On the development and provisioning of vertical applications in the beyond 5G era

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Abstract—The 5th Generation (5G) of mobile networks brings the concept of openness to vertical industries, by enabling new levels of programmability in the network core and edge domains. Openness is enabled through APIs and it creates the field for developing 5G-enabled vertical applications, i.e., applications that can interact with the underlay network. In this context, a programmability framework is envisaged, with major objective to support the development of 5G-enabled vertical applications, as well as, their testing, prior interacting with commercial networks. Implementation directions for the proposed framework are also provided, leading to a bunch of development and research-oriented takeaways.

Index Terms—5G, Vertical Industries, Programmability framework, Experimentation facility

I. INTRODUCTION

The functionality of the 5G core (5GC) has been structured in a Service-Based Architecture (SBA) [1] in order to facilitate the provision of vertical-specific applications. 3GPP defines the SBA as a set of functional components, known as interconnected Network Functions (NFs), where each one can use standardized interfaces, or Service-Based Interfaces (SBIs), to access and consume services of other NFs through an API-based internal communication. Among the various NFs of the 5G, the Network Exposure Function (NEF) offers the means to securely attach services and expose capabilities, provided by the other 5G NFs, to external systems, i.e., NEF offers the appropriate APIs for the usage of SBIs from externals. This openness of the 5GC, provides third-party innovators, also referred to as vertical industries, with the required toolset to control and monitor the deployment process and the performance of their services. The same scope of 5G-core openness to third parties is also served by the APIs that are developed on top of NEF, namely the Vertical Application Enablers (VAEs), the Service Enabler Architecture Layer (SEAL) services [2]; as well as edge services through the Multi-access Edge Computing (MEC) APIs. In view of the openness realized through the above-mentioned exposure features (NEF, VAE, SEAL, EdgeAPP etc.), a new ecosystem emerges, where vertical industries and infrastructure owners redesign their technical and business potential.

On the one hand, with the arrival of 5G, the infrastructure owners have a rich toolbox (that includes cloudification and network slicing features) which allow the creation of logically isolated networks, on top of shared resources, optimized for specific use cases, service types, and business models. Moreover, the capability to interwork with other access technologies (e.g., through network gateways, such as the N3WIF - Non-3GPP Interworking Function) provides infrastructure owners with a clear widening of the service provisioning potential, since radio access technologies, such as WiFi6 and NB-IoT (Narrowband Internet of Things) can be incorporated. On the other hand, the vertical industries are ready to take advantage of openness toolbox and develop new novel applications that interact with the underlay network, namely, 5G-enabled vertical applications.

From the technological point of view, the cornerstone towards unleashing the value proposition for the two stakeholders (i.e., the vertical industries and the 5G infrastructure owners) is the proliferation of the private deployments in vertical industries’ premises of 5G networks, i.e., the so called 5G Non-Public Networks (5G NPN) [3], as well as, the definition of a programmability framework that will enable the utilization of the above-mentioned toolbox from the vertical application developers. The major challenge for such a framework lies on the need for continuous development, test, and evaluation of vertical-specific 5G-enabled applications, on top of realistic configurable 5G infrastructures, prior to their commercial deployment in the mobile networks (operators’ infrastructures).

As a response to this challenge, a framework that could support in long-term the vertical application development and provisioning over mobile networks, is proposed. The framework realizes programmability at the core domain of the mobile network, towards transforming NPN-5G infrastructures to private open service platforms. It is meant to serve as collaborative platform for the infrastructure owners and the vertical industries, and as such, it engages the creation of a vertical-specific market, analogous to the currently available ones for mobile apps (e.g., Play Store, AppStore). More precisely, in this paper:

- The advancements that enable the interaction of vertical application providers and infrastructure owners are analyzed.
- The functional components of a programmability framework that would assist vertical application developers to create, test, and release their vertical-specific 5G-enabled applications are described.
- A proof-of-concept scenario is examined to showcase operational aspects of the proposed framework.

The sections that follow are one-to-one mapped to these three aspects, while an additional section is provided for the major results and takeaways.

