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Business Process Logic Controller: Business Process-aware Network Optimization for Smart Manufacturing

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***Abstract*—In recent years, SDN- and NFV-driven approaches paved the way for more flexible and agile network orchestration and management. With the softwarization of networks, definition of complex network management strategies was facilitated. Consequentially, we aim to close the gap between business processes and network management. Our Business Process Logic Controller (BPLC) moves the definition of KPI requirements to the business logic itself, providing a fast and responsive network management driven by the business needs. In this work, we are introducing the concept of BPLC and highlight its advantages on a smart manufacturing use case, which we at Weidmüller, are currently operating.**

I. Introduction

The softwarization of network functions and components is a hype topic for nearly a decade now. Gaining flexibility and agility, software defined networking (SDN) and network function virtualization (NFV) support companies and organizations to design their networks following application requirements and not necessities of inadequate hardware network components. Organizations like IEEE [1] and ITU-T [2] have established working groups on standardization to foster the proliferation of these technologies by guaranteeing interoperability and common guidelines.

At the same time, other rising trends foster the attraction of SDN/NFV technologies. The development of 5G technologies enable future flexible factory networks [3]. Additionally, in manufacturing, the usage of industrial Internet of things (IIoT) components is increasing rapidly. These IoT devices, hardened for the specific operation in industrial environments, include sensors or actors, providing a significant amount of now available data about the manufacturing process. This enables the companies to enhance the efficiency by optimizing their production parameters or reducing outage times of machines [4].

This is in line with recent developments in manufacturing. The advancing digitalization fostered by processes like Industry 4.0 enables the usage of novel IIoT devices and unfolds their benefits. The gained opportunities and accompanying flexibility of production sites and systems require enhanced communication networks [5]. These approaches take existing and well-known methods to optimize manufacturing systems like Lean concepts [6] to the next level. First step for many companies is integration of centralized monitoring and control systems like manufacturing execution systems (MES) or enterprise resource planning (ERP) systems. Agile, flexible networks are a necessity to benefit from all advantages of such systems [7]. 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 [8].

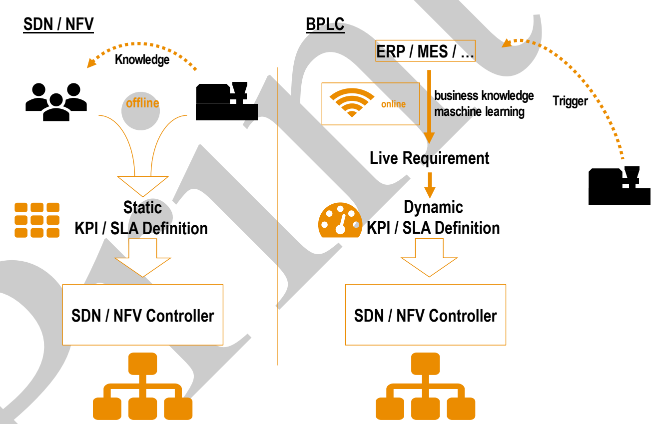

Fig. 1. Business-driven Network Control

One solution to overcome these challenges are SDN and NFV technologies, allowing for an agile and flexible network configuration. Virtualized network elements provide small and manageable components. The combination of several virtual network functions (VNFs) to a network service replaces current hardware solutions for connecting machines to cloud-based services. This enables additional possibilities of data analysis, machine park monitoring and control. Therefore, software defined networks will offer the flexibility for production systems as they are required [9].

However even with the provided flexibility and considered application requirements, SDN and NFV do not take the last step by offering an entire business application integration. In Fig. 1 the common high level work flow for the definition of SDN/NFV networks is illustrated. Based on knowledge

