FTTH/B in a Virtualized & Software Defined Network

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Fibre to the Home Council Europe

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1 Motivation

Traditionally networks have been designed around purpose-built network equipment – such as IP routers, Ethernet switches, mobile gateways, firewalls, load balancers, and so on – based on vendor-specific hardware and software platforms. Deploying these vertically integrated network elements has resulted in long development cycles and overly complex lifecycle management practices for new products and services. This slows service providers' time to market, adds operational inefficiencies and overhead, and increases the levels of investment required. The resulting business models look unsustainable in the present market situation where customer bandwidth demand is growing faster than revenues.

Software defined networking (SDN) and network functions virtualization (NFV) are two promising concepts that could dramatically change the equation for service providers. Originally developed in the IT industry, these concepts are now transitioning to telecommunications. The intersection of telecommunications, internet and IT paradigms combined with advances in hardware and software technologies will create an environment of rapid innovation and disruption. It will result in an ecosystem of extremely flexible networks and virtualized applications that dynamically adapt to the needs of both services and subscribers.

Service providers are responding to the huge rise in end user bandwidth demand with a proliferation of fibre to the home and building (FTTH/B) deployments and the start of a new upgrade cycle to next-generation passive optical networks (NG-PON). In order to scale their networks successfully, service providers will need to make their network architecture more efficient, agile and flexible. SDN and NFV are expected to support this transformation and significantly improve the service provider's business model with innovative services and new business opportunities.

SDN and NFV in conjunction with next-generation fibre deployments will be key enablers for this access network evolution, by lowering the network's total cost of ownership, accelerating new service innovation, and maximizing customer satisfaction. In addition, this approach will allow service providers to shift critical functions to the cloud and make it easier for them to manage networks containing equipment from multiple vendors, while efficiently scaling their networks from small to very large access nodes.

This paper will provide an overview of SDN/NFV in the context of FTTH/B, highlighting the benefits and examining several interesting examples of where it could be applied.

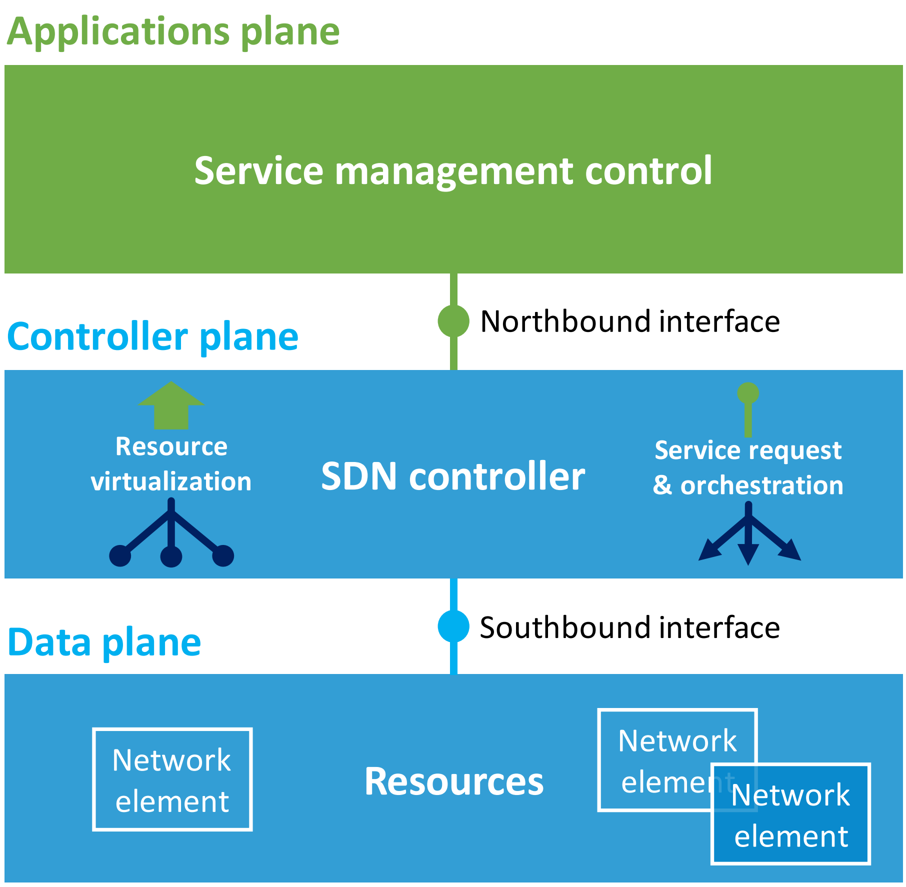
2 What are SDN and NFV?

