Towards a Cloud-Native 5G Service Chaining for IoT and Video Analytics in Smart Campus

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***Abstract*—Providing ubiquitous fifth-generation (5G) connectivity is very appealing to advance a wide range of use cases and industry verticals. However, it is expected that the ultimate capability of 5G networks will only be achievable by a blend of technologies centered around 5G to fulfil the needs for different verticals and use cases. In this regard, this paper presents the key requirements to collectively leverage 5G, artificial intelligence, and cloud computing technologies to enable a smart campus/buildings use case. A comprehensive framework is first presented showing the key enabler constituents of this use case, ranging from the network to cloud and application domains interconnected in a 5G testbed. The description of the individual components in the 5G testbed is then explained. Key technical challenges pertaining to smart campus/buildings use case are then discussed, and potential research directions are outlined.**

***Index Terms*—5G core , new radio, orchestration, virtualization, analytics, and artificial intelligence.**

I. Introduction

Fifth-generation (5G) Industrial and enterprise use cases will be mainly focusing on Internet-of-things (IoT) and video applications [1]. For example, the past few years have witnessed a tremendous increase in using IoT and video applications to track building systems and maximize their efficiency and maintain a comfortable and productive work environment. Such benefits attained via IoT and video applications can be further extended to enable frictionless, touchless, and intuitive experiences by leveraging the most advanced and next-generation emerging technologies centred around 5G.

In details, 5G technology can open up a new set of breakthrough use cases for consumers and businesses that use applications relying on increased connection speeds, improved traffic capacity, low latency, high reliability, and support for massive density of devices. In order to realize the full benefits of 5G, virtualized cloud-based network infrastructure is required to allow resource optimization. Moreover, the blend of 5G and artificial intelligence (AI) technologies would provide a foundation to support new ground-breaking use cases in several verticals. Enterprise and end consumers will enormously benefit from such enhanced capabilities fostered by establishing full ubiquitous 5G networks and assisted by cloud/edge computing and AI technologies. We here focus mainly on devising an innovative solution to enable true transformation towards smart campus/buildings. In principle, the smart campus/buildings use case represents an ideal candidate that can leverage the blend of 5G, virtualization, and AI for the IoT and video applications.

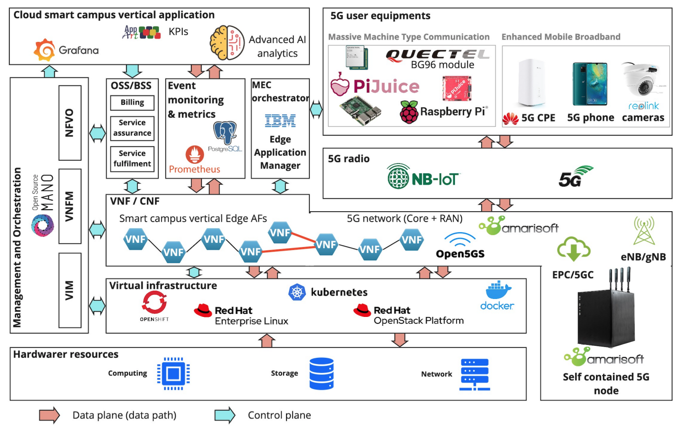

Fig. 1. Holistic view of the enabler technologies and software platforms for the smart building/campus use case.

Next, we present a holistic view of our adopted framework towards smart campus/buildings and the underpinning technologies. We then elaborate on the particular applications and software platforms in our testbed and the main objectives and research directions.

II. Framework for Smart Campus/Buildings

A. Definition of VNF and VNF Chaining

We first explain the concept of virtualization for 5G networks as a key pillar in the adopted framework. Network function virtualization (NFV) along with software defined networking (SDN) are revolutionizing the Telco field as they can solve the problem of increasingly complex network infrastructure for the communication service providers (CSPs). By shifting the deployment model of network services (NSs) from a physical network-centric approach to a virtualized one, CSPs are able to propose more dynamic and elastic services, thereby improving the end-user experience. In this new paradigm, different network appliances, physical network functions as well as various application-specific features are replaced with a chain of virtual network functionss (VNFs). These VNFs are organized in a *service chain* that is deployed on a subset of an underlay network infrastructure, which, in turn, is composed of a more cost-effective general-purpose computing infrastructure. This allows easier and faster service onboarding, update, and termination of NSs. It also improves the resource utilization driven by the deployment of multiple service chains on the same infrastructure. Such multiplexing of services is achievable thanks to the network slicing concept [2], where logically isolated service chains can be hosted on the same network.