II. MOBILE NETWORKS AS SERVICE PROVISIONING PLATFORMS

The evolution of the mobile core system towards an open service provisioning platform is based on three recently

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emerged advancements. First, the definition of the 5G architecture towards a service-based scheme, which exposes advanced 5G capabilities to third parties. Second, the softwareization/cloudification of individual functional components of the network (implemented as Virtual Network Functions-VNFs or Containerised Network Functions-CNFs); an evolution that brought the toolbox of the cloud-based services to the telecommunication sector. And third, the specification of the ways to deploy/migrate the overall network functionality to private infrastructures, defining the concept of 5G NPN.

A. The openness of the service-based architecture

The release of the 5G architecture by 3GPP [1] has officially launched a new era in mobile networks, where, among all the other advances, the key change was the reorganization of the Control and User Plane Separation (CUPS) functions into services. The SBA that was created through this process has provided to the software industry the capability to improve the modularity of products that are offered through the 5G networks. Indeed, a software product can be broken down into fundamental service components, allowing the developers to mix and match services from different vendors into a single product. The various NFs of the 5GC can be clustered based on their functionality to i) network resource management functions, ii) signaling functions, iii) policy control functions, iv) packet control functions, v) location management functions, subscriber management functions, and vi) exposure functions.

The fundamental functionality for a secure realization of 5GC exposure to verticals is provided by the exposure functions i.e., the NEF. In specific, NEF enables external applications to communicate with the 5G core’s SBA via APIs (i.e., Secure provision of information from an external application to 3GPP network). Practically, it adapts and transforms telecom network interfaces to RESTful APIs. Considering the SBA, the main consumer of NF APIs is the Application Function (AF). AF may or may not reside at the domain of the infrastructure owner (operator’s domain) and its main functionality includes the provision of Packet-Flow Descriptors (PFDs) to NEF, and the consumption of RESTful APIs to utilize services and capabilities securely exposed by NEF.

On top of the fundamental exposure from NEF, VAE and SEAL APIs are being developed, while verticals can develop their own APIs by utilizing the Common API Framework (CAPIF) [4] as well. Those aspects are considered in the proposed vertical-oriented programmability framework, as explained later in this paper.

B. The paradigm shift of 5GC towards cloudification

As the 5G mobile core evolves towards enabling a great variety of services, the NFs of the 5GC leverage the benefits of cloud concept. Beyond the virtualization paradigm, the core NFs are modularized and containerized, and as such, they are subject to flexible and scalable lifecycle management. The cloudification of mobile core functions provides operators with extensive capabilities and tools, primarily designed for cloud-native applications. From the software implementation perspective, the 5GC realization with cloud-native refers to three aspects:

1) Realization of core NFs as micro-services. The realization of the 5GC NFs as micro-services (on containerization engines), provides capabilities, such as agile 5GC creation and flexible deployment; while it enables automated and lightweight lifecycle management. The main benefits are: i) the stateless implementation of the NF that facilitates the on-the-fly migration of the 5GC functions in different domains (e.g., to the edge) and ii) the highly efficient sharing of the infrastructure resources. As a cost for those benefits is the complexity for a network-based chaining of the containers, as well as the additional computation cost required for the APIs expose and consuming processes.

2) Emergence of open-source software stack. The use of open-source software stack broadens the potential for on demand network deployment, since autonomous software pieces can be combined and re-used easily to shape network instances tailored to the needs requested from vertical industries. This is a general trend in telecommunications, and it is also applied towards a vendor-independent distributed RAN, under the auspices of the Open RAN (ORAN) alliance. Moreover, the open-source approach defines the era of continuous evolution of the mobile networks, since, instead of defining and release periodically new specifications, any new feature can be directly released as software piece and can be integrated through software versioning.

3) Adoption of agile software development methods. This is a requirement of the new era in service provisioning, where the services should be able to continuously and easily update with improvements that reflect changing market demand. Such an approach is the DevOps methodology, that integrates software development and IT operations.