SDN and NFV represent a new paradigm in the world of communication networks. While new to the broadband access world, however, the principles of SDN and NFV are well established or developing in other digital domains.

2.1 Software Defined Networking

At the heart of software defined networking is the principle of a separation of the control plane and the data plane within a network system. This is not a new principle, as many historical technologies employed similar approaches, but at a much smaller scale. Think about ATM switching and how provisioning tools were used to build circuits across the network. Once the circuits were built, the ATM switches (the data plane), simply passed cells that matched a selection criteria set by the control plane, along a preconfigured data path. However, the ATM provisioning tools (control plane) could not manage Ethernet switches or DSL access multiplexers (DSLAMs), due to the isolation of different technology domains within the service provider's network and the lack of common management standards. Furthermore, a network was often broken into different vendor-specific regions even within one technology domain, which made a holistic view of the entire network almost impossible.

Figure 1: The simplified SDN model. (Reference: Open Networking Foundation)



One of the major goals of SDN is to move away from proprietary network programming implementations towards open, extensible and standardized environments, which are vendor neutral and use open interfaces and common data models. This approach can accelerate the pace with which full end-to-end network programmability can be achieved. The cornerstone of this programmable environment is the SDN architecture (**Figure 1**), which decouples the control plane from the data plane. The control plane makes decisions about the routes in the network, while the data plane moves packets through the network based on the decisions made by the control plane.

SDN-enabled applications communicate their intent to an SDN controller, which takes the basic instructions from the application, and puts them into action through the detailed programming of each network element. By presenting an abstraction of the network infrastructure to the applications, the SDN controller shields them from the underlying details of the actual network, effectively making the programming environment agnostic to the technologies being traversed. SDN controllers come in many shapes and forms with commercial, open source, and hybrid controllers available today. An appropriate selection from different SDN controllers requires careful research to ensure long-term alignment with the user's goals.

In a purist implementation, modern networking protocols such as OpenFlow and NETCONF are used by SDN controllers alongside network element object models written in human readable syntax using YANG. Heavily influenced by some of the worlds' largest operators, there is a strong industry push towards standardization of data models, so that common network elements from different vendors can be managed and controlled via a common YANG data model. This homogenous approach has the potential to deliver substantial reductions in the time required for operators to develop end-to-end automation for new services in a multi-vendor environment.

In a similar vein, many of the network elements, by adopting the persona of an Ethernet switch, exploit the benefits that OpenFlow can bring, for example, by increasing the utilization of network resources or providing additional services, such as security. With OpenFlow-controlled network elements, flow tables can be configured. These flows serve to classify packet types and forward matching packets to their respective flows. Within each flow, destination ports are assigned and any necessary packet header manipulation occurs. Modern access elements, whether PON optical line terminal (OLT), G.fast distribution point unit (DPU) or Wi-Fi access point, are beginning to emerge with OpenFlow capabilities. These next-generation access products are capable of having their functionalities managed by a common SDN controller, while presenting a persona of an OpenFlow Ethernet switch to the applications north-bound of that controller.

Thanks to the significant simplification of the interface in an SDN environment, application and automation developers stand to benefit from significant reductions in the development time and cost associated with new service creation. This automated environment, when coupled with the rapid pace with which OpenFlow flows can be instantiated and the holistic network view maintained by the SDN controller, creates new possibilities for dynamically steering traffic around congested or broken paths or compute resources. We will see later how this capability, when combined with NFV, creates a completely automated environment for new service provisioning and service failover protection scenarios.

2.2 Network Functions Virtualization

NFV works without SDN, but its performance will be enhanced by SDN relying on the separation of control and data planes. At the same time NFV provides the infrastructure to support SDN.

