INFOLYSiS

Technical White Paper

A comparative CAPEX Techno-economic Analysis of NFV Applicability on the ground segment of GEO/MEO/LEO Satellite Systems

INFOLYSiS P.C.
www.infolysis.gr
Keiriadon 44,
11854, Athens,
Greece

Legal Notice

Executive Summary

Emerging technologies for infrastructure and service virtualisation promise radical changes in the way IT and telecommunications systems are designed, operated and managed. The satellite industry, and satcom networking could also benefit from this trend, introducing new methods for network operations and management, with key advantages in terms of agility, flexibility, reprogrammability, scalability. This paper presents a technoeconomic analysis of the capital expenses reduction achieved by the applicability of the virtualisation in comparison to the original HW-based ground segment equipment for three different satellite system configurations. Based upon both the achievable cost effectiveness and economic gains, conclusions are derived on the business opportunity and cost reduction rate of virtualization in the satcom industry.

Keywords: NFV, virtualisation, satellite, techno-economic, cost, reduction

DOI: 10.13140/RG.2.2.19289.11366

DOI: 10.13140/RG.2.2.19289.11366

1. Introduction

Emerging technologies for infrastructure and service virtualisation promise radical changes in the way IT and telecommunications systems, including terrestrial networks, are designed, operated, and managed. Indeed, the increase of commodity IT resources, due to the success of cloud computing, has favoured the general trend of "softwarisation", initially driven by the cost factor (cost vs. gains). More and more specialized tasks that could previously only be implemented in dedicated hardware can now be run as simply as any application program on generic computing platforms - such a low-cost PCs produced at large scales – and for which the offer of available software solutions is extremely rich. This is the concept widely known as Network Functions Virtualisation (NFV) [1].

The satellite industry, and satcom networking could also benefit from this newest trend, introducing new methods and approaches for network operations and management, with key advantages in agility, flexibility, reprogrammability and scalability [2]. More than in any existing telecom sector, satcom requires costly hardware platforms at different stages of the design and production chains before full operational products and systems can be delivered and deployed.

In this context, with NFV, the flexibility and agility introduced by softwarising network functions [3] can be seen so as to significantly contribute to alleviating the current ossification of satellite platforms. By migrating network functionalities to software entities, new network protocols can be deployed rapidly, tested and fine-tuned without affecting the operation of the satellite network [4]. Ultimately, in the long term, this concept could also be applied on-board, adding unprecedented flexibility and reconfigurability to on-board processing. Routing/switching paradigm in future constellation-based systems could also be heavily affected.

In addition, network functions can be offered on-demand to satellite customers in the Virtual Network Function-as-a-Service (VNFaaS) context, significantly expanding the service portfolio of satcom service providers [4]. For this purpose, Virtual Network Functions (VNFs) initially developed for terrestrial networks can be slightly adjusted to match the specificities of satcom and introduced to the satellite domain, thus vastly enriching the functionalities and capabilities of the latter. Finally, expanding the NFV paradigm to also embrace the radio front-end (long-term), allows the full virtualisation of the satellite delivery chain, its slicing and its provision "as-a-Service" to multiple tenants, greatly facilitating the concept of Satellite Virtual Network Operators (SVNOs) [2].

In this framework, this paper presents a technoeconomic analysis, where financial analysis models are described with an appropriate cost effectiveness assessment, estimating a CAPEX cost reduction by the applicability of NFV in comparison to the original HW-based for three different satellite system configurations: Geostationary Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO) respectively. Then, the paper provides a Cost Benefit analysis section, discussing the direct or indirect impacts of the NFV applicability on future satellite telecommunication networks, and

DOI: 10.13140/RG.2.2.19289.11366

identifies economic benefits and constraints. Based upon both the achievable cost effectiveness and economic gains, conclusions are derived on the business opportunity and suitability of the NFV model.

The rest of the paper is organized as follows: Section 2 discusses the business dimensions of the virtualization in the satcom industry. Section 3 presents the existing background works in the field of NFV advantages in terrestrial networks. Section 4 provides the financial technoeconomic analysis of NFV applicability in satcom for the GEO/MEO/LEO systems, while Section 5 provides a comparative cost benefit analysis between the three cases, discussing the potential benefits and providing also a sensitivity analysis on the potential NFV cost reduction rate per satellite system type. Finally, Section 6 concludes the paper.

2. Business dimensions of NFV applicability in satcom

Currently, the business model of the satellite operators is limited to rigid, slow and hard to change schemes, which do not allow fast adaptations. Network architecture today is closed, complicated, and still focused on network elements that only allow individual (and not federated) management. In other words, the current business model of the network provision is closed, protocol-centric and vertically fragmented with management software being embedded within each network node/device, lacking a horizontal approach with coherent and unified management per tenant (i.e. per network slice) [5].

In this context, NFV can be seen by satcom stakeholders as the enabling technology towards a new business model, which moves the current situation from rigidness to elasticity, from slow adaption to fast adaption and from vertical to horizontal provision of the network resources, enabling new network capabilities [6].

