5Growth: An End-to-End Service Platform for Automated Deployment and Management of Vertical Services over 5G Networks

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This article introduces the key innovations of the 5Growth service platform to empower vertical industries with an AI-driven automated 5G end-to-end slicing solution that allows industries to achieve their service requirements. The authors present multiple vertical pilots (Industry 4.0, transportation, and energy), identify the key 5G requirements to enable them, and analyze existing technical and functional gaps as compared to current solutions.

Abstract

This article introduces the key innovations of the 5Growth service platform to empower vertical industries with an AI-driven automated 5G end-to-end slicing solution that allows industries to achieve their service requirements. Specifically, we present multiple vertical pilots (Industry 4.0, transportation, and energy), identify the key 5G requirements to enable them, and analyze existing technical and functional gaps as compared to current solutions. Based on the identified gaps, we propose a set of innovations to address them with: (i) support of 3GPP-based RAN slices by introducing a RAN slicing model and providing automated RAN orchestration and control; (ii) an AI-driven closed-loop for automated service management with service level agreement assurance; and (iii) multi-domain solutions to expand service offerings by aggregating services and resources from different provider domains and also enable the integration of private 5G networks with public networks.

Introduction and Motivation

5G is a key enabler for vertical industries to improve their service flexibility, cost efficiency, and service performance addressing different criteria including latency, reliability, availability, resilience, connection density, coverage area, and so on. Despite the significant progress on 5G standardization and development in creating a powerful 5G technology that verticals can benefit from in improving their services and creating new ones, a set of specific challenges are yet to be solved [1]. The EU 5Growth project[1] is contributing to address some of these challenges.

Network slicing enables effective resource sharing by different verticals with disparate requirements [2]. An open point in 5G specifications is the support for radio access network (RAN) requirements in the network slice information models [3], so RAN control can be part of vertical service provisioning. Solving the challenge of creating standardized interfaces would enable an open and inter-operable ecosystem as well as the support of next-generation RAN [4].

Automation of the service processes is another key aspect for verticals. Moreover, verticals demand stringent performance requirements to meet their critical service level agreements (SLAs) during the whole service lifetime. Thus, zero-touch service and network management is very essential to ensure the required SLAs, even involving shared resources across multiple domains, in an automatic and timely manner. To this aim, 5Growth is exploring closed-loop solutions for automated service management, by exploring the use of artificial intelligence (AI) and machine learning (ML) to:

- Manage vertical service life cycle and SLAs
- Adapt to dynamic changes and/or anomalies in the infrastructure resources
- Jointly optimize radio access, transport, and core and cloud/edge/fog resources across multiple technologies, vendors and domains

In the future, operators can have broader deployment options for vertical services through the deployment of private 5G networks that are dedicated for the verticals [5], namely non-public networks (NPNs), thus expanding the operator footprints (e.g., reaching more customers and areas) in other domains [6]. NPNs offer a dedicated 5G network infrastructure and SLA-compliant 5G services to devices that are within the logical boundaries of vertical premises, which can be deployed as either isolated, standalone networks or partially relying on operators' public networks (PNs) to complement their own deployments. However, the main challenges are:

- Requiring advanced multi-domain solutions to enable different levels of interaction between the different stakeholders involved
- Lack of a dynamic process for NPN-PN integration, allowing the service to be decomposed and connected in an automated and ad hoc manner [7]

The above challenges will be addressed by the 5Growth innovations presented in this article. Compared to other projects, such as 5G-VICTORI [8], 5G-SOLUTIONS [9], and 5G-TOURS [10], 5Growth strongly focuses on supporting different NPN-PN integrations, offering a range of flexible

[1] https://www.5growth.eu/

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multi-domain orchestration options, as well as developing novel AI/ML-based closed-loop control solutions to enhance the service automation process and extending network slicing support toward the next-generation RANs.

The 5Growth Vertical Pilots

In 5Growth, four vertical pilots are being developed for the technical and business validation of 5G technologies and the proposed 5Growth innovations in various use cases.

