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Review on Network Function Virtualization in Information-Centric Networking

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***Abstract*— Network function virtualization (NFV / VNF) and information-centric networking (ICN) are two trending technologies that have attracted expert's attention. NFV is a technique in which network functions (NF) are decoupling from commodity hardware to run on to create virtual communication services. The virtualized class nodes can bring several advantages such as reduce Operating Expenses (OPEX) and Capital Expenses (CAPEX). On the other hand, ICN is a technique that breaks the host-centric paradigm and shifts the focus to "named information" or content-centric. ICN provides highly efficient content retrieval network architecture where popular contents are cached to minimize duplicate transmissions and allow mobile users to access popular contents from caches of network gateways. This paper investigates the implementation of NFV in ICN. Besides, reviewing and discussing the weaknesses and strengths of each architecture in a critical analysis manner of both network architectures. Eventually, highlighted the current issues and future challenges of both architectures.**

Keywords—information-centric networking, network function virtualization, operating expense, capital expenses

I. Introduction

Followed by the emergence of technologies over the past decades, today's telecommunications networks are overloaded with massive and rapidly changing a different proprietary hardware devices [1, 2]. Traditional telecommunication networks often require a high cost of energy, capital investment, and huge technical manpower to launch new network services [3]. These drawbacks of hardware-based appliances have led network service providers to think beyond traditional network systems and further develop standard IT virtualization technologies to be implemented into the network. Network Function Virtualization (NFV) is introduced by telecommunication providers to make the new network services deployment easier and faster while benefits from their revenues and future growth goals. Furthermore, it is a technique that used to decouple the network functions from the physical devices and enable them to run logically due to general-purpose on the CPUs or virtual machines, operating on standard servers [3]. The network functions (NFs) such as firewalls, deep packet inspection, and domain name systems (DNS) can be virtualized as virtual network functions (VNF) in NFV. VNFs can be relocated and instantiated at different network locations without having to buy and install new equipment, these can reduce the space and power consumption of network components [4]. Furthermore, through decoupling the NFs from the propriety hardware they used to run, NFV will cause an exceptional decrease in Operating Expense (OPEX) and Capital Expenses (CAPEX) where else it promotes new service deployment with more agility and much faster than before [4]. In addition, maximizing the usage of virtualization techniques will play an important role in assisting the significant growth in future network architecture trends. Most of the current Internet architecture consists of point-to-point connection network architecture based on the TCP/IP model of packet switching [5]. However, there are several disadvantages of the Internet architecture based on the TCP/IP model which include poor reliability, massive information redundancy, waste of resources, and high complexity system. These motivate the researchers to investigate the viability and feasibility of delivering services over new network architecture which called Information-Centric Networking (ICN) [6, 7]. In ICN, data is accessed by name can provide a high efficient content retrieval network architecture that promotes content distribution to the user with improve network security, increase scalability, and network flexibility that supports location transparency. ICN breaks the host-centric connection model of TCP/IP protocols and shifts the focus to information or content-centric. Computation, storage, and network virtualization are merged into the same platforms in ICN. Thus, complexity service-logic execution can be reduced in ICN service delivery through service function placement and content processing at the edges of the network to trades [6, 9]. In this paper, we investigate NFV in ICN as shown in Fig 1.

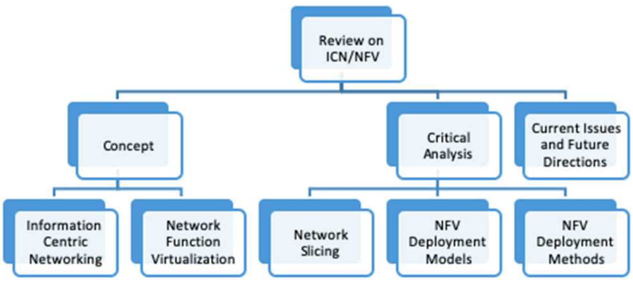

Fig. 1. Information-Centric Networking and Network Function virtualization review

The rest of the paper is organized as follows. Section II discusses the concepts of the ICN and NFV. Section III provides a critical analysis of previously proposed architectures. Then the conclusion and future thoughts about ICN and NFV are discussed in Section V.