SDN, NFV, and slicing are central to 5G networks. They are leveraged together in 5G to enable three isolated yet co-existing service classes, namely, enhanced mobile broadband (eMBB), massive machine-type communication (mMTC) and ultra-reliable low-latency communications (URLLC). These service classes are represented by three distinct network slices running on the same infrastructure. Each network slice is specifically engineered to enable distinct applications with diverse service requirements. Furthermore, these slices can be deployed on-demand and optimized according to the underlying network conditions thanks to intelligent traffic steering.

The implementation of the smart campus use case also encompasses the deployment and chaining of some application-specific VNFs, i.e., application functions (AFs), interconnected to the 5G NS chain. Hence, the overall service chain will consist of the 5G core network VNFs as well as the AFs. We are particularly focused on two use case scenarios centred around IoT and video applications. Such applications can greatly benefit from VNF chaining as it can yield a highly available service at the network edge at very low latency. In addition, the tight integration of the AFs with the 5G network will open prospects for the establishment of a feedback loop between the 5G VNFs and the AFs. This enables the end-to-end adaptation of the NS and its optimization in response to different scenarios and network conditions.

B. Framework Description

The realization of smart campus/buildings use case relies on multiple technologies and software platforms centred around 5G. For example, Fig. 1 describes the adopted framework to build the testbed for smart campus/buildings use case. Starting from the bottom, we have the hardware layer, where the computing, storage, and networking functionalities are accommodated. On top of the hardware resources, the virtual infrastructure exists, which consists of hypervisors and containerization software. The hardware resources and virtualized infrastructure layers can be seen as the underlay virtual network on which the 5G NS chain can be deployed. The layer on top encompasses a chain of VNFs and cloud-native network functionss (CNFs) that represent a mix of the 5G core and radio access network (RAN) functions as well as some vertical AFs particular for IoT and video applications (analytics).

In our framework, the deployment of AFs and 5G core (5GC) VNFs/CNFs at the network edge is particularly to account for an multi-access edge computing (MEC) scenario where all data processing and computation take place close to the source of the data, i.e., the 5G user equipments (UEs). In addition, the MEC is deployed together with the 5G core VNFs to allow low latency, high throughput service access from the MEC host. As illustrated in the MEC scenario for 5G in [3], the MEC consists of MEC system-level orchestrator and a platform manager. The former represents the core component of the MEC architecture as it is responsible for the management and orchestration (MANO) of the MEC workloads on the NFV infrastructure (NFVI). In addition, the latter is represented by a software agent installed on the NFVI and is responsible for lifecycle management (LCM) of the MEC workloads.

The MANO block is needed to orchestrate the 5G NS and manage the different functional layers such as the virtual infrastructure and the 5G layer. This MANO block also interacts with the operations support system (OSS)/business support system (BSS) in order to define the NS configuration. On the other hand, the event monitoring and metrics block stores and streams the time-series data from the NS layer to an edge cloud which, in turn, hosts functionalities such as dashboards and key performance indicator (KPI) visualizations as well as advanced AI analytics. The event monitoring and metrics block can also interface with the OSS/BSS block to provide insights about the NS performance and thus adjust and optimize its configuration. Finally, the 5G radio block represents the 5G UEs attached to the 5G network. Two sets of UEs are considered for our use case, particularly, IoT and video devices.

III. Testbed and Research Areas

A. 5G Testbed

We next describe the key components constituting our 5G testbed for smart campus/buildings use case and review some relevant works. We then highlight the key technical challenges and research directions. Inspired by the adopted framework of Fig. 1, our testbed consists of various constituents that collectively enable the full blend of 5G, cloud computing and virtualization, and AI technologies. First, 5G technology is leveraged to provide cellular connectivity to multiple 5G UEs, e.g., IoT sensors and 4K cameras, which are key pillars for the operation of smart campus/buildings. The 5G network is composed of a 5GC connected to an next-generation node B (gNB). Cloud-native deployment of the 5GC is leveraged where an open-source 5GC, namely, Open5GS [4], is deployed on our private cloud. This 5GC is then integrated to Amarisoft gNB which incorporates the functionalities of eMBB and mMTC network slices. Two logical links are established between the 5GC and the gNB, namely, next generation application protocol (NGAP) and GPRS tunneling protocol (GTP) for the user and control data planes, respectively. Such cloud-based deployment of the 5GC based on VNFs will facilitate resource sharing, dynamic resource allocation, and responsive upscaling and downscaling of cloud resources in respect to the underlying traffic dynamics.

