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Technology pillars in the architecture of future 5G mobile networks: NFV, MEC and SDN

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ABSTRACT

This paper analyzes current standardization situation of 5G and the role network softwarization plays in order to address the challenges the new generation of mobile networks must face. This paper surveys recent documentation from the main stakeholders to pick out the use cases, scenarios and emerging vertical sectors that will be enabled by 5G technologies, and to identify future high-level service requirements. Driven by those service requirements 5G systems will support diverse radio access technology scenarios, meet end-to-end user experienced requirements and provide capability of flexible network deployment and efficient operations. Then, based on the identified requirements, the paper overviews the main 5G technology trends and design principles to address them. In particular, the paper emphasizes the role played by three main technologies, namely SDN, NFV and MEC, and analyzes the main open issues of these technologies in relation to 5G.

1. Introduction

The evolution of mobile communications and its integration in the daily life of the whole society has an obvious influence over the economic and social development in the last years. This influence has turned the design of 5G architecture into one of the pillars of the future 2020 society, as it is intended to support a very wide range of innovative services. 5G will create an ecosystem for technical and business innovation involving vertical markets such as automotive, energy or healthcare and will enable competitive advantages for industry. In consequence, 5G must face up to new demands such as growing traffic volume and service complexity, higher quality of user experience, increasing number and heterogeneity of devices and better affordability by further cost reduction. At the same time, there is the requirement to access those services ubiquitously, while the demand for integration and convergence is intensifying.

In this context, new design paradigms of the 5G network architecture are expected to make the difference in relation to previous generations, introducing major changes not only at air interface, but also from a flexible network management perspective. In particular, 5G will leverage Software Defined Networking (SDN), Network Function Virtualization (NFV) and Mobile Edge Computing (MEC) principles for scalable and flexible network management to deal with short-service life-cycles.

This paper analyzes current standardization situation of 5G and the role SDN/NFV/MEC play in order to address the challenges the new

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generation of mobile networks must face. The paper is organized as follows: Section 2 analyzes the possible directions for standardization from the main Standards Developing Organizations (SDO), regional initiatives and industrial alliances related to 5G architecture definition and to SDN/NFV/MEC technologies. Next, Section 3 reviews recent documentation from those relevant institutions to pick out the expected and emerging use cases that will be enabled by 5G technologies. The objective is to classify these use cases and identify the potential scenarios and vertical sectors that will configure future service requirements. Eventually, this section also offers a brief analysis of the related high-level potential requirements which can be derived from the use cases. Section 4 makes a brief overview of 5G technology trends and design principles to address the aforementioned requirements. Finally, Section 5 provides an analysis of the open issues on the convergence of SDN, NFV and MEC and Section 6 summarizes the main conclusions of the paper.

2. Identification of SDOs and main stakeholders

In the last years, regulatory bodies and other stakeholders, such as research institutions, mobile operators, network equipment bodies and international organizations, have launched the new wave of research efforts that will lead to 5G technology by 2020.

This section introduces an overview of the standardization roadmap related to 5G considering international working groups that we classify in three categories: Standardization bodies, regional initiatives and industrial alliances.

2.1. Standardization bodies

Fig. 1 depicts the expected high-level timeline showing current activities and next steps in standardization that are detailed next.

ITU: The International Telecommunications Union is working on the definition of the framework and overall objectives of the future 5G systems, denoted as IMT-2020 systems in ITU terminology [1]. ITU-R also describes in detail a broad variety of capabilities associated with envisaged usage scenarios, potential user and application trends, growth in traffic, technological trends and spectrum implications.

On the other hand, the focus group on IMT-2020 of ITU-T is developing a report on standards gap analysis [2] that studies several key technical topics related to networking aspects of IMT-2020. This analysis includes high-level network architecture, end-to-end QoS framework, emerging network technologies, mobile front haul and back haul, and network softwarization.

3GPP: The 3rd Generation Partnership Project is planning to split the 5G work into three phases or releases. Release 14 includes a series of Study Items (SI) related to 5G Mobile Network for Advanced Communications. These studies will lead to normative work in the scope of Release 15, addressing a subset of requirements that are important for current commercial needs. Release 16 will look at more features, use cases, detailed requirements, etc.

