**CHAPTER ONE**

**GENERAL Introduction**

*"Network Functions Virtualization (NFV) is a fundamental change in the way network operators architect networks. It provides a new model to design, deploy and manage networking services, which enables a more agile and cost-effective network that can support new revenue-generating services." - Diego R. Lopez, Chair of the European Telecommunications Standards Institute (ETSI) NFV ISG:*

**1.1 Background and context of the study:**

Network Function Virtualization (NFV) is a concept in the field of networking that aims to virtualize network functions traditionally performed by dedicated hardware appliances. These functions include tasks like routing, switching, firewalling, load balancing and intrusion detection/prevention. NFV emerged as a response to the limitations and inefficiencies of traditional network architectures, which rely heavily on specialized hardware for each network function. By virtualizing these functions and running them as standard software on standard hardware. The study of NFV involves various aspects including architecture designs, performance optimization, security considerations, interoperability, management and orchestration and standardization efforts. Researchers and practitioners explore ways to maximize the benefits of NFV while addressing challenges such as performance overhead, service reliability and integration with existing network infrastructure. NFV has gained significant traction in both academia and industry with organizations such as the European Telecommunications Standard Institute (ETSI) leading standardization efforts and initiatives like the NFV Industry Specification Group (NFV ISG) driving adoption and implementation across the telecommunication industry.

The concept of Network Function Virtualization (NFV) originated from the requirement of telecommunication service providers worldwide, to accelerate deployment of new network services and to support their revenue and future growth objectives. Present day telecommunication networks are over populated with a large and increasing variety of proprietary hardware appliances. Therefore, to launch a new network service, it often requires introduction of yet another variety of proprietary hardware requiring to find the space and power to accommodate these arrangements, which is becoming increasingly difficult. This is further compounded by the increasing costs of energy, capital investment, requirement of huge technical manpower etc. The variety of skills necessary to design, integrate and operate increasingly complex hardware-based appliances, poses real challenge to both developer and the network operator.

Moreover, hardware-based appliances rapidly reach end of life and other cost-oriented issues result in little or no revenue benefit. These constraints/limitations of hardware-based appliances (e.g., Routers, firewalls etc.) led experts to think beyond traditional network system and thereby, resulting into development of various IT virtualization technologies, their standards & incorporation of the same into their networks.

**1.2 PROBLEM STATEMENT**

Telecoms networks contain an increasing variety of proprietary hardware appliances. To launch a new network service often requires yet another appliance and finding the space and power to accommodate these boxes is becoming increasingly difficult, in addition to the complexity of integrating and deploying these appliances in a network.

Moreover, hardware-based appliances rapidly reach end of life: technology lifecycles are becoming shorter as innovation accelerates, reducing the return on investment of deploying new services and constraining innovation in an increasingly network-centric world.

Overall, the reliance on specialized hardware appliances limits agility, innovation and cost-effectiveness in network design and operation. Organizations seek a more flexible, scalable and cost-efficient approach to delivering network services, which will ultimately lead to the exploration and deployment of NFV as a potential solution to these challenges.

**1.3 RESEARCH QUESTIONS**

* Is it possible to solve the issue of cost and operational expenditure?
* Is it possible to make the network more flexible?
* Can we scale the network?
* Can we reduce the complexity of the network?
* Is it possible to minimize/manage the consumption of power?

**1.4 RESEARCH HYPOTHESIS**

* Yes, it is possible to limit capital and operational expenditure (capex & oPex).
* Yes, it is possible to make the network more flexible.
* Yes, we can scale the network.
* Yes, we can reduce the complexity of the network.
* Yes, it is possible to minimize/ manage the consumption of power.

**1.5 GOALS AND OBJECTIVES OF NFV**

**1.5.1 GENERAL OBJCTIVES**

Network Functions Virtualization (NFV) aims to address these problems by evolving standard IT virtualization technology to consolidate many network equipment types onto industry standard high-volume servers, switches and storage. It involves implementing network functions in software that can run on a range of industry standard server hardware, and that can be moved to, or instantiated in, various locations in the network as required, without the need to install new equipment.