From a business point of view, NFV offers the potential to radically redefine the architectural logic of satellite networks, by softwarising key network functions at the core and the edge [4], [5]. The business value introduced by NFV to satcom could be identified in the following aspects:

- Consolidation of satcom hardware resources, leading to reduced equipment investment and maintenance costs (reduction of both capital and operating expenses).
- Power consumption reduction and enhanced green fingerprint via consolidation of several functions into a small number of servers.
- Enhanced resource utilization due to sharing/reallocation of resources among different network functions and tenants.
- Enhanced elasticity of satcom resources assigned to each network function, further optimizing resource usage and reducing costs.
- Opportunity to expand the satcom service portfolio with VNFaaS offerings; NFV enables satellite service providers to offer new types of services, creating virtualized service instances specifically for each customer/tenant and customizing them accordingly.
- Accelerated deployment of novel/upgraded satcom functions, leading to significant decrease of Time-To-Market (TTM). Such a reduced TTM, gives to the satcom

DOI: 10.13140/RG.2.2.19289.11366

industry unprecedented flexibility and adaptability to market needs and changes. For this purpose, concerning the impacted product lifecycle, it should be claimed that NFV has the potential to radically speed up the satcom product lifecycle, since it provides a solution towards the fast turn-around of the production evolution by low cost software updates and deployment.

- Promotion of innovation and competition, by opening a part of the satcom market and transforming it to a novel virtual appliance market, facilitating the involvement of software stakeholders. However, this opening could also be seen as a major threat by the most important actors of the sectors (big satcom operators, for instance). For some markets and/or geographical areas where a given provider or operator are in deep competition, open/virtualisation should be seen as valuable differentiators. But, on the other hand, in some well-established businesses, reluctance shall be expected in general on opening and virtualising products and solutions. Arguments are mostly similar to the ones related to the effectiveness of integration between satellite and terrestrial networks.

From a service point of view, the automation of service deployment reduces significantly the time required for delivering new services according to the customer needs [3]. 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 device, usually done manually. NFV is able to leverage the programmability of the network functions using appropriate APIs, shortening the time provision significantly [1].

Moreover, the ability offered by NFV to compose various network services rapidly and efficiently by chaining together virtual network appliances, is very important for satcom operators, who currently deal with a very specific hardware-based service chain, which does not allow any service bundling and assembling. The ability to blend services dynamically will promote a marketing mix, which opens new opportunities to the niche markets of the satellite industry.

Another significant stakeholder interest on NFV and VNF deployment should be spotted on the transformation of the fault resilience and availability cases. For example, in a conventional network, the failure of a hardware system is typically service-affecting and it requires urgent action to replace the failed unit in order to restore the proper level of fault tolerance. With NFV this business process is modified since the failure of a piece of hardware has no more impact on the service delivery except than a temporary reduction in the QoS and performance of a given service, which is accommodated by the rest available hardware resources (e.g. by migrating the VNF from a faulty server to a failover one). With the NFV reform, it is not anymore necessary to replace the failed hardware immediately and the service is continued even at a reduced QoS level. This modified business process introduces significant changes in the operational demands of the satcom provider, providing the business opportunities for new QoS constraints, high availability services and fault resilience schemes.

3. Background Financial Analysis of NFV applicability in terrestrial networks

DOI: 10.13140/RG.2.2.19289.11366

It is fundamental for the accuracy and validity of the financial analysis, to have an accurate and trustworthy estimate of the cost reduction percentage resulting from the use of NFV technology and moving from a HW-based satcom deployment without virtualization to a deployment of SW-based virtualization (NFV enabled).

Several things have to be considered when deploying SW-based virtualization (NFV), including accrued cost savings, business models, and architectural options. Cost must be considered over a full five-year lifecycle that would include both capital expenses (CAPEX) as well as operating expenses (OPEX). CAPEX reductions may become apparent immediately, while OPEX will improve over time. Further, NFV helps service providers avoid the traditional stair-step CAPEX needed to provision capacity in advance of expected demand. Instead, it follows a cloud utility-based business model where capacity is easily and cost-effectively added when you need it.

Within the above framework, three studies [7], [8], [9] for NFV-based terrestrial networks have been taken into account and used as a reference in order to assess and quantify the cost benefits of an NFV-based deployment versus existing HW-based ground segment satcom deployment without virtualization.

According to [8], a virtual Customer Premises Equipment (vCPE) use case is analyzed and findings conclude that NFV deployment can reduce costs for about 18% to 24%, depending on the size of the deployment. Even with increased software costs, the reduction in hardware, installation, configuration, and power costs is more than enough to compensate [8].

Similarly, [7] proved how even a simple application like DNS can benefit enormously from running on an NFV platform. The cost savings analysis is related to three main cost drivers: CAPEX, OPEX infrastructure and OPEX processes. It shows the enormous benefits brought about by NFV even for a simple application such as DNS. In addition, apart from substantial monetary gains, the study determined that running the DNS application on Cloud simplifies complex processes such as healing and software upgrading, which gives service providers greater agility and flexibility. The analysis shows an impressive reduction in most of the process-related costs. In relative numbers, software upgrading and healing show an 83% and 86% reduction, respectively. In the shared scenario, the CAPEX and the OPEX infrastructure-related costs increase their contribution to the savings as the cost of idle capacity is not allocated to DNS. In total, concerning CAPEX and OPEX costs, we have cost savings of 41% and 65% respectively per case scenario.

Finally [9] identified that communication network operators could reduce capital expenditure by 68% and operating expenditure by 67% through the use of NFV. Explaining its findings in greater detail, the research says there are two main sources of cost savings: the use of x86-based hardware with the virtualized solution, compared with proprietary processing blades in the traditional one, and the service flexibility of the virtualized solution next to the traditional technology. Another factor in the cost savings is a reduction in systems management thanks largely to the orchestration capabilities of the virtualized solution. NFV virtualization will cut service deployment time in half, in many cases, thanks to service orchestration, a reduction in the number of manual processes and greater automation.

