ETSI White Paper No. 67

Management and Orchestration of the Telco Cloud: The Role of NFV-MANO and Its Added Value

1st edition – May 2025

Authors:

Xia Haitao, Wenjie Hao, Kostas Katsalis, Yuya Kuno, DongJin Lee, John Leung, Ju Manchang, Faraz Naim, Janusz Pieczerak, Sibylle Schaller, Toshiaki Takahashi, Ildiko Vancsa, Leslie Willis

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

About the authors

Xia Haitao (Huawei, China)

Wenjie Hao (China mobile, China)

Kostas Katsalis (NTT DOCOMO, Germany)

Yuya Kuno (NTT DOCOMO, Japan)

DongJin Lee (SK Telecom, Korea)

John Leung (Intel, USA)

Ju Manchang (ZTE, China)

Faraz Naim (Accenture, UK)

Janusz Pieczerak (Orange, Poland)

Sibylle Schaller (NEC, Germany)

Toshiaki Takahashi (NEC, Japan)

Ildiko Vancsa (OpenInfra, US)

Leslie Willis (BT, UK)

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

Contents

Executive Summary

This white paper emphasizes the role and added value of NFV-MANO in relation to other Standards Development Organizations (SDOs) and open-source projects that contribute to various aspects related to Telco Cloud management and orchestration operations.

Given NFV-MANO's widespread adoption and the ETSI ISG NFV's contributions to the telecommunications industry, the ETSI NFV-MANO framework can be effectively utilized to address the evolving requirements of Telco Cloud management and orchestration.

When assessing the merits of using NFV-MANO to support Telco Cloud and orchestration management processes, the following key considerations must be acknowledged:

- Telco Cloud management and orchestration are inherently complex.
- The current landscape of standardization and open-source developments within the ETSI NFV-MANO framework and the ecosystem is rapidly evolving.
- Different Telco Cloud stakeholders, such as operators, vendors, and application developers, have diverse requirements and varying understandings regarding management and orchestration.

Clause 1.2 presents the standardization landscape for Telco Cloud management. Clause 1.3 summarizes the major open-source initiatives and projects commonly used to support Telco Cloud operations. Clause 2 outlines the essential capabilities of NFV-MANO and highlights the added value it brings to Telco Cloud management and orchestration. Clause 3 identifies the challenges that must be addressed as the telecom industry progresses beyond 5G, while also describing the NFV-MANO approach to address these challenges.

1. The Evolution of Telco Cloud Management & Orchestration

1.1 Introduction

Network Functions Virtualization (NFV) has fundamentally transformed the operation and management of mobile networks. NFV addressed the limitations inherent in traditional network management approaches, where challenges posed by manual processes and static configuration of the network —such as scaling issues, onsite work needed and the lack of interoperability—were difficult to overcome. Since its inception, the primary objectives of NFV have been the exploitation of virtualization technologies to benefit the telecommunications industry by minimizing management complexities, minimizing integration and upgrading difficulty, enabling dynamic network configuration and improving network stability and reliability against unpredictable failures or disasters.

With recent advances in the management and orchestration of containerized deployments and the growing ecosystem of container-based technologies, both industry and standardization efforts have shifted their focus. This shift now encompasses not only leveraging virtualization and containerization to support telecommunications operations but also embracing cloud-native principles[1].

The introduction of Telco Cloud in telecommunications networks opened up the opportunity to build more modern and efficient end-to-end software stacks all the way up to applications and services. Applying cloud-native methods and techniques ensures scalable, flexible and sustainable solutions.

Note that the definition of the so-called Telco Cloud varies across industry groups, forums, standardization, and pre-standardization bodies, as well as academia, reflecting diverse perspectives. From the standpoint of telecommunications operators, these definitions converge following a common rationale: *the Telco Cloud is based on NFV technologies and involves the migration of telecom operations (data plane, control plane, and management plane) to the cloud, in accordance with cloud-native principles.*

In this context, containerization and virtualization are used simultaneously as complementary technologies throughout the cloudification process, and therefore containerization should not be seen as a competitor or successor. According to ETSI ISG NFV, the term "Virtual Network Function (VNF)" encompasses Network Function (NF) deployments utilizing various types of virtualization environments, such as Virtual Machines (VMs) and containers. Additionally, other forms of virtualization, including MicroVMs and serverless architectures, are currently being analyzed by ETSI ISG NFV.

Different perspectives on the values that Telco Cloud brings are listed below:

- From the operator's perspective, a key benefit is the ability to decouple software from dedicated hardware, while enabling additional functionality to efficiently manage telecom applications running in the cloud. To achieve this, APIs are essential for integrating both Telecom Cloud applications and hardware/virtual resources with different kinds (versions) of operating systems and platforms, ensuring a seamless and less complex management process, as described in the ETSI white paper *"In the Light of Ten Years from the NFV Introductory Whitepaper".*

---

[1] See https://github.com/cncf/toc/blob/main/DEFINITION.md.

Furthermore, some additional requirements related to Telco Cloud management and orchestration expected by telecom operators are the following:

- To fully cloudify 5G and prepare for the transition to 6G, the industry recognizes the necessity of a fully automated and intelligent Telco Cloud management system.
- Support for flexible infrastructures that can accommodate a variety of hardware solutions.
- Support for heterogeneous NFV Infrastructure (NFVI) hardware, and other application virtualization forms other than VMs and Operating System (OS) containers (e.g., microVMs).
- Management of multi-vendor and multi-technology acceleration resources and clusters of acceleration pools.
- Support for fine-grained monitoring of inter-/intra- NFs for Root Cause Analysis (RCA).
- Operations considering a unified management layer over hybrid cloud deployments.
- CAPEX/OPEX reduction while maintaining the quality and performance of services.
- Multi-layer high-availability and redundancy.
- Simplification of maintenance procedures.
- Backwards compatibility preservation and long-term stability.
- Intelligent zero-touch management and orchestration operations.
- Energy efficiency towards green NFV.

- From the end user's perspective, maintaining high levels of Quality of Experience (QoE) is essential. This requires enhanced service reliability mechanisms to safeguard against hardware or software failures, as well as to manage increased or fluctuating traffic loads.
- From the vendor's perspective, new business models could be explored. This would allow vendors to shift their focus from managing and supporting hardware to telecom software development and innovation.

