NFV Applicability and Use Cases in Satellite Networks

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***Abstract*— Network Functions Virtualisation (NFV) is currently driving a paradigm shift towards the virtualisation/ softwarisation of network infrastructures, allowing the flexible deployment and management of network functionalities. In this paper, we investigate the applicability of the NFV technologies to satellite communications platforms and identify –via three indicative use cases- the added-value, as well as the associated challenges and considerations. We also present a proof-of-concept implementation of an NFV-enabled satellite network on an emulated testbed. We conclude that NFV adoption seems quite beneficial for the satcom sector in order to maintain its competitiveness, promote its inherent benefits and also to achieve the smooth integration of the satellite components and their indispensable satellite-specific capabilities into the future federated heterogeneous networks, within the 5G context.**

Keywords—satellite networks; network functions virtualisation; softwarisation; 5G

I. Introduction

Future networks are envisaged to consist of heterogeneous wireless and wired physical infrastructures, whose resources are abstracted via virtualisation mechanisms, unified, dynamically pooled and offered in as-a-Service fashion to multiple tenants. The paradigm of Network Functions Virtualisation (NFV) [1] is considered a major driver towards this vision.

The concept of NFV is to leverage standard IT virtualization technology to virtualize network functions (i.e. transform them from physical appliances to software-based Virtual Network Functions – VNFs) and consolidate them onto standard equipment in datacenters. NFV advocates a homogeneous supporting infrastructure providing computing, storage and connectivity mechanisms, which are expected to be accessed through a common virtualization interface by involved software elements that implement the actual network functions.

The advent of NFV within the networking community is promising to radically transform the nature of the infrastructure into a unified, software-driven domain offering flexible and dynamically reprogrammable/reconfigurable network services, that is able to fulfil a wide range of use cases and customer needs.

With regard to satellite networks, their role in today's communication landscape is indeed critical (offering high capacity and ubiquitous connectivity under all circumstances and all locations, with uniform QoS and wide-area broadcast capabilities). However, a paradigm shift to NFV has not yet propagated to the satcom domain. Innovative satellite technologies (e.g., use of Ka, Q/V-band High Throughput Satellites (HTS), LEO/MEO (Low Earth Orbit/Medium Earth Orbit) constellations) are being deployed; yet it is expected that these innovative technologies combined with NFV could ensure end-to-end cost-efficient satellite services and promote new added-value services. In this context, the satcom community is expected to derive significant benefits from the adoption of the NFV model and the interoperability/integration with terrestrial software-based networks. This paper addresses this perspective by discussing the applicability of NFV to satcom platforms via specific use cases and identifies the benefits –as well as the challenges/considerations- associated with satcom-NFV integration.

II. NFV-Enabled Satcom

A. Domains of Application

In a satellite network, Network Functions Virtualisation can be applicable to network functionalities across all layers of the OSI model, from the physical up to the application layer.

Specifically, in a satellite platform, NFV can be used to virtualize:

- core Satellite Gateway (GTW) functions, such as firewalling, Performance Enhancement Proxy (PEP)/acceleration, scheduling, network address translation, media transcoding, etc.
- radio front-end functions, such as modulation and coding (in the so-called "Cloud-RAN" concept, where modulation and coding (MODCOD) operations are off-loaded from hardware units to software processors [2])
- on-board functions in the satellite payload, such as switching and traffic shaping or replication
- per-customer functions offered as a Service (VNFaaS), such as firewalling, traffic inspection, intrusion detection, etc.

These scenarios imply that NFV can be applied at either the satellite gateway and/or the customer side, without excluding the long-term perspective of NFV-enabled satellite payloads, as shown in Fig. 1.

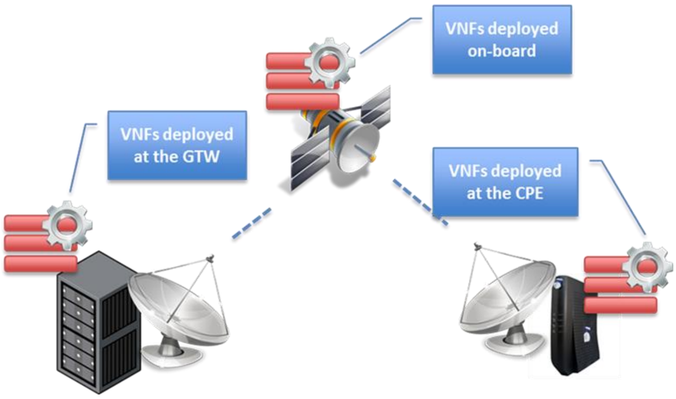


Fig. 1. Satcom NFV: domains of application

Regardless of the exact system configuration to be adopted, the compatibility with the NFV reference architecture [3] proposed by the ETSI NFV ISG is highly recommended, as well as the alignment with the current architectural concepts and terminology introduced by the ETSI recommendations. Also, emerging NFV platforms with strong industrial and community support, such as the Open Platform for NFV (OPNFV) [4] are likely candidates for integration with satcom. Such integration would involve e.g. interfacing with satcom network management (NMS) and OSS/BSS platforms, development of additional control APIs etc.

