
Next Generation Platform-as-a-Service (NGPaaS) From DevOps to Dev-for-Operations

NGPaaS White Paper

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ATOS

Abstract

This white paper introduces the new Dev-for-Operations model which is being developed in the context of the H2020 Next Generation Platform-as-a-Service (NGPaaS) project [1], exploring its main features and potential benefits for network operators. This Dev-for-Operations model is based on the well-known DevOps [2] philosophy that, as known, advocates to break down the barrier between the software development and the operations teams; Dev-for-Operations extends this to fulfil the specific requirements of the future 5G network operators where the interaction of independent parties (software vendors, verticals and the network operator itself) in the software development and operation processes will be the common practice.

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Introduction

Digital transformation is a new trend that is affecting all sectors, but it is often poorly understood as a technological change and not as a complete transformation of business. In telecommunications sector, it is a chance to improve customer experience, but also to expand market, extend support to new digital services and create new ecosystems where communication channels and digital services are becoming software-defined. While telecommunication operators are already present or are entering markets such as entertainment, cloud, security, IoT or artificial intelligence, digital transformation

strategy with the right focus on efficiency improvements and network resource rationalisation is the key to the success and future growth.

Use of cloud is an obvious choice for telecommunication operators to reduce OPEX (operational expense) costs, as well as to significantly improve resource utilisation and Total Cost of Ownership (TCO). Next Generation Platform-as-a-Service (NGPaaS) project is developing Telco-grade enhancements to PaaS platforms to address needs of above mentioned digital

transformation for 5G network operators and support the business demands across key industry verticals, as well as emerging digital ecosystems. In addition, NGPaaS is also developing the concept of "Dev-for-Operations", which is an evolution of the DevOps concept extended across separate organisations. This white paper introduces and outlines the key innovative characteristics of this new "Dev-for-Operations" concept in the context of NGPaaS, exploring also the potential benefits and market opportunities that could arise.

From DevOps to Dev-for-Operations

From a general point of view, the objective of the DevOps methodology is the breaking down of barriers between development and operations departments in software companies [3]. This is usually done by assigning certain operation tasks to developers and vice versa. However, the whole concept goes much further and is best summarised as implementing a

continuous cross-functional mode of working with focus on automation and alignment with the business objectives; this is commonly represented by a kind of "infinite" loop such as the one in Figure 1:

This representation suggests the general concept of "continuity", with main focus on automation, which is usually applied to four main stages: integration, delivery, deployment and monitoring. This has led to the introduction of the following fundamental concepts:

- **Continuous Integration (CI)**, which is commonly considered as a core DevOps practice. It is a process where developers can integrate their changes continuously in the code repositories. While they do so, pre-defined test batteries are automatically executed to find and fix errors in a continuous way. This accelerates the

software development process by reducing the time to validate and publish new software updates.

- **Continuous Delivery (CD)** is usually described as the next step after CI. In short, we can say that, as CI refers to automating the writing process on the code repository, CD refers the automation on extracting the code from it to generate ready-to-use software packages, including also functional testing in the test batteries. CD is commonly used to automatically produce software releases in a regular way.
- **Continuous Deployment (Cd)**, refers to the extension of both CI and CD processes, i.e., the automation of even the deployment phase without human intervention. So, changes from developers could be automatically propagated to the production environment without human intervention if no errors were detected.
- **Continuous Monitoring (CM)** refers to monitoring performed along the whole cycle from development to production and operation environments. The goal is to use real production data for the development and operations teams. Automation also is applied here: instead of relying only on human responses to alerts or relevant events, autonomous responses to certain alarm conditions can be implemented.



Figure 1. DevOps Infinite Loop

From DevOps to Dev-for-Operations

These four blocks are considered the basic pillars on which the DevOps processes are commonly implemented. CD and especially Cd and CM are clearly out of the exclusive domain of the developers and are relying on operation environment parameters.

It is not surprising that telco-grade operators are very interested in the DevOps methodology. After all, typical production and operational environments of telecommunication organisations can be very different from the usual testing environment, with many adjustments to be done. According to [5] telecoms industry is already the biggest adopter of DevOps and seems to be most willing to extend the usage of this methodology. But as digital transformation of the telecommunication sector is pushing towards software-defined communication services, the “traditional” DevOps approach is not sufficient anymore, since in this scenario, development and operation tasks are not just performed by different teams or departments of a single organization; instead they are spanning multiple vendors which independently develop the software (and hardware) resources which are combined together in an operational environment on the telecom operators’ infrastructure. In addition, if we think about the forthcoming 5G networks, it is also necessary to consider that the network can be split in such a way that different network slices could be isolated and assigned to other different industries (verticals). The resulting picture is a complex ecosystem with large network operators working together with a plethora of vendors and verticals to implement and operate their network services under strict Service Level Agreements (SLA).

The Dev-for-Operations model introduced in the NGPaaS project considers these and other challenges to help in adapting a DevOps-like philosophy in the context of the forthcoming next generation telecommunications industry. The theoretical concept was initially introduced as “Dev-for-Ops” in [6], where a model based in a much closer collaboration between operators and network equipment providers is described.

In this white paper we describe how the concepts introduced in that work could actually be put into practice in future 5G networks, and more specifically, using the NGPaaS architecture.