1.2 NFV standardization landscape

Since November 2012, ETSI ISG NFV has been the primary standardization body responsible for the development of Network Functions Virtualization (NFV) concepts and solutions, particularly those related to management and orchestration. Key contributions include the design of the NFV Reference Architecture (NFV-MANO), the development of interfaces and APIs for NFV, the establishment of frameworks for performance and fault management, and considerations surrounding NFV security. For insights into recent developments—such as automation, intent management, and energy efficiency in NFV-refer to the ETSI white paper Evolving NFV towards the next decade".

As the leading organization driving the creation of standard specifications for orchestration and management operations for the Telco Industry, ETSI ISG NFV has cultivated strong collaborative relationships with several Standards Development Organizations (SDOs) over the years. Continuous engagement with these bodies is facilitated through formal liaison exchanges and joint workshops, which promote the sharing of knowledge, foster joint development of NFV-related standards, and ensure the avoidance of redundancies while harmonizing existing standard specifications.

An illustrative list of the primary SDOs involved in NFV-related standardization activities is provided in Table 1.2-1, highlighting those with whom ETSI ISG NFV maintains active bilateral communication. Together, ETSI ISG NFV and the SDOs identified below are anticipated to play a pivotal role in shaping the standardization efforts for Telco Cloud management and orchestration as the industry advances toward 6G future networks.

Table 1.2-1: SDOs related to Telco Cloud management and orchestration operations

SDO	Relationship with NFV–MANO
3GPP SA5	One of the primary NFV-MANO API consumers. Interactions between the 3GPP management system and NFV Orchestrator (NFVO)/VNF Manager (VNFM). are related to the LifeCycle Management (LCM) of VNFs and network services (NSs). (See ETSI GS NFV-IFA 013 and ETSI GS NFV-IFA 008)
IETF	Base technologies for NFV-MANO. For example, NFV-MANO often uses IETF specifications in its Stage 3 specification work (e.g., MPLS, ACTN etc.)
IEEE	Base technologies for NFV-MANO. For example, NFV-MANO often uses IEEE specifications in its Stage 3 specification work (e.g., 802.1Q, IEEE 1588 etc.)
TM Forum	Consumer of NFV-MANO APIs. Integration of NFV automation processes into OSS/BSS systems (Operations and Business Support Systems).
O-RAN	O-RAN alliance WG1, WG6 and WG10 activities reference and exploit ETSI NFV specification for issues related to VNF LCM, descriptors and network management. ETSI GR NFV IFA046 document profiled NFV-MANO in support of the O-RAN framework.
ETSI ISG ZSM	One of NFV-MANO API consumers. ETSI ZSM activities in network automation are exploited by the ETSI NFV framework (see for example Closed Control Loop (CCL) in NFV according to ETSI GR NFV-EVE019, based on the ETSI ZSM framework).
ETSI ISG MEC	One of NFV-MANO APIs consumers. The ETSI NFV Release 3 feature on “enhancement support for MEC in NFV deployment” investigated interactions between the ETSI ISG NFV and ETSI ISG MEC platforms.
ITU-T SG5	Bilateral communication for issues related to energy efficiency.
ITU-T SG13	Bilateral communication for issues related to cloud computing management.
ETSI TC EE	Extensions of NFV specification work for enabling energy efficiency at NFVO level.

SDO	Relationship with NFV–MANO
DMTF	Base technology for NFV-MANO. The Redfish protocol developed by DMTF is considered in ETSI ISG NFV specification work for the management of physical resources (see ETSI GS NFV-IFA 053).
Trusted Computing Group (TCG)	Bilateral communication for issues related to security in NFV.
Global Platform	Bilateral communication for issues related to security in NFV.

1.3 Open-source activities in NFV Management

In real-world deployments, both open-source solutions and proprietary, commercial platforms, which almost always contain open-source building blocks, are utilized, covering a wide range of NFV use cases. These deployments address various requirements, including Network Service and VNF lifecycle management (for both VM-based and container-based deployments), resource management, performance and fault management, scalability, automation, and monitoring.

Given the inherent complexity, it has become evident that no single solution—whether provided by the open-source community or a telecom equipment vendor, even if standards-compliant—can comprehensively address all challenges associated with the management and orchestration of the Telco Cloud.

Since the very beginning, ETSI ISG NFV has anticipated close collaboration with open-source communities to build the foundation for interoperability in the Telco Cloud business. ETSI ISG NFV specification development methodologies (like better coordination between stage 2 and stage 3 developments), efforts like simplifying the NFV-MANO interfaces and models, and introducing VNF generic Operation Administration & Management (OAM) functions and other PaaS (Platform as a Service) services have been evolving. These advances are expected to play a key role in aligning the pacing between standardization and open-source solutions, supporting Telco Cloud operations in a technology and vendor-agnostic way.

Table 1.3-1 summarizes the key open-source projects that can be leveraged to enable efficient management and orchestration of the Telco Cloud and synopsizes their relationship with NFV-MANO.

The primary organizations hosting these initiatives are the OpenInfra Foundation, the Linux Foundation, and ETSI. The Cloud Native Computing Foundation (CNCF) operates as a subsidiary project under the Linux Foundation.

Table 1.3-1: Open-source activities related to Telco Cloud management and orchestration

Host Organization	Project	Description and relationship with NFV-MANO
OpenInfra Foundation (OIF)	OpenStack	Cloud computing platform that provides infrastructure-as-a-service (IaaS) by managing pools of compute, storage, and networking resources. Supports NFVI and Virtualized Infrastructure Manager (VIM) related functionalities. Some components of OpenStack (e.g., Neutron, Nova) can play the role of the VIM and are responsible for managing and controlling the virtualized resources (compute, storage, and networking). OpenStack Tacker project supports NFVO and VNFM functionality.
	StarlingX	Cloud infrastructure platform optimized for distributed systems and edge computing that integrates OpenStack, Kubernetes® and the Linux kernel. Related to NFVI, VIM, Container Infrastructure Service Management (CISM) and Container Infrastructure Service (CIS) clusters. Manages virtualized and containerized infrastructure resources (compute, storage, and networking) needed for VNFs. NFVO functionality can be provided by ONAP® and OSM.
ETSI	Open-Source Mano (OSM)	Open-source realization of the ETSI NFV-MANO framework. Supports NFVO and VNFM related functionalities. OSM is NFVO with integrated VNFM capabilities. Since release 16, it also supports cloud-native management and orchestration for containerized VNFs.
RedHat	Ansible®	Open-source IT automation engine that automates provisioning, configuration management, application deployment, and orchestration. Supports VNFM related functionalities. Ansible can be used for VNF configuration according to ETSI GR NFV-EVE 022 for both VM-based and container-based deployments.
Linux Foundation / Linux Foundation Networking	Anuket™	NFV infrastructure abstractions through a Reference Model (RM), Reference Architectures (RA) and interactions with the VIM through Nf-Vi.
	Linux kernel	The core component of the Linux operating system managing hardware resources, providing the interfaces between hardware and user-space applications.
	DPDK™	Libraries and drivers for high-performance packet processing, allowing fast user-space packet handling on network interface cards (NICs). Supports NFVI related functionalities.
	Nephio	Automation and orchestration of cloud-native network functions (CNFs) and infrastructure using Kubernetes®. Supports NFVO and VNFM related functionalities.