II. The Concept of ICN NFV and ICN

Internet is having tremendous growth and new applications kept being introduced to fulfill emerging needs. Still, the current Internet cannot address adequately many current emerging requirements [10]. Some research community that had identified the limitations of the current Internet, explore, compare, and discuss how the applying of NFV in ICN can bring positive impacts on the current Internet.

A. Information-Centric Networking

ICN can be counted as one of the significant promising approaches of coming future Internet research that could potentially provide better support for ad-hoc connectivity, big data collection, distribution, and mobility [10, 11]. This approach dominances network-caching, replication to make up multi-party communication and senders-receivers divided interaction models [12].

ICN has been introduced as a wireless cache infrastructure that provides content distribution services with distributed cache servers to reflect nowadays and future needs and make the situation much better than the current existing Internet architecture [7, 13]. Current Internet architecture focuses on creating a conversation between two machines as happened in a naming system where URLs (through Domain Name System resolution) show that machine communications happen to receive data or perform an action. ICN architecture is proposed to focus on the process of data fetching, not to focus on connecting to another machine. The main components of ICN include naming, Named Data Objects (NDO), routing and forwarding, security, application programming, and caching. ICN primitives are based on NDO names, so NDO names must be unique to identify different NDOs and persistent to preserve the independence from space and time dimension [14]. Besides naming the data, ICN should also support another function such as retrieving target data and securing the data. The advantage that comes along with the ICN approach is said to be efficient content distribution. To motivate the switching action to a new infrastructure, other advantages are needed such as scalable and cost-efficient distribution, persistent and unique naming, mobility, and disruption tolerance [15]. Current Internet network security using Transport Layer Security (TLS) to secure client-server communications. This requires trust from client to server as the server will deliver the correct information over the platform. ICN significantly reduce security problems such as unwanted data transfers (spam) by only allowing data flow when the user explicitly asked for particular information [10].

ICN network is the layer 3 and above network protocol stack conceptualization [16]. ICN uses in-network caching where nodes are able to cache the high popularity content passing through them based on the remaining caching spaces and deliver the contents to users directly when users request the cached content [17]. With ICN, the time taken to fetch the popular content can be decreased, which significantly reduces the transmission delay while increasing the delivery probabilities of contents to mobile users [18]. After all those compact overviews on Information-centric Networking, we conclude some of the challenges or problems that might be facing ICN. Some research even proposed a novel task-based scheme for overcoming the weakness of the current ICN such as the Network Representation Learning (NRL) scheme [19]. Fig 2. shows the simple logically case of the information-centric networking model.

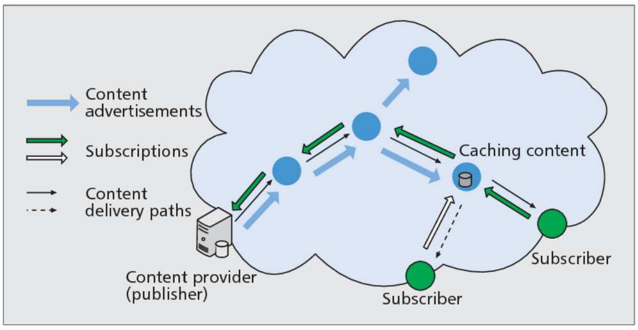

Fig. 2. Traditional Information-Centric Networking Model

B. Network Function Virtualization

Network Virtualization enables more flexible network resource allocation and integration of heterogeneous network architecture and service [20]. Hence, NFV has been proposed to leverage virtualization technology, and offer new style of designing, deploying and managing networking services [21]. Furthermore, its main idea is divide to the physical network equipment from the running functions. NFV reliability depends on both functional ability and underlying hardware reliability [22].

NFV shifts the networking architecture by fully utilizing the virtualization technology to separate software instances from hardware platforms and by decoupling functionality from the location for faster networking service provisioning [21]. As a result of the coupling of massive types of network equipment, large volume servers, switch or even storage might have the possibilities to be placed to the end-users, distributed network nodes, and gigantic data centers.

