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In the Light of Ten Years from the NFV Introductory Whitepaper

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Authors:
BT: Andy Reid
China Mobile: Lingli Deng
DOCOMO: Yoshihiro Nakajima, Yuya Kuno, Joan Triay
KDDI: Hiroshi Tsuji
Orange: Bruno Chatras, Janusz Pieczerak
SK Telecom: DongJin Lee, JoongGunn Park
SoftBank: Daisuke Furukawa, Katsuhiro Horiba, Ashiq Khan
Telefónica: Diego López, Francisco-Javier Ramón
Telenor: Pål Grønsund
Verizon: Abhishek Kumar, Raquel Morera

ETSI
06921 Sophia Antipolis CEDEX, France
Tel +33 4 92 94 42 00
info@etsi.org
www.etsi.org

About the author

This whitepaper has been produced as a collective effort within the ETSI ISG NFV Network Operator Council (NOC), and advisory group ISG NFV uses to steer its technical work and align it with the goals of network service providers, as the users of the technology. In this sense, ISG NFV pioneered the current trend of incorporating *user groups* to technology development communities, whether by standards documents or by open-source implementations.

The authors are active participants in the NFV NOC, with many of them being involved in the development of the technology since its inception ten years ago.

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Executive Summary

Since the inception of NFV ten years ago, the telco industry and the way that telecom networks are deployed and operated has radically changed, and NFV has been a major element of this network transformation in the last decade. In the tenth anniversary of NFV, the intention of this whitepaper is twofold: to provide a view on the evolution and impact of the technology concepts that were coined a decade ago, and to analyse and explore the new application environments and challenges that will shape the technology and its industry adoption in terms of interoperable solutions.

The evolution of the NFV concepts and their translation into formal standards by the ETSI ISG NFV is first considered. This document analyses the goals of the successive specification releases, together with the connection to other means for standardization, aiming to constitute the foundations for facilitating the interoperability and guiding the technology development ecosystem. Further on, the role of the NFV ideas as foundations for network transformation is discussed, including a review of how the pursue of these ideas has also influenced the standardization process itself, adapting it to the quicker pace of current technology evolution. Finally, to conclude the review of NFV impact, an analysis of the original goals identified in the foundational whitepaper in the light of the current status of the technology and its standardization is provided, including some additional benefits, among which the role of NFV as research and innovation accelerator is specifically relevant.

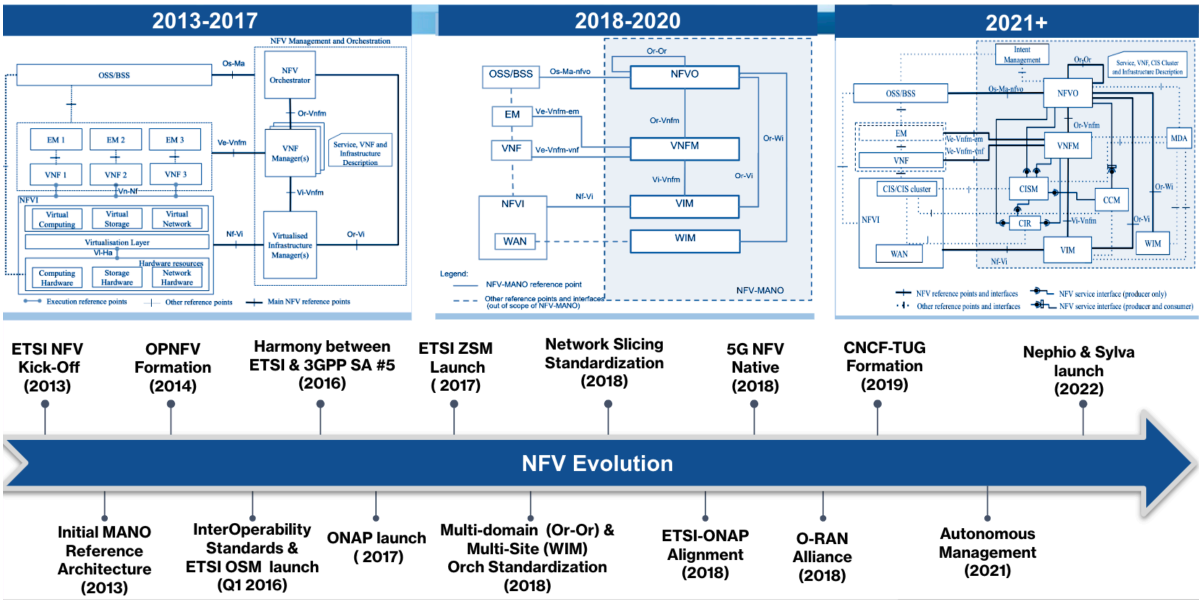
NFV has expanded its application environments since its original inception, acting as a facilitator of network transformation and as a key enabler for technology evolution. The most relevant of those new fields that have been enabled by the NFV concepts and that would likely shape its future evolution are analysed. These fields include 5G consolidation and further evolution, the use and integration of non-public networks, and edge environments. A series of challenges and opportunities for the future of NFV are discussed as well. These challenges have been grouped in categories, that the authors believe will redefine the requirements for interoperable NFV technology. The categories identified here are related to performance trade-offs, the evolution to cloud-native applications, the identification of best practices in lifecycle management and automation, the use of intent declarations and AI in management, the support for industrial networks, the need for energy efficiency, and the consolidation of ecosystems and testbeds.

