Network Function Virtualization
An Architecture for 5G Network

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***Abstract*— The fifth generation (5G) mobile network is expected to support a multitude of new services and applications with very diverse requirements, mainly including higher traffic volume, lower latency, huge number of devices, etc. In order to meet these challenges, 5G should not only improve the link efficiency through exploiting new technologies, but also need a more flexible and scalable architecture for adaption to various scenarios. To realize its potential, 5G must provide considerably higher network capacity, enable massive device connectivity with reduced latency and cost, and achieve considerable energy savings compared to existing wireless technologies. The main objective of this paper is to explore the potential of NFV in enhancing 5G radio access networks functional, architectural, and commercial viability. We discuss how NFV can address critical 5G design challenges through service abstraction and virtualized computing, storage, and network resources. We describe NFV implementation with network and compared it with other technologies like SDN. Furthermore, we provide some insights into the shortcomings and challenges well face while using NFV.**

I. Introduction

In the last decade, wireless technology has emerged as one of the most significant trends in networking. Recent statistics show that mobile wireless broadband penetration has exceeded that of fixed wire line broadband networks. In addition to general broadband access, recent advances in wireless communications and node processing capabilities have made it possible for communication networks to provide support for a wide variety of new multimedia applications and compelling wireless services, which are rapidly and steadily becoming national priorities. This trend is expected to continue in the future at much faster growth rates. By 2018, the global mobile traffic will increase from 2.6 to 15.8 Exabyte.

Addressing the expected exponential growth of rich media underscores the need is to evolve a cellular network which in turn creates a need of 5G. The fifth generation (5G) will support 1000 times the current aggregate data rate and 100 times the user data rate, while enabling a 100 times increase in the number of currently connected devices, 5 times decrease of end-to-end latency, and 10 times increase of battery lifetime .

II. Motivation

To meet the expected three-orders-of-magnitude capacity improvement and massive device connectivity, 5G centers its design objectives on efficiency, scalability, and versatility. To sustain its commercial viability, 5G networks must be significantly efficient in terms of energy, resource management, and cost per bit. Connecting a massive number of terminals and battery operated devices necessitates the development of scalable and versatile network functions that cope with a wider range of service requirements including: low power, low-data-rate machine-type communication, high data rate multimedia and delay-sensitive applications, among many other services.

The efficiency, scalability, and versatility objectives of 5G direct the 5G community toward finding innovative but simple implementations of 5G network functions. Evidently for the realization of the expected 5G system described previously, both the evolution of existing technologies and new radio concepts should be taken into account at the same time, e.g. massive MIMO, millimeter Wave (mm Wave), full duplex, Ultra Dense Networks (UDN), Device-to-Device (D2D), Machine-to-Machine (M2M), local caching, etc. Meanwhile, the mobile network architecture must also be reconsidered for extremely exploring the potential of new technologies and being more flexible and scalable to adapt to various services and applications. Therefore, the design of architecture for future 5G network is very important and becomes the main focus of our work. Motivated by our above discussion, this paper discusses about NFV, its implementation and features which can make 5G a great success.

III. DEFINITION

Network functions virtualization (NFV) (also known as virtual network function (VNF) aims to transform the way that network operators architect networks by evolving standard IT virtualization technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Data Centers, Network Nodes and in the end user premises, as shown in Fig. 1. It involves the implementation of 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 for installation of new equipment. It offers a new way to design, deploy and manage networking services. NFV decouples the network fun, such as network address translation (NAT), firewalling, intrusion detection, domain name service (DNS), and caching, to name a few, from proprietary hardware appliances so they can run in software.

IV. IMPLEMENTATION OF NFV

Implementation of NFV Architecture in 5G-NFV, services is described as a forwarding graph of connected network functions. A forwarding graph defines the sequence of network functions that process different end-to-end flows in the network. For example, Fig. 2 shows a simplified forwarding graph of a mobile Internet service where data flows traverse network functions from the evolved NodeB (eNodeb) to the service gateway (seGW) to the IP backbone until it reaches the application server. . Mobility management and non-access stratum (NAS) protocols flow through different network functions for mobility management, authentication, and policy enforcement. Unlike current cellular networks, where a particular feature is activated network-wide, forwarding graphs enable 5G operators to activate features per service (e.g., becomes active only for predefined service classes) The network functions are virtualized using a separate virtualization layer that decouples service design from service implementation while improving efficiency, resiliency, agility, and flexibility. The NFV reference architecture (Fig. 3) supports a wide range of services described as forwarding graphs by orchestrating the VNF deployment and operation across diverse computing, storage, and networking resources. As shown in Fig. 3, the computing and storage hardware resources are commonly pooled and interconnected by networking resources. Other network resources interconnect the VNFs with external networks and non-virtualized functions, enabling the integration of existing technologies with virtualized 5G network functions.

