IEEE COMSOC MMTC E-Letter

Boosting Satellite & Terrestrial Networks Integration through NFV/SDN Technologies

Ramon Ferrás, Oriol Saltell, Tinku Rasheed, Arianna Morelli, Harilaos Koumaras, George Agapiou, Christelle Boustie, Patrick Gérald, Rachid Mestari, Haritos Makis, Thierry Masson

1Universitat Politècnica de Catalunya (UPC), Spain; 2Center for Research And Telecommunication Experimentation for NETworked communities (CNET), Italy; 3INTECS S.p.A., Italy; 4National Centre for Scientific Research "Demokritos" (NCSR), Greece; 5Hellenic Telecommunications Organization S.A. (OTE), Greece; 6Centre National d’Etudes Spatiales (CNES), France; 7Synaptic SAS, France; 8HellasSAT, Greece; 9One Access, France

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 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.

Acknowledgement

Research leading to these results received funding from the European Union’s H2020 Research and Innovation Action under Grant Agreement H2020-ICT-644843 (VITAL Project).

References


Ramon Ferrús (ramon.ferrus@upc.edu) is Associate Professor at the Universitat Politècnica de Catalunya (UPC). His research interests include network architectures, protocols, radio resource and spectrum management in wireless communications. He has participated in several research projects within the European Commission 6th and 7th Framework Programmes as well as in research and technology transfer projects for private companies. He is co-author of one book on mobile communications and one book on mobile broadband Public Safety communications. He has co-authored over 100 papers published in peer-reviewed journals, magazines, conference proceedings and workshops.

Oriol Sallent (sallent@tsc.upc.edu) is a Professor at the Universitat Politècnica de Catalunya (UPC). He has participated in a wide range of european projects with diverse responsibilities as WPLeader and Coordinator partner and contributed to standardisation bodies such as 3GPP, IEEE and ETSI. He has published 200+ papers mostly in IEEE journals and conferences. His research interests include, among others, Cognitive management in cognitive radio networks, Dynamic spectrum access and management, Self-organising networks and radio network optimization, Integration of satellite and terrestrial networks and QoS provisioning in heterogeneous wireless networks.

Dr. Harilaos Koumaras was born in Athens, Greece in 1980. He received his BSc degree in Physics in 2002 from the University of Athens, Physics Department, his MSc in Electronic Automation and Information Systems in 2004, being scholar of the non-profit organization Alexander S Onassis, from the University of Athens, Computer Science Department and his PhD in 2007 at Computer Science from the University of Athens, Computer Science Department. Dr. Harilaos Koumaras is an active researcher in the field of evaluation of the perceived quality of multimedia services, including video and picture quality assessment, media distribution over SDN/NFV, video traffic modeling, digital terrestrial television and video compression techniques. Dr. Koumaras has been an active research associate since 2003 of Media Net Lab at the National Centre of Scientific Research "Demokritos".

Dr. Tinku Rasheed is a Senior Research staff member, heading the Future Networks Area within CREATE-NET. Before joining CREATE-NET, Dr. Rasheed was research engineer with Orange Labs for a period of 4 years. He received his Ph.D. degree from the Computer Science Department of the University of Paris-Sud XI., in 2007, M.S. degree in 2003 from Aston University, U.K. and bachelor degree in 2002 in Telecommunications from University of Kerala, India. Dr. Rasheed has extensive industrial and academic research experience in the mobile wireless communication area, end-to-end network architectures and services. He has several granted patents and has published more than 60 articles in major journals and conferences. He is a member of the IEEE and ACM.

Dr. George Agapiou is a telecommunications engineer, holding a PhD from the Georgia Institute of Technology. He is the Head of the Measurements and Wireless Technologies Research Laboratory of the Hellenic Telecommunications Organization (OTE S.A.) where he tests and evaluates major technologies, terminals and services. He has participated in various IST, STREP, Eurescom, e-ten, FP6, FP7, H2020 research projects with major role and has published more than 50 papers in scientific journals and proceedings. His research interests include next generation wired and wireless access networks and novel broadband technologies and services.

Mrs Christelle Boustie (F) received the Diploma in Space Telecommunications from the Aeronautical and Space Institute (SUPAERO) of Toulouse (France) in 1999. In 2000, she joined the Centre National d’Etudes Spatiales as Engineer in space ground station development. Since 2008, she is working in mobile space telecommunication research area, as first telecommunication system Engineer, and now as satellite communication project manager. More recently, she had in charge at CNES the technical coordination of activities for the French collaborative project M3 and the Celtic collaborative project Engines.

Ms Arianna Morelli (F) received her Master's Degree in Telecommunications Engineering in 2003 from the University of Pisa. She has been working at Intecs since 2007 on system design and development for telecommunications systems in the professional and defence domains. Since 2009 she has been involved in the FP7 SANDRA Integrated Project, with a focus on Software Defined Radio (SDR). Since 2013 she is involved in CROWD project which aims to define new mechanisms to influence the behaviour of the future extremely dense networks. She is the Intecs delegate within ETSI TC RRS.