The paper concludes with a series of recommendations, specifically focused on ETSI ISG NFV, as the core community for NFV technology.

The NFV Evolution

Network Functions Virtualization (NFV), as a concept, was first introduced in a whitepaper published in October 2012 [NFVWP], co-signed by twelve leading telecom operators. NFV was described therein as a process involving *"the implementation of network functions in software that can run on a range of industry standard server hardware, and that can be moved to, or instantiated in, various locations in the network as required, without the need to install new equipment"*. At that time, NFV was rightly perceived as a disruptive and challenging approach. By shifting network functions from dedicated physical appliances to distributed cloud infrastructures, NFV was indeed a radical change in the way networks were designed, deployed, and operated. Ten years after, NFV has become the norm for deploying network functions and managing their lifecycle. New network functions are natively designed to take advantage of the distributed Virtualization and cloud computing model underpinning NFV; hence, the emergence of the term "cloud-native network functions". According to recent industry analyst reports, investments on virtual EPC (Evolved Packet Core) will reach nearly 95% of the EPC market by the end of 2025. Most, if not all, 5G core network implementations are virtualised. In some cases, NFV is not even an option: it is indispensable, e.g., implementing the concept of 5G network slicing without resorting to Virtualization would not be realistic nor a sustainable economic strategy.

Since its inception, NFV has continuously evolved to leverage advances in cloud computing technologies and to address new use cases and industry requirements. The evolution of NFV can be easily perceived when looking at the successive releases of specifications developed by ETSI's eponymous Industry Specification Group (ISG) that was created as a response to the call for actions concluding the aforementioned whitepaper. NFV Release 1 set the founda**tions**, by defining a terminology commonly accepted by the industry as well as an architectural framework along with high-level requirements applicable to an NFV system. Many Proof-of-Concept (PoCs) demonstrations involving multiple companies from the Telco and IT industries were built on these foundations, thereby demonstrating both the immense enthusiasm from these industries and ultimately the feasibility of the concepts. As field trials and first operational deployments were emerging a couple of years later, the need to address **interoperability** issues became prominent. Indeed, compared to conventional deployments, the disaggregation of network functions implied by NFV brings additional challenges in terms of multi-vendor interoperability. Virtualised Network Functions (VNFs) must be packaged in a way that is independent of the vendor supplying them. They must be able to run on independently deployed and operated NFV infrastructure platforms and to interoperate with independently developed management and orchestration systems. Delivering a set of implementable solutions addressing these challenges was the focus of NFV Release 2. As NFV deployments were moving from field trials to large scale deployments, the need to enhance these specifications with features aimed at addressing **operational** issues (e.g., management of multi-site services, software update/upgrade, troubleshooting, etc.) became blatant. This has been the main goal of NFV Release 3. The decision to launch work on NFV Release 4, with "cloudification and simplification" as a motto, was motivated by the need to leverage advances in cloud computing and network management technologies to simplify NFV deployments. The integration of container management and autonomous networking techniques in NFV management and orchestration were the two spearheads of NFV Release 4. More recently, NFV Release 5 was initiated in 2021, coined with "**consolidation and ecosystem**" as its slogan, with the aim to address further operational issues in areas such as energy efficiency, configuration management, fault management, multi-tenancy, network connectivity, etc., and consider new use cases or technologies developed by other organizations in the ecosystem, as in the case of the O-RAN Alliance.