B. Benefits

Similarly to its impact on the terrestrial domain, NFV offers the potential to radically redefine the architectural logic of satellite networks, by softwarising key network functions at the GTW and the user terminal. NFV is considered to be a crucial driver to enable the faster uptake of future network technologies. Introduction of new protocols and services is greatly facilitated and time-to-market is radically reduced, thus addressing a key limitation of satellite networks, which currently hampers their competitiveness against terrestrial solutions. Such a reduced Time-To-Market (TTM), gives to the satcom industry unprecedented flexibility and adaptability to market needs and changes. For example, the adoption of the Cloud-RAN paradigm for radio front-end virtualization, would allow new satellite radio technologies involving more advanced signal processing schemes that would be deployed by means of a software update, and even differentiated on a per-customer basis. Also, the evolution of features during the operational phase will be easy for NFV-enabled systems.

At the same time, NFV has the potential to promote innovation and competition, by opening a part of the (traditionally hardware-based) satcom market and transforming it to a novel virtual appliance market, facilitating the involvement of software stakeholders, including academia and SMEs.

In addition to faster technology uptake and market openness, all other benefits associated with NFV can be also brought to the satcom domain, including:

- Consolidation of satcom hardware resources, leading to reduced equipment investment and maintenance costs (reduction of both CAPEX and OPEX).
- Enhanced resource utilization and elasticity due to sharing of resources among different network functions and tenants.
- Opportunity to expand the satcom service portfolio with VNF-as-a-Service (VNFaaS) offerings; NFV enables satellite service providers (traditionally providing plain connectivity services) to radically augment their portfolio by offering virtualized service instances specifically for each customer/tenant and customizing them accordingly.

In addition to service customization, the automation offered by emerging NFV platforms significantly reduces service setup time and/or reconfiguration delay. This is a significant improvement in the market performance of satellite operators, for whom currently even a small change or modification in the service delivery chain, requires a corresponding change in the related hardware devices, usually done manually. In the same context, the ability offered by NFV to compose various network services rapidly and efficiently by chaining together virtual network appliances, is very important for satellite operators, who currently deal with a very specific hardware-based service chain, which does not allow any service bundling and assembling.

Moreover, the support of NFV within future satellite payloads, appears as a very promising perspective, since it allows the instant deployment of arbitrary traffic processing modules on-board, paving the way towards truly and totally flexible networking in the sky. However, on-board NFV may be considered only as a long-term vision due to the absence of lightweight IT / OS platforms which can support virtualization and VNF hosting, and at the same time fulfill the strict requirements for their inclusion in a satellite payload (power constrains, rigidness, availability etc.). Currently, supporting IT virtualization in the payload requires significant processing and storage resources which are too costly to be included, in addition to increasing payload size and weight. What is more, the protocols and architectures for NFV management are constantly evolving and are far from being stable enough for on-board deployment.

Last but not least, it is true that network softwarisation is considered a key driver towards the 5G vision. Thus, satcom/NFV synergy significantly facilitates the integration of the satellite components and their indispensable satellite-specific capabilities into the future federated heterogeneous networks, within the 5G context.

C. *Considerations and Challenges*

Although the virtualization of satellite network functions appears as a very promising perspective, there are still some considerations to be taken into account. Availability and performance are two issues often associated with NFV, since virtualized versions of network functions are generally considered less reliable and less performant than their hardware counterparts. Under certain circumstances, these issues may become even more critical in a satcom context. For example, a failure in a core VNF of a satellite gateway serving thousands of nodes may have significant impact. Such circumstances need to be taken into account in a proactive manner, exploiting NFV resilience mechanisms, such as live VNF migration to failover server units. Similarly, performance issues of core VNFs deployed at the GTW may affect a large number of users.

