Professional paper / Stručni rad
Manuscript received: 2017-06-27
Revised: 2017-11-16
Accepted: 2017-11-21
Pages: 95 - 108

Use of a virtualization in the transition of a telecommunication networks toward 5G

Valerij Grasic

Iskratel
Kranj, Slovenia

valerij.grasic@gmx.com

Abstract: We are in the front of the next big step of a new generation of the telecommunications networks, called 5G. The 5G in still in the preparation, but the actual wide spread use is nearby. The move toward 5G is not possible without use of a cloud and a virtualization. In the paper we are dealing with the issues how to incorporate existing fixed networks to the mobile 5G network and how to use a virtualization technology when moving to 5G. From the example of a real telecommunication system we defined issues, dilemmas and suggestions when moving toward 5G networks using virtualization.

Keywords: NFV, OpenStack, 5G, IMS, OpenBaton

INTRODUCTION

We are approaching the path toward a new generation of telecommunications networks, called 5G. These systems will have the characteristics of a powerful networking-computing-storage infrastructure. The functions of such networks will be both distributed and centralized, supporting pervasive connections (both wired and mobile); additionally, it will be characterised by high capacity and very low latency of just a few milliseconds.

Such a move toward 5G is not possible without the "softwarization" of the entire network eco-system; this involves NFV (Network Function Virtualization), and SDN (Software Defined Networks). Starting from telecommunication networks for fixed telephone subscribers, such as IMS (IP Multimedia Subsystem) [1], the question is how to connect existing fixed networks to the mobile network and prepare them for the future 5G network. The second question is how to use virtualization technology when moving to 5 G: specifically, how to virtualize network elements, both old and existing, as well as future elements. In this article, we will address both of these challenges: moving telecommunication network toward 5G and virtualization. We are interested in how existing IMS networks, as well as previous NGN networks, used for fixed telephony subscribers, are incorporated and integrated into the 5G vision. We will use the example of the Iskratel SI3000 telecommunication system. Some of the issues were discussed in [2], but in our case, the focus and the issue are more on the transition from fixed telecommunication networks to 5G and on virtualization issues.

In Chapter 2, the definition of the problem is given when moving towards virtualization and the transition of telecommunication networks toward 5G. Additionally, in Chapter 3 5G, IMS and virtualization are presented. Then in Chapter 4, issues, solutions and suggestions when moving toward 5G using virtualization for our system is given. Discussion about the presented solution is presented in Chapter 5. In the end, the conclusion is given in Chapter 6.

PROBLEM DEFINITION

As stated in [3], network virtualization has been propounded as a diversifying attribute of the future inter-networking paradigm. By allowing multiple heterogeneous network architectures to cohabit on a shared physical substrate, network virtualization provides flexibility, promotes diversity, and promises security and increased manageability.

THE CONCEPT OF MULTIPLE CO-EXISTING NETWORKS

The idea of virtualization is not new: it is a concept based on the idea of multiple co-existing networks [3]. It has appeared in the networking literature several times in different capacities. Authors discuss three such incarnations that are closely related to the concept of network virtualization. A virtual private network, also known as a VPN, is a specialized virtual network that connects multiple distributed sites through tunnels over shared or public networks. An overlay network is yet another form of network virtualization which is typically implemented in the application layer, although various implementations at lower layers of the network stack do exist. It has been extensively used as a weak but effective tool to deploy new features and fixes within the Internet. Active and programmable networks, in contrast, are a concept that enables the customization of network elements based on service providers' requirements.

BIRTH OF NFV

The concept and collaborative work on NFV began in October 2012 when a number of the world's leading TSPs jointly authored a white paper [4] calling for industrial and research action. In November 2012, seven of these operators (AT&T, BT, Deutsche Telekom, Orange, Telecom Italia, Telefonica, and Verizon) selected the European Telecommunications Standards Institute (ETSI) to be the home of the Industry Specification Group for NFV (ETSI ISG NFV).

As shown by [5], network function virtualization was proposed to improve the flexibility of network service provisioning and reduce the time to market for new services. By leveraging virtualization technologies and commercial off-the-shelf programmable hardware, such as general-purpose servers, storage, and switches, NFV decouples the software implementation of network functions from the underlying hardware.