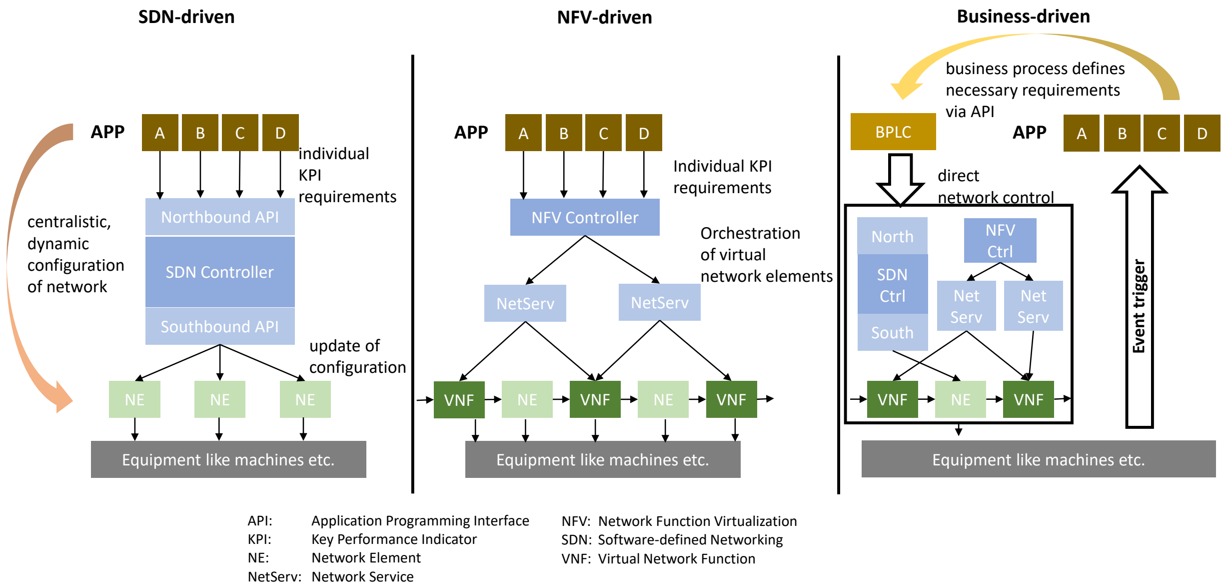

Fig. 2. Comparison of SDN- and NFV-driven network management to the BPLC approach

of manufacturing processes and driven by experience key performance indicators (KPI) or service level agreements (SLA) for the network are defined. This is an offline process, many different situations and use cases are considered and prioritized to specify the KPIs and SLAs. This picture reveals a missing link in the process, with digitized business processes on the one hand and agile, softwarized networks on the other. The consequent next step is to integrate the business process in the network control. Systems like the MES and ERP include the knowledge of the business processes. In most companies with production sites the experts are responsible for the production itself and not for the supporting networks. Hence, those systems are able to deliver dynamic KPIs based on current situations, acting fast and flexible.

This work is based on the EU-funded 5G-PPP research project *5GTANGO* [10]. It addresses the emerging challenges associated with both the development and the validation of vertical services and applications based on SDN. *5GTANGO* provides:

- A Software Development Kit (SDK) to support the development of NFV services.
- A Verification and Validation platform to test all developments and provide all developed network services to the community of users [11].
- A service platform to manage and orchestrate all network services [12].

In [13], the authors introduce an NFV-driven design approach and first implementations for a flexible smart manufacturing using the *5GTANGO* system. Building upon this, in this work, the authors provide a concept for the integration of business logic into network control and management. Therefore, the paper is structured as follows:

- The design concept for our Business Process Logic Controller (BPLC) is introduced in Section II.
- In Section III and Section IV, two use cases are considered in detail to highlight the modus operandi of the BPLC and its benefits in smart manufacturing.
- Finally, we conclude our contribution and give an outlook on potential next steps in Section V.

II. Design Concept for a Business Process Logic Controller

In industry, communication networks support the actual business by enabling production reports and monitoring of the manufacturing process. Therefore, the configuration of the networks should be driven by the business needs. Nowadays, SDN and NFV technologies are used, individual Key Performance Indicator (KPI) requirements are specified and influence the configuration of the network.

Fig. 2 highlights the differences between the SDN/NFV approach and our proposal for a business-driven methodology for network configuration and orchestration. In both cases, using SDN or NFV technologies, specific KPIs are defined for all used applications. In general, the KPIs are defined once for the initial setup of the communication network and are used as a set of rules for the network. If application A is active and requires a minimum data rate of 50 Mbit/s, this KPI is pre-defined via the Northbound API. The SDN controller decides how to react to that requirements in re-configuring the network, e.g. by switching priorities of data flow routes.

A slightly different approach is network function virtualization. The network components themselves are virtualized in software. A specific virtual network function (VNF) provides features such as routing but could integrate higher layer aspects such as managing a physical machine connection as well. In [13], we have introduced an architecture of several VNFs for smart manufacturing. In this setup, VNFs are used for the collection of machine data and their forwarding to a cloud system for further analysis.

Several of these VNFs can be combined to a network service (NetServ). This conjunction is used to summarize the benefits of individual VNFs which can be exchanged and having all needed components for a task such as machine data collection and forwarding.