The **1) Industry 4.0 pilot** led by Innovalia will implement two applications:

- Remote operation of quality equipment, which will allow experts to configure and calibrate specialized machines remotely, to reduce travel costs
- Machine-to-machine (M2M) collaboration to further automatize the quality control process to increase the efficiency of the quality control station within a production site

The **2) Industry 4.0 pilot** hosted by Comau consists of three use cases. The first one is a digital twin application, which provides plant managers with a virtual reproduction of production plants, feeding it with actual information from the production lines. The second one aims to monitor all the machinery and equipment, collecting sensors monitoring data in real time. The last one is to provide workers with digital tutorials and remote support by transmitting live streaming high definition videos from remote offices.

The **3) Transportation pilot** led by EFACEC Engenharia e Sistemas will implement two use cases to improve the safety management of railway level crossings. The first one focuses on replacing wired connections between the sensors and the main controller by 5G connections for safety-critical communications. The second one includes live video streaming of the level crossing sent to both the train driver and the maintenance team, preventing accidents caused by vehicles trapped between the level crossing gates.

The **4) Energy pilot** run by EFACEC Energia aims to improve the maintenance of secondary substations on medium voltage/low voltage (MV/LV) distribution networks. The first use case will provide real-time information from sensors, meters, and cameras to the maintenance teams and the control center to facilitate the assessment of the severity of the impact of the problem they are facing. The second one will explore the low latency provided by 5G to develop a solution enabling meters to use the last gasp of energy before a power outage to send a message with relevant information.

Gap Analysis

This section analyzes the service requirements from different pilot use cases and identifies the technical and functionality gaps, comparing them against current vertical solutions, as summarized in Table 1.

Industry 4.0 Pilots

In a cloud-based robotic system, constant, low-latency, and reliable connectivity for each robot is essential, independent of robot type, its tasks, or its environment. Although wired connections can meet these requirements, they are limited in terms of flexibility, coverage, and density connections. In this sense, wireless connections, in particular 5G, can significantly simplify the overall solution by providing a greater degree of flexibility and increasing the device connectivity required by the targeted Industry 4.0 use cases. As depicted in Table 1, use cases (1), (2), and (3) require 5G not to only guarantee a similar level of latency, bit rate, and availability of the current solutions, but also to meet the requirements on high flexibility and device density, while enabling global connectivity in a geographical area whenever required. In turn, use cases (4) and (5) require continuous service provisioning, capable of automatically adapting to failures or changes in the demand, in order to satisfy the use cases' requirements at all times. As such, all these use cases require smart service orchestration, automated network service management, self-healing, and self-adaptation capabilities to be in place. Additionally, slice-based networking capabilities are of paramount importance in an Industry 4.0 environment where coexisting enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine type communications (mMTC) services are tailored to the specific needs of each use case.

Transportation Pilot

The stringent requirements of certified communications in transportation scenarios, such as the ones involving the different components in railway level crossings (e.g., reliability and safety), have thrown solution providers into providing closed transmission systems based on wired connectivity. The deployed dedicated infrastructures thus contribute to increased total cost of operation (TCO), while generating a considerably independent technological strand from other telecommunications standardization efforts. Conversely, the introduction of 5G in such scenarios releases solution providers from those boundaries, in addition to bringing low-latency and high-bandwidth wireless capabilities that allow the introduction of new service features unable to be supported yet by the current dedicated solution (e.g., send high-definition surveillance footage toward an oncoming train and mobile maintenance crews). Beyond the more concrete use case service requirements provided in Table 1, the transportation pilot illuminates the need for flexible deployment of next-generation RAN, so as to enable 5G providers to swiftly deliver on use cases' demands. Moreover, the heterogeneity of this scenario makes clear the need for coexistence of the three distinct types of slices, according to the characteristics of each service. Concretely, URLLC is of considerable importance to the provisioning of reliable and safe communications associated with the detection of oncoming trains signaling exchange. mMTC is important for the exchange of telemetry information from large numbers of devices in areas of different coverage sizes. eMBB impacts the introduction of the capability of live streaming of high-definition video footage of the level crossing toward the train conductor and the mobile maintenance teams.