BENEFITS OF THE VIRTUALIZATION

The basic standards for the virtualization are defined in [6], [7]. Virtualization is the subject of many papers, studies and research work [8], [9], [10], [5], [11], [12], [3] and [13]. Operators want to standardize different types of networks and, therefore, try to implement an industry standard for all types of network equipment: servers, switches and data storage, and thus the transition to a new network production environment that lowers costs, and increases efficiency and agility.

By decoupling network functions (NFs) [9] from the physical devices on which they run, NFV has the potential to lead to significant reductions in operating expenses (OPEX) and capital expenses (CAPEX) and facilitate the deployment of new services with increased agility and faster time-to-value. The NFV paradigm remains in its infancy [9], and a large spectrum of opportunities exists for the research community to develop new architectures, systems and applications, and to evaluate alternatives and trade-offs in developing technologies for its successful deployment.

There are several other benefits of virtualization. As an emerging technology, as said in [5], NFV brings several challenges to network operators, such as the guarantee of network performance for virtual appliances, their dynamic instantiation and migration, and their efficient placement. According to [12], NFV is poised to change the core structure of telecommunications infrastructure to be more cost-efficient. Based on this, authors have introduced an NFV framework.

DEVELOPMENT OF TELECOMMUNICATION NETWORKS

From the historical perspective [14] 3G standards organizations were developing IP multimedia subsystems (IMS) to achieve seamless integration between Internet and 3G networks. Suggestions were also to make IMS more scalable [14]. As shown [15] the IP Multimedia Subsystem (IMS) defined by the 3GPP has been mainly developed and deployed by telephony vendors on vendor-specific hardware. Recent advances in Network Function Virtualization (NFV) technology paved the way for virtualized hardware and telephony function elasticity. The 3GPP IMS was standardized as the service delivery platform for 3G networks, but it, unfortunately, does not meet several requirements for provisioning applications and services in 4G systems and beyond [16].

A distributed software architecture enabling the deployment of a single software version on multiple cloud platforms has been proposed [15]. This is an increasingly interesting topic, especially as the industry moves from 4G toward 5G mobile networks. As stated [17], new requirements emerge for delivering services. Network services are expected to be designed to allow greater flexibility. To cope with the new user requirements, telcos should reconceptualize their complex and monolithic network architectures as more agile architectures.

USE OF VIRTUALIZATION

There are many open issues in research and discussions regarding virtualization. These issues are from different fields that cover the full range of possible dilemmas that virtualization involves.

The basic question is the platform dilemma. The most commonly used platform is Open Stack [18]. However, there are also other projects. [19] is the Open Platform for NFV Project, which facilitates the development and evolution of NFV components across various open source ecosystems. Through system level integration, deployment and testing, OPNFV creates a reference NFV platform to accelerate the transformation of enterprise and service provider networks.

IMS is the topic for the research of virtualization in many cases [17]. In [20] FOKUS Open IMS Core was used: measured and evaluated on top of an OpenStack cloud.

Another crucial factor is administration. An overview of ETSI NFV Management and Orchestration is presented in [21]. [22] introduce tuneable and scalable mechanisms that provide MANO. [23] introduce tuneable and scalable mechanisms that provide MANO. [Yousaf] presents the proof-of-concept evaluation of a Resource Aware VNF Agnostic (RAVA) NFV orchestration method that is designed to enhance the Quality of Decision (QoD). Open Orchestrator [24] ONAP provides a comprehensive platform for the real-time, policy-driven orchestration and automation of physical and virtual network functions. [25] explains how to handle the automation of Network Function Virtualization.

Service Function Chaining (SFC) provides the ability to define a sequence of network services. Service function chaining is discussed in [26]. [27] identifies two important issues (placement and scaling) in deploying reliably and efficiently SFC with a cloud platform. [28] discusses the practical issues of implementing dynamic chaining of virtual network functions running as virtual machines in the industry-standard OpenStack cloud platform. In [29] authors focus on the placement of Virtualized Network Functions (VNFs) chains in the Network Function Virtualization (NFV) context in which NFV Infrastructures (NFVIs) are used to host the VNFs.

Content that is becoming more and more actual are containers. The Open Container Initiative (OCI) [30] is a lightweight, open governance structure (project), formed under the auspices of the Linux Foundation, for the express purpose of creating open industry standards around container formats and runtime. The OCI was launched in 2015 by Docker, CoreOS, and other leaders in the container industry. There are also other initiatives as OpenContainer.