According to [6] there should be remarkable differences between DevOps and the new Dev-for-Operations model; they are basically the following:

- It should be possible to execute a vendor specific CI/CD loop at the vendor’s site in order to make possible to iteratively develop and debug the service before delivering it towards the operator’s side.
- Usually operators have important insights regarding their networks and customers that influence methods and techniques of deploying, managing and operating services and infrastructure. The Dev-for-Operations model should make possible the communication of those operator specific insights towards the vendor’s environment in some way. This should enable vendors to have a deep understanding of the operational environment, so they can perform a kind of “operation-aware” testing function on their own. This means they should perform CI/CD processes using test batteries already integrating the relevant features of the operational environment (although in a different company).
- DevOps delivers the application, but Dev-for-Operations should make possible to deliver a fully realized service including the core application, monitoring and analytics, as well as the deployment and adaptation capabilities.
- Like in the regular DevOps approach, there should be also a specific feedback loop to propagate the information from the Operator’s side towards the vendor environment, but in this case, the feedback should integrate information not only from the software application itself, but also regarding the associated monitoring and analytics, as well as the deployment and adaptation indicators.

- The feedback mechanism takes on a different character in Dev-for-Operations: it should consider the separation between vendor and operator, but keeping the automatic or semi-automatic mechanisms needed to provide the feedback in a timely manner.

However, besides these general guidelines, in NGPaaS we also consider the following issues:

- Operator and vendors are linked by a contractual relationship typically associated with the development of certain software components. This relationship will be time limited, so the challenge is to manage the situation once the vendor is not present.
- Considering the 5G networks, there is a need to integrate the verticals into the model. They would request certain monitoring data or analytic reports regarding their services; or they could even act as “virtual operators” managing their own network slices.
- The integration of multiple vendors and verticals could have implications on the access control model and the security, privacy and data protection policies and compliance with regulations. Additionally, the access to certain critical elements in the telco network (e.g., the Radio Access Network -RAN- or the billing systems) should be also regulated.
- Software components deployed on the operator’s infrastructure should be in some way “certified” according the operator policies and/or to meet the SLA conditions. This way, a certification service should be available to validate the software components deployed on the NGPaaS platform.
- It is important that the operator continues to have full control over everything that is deployed on its network. In this sense, although automation is key in DevOps, any automation should have a kind of “kill switch” to allow the operator to cease any automation at any time.

Dev-for-Operations Roles

In this section we describe the main roles that could participate in the Dev-for-Operations model in the context of NGPaaS; we consider it is necessary to introduce this before talking about the Dev-for-Operations components and processes. These roles could be played by different actors that would typically be companies of different shapes and sizes, and of course, with different responsibilities. Typically, each company is assumed to play a specific role, although in some circumstances the same actor could play different roles, which are:

- The NGPaaS Operator, is the key role and is initially expected to be played by large telecommunications companies owning (or renting) the necessary equipment to host multiple and high demanding services. From an operational view, the NGPaaS Operator will implement the "BUILD, SHIP and RUN" paradigm on the NGPaaS architecture. In practice, this means the NGPaaS operator will deploy telco-grade quality PaaSes by combining a number of third-party applications (software and hardware).

The NGPaaS operator will interact with other actors in the ecosystem, such as Telco Software Vendors and Vertical Service Providers (see below). Also, the NGPaaS operator may have multiple teams managing the various aspects of the platform; including:

- Selecting and certifying the PaaS, BSS and OSS components.
- Verifying the overall integrity of the platform, using aggregated (and anonymised if required) statistics and health checks from the different components co-existing on the infrastructure.

- Managing the platform evolution.
- Facilitating the interactions between the Vertical Service Providers and Software Vendors.
- Vertical Service Providers (VSPs), which are the NGPaaS operators' customers using the operators' infrastructure to provide services to their end-users. Typically, the VSP has a contract with the NGPaaS Operator to use its infrastructure, meaning the NGPaaS Operator instantiates the necessary resources for the VSP to implement the requested business cases. The VSP could also request access the Dev-for-Operations facilities to manage and monitor the service once it has been deployed. Examples of VSPs could be end-user-oriented service companies, such as Virtual Mobile Network Operators (VMNOs), Automotive Industries, Service Companies, Healthcare or Energy industries or Payment Companies among others.

According to the 5G terminology, VSPs act by requesting "network slices" to the NGPaaS Operator; i.e., they work as tenants of the NGPaaS Operator, which would support multiple VSPs in parallel each of them using a specific slice with adapted requirements. In the end, VSPs core task is to provide services to the End Users using the operator's infrastructure. Depending how the different network slices were configured (e.g., with more or less isolation) VSPs could have more or less autonomy from the NGPaaS Operator, which act as a kind of "vertical integrator" that is requested to deploy services across a wide range of infrastructure by integrating products from many Software Vendors.

- Software Vendors are in charge of developing and deploying the software components requested by VSPs or the NGPaaS Operator. In general, we assume they are contracted by the NGPaaS Operator to develop/deploy/maintain the components required by the service commissioned by the VSP. However, other cases could be considered also (e.g., they could be directly contracted by the VSP and onboarded on the NGPaaS platform by the NGPaaS operator).