In this scope, Technical Specification Group (TSG) Radio Access Network (RAN) is working on the scenarios and requirements for next generation access technologies [3] (Release 14). TSG SA (Service and System Aspects), specifies the service requirements and the overall architecture of the 3GPP system. SA is composed of six working groups. SA1 (Services) is accomplishing a feasibility study on new services and markets technology enablers [4]. SA2 (Architecture) studies the architecture for next generation mobile systems [5], which shall support the new RAT(s), the evolved LTE, non-3GPP accesses, minimize access dependencies and consider scenarios of migration to the new architecture. SA5 (Telecom Management) is working on the management concepts, the management requirements and use cases from operators perspective for mobile networks that include virtualized network functions and introduces the management architecture that provides a mapping between 3GPP and the ETSI NFV-MANO framework for these mobile networks [6]. This working group also analyzes different proposed solutions to coordinate the NFV management architecture and the 3GPP management framework [7], which identifies the management of mobile networks in the aspects of Fault management, Configuration management, Performance management, and Core network lifecycle management.

ETSI: European Telecommunication Standards Institute has defined several Industry Specification Groups (ISG) to develop standards in fields such as SDN, NFV and autonomic network management.

NFV ISG is developing an open and interoperable NFV ecosystem to leverage rapid service innovation for network operators and service suppliers. It is now in its second phase of specification development and focused on technology adoption and areas such as testing-validation, performance/assurance, security, stability, interoperability, reliability, availability and maintainability. As a part of this ISG, Evolution and Ecosystem Work Group (EVE WG) is developing feasibility studies and requirements in relation to new NFV use cases and associated technical features, new technologies for NFV and relationship of NFV with other technologies. NFV Interfaces and Architectures (IFA) WG is responsible for delivering a set of information models and information flows to support interoperability at reference points. At the same time, this WG performs the refinement of the architecture and interfaces

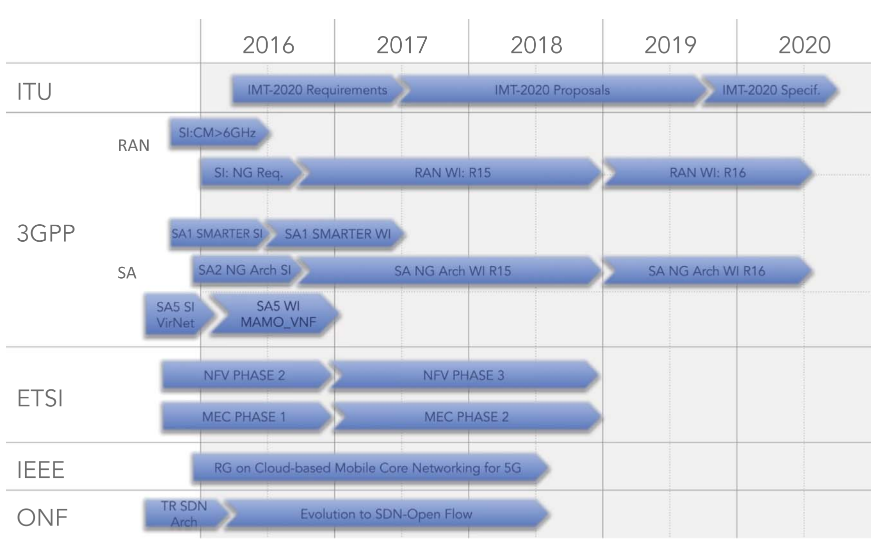

Fig. 1. Standardization timeline.

leading to the production of the set of detailed specifications. NFV Testing, Experimentation and Open Source (TST) WG maintains and evolves the PoC framework and extends testing activities to cover interoperability based on ISG NFV specifications. Besides, ETSI's Open Source Mano (OSM) group, is developing an open source NFV Management and Orchestration stack, OpenMANO [8], which follows strictly the evolution of ETSI NFV standards. Its aim is to be a regularly updated implementation reference of the ETSI NFV. Some of the members of the project are hardware and software vendors (Intel, Red Hat, Canonical), and telecom operators (Telefonica, Telenor). Thus, ETSI OSM promotes the cooperation between standardization and open source approaches by accessing a more diverse set of contributors and developers than would normally be possible.