KFN keeps some practices such as making clear division software and hardware and having flexibility in the deployment of network functions. Besides, It maintains dynamic scaling to achieve some benefits. One of the benefits is to increase the flexibility in opening up the capabilities and services belongs to the network. The next benefit is able to perform deployment and supporting network services in a cheaper and faster way [23]. Between the traditional network-appliance approach and network function virtualization approach, there will be some differences as shown in Fig 3.

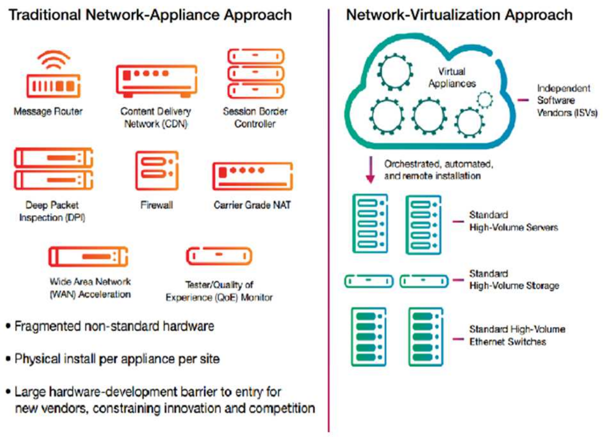

Fig. 3. Traditional Network-Appliance Approach vs NFV Approach

III. Critical Analysis

A. Using Network Slicing to Deliver ICN Services over 5G

To adapt to the rapidly developing fifth-generation (5G) technology, it is better to extend the virtualization technique as the end-to-end IP services are no longer sufficient for future network architectures [12]. 5G networks emphasize flexibility by providing different transmission speed, capacity, coverage, and security so that they can be dynamically adjusted to meet the requirements of different applications. Information-centric networking (ICN) has been proposed in [24] as suitable network architecture where the use of different data plans can be realized without the need for different physical network infrastructure.

Network slicing divides a physical network into multiple virtual environments corresponding to different application services through network function virtualization (NFV) and this is crucial for proper experiment isolation [25]. The virtualization of networks over 5G-ICN provides optimal, dynamic, and secure services. One of the views proposed in [24], that the support for name-based networking, in-network storage, edge computing [26], security [27, 28], and mobility of ICN can be very useful in 5G architecture. The ability to slices the endpoints, access and core transport, and compute and storage resources, among multiple services, is made possible because of network virtualization. ICN can be seen as a slice composing hardware and software resources over which the services can be delivered in 5G architecture driven by network slicing frameworks.

B. NFV Deployment models

NFV architectures make a breakthrough by virtualized network functions from proprietary hardware-based service provision [29]. In NFV, the entire class at network mode functions is virtualized to run as software on a single or several hosts, mostly inside virtual machines [30]. According to [30], NFV can be deployed in any data plan packet processing and control plane functions in fixed and mobile network infrastructure using the following 4 types of models.

i. Centralized Model

The centralized model is the most basic and general model used by the service providers for NFV deployment. All the VNFs are placed at a data center or operation premises of telecommunication services providers. Because of this, VNFs can be deployed at their data center. However, VNFs can be accessed from the centralized server using an Ethernet connection. Fig. 4 depicts the centralized model of VNF deployment.

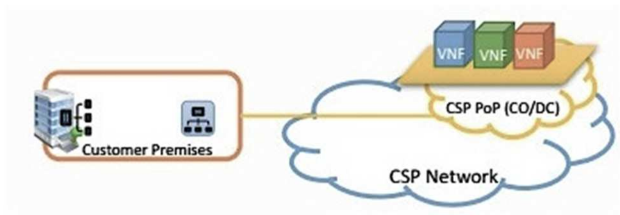

Fig 4. Centralized VNF Deployment Model

ii. Decentralized Model

In the decentralized model of NFV deployment, all VNFs are located at customer premises. There are no VNFs placed at the central data center. Fig. 5 represents the deployment of VNF using a decentralized model.