Using the concept of network slices, the tailoring of NetServ to specific application requirements is enabled. Available resources can be split following pre-defined rules to prioritize applications with high requirements or to guarantee the operation of basic network applications.

Both concepts, SDN and NFV, lack of direct involvement of applications. The current needs are considered indirectly via pre-defined KPIs or SLAs. The novel approach introducing a BPLC will close this gap. As depicted on the right hand side of Fig. 2, the BPLC is the link between applications and network control components. The aim is to use application programming interfaces (API) to define the current requirements of the applications directly.

Additionally, a huge advantage is the enhanced event trigger management. In conventional SDN/NFV networks, the system is reacting to the current situation. For example, if an issue occurs and a machine is stopped, additional network resources might be needed to support the solution process by enabling additional services or increase machine data transfer. In case of SDN, the SDN controller recognizes the changed data traffic and reacts. In case of NFV, network slicing might be activated or a manual procedure takes place. Taking a deeper look at common business procedures, this should be avoided. The machine will report the issue to a MES in any case, the MES has a rule set for the handling of such situations, including the start of counter-measures. This information shall be used for direct network control to avoid needless intermediate steps. BPLC enables a pro-active planning of the network structure before the traffic changes. Following this approach, KPIs and SLAs will be created dynamically situation- and context-aware. This enables the usage of heuristics and machine learning procedures to optimize the system behavior. For certain types of situations, the same procedures repeat, the BPLC system can improve itself by learning from this situation for future incidents.

III. Use Case AR-Maintenance

In the following two sections, we are demonstrating the advantages of this approach and its impact on smart manufacturing processes using exemplary use cases. The first one is a plannable event, the maintenance of a production machine. The second use case considers a machine outage which requires fast and immediate reactions.

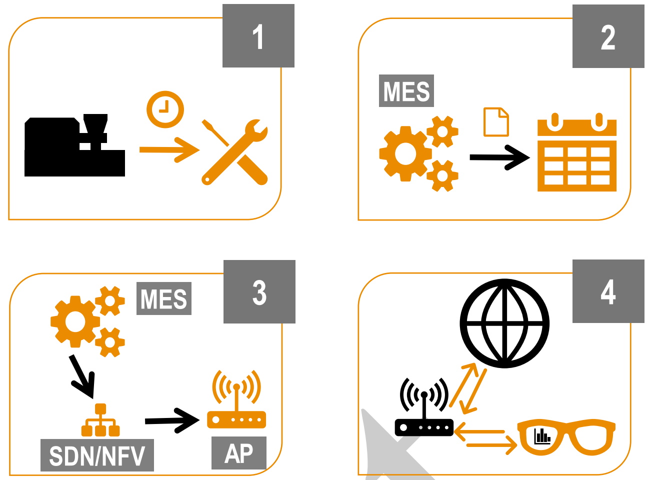

Fig. 3. Use case AR maintenance

Fig. 4. View of HoloLens user during remote maintenance session

This use case, AR-maintenance, has been defined for the 5GTANGO project to demonstrate the advantage of NFV technology for on-demand services [14]. BPLC will be the consequent next step, minimizing human interaction and increase the automation of network control.

In Fig. 3 the use case is depicted. The assumption is a running NFV-system for machine data collection and cloud connection, transferring all machine data to a cloud storage. Here, a routine machine maintenance must be scheduled. The maintenance is supported by an AR device like the Microsoft HoloLens[1]. The AR device visualizes machine data and facilitates the maintenance procedure. Temporarily, a WiFi access point (AP) should be active for the duration of the maintenance to establish an Internet connection for the AR device. This on-demand service, the WiFi-based Internet connection, is controlled by the NFV management and orchestration component. Additionally, for the time of the maintenance all machine data should be available. This is a difference to the daily work routine, for this just a subset of machine data is needed. To give an idea, a molding machine delivers approximately 10-20 parameters which are reported permanently for the operation