Additionally, ETSI MEC (Multi-access Edge Computing, former Mobile Edge Computing) ISG provides a new value chain offering application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers. The objective is to take advantage from the existing NFV infrastructure to enable new vertical business segments and services for consumers and enterprise customers [9].

On the other hand, ETSI NGP (Next Generation Protocols) ISG is working on the identification of the requirements for next generation protocols and network architectures, from all interested user and industry groups. This ISG is seen as a vehicle for the 5G community (and others of interest) to first gather their thoughts and prepare the case for the Internet community's engagement in a complementary and synchronized modernization effort.

IEEE: The Institute of Electrical and Electronics Engineers has just started the standardization work on future 5G systems. Among others, it has launched pre-standardization Research Group on Cloud-based Mobile Core to analyze SDN/NFV concepts applied to 5G.

ONF: Open Networking Foundation is a user-driven organization dedicated to the promotion and adoption of SDN through open standards development. ONF emphasizes on an open, collaborative development process that is driven from the end-user perspective. The Specification Area of ONF comprises six subgroups, including Mobile Networks. This subgroup defines extensions to OpenFlow to support abstractions necessary in mobile networks and, in particular, works to identify opportunities in 5G networks in support of standards development (e.g., NGMN, 3GPP) related to SDN.

The main outcome of ONF is the OpenFlow Standard [10], considered as the first SDN standard [11], which enables remote programming of the forwarding plane from a centralized control plane element. ONF encourages conformity certification for devices supporting OpenFlow. A number of hardware vendors like Cisco, Juniper, Dell, HP, BigSwitch Networks, Brocade Communications and Alcatel-Lucent have OpenFlow implementation in some of their products.

2.2. Regional initiatives

FP-7 (*Europe*): The RAS (Radio Access and Spectrum) is a cluster activity that comprises the research effort on radio access and spectrum in the area of future networks of the Seventh Framework Programme of the EU. This cluster is analyzing architecture aspects of 5G mobile and wireless communication systems [12], considering both wireless and wired parts targeting a fully integrated solution.

5G-PPP (*Europe*): 5G Public Private Partnership Program has been initiated by the EU Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers. 5G-PPP is working to develop the next generation of network technologies taking into account key societal challenges and their networking requirements [13]. This initiative comprehends several work groups, including 5G Architecture WG, to serve as common platform and facilitate consensus building on the 5G architecture, and SDN/NFV WG, with the purpose of analyzing and addressing unification and application of key research topics to software networking.

5G Forum (*Korea*): 5G Forum is leading the development of key candidate next-generation communications technologies in Korea through full-scale research and exchange among all interested parties of the new mobile communications infrastructure, including those in the IoT/Cloud/Big Data/Mobile fields, industry-academic-research institutions, as well as the manufacturers and service providers [14].

5G Promotion Group (*China*): IMT2020 (5G) Promotion Group is working in the analysis of the main technical scenarios, challenges, and key enabling technologies for 5G [15]. The objective is to define the 5G new network architecture, infrastructure platform and network key technologies, define the network design principles and technology roadmap and form the consensus on the 5G network technology framework, in order to guide 5G international standardization and promote industrial development [16].

5GMF (*Japan*): The Fifth Generation Mobile Communications Promotion Group was created to conduct research and development concerning the 5G Mobile Communications Systems and research and study pertaining to standardization thereof. The objective is the study of the overall network architecture for 5G mobile and the analysis of the requirements and technologies for network infrastructure [17].

5G America's: 5G Americas is an industry trade organization composed of leading telecommunications service providers and manufacturers. Its mission is to foster the advancement and full capabilities of LTE wireless technology and its evolution beyond to 5G. Furthermore, this organization is examining the 5G market drivers, use cases, requirements, regulatory considerations and technology elements for the purpose of being considered for the further development of the end-to-end 5G system [18].

2.3. Industry alliances

NGMN: Next Generation Mobile Networks alliance has developed the requirements for 5G mobile broadband technologies. Particular focus during this process has been on the needs of mobile network operators [19] to establish clear functionality and performance targets as well as fundamental requirements for deployment scenarios and network operations, and leading to the implementation of a cost-effective network evolution.