Energy Pilot

This pilot poses a challenging performance- and feature-oriented scenario, demanding a communications solution that is simultaneously able to

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			Service requirements							
Pilot	**Use case**	**Solution**	**Latency**	**Bit rate**	**Packet loss**	**Availability**	**Flexibility**	**Device density**	**Global device connectiivty**
Industry 4.0	1) Digital Twin	Current solution	2–5 ms	1 Gb/s	N/A	99.99999%	Low	Low	Not supported
		5Growth	5–7 ms	1 Gb/s	N/A	99.999%	High	High	Optional
	2) Telemetry	Current solution	2–5 ms	100 Mb/s	N/A	99.99999%	Low	Low	Not supported
		5Growth	5–7 ms	100 Mb/s	N/A	99.999%	High	High	Yes
	3) Remote support	Current solution	Use case not supported						
		5Growth	N/A	N/A	N/A	99.999%	High	High	Yes
	4) Connected worker for remote operation	Current solution	Use case not supported						
		5Growth	<5 ms	10 Mb/s	0.1%	99.99%	Low	Low	Yes
	5) Augmented ZDM decision support system	Current solution	Use case not supported						
		5Growth	<5 ms	1 Gb/s	0.1%	99.99%	Medium	Low	Optional
Transportation	1) Train detection	Current solution	<800 ms	No limitation (dedicated connection)	0	99.99%	Very low	Low	Not supported
		5Growth	<10 ms (one way)	70–100 Mb/s	0.1%	99.99%	Low	Low	Yes
	2) Video survaillance	Current solution	Use case not supported						
		5Growth	<10ms (one-way)	70–100 Mb/s	0.1%	99.99%	Medium	Low	Yes
Energy	1) Substation maintenance	Current solution (alarms)	< 1 s (GPRS) <40 ms (4G)	50 kb/s (GPRS) 30 Mb/s (4G)	0.1%	99.99–99.95%	Low	Low	Optional
		5Growth (alarms)	<5 ms (one-way)	100 Mb/s	0.1%	99.99%	High	Low	Yes
		Current solution (video)	Use case not supported						
		5Growth (video)	<100 ms	100 Mb/s	0.1%	99.99%	Medium	Medium	Yes
	2) Last gasp	Current solution	Use case not supported						
		5Growth	<5 ms (one way)	1 kb/s	0.1%	99.99%	Low	Low	Yes

N/A: Not Applicable

TABLE 1. Summary of vertical service requirements in comparison to current solutions.

provide wireless security, isolation, and low latency (i.e., for fast telemetry and smart grid last-gasp communications), but also allowing new capabilities resulting from high bandwidth mobile communications (e.g., high-definition surveillance video). This is further exacerbated with the often wide (or even global) geographical dispersion of energy grid assets, which have typically mandated the aggregated and inflexible usage of different communication technologies, belonging to different providers and technological solutions. 5G capabilities empowered by 5Growth innovations provide the necessary differentiated communication needs for this setting, beyond the original performance enhancements from 5G communications with much higher data rate and low latency, as shown in Table 1. As in the transportation pilot, a next-generation RAN solution is also needed in this pilot to adequately support specific service capabilities that fulfill the different needs of each service, but in an isolated manner through network slicing (e.g., preventing impacts not only between the different services themselves, but also from the traffic belonging to other [public] users under the same coverage area), thus isolating service provisioning without demanding dedicated infrastructure. Both the transportation and energy pilots require nation-wide coverage to connect level crossings or energy plants across the country, thus demanding nation-wide 5G private networks that will be entirely shared with the PNs, which may be owned by different mobile operators. Thus, advanced multi-domain solutions are needed to dynamically and flexibly reach into coverage belonging to different operators, while maintaining service characteristics.