NFV has its origins in the data centre world where solutions from companies such as VMware and Microsoft permitted traditional single-purpose hardware servers to be segmented into multiple logical or virtual servers. This approach enabled substantial efficiency improvements in server hardware, while also creating the capability for service portability where, for high availability reasons, a service could be dynamically relocated from one set of server hardware to a different set of hardware. Largely thanks to increasing compute resources and falling compute costs, this concept has been taken further: many network applications traditionally mandated by specialized hardware can instead run on x86 hardware platforms.

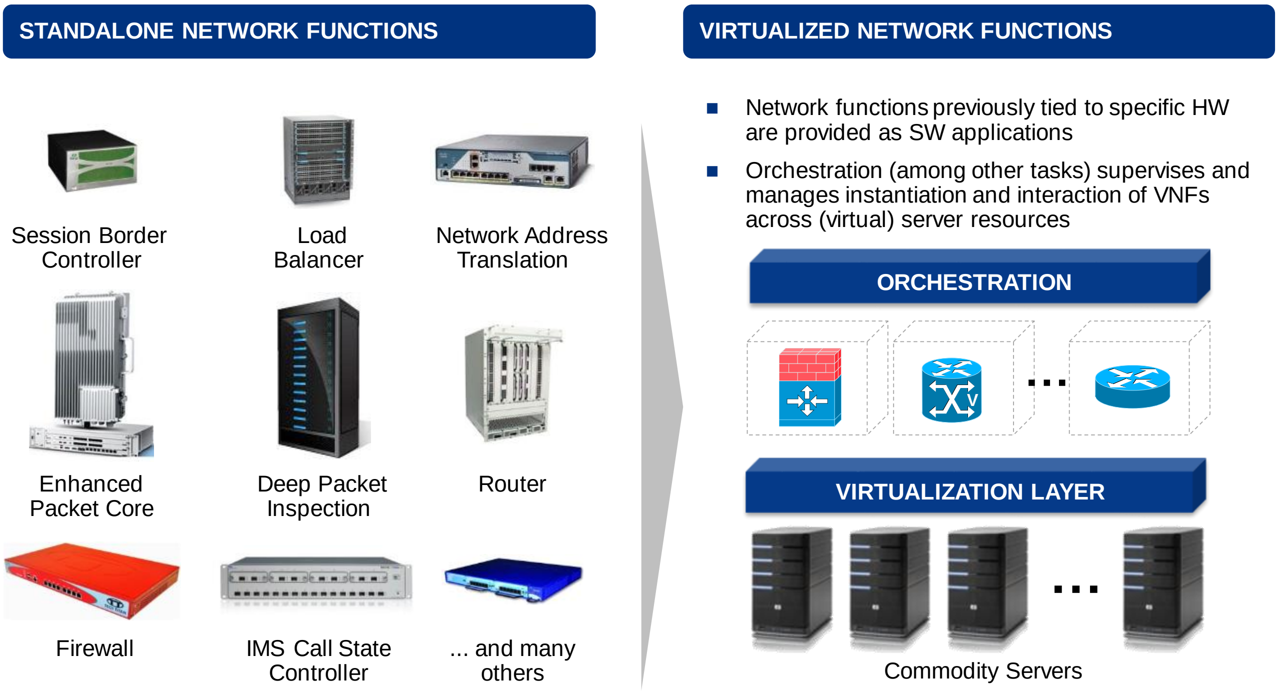
This capability to take a traditional network function and run it in an x86 environment, when coupled with high-speed broadband, allows operators to rethink how network functions are deployed. Consider the traditional carrier service delivery model for enterprise services, which frequently requires an operator to deploy a new piece of hardware on the customer premises for each new service ordered. There may be multiple routers, firewalls, enterprise session border controllers, WAN optimization devices, Wi-Fi controllers and other equipment for each customer, and each consumes more power. Procuring ever-increasing amounts of customer premises hardware is a headache for the operator. Each device requires a technician to visit to the customer premises to install and maintain it. The provisioning time for each piece of hardware could be in the order of weeks, if not months.

NFV, when coupled with ultrafast broadband connections, allows the operator to take many of the network functions that traditionally resided in dedicated network appliances on the customer premises and instead deploy them as virtual network functions (VNFs) operating on cloud-based x86 servers. This approach has substantial implications for both the operators and the end users of the service. With NFV, when deployed in an SDN environment, full service automation can be achieved with great efficiency, enabling the rapid development of automated service delivery environments that can facilitate customer self-service in many cases. Thanks to the virtualization of those network services, they can be instantiated with immediate effect, thus reducing the cost of holding stock and spares, speeding up time-to-market, improving customer satisfaction and shortening the time to revenue generation.