SCF: Small Cell Forum is aimed to drive the wide-scale adoption of small cells and to influence and deliver technical inputs that inform and enhance the standards process [20]. The priorities of SCF include the understanding and enablement of future network transformations with a particular focus on virtualization of small cell layer and the preparation of small cell technology for mass deployment in heterogeneous networks exploiting self organizing capabilities.

3. Identification of use case categories, scenarios, vertical sectors and requirements

Communications beyond 2020 will comprise a combination of current and emerging systems. In consequence, the definition of 5G will be marked, to a great extent, by the collection of components and systems needed to handle the requirements of existing and future use cases. At the same time, these use cases will operate in scenarios that exhibit a collection of characteristics that limit the service provision. On the other hand, operators will support vertical industries to contribute to the creation of new business models and update industry processes.

From the documentation released by the SDOs and main stakeholders of Section 2, this section identifies a collection of use cases expected for 5G that will probably be the driver for the technology. Then, these use cases are classified into four main scenarios and also are assorted according to envisioned vertical sectors.

This identification of prospective use cases, scenarios and vertical sectors is useful to clarify and organize system requirements of the

	Standard. bodies			Regional initiatives						Indust. allian.	
	ITU	3GPP	ETSI	FP-7	5G-PPP	5G Forum	5G Promotion Group	5GMF	5G America's	NGMN	SCF
1. Pervasive video	✔	✔	✔	✔		✔	✔		✔	✔	✔
2. Operator Cloud Services	✔	✔	✔	✔	✔		✔			✔	✔
3. Dense urban society /Smart city				✔	✔		✔			✔	✔
4. Smart office/Unified enterprise communication	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔
5. Smart home		✔		✔		✔	✔		✔		✔
6. HD video/photo sharing in open-air gathering	✔			✔		✔	✔	✔	✔	✔	✔
7. 50+ Mbps everywhere		✔						✔		✔	✔
8. Location aware services	✔	✔	✔			✔					✔
9. Ultra-low cost networks				✔						✔	
10. High speed vehicles	✔	✔		✔		✔	✔			✔	✔
11. Moving hot-spots		✔		✔				✔		✔	✔
12. Remote computing and industrial control	✔	✔		✔						✔	
13. Vehicular networks	✔		✔	✔		✔	✔		✔		✔
14. 3D connectivity	✔	✔				✔				✔	
15. Fleet management/Logistics		✔					✔				
16. Smart wearables	✔	✔		✔	✔	✔	✔			✔	
17. Sensor networks	✔	✔		✔	✔	✔	✔			✔	✔
18. Online trading	✔				✔	✔		✔			
19. Machine-to-machine (M2M)	✔	✔		✔	✔	✔	✔		✔		✔
20. Mobile video surveillance			✔	✔						✔	✔
21. Tactile internet	✔	✔		✔		✔	✔		✔	✔	
22. Gaming	✔		✔	✔			✔		✔		
23. Augmented/virtual/assisted reality	✔	✔	✔	✔	✔	✔	✔	✔	✔		
24. Natural disaster actions	✔	✔		✔		✔			✔	✔	✔
25. Military actions		✔		✔		✔					✔
26. Mission critical systems	✔	✔		✔		✔					✔
27. Smart Grid and critical infrasructure monitoring	✔				✔		✔	✔	✔		
28. Automatic traffic control and driving	✔	✔		✔		✔	✔	✔		✔	
29. Collaborative robots	✔	✔			✔	✔	✔			✔	
30. Remote object manipulation/Remote surgery		✔		✔	✔	✔	✔		✔	✔	
31.eHealth: extreme life critical	✔	✔		✔	✔	✔	✔	✔	✔	✔	
32. News and information		✔				✔				✔	✔
33. Broadcast-like services: local, regional, national	✔	✔				✔				✔	
34. Context-aware services						✔					✔
35. Remote education						✔	✔				

Fig. 2. Application use cases.

services that will be deployed and scaled on demand in an agile and cost efficient manner.

3.1. Use cases

5G will be a complete communication ecosystem to enable a fully mobile and connected society that will create value through new business models. Future mobile broadband will have significantly increased traffic volumes and data transmissions rates, but also many more use cases. In addition to reinforcing the evolution of the established prominent mobile broadband use cases, 5G will also support countless emerging services with a high variety of applications. In consequence, 5G will allow to cover use cases ranging from applications with very low bandwidth requirements to use cases with a very high demand on data rate and latency.