5Growth Baseline Architecture

The 5Growth baseline architecture, leveraging the 5G-TRANSFORMER platform [11], consists of three layers, also shown in Fig. 1. Based on this baseline, each layer is extended with a set of new functionalities to support the 5Growth innovations described later.

The vertical slicer (5Gr-VS) serves as the vertical portal to request and manage vertical services, and create custom network slice(s) tailored to the service needs. In particular, it provides a simplified, service-oriented northbound interface, through which the verticals can request a service from a catalogue of vertical service blueprints (VSBs) offered by the system, and then provide service-oriented parameters that customize the specific service instance through vertical service descriptors (VSDs). Based on that, the 5Gr-VS builds customized network slices, which are deployed through network-function-virtualization-defined network services (NFV-NS), composed of a set of virtual or physical network functions (VNFs/PNFs). Hence, the 5Gr-VS translates the VSD into the network service descriptor (NSD) for building corresponding network slices. Furthermore, it also includes network slice management functionalities that correspond to the communication service management function (CSMF), the network slice management function (NSMF), and the network slice subnet management function (NSSMF), defined by the Third Generation Partnership Project (3GPP). In 5Growth, the communication services are extended to support the wider concept of vertical services, which include vertical applications in the end-to-end (E2E) service chain, as modeled in the VSDs. Therefore, the CSMF becomes a vertical service management function (VSMF), introducing additional functionalities for translating vertical requirements into network slice requirements. Moreover, related slice mapping and sharing functionalities are enhanced in 5Growth.

The Service Orchestrator (5Gr-SO) is in charge of:
- E2E service and resource orchestration of the NFV-NS and management their service lifecycles (including on-boarding, instantiation, scale, termination, etc.)
- NFV-NS monitoring and SLA management,
- Deciding the optimum placement of the VNFs and allocating virtual resources across a single or multiple domains, based on service requirements and availability of the resources offered by the local domain and each of the peer administrative domains. The latter case is realized through a service federation process across administrative domains through its eastbound-westbound interfaces.

The Resource Layer (5Gr-RL) is responsible for managing the physical/virtual infrastructure resources to deploy the network services and the required transport connections to interconnect them, as requested by the 5Gr-SO. It manages all the complexity of the transport, mobile, storage and compute resources and provides a unified view of the underlying networks to the 5Gr-SO with a suitable abstraction. Moreover, it handles multi-technology domain integration (across wireless, optical, etc.) and controls the configuration of heterogeneous resources through different plugins: the transport Wide Infrastructure Manager (WIM) plugins, the Virtual Infrastructure Manager (VIM) plugins, the MEC plugins, and the RAN plugins.