Building on the high-availability mechanisms developed for the data centre industry, these virtual network functions can achieve greater availability than their on-premises appliance-based counterparts. The centralization of common VNFs, coupled with the ability to rapidly move those functions to new server resources, allows operators to move away from the traditional model where they have hundreds of thousands of customer appliances, many with different software versions, that often require laborious upgrades when new services are to be deployed. With NFV, parallel VNFs can be instantiated with the latest required software, and the flows can be dynamically mapped from existing VNFs during maintenance windows, in much less time than it would take to upgrade on-premises equipment.

Service providers have quickly realized that these methods can be applied to residential subscribers, simplifying their in-home equipment, and providing centralized management and monitoring of the customer's service. Together this creates a fantastic opportunity to improve customer satisfaction. By moving to VNFs for network functions such as subscriber gateways, operators can also benefit from operating a single virtual subscriber gateway (vSG) regardless of the access medium used to connect the subscriber. This delivers feature consistency across the customer base while simultaneously reducing the complexity of the network environment. Further details of the new architecture's impact on NFV, such as distributed cloud or edge cloud, are beyond the scope of this paper, however.

Figure 2: The basic concept of NFV



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2.3 Relevant Standards & Industry Organizations

SDN/NFV methodologies have grown in acceptance, and so too have the number of related initiatives within standards bodies. Today there are many organizations contributing towards the standardization of SDN and NFV, embodying a new approach to standards building. Standards bodies have multiple active liaisons with industry forums and open source initiatives, which actively contribute to the definition of standards. Below is a list of key industry bodies participating in the SDN standardization process.

2.3.1 Standards Organizations

broadband forum	Evolution of broadband network systems towards the NFV/SDN paradigm in transport and fixed access networks
tmforumzoom	Create a living blueprint for a new generation of NFV/SDN based service provider support systems to deliver business agility and new digital services.
ETSI World Class Standards	Design principles and the high-level functional decomposition of NFV (network functions virtualization) and MEC (mobile edge computing) architectures
3GPP A GLOBAL INITIATIVE	Evolution of 3GPP mobile network architecture towards 5G goals, which encompass widespread utilization of NFV/SDN paradigm (with explicit separation of the data and control planes in the evolved packet core).
ITU	Study Group 13 (SG13) is the lead study group of SDN in ITU-T, and develops the SDN framework, including SDN terminology, as the baseline for all ITU-T SDN standardisation activities, including SG11, SG15, SG16, SG17.
IETF	Multiple activities: service function chaining (SFC), NFV Research Group (NFVRG), SDN Research Group (SDNRG), NETCONF, YANG.
IEEE	The IEEE P1903 WG (NGSON) is currently working on the specification of service-enabling functions which can be provided as VNFs to support NFV applications.

2.3.2 Open Source Initiatives

ONF OPEN NETWORKING FOUNDATION	Open standards development through the adoption of software-defined networks; Introduces the OpenFlow standard, which enables remote programming of the forwarding plane.
OPEN DAYLIGHT	Platform for programmable, software-defined networks – under the stewardship of the Linux Foundation
ONOS Open Network Operating System	Platform for programmable, software-defined networks. Under the scope of the Open Networking Lab (ON.Lab), (now in the process of merging with ONF).
openstack™ CLOUD SOFTWARE	Cloud operating system that controls large pools of compute, storage, and networking resources throughout a datacenter
OPNFV	Open Platform for NFV (OPNFV) facilitates the development and evolution of carrier-grade NFV components across various open source ecosystems. – under the scope of the Linux Foundation
Open Source MANO	ETSI-hosted project to develop an Open Source NFV Management and Orchestration (MANO) software stack aligned with ETSI NFV
DPDK	Libraries and drivers for fast packet processing (data path) in Linux.
CORD Central Office Re-architected as a Datacenter	Central Office Re-architected as a Datacenter (CORD) – leverages SDN and NFV to promote the use of commodity hardware to support flexible and rapid service creation.
OvS Open vSwitch	Multilayer virtual switch designed to enable massive network automation through programmatic extension while still supporting standard management interfaces and protocols.

