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Input paper on Potential Regulatory Implications of Software-Defined Networking and Network Functions Virtualisation

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Executive Summary

In recent years the electronic communications sector (together with the IT sector) has been working very intensely on two new fundamental technological developments: Software-Defined Networking (SDN) and Network Functions Virtualisation (NFV). Both aim to transform the way that network operators design and operate networks. In order to support NRA to cope with the possible regulatory challenges related to these new technological developments appropriately and to respond to the request of the European Commission for a BEREC opinion on the review of the regulatory framework with regard to SDN and NFV, this document has the following two objectives. Firstly, it aims to identify potential regulatory implications of SDN and NFV. Secondly, it aims to answer the questions of the request of the European Commission and to identify which adaptations of the regulatory framework are needed.

SDN is a new architecture where network control is logically centralized (decoupling of control and data planes), directly programmable and the underlying network infrastructure is abstracted from the applications. NFV transforms network architectures by evolving standard IT virtualisation technology to consolidate a large and increasing variety of purpose-built hardware appliances used in the networks today onto industry standard high volume servers, storage and switches and implements network functions in software. SDN and NFV are highly complementary and ultimately will become less distinguishable as independent topics, being subsumed into a unified software-based networking paradigm.

To date SDN and NFV are still in their early days of development and deployment and far away from realising their full potential. Therefore, today it is rather unclear whether and to what extent the potential, that SDN and NFV have, will actually be realised.

The following regulatory impacts of SDN and NFV are analysed:

- Access to passive network infrastructure: In networks based on SDN and NFV, passive network infrastructure is used in the same way as in the networks of today. Therefore, SDN and NFV do not have any impact on the access to passive network infrastructure.

- Fixed network access: SDN and NFV have the potential to enable new forms of fixed network access which provide alternative network operators with more control over the network of the incumbent compared to current Layer 2 wholesale access products (e.g. VULA). However, today this is not the case and it needs to be seen whether SDN and NFV will be developed further in order to enable such new forms of fixed network access.

- Mobile virtual networks and sharing of network elements: SDN and NFV have the potential to enable new forms of mobile virtual networks and sharing of network elements (e.g. mobile base stations). Whether and which new forms of mobile network sharing and sharing of network elements will actually be enabled by SDN and NFV will be shown by the outcome of the further development of SDN and NFV.

- Calculation of network costs: Benefits of networks based on SDN and NFV are reduced network equipment costs and operational costs. Therefore, in the future it may be necessary to update cost models used for the calculation of network costs.

- Current value chains: SDN and NFV enable new types of services and have the potential to change current value chains. However, today it is too early to determine the impact that the changes of the value chains will have on the consumer, industry, regulation and the networking ecosystem.

This analysis and the current state of development of SDN and NFV result in the following consequences for the review of the regulatory framework. The new regulatory framework needs to be flexible enough to cope with the dynamic development of SDN and NFV and the uncertainty of the outcome of this development. Furthermore the new regulatory framework must ensure that NRA will be able to respond to this dynamic development of SDN and NFV appropriately.

1 Introduction and objective

In recent years the electronic communications sector (together with the IT sector) has been working very intensely on two new fundamental technological developments: Software-Defined Networking (SDN) and Network Functions Virtualisation (NFV). Both aim to transform the way that network operators design and operate networks. In order to support NRA to cope with the possible regulatory challenges related to these new technological developments appropriately and to respond to the request of the European Commission for a BEREC opinion on the review of the regulatory framework with regard to SDN and NFV, this document has the following two objectives. Firstly, it aims to identify potential regulatory implications of SDN and NFV. Secondly, it aims to answer the questions[1] of the request of the European Commission and to identify which adaptations of the regulatory framework are needed.

This document first gives an overview of what SDN and NFV is (see section 2) and on the current state of development of SDN and NFV (see section 3). Then regulatory implications of SDN and NFV are analysed (see section 4) and the requirements the revised regulatory framework needs to fulfil are discussed (see section 5).