We adopt the European telecommunications standards Institute (ETSI) network function virtualisation architecture (NFVA) in order to leverage the dynamism provided by NFV and SDN primitives. This NFVA is composed of NFVI, virtual infrastructure manager (VIM), VNF manager (VNFM), and the NFV orchestrator (NFVO). The VIM is responsible for the control and LCM of the VNFs, and the interaction between VNFs and the NFVI hardware resources. Meanwhile, NFVO is responsible for the deployment NSs by embedding what is defined in VNF and NS descriptors into the NFVI. That said, the allocation of the required virtual networking, compute and storage resources to start VNFs and allow communications between them is defined in the NS and VNF descriptors. In our work, we adopt RedHat OpenStack and open source MANO (OSM) for the VIM and NFVO, respectively. Besides the realization of NSs, OSM is also able to gather information about the NFVI such as allocated resources, performance metrics about VNFs and virtual links, and NFVI faults information. This information among others, could be further used to monitor and update the NSs. In our testbed, monitoring data is collected from the OSM monitoring module and external tools such as Promethus.

Importantly, proof-of-concept realization of 5G and fourth-generation (4G) networks was carried out in prior work in the literature, e.g., see [5]–[8]. For example, the authors in [5] adopted OpneStack and OSM to implement an MEC-enabled 5G platform to study the VNF LCM challenges. In addition, the work in [6] used OSM to demonstrate how 5G envisions NFV MANO for instantiating NSs, e.g., 4G core network and SDN controllers. Moreover, we measured the performance of standalone (SA) and non-standalone (NSA) 5G networks in [8].

B. AI for Resource Allocation and Analytics

Driven by the dynamicity of cloud resources, AI can be leveraged to allow for an unprecedented level of cognitive automation, enabling 5G networks to conduct intelligent, agile, responsive network and service operations. Particularly, AI can allow zero-touch, automated, and optimized provisioning of cloud resources so as to improve the perceived service. This will effectively have a pivotal impact on reducing operational costs, automating workflows, and lowering data processing latency. AI is actually becoming very crucial for applications where near real-time feedback and optimization are a priority. Importantly, the use of AI for proactive Telco cloud resource allocation is recently studied in the literature, see, e.g., [9]–[11]. For example, the authors in [9] investigated how should the NFV providers (NFVPs) purchase cloud resources to provide NFV services to their customers while minimizing the overall expenses. They particularly performed traffic and cloud price predictions via long-short term memory (LSTM). In addition, low-complexity slices' traffics predictor was proposed in [10] based on a soft gated recurrent unit (GRU) and joint multi-slice deep neural networks (DNNs) to estimate the required resources based on the per-slice traffic. Meanwhile, the authors in [11] proposed a forecasting scheme to estimate the capacity needed to accommodate future traffic demands per each network slice.

In addition to its vital role in cloud resource allocation, AI is also a key player in smart city and campus related applications centred on IoT and video analytics. For example, real-time monitoring and historical information available from IoT sensors and the underlying environment can be fed into novel machine learning algorithms based on, e.g., deep recurrent neural networks to revolutionize applications such as anomaly detection, predictive analysis, and response coordination. Additionally, novel video analytics based on AI would also facilitate intelligent anomaly and object detection and behaviour monitoring in smart campus/buildings.

IV. Conclusions and Future Work

This paper has provided a comprehensive framework to enable a smart campus/buildings use case based on 5G, cloud computing and virtualization, and AI. We showed that the blend of these technologies helps achieve the full feature of 5G networks as it represents a key enabler for many use cases and industry verticals. We further described the key technologies and software platforms adopted to build our 5G testbed for smart campus/buildings. Our future work will be focused on leveraging this testbed to build a proof-of-concept case study for smart campus/buildings based on three pillars, namely, 5G, cloud computing and virtualization, and AI technologies.

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