3 Use Cases in Fixed Access

3.1 Use Case: vOLT and vCPE in FTTH

Recent announcements from the industry have seen the introduction of virtual optical line terminals (vOLT) as well as virtual customer premises equipment and subscriber gateways (vCPE and vSG, respectively). These are software implementations of products that were traditionally integrated in a monolithic fashion within their hardware equivalents. Their new virtual form provides operators with a degree of flexibility that was not possible before.

The vOLT is a novel approach to hardware that can remain in operation for decades. All of the complex software-based functions that traditionally were deeply integrated within an OLT hardware platform are refined so they can operate in a standard x86 environment as a VNF. The capabilities remaining within the OLT hardware can be boiled down to an OpenFlow Ethernet switch that can perform media conversion between the respective flavours of PON and high-speed Ethernet uplinks. As part of the media conversion, the OLT takes the management messages destined for the optical networking unit (ONU) and translates them into more traditional ONU management and control interface (OMCI) messages.

The vOLT VNF deals with activities like on-boarding the ONUs when they connect to the OLT, by communicating via the SDN controller to the service orchestrator and onwards to the operators' OSS. Once an ONU has been verified as a valid or an approved device, the authentication process begins within the authentication, authorization, and accounting (AAA) environment. Once authenticated, the vOLT will signal to the service orchestrator to instantiate a vSG instance for that ONU connection. The SDN controller will establish the respective OpenFlow flows between the GEM (GPON Encapsulation Method) or VLAN ports and the respective VLANs that will connect it to the servers hosting the respective vSG instance.

The vCPE is a crucial application that moves most of the CPE functionality to the cloud. The vSG assumes the software role of a traditional residential gateway. The hardware functions of a residential gateway remain on the customer premises. So, for example, the WAN port, LAN port, and any POTS (plain old telephone service) or integrated Wi-Fi hardware interfaces remain in the CPE. Software functions such as DHCP server, firewall, NAT, etc. can be run either within a vSG VNF or, if desirable, in discrete VNFs.

The combination of ONU, residential gateway, OLT hardware, vOLT, and vCPE creates a service chain. The service chain is constructed from the mix of hardware and software functions linked together by OpenFlow flows that are instantiated by the SDN controller. In this environment, any of the VNFs can be relocated to other server resources, and the respective flow table entries updated to ensure the users of said VNFs are dynamically mapped to the new server location of the VNF. This superior flexibility provides elasticity in capacity planning, while also permitting high-availability scenarios that were impossible with traditional vertically integrated OLTs and residential gateways. Examples include, but are not limited to, dynamic VNF relocation upon server congestion or failure, or in NG-PON2 deployments, the dynamic reallocation of ONUs onto a standby OLT wavelength in the event of their live OLT port failing.

3.2 Use Case: G.Fast with Virtualization

The industry has also sought to develop and implement SDN capabilities in G.fast scenarios. In the FTTH Council endorsed FTTB deployment model for G.fast, the number of micro-nodes deployed will increase exponentially, resulting in a similar increase in the number of active network elements that must be managed within the network. To address this management challenge in the context of SDN, the industry has developed G.fast DPUs or micro-DSLAMs using the same NETCONF protocols and YANG-based data models. The concept of a Persistent Management Agent Aggregator (PMAA) has been introduced to shield the operator's OSS from the exponential increase in the number of active network elements. The Persistent Management Agent (PMA) provides the OSS with an interface representing the DPU, which is available all the time even if the DPU is powered off (which in reverse-powered scenarios may be a common occurrence). There is one PMA instance per DPU deployed and, in order to eliminate the need for massive OSS scaling, the PMAA aggregates many PMAs into a single management entity. The Broadband Forum Working Text WT-358 describes how the PMAA can be deployed in cloud based x86 server infrastructures, abstracting this control plane element from the network hardware.

3.3 Use Case: Hybrid Fibre Coax and vCCAP

Cloud access and OTT-based services are changing data usage patterns by creating a shift towards more non-linear content consumption. To address this evolution, cable multiple system operators (MSOs) have responded by offering IP video services and converting the legacy video channels to DOCSIS (Data Over Cable Service Interface Specification). Cable MSO access networks are typically hybrid networks with fibre in the feeder and coaxial cable for the distribution network. To accommodate increased bandwidth demands and gigabit services, cable MSOs are deploying fibre deeper into their existing networks while at the same time expanding into new territories with FTTH.