There are also other topics covered within the context of the virtualization. [31], using platform OpenStack, puts forward a method to make the communication of virtual machines more efficient by using para-virtualization. [32] propose a dependability benchmark to support NFV providers in making informed decisions about which virtualization, management, and application-level solutions can achieve the best dependability. Traffic issues are discussed in [12]. To reduce signalling traffic and achieve better performance, the aforementioned article proposes a criterion to bundle multiple functions of a virtualized evolved packet core in a single physical device or a group of adjacent devices. The analysis shows that the proposed grouping can reduce network control traffic by 70 per cent.

TOWARDS 5G

5G

The technology and network 5G is not yet fully standardized. 5G technology is the cornerstone of the transformation of the telecoms industry and enables the simultaneous operation of various services. It will enable the use of 5G in solutions such as smart cities, intelligent transport systems and logistics, energy, industrial production, public safety, e-health, and elsewhere. However, the first installations exist, such as 5G Berlin [33], or as initiative 5G PPP [34]. The first wider serious use for 5G is foreseen for 2020. 3GPP Release 14, which closed in June 2017, specifies the Next Generation (NG) Core for 5G, which is the new name, replacing Evolved Packet Core (EPC).

From a technological point of view, upgrading to 5G will require major changes throughout the network, not just on radio access. The entire network will be thoroughly upgraded to respond in a commercially efficient manner to the requirements for higher bandwidths, an increase in a number of various connected devices, more demanding and diverse signalling, greater reliability and smaller delays. Above all, it will enable new business models and services where the virtualized network can be used for different industries and applications, and allow the development of solutions that can address different needs of users. Examples of use in different verticals are given in [35], and examples of use for management in [36].

IMS BASED NETWORKS

The telecommunication networks for fixed phone subscribers are based on IMS [37]. The basic idea of IMS is the convergence of voice, data, and multimedia applications within a common network. For IMS, the main protocol is SIP [38], but Diameter is also very important. Multi-layer architecture is achieved by dividing logic into service, control, and access planes as defined by 3GPP/TISPAN standards for IMS. Figure 1 shows such architecture. Due to historical reasons, such a system also includes the previous NGN networks, as well as previous SS7 based networks.

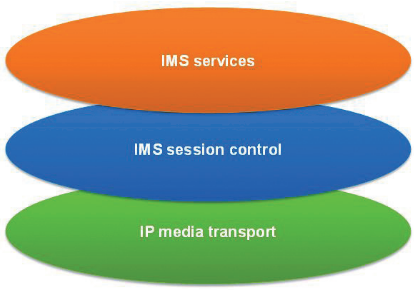

Figure 1: IMS architecture defined by service, control and access plane (adapted from [39]).

VIRTUALIZATION

The concept of NFV (Network Functions Virtualization) was created in October 2012, when NFV group was established, with a white paper [4] calling for industrial and research activities. Later, additional white papers appeared [40, 41, 42]. NFV aims to consolidate a variety of the network equipment onto industry standard high-volume servers by giving operators the freedom to locate servers at the different network nodes and premises. NFV may consist of one or more virtual machines running different software and process to replace dedicated HW. The group has defined the framework and the architecture of NFV. Network functions virtualization (NFV) has been defined as a network architecture concept virtualizes entire classes of network functions into building blocks that may connect, or chain together to create communication services.

As defined in [4], Network Functions Virtualization aims to address these problems by leveraging standard IT virtualization technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Datacentres, Network Nodes and in the end user premises. The authors believe Network Functions Virtualization is applicable to any data plane packet processing and control plane function in fixed and mobile network infrastructures.

According to ETSI [7], the NFV Architecture is composed of three key elements: Network Function Virtualization Infrastructure (NFVI), VNFs and NFV MANO:

- The NFVI is the combination of both hardware and software resources which make up the environment in which VNFs are deployed. NFVI supports the execution of the VNFs. It represents standardized infrastructure abstraction layer to different virtualization technologies (e.g. KVM, VMware, Xen, Hyper-V, Docker).
- Virtualized Network Function (VNF) is the software implementation of a network function THAT is capable of running over the NFVI.
- NFV Management and Orchestration, which covers the orchestration and lifecycle management of VNFs and resource reservation using NFVI interfaces.