A timeline of ETSI NFV architecture evolution

NFV is emblematic of the convergence between the IT and Telco industries. It has continuously evolved to take advantage of the IT industry progress and will continue to do so. The rapid transition from virtual machines to containers as the prime Virtualization technology for hosting VNFs is an easy-to-understand example. Indeed, while EPC network functions have been primarily deployed in virtual machines, most 5G solutions are currently relying on containers. It is expected that NFV will further evolve in the coming years to take advantage of other emerging technologies such as serverless computing, disaggregated computing, in-network computing, etc.

The evolution of the standards and open-source ecosystem around NFV is worth noting as well. While ETSI has pioneered the NFV effort by creating a dedicated ISG, NFV has been considered and embraced by many other standards organizations over the past ten years. This includes organizations developing specifications of network functions from all network segments and network planes (such as 3GPP, Broadband Forum, etc.), as well as organizations developing standards leveraged by NFV specifications, like the OASIS TOSCA case. The relation to open source has been continuously evolving as well. The implementation of NFV systems has been relying from the very beginning upon a wide range of open-source software in areas like operating systems, hypervisors, cloud infrastructure managers, software acceleration, etc. At the same time, NFV has been acting as a catalyst to create new open-source initiatives, starting with the OPNFV project (now part of the Linux Foundation's Anuket project), continuing with multiple initiatives aimed at delivering open-source solutions for NFV orchestration, including the ETSI-hosted Open-Source MANO (OSM) project and the Open Network Automation Platform (ONAP) hosted by the Linux Foundation.

Additionally, although NFV was conceived to enable VNFs to be freely moved across various locations, one can observe an evolution of deployment scenarios for NFV infrastructures. While the initial focus of the Telco industry has been on using private central clouds as NFV infrastructures, extending the NFV infrastructure to the edge is going mainstream, and solutions resorting to public and hybrid clouds have emerged at a fast pace. Extending the NFV infrastructure beyond the edge, down to the customer equipment, is likely to be one of the next major evolution trends. Therefore, it is expected that NFV orchestration solutions will have to cope with the management of a highly distributed infrastructure, made up of a huge number of small capacity hosts, possibly ephemeral and mobile.

A Key Role in Network Transformation

ETSI ISG NFV created and consolidated completely new concepts that were instrumental in a deep transformation in the telco industry. This transformation has brought a clear convergence path between IT and telco industries that is accelerating, reshaping the vision of how telecommunications networks and the services connected by them will evolve in the future. The ISG NFV community managed to make the original concepts, received with scepticism and in some cases disbelief, a widely accepted knowledge corpus. Applying NFV solutions is not any longer something that must be justified, but on the contrary: not using them is what requires a detailed rationale. And this evolutionary path continues as the quest for *cloud-native* solutions is gaining momentum, within the ISG NFV itself, and among the wider community of technology developers focused on this transformation of networking technologies triggered by NFV.