2 What is SDN and NFV?

SDN and NFV aim to transform the way that network operators design and operate networks.[2] In the view of Arthur D. Little and Bell Labs, SDN and NFV could be as significant as the introduction of IP networks themselves.[3] It is expected that also future 5G mobile networks will heavily rely on SDN and NFV.[4]

NFV transforms network architectures by evolving standard IT virtualisation technology to consolidate a large and increasing variety of purpose-built hardware appliances used in the networks today onto industry standard high volume servers, storage and switches and implements network functions in software (see Figure 1). NFV transforms network operations because the software can dynamically be moved to, or instantiated in, various locations in the network as required, without the need for installation of new equipment.[5]

SDN is a new architecture where network control is logically centralized (decoupling of control and data planes), directly programmable and the underlying network infrastructure is abstracted from the applications (see Annex 1).[6]

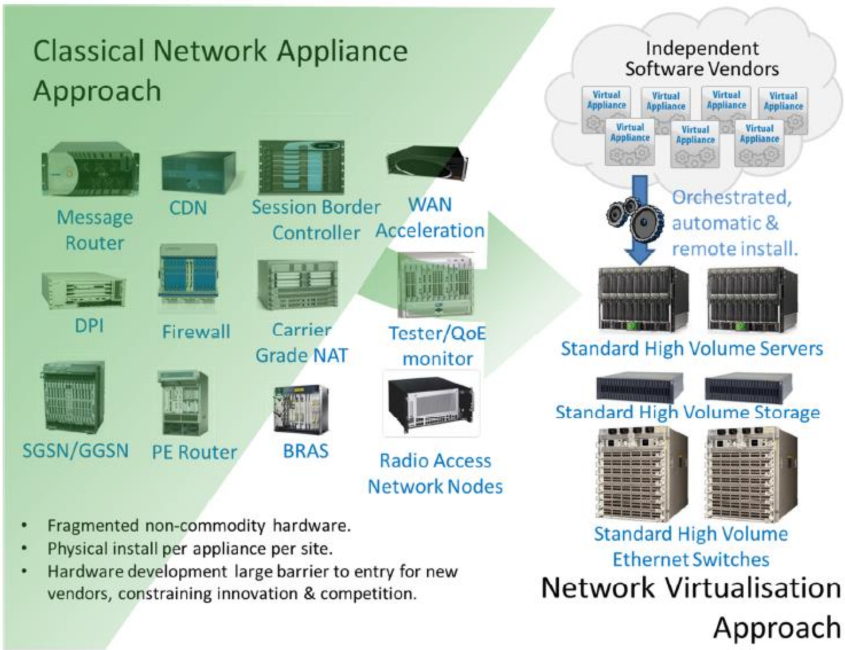
SDN and NFV are highly complementary but not dependent on each other.[7] Ultimately, NFV and SDN will become less distinguishable as independent topics, being subsumed into a unified software-based networking paradigm.[8] Many possibilities exist for how to combine SDN

[1] These questions are (see Annex 2, II. d 4 of the request of the European Commission): Is the emergence of the network virtualization phenomenon combined with the emergence of new network platforms likely to impact the demand for regulated wholesale access and interconnection products under the relevant timeframe of this Review? What regulatory adaptations are needed to cope with future needs in that area?
[2] SDN and NFV are also possible in cable networks (see e.g. CableLabs 2016).
[3] Arthur D. Little, Bell Labs (2015), p. 3.
[4] 5G-PPP (2015), p. 4.
[5] NO ETSI ISG (2012, 2013, 2014).
[6] ONF (2012, 2014).
[7] NO ETSI (2012), p. 5.
[8] NO ETSI (2014) p. 16.

and NFV and it needs to be seen which combination(s) will actually be implemented in networks (compare section 3).[9]

The benefits of SDN/NFV are seen in:[10]

- carriers gain unprecedented programmability, automation, and network control, enabling them to build highly scalable, flexible networks that readily adapt to changing business needs;
- reduced equipment costs (CAPEX) and reduced operational costs (OPEX);
- rapid innovation;
- much more efficient test and integration;
- targeted service introduction based on geography or customer sets;
- enabling a wide variety of eco-systems and encouraging openness;
- optimizing network configuration and/or topology in near real time;
- supporting multi-tenancy;[11]
- improved operational efficiency and
- reduced network specific investments (reduced risk of sunk costs).



