Enhancing Satellite & Terrestrial Networks Integration through NFV/SDN technologies

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1. Introduction

The combination of satellite and terrestrial components to form a single/integrated telecom network has been regarded for a long time as a promising approach to significantly improve the delivery of communications services [1][2]. Multiple compelling benefits are expected:

- *Improved service coverage and footprint expansion.* Satellite can complement terrestrial offerings and provide coverage extension to un-served or poorly served areas (e.g., rural areas) as well as connectivity to terrestrial vehicles (e.g., trains, buses), aircrafts, and vessels.
- *Rapid, dynamic and/or infrastructure-independent service deployment.* Satellite links can provide backhauling solutions for ad hoc deployment of fixed or mobile terrestrial systems (e.g., deployment of a transportable base station for a large event or disaster scenario).
- *Increased network resilience.* Satellite can provide redundancy for critical communication links. In addition, terrestrial equipment such as base stations could support fallback/safe operational modes over backup satellite backhauls to improve service availability and network resilience in face of potential failures of terrestrial backhaul links.
- *Broader range of service provisioning with lower costs for customers and operators.* Satellite broadcast/multicast capabilities can be exploited for off-loading video or other high bandwidth traffic that otherwise may not be cost-efficiently delivered over the terrestrial infrastructure (e.g., feed of Content Delivery Network (CDN) nodes placed at terrestrial network edges). Moreover, satellite broadcast/multicast capabilities can help operators to deliver high quality video content to home networks.
- *Improved Quality-of-Service/Quality-of-Experience (QoS/QoE) for end users.* Combined pooling and management of both satellite and terrestrial network resources can improve service delivery in areas where QoS/QoE delivered by terrestrial access alone may be not satisfactory (e.g. higher speed broadband Internet access in low density populated areas with limited xDSL coverage).

The integration of satellite and terrestrial networks to fully achieve the above-mentioned benefits still has to deal with many challenges as of today. Despite the important and continued advances in satellite communications technologies, satellite communications offerings have not evolved at the same pace as terrestrial communications systems have done due to much lower economies of scale and inherent associated technological complexities [3]. Historically, the use of satellite as a means of communication was restricted to satellite niche areas (e.g., professional use in areas where there are no terrestrial networks) and to Direct-To-Home TV market (DTH), the first service with strong commercial interest. Now with Ka band satellite communication systems, satellite bidirectional broadband services (Direct-To-Customers) begin to emerge. Thanks to the emergence of the satellite broadband services, the satellite industry is keen to develop and deploy flexible and also cost-effective solutions to prepare the future satellite system infrastructure. Some of the key limitations of current SatCom platforms under the focus of the satellite industry are the following:

- Establishment and configuration of networking services across satellite and terrestrial segments is mostly performed manually, thus involving considerable setup and reconfiguration delays, as well as high associated operating and maintenance costs.
- New network technologies, algorithms and protocols cannot be rapidly introduced into the market since they involve time-consuming and costly SatCom and terrestrial hardware upgrades and are thus associated with significant CAPEX investments.
- Lack of flexibility in the management of the satellite resources to achieve a better match with users' demand and optimization of the resources in use.
- SatCom services are mostly associated with plain connectivity (with or without QoS), without the ability to insert on-demand in-network services (e.g. firewalling, proxying for traffic optimization, caching, media transcoding, etc.) for network-side traffic processing.
- Many satellite specific settings and the lack of common prevalent standards for the integration

with terrestrial systems do not provide transparency for the applicability and continuity of policies for routing, QoS, security, management and connectivity (Ethernet, MPLS, etc.) and so on across both segments.

- Limited control by service providers for global resource management when relying on multiple satellite network operators' platforms. The satellite network operators enable service providers to connect their customers to the information servers hosted in data centers. This interconnection is achieved by providing connectivity from the satellite ground segment to terrestrial network nodes. The purpose of a service provider is to be able to offer its entire catalog of services to its customers through different network infrastructures (provided by different operators) in a transparent manner. Service providers are facing some difficulties, such as the management of various resources transmitted on various transport infrastructures, consisting of a set of equipment managed by each operator independently and with specific characteristics (terrestrial/satellite).

In this context, the satellite industry is clearly committed to revisit and revamp the role of satellite communications in the context of next generation 5G networks [4][5]. Indeed, considering the actual and future challenges being pursued under 5G, it is of utmost importance that the standardized network architecture be based on multiple layers and heterogeneity of network technologies, including satellite communications.

2. NFV/SDN as enabling technologies

In the terrestrial domain, limitations such as the lack of automation, limited flexibility in scaling/upgrading networking equipment and services noted above for satellite communications are also present but gradually being confronted via a major technological transition sustained in the still emerging concepts and technologies related to network function virtualization (NFV) and software-defined networking (SDN). In addition to network flexibility, NFV/SDN technologies are also expected to result in reduced equipment and, remarkably, lower operational costs. Indeed, the adoption of NFV/SDN architectural frameworks enables the creation of more intelligent networks that are open, programmable and application aware. It creates network abstractions that are essential for the integration and consistent operation of the underlying networking functions, facilitating the combination of diverse technologies (satellite/terrestrial access systems, core networking equipment, service delivery platforms, etc.) for the deployment of optimized network architectures tailored to specific application' requirements. This gives operators greater control over their equipment, simplifying network management to a great extent and more ability to create innovative services, allowing also the centralized management and control of networking devices from multiple vendors. SDN applicability can cover many distinct operational areas, ranging from the control of fine-grained, distributed enforcement of QoS polices with an integrated network-wide view (which leads to better end user experience) to the real-time control of network resources in a localized area when coping with a congestion situation. Therefore, being able to tap into NFV and SDN is claimed to be of utmost importance for the satellite communications industry, keeping it aligned to mainstream technological evolution driven from the more large scale markets of fixed/mobile broadband communications and data centers and definitively paving the way for fully integrated terrestrial and satellite network services. Ultimately, unified terrestrial and satellite networks sustained on NFV/SDN technologies and exploited through smart and advanced resource management mechanisms will result in a win-win solution for both domains as well as for the end-users.