This wider community focused on network transformation is composed both by groups that adopted the NFV approach to address their own problem spaces, as well as newly formed initiatives around the foundations provided by the NFV concepts. Among the first ones, it is important to remark the early interest of the TM Forum, with their ZOOM project, the impact of NFV in 3GPP specifications, when consolidating the 4G-related standards and especially as 5G took shape, the approach to virtualised connectivity services adopted by BBF, and the fact that the foundations of the O-RAN Alliance are grounded, among others, on NFV principles. The IRTF acknowledged the impact of NFV on the evolution of the Internet with the creation of the NFVRG, very much related to the ISG NFV Research Agenda. There are at least two activities within ETSI we could qualify as “spin offs” of NFV, related to edge services (ISG MEC) and automation (ISG ZSM), and other new activities that have been deeply and directly influenced by the NFV approach. To cite a few in this category, we can consider ISG ENI, ISG SAI, ISG F5G and ISG IPE.

The very nature of the network transformation endeavour and the need to converge with widely used practices in the cloud industry made ISG NFV to explore and set new ways of defining standards. We adapted to times of change, trying more agile ways for developing reports and finding consensus on specifications, and facilitating the collaboration with the wider community of potential technology providers and users. The ISG pioneered the open access to all its drafts as work progressed, facilitating direct feedback from the widest possible community of standards users, and established mechanisms for what we called *demonstrative* deliverables, via the PoC framework, which has been assimilated in many other bodies, and the execution of early Plugtests events. The main goals of these demonstrative activities were the assessment of the feasibility of the proposed solutions and the early evaluation of interoperability hurdles and opportunities.

To conclude this quick review of the impact of NFV on network transformation, let us remark the interaction with open source, a breakthrough in telco technology evolution. This involvement was justified not only by the direct applicability of open-source cloud orchestration solutions to support the NFV proposals, but also by the willingness to explore new paths to standardization mentioned above. The foundations of the first open-source community related to NFV, OPNFV, were set during an ETSI ISG NFV plenary meeting, and the OSM initiative was directly hosted in ETSI, as the first stage of a new path to explore standards definition and consolidation by means of open-source development. Practically all influential open-source communities related to network transformation have been connected to ISG NFV, from the ONAP automation initiative to the recent certification-focused projects consolidated by Anuket.

A View on the Intended Benefits of NFV

Ten years ago, we identified a wide variety of benefits that NFV would potentially unlock. In summary, these were:

- Reduced hardware costs.
- Improved time to market for new services with no need to install new hardware for new services, improved service introduction processes (anticipating CI/CD style agile service development).
- New highly targeted services otherwise not economically viable.
- A new ecosystem for the telco industry with greater openness and easy entry for new players as well as easier access for academia.
- Near real-time optimisation of resources to changing load and functional requirements, support for more than one operator’s network on the same physical infrastructure.
- Reduced energy consumption.
- Improved operational efficiencies including automated development and deployment of new services using orchestration, in-service upgrades, rapid reconfiguration for exceptional events and/or failure scenarios.

At the time, these were set out in no particular order, and stated as such in the white paper, as different operators then had distinct use cases and saw early opportunities from NFV arising in different ways. While this has undoubtedly turned out to be the case, it is also true that the decision by 3GPP that the 5G architecture would be based on NFV has also provided a unifying focus for the exploitation of NFV across the industry. As a result, many of these benefits have come together as the industry deploys 5G networks and starts to exploit them. In many ways, the anticipated benefits of NFV have become linked to the deployment of 5G and its exploitation as a global service platform. Indeed, at the launch of 5G, most of the benefits anticipated in the first white paper became some of the basic assumptions for 5G.

Two aspects that this first list of benefits did not explicitly include, and which have subsequently become much discussed features of 5G, are edge computing and applications connecting to IoT devices. In both cases, however, there were early discussions within NFV anticipating these developments and the benefits of NFV set out in the first paper underpin key enablers for both.

Edge compute infrastructure is only commercially viable if it can rely on income from many applications running simultaneously, and this is unrealistic without considering NFV. This was anticipated as one of the benefits which enable targeted services, together with the operational efficiencies of software deployment.