Host Organization	Project	Description and relationship with NFV-MANO
	ONAP®	Platform for the automation, orchestration, and management of large-scale, complex network services. Supports NFVO-related functionalities. Regarding descriptors, VNF Descriptors (VNFD) and Application Service Descriptors (ASD) are supported.
	O-RAN SC	Software for disaggregated RAN based on the Open RAN architecture specified by the O-RAN Alliance. Related to NFVO, VNFM, VIM and CISM functionalities.
	Sylva	Cloud Layer convergence and Telco-friendly CaaS (CIS Cluster) ETSI GS NFV-SOL018 (K8S control plane) and ETSI GS NFV-SOL 020 (cluster API) are supported to enable a convergent Cloud Layer that supports CaaS layer operations.
	XGVela™	PaaS capabilities tailored for 5G networks. Related to PaaS functionalities according to ETSI GS NFV-IFA049.
CNCF®	eBPF	Sandboxed programs in the Linux kernel without changing kernel source code or loading a kernel module (CISI).
	Cilium™	Project focused on networking and security that provides eBPF-based networking capabilities. Supports functionalities related to Container Infrastructure Service Instance (CISI) networking.
	Cloud Foundry ®	Open-source Platform-as-a-Service (PaaS). Related to PaaS functionalities according to ETSI GS NFV-IFA049.
	Cloud Hypervisor	Virtual Machine Monitor (VMM) for running virtualized workloads. Supports NFVI related functionalities.
	CNI™	Standard for configuring network interfaces in Linux containers. Supports CISI related functionalities.
	Fluentd®	Data collector for unified logging, allowing for the aggregation, filtering, and routing of logs. Supports PaaS related functionalities according to ETSI GS NFV-IFA 049.
	Flux™	Automates the deployment of code updates based on version control to Kubernetes® clusters using GitOps principles (a part of VNFM's functionalities).
	Istio®/Envoy®	A service mesh (Istio) built on Envoy proxy that provides advanced traffic management, security, and observability for microservices. Supports PaaS related functionalities according to ETSI GS NFV-IFA 049.

Host Organization	Project	Description and relationship with NFV-MANO
	Kubernetes®	Orchestration framework automating the deployment, scaling, and management of containerized applications. Supports CISM related functionalities. ETSI NFV MANO supports all the core K8S functionalities (CRI, CNI, CSI, control plane, Helm 3 client and Helm chart, cluster management). CISM operations and interfaces are profiled using K8s API, Helm charts and Docker™ registry (see ETSI GS NFV-SOL 018). CCM operations and interfaces are profiled using the K8S Cluster API (see ETSI GS NFV-SOL 020). Ongoing work in NFV is about incorporating CRDs and operators' management.
	Operator framework™	A set of Kubernetes® tools that facilitate automating the management, scaling, and lifecycle of complex, stateful applications using Kubernetes® operators/controllers (which can be part of functionalities provided by NFVO and VNFM). Support for CRDs and operators is ongoing work in ETSI NFV. See ETSI GS NFV-SOL 024 activities for the specification of PaaS Services (Stage 3).
	Prometheus®	Monitoring and alerting the toolkit. Related to PaaS functionalities according to ETSI GS NFV-IFA 049.
	Tinkerbell	Bare metal provisioning engine. Related to PIM functionalities according to ETSI GS NFV-IFA 053.
DMTF	Redfish® client toolbox	Toolbox for remote clients to perform Redfish tasks: firmware update, read and record events, interacting with devices, executing actions and providing basic query abilities, etc. The toolbox includes the Redfish Tacklebox. The Redfish Tacklebox contains tools to discover Redfish services, get system inventory, reset power, boot override, manage certificates, manage licenses, update firmware, test events, configure manager, and get a sensor list. The Redfish client toolbox can be used to accelerate implementation of some of the PIM services to manage resources by exposing a Redfish interface. Redfish clients have been implemented in various languages (C, Python), and the language support is based on requests. Related to PIM functionalities according to ETSI GS NFV-IFA 053.
	Redfish® service emulators	Two emulators: Interface Emulator and Mockup Server. The Redfish Interface Emulator can emulate a Redfish-based interface statically (GET) or dynamically (POST, PATCH, DELETE); The Redfish Mockup Server is a program that can be placed at the root of any Redfish mockup tree and serves Redfish requests. The Redfish service emulator can be useful for testing PIM implementations without having to purchase a system. Since the emulator can be launched in a Cloud Foundry, multiple Redfish services can be emulated. It is related to PIM functionalities according to ETSI GS NFV-IFA 053.

See ETSI White Paper [Evolving NFV towards the next decade] regarding potential cloud-native implementation choices for telecom network operators.

2. Management & Orchestration of the Telco Cloud with NFV-MANO

2.1 NFV-MANO approach towards cloud-native

ETSI NFV-MANO framework is responsible for the lifecycle management of virtualized and containerized network functions and Network Services (NSs), ensuring that network services can be deployed, configured, scaled, and optimized efficiently within an NFV infrastructure (NFVI).

Managing the lifecycle of VNFs and network services is both crucial and challenging. This is because overseeing a single VNF/CNF instance involves managing multiple components (such as VMs or Pods) as well as the underlying network infrastructure.

Implementing effective maintenance, recovery mechanisms, and continuous optimization and upgrades is vital to ensuring long-term operational sustainability. ETSI NFV-MANO provides an abstraction layer that simplifies these complex dependencies and operations, enabling seamless integration with the OSS.

In ETSI ISG NFV, VNF specifications have been extensively extended to cover containerized deployments and the terms virtualization and cloudification are used interchangeably. In more detail, in ETSI ISG NFV, the term *VNF*, is also used to characterize/describe NFs deployed in VMs but also cloudified NFs deployed in OS containers.