**1.5.2 SPECIFIC OBJECTIVES**

The specific objectives of NFV are to:

* To reduce capital and operational expenditure.
* To enable the rapid deployment, scaling and modification of network functions.
* To provide scalability.
* To optimize resource utilization.
* To foster innovation.
* To simplify network operation and management.
* To promote interoperability
* To enhance security.

Overall, the objectives of NFV revolve around improving the efficiency, flexibility, scalability and innovation capabilities of network infrastructures while reducing costs and complexity.

**1.6 IMPORTANCE OF THIS STUDY FOR EDUCATION AND BUSINESS COMMUNITY**

The study of Network Function Virtualization (NFV) holds significant importance for both the education and business communities:

**1.6.1 Education Community:**

* **Training and Curriculum Development:** NFV provides opportunities for educators to develop specialized courses, workshops, and training programs focused on virtualized networking technologies. This helps students gain practical skills and knowledge relevant to modern networking environments.
* **Research and Innovation**: NFV offers a rich area for academic research and innovation, driving advancements in network architecture, virtualization techniques, performance optimization, security, and management. Academic institutions can contribute to the development of new NFV technologies and solutions through research projects and collaborations.
* **Skill Development:** By studying NFV concepts and technologies, students can acquire valuable skills in software-defined networking, virtualization, cloud computing, and network management. These skills are in high demand in the IT industry and can enhance students' employability and career prospects.

**1.6.2 Business Community:**

* **Cost Reduction:** NFV enables businesses to reduce capital and operational expenditures by replacing expensive hardware appliances with cost-effective software-based solutions. This can lead to significant cost savings for organizations deploying and managing network infrastructure.
* **Agility and Innovation**: NFV allows businesses to innovate and adapt more quickly to changing market demands by providing flexible, scalable, and programmable network services. This agility enables businesses to launch new services faster, respond to customer needs more effectively, and gain a competitive edge in the market.
* **Operational Efficiency:** NFV streamlines network operations and management tasks, simplifying deployment, configuration, monitoring, and troubleshooting processes. This improves operational efficiency, reduces time-to-market for new services, and enhances overall productivity.
* **Scalability and Flexibility:** NFV provides businesses with the ability to scale network capacity and functionality dynamically, allowing them to support growing workloads, handle traffic spikes, and adapt to evolving business requirements without overprovisioning hardware.
* **Security and Resilience:** NFV enhances security and resilience by enabling businesses to implement robust security measures, isolate and segment network functions, and deploy redundancy and failover mechanisms more effectively. This helps organizations mitigate security threats, minimize downtime, and ensure business continuity.

In summary, the study of NFV is crucial for both the education and business communities as it offers opportunities for skill development, research, innovation, cost reduction, agility, operational efficiency, and enhanced security in networking environments.

**1.7 SIGNIFICANCE/ ACHIEVEMENTS OF THE STUDY**

The study of Network Function Virtualization (NFV) has led to several significant achievements and contributions to the field of networking:

* **Transformation of Network Architecture:** NFV has fundamentally transformed traditional network architectures by virtualizing network functions that were traditionally performed by dedicated hardware appliances. This shift towards software-based networking has enabled greater flexibility, scalability, and agility in network design and operation.
* **Cost Reduction:** NFV has helped organizations reduce capital and operational expenditures associated with network infrastructure by replacing expensive hardware appliances with more cost-effective software-based solutions. This cost reduction has made advanced networking capabilities more accessible to a wider range of organizations, including small and medium-sized businesses.
* **Improved Resource Utilization:** NFV optimizes resource utilization by consolidating multiple network functions onto shared hardware infrastructure, leading to better utilization of computing resources, reduced power consumption, and improved overall efficiency in data centers and network facilities.
* **Service Innovation:** NFV has fostered innovation in the development of new network services and functionalities by enabling the rapid deployment, chaining, and customization of virtualized network functions. This has led to the creation of innovative services and solutions that address emerging market demands and customer needs.
* **Enhanced Flexibility and Scalability:** NFV provides organizations with greater flexibility and scalability in deploying and managing network services. Virtualized network functions can be easily scaled up or down, deployed on-demand, and migrated across different hardware platforms, allowing organizations to adapt quickly to changing requirements and traffic patterns.
* **Simplified Network Management:** NFV simplifies network management and operations by centralizing the management and orchestration of virtualized network functions. This simplification reduces complexity, automates routine tasks, and improves overall efficiency in network deployment, configuration, monitoring, and troubleshooting.
* **Interoperability and Standardization:** NFV promotes interoperability and standardization by defining common interfaces and protocols for virtualized network functions, enabling seamless integration with existing network infrastructure and facilitating vendor-neutral solutions. This interoperability simplifies deployment and management tasks and promotes innovation through collaboration and ecosystem development.