Fig. 2 (based on [21]) summarizes and compiles the use cases identified by the organizations mentioned in Section 2, indicating the institutions that consider each use case in their public documentation. This compilation is not meant to be exhaustive, but rather a measure of the level of flexibility required. 5G will include not only traffic between humans, but also between humans, sensors, and actuators in their environment, as well as between sensors and actuators themselves. Among the listed use cases, there are classic examples, such as smart office and pervasive video, which are mentioned by almost all the consulted organizations. But 5G technologies are also envisioned to promote emerging use cases like machine-to-machine communications, augmented/virtual/assisted reality or eHealth, which are focusing significative attention, as well as promising fields such as industrial control.

Focusing in the final user perspective, Fig. 3 proposes a classification of the use cases listed in Fig. 2 into eight large families: broadband access in dense areas, broadband access everywhere, high user mobility, massive internet of things, extreme real-time communication, lifeline communication, ultra-reliable communication and broadcast-like services. This classification serves as input for stipulating requirements and defining the building blocks of the 5G architecture, which will be analyzed in the next sections. The eight families have been further divided into related categories based on similar requirements. In this process some use cases have been identified as being relevant to more than one category and/or family.

Finally, in addition to the application use cases, which are described from a final user point of view, there is a new group of use cases that are particularly related to network operation in order to address the emerging application services and their requirements. Unlike previous mobile networking systems that offered 'one size fits all' solutions, 5G is expected to be able to simultaneously provide optimized support for different configurations through various means. In addition, the mobile network must be able to dynamically control and allocate network

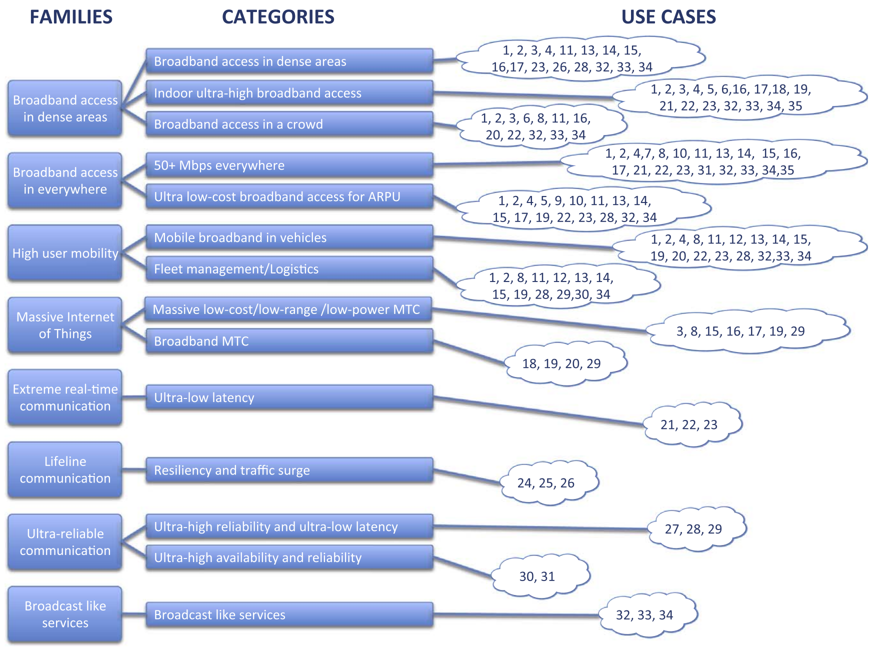

Fig. 3. Classification of application use cases based on [19].

resources to provide flexibly adjustable capacity based on the variation in demand. Mobility management and efficient content delivery procedures must be enhanced as well. An, in addition to the new services derived from the use cases listed in Fig. 2, there are already a large number of services in the cellular networks of the current generations.

The network operation use cases attempt to address the mentioned issues related to flexible system functions and capabilities, new value creation, migration and internetworking, network optimization and security. Fig. 4 collects this category of use cases identified in the documentation released by the aforementioned organizations.