Through the Dev-for-Operations functionalities Software Vendors can bring in their own Virtual Network Function (VNF) images, PaaS deployments, updated deployment or configuration workflows. After validation (CI/CD process), the Software Vendor components can be accepted by the NGPaaS Operator, which could deploy them on its infrastructure.

Since deployment of network services is expected to be performed by one or more software vendors working in a close relationship with the NGPaaS Operator, the overall effort in terms of integration needs special planning and consideration.

- End-Users. They basically consume the services provided by VSPs or by the NGPaaS Operator. They are typically expected to be individuals, but in the upcoming 5G networks we have to consider also autonomous devices (e.g., vehicles, IoT sensors and other devices in M2M networks) to act as End-Users.

The following Figure 2 illustrates a possible landscape considering these actors and roles in a graphical way.

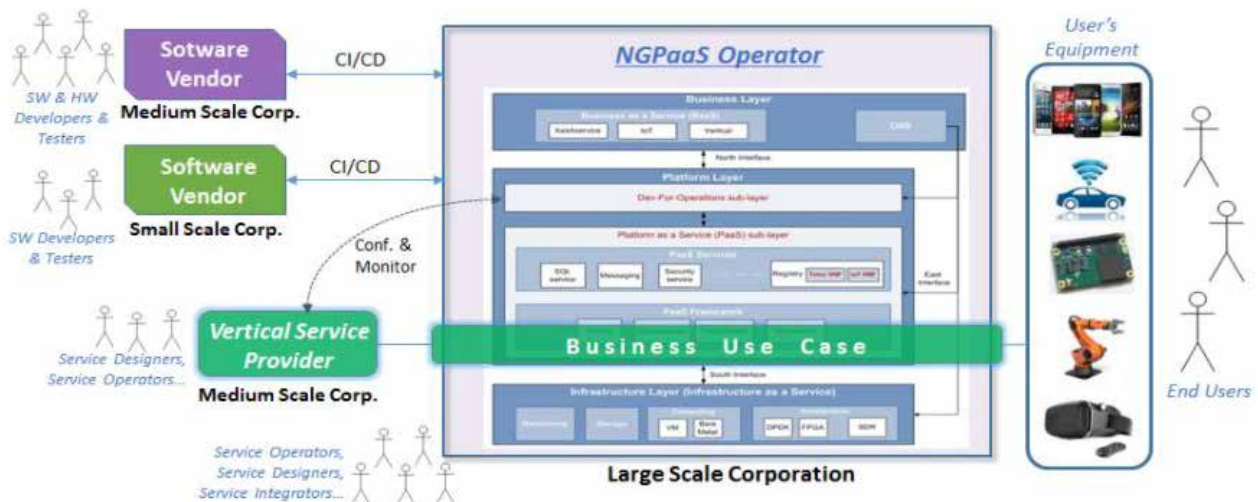


Figure 2. Typical Roles in NGPaaS [9]

Dev-for-Operations in the NGPaaS Architecture

The current status regarding the NGPaaS architecture is described in [7]. From the Dev-for-Operations perspective, the envisioned NGPaaS architecture aims to enable a new cloud-based eco-system with multiple development and operation teams from different companies, as explained before. This NGPaaS cloud stack moves away from

the classic hierarchical cloud model where a fixed feature-set is imposed to the users, and it embraces the fact that there is no “one-size-fits-all” solution. Features can be added or updated by many different actors and use-case specific platforms can be devised “on-demand”. This is illustrated in Figure 3, where the NGPaaS platform is in fact presented as

a multi-PaaS environment where specialized PaaSes target the orchestration, monitoring and other operational enhancements of a specific infrastructure pool. This PaaS layer is controlled by an upper Business Layer, which implements the overall BaaS/OSS1 related functions.