DOI: 10.13140/RG.2.2.19289.11366

Study	Cost Savings %
Hewlett-Packard (2014)	24%
Alcatel-Lucent (2014)	65%
ACG Research (2013)	67,5%
NFV Cost Reduction Rate	**52%**

Table 1 NFV cost reduction rates for terrestrial networks/use cases

Summarising the findings of the three studies, as Table 1 shows, we deduce an average NFV-based cost reduction rate of 52% for the case of terrestrial networks/use-cases, which will be used as input to our financial analysis of NFV applicability in satcom industry, since relevant satellite studies –to the best of our knowledge- are not available yet. Therefore, this cost reduction rate will be used in our analysis for estimating the cost benefit due to the virtualisation of any satellite ground segment equipment, for which a softwarised/virtualised version is not commercially available. For all the rest components, where softwarised/virtualised versions are commercially available, our analysis is based on actual market prices and costs.

4. Financial Analysis of NFV applicability in satcom

a. Assumptions of the Analysis

In order to form a sound framework for evaluating the NFV applicability on satcom in a financial context, particular reasonable and realistic assumptions have to be made. More specifically, the assumptions, on which the proposed financial analysis is based, are the following:

- Two type of deployments are compared in our financial analysis for CAPEX benchmarking of the three satellite systems (GEO, MEO, LEO):
  1. A typical HW-based satcom deployment without virtualization (which will be used as a benchmarking case) and
  2. A future NFV-based satcom deployment, in which the elements that are capable of being softwarised, have been virtualized and the relevant cost reductions have been estimated.
- NFV-related hardware and software investments/costs as well as installation/configuration/license fees (for a 5-year period) are considered as part of the calculated CAPEX.
- Establishment costs, such as space leasing, personnel, salaries, extra training, compensations etc., are not taken into account, since the financial analysis considers an existing and already operational satcom enterprise.
- Cost, price, rates and charges suggestions for the CAPEX and OPEX calculations are result of market research and represent rates, cost and prices of actual market hardware, software products and/or services.
- CAPEX costs are recorded as initial investment expense in year zero (Y0).
- All amounts are in Euro currency. Current currency conversion rates have been applied whenever required.

DOI: 10.13140/RG.2.2.19289.11366

- Analysis is made and presented by the perspective of well-established business entities.
- Markets are characterized by economic stability (fixed rates and variables) unless otherwise stated.
- Regulatory framework is not restrictive to NFV network model.
- Data consistency and quality is ensured throughout the analysis.
- The table below summarizes the major differences among LEO, MEO and GEO satellite systems. It is important to point out the difference in the terrestrial gateway cost which highly affects the CAPEX estimates of this analysis.

Parameter	LEO	MEO	GEO
Satellite Height	700 to 1400 Km	10,000 to 15,000 Km	36,000 Km
Orbital Period	10-40 minutes	2-8 hours	24 hours
Number of Satellites per operator	40 +	10 to 15	3 to 4
Satellite Life	3 to 7 yrs	10 to 15 yrs	10 to 15 yrs
Space Segment Cost	High	Low	Medium
Terrestrial Gateway Cost	High	Medium	Low
Propagation Loss	Least	High	Highest

Table 2 Satellite systems differences

b. Benchmarking analysis case 1: GEO

This section provides the CAPEX financial analysis of a typical GEO satellite system HW-based versus an NFV-based deployment. This benchmarking process is a good indicator of proving the actual cost reduction that occurs when a GEO satcom infrastructure deployment is SW-based and virtualization-capable as NFV proposes.

i. Typical GEO HW-based Satcom deployment without virtualization

In order to establish a GEO HW-based satcom deployment, a typical satellite hub infrastructure should be developed (we consider a single hub for GEO configuration). This infrastructure is part of the initial investment cost which is composed by the components of Table 3. The cost of all components results from market research and represents cost and prices of actual market hardware, software products and/or services.

Typical satellite hub infrastructure (GEO HW based)	Representative Cost
Outdoor unit (eg Antenna, RF front-end etc)	70,000.00 €
Modulator	250,000.00 €
Encapsulator/Multiplexer	

DOI: 10.13140/RG.2.2.19289.11366

Return Link sub-system	
GW Management & Access Control	
Terrestrial interface subsystem (firewall) 5 year license	25,000.00 €
Terrestrial interface subsystem (PEP)	4,500.00 €
Terrestrial interface subsystem (router)	10,000.00 €
TOTAL	359,500.00 €

Table 3 GEO H/W based deployment CAPEX

The provided representative costs will be used for comparison purposes against the corresponding findings of the GEO SW-based/NFV-enabled Satcom deployment case, following in the next sub-section.

ii. GEO with NFV-enabled/software-based ground segment

This section provides the financial analysis of a GEO full stack SW-based satcom deployment with use of virtualization through NFV. The results of this analysis will be compared against the corresponding results of GEO HW-based satcom deployment as presented in the previous sub-section. This benchmarking process will estimate the actual cost reduction that occurs when a satcom infrastructure deployment is SW-based and virtualization-capable, as NFV defines, compared to the typical HW-based infrastructures without the use of virtualization.

In this scenario, we consider the development of a typical satellite hub infrastructure with software/NFV capability. The same satellite hub infrastructure presented previously, is used again but with several HW-based components/services being replaced by SW-based. In addition, extra components are introduced in order the additional software needs to be served efficiently, such as NFV Infrastructure Points of Presence (NFVI-PoP), which are comprised of generic servers hosting the Virtual Network Functions (VNFs), the NFV Orchestrator for the management and coordination of the NFV-related actions and the rest generic servers hosting the virtualization of the satellite gateway systems.