In traditional cable network hybrid fibre-coax (HFC) architectures, customers are connected in large service groups with a correspondingly large hardware footprint in the central hub: this results in high operational costs related to real estate, power and cooling requirements. Capacity expansions are also expensive due to the presence of analogue electronics and the use of analogue lasers on the feeder fibre.

SDN and NFV can support the evolution to handle increased bandwidth demands and support the network transformation to all-IP. A disaggregated architecture moves the physical DOCSIS network functions and analogue optics out of the central hub and pushes them out to a fibre-fed access node. The higher layer functions are decoupled and run in a distributed cloud environment which reduces the centralized network's hardware footprint. This approach is called a virtualized converged cable access platform (vCCAP) and saves space and power compared to purpose built CCAP hardware. Extending fibre deeper into the network increases performance while the remote access node brings more bandwidth to smaller service groups.

The vCCAP architecture addresses the capacity needs of residential and enterprise customers and is a stepping stone to FTTH/B and next-generation access technologies. SDN control is the key to efficiently manage all components of the vCCAP solution: the controller is abstracted from the network hardware and

can run on commercial off-the-shelf x86 systems, while many CCAP capabilities are disaggregated into general-purpose functions, such as subscriber management or IP network management. The equipment in the central hub and the access network infrastructure in the field can evolve and scale independently while supporting faster innovation cycles.

3.4 Use Case: Network Slicing

Network virtualization or “slicing” is an SDN use case in which a single physical network is partitioned into multiple virtual network “slices”, each of which can be independently controlled to address the specific needs of different types of traffic that would otherwise require bespoke networks.

There are several applications of network virtualization including:

- **Open access:** allows virtual network operators (VNOs) to share the use of a common physical network. SDN can enable such open access through virtualization and slicing of network resources. Traffic flows, representing services between each provider and their end customers, are defined in the central controller, bound to specific policies, attached to resources, and measured at service time. Slicing can be achieved by providing network abstractions presented to each operator as an SDN programmable infrastructure. Policy constraints will determine the level of control available to access seekers enjoying physical unbundling, while ensuring the logical separation of traffic and configuration between tenants.

- **Service partitioning:** enables independently managed slices of the network for different types of service – enterprise, residential, mobile backhaul, virtual private network, etc. – with a greater granularity and flexibility than engineered partitioning. One such network service requiring dynamic reconfiguration is the transport of next-generation 5G mobile traffic. 5G is expected to require much denser deployments of wireless access points and base stations, which creates opportunities to unify the transport infrastructure for fixed and wireless access. However, the requirements for transporting 5G traffic dictate low latencies and high throughput. For wireless traffic to share link capacity with residential network services, network element functions will need to be dynamically reconfigured in response to changing traffic patterns. Another example is the need to serve specific kinds of business verticals with specific services, even within 5G: for example, automotive networks and mobile internet browsing have completely different sets of requirements and must be kept separate. Network slicing provides the means for that separation.

4 SDN & NFV Benefits

Although SDN and NFV are independent concepts, they are even more powerful when combined. Frequently the benefits are maximized when they are used together. For our purposes, we shall initially focus on each concept individually, and later examine how, in combination, they have even greater potential to transform broadband access service delivery, particularly in FTTH/B networks.

4.1 Technology & Network Operations

4.1.1 Operational Efficiencies

Elastic scaling: Operators can scale VNF capacity in line with the demand and requirements of specific use cases. The ability to dynamically provide existing services on demand should lead to a price premium relative to that of a statically provisioned service. It also allows the service provider to address subscribers in situations where a rigidly defined service offer would not be cost effective.

Automate operations and management (OAM): With virtualized network functions and the means to intervene directly in the network behaviour provided by SDN, some extent of autonomous behaviour will certainly arise, closing control loops that lead to networks that are increasingly self-organised. One obvious case of autonomous OAM is the ability to perform self-healing based on dynamic VNF placement, reconfiguration and provisioning, and SDN-based reconfiguration of VNF service chains.

Reduce capex: SDN and NFV reduce the need to purchase purpose-built hardware and support pay-as-you-grow models that eliminate wasteful over-provisioning.