3.2. Scenarios and vertical sectors

As a consequence of the variety of the expected use cases introduced in the previous section, 5G is envisaged to support diverse usage scenarios and applications that will continue beyond 2020. The capabilities needed to serve all those use cases are tightly coupled with the characteristics of the environment and thus, the identification of the scenarios becomes relevant in order to demarcate the constraints. Therefore, this subsection briefly introduces four main usage scenarios, to later classify the use cases identified in 3.1 into these four categories.

Residential: Residential scenario [22] is a mature market target that covers home and small office spaces, typically indoor.

Enterprise: Enterprise scenarios [23] are an evolution of home

	Standard. bodies		Regional initiatives				Ind. allia.
	3GPP	ETSI	5G-PPP	5G Forum	5G Promotion Group	5G America's	NGMN
36. Data analytics		✔	✔	✔			✔
37. Scalable network slicing	✔						✔
38. Scalable network slicing – Roaming	✔						✔
39. Migration and interworking of services from earlier generations	✔					✔	
40. Lightweight device configuration	✔						
41. Access from less trusted networks	✔						
42. Multi-access network integration	✔					✔	✔
43. Multiple RAT connectivity and RAT selection	✔				✔	✔	✔
44. Temporary service for users of other operators in emergency case	✔						
45. In-network and device catching	✔						
46. ICN-based content retrieval	✔						✔
47. Network capability exposure	✔						✔
48. Self backhauling	✔						
49. Fronthaul/backhaul network sharing	✔						✔
50. User multi-connectivity across operators	✔						✔
51 Wireless local loop	✔						

Fig. 4. Network operation use cases.

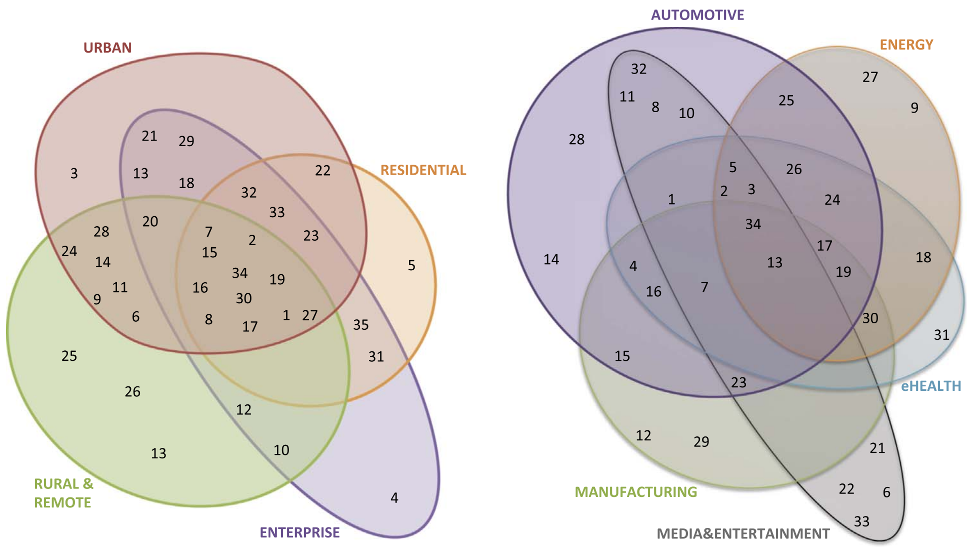

Fig. 5. Classification of application use cases in different scenarios and vertical sectors.

office. Described as generally indoor, may involve large geographic areas and high numbers of users. The key characteristics of this deployment scenario are high capacity, high user density and consistent user experience indoor [3].

Urban: Urban scenarios [24] comprise fully accessible public dense environments such as city center hot-zones, transportation hubs, retail and any other public space both indoor and outdoor. The key characteristics of this deployment scenario are high traffic loads, outdoor and outdoor-to-indoor coverage with continuous and ubiquitous coverage in urban areas [3].

Rural and remote: Rural and remote scenarios [25] include underserved communities beyond the range of normal service. This is the case of remote industrial facilities, rapid reinstatement of coverage after extensive damage to mobile infrastructure and support for emergency services, first responders and humanitarian efforts or services for temporary planned gatherings. The key characteristics of this scenario are continuous wide area coverage supporting high speed vehicles [3].