NFV management and orchestration comprises resource provisioning modules that achieve the promised benefits of NFV. The VNF managers(s) (Fig. 3) perform two main functions: operation and resource provisioning. VNF operation consists of infrastructure management, fault management, performance management, and capacity planning and optimization. Resource provisioning ensures optimal resource allocation (e.g., allocate virtual machines, VMs, to servers), optimal connectivity between VNFs, energy conservation, and resource reclamation. Moreover, resource managers discover computing, storage, and network resources in the infrastructure. Efficient design of a VNF manager leverages the peak benefits of NFV to reduce CAPEX(Capital Expenses) and OPEX(Operational Expenses) in 5G by means of dynamic resource allocation, traffic load balancing, and easier operation and maintenance.

V. Benefits and Relevance to 5G

We believe the application of Network Functions Virtualization brings many benefits to network operators, contributing to a dramatic change in the telecommunications industry landscape. Benefits we foresee include :

- Reduced equipment costs and reduced power consumption through consolidating equipment and exploiting the economies of scale of the IT industry .
- Increased velocity of Time to Market by minimizing the typical network operator cycle of innovation. Economies of scale required to cover investments in hardware-based functionalities are no longer applicable for software-based development, making feasible other modes of feature evolution. Network Functions Virtualization should enable network operators to significantly reduce the maturation cycle.
- The possibility of running production, test and reference facilities on the same infrastructure provides much more efficient test and integration, reducing development costs and time to market.
- Targeted service introduction based on geography or customer sets is possible. Services can be rapidly scaled up/down as required. In addition, service velocity is improved by provisioning remotely in software without any site visits required to install new hardware.
- Enabling a wide variety of ecosystems and encouraging openness. It opens the virtual appliance market to pure software entrants, small players and academia, encouraging more innovation to bring new services and new revenue streams quickly at much lower risk.
- Optimizing network configuration and/or topology in near real time based on the actual traffic/mobility patterns and service demand. For example, optimization of the location and assignment of resources to network functions automatically and in near real time could provide protection against failures without engineering full 1+1 resiliency.
- Supporting multi-tenancy thereby allowing network operators to provide tailored services and connectivity for multiple users, applications or internal systems or other network operators, all co-existing on the same hardware with appropriate secure separation of administrative domains.
- Reduced energy consumption by exploiting power management features in standard servers and storage, as well as workload consolidation and location optimization. For example, relying on virtualization techniques it would be possible to concentrate the workload on a smaller number of servers during off-peak hours (e.g. overnight) so that all the other servers can be switched off or put into an energy saving mode.
- Improved operational efficiency by taking advantage of the higher uniformity of the physical network platform and its homogeneity to other support platforms.

VI. Performance in comparison to other technologies

Software-defined networking (SDN), network functions virtualization (NFV), and network virtualization (NV) are all complementary approaches. They each offer a new way to design deploy and manage the network and its services:-

1) SDN: Software-defined networking (SDN) is an approach to computer networking that allows network administrators to manage network services through abstraction of lower-level functionality. SDN is meant to address the fact that the static architecture of traditional networks doesn't support the dynamic, scalable computing and storage needs of more modern computing environments such as data centers. This is done by decoupling or disassociating the system that makes

decisions about where traffic is sent (the control plane) from the underlying systems that forward traffic to the selected destination (the data plane).it basically separates the networks control (brains) and forwarding (muscle) planes and provides a centralized view of the distributed network for more efficient orchestration and automation of network services.

2) NFV: NFV focuses on optimizing the network services themselves. NFV decouples the network functions, such as DNS, Caching, etc., from proprietary hardware appliances, so they can run in software to accelerate service innovation and provisioning, particularly within service provider environments.
3) NV : NV ensures the network can integrate with and support the demands of virtualized architectures, particularly those with multi-tenancy requirements.

- **Commonalities**
  SDN, NFV, and NV each aim to advance a software-based approach to networking for more scalable, agile, and innovative networks that can better align and support the overall IT objectives of the business. It is not surprising that some common doctrines guide the development of each. For example, they each aim to:
  1) Move functionality to software
  2) Use commodity servers and switches over proprietary appliances
  3) Leverage application program interfaces (APIs)
  4) Support more efficient orchestration, virtualization, and automation of network services
- **Relationship with Software Defined Networks**
  As shown in Figure 4, Network Functions Virtualization is highly complementary to Software Defined Networking (SDN), but not dependent on it (or vice versa). Network Functions Virtualization can be implemented without a SDN being required, although the two concepts and solutions can be combined and potentially greater value accrued.
  Network Functions Virtualization goals can be achieved using non-SDN mechanisms, relying on the techniques currently in use in many data centers. But approaches relying on the separation of the control and data forwarding planes as proposed by SDN can enhance performance, simplify compatibility with existing deployments, and facilitate operation and maintenance procedures. Network Functions Virtualization is able to support SDN by providing the infrastructure upon which the SDN software can be run. Furthermore, Network Functions Virtualization aligns closely with the SDN objectives to use commodity servers and switches.
- **SDN and NFV Are Better Together**
  The main features of 5G mobile network can be satisfied By the combination of SDN and NFV which brings the deep programmability, flexibility, scalability and network virtualization into future network through decoupling software from hardware, separating the control plane from data plane and centralizing the network intelligence in the network controller. Therefore, SDN and NFV become two potential technologies for the design of 5G network architecture, and have attract more attention in academic and industrial fields. Much research is going on to merge these fields to create a new architecture which can provide such a platform to support 5G.