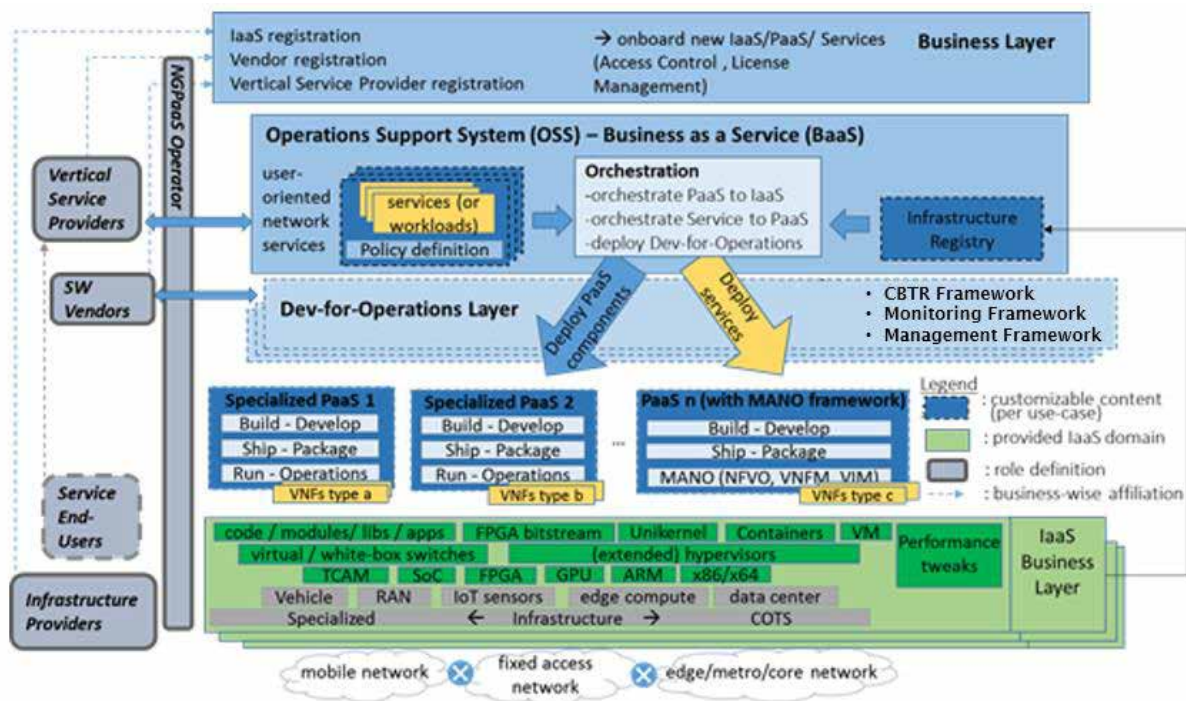


Figure 3. Simplified NGPaaS Architecture [7]

As the figure shows, besides that Business Layer (including BaaS and OSS) and the specialized PaaS layer, a specific Dev-for-Operations layer has been introduced. Different instances of this Dev-for-Operations layer could exist for both: vendors and the operator itself, i.e., different instances can be allocated for the different vendors participating in the development of a project (to perform their specific development tasks) and for the operator (to integrate, monitor and manage the work released by

vendors). The allocation of these instances is planned to be performed using the same “build-to-order” paradigm used to deploy the service components (e.g., VNfs). In the Dev-for-Operations layer we also introduce the notion of “frameworks” which basically group together sets of tools or services for a specific purpose; so, in each layer instance, three different frameworks can be issued:

- CBTR Framework, grouping the “coding”, “building”, “testing” and “releasing” tools for implementing the CI/CD and Cd processes.

- Monitoring Framework, with tools to perform the continuous monitoring functions (e.g., logs processing, real-time analytics or alarms system).
- Management Framework, with the tools to perform the management associated to the Dev-for-Operations functions. These three frameworks are available for both, the vendor’s specific instances and the operator instances as well (see Figure 4). They would be accessed from a common Unified Dashboard in order to provide

Dev-for-Operations in the NGPaaS Architecture

the vendor and the operator with their own development, management and configuration tools. Each framework in each Dev-for-Operations instance is planned to be fully customizable according to the specific needs of each vendor or the operator in each project. For instance, the operator will normally have only the Testing Tools in the CBTR

Framework since it typically just requires performing integration testing tasks (i.e., the operator normally does not perform code development), while certain vendors could be hired just to perform monitoring and data analysis tasks, with the rest of the tools in the CBTR or Management Framework disabled for them.

In general, it should be possible to execute a vendor specific CI/CD loop at the vendor's side to make possible to iteratively develop and debug the service before delivering it towards the operator's side. Like in the regular DevOps approach, there should be also a specific feedback loop to propagate the information from the Operator's side towards the vendor environment, but in this case, the feedback should integrate information not only from the software application itself, but also regarding the associated monitoring and analytics, as well as the deployment and adaptation indicators.