3. Integrated terrestrial and satellite networking infrastructures

This paper advocates for the introduction and exploitation of the NFV/SDN paradigms and technologies into the satellite networking domain, as central enablers towards improved and more flexible integration of satellite and terrestrial segments, network service innovation and business agility, and network resources management. An illustration of such conceptual approach is depicted in Figure 1.

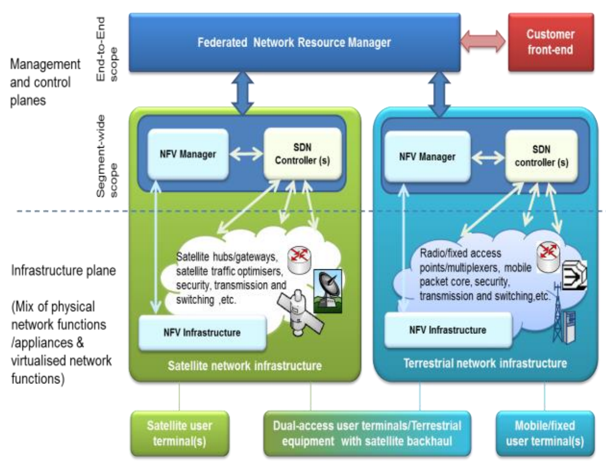

Figure 1. Conceptual framework for the combination of terrestrial and satellite communications segments.

The realization of a given end-to-end network service may require the combination of a number of constituent, interconnected network functions across the different segments (e.g. satellite hubs/terminals, terrestrial access points/base stations, switching/routing, mobility packet core functions, policy enforcement, caches and video transcoding/adaptation, network/transport/application optimization, security functions). In this respect, as illustrated in Figure 1, it is anticipated that some network functions within both terrestrial and satellite segments will be virtualized network functions (VNFs) running on top of NFV-Infrastructures (NFVI), which include the physical resources and the virtualization layer for the use of these resources by the VNFs. The NFVI can span across several locations and data centers. Therefore, the infrastructure plane of both satellite and terrestrial segments is considered to comprise of a mix of network functions implemented as bespoke hardware appliances together with virtualized network functions running on top of a number of NFVI platforms.

Above the infrastructure plane, the management and control plane inside each of the involved terrestrial and/or satellite infrastructure segments will host two central functions: a (set of) NFV manager(s) and a (set of) SDN controller(s). The former will be in charge of the segment-wide network orchestration and management of NFV (infrastructure and software) resources, focusing on virtualization-specific management tasks (e.g. control of the lifecycle of all VNFs running in the NFV infrastructure). On the other hand, the SDN controller(s) will exploit a number of programmatic interfaces to the different network functions, regardless of whether they are virtualized on top of the NFVI or implemented in specialized hardware, to consolidate the execution of some control plane functions in a segment-wide, centralized point.

On this basis, the proposed approach for the combination of the terrestrial and satellite segments also introduces the concept of the federated network resource manager. This entity, illustrated in Figure 1, provides a set of APIs to the operator/customer front-end for the specification of the end-to-end service and network description. Based on this network specification, the federated network resource manager would make decisions regarding the availability of the resources requested by the operator/customer and will enforce the decided resources in a unified way, to the underlying infrastructures, regardless of whether it is a satellite or a terrestrial one. To that end, the federated network resource manager is to be responsible for the coordinated management and operation of both NFV resources and SDN-enabled control plane functionalities of the deployed end-to-end network service across the satellite and terrestrial segments. In this way, consistent end-to-end policies can be enforced.

The proposed overall architecture shall be able to provide virtualized network services (Network as a Service, NaaS). Simultaneous provision of multiple network slices on the same platform will be supported (i.e., multi-tenancy). Each network slice can have a distinct policy and be controlled by a different entity (e.g. mobile/fixed network operator, service content provider, enterprise, etc.). Virtualized network services could be offered as per demand and on a dynamic basis, subject to e.g. time and availability of resources.

The development of the conceptual framework described in this paper is currently being undertaken by EU H2020 VITAL research project [6].

4. Conclusions

NFV and SDN technologies can become key facilitators for the combination of terrestrial and satellite networks. Enabling NFV into the SatCom domain will provide operators with appropriate tools and interfaces in order to establish end-to-end fully operable virtualized satellite networks to be offered to third-party operators/service providers. Enabling SDN-based, federated resource management paves way for a unified control plane that would allow operators to efficiently manage and optimize the operation of the hybrid network.

The proposed solution is expected to bring improved coverage, optimized communication resources use and better network resilience, along with improved innovation capacity and business agility for deploying communications services over combined networks.

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