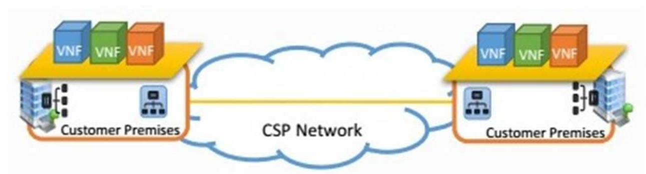

Fig 5. Decentralized VNF Deployment Model

iii. Distributed Model

A distributed model of the NFV deployment technique is a balanced mix of a centralized and decentralized model. VNFs are distributed between the data center and customer premises. VNFs are ordered, configure, and chained randomly in a distributed model. In this model, scalability, performance, reliability, and feasibility of VNFs deployment are optimized and at the same time, network latency can be avoided. Fig. 6 shows the distributed model of deploying VNFs.

Fig 6. Distributed VNF Deployment Model

iv. Dynamic Virtual Networks-Edge (DVNe) Model

In the DVNe model, virtualized network services are deployed at the network edge, onsite as a virtual CPE. Cloud edge is integrated into the NFV infrastructure in this model. Unlike those previous models, VNFs not only distributed between the data center of network operators and customer premises but also in cloud edge. Fig. 7 depicts the DVNe model.

Fig 7. DVNe model

C. Methods of NFV Deployment in ICN

ICN architecture is one of the proposed architecture of future Internet by both academia and industries in which in ICN the focus is on content instead of IP address [31]. Several deployment methods have been proposed to assist current network devices to cope with innovative techniques and the high cost of network upgrades.

i. Clean-slate Approach
According to [3], it is more beneficial to clients if ICN architectures are deployed at the Level 2 network layer, which also known as the clean-slate approach. The goal of the clean-slate approach is to replace the existing IP infrastructure with applications that are directly tied to the ICP/IP protocol stack and IP routers. Thus, existing hardware devices and ancillary services are not necessarily needed in clean-slate ICN deployment method as existing IP routers will be replaced by ICN-specific forwarding and routing elements like Named Data Networking Forwarding Daemon (NFD), CCN routers, or PURSUIT forwarding nodes.

ii. Overlay Deployment Method
According to [3], ICN deployment as an overlay is the most common method nowadays as this method can achieve similar performance to the clean-slate deployment method but with lower latency and cheaper traffic engineering. The overlay method works on top of the layer 3 networks. The overlay method works on top of the layer 3 networks. ICN architectures such as CCNx and OpenNetInf are deployed using this method. ICN can be deployed as an overlay in IP infrastructure in either edge or core networks. In the overlay method, ICN protocols that are implemented at some dedicated content routers and ICN packets that should be delivered between two dedicated content routers are needed to traverse ordinary routers that are not interoperable to ICN protocols. Barriers to deploying ICN-related innovations can be reduced through overlay deployment as it does not require the underlying network to change. However, also proposed the challenges faced by overlay deployments. One of them is overhead due to overlay management and packet processing. Next, topology mismatch and independent failures are hard to avoid when constructing an overlay topology as developers have no idea about the underlying physical network. Other than that, some network layer benefits such as hop-by-hop flow balance which can minimize network congestion significantly are not achievable by the overlay deployment method.

IV. NFV Implementation Challenges

Network function virtualization has its benefits in the ever-expanding world of IT, but even though it almost widely used in developed countries, Network function virtualization services are still considered to be in their early stages. This is because NFV is considered something that far from reach yet and there are a lot of things that need to investigated and a lot of practical stages could be enforced. The NFV that currently used have given the current management systems a great challenge and if it does not operate and managed as it's required to do such as providing network and service solution that has been done before, it may lead to some functions that served to provide customer scatted across different server pools [23]. This will be a challenge as the acceptance of orchestration level need to be sure that a service level per user is instantiated coherent and on-demand in its required functions, and ensuring that any problem has its own solution that can be manageable.

Other than that, NFV has some other challenges in making. It is more popular with the masses as it has major problems and issues that are currently holding it back from being more successful in been commercially deployed. Based on a study by The IHS Markit 2017 Carrier NFV Strategies [32], 76% of respondents think the problem for the commercialization is that it is still not mature or fully developed. 52% of respondents also responded that the problem is integrating the NFV itself into the existing networks that are currently been used. Finally, the last major respondents that are 39% and 33% responded that the problem is the lack of knowledge or experience and there is still incomplete standards respectably [32]. Even with all these challenges, overcoming them is not an impossible thing to be done as there are a few best practices that can be learned or experienced such as having training in understanding the process and the technology itself. There can also be an open-source that is dedicated to understanding NFV and it is not locked to any individual [32].