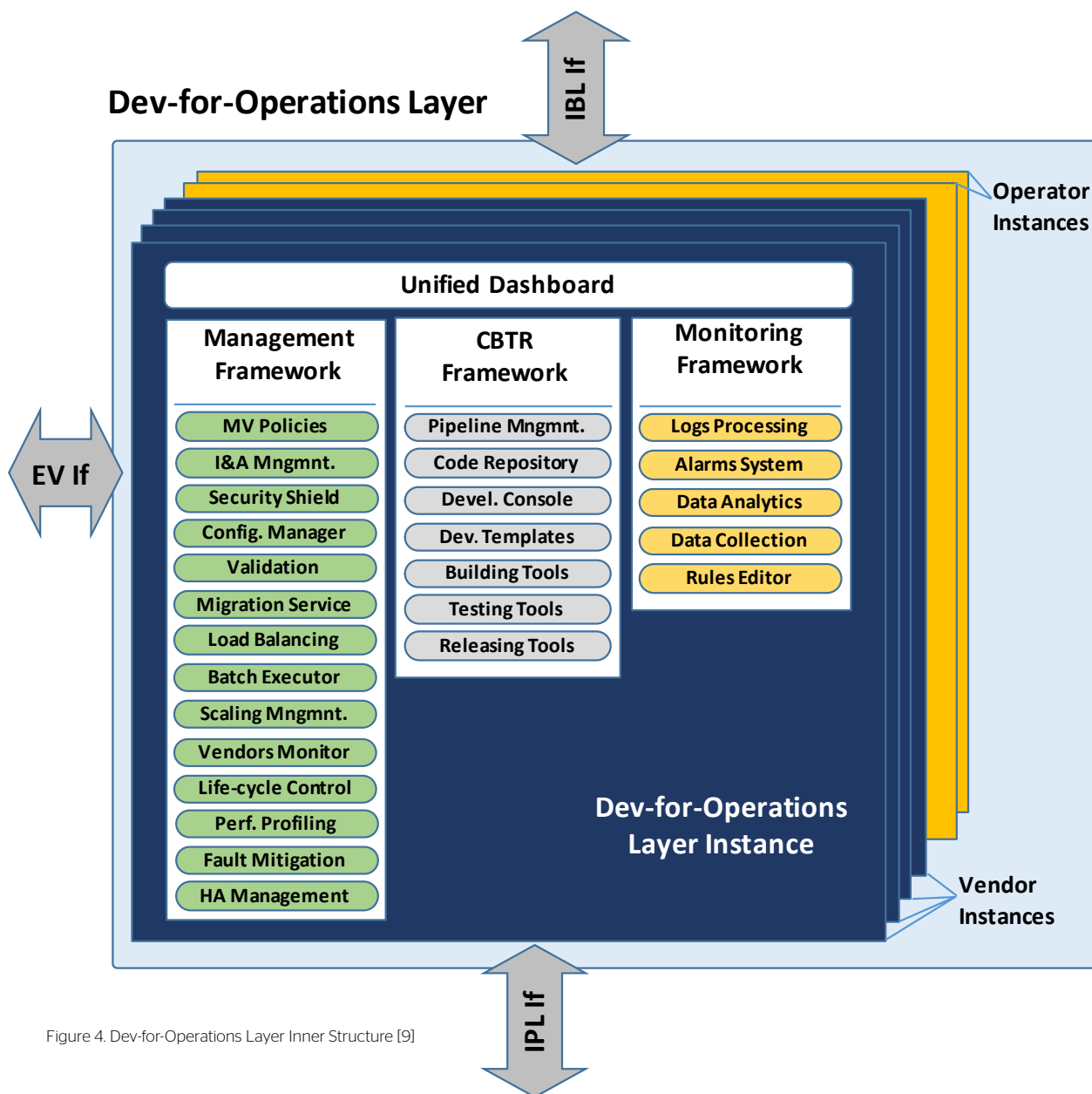


Figure 4. Dev-for-Operations Layer Inner Structure [9]

Dev-for-Operations Workflows

As with DevOps, Dev-for-Operations workflows will be divided into different stages (e.g., coding, building, configuring, testing, packaging, releasing, monitoring...) that can be concurrently executed by the different actors (e.g., developers, testers, integrators...). These workflows will allow to continuously integrate new changes (e.g., test cases, code updates, documentation...) without adversely affecting to what it could be already deployed (or allowing a quick roll-back to a safe scenario if some undesirable effect happens). In DevOps this methodology is implemented by breaking down the boundaries between the development and operations teams.

In our specific case this is something challenging to implement, because development and operations roles are commonly in separate companies, and vendors are assumed to be hired by the NGPaaS Operator to implement the business cases (for the operator itself, or to meet the VSPs requirements). As already commented, this vendor-operator relationship will be surely regulated by a time-limited contract, which implies that the “Dev” part in the DevOps methodology could disappear at certain point. Also, VSPs could request to participate in the operation activities as well

(e.g., by requesting to monitor their relevant service KPIs), which adds a new degree of complexity.

In order to address these challenges it is necessary to devise new Dev-for-Operations specific workflows integrating also vendors and verticals, but keeping the “never ending loop” concept from the original DevOps model as far as possible. Figure 5 below illustrates a high-level approach that we are considering, comparing both: the typical IT DevOps approach and the new Dev-for-Operations workflow.