Fig. 5 (left) depicts the classification of the application use cases listed in Fig. 2 into the four detailed scenarios. Some use cases may fit in more than one scenario, so the groups are not exclusive and the areas appear overlapped. The interpretation of the resulting grouping is twofold. On the one hand, the result of the grouping is a sign of how the operation of future use cases may be constrained by the particularities of the scenarios they run on. On the other hand this grouping is also a measure of the variety of requirements that will be demanded in each scenario according to the use cases they are supposed to support. As a consequence of the latter interpretation, this figure also shows the requirements that will apply to some or all the scenarios and the relevance of the requirements that are specific in each scenario.

Changing the point of view of the requirements identification, 5G network infrastructure is envisaged as a key enabler to make society and economy more efficient and to increase global competitiveness, providing new value chains and business models. In this context, the most relevant vertical sectors at the moment are: Manufacturing, Automotive, eHealth, Energy and Media & Entertainment.

Fig. 5 (right) shows a classification of the use cases listed in Fig. 2 into the five specified vertical sectors. Again, this classification helps the identification of commonalities in the definition of requirements for future 5G systems, in this case according to the industrial sector that will host each use case. Unlike the previous scenario classification, this figure shows a greater dispersion of the use cases through the considered vertical sectors. This means that each vertical sector will exhibit more specific requirements.

3.3. Requirements

As previously discussed, 5G technologies will demand a broad variety of capabilities, tightly coupled with intended usage scenarios and applications. Different usage scenarios along with the current and future trends will result in a great diversity/variety of requirements. One of the main challenges of 5G is to support such variety of use cases in a flexible, reliable and cost-effective way. This section provides a brief analysis of the requirements of vertical industries analyzed in Section 3.2 on seven dimensions shown in Fig. 6: data rate, mobility (speed), (low) latency, density, reliability, positioning accuracy and coverage. This figure analyzes the commonality of requirements in support of a vertical sector, represented by several relevant use cases.

ITU-R and 3GPP are starting already to define requirements for IMT-2020/5G based on the classes of use cases and verticals described in the previous section. Some use cases may require to optimize multiple dimensions while others focus only on one key performance indicator (KPI). The spider diagram of Fig. 6 illustrates the main differences between verticals, and thus, the need for a 5G system to be able to support optimized configurations for a diverse set of requirements, which may be in opposition. For example, eHealth applications require support for high reliability, low latency and low device density while media and entertainment sector also requires support for low latency but lower reliability and higher device density.

Unlike previous 3GPP systems, which tried to provide a universal system fitting all use cases, the 5G technologies are expected to be able to simultaneously provide optimized support for these different configurations using, among others, NFV, SDN, and network slicing. This flexibility and adaptability is a key distinguishing feature of a 5G system.

4. 5G technology trends and design principles

As anticipated already in the previous sections, flexibility for a wide range of use cases and services, and scalability to provide these services in a cost-efficient way, will be one of the key design principles for the 5G communication system. With this objective, network programmability, or softwarization, represents one key trend for designing, implementing, deploying, managing and maintaining network equipment and components whereby software programming.

The concept of network softwarization, introduced in the first IEEE Conference on Network Softwarization (NetSoft 2015) [26], involves wider interest on SDN, NFV, MEC, Cloud and IoT technologies, allowing the exploitation of the characteristics of software such as