As defined in [40], virtualization eliminates the dependency between a network function (NF) and its hardware, as seen in typical physical network appliances by creating a standardised execution environment and management interfaces for the Virtualised Network Functions (VNFs). This results in the sharing of the physical hardware by multiple VNFs in the form of virtual machines (VM). Further pooling of the hardware facilitates a massive and agile sharing of NFV Infrastructure (NFVI) resources by the VNFs; a phenomenon which is already seen in cloud computing infrastructure. This creates new business opportunities analogous to the cloud computing Service Models of Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS); where, for example, a VNF owner does not necessarily own the NFV Infrastructure needed for the proper functioning and operation of the VNF.

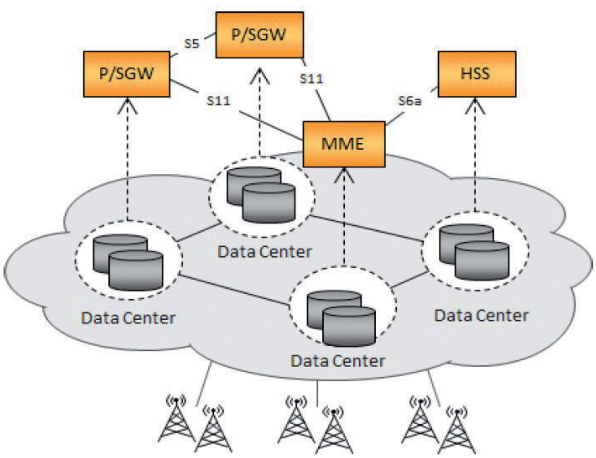

Figure 2: Virtualization of EPC (adapted from [6]).

For example in the mobile network, i.e. Evolved Packet Core (EPC) and IP Multimedia System (IMS) NFs, potential candidates for virtualization can be a Mobility Management Entity (MME), a Serving and Packet Data Networks Gateway (S/P-GW), Call Session Control Functions (CSCFs), as well as Base Stations using different wireless standards. The EPC and IMS NFs can be consolidated on the same hardware resource pool. Virtualization of EPC as defined by ETSI [6] is shown in Figure 2.

SUGGESTIONS FOR VIRTUALIZATION

ARCHITECTURE

For our case, we have defined these main points of the virtualization architecture:

- use of virtualization, cloud-based and open-source solutions,
- use of IMS within 5G for real-time multimedia communications,
- the core 5G data network is based on EPC architecture, which is already known from LTE, and is now upgraded within 3GPP standards into Next Generation Core (NG Core),
- virtualization of IMS network elements, and
- centralized management and automation of the management service based on the MANO concept (ETSI).

Figure 3 shows such a virtualization architecture.

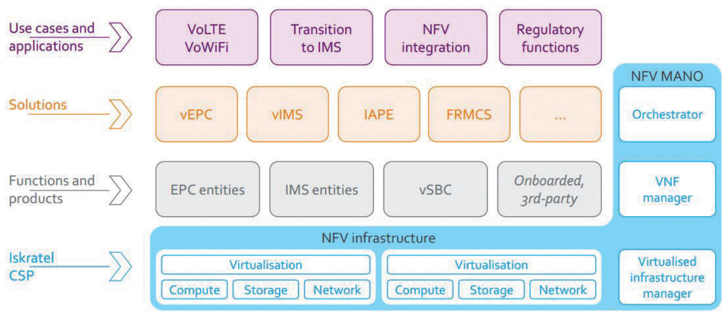

Figure 3: Iskratel SI3000 virtualization architecture (adapted from [43]).

CLOUD SERVICES PLATFORM (CSP)

Cloud Services Platform (CSP) is Iskratel cloud-services platform that guarantees high availability and geo-redundancy of cloud services for different industry verticals on an open, ETSI NFV-compliant architecture. It enables grouping of services from different industry verticals into unique solutions. CSP fully follows the standard ETSI NFV architecture. The solution uses mature, OPNFV (Open Platform for NFV), approved open-source technology, enriched with Iskratel's own extensions that provide high availability and low-latency operation.