Applications based on IoT devices are now commonly considered as 5G applications; indeed, 5G explicitly provides slicing capabilities, as well as edge and compute capabilities, to support these applications. IoT applications were part of those early NFV discussions around the “highly targeted services” even if much of the details had not been worked out 10 years ago.

As a final note, it is interesting to reflect on the anticipated benefit of allowing easy access by academia to the overall ecosystem. Over the last ten years, academia has played a pivotal role in the development of

5G (for example, in many European Horizon 2020 projects dedicated to it). The Virtualization of network functionality played a critical role in these projects enabling academics and other researchers to build and deploy experimental environments very rapidly, without the need for any specific hardware, often participating in industry open-source projects arising directly from NFV. This would have been wholly impossible without NFV.

New Fields of Application

As introduced above, during its lifetime, NFV has expanded its application environments, acting as a facilitator of network transformation and as a key enabler for technology evolution. Let's analyse the impact on the most relevant new fields, including 5G consolidation, the use of non-public networks and edge environments.

The goal of 5G is to cost-effectively deliver new communication patterns in mobile networks, characterized by the initial ones identified in its foundational proposals: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communication (URLLC), and Massive Machine Type Communication (mMTC). To meet the requirements for scale, throughput, latency, and reliability, 5G architecture has adopted and made NFV and cloud implementations evolve, to streamline network and service deployment, operations, and management.

NFV embraced this journey with enhancements to its standards stack, including support for slicing, container-based deployment, and autonomous networks. Specific updates have been made to the Management and Orchestration (MANO) stack and to the service descriptors to support lightweight container-based Virtualization as well as associated aspects of network slicing. There is ongoing work focused on another essential enabler to address the full 5G promise: autonomous network features.

Compared with the previous generations of mobile networks, a main change of the 5G network is its broader scope, which not only covers traditional personal data and communication services, but also covers the new vertical industry communication needs. Typical usage scenarios include manufacturing, inner-park communication, IoT device management, enterprise IT, etc. As the business scope has broadened, the mobile network also gradually expands from the public network to a hybrid network which combines public and private segments. And as the basis of the mobile network's infrastructure, the NFV system needs to adapt to new requirements for enhanced automation and operability.

In the recent years, ETSI ISG NFV has already made a few studies and enhancements to support distributed deployment of the NFV system, addressing multi-site connectivity services, the separation of administrative controls (for NFV-related lifecycle management and resource management) between MANO and the underlying cloud platform, either private cloud or hyperscalers, and the interconnection of MANO stacks deployed in different administrative domains. Introducing these features makes it possible for a distributed deployment of the NFV system, and supports use cases like local user plane deployment, and intercommunication between the local user plane and central control plane network functions. Such design patterns and methodologies to adopt cloud-native architecture are hailed as disruptive now. However, such architectural considerations were thoroughly researched and analysed then by the ETSI ISG NFV and are now considered critical milestones in order to succeed in the cloud-native NFV transformation journey.

In vertical industry use cases, it is quite common that enterprises require not only mobile network services, but also efficient utilization of computing resources or services. In particular, for some use cases that require low latency and large bandwidth (such as video processing, virtual PLC, etc.), it is very suitable to utilize the computing resources offered by the mobile network providers, which are deployed closely with the network. This enables reducing the delay and the amount of data transferred through the network. This kind of service is the focus of standardization by the ETSI ISG MEC.

ETSI ISG MEC defines a reference architecture and related protocols for edge computing. One of the options in their reference architecture, called “MEC in NFV”, utilizes the NFV system to deploy and manage the edge computing platform (the MEP) and the applications running on top of it. Edge computing has been widely deployed, tested, and commercialised all over the world. Using this “MEC in NFV” solution, operators can reuse the NFV infrastructure to host both Telco Network Functions (NFs) and MEC applications and maximise the value of their cloud infrastructure. This also helps simplifying the management domain, for instance, by using a single management system to support both 5G and MEC business scenarios. ISG NFV and ISG MEC are working closely together to align their interface and descriptor designs, addressing a converged standard solution. A relevant aspect to address is related to the integration of different infrastructures, as enterprises using edge services may not necessarily consume them solely from network operators, but they may need to include their own private cloud applications and use services from hyperscalers as well.