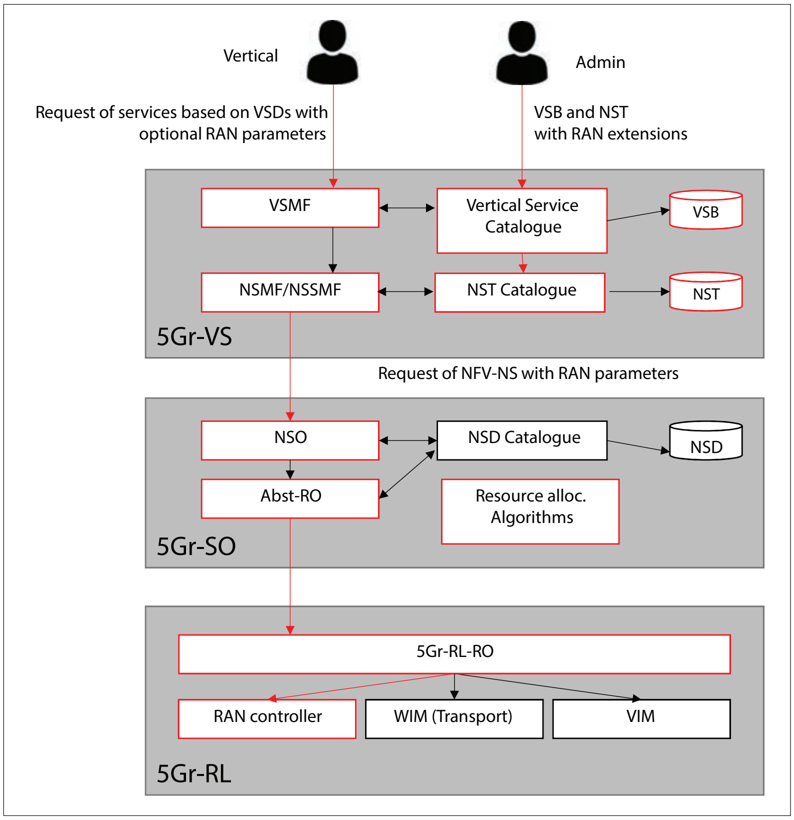

FIGURE 1. Functional architecture to integrate RAN in the 5Growth stack.

5Growth Innovations

From Service Requirements to Innovations

- Need for vertical-specific slices, due to the diverse requirements, which can be mapped to 3GPP-defined slice types. These slices must be E2E, including the next-generation RAN; thus, the need to specify RAN requirements and provide automated RAN control is supported.
- The flexibility demanded from vertical devices (e.g., using high-capacity wireless links instead of cables) triggers E2E implications in the way in which services and the underlying slices dynamically adapt, identify issues, and automatically heal themselves. AI/ML-based frameworks applied to network management are expected to help in this direction.
- Supporting multiple geographically dispersed sites — served by multiple operators in many cases — while having an E2E orchestration to fulfill the stringent requirements of the services. Furthermore, these operators may have different preferred mechanisms for inter-provider domain service deployment.

To offer the above required functionalities, we propose the design and implementation of three key innovations:
- Next-generation RANs: This includes:
  - Modeling of the RAN requirements in network slice information models, based on the latest 3GPP specs.
  - Developing 5Gr-VS, 5Gr-SO, and 5Gr-RL logic to handle the RAN segment of network slices.
  - RAN orchestration capabilities, including control RAN functions, radio and computing

[2] https://www.o-ran.org/

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resources, and UE profiling. Our design is inspired by the O-RAN reference architecture,[2] which is based on well-defined, standardized interfaces.

- AI/ML-assisted closed-loop control: The 5Growth platform aims to provide closed-loop automation for vertical service life cycle management throughout the system across different layers. These closed loops include the process of collecting monitoring data from the services and networks, performing real-time data analytics for identifying events to handle, and making proper decisions for optimization and re-configuration of the system.
- Multi-domain: 5Growth service providers will extend their offerings by exploring different multi-domain solutions to aggregate the service catalogue and resources from other providers. The multi-domain interactions can be done at the different layers of the 5Growth stack.

The key concepts of individual innovations are described in the following subsections.

Next-Generation RANs

RAN management allows guaranteeing true E2E network slicing, with quality of service (QoS) differentiation based on the requirements of the vertical services and the type of the requested slices (e.g., eMBB, URLLC, mMTC), which, in turn, specify mobile traffic requirements (e.g., coverage area, data rate, mobility, latency). Service and slice profiles are defined in the latest 3GPP standards [4]. The above has several implications at the different layers of the 5Growth architecture, as highlighted in red in Fig. 1. In summary, the main updates in each layer are the following:

- 5Gr-VS: The VSMF has been extended with VSBs defining macro-categories of services characterized by different RAN requirements. Starting from these abstract categories, the translation procedure identifies the target network slice template (NST), which includes the RAN modeling in compliance with [4]. The NSMF has introduced the new information models in the NST catalogue and the capability to request NFV-NS with RAN parameters extensions to the 5Gr-SO.
- 5Gr-SO: The REST application programming interface (API) exposed by the network service orchestrator (NSO) has been extended to support the specification of RAN parameters in the 5Gr-VS requests. These parameters are given as input to the new RAN-aware resource placement and allocation algorithms that operate over a RAN abstraction exposed by the 5Gr-RL to the abstract resource orchestrator (Abst-RO) component of the 5Gr-SO. At the southbound, the interaction with 5Gr-RL is enhanced to request the on-demand RAN configuration.
- 5Gr-RL: It provides a technology-agnostic abstraction of the RAN domain to the 5Gr-SO. In order to better optimize the placement of the PNF/VNF, an abstraction layer has been introduced that combines the RAN and transport resources, unifying the management of all the different kinds of resources through the 5Gr-RL resource orchestration (5Gr-RL-RO) component. The 5Gr-RL defines such an abstraction view, translates the infrastructure parameters that are technology-dependen into service parameters (e.g. bandwidth, delay) that are exposed to the 5Gr-SO. This abstraction view improves the optimization of the resources usage and allows selecting the resource considering both RAN and transport concurrently. The enforcement of RAN configuration, also including the management of related PNFs (e.g., gNBs), is mediated through a specialized radio plugin that interacts with RAN controllers customized according to the capabilities of the radio infrastructure.

It should be noted that the approach proposed for the allocation of RAN resources in a network slice is quite similar to the procedures usually adopted for the management of the transport network, where an SDN controller acting as a WAN infrastructure manager is responsible for establishing network paths enabling VNFs communications or interactions between multiple slice subnets. In the case of the RAN, a specific RAN controller is used to configure RAN resources in given coverage areas. This configuration is driven by the orchestrator according to the traffic and slice profiles requested for the mobile users, rather than based on the VNFs' interconnectivity as in the WIM case.

AI/ML-Assisted Closed-Loop Control

5Growth's second major innovation is a tight integration of AI models. A workflow of the system is depicted in Fig. 2, with two main functional blocks assisting the 5Growth platform: the 5Gr-AIMLP — a platform that manages (deploys, configures, and trains) AI models — and the 5Growth Vertical-oriented Monitoring System (5Gr-VoMS). Note that Fig. 2 extends the baseline 5Growth architecture in Fig. 1 to support this innovation. This figure explains how the typical data engineering pipeline layers have been mapped to the 5Growth architecture and provides some examples of tools for each layer. For the 5Gr-VoMS, the original 5G-TRANSFORMER monitoring platform, based on Prometheus, has been extended to automate the deployment of custom monitoring probes and to fully support data streaming as an enabler for the efficient analysis of large datasets, required by AI/ML techniques. Each decision making entity (*agent* hereafter) in the 5Growth platform is ultimately the entity that executes the model. The details of the workflow are introduced in [12], and the basic logic for usual forecasting and classification problems are the following:

- The 5Gr-AIMLP exposes a catalogue of models that can be tuned/chained to compose more complex models.
- The 5Gr-AIMLP requests the 5Gr-VoMS for orchestration of monitoring probes and retrieves on-demand context information (e.g., current number of users) and performance metrics (e.g., CPU consumption), to train a model or compute its reward.
- The 5Growth platform related layer (e.g., 5Gr-SO) configures all needed data pipeline components to run the optimized model, which is passed down to the agent for online execution by exploiting performance metrics coming from 5Gr-VoMS.