A major prerequisite for achieving an accurate CAPEX calculation for such a deployment is the precise cost estimate of the involved software components. Based on the three business studies [7], [8], [9] presented and analyzed in section 3, the NFV Cost Reduction Rate of 52% will be applied for the cost reduction calculation of the typical HW-based hub components, for which a SW-based version is not yet commercially available. In specific the cost of all hardware components of the typical GEO HW-based satellite hub infrastructure, which are physically capable of virtualization, will be discounted by 52% (i.e. the terrestrial derived NFV-cost reduction rate) in order to provide an accurate cost estimation of their software-based versions. For all the rest components, for which softwarised versions commercially exist, costs and prices of actual market products have been identified and used. However, further down in Section 5, a sensitivity analysis is performed on the 52% terrestrial based NFV-cost reduction rate in order to assess the impact of potentially different (higher or lower) reduction rates to the total estimated cost for the satcom business case.

Table 4 presents the cost reduction process for those hardware components with enabled software capability plus the additional ones needed for such a deployment.

DOI: 10.13140/RG.2.2.19289.11366

Typical satellite hub infrastructure (GEO HW-based)	HW-based Cost	Capable of Virtualization	NFV Cost Reduction Rate	GEO SW-based virtualization Cost
Outdoor unit (eg Antenna, RF front-end etc)	70,000.00 €	NO	-	70,000.00 €
Modulator Encapsulator/Multiplexer Return Link sub-system GW Management & Access Control	250,000.00 €	YES	52%	120,000.00 €
Terrestrial interface subsystem (firewall) with 5 year license	25,000.00 €	YES	-	17,500.00 €
Terrestrial interface subsystem (PEP)	4,500.00 €	YES	-	2,500.00 €
Terrestrial interface subsystem (router)	10,000.00 €	NO	-	10,000.00 €
Plus additional components/services required for a SW-based virtualization deployment				
Satellite Hub Generic Server HW (2 servers each)	-	-	-	10,000.00 €
Satellite Hub Generic Server Software Configuration	-	-	-	3,500.00 €
NFVI PoP SW + License + Configuration	-	-	-	3,500.00 €
NFVI PoP HW (5 servers each)	-	-	-	25,000.00 €
Orchestrator (HW/SW)				30,000.00 €
TOTAL	**359,500.00 €**			**292,000.00 €**
GEO CAPEX NFV-based cost reduction rate				**18.78%**

Table 4. GEO Cost reduction Process

The initial cost of all components results from market research and represents cost and prices of actual market hardware, software products and/or services which are discounted (wherever applicable) by the NFV Cost Reduction Rate of 52%. Although detailed comparative evaluation of financial results of the two deployments (HW-based without virtualization vs SW-based virtualization) will be presented in section 5, it is worth mentioning that initial investment cost (CAPEX) has been **reduced from 359,500€**

DOI: 10.13140/RG.2.2.19289.11366

to 292,000€, a cost reduction of 18.78%, as result of the SW-based virtualization capability of the GEO satcom deployment.

c. Benchmarking analysis case 2: MEO

This section provides the CAPEX financial analysis of a typical MEO satellite system HW-based satcom deployment versus an NFV-enabled configuration. This benchmarking process is a good indicator of proving the actual cost reduction that occurs when a satcom infrastructure deployment is MEO, SW-based and virtualization-capable.

For this MEO benchmarking case analysis:

- The characteristics of a typical MEO operator have been used (e.g. O3B [10])
- Both the HW and SW based configuration is based on the use of 10 terrestrial gateways and their corresponding components.
- One typical MEO Gateway cost is set at 340,000 €

i. Typical MEO HW-based Satcom deployment without virtualization

In order to establish a MEO HW-based satcom deployment, a typical MEO satellite hub infrastructure should be developed (composing of 10 terrestrial gateways). This infrastructure is part of the initial investment cost which is composed by the components presented at Table 5. The cost of all components results from market research and represents cost and prices of actual market hardware, software products and/or services.

Typical satellite hub infrastructure for 10 gateways (MEO HW based)	Cost per Unit	Units for 10 gateways	Cost
Outdoor units	100,000.00 €	10	1,000,000.00€
Modulator	340,000.00 €	10	3,400,000.00€
Encapsulator/Multiplexer			
Return Link sub-system			
GW Management & Access Control			
Fibre Leased Lines (1 GBps annual cost + initial installation)	30,000.00 €	10	300,000.00 €
Terrestrial interface subsystem (firewall) 5 year license	25,000.00 €	10	250,000.00 €
Terrestrial interface subsystem (PEP)	4,500.00 €	10	45,000.00 €
Terrestrial interface subsystem (router)	10,000.00 €	10	100,000.00 €
TOTAL			5,095,000.00€

Table 5. MEO H/W based deployment CAPEX

Since this case is used for benchmarking purposes we will not proceed with detailed analysis/interpretation of findings at this point. All results will be used for comparison

DOI: 10.13140/RG.2.2.19289.11366

purposes against the corresponding findings of the MEO SW-based satcom deployment case, following in the next subsection.

ii. MEO with NFV-enabled/software-based ground segment

This subsection provides the financial analysis of an NFV-enabled MEO satcom system. This benchmarking process will prove the actual cost reduction that occurs when a satcom infrastructure deployment is SW-based and virtualization-capable, as NFV defines, compared to the typical HW-based infrastructures without the use of virtualization.