Security issues may also arise, since software VNFs are considered more vulnerable than hardware appliances due to software bugs and/or misconfigurations. Especially VNFs residing at the Satellite Gateway (which can be actually a single point of failure for the entire satellite network) need to be carefully validated and monitored to prevent malicious or accidental malfunctions which would affect the stability of the system and/or trigger security incidents such as traffic eavesdropping or modification, caused by compromised VNFs.

Last but not least, NFV resource requirements and also management signaling overhead can be an issue in satcom networks. Lightweight virtualization mechanisms need to be adopted for deploying VNFs in resource-constrained segments (e.g. payload or terminal). Additionally, the signaling protocols and procedures for VNF management and control need to be optimized in order to be able to manage hundreds or thousands of VNFs remotely over the satellite link with minimal overhead. This constraint is currently not being considered in terrestrial NFV architectures and solutions.

III. USE CASES FOR NFV IN SATCOM

In this section we propose three indicative NFV use cases especially tailored for satcom environments. This list is not exhaustive; it can be observed that most of the general use cases identified for NFV [6] are also applicable in a satcom environment.

A. *UC1: Virtualisation of core gateway functions*

This use case is internal to the satcom service provider; it involves the virtualization of certain functionalities of the gateway and their deployment as software components in commodity servers. The expected benefits are lower CAPEX and OPEX, easier maintenance and frequent upgrades.

Candidate functions for virtualization are: PEP including an acceleration function to mitigate the long satellite round-trip time, firewall, Network Address Translation (NAT) and scheduler/QoS control.

Under certain circumstances, it should be beneficial to extend the virtualization concept to lower-layer functions (L2/L1), following for example the “Cloud-RAN” paradigm. This should be particularly considered in multi-gateway configurations, where several gateways are dispersed to serve e.g. a MEO or LEO constellation of satellites. In this case, the baseband signals could be centrally prepared in a data center and then distributed to the network of gateways, which, in this case, would act as transparent remote radio heads (RRHs). Of course, in such a case, transmission latency between the data centre and the RRHs, as well as backhaul bandwidth requirements, would be significant issues. Therefore, the service provider should carefully select the set of functions to be off-loaded to the data center and the ones to be kept local to the RRH.

B. *UC2: Satellite Virtual Network Operator (SVNO)*

This use case is inherited from the concepts of virtual network operators (VNOs) in terrestrial wired infrastructures and Mobile VNOs (MVNOs) in cellular networks. During the last years, the VNO concept has extended to encompass the satellite segment, and Satellite Virtual Network Operator (SVNO) offerings have emerged. The DVB-RCS2 technology [5] supports SVNO by dividing the capacity into several logical and independent networks – Operator Virtual Networks (OVN).

The NFV-enabled SVNO scenario involves the partitioning of the satcom gateway infrastructure into logically isolated end-to-end slices with dedicated network, IT and radio resources. These slices, in the form of “virtual gateways” are leased as-a-Service to several SVNOs, who are offered full control of the virtual infrastructure, as if it were a physical network. In other words, by exploiting the virtualization paradigm, this scenario extends the SVNO concept from the plain slicing of capacity, to the full virtualization of the entire hub – i.e. the core gateway and front-end functions, including traffic control (caching, firewalling, PEP etc.), multiplexing, multiple-access and also radio (coding and modulation). Each of these functions are implemented in logically isolated virtualized appliances (VNFs) and are chained together to become components of a “virtual hub”- and eventually of an end-to-end SVNO service (Fig.2)

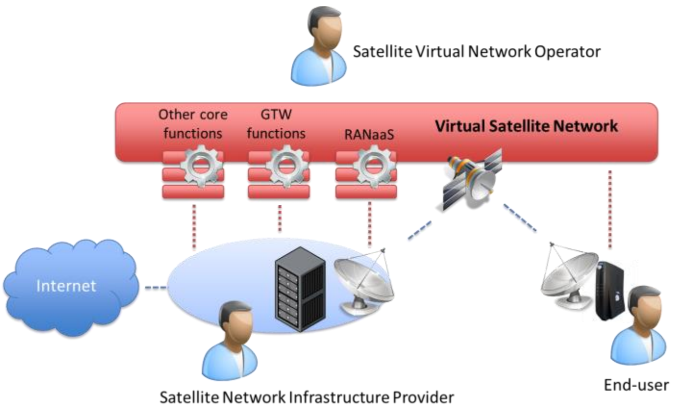


Fig. 2. SVNO use case

The SVNO is able to manage all the virtual appliances involved in the service independently, as if he/she was managing physical devices. For example, he/she could configure the PEP, change scheduler priorities, manage the multiplexing process and even fine-tune the modulation/coding parameters – respecting of course the satellite power and link budget constraints. Another benefit, which can be potentially offered to the SVNO under this scenario, is the capability to choose among multiple virtual appliances and combine (chain) them as desired into mix-and-match configurations, for reduced CAPEX/OPEX horizontal market deployments. For instance, the SVNO service could combine the virtual firewall of vendor A with the virtual multiplexer of vendor B and the virtual modulator of vendor C.