Challenges and Opportunities Ahead

Evolution to cloud-native applications

When it comes to technology evolution, the lifecycle requirements of systems using NFV can be divided into those we can consider ‘cutting-edge' and those which fall under the general 'legacy' term. Many use cases for NFV are focused on fast-evolving technologies, such as 5G (and beyond) or vRAN. Adopting evolving technology and maintaining transformational agility for new deployments is critical for these use cases, and the current trend towards cloud-native solutions is a future-proof approach for this kind of functions.

On the other hand, 'legacy' telecom applications such as fixed network, IMS and so on, will not require a so rapid evolution in terms of functional capabilities, but they can require rapid software updates to fix security issues and rapid changes in terms of capacity. In these cases, it is important to address stability and cost efficiency for sustainable service provision. NFV also provides benefits in these cases by decoupling the hardware and software lifecycle, but the cost of frequent changes may be too high for this kind of network functionality, so there is not much motivation to adopt breakthrough technologies. Therefore, the lifetime of these network functions is likely to be extended and NFV platforms must continue supporting the technologies they use.

Container technology has been widely recognized as the next technology which should be incorporated by the telco industry, especially to address cloud-native requirements. However, it presents some differences compared to existing technology and requires some adjustments to current practices, in an environment where it is complicated to make drastic changes. Operators need to cater with these architectural changes while guaranteeing service features at reasonable costs, as strict SLAs and complex VNFs will still need to be supported. On the other hand, it must be noted that, around container-as-a-service technologies, IT industry has been consolidating a set of best practices for well-behaved container workloads that are now commonplace for the operation of large-scale container deployments, and which might also benefit telco industry if properly assessed, and possibly extended for specific needs of some telco workload requirements, leveraging as much as possible the high degree of maturity that has been already achieved in other sectors.

While container orchestration technology is being introduced for NFV, the declarative API design model has become an emerging alternative to the traditional imperative API model. Declarative APIs can help ease the handling logic of the API consumer by focusing on describing the desired status of managed objects instead of the corresponding operation details. Hence the introduction of the declarative API is expected to reduce the complexity for operators to manage the NFV system. However, this API design paradigm also requires higher observability of corresponding API objects in NFV, which is an aspect that should be further analysed and addressed.

Performance trade-offs

The trade-off between flexibility and efficiency is that increased flexibility when considering software solutions may come at the cost of performance, and performance often comes at the expense of low flexibility (build options and product selection). This is a big challenge that was identified early on at the beginning of NFV, and which has not been entirely resolved. Vendors, and the ecosystem in general, have made a big effort using different approaches, such as SR-IOV and vDPA, to keep compatibility with NFV specifications. However, the heterogeneity of acceleration solutions in the industry is increasing and makes it necessary to standardize an acceleration abstraction layer.

Best practices in lifecycle management and automation

Ten years ago, most of the industry envisioned a network with a physical (PNF) and virtual (VNF) function mixture. However, many operators have achieved 70% or more Virtualization of their network assets by this time. As Virtualization, containerization and the consequent cloudification become even more prevalent, lifecycle management focused only on a single network domain is not sufficient anymore. End-to-End Orchestration (E2EO), including access functions (vRAN and disaggregated optical devices), becomes an undeniable necessity. Sufficient attention has to be put on the modularity of the E2EO components, so that an operator can pick and choose or add new modules with ease, according to its operational needs. Procurement, integration, and holistic utilization of presently available per-domain orchestration and management are significant challenges for operators.

To advance NFVI for flexibility and reliability, a unified way to provide E2E service-level load distribution, QoS control, resiliency, and monitoring for all NFs is needed. An increasing number of newer 3GPP NFs for emerging services are observed, which could increase the deployment, verification, and integration complexity to be performed by the network operator. Therefore, it is important for developers of cloud-native NFs to focus more on application and business logic instead, leaving the rest of traditional features such as network configuration and load distribution to the platform. In order to simplify the network operations for telcos, the redundant functionalities exercised by element management systems (EMS) designed specifically for one or a few network functions require rationalization due to the availability of widely used equivalent open-source tools, suitable to be used in PaaS mode, and which can reduce the operational burden on the operators.