C. The introduction of 5G non-public networks

A 5G non-public network (NPN) refers to a 5G system deployment that is dedicated to providing 5G network services for private use (i.e., to a specific organization e.g., inside a factory). Such a network is deployed on the organization’s premises, for instance, inside a factory.

The introduction of 5G NPN [3], is beneficial for the verticals for a series of reasons, but, mainly due to the potential to isolate from other (public) networks. This isolation is desirable for reasons such as performance, security, and privacy. There are a few deployment options for the 5G NPN, that can be primarily clustered in two groups:

1) Standalone Non-Public Network (SNPN), an isolated network operated by an NPN operator. The NPN operator can be either the vertical itself, by using locally available 5G spectrum, or by an operator (that potentially deploys also the NPN at vertical’s premises), by using licensed 5G frequencies. The key aspect in this category is that deployments do not rely on network functions provided by a public network.

2) Public Network Integrated NPN (PNI-NPN), a non-public network deployed with the support of a public network. The above-mentioned support can include different levels of interaction with the public network at any domain of the service provisioning chain (RAN, edge, or core). The key enabler for this deployment is the concept of Network Slicing.

III. Vertical-Oriented Programmability Framework

The evolution described in the previous section requires a dynamic, yet challenging, ecosystem for the long-term support of vertical-oriented service development and release. Two interlinked components are identified and depicted in Figure 1, namely: i) an open experimentation facility, and ii) a development and validation platform. These components are
discussed in the following subsections.

A. Open experimentation facility

The open experimentation facility of the proposed framework includes the infrastructure that composes a mobile network, as well as all the required functionalities for providing the mobile network as a service to verticals. The openness of the facility refers not only to the support of exposure APIs, but also to the capability of onboarding external functions or probes upon request from the vertical application developer. On the one hand, the openness though APIs is proposed to be based on the common API framework (CAPIF) [4]. Conversely, for the onboarding capabilities and provisioning of the infrastructure as a service, the toolset of ETSI Management and orchestration (MANO) are proposed. The building blocks of the proposed framework’s experimentation facility are listed below.

1) MANO-enabled end-to-end 5G infrastructure. The software and hardware components that realize the full protocol stack of the mobile network is a fundamental part of the open experimentation facility. This set of components is complemented by tools for the management of computation, network and storage resources; such as those provided by the MANO architecture, in the context of the requirements that 3GPP presents in TS 28.533 [5]. Overall, any mobile network infrastructure that can: i) incorporate new features or upgrades in the protocol stack, while maintaining the API exposure and onboarding capabilities, and ii) expand its access domain, with IP or ethernet based (e.g., Time Sensitive Networks - TSN) external infrastructures (with other access technologies), complies with the proposed framework. These are key principles that enable a long-term evolution of the proposed framework, including the 6G infrastructures in the future.

2) The (e)CAPIF concept. To avoid duplication and inconsistency of approach between different exposure-API specifications, 3GPP has considered the development of CAPIF that includes common aspects applicable to any northbound service API of the 5GC. CAPIF has been introduced in 3GPP Rel. 15 and it has been also revised in 3GPP Rel. 16, under the term eCAPIF. The major addition of eCAPIF is the support of 3rd party domains, i.e., the additions of features that allow 3rd party API providers to leverage the CAPIF framework. This implies the creation of a supplementary exposure levels of the 5G network (supplementary to the fundamental exposure functionality represented by NEF), since verticals can develop their APIs for exploiting network capabilities. The main components defined in CAPIF are the API invoker(s), the CAPIF Core Function (CCF), as well as the API Exposure Function (AEF), Publishing Function (APF) and Management Function (AMF). API invoker(s) refers to the application(s) that requires service from the service providers (verticals). The CCF hosts all the APIs (including the NEF APIs) and implements authentication, as well as onboarding/ off-boarding procedures for API invokers. The CCF APIs are exposed, published, and managed through the AEF, APF, and AMF entities, respectively. Especially the AEF, translates those APIs to a set of vertical-oriented ones enabling the potential for further exploitation from developers of a related vertical sector.