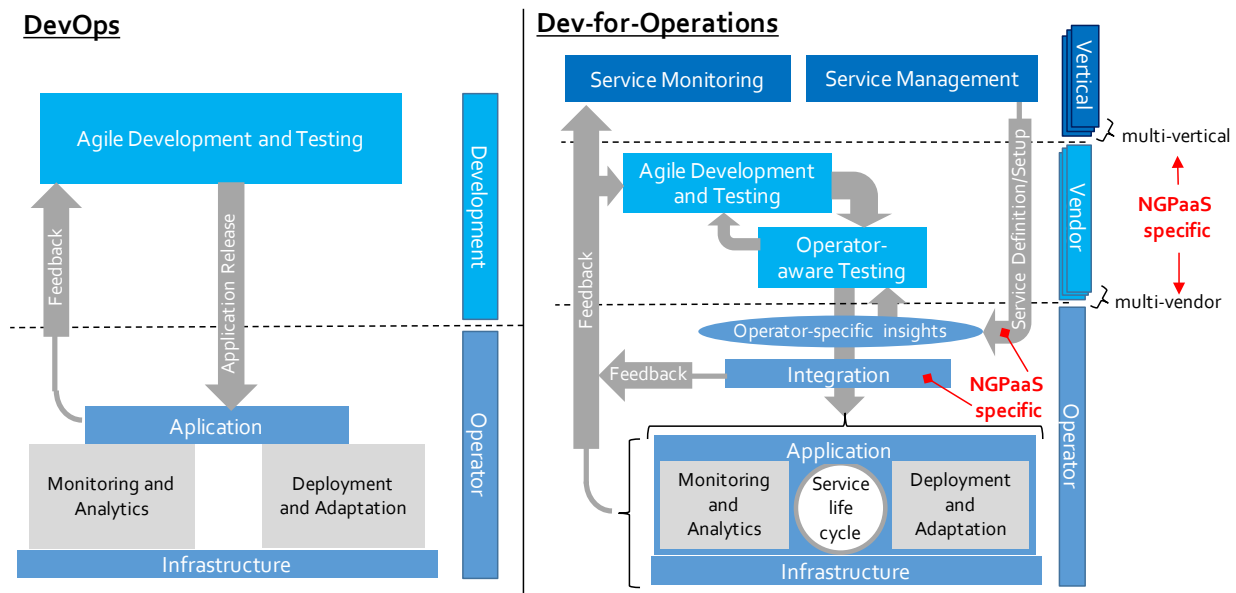


Figure 5. DevOps vs Dev-for-Operations Workflow

The left side of this Figure 5 has been taken from [6] and represents the typical DevOps methodology, where there is only a single feedback loop between the operations and the development teams. On the other hand, the right side represents the Dev-for-Operations approach, where besides that operations-developers loop, we consider also the multi-vendor and multi-vertical paradigms with their own specific feedback loops: a vendor-specific inner loop based on a specific operator-aware testing block, and the service management loop that could be performed from the verticals based on the operator’s monitoring information.

At the vendor’s side, the Operator-aware Testing block is expected to work based on the Operator-specific Insights block, which represents the transference of knowledge

from the operator for vendors and verticals. This Operator-specific Insights block is very important also for the operator itself, since it makes possible to perform the integration tasks when it comes to integrate the different software components coming from different vendors to form a complete network service properly adapted to the operator’s infrastructure. So, this Operator-specific Insights block makes possible to deliver complete applications including even the monitoring/analytics part and the deployment and adaptation capabilities, as well as the specific service life-cycle management functions (see figure above).

An online video with a more specific workflow example based on this high-level description can be found in [8] (NGPaaS YouTube Channel), where a Vertical Service Provider

request the NGPaaS Operator to deploy a business case which should be jointly developed by 2 vendors and integrated on the NGPaaS Operator premises. Of course, other configurations could be considered (e.g., with more vendors involved, or perhaps, the VSP directly interacting with vendors); anyway, for this initial stage, we consider this scenario general enough to address our main concerns. In this example we can see how the Dev-for-Operations loop can be closed even when the commissioning phase is completed by re-activating the Dev-for-Operations layer instances when necessary. Although we consider this example cannot yet be considered “the general” NGPaaS Dev-for-Operations workflow (the number of cases and real-life situations can be diverse), we think it is general enough, so it could be used as a reference for extrapolation to other more complex scenarios.

Software Provider Perspective

In this context we consider software providers can work in two main ways:

- As Software Vendor as defined in Section 3, i.e., working to implement those business cases requested by VSPs (or the Operator also) on the Operator's infrastructure, and
- As Technology Provider, supporting the Operator to deploy and/or manage the necessary software resources to implement the Dev-for-Operations functionalities (for the Operator, VSPs or other vendors).

In the following we describe more in detail these two possible roles.

Software Vendor

The Dev-for-Operations model makes it possible for external vendors working for the operator as use case developers to get similar benefits as those of the development departments in companies already relying on the DevOps methodology, e.g.: to increase frequency of deployments, faster recovery from failures, improved quality and performance of deployed applications, reduced deployment times and reduction in efforts on development and testing among many others. Also, as with DevOps, all this can be done using well-defined workflows that can be implemented with an open and customizable set of tools.

As mentioned, vendors have access to the NGPaaS platform through specific Dev-for-Operations layer instances. Contracting and on-boarding of these entities is managed by the NGPaaS Operator, and the type of vendors could range from VNF suppliers to open source or added value software artifacts.

In a traditional business model, vendors (or suppliers) are interacting with operators and verticals in a disjointed manner, with separated integration and testing environments. However, in the NGPaaS business model, specific Dev-for-Operations instances are on-boarded to improve efficiency and speed up time to market. An important fact in relation to this is that these specific instances are highly customizable to adapt them to each vendor and to the specific requirements of the business case to be implemented. So, the different frameworks in each instance (CBTR, Monitoring and Management) can be customized containing the necessary tools and services for each case. For instance, certain software vendors could have their Dev-for-Operations instances customized to also receive monitoring feedback from the operational environment, so they could adapt their developments accordingly, which could result in different parallel versions for the same software product.

It is commonly said that DevOps breaks barriers between "us and them" referring to development and operational teams or departments. In the case of Dev-for-Operations this extends even further to organizational boundaries, which means that in addition to the well-known DevOps' specific challenges we must consider also additional Dev-for-Operations specific requirements that software vendors must comply with, for instance:

- Security Means. After all the Operator is opening its network to the different vendors, so the necessary security means should be granted (for the operator itself and for

the participant vendors as well). The security function should enable access only to trusted parties, and bring protection from undesired communications, DDoS attacks, trojans, viruses and other malicious software attacks.

- Software Certification. Software components deployed on the operator's infrastructure should be "certified" according the operator policies, IPRs and to meet the SLA conditions.
- The operator rules. As already mentioned, although automation is the cornerstone in DevOps, the Operator should continue having full control over everything deployed on its network. In the telcos market the reputational cost of a failure can be extremely high.