NFV-MANO core features for both VM-based and OS container-based deployments are:

- Automation and orchestration of VNFs deployed in VMs and/or containers.
- Orchestration of network services combining cloud-native VNFs and VM-based VNFs.
- Automation functions (MDAF, Intent Management).
- Functions for the management of container clusters and workloads LCM (CISM, CCM).
- Functions for managing virtual and physical infrastructure resources (VIM, PIM).
- Real-time monitoring and analytics.
- Scalability and flexibility.
- Security and compliance support.

A visual representation of the NFV-MANO architecture and its components is depicted in Figure 2.1-1.

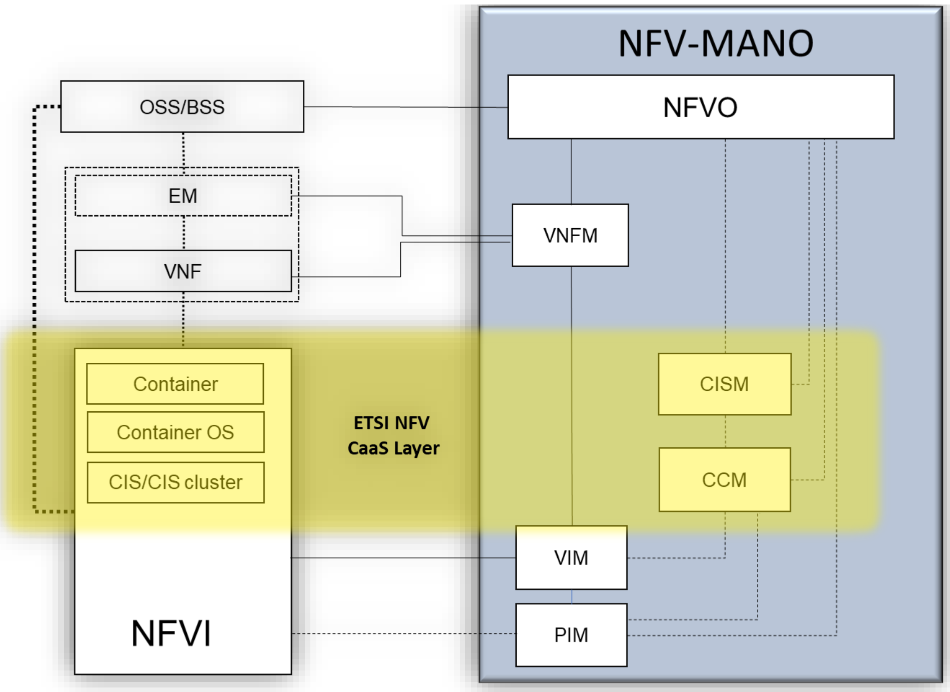

Figure 2.1-1: NFV- MANO architecture according to the developments in Release 4 and beyond (see ETSI GS NFV-006)

To support technology-agnostic operations and management, the enhancements to the NFV-MANO reference architecture introduced logical functions related to Container Cluster Management (CCM) and Container Infrastructure Service Management (CISM). These functions enable the ETSI NFV-MANO framework to manage containerized VNFs, as well as multiple container clusters, and are responsible for the implementation of CaaS layer operations within ETSI NFV.

The flexible management of container clusters allows operators to create the necessary isolation for containerized network functions as required in telecommunications networks. These enhancements provide a smooth evolutionary path for operators' NFV infrastructures, supporting VM- based implementations, VM-based containerized implementations, and bare-metal containerized network functions concurrently.

Moreover, new templates for modeling information have been developed to accommodate container-based deployments and the management of container clusters. New interfaces have been specified for the updated NFV-MANO functions, while existing interfaces have been revised to better support containerized VNFs, while maintaining backward compatibility.

With these updates, ETSI NFV-MANO can seamlessly support CaaS layer operations, aligning with the latest industry trends. ETSI NFV specifications are regularly updated, with new Group Reports and Group Specifications being developed as necessary.

Table 2.1-1 summarizes the latest enhancements in the NFV framework.

Table 2.1-1: New Features in Releases 5 and 6

Feature	Description	Related specification/report
FEAT24	Generic OAM Functions and Telco PaaS	ETSI GS NFV-IFA 049
FEAT27	Virtualization of the RAN	ETSI GR NFV-IFA 046
FEAT29	Green NFV	ETSI GR NFV-EVE 021 and ETSI GS NFV-IFA 027
FEAT33	Physical Infrastructure Management	ETSI GS NFV-IFA 053
FEAT36	New infrastructure resources for NFV	ETSI GR NFV-EVE 023
FEAT37	Latency aspects and new communication technologies for NFV	ETSI GR NFV-EVE 024
FEAT38	Serverless and other application virtualization forms in NFV	ETSI GR NFV-EVE 025
FEAT39	NFV evolution (new NFV-MANO design)	ETSI GR NFV-IFA 054
FEAT40	NFV support for computing and network convergence	ETSI GR NFV-EVE 026
FEAT41	MAAS Model as a Service	ETSI GR NFV-EVE 027

2.2 NFV-MANO added value

For many years now, ETSI ISG NFV has been contributing to the realization of the concept of decoupling telecommunication software from dedicated appliance equipment using deployments exploiting Commercial off the Shelf (COTS) hardware. On the management and orchestration plane, NFV-MANO facilitates dynamic network configuration and automated operations related to VNF and Network Service lifecycle management.

In the telco business a typical telecom network operator is the owner of the whole protocol stack acting both as an infrastructure provider and service provider, while at the same time managing vertically and horizontally all types of services. Substantial efforts have been made by the industry in trying to cope with the complexity of management and orchestration of services and infrastructures.

NOTE: Different business models can apply to Mobile Virtual Network Operators (MVNOs) or operators who use managed services. For MVNOs service, differentiation is based on offering specialized services, while access to the infrastructure is leased from Mobile Network Operators. Different business models are also applicable in case the telecom operator exploits services offered by third parties like hyper-scalers.

