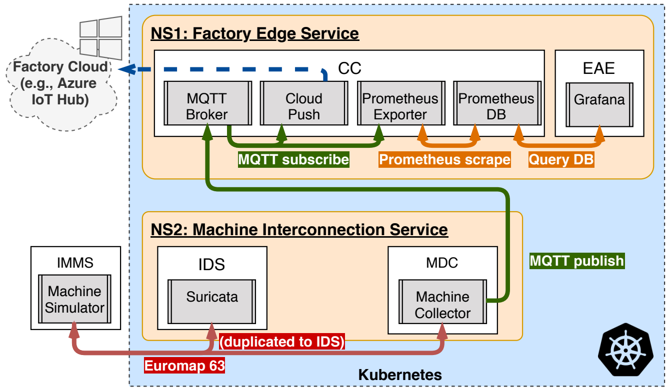

Fig. 1: Logical data flow through the smart manufacturing network services (yellow), VNFs (white), and containers (gray).

and alarms at the edge with minimal latency, e.g., to quickly react to sudden changes in machine data.

Moreover, each instance of NS2 contains an intrusion detection system (IDS) to monitor incoming traffic and detect potential threats. In case of a detected threat, the connection to NS1 is immediately dropped and replaced by an isolated quarantine instance of NS1 without access to the factory cloud. In doing so, the incoming data of this machine is isolated but still stored in a separate local database such that no data is lost. Once the threat is contained, the data can be merged and pushed to the factory cloud.

Overall, our smart manufacturing use cases involve two network services, four VNFs, and seven containers, which we implemented, integrated, and deploy on Kubernetes.

B. Deployment on Kubernetes using 5GTANGO

To realize the described scenario in a production environment, we evolved our network services for deployment on Kubernetes. This required adjusting our container-based implementation and creating suitable NFV descriptors and packages. For deployment, we leveraged the 5GTANGO service platform, which is a management and orchestration (MANO) platform that integrates with Kubernetes and allows on-boarding network services using typical NFV descriptors.

The 5GTANGO service platform handles the automatic creation of Kubernetes pods and services to facilitate the deployment and interconnection of the described network services. In particular, it deploys all containers of one VNF inside a single pod, enabling simple, direct communication of containers within the VNF. As pods are isolated by default, the service platform utilizes Kubernetes services to interconnect different VNFs or allow external access.

III. Demonstration

The demonstration illustrates the process of deploying network services NS1 and NS2 on Kubernetes using the 5GTANGO service platform. Using these services, it shows the easy configuration and connection of manufacturing machines as well as their data retrieval and visualization. Demo steps:

1) Presentation of cloud-native VNF and service descriptors for packaging, on-boarding, and deployment of NS1
2) Deployment of NS2 and connection to NS1
3) Connection of a simulated manufacturing machine to NS2
4) Visualization and edge analytics of the machine data
5) In case of a threat: Threat detection and containment

The demonstration requires our container-based network service implementation [12] and a (remote) machine with the 5GTANGO service platform and Kubernetes installed. A video showing the demo workflow is available online[1].

IV. Conclusion

We demonstrate one of the first cloud-native production deployments of real-world smart manufacturing use cases. This goes beyond existing high-level scenarios and trials deployed on emulation-based infrastructure. The light-weight, stateless deployment on Kubernetes through the 5GTANGO service platform enables rapid service startup and scaling as well as threat detection and containment. The resulting smart manufacturing scenario can improve manufacturing productivity and reliability and will be shown as one of the 5GTANGO vertical pilots. All presented components are open source [12].

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