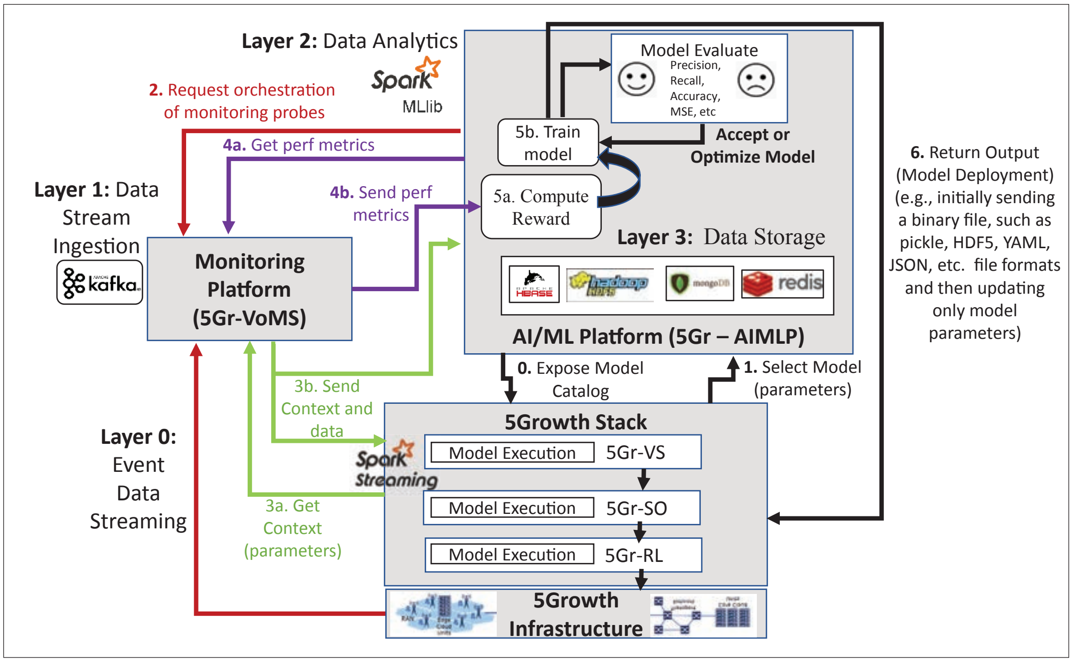

FIGURE 2. 5Growth AI/ML workflow. Reproduced from [12].

5Growth extends the base federation offering from 5G-TRANSFORMER with algorithms for the selection of the best provider to which a sub-service should be delegated or resources requested. Additionally, as a continuation of the SLA management work, it also extends the handling of scaling operation to consider multiple domains toward E2E SLA compliance.

In the current implementation [13], we have developed closed-loop control of the 5Gr-SO layer to automatically scale NFV-NSs. More specifically, the NSD is extended to embed an AI information element (IE) specifying the specific optimization problem (e.g., scaling) as well as the related metrics used as input of the AI model (e.g., a random forest classifier model) to compute the output decision. This element is parsed by the SLA manager of the 5Gr-SO, which configures an Apache Kafka topic to ingest the required metrics (together with the monitoring manager of the 5Gr-SO). The SLA manager also maps the given problem to a specific AI model that has been downloaded and configured to generate optimization decisions based on a pre-trained model. It is also in charge of parsing this output and acting accordingly (e.g., scale an NFV-NS toward a new instantiation level). Additional example use cases, concerning virtual network embedding and dynamic profiling, using 5Gr-AIMLP to implement a Q-Learning model and a decision tree learning model, respectively, are presented in [12].

Multi-Domain

Based on the service requirements identified earlier, one of the key required functions is multi-domain/federation. The federation concept is generalized in 5Growth compared to 5G-TRANSFORMER. Given the variety of NPN-PN scenarios to be supported, multiple inter-provider interactions are defined in Fig. 3, which provide varying levels of control shared between domains. The first two options cover the *vertical slicer layer federation* supporting *dynamic service composition*, while the rest cover the *service orchestrator level federation*.

The first option considers the multi-domain interaction at the VSMF level (i.e., vertical service level). It can also be referred to as vertical service federation. In this interaction, the VSMF of the consumer domain is the only building block with an E2E view of the vertical service. Upon the reception of a new vertical service request, it decomposes the vertical service into sub-services, managing the sub-service requests either locally or toward the VSMF of a provider domain. In this case, inter-domain requests stay at the vertical service functional components, and requirements and resource management are left to each of the domains involved. Therefore, parts of the E2E service are delegated to peering domains, which handle them according to their own policies.