CSP is a flexible platform for hosting virtualized network functions (VNFs), virtualized legacy applications, and containers. The platform is comprised of four building blocks: NFVO (orchestrator for service lifecycle and service chaining), VNFM (VNF manager for VNF lifecycle), VIM (Virtualized infrastructure manager), and NFVI (NFV infrastructure).

The major open source components used in CSP are OpenStack [18], OpenBaton [44], and Ceph [45]. NFVO implemented in Iskratel's CSP is based on OpenBaton with Iskratel extensions. VNFM implemented in Iskratel's CSP is based on OpenBaton's VNFM with Iskratel extensions for carrier grade availability of VNFs. The NFVI (Network Function Virtualization Infrastructure) is a key component of ETSI NFV architecture. It represents a set of computing, storage, and network resources which are used to build NFV solutions. NFVI has implemented APIs for using resources which are provided by hardware or by a virtualization hypervisor. It works with VNFs and Virtual Infrastructure Manager (VIM) in collaboration with NFVO. NFVI architecture in Iskratel's CSP is based on OpenStack. OpenStack APIs are used for managing NFVI. For storage infrastructure, CephFS is used. Figure 4 shows the Cloud Service Platform (CSP).

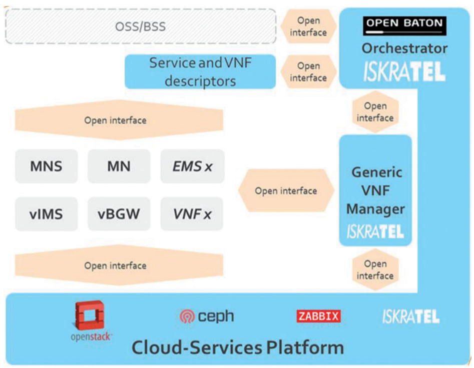

Figure 4: Cloud Service Platform (CSP) (adapted from [39]).

The major CSP services are the onboarding of VNFs, Management and Orchestration (MANO), Network Connectivity of VNFs, availability and reliability of NFVI, support for High-Availability of VNFs, diagnostics of NFVI and VNF cloud resources, quality metrics of NFVI and VM resources for Orchestration and SLA supervision.

IMS

The Iskratel SI3000 vIMS solution includes the virtualization of all major IMS entities according to the ETSI NFV Architecture. These entities are vIMS TAS (Telephony Application Server), vIMS Core (including S-CSCF, I-CSCF, P-CSCF), vIMS Edge (including BGCF, MGCF, AGCF, RGCF, and MRFC), HSS, DNS/ENUM Server, and SBC. All required functionalities for all virtualized vIMS network functions are ensured according to the standard ETSI NFV architecture, and they can be presented as Virtual Network Functions.

In addition company based products, other 3rd party products are used. The main 3rd party products are Open Stack [18] (open source NFV IaaS platform), OpenBaton [44] (open source implementation of NFV ETSI MANO orchestrator), Zabbix [46] (open source NFV monitoring solution) and CepH [45] (open source NFV storage platform).

NEXT GENERATION CORE (EPC)

As a VNF, EPC is deployed on Cloud Service Platform (CSP). In the employment of EPC as VNF in the Cloud, some challenges have appeared. The first key issue is performance. There is a performance cost of virtualization that can be problematic for UP functions, like SGW and PGW. The solution relies on Intel's Data Plane Development Kit (DPDK) that increases and optimizes packet processing per second. Latency is another issue with the virtualization that affects MME, which requires tight time limitations to respond to procedures towards the access network and device.

CLOUD OPERATING SYSTEM (OPENSTACK)

OpenStack [18] is a cloud operating system that controls large pools of computing, storage, and networking resources within a given data centre. All these pools are managed through a dashboard that gives administrators control while enabling their users to provision resources through a web interface. As defined by [18] the OpenStack platform provides the foundation for the NFV architecture, which is essentially a fit-for-purpose cloud for deploying, orchestrating and managing virtual network functions. OpenStack enables multiple datacentre management from a single screen, complete with common security, identity services, APIs, and user interfaces. The open, modular and interoperable framework of the OpenStack project offers telecoms and enterprises the ability to design the NFV system of their choosing, without unnecessary components.