Considering the functionality set in the (e)CAPIF framework there are various implementation options, using the NEF and AF entities of the 5GC. For the proposed framework we consider the following. The NEF implements the CCF and the AEF, while the AF realizes the API invoker. As it can be observed in Figure 1, the API invoker invokes the service APIs in the PLMN trust domain and the service APIs in the 3rd party trust domain via CAPIF-2e (from outside the trust domains, interacts with the CAPIF core function via CAPIF-1e, not depicted in Figure 1). The interfaces CAPIF 3e, 4e and 5e are used for the interaction of the CCF with the AEF, APF and AMF, respectively.

B. Development and validation platform

The development and validation platform, is a component of the proposed framework that enables verticals to create new services and features, as well as to utilize a set of tools that are needed for performance evaluation and stress testing of the developed applications. More precisely, the verticals can exploit the platform to: i) develop applications that are capable of residing at the network side and exploit 5G performance capabilities and management flexibility, ii) implement vertical-specific API invokers (as defined in eCAPIF), as an effort to enable other parties/third parties to develop their applications, as well as iii) perform automated service validation tests and collect/study/visualize the validation results.

1) Application and API Invokers development. The vertical services (application and/or the API invoker) are considered as microservices or VNF artefacts, that offers features for various functionalities of 5G-enabled use cases. For the development procedure, a Continuous Integration/Continuous Development (CI/CD) environment is consists with all the major functionality, namely, of i) source control, acting as code repository and allowing code versioning, ii) automated build and testing, iii) containerization of services and components, iv) software development and debugging. The
developments are hosted in a repository accessible outside the development area to be available for validation in the experimentation facility of the framework.

2) Validation tools. The main role of the validation tools is to provide capabilities for running automated tests under well-defined configuration/parametrization of the facility. Four main features are considered:

- **Onboarding controller.** The developments are imported into third party servers that are part of the open experimentation facility in order to be validated and tested; thus, capabilities for controlling the onboarding process are added to the platform. To make this procedure dynamic a set of virtual infrastructure managers (VIMs) and orchestrators at the facility is required.

- **Test execution manager.** It is responsible for configuring and scheduling the facility based on the target validation tests. This is performed by using the information available from the facility of the proposed framework in conjunction with a test descriptor. The test descriptor is a structured form of information needed for conducting a test. Already, there is comprehensive work on that direction from EC Horizon 2020 5GPPP projects and, here, we consider the structure provided in the related white paper [6].

- **Test automation tool.** It is responsible for applying the commands from the test execution manager to the facility and to host agents or plugins required for executing a test. This is an important part of the framework since it allows the verticals to re-use a pool of tests and related plugins on demand. Thus, the design of the test and the implementation of the related agents is decoupled from the vertical service development process.

- **Results analysis and visualization.** Vertical to network level measurement campaigns are considered in the proposed framework. The measurements can be collected from exposure APIs and directly from agents. The diversity of the available data and their volume can enable analytics. The visualization of the results is also provided, for real-time network resource monitoring, and, also, for dashboarding of post-processed data.

IV. IMPLEMENTATION ASPECTS AND PROOF OF CONCEPT

A meaningful subset of the framework has been realized to prove efficiency and usability of the proposed framework, as well as to reveal additional aspects not foreseen during the framework design process. The target was to: i) implement the proposed framework with open-source software, ii) exemplify the usage of the framework by running the development and validation processes for a representative vertical application, and iii) retrieve the benefits that the application owner gets by using the framework.

A. Open-source implementation

The realization process targeted the two major parts of the framework, i.e., the implementation of an open experimentation facility with an integrated development and validation platform, while implementation directions are provided for the third part of the framework, i.e., the marketplace. The tools that were used for the Proof of Concept (PoC) realization are listed in Table 1.

1) Open experimentation facility. There are many infrastructure owners that have provided remote access to core network components for experimentation purposes. This is due to the full cloudification of the protocol stack of the core network. For instance, the open5Gcore, and the OpenAir Interface (OAI) 5G core. For the radio part, the experimentation with Ettus SDRs and OAI RAN protocol stack is the most common fully open solution. There are also all-in-one solutions like that provided from Amarisoft (the so-called amari-lte-callbox). For the evaluation of the proposed framework, the realization of the infrastructure was based on a full virtualized OAI solution and commercial end devices (UEs).