Reduce opex: Virtualised networks will have reduced space, power and cooling requirements for equipment. The roll-out and management of network services will be simplified.

Architecture development: SDN and NFV enable efficient transformation of the network architecture towards a cloud-optimized solution.

Network migration: By providing an abstraction level above the physical layers, virtualization can accelerate the migration from one technology, such as G.fast or HFC cable networks, to another more future-proof option, FTTH/B. It provides operators with the ability to rapidly and inexpensively deploy, configure, launch and upgrade services, leading to a time-to-market advantage.

Access agnostic: SDN-enabled networks can provide seamless, convergent and resilient services over the various interconnected fixed and mobile networks underneath.

Open access: The ability to provide access with different and controlled characteristics to multiple virtual VNOs over the same physical line can offer drastic changes in business models and innovation. Indeed, the extended sharing of a common physical network could lead to the sharing of fixed costs at all levels – local, regional and national – between even more new services and providers.

4.1.2 Business Transformation

Accelerate time to market: Network virtualisation reduces the time to create and deploy new network services to support changing business requirements, seize new market opportunities and improve the return on investment. Also, by lowering the risks associated with rolling out new services, it allows service providers to trial and develop services to determine what best meets the needs of their customers.

New services: Granular network slices allow operators to provide new and customized applications to different users, potentially creating a larger portfolio of enhanced and highly customizable digitally delivered services and the associated revenue opportunities.

Deliver agility and flexibility: Quickly scale services up or down to address changing demands; support innovation by enabling services to be delivered via software on any industry-standard server hardware.

New business creation: The ability to provide network connectivity services at a granularity consistent with demand enables operators to penetrate new market segments. Granular offerings also attract smaller customers – such as virtual network operators, small rural service providers, machine-to-machine service providers and small and medium enterprises (SMEs) – who cannot afford to invest in their own FTTH infrastructure for these functions.

5 Conclusions & Recommendations

Network virtualization is an essential part of our future communications infrastructure. It will enable network operators to provide services flexibly and cost-effectively across their fixed and mobile networks. As the target of the fixed access network architecture, FTTH/B networks will also benefit from the virtualization technologies of software-defined networking (SDN) and network functions virtualization (NFV).

Research and development into use cases for SDN and NFV is ongoing. Some examples introduced in this paper show the way forward, and some are almost ready for commercial implementation. Moreover, the virtualization of FTTH/B-based network equipment will support network slicing, which is a key concept in 5G networks.

The challenge for the industry will be to coordinate fixed and mobile networks based on SDN and NFV, and migrate networks from the current infrastructure to a virtualized platform. For network operators, these challenges are both technological and operational, and may even necessitate corporate reorganization.

It's clear that regulatory organisations, network operators and vendors need to work closely together to analyse and understand the role SDN and NFV have to play in their future business.

Recommendations:

- **For regulators**: Those responsible for European telecommunications policy and regulation are encouraged to take an active role in supporting initiatives that facilitate the SDN/NFV paradigm. The promise that these innovative approaches bring to next-generation access networks should not be underestimated. For any innovation in networking technology to succeed, especially in the shift from a proprietary management model to an open management model, it's important to set standards that the industry can agree and adopt. These methodologies and architectures, when combined with next-generation access technologies, will be the foundation of Europe's Gigabit Society to ensure our future prosperity and security.

- **For network operators**: Network operators are craving greater network flexibility alongside increased access network capacity. These new approaches differ from the traditional means for building and operating networks. The support of the operator community is the key to bringing SDN/NFV benefits to network operator environments. This will enhance and empower the development and adoption of SDN and NFV capabilities in today's networks. We recommend that network operators work together with vendors and industry bodies to identify relevant use cases for next-generation access networks and examine the value it can bring to their business.

- **For vendors**: It is vital that the vendor community continues to develop efficient technical solutions and simplify the migration work for network operators. They should deliver on the visions that have been outlined to the industry, and seek to do so in a manner that permits the maximum level of service innovation and network utilization by both actual and virtual network operators.

The new paradigm has arrived. It would be short sighted not to analyse the impact of SDN and NFV, in order to understand the role they will play in the future business decisions of network operators.

References

FTTH Business Guide 2016, (Fifth Edition) by the Financing Committee, FTTH Council Europe.

Notes