ETSI NFV-MANO enhances the effectiveness of management and orchestration practices, ensuring better performance and efficiency. To this end, NFV-MANO:

- provides the mechanisms to support efficient resource allocation and high levels of automation, avoiding over-provisioning or underutilization that can lead to increased CAPEX and OPEX;
- supports multiple OAM tasks that a network operator performs for a wide range of network functions. In the sub-optimal case where NFV-MANO is not used, multiple management systems are needed, each dedicated to specific tasks and parts of the network. In this case, these are typically tailored and coupled with specific elements of the network, leading to vendor lock-ins;
- is used to avoid security vulnerabilities due to misconfigurations and lack of compliance;
- is used to avoid performance degradation, for example, due to a lack of automated scaling and an inability to adapt to varied traffic load conditions;
- can be used to hide the implementation complexity introduced by handling the VNF/CNF/NS LCM, along with resource management through the necessary abstractions, from OSS. If this abstraction layer introduced by NFV-MANO is missing, then all the complexity is introduced to OSS/BSS;
- avoids vendor lock-ins leading to reduced CAPEX and OPEX.

The above analysis urges that the ETSI NFV-MANO framework, with its unique characteristics and the proven ability to perform management and orchestration of telecom networks can serve as the foundation for interoperability in the Telco Cloud business.

The NFV-MANO added value proposition is based on the abstractions used to integrate various open-source solutions or commercial products in a vendor and technology-agnostic way.

The NFV-MANO abstraction can support and enable automation, reduce system integration costs, and ensure long-term stability in operations and maintenance.

Technological aspects:

- **Unified Abstraction Layer:** Hiding the complexity of resource management and VNF/NS lifecycle management (LCM) from OSS/BSS. Enhancing network and communication connectivity to enable seamless integration with SDN.
- **Integration with Open-source**: Integration with systems like OpenStack and Kubernetes® enhancing cloud-native compatibility, enabling the declarative management of VM-based and containerized-based VNFs/NSs.

- **Telco PaaS:** Introduction of standardized PaaS interfaces to support generic OAM functionalities, ensuring consistency across diverse infrastructures, simplifying integration processes and reducing development time.
- **Advanced Automation Functions:** Supporting MDAF and intent management to automate network operations and reduce manual intervention.
- **Standardized Management Interfaces:** Providing standardized interfaces for configuration, fault, and performance management, simplifying monitoring and troubleshooting, enhancing interoperability across multi-vendor solutions, and supporting long-term sustainable operations.

Ecosystem aspects:

- **Extensive Ecosystem Support:** A well-established ecosystem designed to enable and accelerate commercial deployments.
- **High-Quality Standardization:** Providing widely adopted standardization frameworks to ensure reliability, consistency, and alignment with industry's best practices.
- **Collaboration with Open-Source Communities:** A long-term commitment to open-source collaboration, driving continuous innovation and fostering a thriving ecosystem.
- **Coordination with Standards Development Organizations (SDOs):** Active engagement with established SDOs to align with global standards and enhance interoperability across solutions.
- **Efficient Standardized Procedures:** Proven to reduce both CAPEX and OPEX through the implementation of streamlined and standardized operational procedures.

Figures 2.2-1 and 2.2-2 provide a market overview from telecom operators, industry experts and open-source communities on how NFV-MANO is used and how it has improved their network operations. The results are based on an online survey conducted between July and September 2021, with a total of 28 responders.

While functionalities related to network resource allocation, VNF upgrade, and VNF healing are also widely used in real deployments, the most used NFV-MANO functionality is related to instantiation and initial configuration.

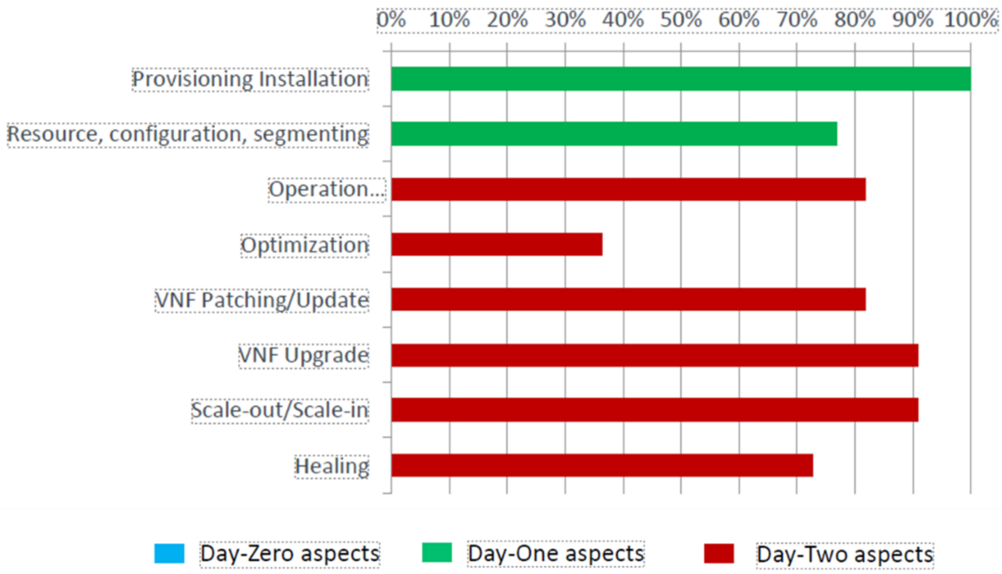

Figure 2.2-1: What functionalities are provided by manufacturers

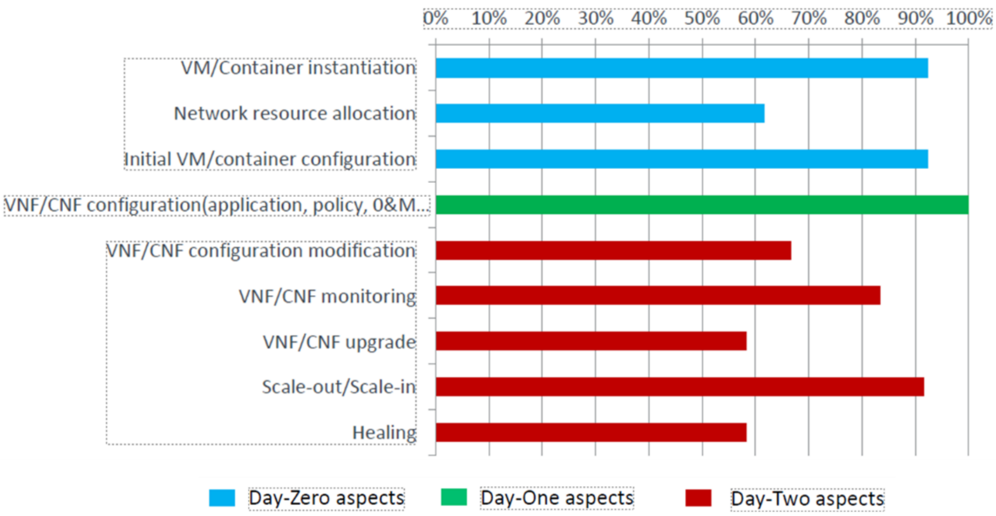

Figure 2.2-2: What functionalities are used by network operators

Figure 2.2-3 summarizes the reporting across different dimensions in terms of business benefits. As shown, the results exceed expectations in areas such as avoiding vendor lock-in, enabling fast service failover, and accelerating service deployment.