C. UC3: Satcom Customer functions virtualization

This scenario is based on the VNF-as-a-Service (VNFaaS) NFV use case, as documented by ETSI in [6] and assumes the dynamic offering of virtual network appliances to satcom customers as VNFs (e.g. firewalls, traffic filters, home gateway functionalities, media storage and processing etc.). According to their nature, these VNFs can be instantiated either at the satellite gateway or at VNF-enabled satellite terminals. This perspective appears as a great added-value for the satcom market, whose primary offering for decades has been plain connectivity, lacking any custom in-network functionalities.

Some indicative examples of VNFs which would bring added-value when offered as-a-service in a satcom context would be: Firewalling and content filtering; Application classification; Caching; Media transcoding; Performance Enhancement Proxy (PEP).

Regarding the deployment and management of the service, in a more static scenario, the satcom service provider manually deploys and interconnects the VNFs, following a customer request. In a more interactive and dynamic approach, the customer composes the NFV service in a completely automated manner by accessing a Service Portal, browsing the VNF catalogue, selecting the VNFs which best match his/her needs (choosing from a VNF Catalogue) and integrating them into a satcom service package, as visualized in Fig.3. This is the concept of the "NFV Marketplace", as developed e.g. by the EU T-NOVA project [7][8]. The same Service Portal could then be used for the monitoring and the management of the service. VNFs may be managed either via the portal or via individual management interfaces.

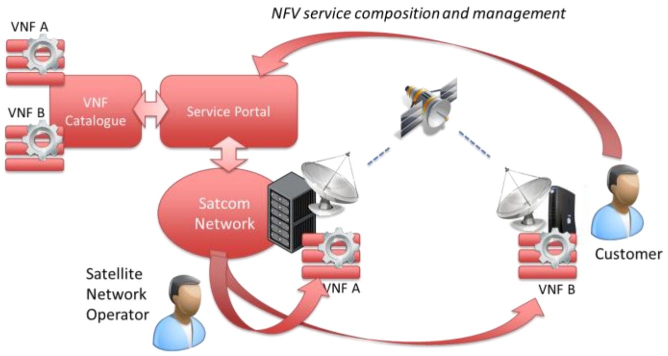


Fig. 3. Customer functions virtualization use case

IV. USE CASE PROOF-OF-CONCEPT

In this section we present the proof-of-concept implementation and functional validation of the third of the use cases mentioned in the previous section (satcom customer functions virtualization). We set up an emulated NFV-capable satellite network where customer functions can be deployed and interconnected. We assume a customer requesting three VNFs: a virtual firewall and a TCP accelerator (instantiated at Gateway side) as well as a web proxy/cache (instantiated at the customer terminal).

In order to emulate a functional satellite network, we used the OpenSAND emulator [9]. OpenSAND is able to emulate the behavior and communication capabilities of a GEO (Geostationary Earth Orbit) network and comprises emulated modules of satellite gateway, transparent or regenerative satellite and customer terminal.

For the establishment of the virtualization-capable NFV infrastructure, we used the OpenStack platform [10], deployed on three high-end servers. OpenStack is currently the dominant open-source cloud platform and it is also a popular virtualization framework for NFV infrastructures. We used Openstack to manage the deployment and entire lifecycle of the VNFs which are instantiated as virtual machines (VMs) at Gateway side. At the terminal side, a plain hypervisor (KVM [11]) was used to manage the local VNFs.

For the end-to-end control of the network, we used the OpenDaylight network controller [12]. OpenDaylight maintains the overall view of the network and dictates per-flow policies in the intermediate network nodes, using Openflow and also other protocols; we used it to steer the traffic through the deployed VNFs before eventually reaching the user. As with OpenStack, OpenDaylight is currently considered the most promising candidate network controller platform for NFV infrastructures. In this way, our testbed is kept aligned with latest technological trends in the NFV community.

Furthermore, we developed a custom software module to act as "orchestrator" and control the OpenStack and OpenDaylight controllers (via the northbound APIs which they expose) in order to automatically instantiate and interconnect the VNFs i.e. demonstrate the automated deployment of the entire end-to-end NFV service at user request.