The second option considers the multi-domain interaction between the VSMF of a consumer domain and the NSMF from one or more provider domains. Like the previous option, the VSMF of the consumer domain is the only entity with an E2E view of the vertical service. As such, it decides on its decomposition, after which it requests the deployment of each portion of the E2E slice either to the local NSMF or toward the NSMFs of other provider domains. An interface is required to request network slices, modeled through NSTs, which are derived from VSDs by the 5Gr-VS. Modeling and advertisement of NSTs is done through dedicated catalogues in each 5Gr-VS.

The third and fourth options consider the federation between peering 5Gr-SOs. In this sense, they represent a tighter interaction between domains, since not only service but also resource-level information is exchanged. This allows for full control of the E2E resources assigned to the service, and hence more fine-grained SLA control. In fact, IFA013 interfaces (service federation) and IFA005 interfaces (resource federation) are used to specify the corresponding resource requirements. In the former, resource control is fully delegated to the provider domain, so the consumer domain will stitch the various delegated sub-services to fulfill the E2E requirements at the service level. As for resource federation, the needed resources are directly requested of the provider domain, which is also acquiring the full control of those resources as if they were local. Furthermore, the peering 5Gr-SO interactions are totally transparent to the

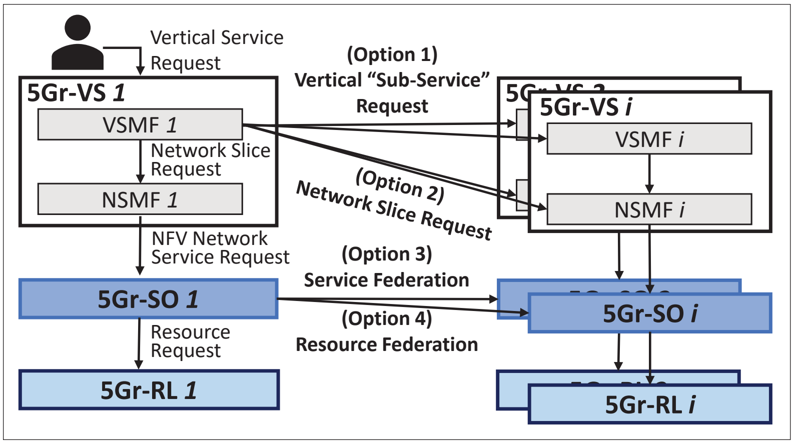

FIGURE 3. 5Growth multi-domain approaches.

5Gr-VS, which sees the service as if locally instantiated.

5Growth extends the base federation offering from 5G-TRANSFORMER [7, 14] with algorithms for the selection of the best provider to which a sub-service should be delegated or resources requested. Additionally, as a continuation of the SLA management work, it also extends the handling of scaling operation to consider multiple domains toward E2E SLA compliance.

Summary and Conclusions

In this article we present several key innovations to support vertical industries with an AI-driven automated 5G end-to-end slicing solution as developed within the 5Growth project. Three vertical pilots, namely Industry 4.0, transportation, and energy, are described and their key 5G requirements analyzed. Based on the identified gaps as compared to current available solutions, three key innovations were defined:

- Support of 3GPP-based RAN slices by introducing a RAN slicing model and providing automated RAN orchestration and control
- AI-driven closed-loop for automated vertical service management with SLA assurance
- Multi-domain solutions for the integration of PNs and NPNs aggregating services and resources from multiple provider domains

As a result, the initial software implementation of the 5Growth platform has been released [13], integrating these innovations into a multi-vertical framework able to meet all diverse requirements from the verticals involved *simultaneously* over the same infrastructure. We are now working on deploying our solutions in the different pilots along with their vertical applications, to validate these innovations and evaluate their gains through experimental results, which will be shared with the research community in future publications.

Acknowledgment

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