MANO (OPENBATON)

Management and Orchestration (MANO) [21] service covers the orchestration and lifecycle management of resources that support the infrastructure virtualization and the lifecycle management of VNFs. MANO focuses on the virtualization-specific management tasks necessary in the NFV framework; it has three main functional blocks: NFV orchestrators, VNF managers and virtualized infrastructure managers (VIMs). Open Baton [44] is an ETSI NFV MANO compliant framework, which can be used for the management and orchestration of NFV environments. In SI3000 CSP it is integrated with OpenStack's VIM and is primarily used as VNFM and NFVO.

The main components of CSP MANO are the main application, VNFMs (Virtual Network Function Element Managers), EMs (Element Managers) FMS (Fault Monitoring System), and PQMS (Performance and Quality Monitoring System). The advantage in the case of CSP is that the same NFVI infrastructure for NFV ready systems and legacy systems

(LNFV) is implemented. NFV demands are too complex for legacy systems, and the possibility of orchestrating legacy systems depends on legacy system implementation itself.

STORAGE PLATFORM (CEPH)

Ceph [45] is an open source storage platform implemented on a single distributed computer cluster, providing interfaces for an object, block and file-level storage. Ceph primarily aims for completely distributed operation without a single point of failure scalable to the exabyte level. Ceph replicates data and makes it fault tolerant using commodity hardware and requiring no specific hardware support. As a result of its design, the system is self-healing and a self-managing, aiming to minimize administration time and other costs. In SI3000 CSP it is used for all three types of storage and is also intended for DBaaS solutions.

MONITORING

To supervise the cloud operation and the SLA of services hosted in the cloud, CSP according to ETSI NFV recommendations supports the monitoring and collection of different quality metrics. Monitoring availability and performances of infrastructure are done by Zabbix [46]. It automatically discovers network servers and devices. Zabbix is configured with many templates and provides several methods for collecting performance and availability information from monitored infrastructure.

DISCUSSION

CURRENT STATUS

As can be seen, the solution based on the SI3000 product line is in step with other current solutions used for the transition of the networks toward 5G. The main technologies needed in such a transition are virtualization with NFV, OpenStack, and MANO. Virtualization and NFV are poised to change the core structure of telecommunications infrastructure to be more cost-efficient [12]. OpenStack has become the *de facto* standard for cloud-based solutions. The role of NFV MANO [21] functionality is to control the entire life cycle of such services, from instantiation and configuration to monitoring, migrating, scaling and, terminating them.

MAIN ISSUES FOR THE FUTURE

From the research papers and based on the existing work on the product SI3000, some of the main issues can be seen for the future, which are interesting for work on SI3000 products. These main issues are the use of containers, placement, automation, and communication improvements and scalability issues.

[32] presents a benchmarking case study on two alternatives, production-grade virtualization solutions, namely VMware ESXi/vSphere (hypervisor-based) and Linux/Docker (container-based), on which they deploy an NFV-oriented IMS system. Their experiments suggest that the container-based configuration can be less dependable than the hypervisor-based one. A proposal for using microservices is also given in [17]. As proposed by the Open Container Initiative [30], it is expected that the use of containers will have an ever-increasing impact, which raises questions regarding which applications will not be suitable for using microservices.

Placement improvement makes it possible to better utilize the equipment, which is very interesting in the case of large-scale environments [29]. Automation improvement with the automation of Network Function Virtualization is proposed in [25]. With communication improvements, as suggested in [31], communication efficiency improves.

For the future, scaling is a vital issue. [27] proposes, in addition to the default deployment methods provided in OpenStack, an additional policy of scaling, which needs to be improved. Improving the utilization of cloud platform for deploying service function chaining is suggested. A similar proposal was also proposed in [26]. Suggestions for IMS scalability improvement using virtualization are also proposed in [15], [26] and [14].

CONCLUSION

In this article, we have examined the issues, dilemmas, and suggestions when moving toward 5G networks. We showed how virtually all the elements of the existing IMS network can be virtualized and as such prepared for any cloud-based hardware. This is valid for elements of the IMS core and for the edge of such a network. Such a system can be integrated into the 5G telecommunication system.

We have shown that virtualization is a significant issue, with many challenges. Some of the main solutions are clearly visible, such as the use of OpenStack and OpenBaton. There are, however, also many minor dilemmas. Such dilemmas are issues of scalability and the dynamic management of orchestration. For a wider use of 5G there is still some time, and by that time all these matters should be clarified, elaborated, and resolved.