VII. Fields of Application

Network Functions Virtualization is applicable to any data plane packet processing and control plane function in mobile and fixed networks. Potential examples that can be listed include:

- Switching elements: BNG, CG-NAT, routers.
- Mobile network nodes: HLR/HSS, MME, SGSN, GGSN/PDN-GW, RNC, Node B, eNode B.
- Functions contained in home routers and set top boxes to create virtualized home environments.
- Tunneling gateway elements: IPSec/SSL VPN gateways.
- Traffic analysis: DPI, QoE measurement.
- NGN signaling: SBCs, IMS.
- Converged and network-wide functions: AAA servers, policy control and charging platforms.
- Application-level optimization: CDNs, Cache Servers, Load Balancers, Application Accelerators.
- Security functions: Firewalls, virus scanners, intrusion detection systems, spam protection.

VIII. Challenges and shortcomings

There are a number of challenges to implement Network Functions Virtualization which need to be addressed by the community interested in accelerating progress.. Challenges we have identified are:

- Portability/Interoperability- The ability to load and execute virtual appliances in different but standardized data center environments, provided by different vendors for different operators. The challenge is to define a unified interface which clearly decouples the software instances from the underlying hardware, as represented by virtual machines and their hypervisors. Portability and Interoperability is very important as it creates different ecosystems for virtual appliance vendors and data center vendors, while both ecosystems are clearly coupled and depend on each other.
- Performance Trade-Off- Since the Network Functions Virtualization approach is based on industry standard hardware (i.e. avoiding any proprietary hardware) a probable decrease in performance has to be taken into account. The challenge is how to keep the performance degradation small by using appropriate hyper visors and modern software technologies, so that the effects on latency, throughput and processing overhead are minimized.
- Migration and coexistence of legacy and compatibility with existing platforms-Implementations of Network

Functions Virtualization 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 todays 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 existing Northbound Interfaces (for management and control) and inter-work with physical appliances implementing the same functions.

- Management and Orchestration- A consistent management and orchestration architecture is required. Network Functions Virtualization presents an opportunity, through the flexibility afforded by software network appliances operating in an open and standardized infrastructure, to rapidly align management and orchestration North Bound Interfaces to well defined standards and abstract specifications. This will greatly reduce the cost and time to integrate new virtual appliances into a network operators operating environment. Software Defined Networking (SDN) further extends this to streamlining the integration of packet and optical switches into the system e.g. a virtual appliance or Network Functions Virtualization orchestration system may control the forwarding behaviors of physical switches using SDN.
- Security and Resilience- Network operators need to be assured that the security, resilience and availability of their networks are not impaired when virtualized network functions are introduced. Our 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.
- Network Stability- Ensuring stability of the network is not impacted when managing and orchestrating a large number of virtual appliances between different hardware vendors and hypervisors. This is particularly important when, for example, virtual functions are relocated, or during re-configuration events (e.g. due to hardware and software failures) or due to cyber-attack. This challenge is not unique to Network Functions Virtualization. Potential instability might also occur in current networks, depending on unwanted combinations of diverse control and optimization mechanisms, for example acting on either the underlying transport network or on the higher layers components (e.g. flow admission control, congestion control, dynamic routing and allocations, etc.).
- Simplicity- Ensuring that virtualized network platforms will be simpler to operate than those that exist today. A significant and topical focus for network operators is 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.
- Integration- Seamless integration of multiple virtual appliances onto existing industry standard high volume servers and hypervisors is a key challenge for Network Functions Virtualization. Network operators need to be able to mix and match servers from different vendors, hypervisors from different vendors and virtual appliances from different vendors without incurring significant integration costs and avoiding lock-in. The ecosystem must offer integration services and maintenance and third-party support; it must be possible to resolve integration issues between several parties. The ecosystem will require mechanisms to validate new Network Functions Virtualization products. Tools must be identified and/or created to address these issues.

IX. Call for Action

Network Functions Virtualization is already occurring. In a few years, we can expect the communications industry to look and feel similar to the IT industry. There will be a wider range of business models more suited to a software industry. Operations complexity will be abstracted away by more automation and self-provisioning will be more common. As detailed in this paper, Network Functions Virtualization will deliver many benefits for network operators and their partners and customers whilst offering the opportunity to create new types of ecosystems (alongside traditional supply models based on preferred strategic partners) which will encourage and support rapid innovation with reduced cost and reduced risk. To reap these benefits the technical challenges, as described above, must be addressed by the industry.

X. Conclusion

In this paper, we firstly conclude the key features of 5G mobile network architecture through analyzing the main requirements of 5G network individually. Secondly, based on the concept of NFV, a high-level architecture for 5G mobile network is proposed. Then the corresponding advantages of the proposed architecture are discussed .Finally, we discussed the challenges in a way of NFV implementations.

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