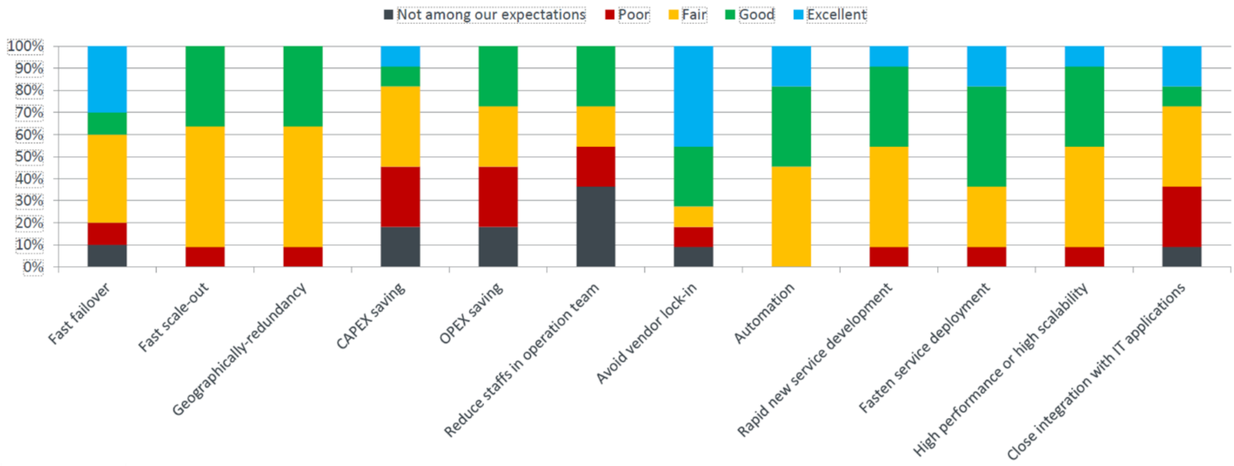

Figure 2.2-3: NFV-MANO business benefits in practice

3. Management of Cloud-native Telco systems: Challenges and available NFV-MANO mechanisms

Despite the substantial ongoing efforts by ETSI ISG NFV, other standards development organizations, open-source communities, and telecom equipment vendors to fully realize the potential of adopting the cloud-native design paradigm within the telecommunications industry; several challenges still remain.

Table 3-1 summarizes these challenges together with the NFV-MANO available mechanisms to address them.

The challenges outlined in Table 3-1 underscore the urgent need for standardization to address interoperability issues and prevent the fragmentation of solutions.

Table 3-1: Challenges and available NFV-MANO mechanisms

	Challenge Description	Available NFV-MANO mechanisms
Challenge#1 **Preventing orchestration chaos**	As RAN virtualization concepts and related standardization work have advanced to a more refined and developed stage (e.g., O-RAN Alliance ongoing activities), the coupling between OSS and orchestration frameworks like SMO, ETSI NFV-MANO (i.e., NFVO/VNFM), and open-source solutions like Nephio is rather fuzzy and requires a deep multi-faceted analysis. In addition, open-source solutions provide varying levels of modularity and extensibility.	NFV MANO provides an abstraction layer for OSS/BSS. It handles tasks such as resource management, satisfying complex affinity and anti-affinity requirements, management of VNFs networks, and overseeing cloudified VNFs and Network Service lifecycle management (LCM). By doing so, NFV MANO offloads OSS/BSS from unnecessary complexities. Furthermore, NFV-MANO can be used to support management and orchestration operations for both the cloudified Core and the cloudified RAN. Although NFV-MANO cannot fully cover all the aspects considered by the O-RAN Alliance for the virtualization of RAN, compatibility of NFV-MANO with the O-RAN SMO has been investigated in ETSI GR NFV-IFA 046.
Challenge#2: **End-to-end automation**	End-to-end automation will have a profound and lasting influence on mobile network operations. Nevertheless, high levels of maturity in production can be easily disputed. For example, automation boundaries are not well defined, like also the distinction between control plane and management plane automation operations is becoming increasingly blurred.	NFV-MANO cannot fully address End-to-end automation, nevertheless several mechanisms are available and could be exploited as part of an integrated solution. The ETSI NFV automation framework currently supports: - Management Data Analytics (ETSI GS NFV-IFA 047/ETSI GS NFV-SOL 025) - Intent Management (ETSI GS NFV-IFA 050/SOL currently started stage 3) - Model as a Service (MaaS) (ETSI GR NFV-EVE 027) - Policy management (ETSI GS NFV-IFA 013/ETSI GS NFV-IFA 048/ ETSI GS NFV-SOL 012)

	Challenge Description	Available NFV-MANO mechanisms
Challenge#3 **Full automation and potential vendor lock-ins**	Full automation refers to reducing at the minimum manual intervention throughout the entire lifecycle of cloud-based infrastructure and services. Full automation may lead to potential vendor lock-ins. For example, standardization work is progressing fast regarding the specification of the interfaces exposed by Intent Management functions. However, there is no discussion on how an Intent Management function is able to satisfy an Intent, leading to potential new "black-boxes", where the operator can apply no level of control. The same problem exists in the case of closed-control loops.	In case an Intent Management function is using NFV-MANO services to support VNF/NS LCM and resource management related operations, standardized interfaces and processes inside NFV-MANO are used thus avoiding potential vendor lock-ins. How Intent Management functions can use NFV-MANO interfaces and mechanisms is an open issue.
Challenge#4: **Performance and Fault Management**	As the scale of Telco Cloud infrastructures becomes bigger and more heterogeneous maintenance and upgrade procedures become increasingly prolonged and complex; end-to-end performance and faults management are not trivial and complex dynamic allocation of resources is needed to guarantee performance.	ETSI GS NFV-IFA 027 is about performance measurements specification in NFV and ETSI GS NFV-IFA 045 is about Faults and alarms modelling specification in NFV. In both cases there have been a generalization and decoupling of the performance measurements, faults and alarms from producers, and instead have been associated with the actual measured object types. This improved the specifications for reusability within the ETSI NFV-MANO framework (as it evolves) and for potential referencing and/or reuse by other organizations. From the OSS/BSS point of view complex operations related to resource management and performance are hidden because of the necessary abstractions offered by NFV-MANO. Which resource allocation mechanisms are in effect to guarantee performance, is out of scope of NFV-MANO specification work.