Source: NO ETSI NFV ISG (2012), p.5

Figure 1: Vision for NFV

An overview on the SDN architecture and the high-level NFV framework is given in Annex 1 and Annex 2 and an overview of a possible future architecture of the carrier network enabled by SDN and NFV in Annex 3.

[9] See e.g. ETSI (2015), ONF (2014) p.9.
[10] NO ETSI NFV ISG (2012), p. 8, ONF (2012), p. 2, Athur D. Little, Bell Labs (2015).
[11] Thereby allowing network operators to provide tailored services and connectivity for multiple users, applications or internal systems or other network operators, all co-existing on the same hardware with appropriate secure separation of administrative domains.

3 Current state of development of SDN and NFV

SDN and NFV aim to transform how network operators design and operate networks. However, to date SDN and NFV are still in their early days of development and deployment and far away from realising their full potential.[12] Therefore, today there is no common view on solutions based on SDN and NFV that will be offered in the future. Future networks based on SDN and NFV depend, on the one hand, on the interests and objectives of the involved network operators, vendors and other partner organisations which together develop SDN and NFV and, on the other hand, what solutions they can find and are seen as appropriate by them. Today this is not foreseeable. As a consequence today it is rather unclear whether and to what extent the potential, that SDN and NFV have, will actually be realized.

In the current initial stage, when everything is new, the development of SDN and NFV focuses on the use of SDN and NFV within the domain of one single network operator (not across multiple network operator domains), which helps to avoid too much complexity in this initial phase of development. Furthermore a single network operator approach is clearly in the interest of network operators which demand and deploy SDN and NFV.

The development of SDN and NFV is very dynamic and differs from the development of the technologies used in networks today, which are typically based on standards developed by standard development organisations. In contrast to this, SDN and NFV are very strongly developed in a large variety of open source projects and today there is uncertainty on what role traditional standard development approaches will play in the future and whether they may be superseded by developments in open source communities.[13] A need is seen in integration of the activities of open source projects (e.g. OPNFV).[14]

4 Regulatory implications of SDN and NFV

This section analyses the following regulatory impacts of SDN and NFV:

- access to passive network infrastructure;
- fixed network access;
- mobile virtual networks and sharing of network elements;
- calculation of network costs and
- current value chains.

4.1 Access to passive network infrastructure

SDN and NFV virtualize network infrastructure enabling new forms of managing networks but do not create new passive network infrastructure.[15] In networks based on SDN and NFV, passive network infrastructure is used in the same way as in the networks of today. Therefore, SDN and NFV do not have any impact on the access to passive network infrastructure however they are, in principle, applicable to all networks regardless of the passive network infrastructure (e.g. optical fibre, twisted copper pair, coax cable) on which they are built upon.

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[12] BEREC (2016), Athur D. Little, Bell Labs (2015), p. 9.
[13] See ETSI NFV ISG (2016), p. 9. For an overview on open source projects for network access see e.g. MEF (2016), p. 12, Hewlett Packard (2016), p. 27.
[14] See BEREC (2016).
[15] Below Layer 1 of the OSI reference model.

4.2 Fixed network access

SDN and NFV have the potential to enable new forms of fixed network access which provide alternative network operators (ANO) with more control over the network of the incumbent compared to current Layer 2 wholesale access products (e.g. VULA).[14] The virtualization of fixed network access might also enable new forms of access to individual end users which are connected to a network which does not support unbundling of individual subscriber access lines (e.g. cable network).[16]

Today new forms of fixed network access which provide ANO with more control over the network of the incumbent compared to current Layer 2 wholesale access products are not available. In order to enable such new forms of fixed network access, SDN and NFV with multi-tenancy capabilities, which enable several parties to control the same physical network, need to be developed, which increases the complexity of SDN and NFV significantly. A further development of the ETSI NFV Architectural Framework may be necessary, because today it does not explicitly identify an inter-provider interface or reference point.[17] Several (at least) potential difficult further issues need to be resolved (e.g. security, trust models, SLA measurement and enforcement, fault detection) in order to enable such multi-tenancy capabilities.[18]