Moreover, NFV has usually more focus on remote programmability that uses network resources as its functions and this may lead to few potential threats or harmful attacks that can cause a major problem within the non-NFV environment. There is also a recently drafted document from the group security of ETSI NFV which has defined the potential of security threats that may bring to the networks. The document has stated more possible treats that may happen and has not yet proposed ways to tackle them. And because of this, the security within VNF is still underdeveloped [33]. It is difficult to overcome these challenges because of the lack of real support. The most important security challenge is to detect and block as many intrusion especially in a multi-vendor environment.

Furthermore, there are other more challenges that are much more important than security which is related to the improvement of the NFV performance. For the NFV local performance, the first challenge is realizing that the NFV is to attain high-performance processing within the packet itself in a virtualized environment. In optimizing the local performance it may involve software with kernels and network stacks in a virtualizing architecture [34]. The challenge of attempting to realize the performance is the overhead that is imposed by the software itself and by the virtualization stacks. Other than local performance the challenge of optimizing the software stack of NFV or the local performance is being complemented by optimizing the global performance of the network functions in the whole network. Research has been made that shows that the spilling state and function can ease the global scale of network functions.

Furthermore, the network performance of the VNF has faced some challenges in making it work the way it is supposed to be. Especially, within the telecommunication industry where it has centered itself onto the software virtualization framework. It has measured the end-to-end networking performance of a cloud service by Amazon EC2 and shows that the sharing processors of TCP/UDP throughput is very unstable, even though the network is not that crowded and this unstable networking can cause major performance dropout within the deployment of the virtual appliance [35]. There is a way to improve the speed or the performance but this task cannot be done easily especially if not having the right tools or support that it is needed.

When talking about security every network needs to be secured to prevent from unwanted people attacking the network and because of this NFV also needs to be secured especially the newer NFV. These newer ones have a few security challenges such as the dispersion of a VMS within VNF data centers. And because of some migration of VMS, it makes it impossible to do a manual define or managing the security [36]. There are a few service providers that have set a few tools that can help in making good practices in avoiding the existing problems within the NFV. The issues within the security probably may be resolved as some of the traditional network's firewalls protects the entire zone within the networks and smaller dedicated virtual have their own task in making sure the balance within the networks without any problem [36].

V. CONCLUSION AND FUTURE DIRECTIONS

Network Function Virtualization is seeming to be the important key to deliver lots of benefits for the network operators or the customer by offering them chances to create modern ecosystems. This might just give out huge support and encourage rapid innovation where the risk is reduced to the slightest level. To reap the benefits that are desired, the industry must try in addressing any technical challenge which might come up. In the effort of solving those technical challenges with the possible solution or approach, IT and Telecom Network industries would take our first step by combining their resources and complementary expertise through collaboration. This effort enables them to produce broad agreement on the standard and common architecture. The broad agreement is important as it plays the role as a standard to address those technical challenges that they might be facing in the future and provides a tested and interoperable approach for the end virtualized services delivery with economic' scale. NFV can be taken into the count as an effort for border transformation and this might call for significant changes and progressive efforts from the service provider. The need for coordination of three inter-linked yet separate development paths which are automation, orchestration, and virtualization is strongly needed to maximize the operational of NFV. NFV included in the listing of consideration to be a disruptive technology in the coming days. One of its specialties is that it is presumed to change the way how the existing networks are being built, operated, and managed. The NFV's multivendor management and orchestration objective is required to be well organized towards smooth migration. In moving towards the end, we can make a conclusion that NFV is slowly growing into a technology that may impact the world just like how the first cloud computing was introduced. NFV is still growing and its full potential has not explored, and it might have some issues or challenges. As time flows, there is a hope that all the issues are fully uncovered and can be used t to their fullest benefits. Even in the present, some have come up with a solution and this is proof that the bright future is just around the corner.

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