At the same time, any conceivable NFVI is inherently a multi-cloud infrastructure. It would be more so with the appearance of vRAN, edge, and customer-premise services. The MANO stack needs to be extended to encompass multiple elements at each level, and to go beyond current static resource pool management. In addition, network slicing has the potential to extend an operator's logical network into another operator's network. Federation among operator edge sites will also become necessary to extend edge coverage.

Hence, inter-operator MANO interfaces need to be defined and standardized. Reconciling the need for holistic E2E orchestration with the implications of multi-cloud and multi-operator coordination requires the consolidation of best practices in NFV lifecycle management.

The way different VNFs consume infrastructure resources (bootstrap procedures, QoS enforcement, the application of affinity rules, management networks, configuration mechanisms, etc.) are different, and the interactions between the VNFs and MANO components became also differentiated (for instantiation, scaling, update/upgrade, etc.). In the current practice, this has led to the need of specific procedures, on a per VNF basis, to reduce errors in these processes. Such differences in VNF operation procedures should disappear with a generalized and strict compliance to ETSI NFV standards. While automation is sometimes perceived as an implementation matter, standard workload packages applying standardized information and data models can greatly facilitate it. Instantaneous plug-and-play of workloads to E2E orchestration is not an impossible feat to achieve.

The management of NFV towards automation is bringing profound changes to the operations and maintenance of telco networks, e.g., the combination of DevOps and cloud increases the telco software delivery efficiency. While NFV-MANO pays attention to the lifecycle management of the running VNFs, continuous integration (CI), continuous delivery (CD) and continuous testing (CT) are becoming more prominent to deploy and manage telco networks in a more agile way and to reduce time to market. In order to provide better services to telecom network users, NFV development, operation and testing stakeholders should cooperate more closely to deal with the increasing system complexity.

A major challenge experienced with NFV so far is the high complexity in integration, operation and automation of VNFs from multiple vendors on a vendor agnostic NFV platform. One example of this is the tensions and challenges with using generic VNF managers, at least when implemented as proprietary solutions, leading to more complex MANO deployments that often fail to align integrations when deploying or upgrading software components. To succeed with this vision going forward there is need for transformation wider than technology only, including ecosystems, business models, operating models and service delivery models that support the standards, open-source reference implementations and split-of-responsibility while embracing the cloud native way of work. It is necessary to engage the relevant industry and open-source forums to jointly proceed in realizing this vision.

Intent management and AI-enabled MANO

With the continuous expansion of network scale and rapid growth of network traffic, network management becomes extremely complex and error prone. In the past few years, intent-based networking (IBN) has gained more traction in the industry. IBN translates user intent into corresponding network operations, monitors network status changes, and finally realizes automatic management of the network to meet the intent. To automatically achieve user intent, continuous monitoring of the network status and its processing through artificial intelligence is assumed to be available.

However, the actual implementation of intent management in NFV still faces many challenges. A key step for IBN is the translation from intent to network operations. At present, there is no unified method for this translation, and most of the existing methods remain in an experimental stage. In an IBN-based closed-loop, if an error occurs at one step, it may lead to a series of faults, or even cause the network to stop providing service. In cross-domain end-to-end orchestration, this risk may be further amplified across domains, which also increases the difficulty of deploying IBN in telco networks.

AI technology, as an essential enabler to push forward the progress of information technologies in recent years, is also expected by operators to improve the management capability of the MANO system. ETSI ISG NFV is now starting to specify the AI-enabled MANO that involves monitoring data collection and analytics to apply real-time operational intelligence whenever deterministic behaviours are not sufficient.