In order to foster the development of SDN and NFV which provide third-parties with more control over the network of the incumbent compared to current Layer 2 wholesale access products, interested parties (i.e. ANO) need to coordinate their interest and participate actively in the development and standardization of SDN and NFV. The uncertainty on what role traditional standard development approaches will play in the future and whether they may be superseded by developments in open source communities and the large variety of open source projects that exists (see section 3) makes it difficult for ANO to engage themselves in the development of SDN and NFV. Furthermore, access to physical network infrastructure may be preferred by ANO to such new forms of active access products based on SDN and NFV, which may reduce their willingness to participate in development processes of such active access products. Last but not least, it is likely that incumbent network operators which are also involved in the development of SDN and NFV (and probably much stronger) will be reluctant to develop or support such solutions.

Therefore, it needs to be seen whether SDN and NFV, which enable fixed network access which provides ANO with more control over the network of the incumbent compared to current Layer 2 wholesale access products, will actually be developed. If this is the case, then it is likely that such solutions will only be implemented in the network of the incumbent/SMP operator, if imposed by regulatory decisions. Such decisions need to balance the benefit for ANO and end users with the additional costs of the imposed measure for the incumbent/SMP operator.

[16] In networks which do not support individual subscriber access, it is not possible to obtain physically unbundled access on a per subscriber level.
[17] ETSI NFV ISG (2016), p. 9.
[18] See Telefonica (2016), p. 9.

4.3 Mobile virtual networks and sharing of network elements

SDN and NFV have the potential to enable new forms of mobile virtual networks and sharing of network elements (e.g. mobile base stations).[14]

Networks based on SDN and NFV consist of different layers and in principle it is possible that different layers are provided by different network operators.[19] If an operator of an underlying layer offer this layer as a service to other operators then these operators can build upon this layer their own network without the need to own the infrastructure of the underlying layer. At the level of network elements this leads to sharing of network elements; at the level of mobile networks this leads to new forms of mobile virtual networks. For example if one operator provides the physical infrastructure (NFVI) of a common base band unit then other network operators can build on this their own e.g. 2G, 3G and WiFi radio access technology (VNF) and share this underlying physical infrastructure (NFVI).[20]

Whether and which new forms of mobile network sharing and sharing of network elements will actually be enabled by SDN and NFV will be shown by the outcome of the development of SDN and NFV depending on the interest of mobile network operators.

4.4 Calculation of network costs

A benefit of networks based on SDN and NFV is reduced network equipment costs due to the use of industry standard hardware resources (server, storage, switch) instead of a variety of purpose built hardware resources and reduced operational costs[21] due to a new dimension of programmability, automation and network control and also reduced power consumption (see section 2).

The availability or introduction of SDN and NFV in the networks of the network operators will have an impact on the calculation of network costs on which the price regulation is based on. Therefore, in the future it may be necessary to update cost models used for the calculation of network costs or even to develop or purchase new cost models. Examples of cost models which are potentially concerned are bottom-up cost models for the calculation of fixed and mobile termination rates.[22]

4.5 Current value chains

SDN and NFV enable new types of services and have the potential to change current value chains.[14]

In networks based on SDN and NFV the virtualized physical network infrastructure, the so-called NFV infrastructure, can be offered as a service to third parties (NFVIaaS).[23] This enables third parties to use (but not control) the NFV infrastructure similar to (cloud) infrastructure as a service (IaaS) in the area of cloud computing which enables third parties to use the cloud

[19] See Figure 3 and Figure 4 in the annex.
[20] For virtualization of mobile base stations see ETSI (2013), p. 33-36. For an explanation of the terms NFV infrastructure (NFVI) and virtualized network functions (VNF) see Annex 2 and Figure 3.
[21] Including also lower maintenance costs
[22] The termination rates (based on Pure LRIC) are based on the total network costs (two calculations, one with and the other without the termination traffic). Therefore in the future probably cost models are needed which enable to calculate the total costs of networks based on SDN and NFV.
[23] See Annex 2 and Figure 4.