2) Development and validation platform. For the development and validation platform, the following tools are available:

- **Development tools.** In the proposed framework, representative tools for the development process were used, namely the Gitlab (repository), the Jenkins (automated build), and the Android studio (code development).

- **Validation tools.** The most common VIMs (Openstack and OpenNebula) and orchestrators (OSM and OpenBaton) were considered to realise the onboarding procedure. The key opensource solution for test automation i.e., the OpenTAP from Keysight was chosen. For the experiment lifecycle management, the use of the openly released features of open5GENESIS suite (available online at https://github.com/5genesis) was considered. Also, The NetDATA tool was used for the visualization of the network resources consumed and the Grafana tool for the dashboarding of the performance results.

### TABLE 1 FEATURES OF THE PoC FRAMEWORK

<table>
<thead>
<tr>
<th>Component</th>
<th>Feature</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>QoE App that extracts the QoE-based video performance Fingerprint</td>
<td></td>
</tr>
<tr>
<td>API invoker</td>
<td>YouTube API invoker (consumes 5G API and utilizes YouTube APIs to assist the QoE App)</td>
<td></td>
</tr>
<tr>
<td>NEF services</td>
<td>Resource management and Network reporting (Analyticsexposure API)</td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Ettus SDRs N300, commercial UEs, and protocol stack from EURECOM Open Air Interface (for both the core and access part). Stand Alone (SA) mode with NEF API emulation capabilities.</td>
<td></td>
</tr>
<tr>
<td>Source control</td>
<td>Github</td>
<td></td>
</tr>
<tr>
<td>Automatic build</td>
<td>Maven (supported by Jenkins CI tool)</td>
<td></td>
</tr>
<tr>
<td>App Development</td>
<td>Android Studio</td>
<td></td>
</tr>
<tr>
<td>Test execution manager</td>
<td>Related component from the open5GENESIS suite and app-specific test case descriptor</td>
<td></td>
</tr>
<tr>
<td>Automation tool</td>
<td>Open TAP with the addition of related plugins</td>
<td></td>
</tr>
<tr>
<td>Visualisation</td>
<td>NetDATA for network resources and Grafana for application layer measurements</td>
<td></td>
</tr>
<tr>
<td>Onboarding control</td>
<td>Openstack (VIM) and OSM (orchestrator)</td>
<td></td>
</tr>
</tbody>
</table>

B. Exemplify with a vertical application

For the assessments on top of the PoC framework an application that evaluates the QoE Performance Fingerprint - QPF of videos consumed through the YouTube platform was developed. It utilizes YouTube API invoker and requires Resource management and Network reporting services from the 5G northbound API. More precisely the QPF App, is composed of a video consumption client, where any video from the YouTube platform can be selected for consumption. The client can operate either in auto mode, where no end-user is required, or in manual mode, where end-users provide subjective opinions on the quality of the consumed video. In both cases, the YouTube API is exploited to retrieve QoE-related factors, such as video initialization time, and number/duration of playback interruptions.

The feedback that provided to the vertical application
developers has been structured in three layers, as listed in Table 2, namely: i) Assessment of the deployment process over a real mobile network; ii) Network resources consumed to support the application; and iii) Application-layer measurements. As can be observed in Table 2, the measurements that belong to the first two layers are not available in the conventional interaction among verticals and MNOs, where only application layer metrics can be collected at the vertical side. Indeed, the use of 5G infrastructure and 5G standardized APIs during the development process is a valuable gain for the application developers, since they are becoming aware of the resource consumption fingerprint that the app leaves on the network and they can test the compliance of their app against standardized APIs. A clear message from the procedure executed is that the use of test automation tools and related methodologies [7], provides acceleration in the development process and reliability to the validation results. However, a side effect is the fact that the specificities of the implementation of the visualized/cloudification part affects the performance, especially in terms of network slice creation times, isolation level, and security guarantees. A consequent result of that performance variation is that potentially the charging models that will be used for the vertical applications (onboarded in a 5G network) could be based on those already used in cloud sector (as for instance the pricing options offered by Amazon).