Overall, the study of NFV has had a profound impact on the networking industry, leading to significant advancements in network architecture, cost reduction, resource utilization, service innovation, flexibility, scalability, management efficiency, interoperability, and standardization. These achievements have contributed to the evolution of networking technologies and have paved the way for the development of more agile, efficient, and innovative network infrastructures.

**1.8 SCOPE OF THE STUDY**

The scope of the study of Network Function Virtualization (NFV) is broad and encompasses various aspects of virtualized networking technologies, architectures, implementations, and applications. Some key areas within the scope of NFV include:

* **Architecture Design:** Studying the design principles, components, and interactions of NFV architectures, including virtualized network functions (VNFs), NFV infrastructure (NFVI), and NFV management and orchestration (MANO) systems.
* **Virtualized Network Functions (VNFs):** Analyzing the characteristics, performance, and functionality of individual VNFs, including routing, firewalling, load balancing, intrusion detection, and other network functions.
* **Performance Evaluation:** Assessing the performance, scalability, and efficiency of NFV solutions in terms of throughput, latency, resource utilization, and scalability under different traffic loads and network conditions.
* **Resource Management:** Investigating resource allocation, scheduling, and optimization techniques for virtualized network functions to maximize resource utilization, minimize contention, and ensure quality of service (QoS).
* **Security and Isolation:** Examining security mechanisms, isolation techniques, and best practices for protecting virtualized network functions and infrastructure from unauthorized access, data breaches, and security threats.
* **Service Chaining:** Exploring strategies and algorithms for orchestrating and chaining multiple VNFs to create end-to-end network services that meet specific service requirements and performance objectives.
* **Management and Orchestration:** Studying the design, implementation, and operation of NFV management and orchestration systems for automating service lifecycle management, resource provisioning, configuration, monitoring, and troubleshooting tasks.
* **Interoperability and Standards:** Analyzing interoperability challenges, standards gaps, and best practices for ensuring compatibility, interoperability, and portability of NFV solutions across different vendors, platforms, and environments.
* **Economic Considerations:** Investigating the cost implications, return on investment (ROI), and total cost of ownership (TCO) of deploying NFV solutions compared to traditional hardware-based approaches, including capital expenditure (CapEx) and operational expenditure (OpEx) considerations.
* **Use Cases and Applications:** Exploring real-world use cases, applications, and deployments of NFV across various industry sectors, including telecommunications, cloud computing, data centers, edge computing, Internet of Things (IoT), and enterprise networking.

The scope of the study of NFV is interdisciplinary, spanning aspects of computer networking, virtualization, cloud computing, software engineering, system architecture, security, economics, and business management. It offers opportunities for research, innovation, and collaboration among academia, industry, standardization bodies, and regulatory organizations to advance the state-of-the-art in virtualized networking technologies and their applications.

* 1. **DELIMITATION OF THE STUDY**

**1.9.1 Technical Requirement/Challenges for Network Function Virtualization**

As an emerging technology in network industry, NFV brings several challenges to network operators, such as the guarantee of network performance for virtual appliances, their dynamic installation and migration, and their efficient placements etc. These challenges to implement the Network Functions Virtualization need to be addressed before implementing the same.