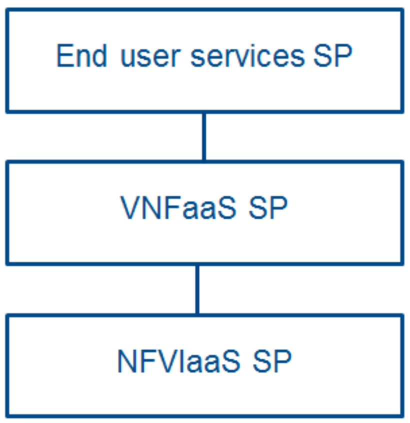
infrastructure and deploy and run arbitrary software (incl. operating systems and applications) but not manage and control the underlying cloud infrastructure.[24]

In networks based on SDN and NFV network functions are implemented in software and the software implementation of a network function, the so-called virtualized network function (VNF) can also be offered as a service to third parties (VNFaaS). This enables third parties to consume this service (but not to manage and control the NFVI and VNF) similar to (cloud) software as a service (SaaS) in the area of cloud computing which enables third parties to use applications running on a cloud infrastructure but not to manage and control the underlying cloud infrastructure.[25]

These new types of services can change current value chains. For example, a service provider (SP) may offer services to end users based on VNFaaS by other operators and the VNF offered by these operators may be based on NFVIaaS by further third parties (see Figure 2). Furthermore, it is possible that a SP which offers services to end users implements and operates VNF and NFVI in its own network and only consumes VNFaaS for some VNFs and NFVIaaS only for some locations. In the end this could result in more complex value chains.[26]

It is also possible that services may be offered by new parties as vendors or even end users (e.g. enterprises). SDN and NFV are not inherently restricted to communications service providers as indeed the basic technology is largely adopted from the IT industry. The lines between networks based on SDN and NFV and the OTT cloud may be blurring. This may raise issues e.g. about the regulatory status of providers of new services in the value chain.

New forms of fixed network access as discussed in section 4.2 also have an impact on value chains. However the current approach particularly of incumbents is to have all roles vertically integrated inside the network operator to allow for more flexibility and cost savings. While extended third-party control over the infrastructure is considered theoretically possible, it needs to be seen whether it will actually be offered by network operators.



Source: BEREC (based on ETSI (2013), p.10 et seqq., Hewlett Packard, p. 21)

Figure 2: Example of possible impact of SDN and NFV on current value chains

The impact that SDN and NFV will have on current value chains depend on the interest of all involved parties who will offer these new services (e.g. NFVI as a service, VNF as a service),

[24] See ETSI (2013), p.10-15, NIST (2012), p.2-2.
[25] See ETSI (2013), p.15-20, NIST (2012), p.2-1.
[26] See Hewlett Packard (2016), p. 21.

the acceptance of all who should consume these services as well as on the economically efficiency and technical feasibility of the resulting new value chains. This is today, of course, widely unknown. Therefore it is too early to determine the impact that the changes of the value chains will have on the consumer, industry, regulation and the networking ecosystem.

5 Adaptations of the regulatory framework

SDN and NFV aim to transform how network operators design and operate networks. However, to date SDN and NFV are still in their early days of development and deployment and far away from realising their full potential. Today it is rather unclear whether and to what extent the potential, that SDN and NFV have, will actually be realised (see section 3). This results in the following consequences for the review of the regulatory framework. The new regulatory framework needs to be flexible enough to cope with the dynamic development of SDN and NFV and the uncertainty of the outcome of this development. Furthermore the new regulatory framework must ensure that NRA will be able to respond to this dynamic development of SDN and NFV appropriately.

For example, the Access Directive needs to be flexible enough in order to ensure that NRA are able to impose in the future new forms of fixed network access based on SDN and NFV on SMP operators if appropriate (see section 4.2). Especially, if the revised regulatory framework defines characteristics which have to be fulfilled by access products (as it was foreseen in the proposed Single Telecom Market[27]) then care needs to be taken in order to ensure that such a definition does not exclude fixed access products based on SDN and NFV.

Furthermore the European Commission has also the possibility to foster the development of SDN and NFV in a direction which is desirable from a regulatory perspective e.g. with a mandate to ETSI or a focus in research programs of the European Commission which aim at the development of SDN and NFV with multi-tenancy capabilities which provide third-parties with more control over the network of the incumbent compared to current Layer 2 wholesale access products (see section 4.2).