<table>
<thead>
<tr>
<th>Feedback type</th>
<th>Proposed framework</th>
<th>Conventional approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of the deployment process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Slice Placement Time</td>
<td>-10-20 msec</td>
<td>The values are related to the technical implementation of the visualized environment</td>
</tr>
<tr>
<td>Network Slice Deployment Time</td>
<td>~1-5 sec</td>
<td></td>
</tr>
<tr>
<td>Network Slice Provisioning Time</td>
<td>~1-5 min</td>
<td></td>
</tr>
<tr>
<td>Assessment of the resources consumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used RAM per CN function VM</td>
<td>4%</td>
<td>Can be provided through the exposure KPIs from the network.</td>
</tr>
<tr>
<td>Inbound/Outbound rate in CN-function VMs</td>
<td>In:~128Kbs Out:~4Mbs</td>
<td></td>
</tr>
<tr>
<td>Application-specific measurements (QoE-related factors)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of each video consumed</td>
<td>5-10 min</td>
<td>A related network app from the marketplace can be utilised</td>
</tr>
<tr>
<td>Initialisation/waiting time</td>
<td>8-15 sec</td>
<td></td>
</tr>
<tr>
<td>Number and duration of network-related video interruptions</td>
<td>1-3 (duration of ~200ms each)</td>
<td></td>
</tr>
<tr>
<td>Number and duration of ads-related video interruptions</td>
<td>1-3 (duration of ~2s each)</td>
<td></td>
</tr>
<tr>
<td>Mean Required Downlink rate</td>
<td>1-10 Mbs</td>
<td>Available through real time monitoring.</td>
</tr>
<tr>
<td>Mean Required Uplink rate</td>
<td>1-10 Mbs</td>
<td></td>
</tr>
</tbody>
</table>

V. CONCLUSIONS AND KEY TAKEAWAYS

A conceptional and practical study on the vertical service development and provisioning in the B5G era has been provided. Based on the study, insights are listed below to serve as directions for related research studies and vertical-driven application development.

- With 5G NPN already emerged, the existing experimentation platforms around Europe should increase the development pace to incorporate realistic business cases for the use of 5G in vertical industries. In this endeavor, the directions currently provided by 3GPPP, should be considered, as an effort to provide verticals with a common ground for the development of 5G-enabled applications. A first contribution to that is the proposed framework, where the CAPIF and NEF aspects (as well as any NEF based expansion, such as SEAL and VAEs) define the main functionality for the interaction of the vertical domain (e.g., the IT department of a factory) with the control plane of a 5G NPN infrastructure.
- It is expected that in the 5G and beyond era, the killer feature of mobile networks will be the cloud-native programmability. However, as revealed in the PoC realization of the proposed framework, the technologies and the configuration that are used or the underlying virtualization/cloudification environment affect the performance footprint of a vertical application in terms of network resource usage and service set up time. For instance, as depicted in Table 2, the slice set up time can vary or memory/processing resource usage.
- The emerging 5G ecosystem will be beneficial for multiple and heterogeneous vertical industries. However, more effort should be allocated to vertical-specific approaches that will allow for clear contributions and deeper analysis on the expected impact. Frameworks, like the proposed one, are part of the effort towards verticals familiarization and positioning in the new market of 5G-enabled applications that is currently emerging. More precisely, the development and validation component of the proposed framework assist on the familiarization with Northbound APIs (NEF, VAE and SEAL APIs) for vertical-specific interaction with the mobile network infrastructure.

Overall, it is apparent that the convergence of the cloud/IT sector with the telecom one has brought new potentials for both the operators and the verticals. This aspect is expected to disrupt the B5G market, much more rapidly than the performance gains provided by the 5G RAN advancements, and in this context, research projects like the forthcoming H2020 5GPPP EVOLVED-5G, are expected to provide related developments.

REFERENCES