A major prerequisite for achieving an accurate CAPEX calculation for MEO deployment is the precise cost estimate of the involved GW software components. Based on the three NFV cost reduction studies [7], [8], [9] presented and analyzed in section 3, the average NFV Cost Reduction Rate of 52% (as calculated for terrestrial network components) will be applied for the NFV cost reduction calculation of the MEO HW-based GWs.

However, for the MEO case, beyond the cost reduction of the a single MEO GW, it must be mentioned that in order to establish a MEO satcom deployment worldwide, a group of an average 10 MEO gateways should be considered for virtualization at distributed NFVI-PoPs at the geographical areas of interest. However, instead of considering an 1-to-1 cardinality between each GW and NFVI PoP, one of the added-values of the NFV approach is the ability to collocate more than one NFV-based MEO GWs within the same cloud data centre (i.e. NFVI PoP), achieving by this way multiple cost reduction. In this direction, we consider in our analysis that the initially 10 deployed GWs will be virtually instantiated at 7 NFVI PoPs. The relative ratio of using 7 NFVI-PoP units (instead of 10) results to an additional 30% cost reduction to the initial cost needed for 10 units in terms of network equipment and network elements.

However, this concentration of the SW-based GWs to less NFVI-PoPs has as a result the cost increase of the Fibre Leased Lines needed for connectivity in comparison to the cost estimated for 10 HW-based GWs. The reason for the increased connectivity cost is that in the virtualization case, it is created the need to connect the ODUs to the NFVI-PoPs and then each NFVI-PoP to the network. Therefore, we consider an increase by 50% in the initial connectivity cost (estimating 15 connections instead of 10 connections).

Typical satellite hub infrastructure (MEO HW-based)	HW-based Cost (for 10 gateways)	Capable of Virtualization	Cost Reduction/Increase Rate	MEO SW-based virtualization Cost
Outdoor units	1,000,000.00€	NO	-	1,000,000.00 €
Modulator	3,400,000.00€	YES	NFV Cost Reduction - 52%	1,632,000.00 €
Encapsulator/Multiplexer				
Return Link sub-system				
GW Management & Access Control				

DOI: 10.13140/RG.2.2.19289.11366

Fibre Leased Lines (1 GBps annual cost + initial installation)	300,000.00 €	NO	(for 15 units) +50%	450,000.00 €
Terrestrial interface subsystem (firewall) with 5 year license	250,000.00 €	YES	(17,500*7) -30%	122,500.00 €
Terrestrial interface subsystem (PEP)	45,000.00 €	YES	(2,500*7) -30%	17,500.00 €
Terrestrial interface subsystem (router)	100,000.00 €	YES	(7 units) -30%	70,000.00 €
Plus additional components/services required for a SW-based virtualization deployment				
Satellite Hub Generic Server HW (2 servers at 10,000€)	-	-	(7 units)	70,000.00 €
Satellite Hub Generic Server Software Configuration (3,000€)	-	-	(7 units)	24,500.00 €
NFVI PoP SW + License + Configuration(3,000€)	-	-	(7 units)	24,500.00 €
NFVI PoP HW (5 servers at 25,000€)	-	-	(7 units)	175,000.00 €
Orchestrator (HW/SW)	-	-	-	30,000.00 €
TOTAL	**5,095,00.00 €**			**3,616,000.00 €**
MEO CAPEX NFV-based cost reduction rate				**29.03%**

Table 6. MEO Cost reduction Process

The cost values of all the components results from market research and represents cost and prices of actual market hardware, software products and/or services.

Although detailed evaluation of financial results of the two MEO deployments (HW-based without virtualization vs SW-based virtualization) will be presented in section 5, it is worth mentioning that initial investment cost (CAPEX) has been **reduced from 5,095,00.00 € to 3,616,000.00 €, a cost reduction of 29.03%,** as result of the SW-based MEO satcom deployment and the centralization of the GW function to less in number NFVI-PoPs.

d. Benchmarking analysis case 3: LEO

This section provides the CAPEX financial analysis of a typical LEO satellite system HW-based satcom deployment versus a SW-based LEO system.

For this LEO benchmarking case analysis:

- The characteristics of a typical LEO operator are considered (e.g. OneWeb [11]).
- Both the HW and SW based configuration is based on the use of 50 terrestrial gateways and their corresponding components.
- One typical LEO terrestrial gateway cost is set at 750,000 €

i. Typical LEO HW-based Satcom deployment without virtualization

DOI: 10.13140/RG.2.2.19289.11366

In order to establish a typical LEO HW-based satcom network, we assume the deployment of 50 terrestrial gateways worldwide. This infrastructure is part of the initial investment cost which is composed by the following components as listed in Table 7. The cost of all components results from market research and represents cost and prices of actual market hardware, software products and/or services.

Typical satellite hub infrastructure for 50 gateways (LEO HW based)	Cost per Unit	Units for 50 gateways	Cost
Outdoor units	100,000.00 €	50	5,000,000.00€
Modulator	750,000.00 €	50	37,500,000.00€
Encapsulator/Multiplexer			
Return Link sub-system			
GW Management & Access Control			
Fibre Leased Lines (1 GBps annual cost + initial installation)	30,000.00 €	50	1,500,000.00 €
Terrestrial interface subsystem (firewall) 5 year license	25,000.00 €	50	1,250,000.00 €
Terrestrial interface subsystem (PEP)	4,500.00 €	50	225,000.00 €
Terrestrial interface subsystem (router)	10,000.00 €	50	500,000.00 €
TOTAL			45,975,000.00€

Table 7. LEO H/W based deployment CAPEX

Since this case is used for benchmarking purposes we will not proceed with detailed analysis/interpretation of findings at this point. All results will be used for comparison purposes against the corresponding findings of the LEO SW-based satcom deployment case, following in the next section.

ii. LEO with NFV-enabled/software-based ground segment

This section provides the financial analysis of a LEO full stack SW-based satcom deployment with use of virtualization through NFV. The results of this analysis will be compared against the corresponding results of LEO HW-based satcom deployment as presented in the previous section. This benchmarking process will prove the actual cost reduction that occurs when a satcom infrastructure deployment is SW-based and virtualization-capable, as NFV defines, compared to the typical HW-based infrastructures without the use of virtualization.