REFERENCES

[1] Camarilla, G. and Garcia-Martin, M.A. (2006). The 3G IP Multimedia Subsystem (IMS):Merging the Internet and the Cellular Worlds. Second Edition. John Wiley & Sons Ltd.

[2] Slapar, D. and Jezeršek, G. and Robnik, A. (2017). From Broadband to 5G. Zbornik referatov 33. delavnice o telekomunikacijah VITEL, pp. 72-77.

[3] Chowdhury, N. M. M. K. and Boutaba, R. (2010). A survey of network virtualization. Computer Networks, no. 5, vol. 54, pp. 862–876.

[4] ETSI. (October 2012). Network Functions Virtualisation,. White paper. portal.etsi.org/NFV/NFV_White_Paper.pdf

[5] Han, B., Gopalakrishnan, V., Ji, L. and Lee, S. (2015). Network function virtualization: challenges and opportunities for innovations. IEEE Communications Magazine, no. 2, vol. 53, pp. 90–97.

[6] ETSI GS NFV 001. (October 2013). Network Functions Virtualisation (NFV); Use Cases.

[7] ETSI. GS NFV 002. (October 2013). Network Functions Virtualisation (NFV); Architectural Framework.

[8] Nadeau, T. (2015). Network Function Virtualization. San Francisco: Morgan Kaufmann.

[9] Mijumbi, R., Serrat, J., Gorricho, J.-L., Latre, S., Charalambides, M., Lopez, D. (2016). Management and orchestration challenges in network functions virtualization. IEEE Communication Magazine, no. 1, vol. 54, pp. 98–105.

[10] Mijumbi, R., Serrat, J., Gorricho, J. et al. (2015). Network function virtualization: state-of-the-art and research challenges. IEEE Communications Surveys and Tutorials, vol. 18, issue: 1, pp. 236–262.

[11] John, W., Moradi, F., Pechenot, B. and Sköldström, P. (2017). Meeting the observability challenges for VNFs in 5G systems. 2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM), Lisbon, pp. 1127-1130.

[12] Hawilo, H., Shami, A., Mirahmadi, M. and Asal, R. (2014). NFV: state of the art, challenges, and implementation in next generation mobile networks (vEPC). IEEE Network, vol. 28, no. 6, pp. 18-26.

[13] Bellavista, P., Foschini, L., Venanzi, R. and Carella, G. (2017). Extensible Orchestration of Elastic IP Multimedia Subsystem as a Service Using Open Baton. 2017 5th IEEE International Conference on Mobile Cloud Computing, Services, and Engineering (MobileCloud), San Francisco, CA, pp. 88-95.

[14] Agrawal, P., et al. (2008). IP multimedia subsystems in 3GPP and 3GPP2: overview and scalability issues. IEEE Communications Magazine, vol: 46, no. 1, pp. 138–145.

[15] Potvin, P., Gamardo, H.G., Nguyen, KK. and Cheriet, M. (2016) Hyper Heterogeneous Cloud-Based IMS Software Architecture: A Proof-of-Concept and Empirical Analysis. Leon-Garcia A. et al. (eds) Smart City 360°. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 166. Springer, Cham.

[16] Abu-Lebdeh, M., Sahoo, J., Glitho, R. and Tchouati, C. W. (2016). Cloudifying the 3GPP IP multimedia subsystem for 4G and beyond: A survey. IEEE Communications Magazine, vol. 54, no. 1, pp. 91-97.

[17] Boubendir, A., Bertin, E. and Simoni, N. (2017). A VNF-as-a-service design through micro-services disassembling the IMS. 20th Conference on Innovations in Clouds, Internet and Networks (ICIN), Paris, pp. 203-210.

[18] (2017-11-15). Open Stack. www.openstack.org

[19] (2017-11-15). Open Platform for NFV (OPNFV): Open Platform for NFV Project. www.opnfv.org

[20] Carella, G. et al. (2014). Cloudified IP Multimedia Subsystem (IMS) for Network Function Virtualization (NFV)-based architectures. 2014 IEEE Symposium on Computers and Communications (ISCC), Funchal, pp. 1-6.