	Challenge Description	Available NFV-MANO mechanisms
Challenge#5: **Network connectivity complexity**	Indisputably a compelling new endeavor is the inclusion of the RAN in the Telco Cloud. One of the key compulsory issues however still to address is the control and management of the network connectivity part, where both underlay and overlay network management dimensions need to be considered in an end-to-end fashion. Moreover, interactions between the cloudified RAN part through gateway systems and the transport network have not yet been investigated well. Network demarcation points between the RAN cloud network part and the transport network are still not well defined in a standardized way.	In NFV-MANO on the network level different abstractions (e.g., Connection Points (CPs), Virtual Links (VLs) and Multisite Connectivity Service (MSCS)) are used to enable connectivity between VNFs and other entities residing in the same or different NFVI-PoPs. On the NFVI-PoP gateway side, different options can be supported regarding the network demarcation between the NFVI side and the Transport network side. See ETSI GS NFV-SOL 005. See ETSI GR NFV-IFA 046 for an analysis of the case of the virtualized RAN, when an NFV-MANO management solution is considered to support O-Cloud network related operations.
Challenge#6: **System integration complexity**	Overall evolution of telecom architectures together with Telco cloud operations towards being cloud-native is dramatically increasing the integration complexity and consequently CAPEX and OPEX. The reason is that multiple open-source solutions, inevitable customizations on top of standard and non-standard solutions and proprietary solutions need to harmonically work together to support the end-to-end business. The same issues can be articulated when it comes to the case of end-to-end testing.	In real deployments, lack of compliance with standardized solutions for the sake of having functional systems fast, leads to increased system complexity, concealing the danger of unviable and unsustainable business. NFV-MANO's abstraction layer eases integration by hiding complexities of the underlying systems and infrastructures. NFV-MANO provides standardized interfaces that allow Network Service and VNF LCM and resource management to be solved in an agnostic way.

	Challenge Description	Available NFV-MANO mechanisms
Challenge#7: **Operation in hybrid clouds**	Due to the indisputable merits of migrating mobile network operations to hyper-scalers, many operators' deployments have already considered or are now moving to hybrid cloud solutions. Defining the management scopes of the NFV-MANO and the cloud service provider management systems need to be delineated. Furthermore, interactions and modelling between NFV-MANO and the cloud service provider systems can vary between operators regarding the interfaces and specific APIs used, while different approaches can be considered regarding the descriptors used. Additional challenges are related to the management of the telco cloud network since hyper-scaler systems are not optimized to satisfy the strict requirements set by mobile network operators (e.g., for the fronthaul network and more generally the Xhaul network).	ETSI GR NFV-EVE 023 studies possible extensions and evolution of the NFVI. Considerations include new locations for infrastructure resources, new types of infrastructure resources (e.g., SmartNICs) and new sources of infrastructure resources (e.g., Cloud hyper-scalers) adding more heterogeneity are becoming prominent for the development of the Telco Cloud. Additional standardization work in stage 2 and stage 3 is expected based on the findings of ETSI GR NFV-EVE 023.
Challenge#8: **Need for identification of the role of Telco PaaS**	Telco PaaS can be used to reduce integration costs and improve operational efficiency by enabling integrated OAM and infrastructure management. The demarcation point, however, between Telco PaaS and Telco IaaS services is difficult to be defined and ratified. Furthermore, the role of Telco PaaS Services in VNF LCM or even NS LCM cannot be precluded.	ETSI GR NFV-EVE 019 (stage 1), ETSI GS NFV-IFA 049 (stage 2) and ETSI GS NFV-SOL 024 (stage 3) define the NFV PaaS framework. The NFV PaaS was initially designed to accommodate several VNF generic OAM functions, however the concept has been extended and operations related for example to Configuration Servers and VNF Policy management are also accommodated as generic Telco PaaS services. The open-source solutions profiled in ETSI GS NFV-SOL 024, such as Prometheus, are widely adopted in the industry. Additional standardization work is expected on the way NFV-MANO can exploit a Telco PaaS layer.

	Challenge Description	Available NFV-MANO mechanisms
Challenge#9: **Towards a Green Telco cloud**	There is an increase in the development of infrastructure software components aimed at reducing and optimizing resource usage for Telco Clouds. Nevertheless, due to the stochastics related to the resource usage, big deviations from the actual energy consumption make it extremely difficult to precisely control jointly the different power states of NFVI components and the power states of VNFs/VNFCs to minimize energy consumption without sacrificing performance.	NFV feature on “Green NFV” analyzes aspects of NFV (VNF design, NFV-MANO and VNF operation, deployment configuration of NFV-MANO, NFVI, etc.) that have an impact on energy consumption and those that can enable smart energy NFV and power saving features. Power consumption of physical equipment (chassis, compute server, network devices, storage etc.) can be exposed through standardized interfaces (e.g., DMTF DSP2046), while power consumption of virtualized/cloudified elements can also be available according to ETSI GS NFV IFA 027. Nevertheless, in the former case the measurements refer to actual consumption, while in the latter case to estimations based on available models. ETSI GR NFV-EVE 021 documents potential solutions and provides recommendations for enhancements to the NFV architectural framework and its functionality to address energy efficiency objectives.

	Challenge Description	Available NFV-MANO mechanisms
Challenge#10: **Standardization and open-source interoperability**	While several open-source projects have emerged trying to address specific aspects towards building a true cloud-native ecosystem for the telecom business, the inherent extreme complexity requires additional means to address discrepancies between telco cloud management frameworks. Industry trends like fully automated Telco cloud operations, support for hybrid cloud infrastructures, Intent driven management and Energy efficient network operations urge for stipulated certain conditions regarding management and orchestration. Nevertheless, from a telecom operator perspective, historically massive use of new techniques and technologies without considering standardized interfaces and methodologies leads to lack of interoperability and unsolvable impediments towards maintaining a sustainable business. Improvisations and the "quick-hack" software extension approach can easily create interoperability risks and unsolvable issues for the future maintenance and evolution of the mobile network.	Since the very beginning, ETSI NFV anticipated close collaboration with open-source communities towards building the foundation for interoperability in the Telco cloud business. A standardized NFV-MANO-based approach helps to ensure consistency and scalability on a global level. Open-source solutions are unable to solve specific problems, such as interoperability across diverse ecosystems and compliance with legal requirements.
Challenge#11: **New Business models are needed**	Telecom business has been accused in the past of being conservative and not open to changes. This is rather a fallacy, since for example radically new ideas like the concept of NFV originate and have been applied to telecom business operations creating a paradigm shift. Moving on with the adoption of cloud-native deployments, it is expected that the lifetime of services will be too short. Thus, MNOs want shorter development and R&D time, directly impacting the business models of telecom operators.	Depending on the scale operators might need to change their existing ways of mobile network development and operation towards being cloud native. Management and orchestration of the Telco Cloud based on an evolution of the existing NFV-MANO framework is investigated in ETSI GR NFV-IFA 054.