NFV to vertical industries

As 5G is going into commercial use worldwide, NFV is expected to help realize Internet-of-Things connectivity for vertical industries. Rather than traditional dedicated hardware and embedded communication software, the NFV technologies provide a solution that could make current 5G networks suitable while addressing the various requirements of the vertical industries with a relatively low investment and maintenance cost. In the era of digital transformation, telecom operators are exploring how to establish collaboration patterns between the edge and the cloud to provide data communication services with industrial SLAs for enterprises. On this issue, NFV also faces new challenges such as simplified on-demand deployment, multi-tenancy, multi-site orchestration, hybrid private-public cloud infrastructure, etc.

Energy efficiency

Energy efficiency is one of the most important issues for any industry, and in particular for telecommunications. This need has become more stringent in the light of the recent events that pose concerns on a stable and growing energy supply. NFV offers additional tools for the network operator to support the allocation of resources to network functions as needed; based on the demand, scaling VNFs has been used for such dynamic resource allocation from an NFV lifecycle perspective. To further reduce power consumption, it is time to consider dynamic power saving or processing mode switching based on the actual traffic and capacity demands.

Dynamic power management requires a real-time control and data traffic analysis and full observability. Observation capabilities are the core of automatic power management and power consumption assessment. Throughput and latency impact on VNF performance should be carefully considered along with dimensioning rules. From a standardization perspective, metrics data format and data collection protocols have to be considered. The information must be unified for the different network segments, such as radio access and core network elements.

Ecosystem and testbed consolidation

The adoption of NFV has implied a direct collaboration between standards and open-source communities, as well as the support for early interoperability assessment, creating a collaborative ecosystem that needs to evolve and consolidate. Open testbeds will play a major role in the development and testing of different NFV lifecycle management and automation components including, including the support of high-quality, interoperable VNF and MANO products, in a faster and cost-efficient manner. We expect the ETSI ISG NFV to take a leadership role in this.

Recommendations

The authors of this white paper recommend that the ETSI ISG NFV undertakes actions in the following directions:

- Embrace the rapid evolution of a combination of cloud-native and multi-cloud maturity models as well as new virtualization technologies, such as Unikernels and Serverless.
- Expand the use of NFV standards in all telecommunication network domains to make possible the realization of holistic E2E orchestration and unified management of virtual and cloud infrastructure resources.
- Find a trade-off between developing specifications that are abstract enough to cope with the fast evolution of underlying technologies and developing specifications that are precise enough to enable interoperability.
- Seek more agile specification methods that will enable accelerating the path to deliver implementable (“Stage 3”) specifications. Timely availability of such specifications is critical to industry adoption and contributes to preventing industry fragmentation. This includes reducing the time spent on the development of feasibility studies and functional (“Stage 2”) specifications.
- Better characterize what prevents the NFV community to adopt “as is” cloud-native technologies. Focus on areas where ETSI’s work on NFV has a clear added value compared to other organizations. Promote broader adoption of standards by addressing the gaps and limitations of existing specifications.
- Engage relevant industry and open-source forums to foster industry transformation in accepting and adopting to the use of VNF agnostic NFV platforms supporting VNFs from multiple vendors, considering the change required in ecosystems, business models, operating models, and service delivery models.
- Look for more proactive collaboration with other communities, developing NFV-specific extensions to open-source solutions where appropriate. A canonical example would be the definition of NFV-specific custom resource descriptors and the development of the corresponding operators, hosting these artifacts in an open repository.
- Proactively cooperate with other telecommunication organizations, like TM Forum and 3GPP, to promote the autonomous network evolution in network management, specifically on the usage of AI-driven intelligence, close-loop intent management, and continuous integration, delivery, and testing within the NFV system.
- Foster industry involvement and encourage academia collaboration in ISG standardization activities, as the best choice to build a common understanding on technology evolution, guarantee solution interoperability, reduce market fragmentation, and demonstrate emerging concepts as Cognitive Learning and Green NFV, to help accelerate the achievement of sustainable development goals within the scope of NFV.

ETSI
06921 Sophia Antipolis CEDEX, France
Tel +33 4 92 94 42 00
info@etsi.org
www.etsi.org