For the VNFs themselves, we used VMs hosting existing open-source software implementing the three functionalities (firewal, TCP acceleration and Web proxying).

The overall topology of the testbed is shown in Fig. 4, where also the route of the customer traffic is visualized.

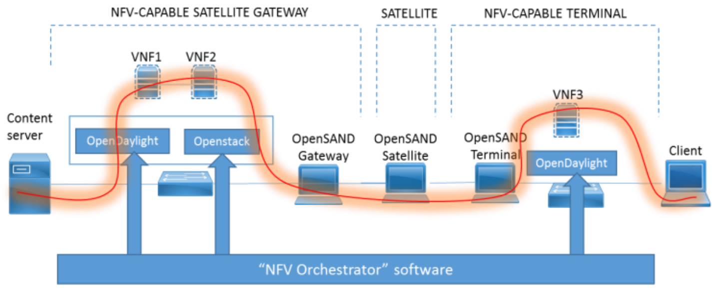


Fig. 4. Testbed configuration

Fig. 5 zooms in the Openstack cloud computing platform, where VNF-1 and VNF-2 are hosted. More specifically, the figure presents the complex L2/L3 traffic steering process, which is achieved using SDN/Openflow mechanisms.

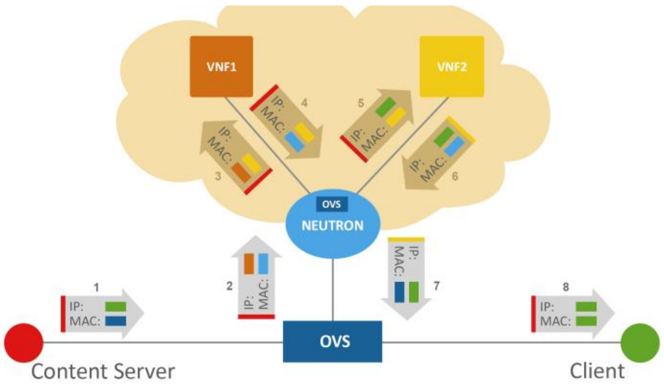
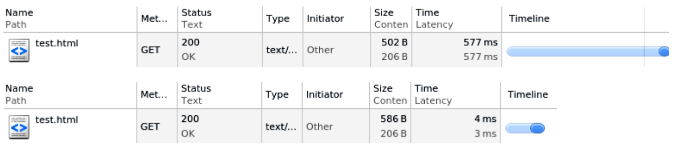


Fig. 5. Openflow-based traffic steering within Openstack platform

As seen in Fig. 5, we use Open vSwitches (OVS: software-based Openflow-capable virtual switches), in order to divert the traffic through VNF1 and VNF2 by altering the destination MAC and IP address fields of the packets. The OpenStack network node (Neutron) plays an active role in the process.

The overall service setup time, from the customer request to the establishment of the end-to-end NFV service was measured at approximately 40 seconds. If the service is paused (i.e. the VMs hosting the VNFs are paused), it can be restarted in less than 5 seconds. In a non-virtualised configuration, the same effect would require physical devices to be acquired and manually interconnected, which would take several days or even months.

The screenshots in Fig.6 illustrate the fetching of a test web page by the client from the content server and verify that the web proxy function was deployed at the terminal and the traffic properly steered. Before the deployment of the NFV service, the page response time is 577 msec (measured through the browser's console) which is due to the (emulated) satellite delivery delay. After NFV service instantiation, the proxy VNF is deployed and the traffic is steered through it. The page is served locally by the VNF, dropping the response time to 4msec.



Name Path	Met...	Status Text	Type	Initiator	Size Conten	Time Latency	Timeline
test.html	GET	200 OK	text/...	Other	502 B 206 B	577 ms 577 ms	

Name Path	Met...	Status Text	Type	Initiator	Size Conten	Time Latency	Timeline
test.html	GET	200 OK	text/...	Other	586 B 206 B	4 ms 3 ms	

Fig. 6. Web page delivery over satellite; before (top) and after (bottom) the instantiation of the proxy VNF.

V. CONCLUSIONS

It becomes clear that the support of the NFV paradigm in future satellite communications platforms, although it has not attracted significant attention up to now, seems crucial in order to maintain the competitiveness of the satcom sector. In addition, the agility offered via infrastructure virtualization can be considered a key driver to enhance satellite platforms with unprecedented flexibility and reconfigurability, as well as to develop satcom service offerings with additional added-value features and services.

ACKNOWLEDGMENT

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