[1]https://www.microsoft.com/en-IE/hololens

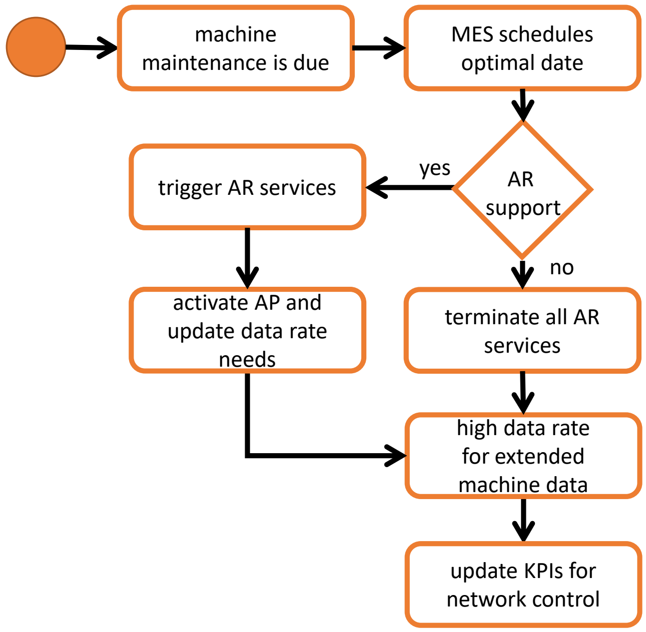

Fig. 5. Flow chart AR maintenance

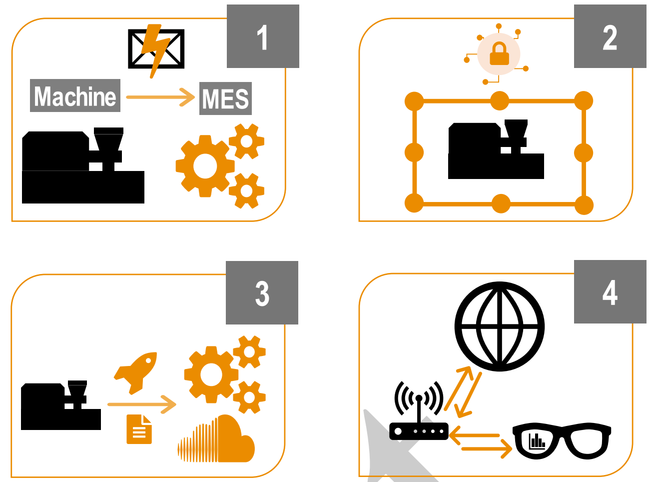

Fig. 6. Use case machine outage

of an MES but is able to deliver up to several hundreds of parameters depending on the vendor. Not all parameters are needed high frequently but the network traffic increases significantly anyhow.

In conventional, non-SDN/NFV networks, the intermittent activation of additional services requires manual reconfiguration of routers and gateways. This is time-consuming and inefficient. SDN/NFV facilitate the process significantly by providing functionalities to start/stop software components and gain flexibility. Nevertheless, the work flow is done manually by a network administrator. Therefore, flexibility is gained and the work flow is more efficient but manual interaction is still needed. This is where BPLC comes in.

Fig. 5 illustrates the changed work flow using SDN/NFV and BPLC. First of all, the maintenance should be scheduled by the MES/ERP system itself. All needed information about current order backlog, further available machines of the same type and resources are there and should be used to schedule the optimal date. Not all maintenance procedures are the same, it might be a fast production quality monitoring or a complete check of all components used in the machine. Therefore, the needed support differentiates. AR devices are used twofold, either for remote support (cf. Fig. 4) provided by the machine vendor and/or for visualizing production data e.g. pressures, temperatures or produced quantities. If needed, AR services must be made available by the network controller. As mentioned before, for a maintenance procedure the whole set of available data is needed. In this case, data rate capacity must be increased. The information what is needed for this maintenance type is already defined in the MES. Consequently, the MES can define KPIs like the following just-in-time:

1) AR services are needed $\rightarrow$ start respective network service with high data rate and low latency SLA.
2) Increased data rate for additional machine data is needed $\rightarrow$ prioritize network segment with this machine.

IV. Use case machine outage

A more complex use case is a machine outage. Such a breakdown and the following downtime is cost-expensive because of production stoppage and employee hours to fix the issue. Hence, the handling of that situation is very important for the company. In Fig. 6 typical reactions are illustrated. In modern MES, the worker or even the machine itself report an issue directly. Afterwards, appropriate countermeasures can start. Here the benefits of a direct involvement of network control into the production systems become evident in contrast to existing methodologies.

The issue type determines methodologies to find a solution. If remote support is needed, network capacity must be available for a video conference. Additionally, the set of written machine data might be extended to provide a full overview of the machine status. Therefore, the network must be adapted to the current needs. It is also important to emphasize the supporting role of the network in that case. Experts for the machines are needed but no network administrators. Consequently, all network adaptations should be started by the MES.