Also, beyond the strictly technical aspects, considering that Dev-for-Operations makes possible for vendors to integrate the VSP's business cases into the operator's infrastructure, from a business perspective Dev-for-Operations can also be seen as an enabler to include vendors as one of the sides in an implementation of the well-known multi-sided platform (MSP) business model [4]. In this model, a vendor could contribute to the operator's platform using it as a repository for its software components; although these components could be initially designed to be part of certain service requested by the operator, they could be also used later for different purposes, e.g., to implement a new business case for a vertical industry. The vendor could get benefit from that by selling or renting its component to be used in a different service. The Operator could get also benefits from hosting the vendor's component and making that new business case possible and operational; this way a so-called "network

Software Provider Perspective

effect” (a relevant feature in the MSP model) appears: the more components in the operator’s network, the more verticals and third-parties could be attracted to be part of the platform, which in turn could attract more vendors to host their components in the platform as well. In our case, the idea would be to bring the MSP model already implemented on other digital IT platforms into a telco-grade operator infrastructure [9].

Experience in DevOps shows its implementation is mostly related to

organization and processes transformation and less regarding tooling and technology. In a multi-stakeholder environment around Dev-for-Operations we can expect even higher percentage of success attributed to organisational issues, such as onboarding of stakeholders, especially software vendors. While it is well-known that in multi-sided markets networking effect plays a key role (the more VSP are present in the NGPaaS platform, more it will be attractive for software vendors, and vice versa), there are factors to consider as well.

As with DevOps, mindset and culture of software vendors must change. They should be ready to show willingness to refine and change their components rapidly, as well as to collaborate and integrate their software with the third-party vendors, sometimes even competitors. An agile contracting framework will also put constraints on time and cost, so understanding the future relationships with the other stakeholder in the ecosystem is crucial (see Figure 6).

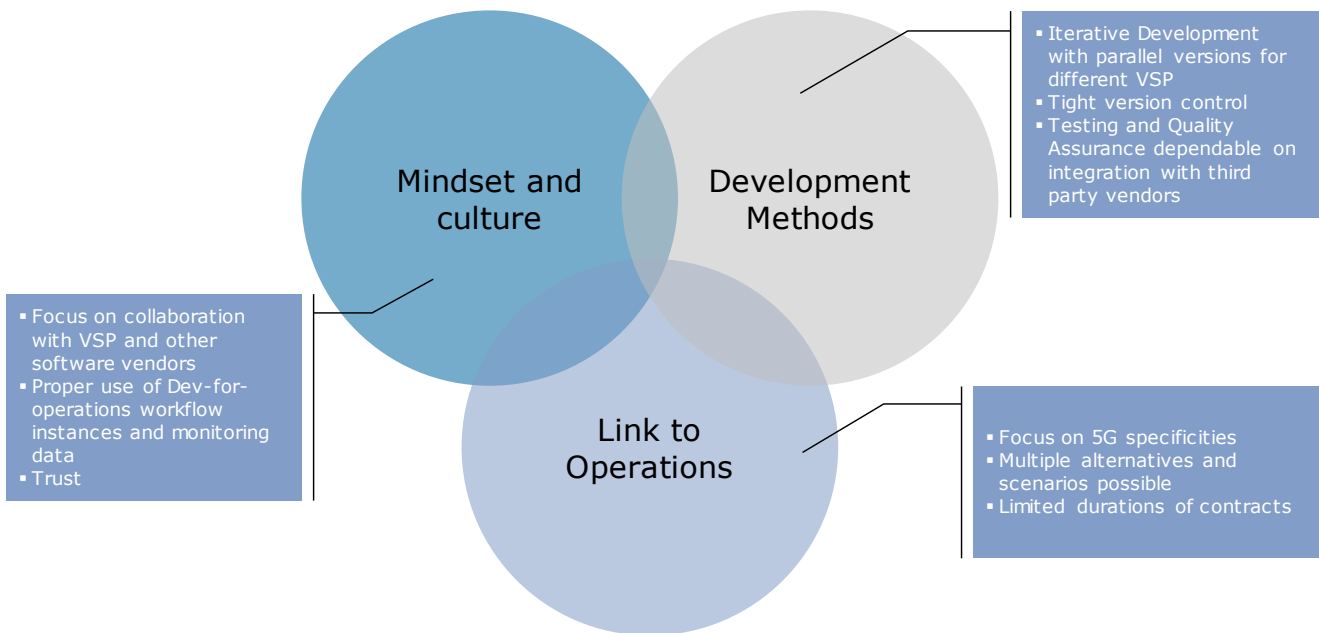


Figure 6. Dev-for-Operations intersection of challenges

Software Provider Perspective

Technology Provider

Technology Providers can contribute to create and/or manage parts of the NGPaaS platform which is operated by NGPaaS operator. This includes the whole Dev-for-Operations layer or certain specific frameworks or tools within them. For instance, a vendor could be hired by the operator to implement and configure the complete set of Dev-for-Operations instances for a specific service; or perhaps, a vendor could be requested to manage or monitor a service already in production using the corresponding Dev-for-Operations frameworks previously deployed.