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Abbreviations

ANO	Alternative Network Operator
API	Application Programming Interface
BEREC	Body of European Regulators for Electronic Communications
CDN	Content Delivery Network
COTS	Commercial-Off-The-Shelf
ETSI	European Telecommunications Standards Institute
GS	Group Specification
IaaS	Infrastructure as a Service
ISG	Industry Specification Group
LTE	Long Term Evolution
MVNO	Mobile Virtual Network Operator
NaaS	Network as a Service
NF	Network Functions
NFaaS	Network Function as a Service

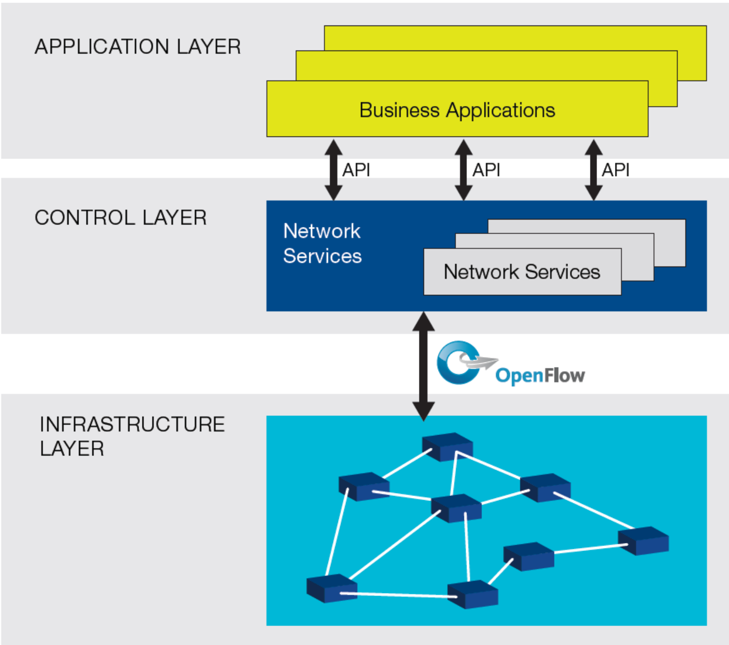
NFV	Network Functions Virtualisation
NFVI	NFV Infrastructure
NFVIaaS	NFVI as a Service
NO	Network Operator
NRA	National Regulatory Authority
ONF	Open Networking Foundation
OTT	Over-The-Top
PaaS	Platform as a Service
PoH	Point of Handover
SaaS	(Cloud) Software as a Service
SDN	Software Defined Networking
SMP	Significant Market Power
SP	Service Provider
UCaaS	Unified Communications as a Service
UMTS	Universal Mobile Telecommunications System
vBNG	Virtualised Broadband Network Gateway
vCDN	Virtualised Content Delivery Network
VNF	Virtualised Network Functions
VNFaaS	VNF as a Service
vDNS	Virtualised Domain Name Server
vDPI	Virtualised Deep Packet Inspection
vEPC	Virtualised Evolved Packet Core
vHSS	Virtualised Home Subscriber Server
vIDS/IPS	Virtualised Intrusion Detection/Prevention System
vIMS	Virtualised IP Multimedia Subsystem
vUC	Virtualised Unified Communications

Annex 1: SDN architecture

According to the Open Networking Foundation (ONF) which was launched in 2011 by Deutsche Telekom, Facebook, Google, Microsoft, Verizon, and Yahoo!, ONF is taking the lead in SDN standardization, and has defined an SDN architecture model as depicted in Figure 3.

The ONF/SDN architecture consists of three distinct layers that are accessible through open Application programming interfaces (APIs):[28]

- The Application Layer consists of the end-user business applications that consume the SDN communications services. The boundary between the Application Layer and the Control Layer is traversed by the so-called northbound API.[29]
- The Control Layer provides the logically centralized control functionality that supervises the network forwarding behavior through an open southbound interface (OpenFlow).[30]
- The Infrastructure Layer consists of the network elements and devices that provide packet switching and forwarding.