* **Interoperability and Compatibility:**

The key requirement/issue for NFV is to design standard interfaces between not only a range of virtual appliances but also between the virtualized implementations and the legacy equipment. One of the goals of NFV is to promote openness, therefore network carriers may need to integrate and operate servers, hypervisors and virtual appliances from different vendors in a multi-tenant NFV environment. Their seamless integration requires a unified interface to facilitate the interoperability among them. The developed NFV solutions need to be compatible with existing Operation and Business Support Systems (OSS/BSS) and Element and Network Management Systems (EMS/NMS), and work in a hybrid environment with both physical and virtual network functions. In the long run, network operators must be able to migrate smoothly from proprietary physical appliances to open standard based virtual ones, since they may not be able to keep updated all their existing services and equipment in proprietary physical network appliance-based solutions.

* **Performance Trade-Off:**

Since the Network Functions Virtualization approach is based on using industry standard hardware (i.e., avoiding any proprietary hardware such as acceleration engines) along with a virtualized network & appliances, a probable decrease in performance may arise. The challenge is how to keep the performance degradation as small as possible by using appropriate hypervisors and modern software technologies, so that the adverse effects on latency and throughput are minimized. The available performance of the underlying platform needs to be clearly identified/ understood, so that virtual appliances know what they can get from the hardware. Using the right technology choice will allow virtualization, not only of network control functions but also of data/user plane functions.

* **Migration from and co-existence of legacy while ensuring compatibility with existing platforms:**

Implementations of Network Functions Virtualization (NFV) must co-exist with network operators’ legacy network equipment and be compatible with their existing Element Management Systems, Network Management Systems, OSS and BSS, and potentially existing IT orchestration systems, if Network Functions Virtualization orchestration and IT orchestration are to converge. The Network Functions Virtualization architecture must support a migration path from today’s proprietary physical network appliance-based solutions to more open standards based virtual network appliance solutions. In other words, Network Functions Virtualization must work in a hybrid network composed of classical physical network appliances and virtual network appliances. Virtual appliances must, therefore, use/support existing North Bound Interfaces (for management & control) and interwork with physical appliances implementing the same functions.

* **Security & Resilience:**

When deploying virtualized network functions, operators need to ensure that the security features of their network will not be adversely affected. NFV may bring in new security concerns along with its benefits. Initial expectations are that Network Functions Virtualization improves network resilience and availability by allowing network functions to be recreated on demand after a failure. A virtual appliance should be as secure as a physical appliance if the infrastructure, especially the hypervisor and its configuration, is secure. Network operators will be seeking tools to control and verify hypervisor configurations. They will also require security certified hypervisors and virtual appliances.

* **Reliability and Stability:**

Reliability is an important requirement for network operators when offering specific services (e.g., voice call and video on demand), no matter through physical or virtual network appliances. Carriers need to guarantee that service reliability and service level agreement are not adversely affected when evolving to NFV. To meet the reliability requirement, NFV needs to build the resilience into software when moving to error-prone hardware platforms. All these operations create new points of failure that should be handled automatically.

In addition, ensuring service stability poses another challenge to NFV, especially when reconfiguring or relocating a large number of software-based virtual appliances from different vendors and running on different hypervisors. Network operators should be able to move VNF components from one hardware platform onto a different platform while still satisfying the service continuity requirement. They also need to specify the values of several key performance indicators to achieve service stability and continuity, including maximum non-intentional packet loss rate and call/session drop rate, maximum per-flow delay and latency variation, and maximum time to detect and recover from failures.

* **Simplicity:**

It needs to be ensured that virtualized network platforms will be simpler to operate than those that exist today. A significant and topical focus for network operators is therefore, on simplification of the plethora of complex network platforms and support systems which have evolved over decades of network technology evolution, while maintaining continuity to support important revenue generating services. It is important to avoid trading one set of operational headaches for a different but equally intractable set of operational headaches.

Despite its many benefits and potential, the study of Network Function Virtualization (NFV) also has some limitations as mentioned above. Overall, while NFV offers numerous benefits in terms of cost reduction, flexibility, scalability, and innovation, addressing these limitations and challenges is essential to realizing its full potential and ensuring successful adoption and deployment in real-world networking environments.