	Challenge Description	Available NFV-MANO mechanisms
Challenge#12: **Automated certificate management**	Within the Telcom ecosystem the need for deployment of X.509 certificates for server and client authentication is increasing as management and control plane protocols shift to more standardized (e.g., RESTful) APIs. The architecture becoming more disaggregated and the rise of the cloud continuum drives the requirement for the existence of a parallel trust continuum. With the ever-increasing complexity of Telecom networks and the drive for Zero Trust, the need for and importance of trust bootstrapping management of certificates becomes a challenge.	ETSI GR NFV-SEC 005 examined the various aspects of certificate management and suggested several methods by which certificate automation could be achieved. One of the cornerstones of certificate management is the need for a standard identity framework which is being covered by ETSI GS NFV-SEC 020. ETSI GS NFV-IFA 026, ETSI GS NFV-IFA 033 (stage 2) and ETSI GS NFV-SOL 023 (stage 3) standardize the interfaces, reference points and API for certificate automation in NFV.
Challenge#13: **Security of AI/ML models**	The use of Artificial Intelligence and Machine Learning within Telecom Networks, core, edge and connected devices (e.g., smartphones, cars, IoT, etc.) will pose a challenge to security not only of the data being fed into the models and algorithms but also of the models themselves.	As the use of AI/ML grows, regulations and Governmental requirements are being drafted as well as standards being developed by the likes of ETSI TC SAI. ETSI GS NFV-EVE 027 examines Model as a Service (MaaS) within the NFV architecture.
Challenge#14: **Acceleration management**	The introduction of new acceleration technologies has posed additional challenges to the management plane. The absence of standards for containerized deployments makes operations related to acceleration system upgrades, fault management, and performance management exceedingly difficult, particularly with regard to interoperability.	The ETSI NFV acceleration abstraction framework is specified in ETSI GS NFV-IFA 002. Acceleration management aspects are in ETSI GS NFV-IFA 004 and ETSI GS NFV-IFA 019. Management of physical infrastructure is available in ETSI GS NFV-IFA 053.
Challenge#15: **End-to-end Security**	In the case of heterogenous infrastructures different security strategies can be supported, leading to increased complexity. In addition, when incorporating automation functions and new technology additional security risks can be introduced in infrastructure, VNF and NS, and operation and management.	End-to-end security has been and continues to be considered within ETSI NFV such as secure end-to-end VNF and NS management, isolation and trust domain, certificate management and AI/ML security challenge. See also challenges #12 and #13

4. Conclusion

The core functionalities expected by a Telco Cloud management and orchestration system are supported by NFV-MANO, while it is anticipated that planned enhancements will further expand the capabilities of the framework and are planned to be developed by the ETSI ISG NFV. For example, capabilities related to operations in hybrid clouds, support for end-to-end energy efficiency, automated and intelligent zero touch management, together with the primary value propositions of NFV-MANO can bring indisputable merits for building a stable and sustainable Telco Cloud business.

It is also important to recognize that open source plays a vital role in the telecom ecosystem, being present in every layer of the stack. Standards organizations, like ETSI, have been monitoring and on occasions working with relevant communities. To ensure that open-source projects can build on the requirements and feedback of their users, readers are encouraged to participate and invest in these projects.

Readers are encouraged to explore the latest version of the NFV-MANO architecture and investigate the new activities related to its evolution towards a fully cloud-native and fully automated management and orchestration approach. Stakeholders are encouraged to participate in ETSI ISG NFV activities and contribute to the development of standards related to Telco cloud management and orchestration.

5. Appendix

5.1 Sources of information

- ETSI ISG NFV: https://www.etsi.org/technologies/nfv
- Published deliverables: https://docbox.etsi.org/ISG/NFV/Open/Publications_pdf/Specs-Reports
- Draft deliverables: https://docbox.etsi.org/ISG/NFV/Open/Drafts
- Feature tracking: https://nfvwiki.etsi.org/index.php?title=Feature_Tracking
- White Paper "Evolving NFV towards the next decade"
  https://www.etsi.org/images/files/ETSIWhitePapers/ETSI-WP-54-Evolving_NFV_towards_the_next_decade.pdf
- White Paper "In the Light of Ten Years from the NFV Introductory Whitepaper"
  https://www.etsi.org/images/files/ETSIWhitePapers/ETSI-WP-53-In-the-Light-of-Ten-ears-from-the-NFV-Introductory-Whitepaper.pdf
- White Paper "MEC_support_towards_Edge_native"
  https://www.etsi.org/images/files/ETSIWhitePapers/ETSI-WP55-MEC_support_towards_Edge_native.pdf
- White Paper "Unlocking-Digital-Transformation-with-Autonomous-Networks"
  https://www.etsi.org/images/files/ETSIWhitePapers/ETSI-WP56_Unlocking-Digital-Transformation-with-Autonomous-Networks.pdf
- White Paper "Vision_for_Telecommunications"
  https://www.etsi.org/images/files/ETSIWhitePapers/ETSI-WP-62-Vision_for_Telecommunications.pdf

NFV Releases Descriptions:

- NFV Release 3 (v3.7.1):
  https://www.etsi.org/deliver/etsi_gr/NFV/001_099/007/03.07.01_60/gr_NFV007v030701p.pdf
- NFV Release 4 (v4.5.1):
  https://www.etsi.org/deliver/etsi_gr/NFV/001_099/007/04.05.01_60/gr_NFV007v040501p.pdf
- NFV Release 5 (v5.1.1)
  https://www.etsi.org/deliver/etsi_gr/NFV/001_099/007/05.01.01_60/gr_nfv007v050101p.pdf

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