In order to establish a LEO satcom deployment of SW-based virtualization, a typical LEO satellite hub infrastructure (with 50 terrestrial gateways) should be developed but with virtualization capability. The satellite hub infrastructure presented in previous section, is used again but with several HW-based components/services being replaced by SW-based ones. In addition, extra components are introduced in order the additional software needs to be served efficiently.

DOI: 10.13140/RG.2.2.19289.11366

A major prerequisite for achieving an accurate CAPEX calculation for such a deployment is the precise cost estimate of the involved software components. Based again on the three business studies [7], [8], [9], presented and analyzed in section 3, the NFV Cost Reduction Rate of 52% will be applied for the cost reduction calculation. In specific the cost of all software enabled hardware components of the typical LEO HW-based satellite hub infrastructure will be discounted by 52% in order to estimate the corresponding investment cost of a LEO satcom deployment of SW-based virtualization.

The table below presents the cost reduction process for those hardware components with enabled software capability plus the additional ones needed for such a LEO deployment. Please note that specific components (e.g. leased lines, terrestrial interface, servers, NFVI PoP SW/HW etc) have a cost value reduced by 50%. This is due to the available virtualization services (i.e. NFV) that allow these components to serve more gateways and consequently to need less units in our MEO SW-based virtualization installation (25 instead of 50 units). The relative ratio of using 25 units instead of 50 is equivalent to a 50% cost reduction to the initial cost of 50 units.

In addition the Fibre Leased Lines cost, as estimated for the 50 gateways, is increased by 50% (using 75 units instead of 50) since due to the virtualization services several clouds should be used and more communication lines are required (not just for the 50 gateways).

Typical satellite hub infrastructure (LEO HW-based)	HW-based Cost (for 50 gateways)	Capable of Virtualization	Cost Reduction/Increase Rate	LEO SW-based virtualization Cost
Outdoor units	5,000,000.00€	NO	-	5,000,000.00 €
Modulator Encapsulator/Multiplexer Return Link sub-system GW Management & Access Control	37,500,000.00€	YES	NFV Cost Reduction -52%	18,000,000.00 €
Fibre Leased Lines (1 GBps annual cost + initial installation)	1,500,000.00 €	NO	(75 units) +50%	2,250,000.00 €
Terrestrial interface subsystem (firewall) with 5 year license	1,250,000.00 €	YES	(17,500*25) -50%	437,500.00 €
Terrestrial interface subsystem (PEP)	225,000.00 €	YES	(2,500*25) -50%	62,500.00 €
Terrestrial interface subsystem (router)	500,000.00 €	YES	-50%	250,000.00 €
Plus additional components/services required for a SW-based virtualization deployment				
Satellite Hub Generic Server HW (2 servers at 10,000€)	-	-	(25 units) -50%	250,000.00 €

DOI: 10.13140/RG.2.2.19289.11366

Satellite Hub Generic Server Software Configuration (3,500€)	-	-	(25 units) -50%	87,500.00 €
NFVI PoP SW + License + Configuration(3,500€)	-	-	(25 units) -50%	87,500.00 €
NFVI PoP HW (5 servers at 25,000€)	-	-	(25 units) -50%	625,000.00 €
Orchestrator (HW/SW)	-	-	-	30,000.00 €
TOTAL	**45,975,00.00€**			**27,080,000.00€**
LEO CAPEX NFV-based cost reduction rate				**41.10%**

Table 8. LEO Cost reduction Process

The initial cost of all components results from market research and represents cost and prices of actual market hardware, software products and/or services which are discounted (wherever applicable) by the NFV Cost Reduction Rate of 52%.

Although detailed evaluation of financial results of the two LEO deployments (HW-based without virtualization vs SW-based virtualization) will be presented in section 3.2.5 (CAPEX based Cost Benefit Analysis of Benchmarking cases), it is worth mentioning that initial investment cost (CAPEX) has been **reduced from 45,975,00.00€ to 27,080,000.00€, a cost reduction of 41.10%,** as result of the SW-based virtualization capability of the LEO satcom deployment.

5. CAPEX-based Cost Benefit Analysis of GEO/MEO/LEO Cases

In this section, a benchmarking analysis of CAPEX figures of section 4 is presented by comparing the CAPEX financial analysis results of a HW-based vs a SW-based deployment for the three satellite systems (GEO, MEO, LEO). Table 9 summarizes and compares the CAPEX cost for the deployment scenarios (HW and SW/NFV) for the three satellite systems (GEO, MEO, LEO). Amounts refer to the total CAPEX amount per case.

Satellite System	CAPEX (HW-based case)	CAPEX (SW-Based with virtualization case)	Cost Reduction Percentage (%)
GEO	359,500.00 €	292,000.00 €	18.78%
MEO (10 gateways)	5,095,000.00 €	3,616,000.00 €	29.03%
LEO (50 gateways)	45,975,000.00 €	27,080,000.00 €	41.10%

Table 9. Benchmarking cases – Comparison of CAPEX financial figures

In specific, below figures show graphically the CAPEX amount cost reduction per benchmarking case, revealing that significantly higher amounts are saved when the deployment type requires many GWs, such as MEO, but even more in LEO case.