Source: ONF (2014), p. 3

Figure 3: ONF/SDN architecture

According to this model, an SDN architecture is characterized by three key attributes:[31]

- Logically centralized intelligence. In the ONF/SDN architecture, the network intelligence is (logically) centralized in software-based SDN controllers in the Control Layer, which maintain a global view of the network. By centralizing network intelligence, decision-making is facilitated based on a global (or domain) view of the network of an

[28] See ONF (2014), p. 3 and ONF (2012), p. 7-8. This is consistent with the framework of SDN defined by the ITU-T (ITU-T 2014).
[29] Also called application-control interface (see ITU-T 2014, p. 3)
[30] Also called resource-control interface (see ITU-T 2014, p. 3)
[31] See ONF (2014), p. 3-4

operator, as opposed to today's networks, which are built on an autonomous system view where nodes are unaware of the overall state of the network.

- Programmability. SDN networks are inherently controlled by software functionality, which may be provided by vendors or the network operators themselves. Such programmability enables network configuration to be automated, influenced by rapid adoption of the cloud. By providing open APIs for applications to interact with the network, SDN networks can in the view of ONF achieve unprecedented innovation and differentiation.
- Abstraction. In an SDN network, the business applications that consume SDN services are abstracted from the underlying network technologies. Network devices are also abstracted from the SDN Control Layer to ensure portability and future-proofing of investments in network services, the network software resident in the Control Layer.

Annex 2: High-level NFV framework

Figure 4 illustrates the high-level NFV framework defined by the ETSI NFV Industry Specification Group which was formed in late 2012 by over twenty of the world's largest telecommunications service providers. NFV envisages the implementation of network functions (NF) as software-only entities that run over the so-called NFV Infrastructure (NFVI).

The high-level NFV framework distinguishes between three main working domains on NFV:[32]

- Virtualised Network Functions (VNF),
- NFV Infrastructure (NFVI) and
- NFV Management and Orchestration

Virtualised Network Functions (VNF)

A VNF is a virtualisation and software implementation of a network function in a legacy non-virtualised network. This software needs to be capable to run over the NFVI. Examples of NFs are

- 3GPP™ Evolved Packet Core (EPC) network elements, e.g. Mobility Management Entity (MME), Serving Gateway (SGW), Packet Data Network Gateway (PGW);
- elements in a home network, e.g. Residential Gateway (RGW); and
- conventional network functions, e.g. Dynamic Host Configuration Protocol (DHCP) servers, firewalls, etc.[33]

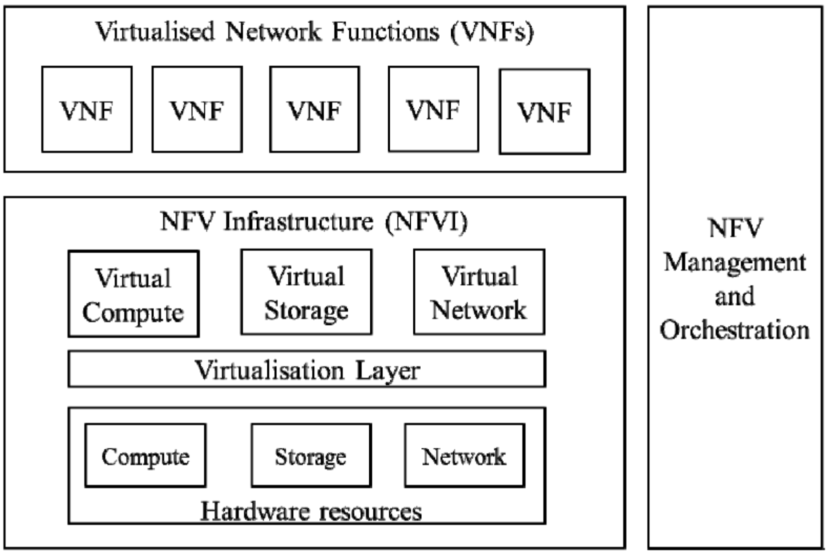
NFV Infrastructure (NFVI).

The NFV Infrastructure is the totality of all hardware and software components which build up the environment in which VNFs are deployed, managed and executed. The NFV Infrastructure can span across several locations. The network providing connectivity between these locations is regarded to be part of the NFV Infrastructure.