Fig. 7 illustrates an exemplary flow chart for the decision making done by the MES. Following the issue report, the first question is if the machine must be isolated. If the issue is noticed by an intrusion detection system (IDS) and an attack on the factory cannot be excluded, a first emergency response might be to isolate the machine to prevent further spread of the attacking component. In that case, a fast and immediate reaction is needed, manual intervention and the associated loss of time leads to the risk of major damage. A complementary step is to move the machine and into a separate, isolated quarantine network segment. Using local data bases, machine data is stored for further analysis of the attack. If the intrusion is prevented, the machine data can be checked for corruption and possibly transferred to the MES or a cloud system.

Assuming that it is no cyber security attack, additional machine data is supporting the malfunction repair. KPI levels for data rates must be adapted following this need. One example for the needed information is the sampling rate. During usual operation a rate of 1 Hz for machine pressures, engine speed, temperatures etc. is sufficient but to detect the failure a sampling rate of 10 Hz is supportive. Additionally, more machine parameters are helpful. Statistical values such as energy consumption might deliver a hint to find the error. Another example is the activation of further sensor systems. Vibration detection sensors monitor bearings and identify small deviations. All these procedures cause an increase of the network traffic by the factor ten or more. Network adaptation is necessary to fulfill this need. Again, a direct interaction of business process systems and network control is helpful. If machines are currently in idle mode because they are prepared for the next product, the network traffic can be stopped completely saving network capacity for more important tasks.

Finally, AR support might be needed, provided by the machine manufacturer or for visualizing machine information. This on-demand service is triggered in the MES as well, either automatically or by the machine fitter. In both ways, impact on the network is defined, adaptations should start immediately.

To summarize, for the use case of a machine outage, several ways to solve the issue are defined, the MES is aware of the current status of production and machines and is therefore in a position to decide on consequent network adaptations. Exemplary KPIs are:

1) Turn down machine connection, e.g. via a network service, immediately to prevent a spread of the attack.
2) Increased data rate for additional machine data is needed $\rightarrow$ prioritize network segment with this machine, if needed stop network traffic for other machines if they are in idle mode.
3) AR services are needed $\rightarrow$ start respective network service with high data rate and low latency SLA.

V. Conclusion & Outlook

In this work, we are providing a concept for a business process logic controller enabling a direct network control for the business process systems like an MES or ERP. With increasing automation in manufacturing such systems have a full overview of all ongoing processes. Therefore, it is consequential to use this knowledge for fast reactions on the network topology. Using SDN/NFV technology as a basis, this approach fosters further automation and enables companies with small network administrations to benefit from current developments in network design. From our point of view, this is the necessary next step to leverage SDN/NFV technology.

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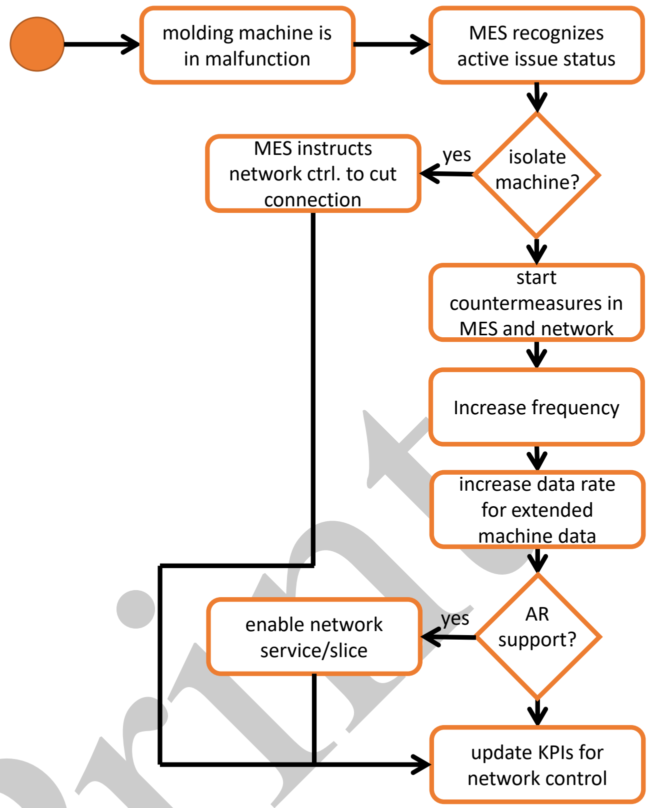

Fig. 7. Exemplary flow chart for issue handling

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