DOI: 10.13140/RG.2.2.19289.11366

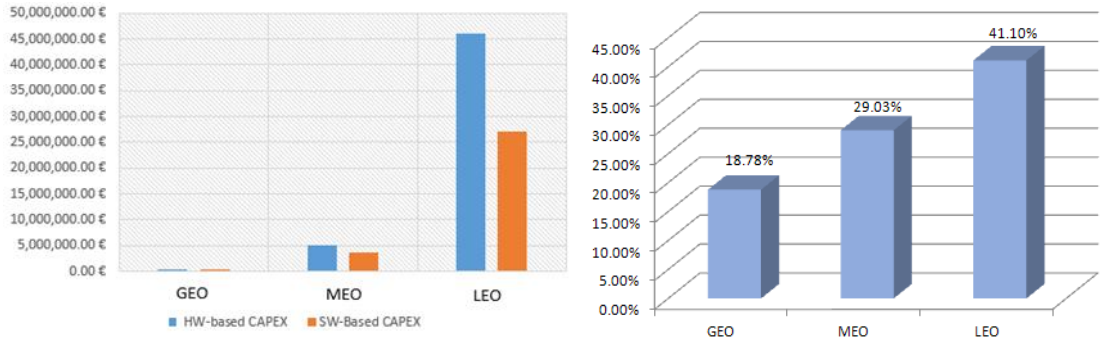

Figure 1. Benchmarking GEO/MEO/LEO – CAPEX cost reduction

Overall, we conclude that introducing a SW-based satcom deployment with virtualization capabilities reduces the initial investment cost (CAPEX) compared to a HW-based one, no matter the selected satellite system (GEO, MEO, LEO), while for satellite systems that require multiple satellite gateways that cost benefits are even higher, reaching up to 41.10%.

The financial analysis in this paper has been based on the use of the averaged NFV cost reduction rate for terrestrial networks/components (i.e. 52%) for any satellite hub component, which is not commercially available to a software version. By using this terrestrial-based NFV Cost Reduction factor of 52%, our analysis has provided a cost reduction of 18.78%, 29.03% and 41.10% for GEO, MEO and LEO respectively.

SAT CAPEX Cost Reduction	NFV Terrestrial Cost Reduction percentages								
	30%	35%	40%	45%	52%	55%	60%	65%	70%
GEO	3.48%	6.95%	10.43%	13.91%	**18.78%**	20.86%	24.34%	27.82%	31.29%
MEO	14.35%	17.68%	21.02%	24.36%	**29.03%**	31.03%	34.37%	37.70%	41.04%
LEO	23.15%	27.23%	31.31%	35.39%	**41.10%**	43.55%	47.62%	51.70%	55.78%

Table 10. Sensitivity Analysis: Benchmarking cases GEO, MEO, LEO

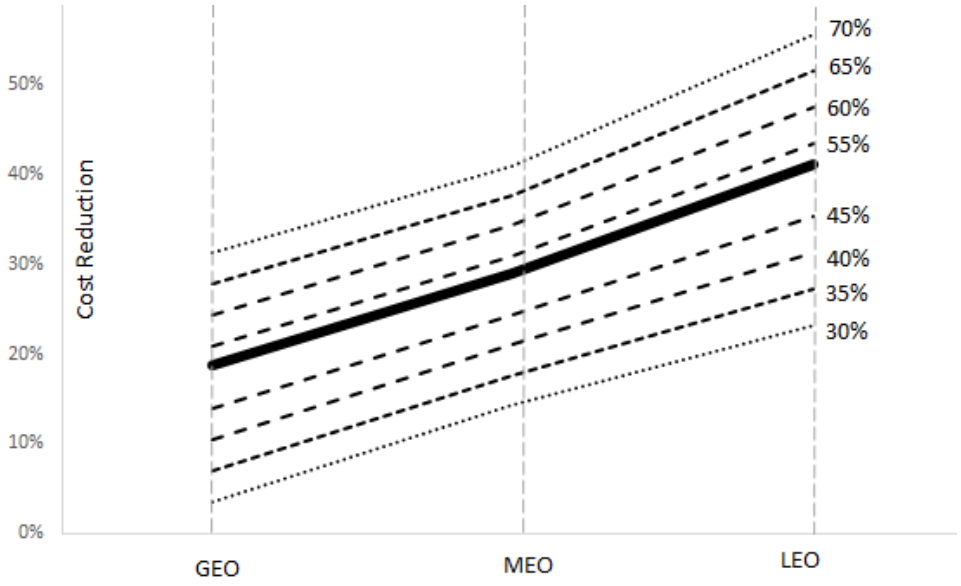

Figure 2. Sensitivity Analysis Graph: Benchmarking cases GEO, MEO, LEO

DOI: 10.13140/RG.2.2.19289.11366

However, in order to verify the sensitivity of our financial results and the corresponding estimated cost reduction percentages, a sensitivity analysis on the impact of the terrestrial NFV-cost reduction rate (i.e. 52%) has been performed per GEO/MEO/LEO case, using different NFV Cost Reduction factors as input to our analysis (i.e. higher or lower than 52%), ranging from 30% up to 70%. Table 10 and Figure 2 summarize the findings of the sensitivity analysis both quantitatively and graphically for better understanding and conception of the potential cost reduction trends.