[32] ETSI (2014), p. 10, 14-15

[33] ETSI (2013) provides a list of use cases and examples of target network functions (NFs) for virtualization.

From the VNF's perspective, the virtualisation layer and the hardware resources look like a single entity providing the VNF with desired virtualised resources.



Source: ETSI (2014), p. 10

Figure 4: High-level NFV framework

The virtualisation layer abstracts the hardware resources and decouples the VNF software from the underlying hardware, thus ensuring a hardware independent lifecycle for the VNFs. The virtualisation layer is responsible for:

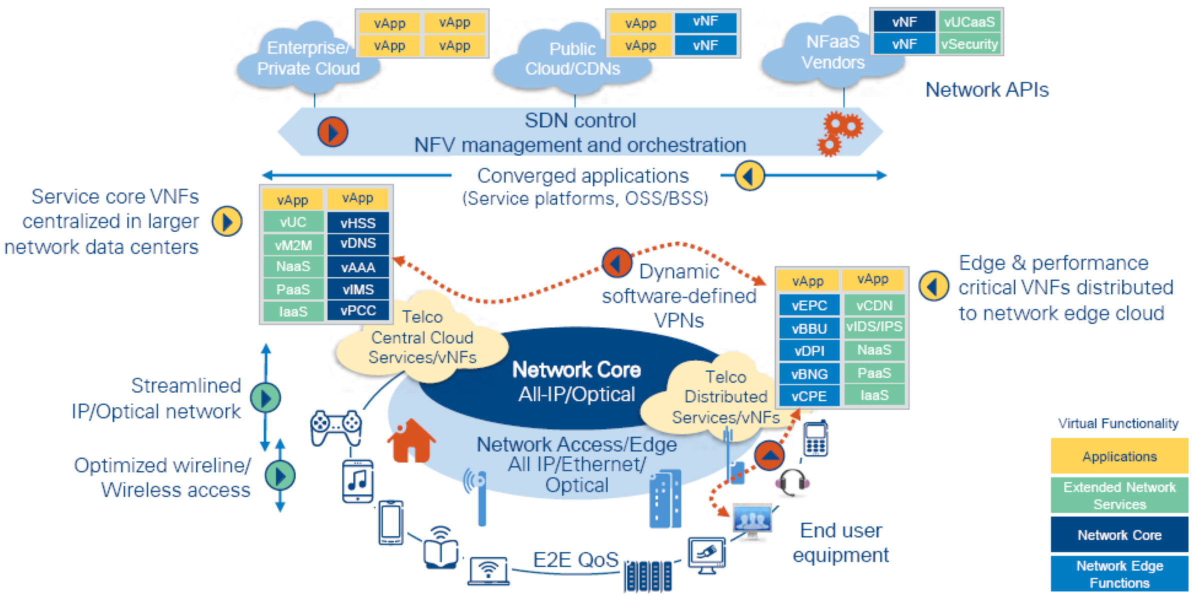
- Abstracting and logically partitioning physical resources, commonly as a hardware abstraction layer.
- Enabling the software that implements the VNF to use the underlying virtualised infrastructure.
- Providing virtualised resources to the VNF, so that the latter can be executed.

NFV Management and Orchestration

The NFV Management and Orchestration covers the orchestration and lifecycle management of physical and/or software resources that support the infrastructure virtualisation, and the lifecycle management of VNFs.

Annex 3: Future architecture of the carrier network enabled by SDN and NFV

Figure 5 gives an overview of a possible future architecture of the carrier network enabled by SDN and NFV. The network is based on a streamlined IP/optical network and an optimised wireline/wireless access. Virtualised network functions are implemented in larger network data centers in the core network (e.g. vHSS, vDNS, vIMS) and at the network edge (e.g. vEPC, vDPI, vBNG). Network connectivity e.g. between core and edge is provided based on software-defined VPNs. In the network also extended network services e.g. vCDN, vUC, vIDS/IPS, NaaS, PaaS and Iaas may be implemented.



Source: Athur D. Little, Bell Labs (2015), p. 12

Figure 5: Future architecture of the carrier network enabled by SDN and NFV