There is a tendency towards convergence or partnerships between system integrators and technology providers, especially in the segments related to cloud computing. The traditional business model of selling technology, under contractual and license terms, is frequently replaced by value exchange, where value added services such as consulting, play an

increasing role. From the perspective of a Dev-for-Operations technology provider, the following value considerations can be addressed:

- Decrease risk of wrong investment e.g. in evolution or maintenance of technology implementations.
- Help to reduce time to market, as well as reactivity to business offer by entering partnerships.
- Speed up enhancements and evolution.
- Allows to gain additional revenues and open new channels.

Many technology providers already collaborate with system integrators and the value proposition is based on partnership or reseller contracts. This win-win situation is taking the best expertise from technology providers as well as from integrators, while revenue model is based either on time and material (T&M) or fixed price scheme. In case of NGPaaS Dev-for-Operations natural clients would be NGPaaS operators, but as mentioned, the value net could be further extended as a multi-side platform to include even triple partnership with the operator, other vendors and VSPs. Also, another

possible business model for technology providers is the commercialization of technology outside NGPaaS platform (e.g., for the associated VSPs).

In Figure 7 we envisage the possible effect of introducing Dev-for-Operations, where the further advance of digital transformation in organisations becomes much more predictable thanks to timely monitoring feedback integration and better alignment of previously disparate components. In this sense, the role of a Dev-for-Operations technology provider is to enable onboarding of the relevant stakeholders and establish proper interfaces. However, what could be needed is also added value services such as change management, or an approach that builds organizational resilience and capacity to respond to external pressures and demand in time. In this direction technology providers might also contribute to develop an "onboarding and continuous improvement" methodology, as well as best practice guidelines for all stakeholders involved in NGPaaS platform. Other challenges that can be tackled either by technology provider alone or in partnership with service providers are related to interoperability and standardization.

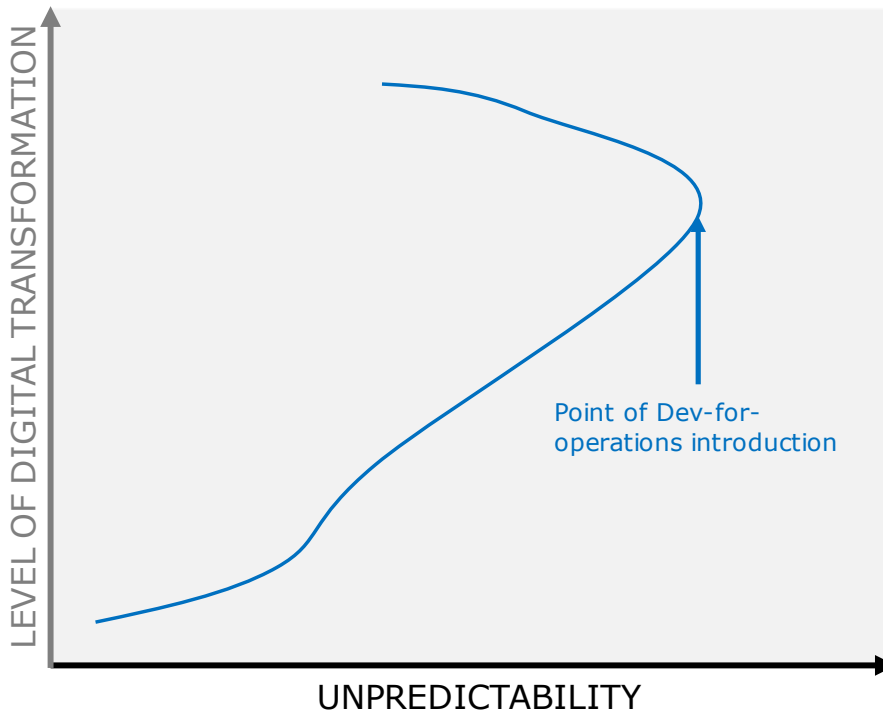


Figure 7. Level of Digital Transformation vs Unpredictability by introducing Dev-for-Operations challenges

Closing Remarks and Remaining Challenges

This paper has outlined the new Dev-for-Operations model which is being developed in the context of the H2020 Next Generation Platform-as-a-Service (NGPaaS) project. As mentioned, this work is still in progress, but we already consider the adoption of this new model could bring the future 5G operators the technical and business benefits derived

from the well-known IT DevOps model together with the specific Dev-for-Operations enhancements introduced here. Of course, still some remaining challenges are open. The main ones are related to a more generic definition of the Dev-for-Operations workflows and a more specific definition of certain components and services in the different Dev-for-Operations layer frameworks. Also, the specific way the different Dev

for-Operations instances are created is being addressed meanwhile this white paper is being written. Besides, beyond the conceptual design, it is also planned that at the time of the project completion a practical Proof-of-Concept will be implemented to demonstrate the value of the concept by showing how the different actors (software vendors, VSPs and operators) could interact using the Dev-for-Operations model in a multi-sided NGPaaS eco-system.

Acknowledgements

This work has been performed in the framework of the NGPaaS project, funded by the European Commission under the Horizon 2020 and 5G-PPP Phase2 programmes, under Grant Agreement No. 761 557. The authors acknowledge the contributions made by all the other partners in the NGPaaS consortium.

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