It is derived that higher NFV-cost reduction rates have a positive impact on the LEO systems, while GEO and MEO systems are proved less sensitive to different rate values. It is evident that the high number of satellite gateways involved in a LEO system has as a result multiple cost benefits by the virtualization and centralization of the systems due to the collocation of them within the same NFVI-PoPs. For the GEO and MEO systems the smaller number of the required gateways minimizes the potential impact of the NFV cost reduction rate on the overall investment expenditure. Similarly, for lower than 52% NFV cost reduction rates, it is observed that the LEO system is affected more by decreasing its overall cost reduction trend in comparison to the GEO and MEO systems.

Summarizing, it is deduced that by introducing a SW-based/NFV-enabled satcom deployment, the initial investment cost (CAPEX) compared to a HW-based one, for any satellite system (GEO, MEO or LEO) is reduced on an overall rate, which is dependent on the virtualization level (i.e. the NFV cost reduction rate). The higher the NFV cost reduction rate (i.e. the virtualization level of the deployment), the more reduced is the overall cost of the investment.

6. Conclusions

This paper has provided a detailed techno-economic analysis of the NFV applicability in the satcom industry, describing the various aspects of the potential business benefits and opportunities that will lead to economic benefit. Financial analysis models are described with an appropriate cost-effectiveness assessment, benchmarking the cost savings of the HW-based and NFV-based satellite GW. The analysis estimates a CAPEX cost reduction, in comparison to the original HW-based, of approximately 18.78%, 29.03% and 41.10% for the GEO, MEO, LEO satellite systems respectively. Finally, the document provides a comparative analysis, discussing the impact of the NFV applicability and virtualization level on the overall cost of investment for the future satellite telecommunication networks.

References

[1] J. Matias, J. Garay, N. Toledo, J. Unzilla and E. Jacob, "Toward an SDN-enabled NFV architecture," *IEEE Communications Magazine ,* vol. 53, no. 4, pp. 187-193, 2015.

[2] L. Bertaux, S. Medjiah, P. Berthou, S. Abdellatif and A. Hakiri, "Software DeFIned Networking and Virtualization for Broadband Satellite Networks," *IEEE Communications Magazine,* vol. 53, no. 3, pp. 54-60, 2015.

DOI: 10.13140/RG.2.2.19289.11366

[3] R. Jain and S. Paul, "Network virtualization and software defined networking for cloud computing: A survey," *IEEE Commun. Mag.,* vol. 51, no. 11, pp. 24 -31, 2013 .

[4] R. Ferrús, H. Koumaras, O. Sallent, G. Agapiou, T. Rasheed, M. A. Kourtis, C. Boustie, P. Gélard and T. Ahmed, "SDN/NFV-enabled Satellite Communications Networks: Opportunities, Scenarios and Challenges," *International journal Physical Communication, Elsevier,* 2015.

[5] R. Ferrús, O. Sallent, T. Rasheed, A. Morelli, H. Koumaras, G. Agapiou, C. Boustie, P. Gélard, R. Mestari, H. Makis and T. Masson, "Enhancing Satellite & Terrestrial Networks Integration through NFV/SDN technologies," *IEEE COMSOC MMTC E-Letter,* vol. 10, no. 4, pp. 17-21, 2015.

[6] B. Evans, M. Werner, E. Lutz, M. Bousquet, G. Corazza, G. Maral and R. Rumeau, "Integration of satellite and terrestrial systems in future multimedia communications," *IEEE Wireless Communications,* vol. 12, no. 5, pp. 72-80, 2005.

[7] Alcatel-Lucent, "Business Case for Moving DNS to the Cloud," 2014.

[8] Hewlett-Packard, "The Reality of Cost Reduction," 2014.

[9] ACG Research study, "NFV Promises Cost Savings of Nearly 70%," 2013.

[10] O3B, "O3B Networks - The reach of satellite with the speed of fiber," O3B Networks, 9 February 2016. [Online]. Available: http://www.o3bnetworks.com/. [Accessed 9 February 2016].

[11] OneWeb, "OneWeb - Oneworld," One Web, 2 February 2016. [Online]. Available: http://oneweb.world/. [Accessed 2 February 2016].

[12] D. Kreutz, F. Ramos, P. Esteves Verissimo, C. Esteve Rothenberg, S. Azodolmolky and S. Uhlig, "Software-Defined Networking: A Comprehensive Survey," *Proceedings of the IEEE,* vol. 103, no. 1, pp. 14-76, 2015.

[13] B. Nunes, M. Mendonca, X.-N. Nguyen, K. Obraczka and T. Turletti, "A survey of software-defined networking: Past, present, future of programmable networks," *IEEE Commun. Surv. Tut.,* vol. 16, no. 3, pp. 1617 -1634, 2014.

[14] A. Lara, A. Kolasani and B. Ramamurthy, "Network innovation using OpenFlow: A survey," *IEEE Commun. Surv. Tut.,* vol. 16, no. 1, pp. 493 -512, 2014.

[15] S. Watts and O. Glenn, "5G resilient backhaul using integrated satellite networks," in *Advanced Satellite Multimedia Systems Conference, 7th, IEEE.*, 2014.

[16] T. Rossi, M. De Sanctis, E. Cianca, C. Fragale, M. Ruggieri and H. Fenech, "Future space-based communications infrastructures based on High Throughput Satellites and Software Defined Networking," in *IEEE International Symposium on Systems Engineering (ISSE)*, 2015.

DOI: 10.13140/RG.2.2.19289.11366