[21] Ersue, M. (2017-11-15). ETSI NFV Management and Orchestration - An Overview. www.ietf.org/proceedings/88/slides/slides-88-opsawg-6.pdf

[22] Soenen, T., Tavernier, W., Colle, D. and Pickavet, M. (2017). Optimising microservice-based reliable NFV management & orchestration architectures. 2017 9th International Workshop on Resilient Networks Design and Modeling (RNDM), Alghero, Italy, pp. 1-7.

[23] Yousaf, F.Z., Goncalves, C., Moreira-Matias, L., Perez, X.C. (2016). RAVA - resource aware VNF agnostic NFV orchestration method for virtualized networks. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC).

[24] (2017-11-15). Open Orchestrator. www.open-o.org

[25] Komarek, A., Pavlik, J., Sobeslav, V. (2017) Orchestration and Automation of NVF. Xhafa F., Caballé S., Barolli L. (eds) Advances on P2P, Parallel, Grid, Cloud and Internet Computing. 3PGCIC 2017. Lecture Notes on Data Engineering and Communications Technologies, vol 13. Springer, Cham.

[26] Medhat, A.M., Taleb, T., Elmangoush, A., Carella, G.A., Covaci, S., Magedanz, T. (2017). Service function chaining in next generation networks: state of the art and research challenges. IEEE Communication Magazine, vol: 55, (2), pp. 216–223.

[27] Chen, J., Chen, Y., Tsai, S. C. and Lin, Y. B. (2017), Implementing NFV system with OpenStack. *2017 IEEE Conference on Dependable and Secure Computing*, Taipei, pp. 188-194.

[28] Callegati, F., Cerroni, W., Contoli, C. and Santandrea, G. (2015). Implementing dynamic chaining of Virtual Network Functions in OpenStack platform. 2015 17th International Conference on Transparent Optical Networks (ICTON), Budapest.

[29] Khebbache, S., Hadji, M. and Zeghlache, D. (2017). Virtualized network functions chaining and routing algorithms. Computer Networks, vol. 114, pp. 95-110.

[30] Open Container Initiative. (2017-11-15). opencontainers.org

[31] Chen, J., Xu, S., Zhang, H. and Wang, Z. (2016). A Virtual Machine Data Communication Mechanism on Openstack. Zu, Q., Hu, B. (eds) Human Centered Computing. HCC 2016. Lecture Notes in Computer Science, vol 9567. Cham: Springer.

[32] Cotroneo, D., De Simone, L. and Natella, R. (2017). NFV-Bench: A Dependability Benchmark for Network Function Virtualization Systems. IEEE Transactions on Network and Service Management, vol. PP, no. 99, pp. 1-1.

[33] (2017-11-15). 5G Berlin. www.5g-berlin.org

[34] (2017-11-15). 5G PPP. The 5G Infrastructure Public Private Partnership. 5g-ppp.eu

[35] 5GPPP (2016). 5G empowering vertical industries. 5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

[36] (Februar 2015). NGMN. NGMN 5G White paper.

[37] www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

[38] ETSI. TS 123.228. IP Multimedia Subsystem (IMS); Stage 2.

[39] ETSI. TS 124 229. Internet Protocol (IP) multimedia call control protocol based on Session Initiation Protocol (SIP) and Session Description Protocol (SDP); Stage 3.

[40] Iskratel. (2017). SI3000 vIMS System Description.

[41] ETSI. (October 2013). Network Functions Virtualisation – Update White Paper. White paper. portal.etsi.org/NFV/NFV_White_Paper2.pdf

[42] ETSI. (October 2014). Network Functions Virtualisation – White Paper #3. White paper. portal.etsi.org/NFV/NFV_White_Paper3.pdf

[43] ETSI. (Februar 2017). Network Functions Virtualisation – White Paper on NFV priorities for 5G. White paper. portal.etsi.org/NFV/NFV_White_Paper_5G.pdf

[44] Slapar, D. (2017). Building Rock-Solid Cloud Solutions on a Non-consolidated Foundation The Sand of Everything. SDN NFV World Congress 2017, The Hague.

[45] (2017-11-15). OpenBaton. www.openbaton.org

[46] (2017-11-15). CepH. www.ceph.com

[47] (2017-11-15). Zabbix. www.zabbix.com