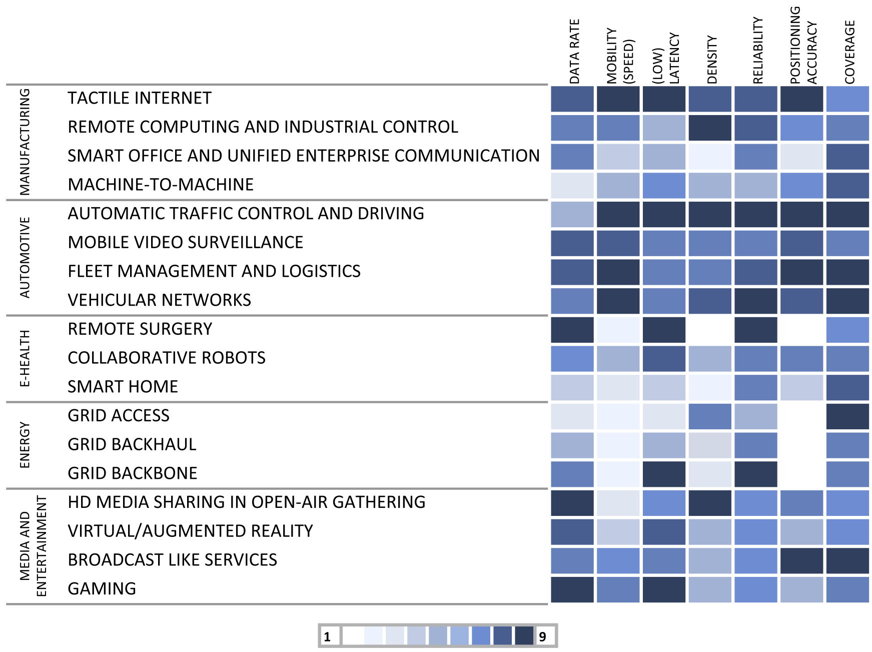

Fig. 6. Technical requirements of vertical sectors.

flexibility and rapidity of design, development and deployment throughout the lifecycle of network equipment and components. This creates the conditions that enable the redesign of the network architecture and services, it allows optimization of costs and processes and enables automated network management.

4.1. Technology trends

Standardization work on 5G technology has recently started. ITU identifies the following technology trends in its overall vision of future 5G systems [1,2]: 1) Technologies to enhance the radio interface, 2) network technologies such as NFV, SDN and C-RAN, 3) technologies to provide mobile broadband communications, 4) technologies to leverage massive machine-type communications, 5) technologies to establish ultra-reliable and low latency communications, 6) technologies to improve network energy efficiency, 7) advanced mobile terminal technologies, 8) technologies to enhance privacy and security, and 9) technologies enabling higher data rates.

It is expected that standardization efforts will focus on the main areas of enhanced radio technologies and novel system architectures. The former will support new wireless technologies with increased capacity and centralized operation, while the latter will enable an increased efficiency of resources through network softwarization principles. ITU will continue with the specification process during 2016, while the different candidate solutions are expected to be available at the involved standardization organisms by 2018-2019. As already mentioned in Section 2, 3GPP is working on different aspects related to 5G Mobile Network for Advanced Communications that will lead to normative work in the scope of the Release 15 (expected in June to December 2018) [2].

4.2. High level architecture

Although the work on the future 5G system in ITU and 3GPP is still in its embryonic phase, the first outcomes of the involved workgroups allow a glimpse of the main working assumptions for the future mobile broadband networks. The work in [1] provides a high-level network architecture (Fig. 7) based on the analysis of the requirements, which will be more elaborated or changed in upcoming standardization phases.

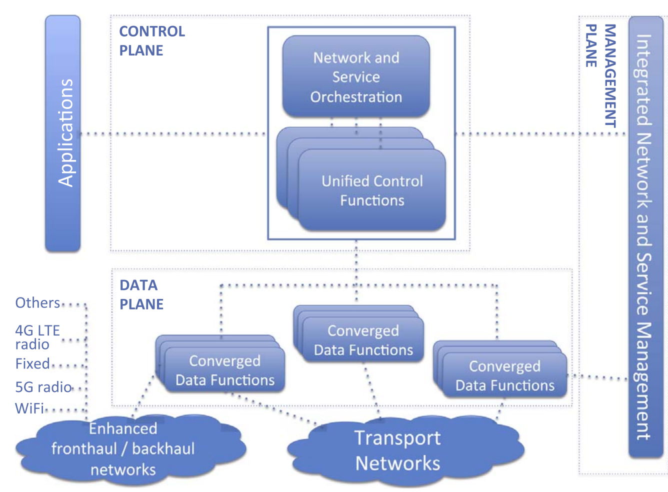

Fig. 7. High level network architecture of 5G based on [1].

In [4], 3GPP SA1 identifies the list of potential requirements for future mobile networks. Together with the different use cases, the Network Operation (NEO) building block includes issues related to system flexibility, scalability, mobility support, efficient content delivery, self-backhauling and interworking with 4G [?].

One of the key challenges of [5] (developed by the 3GPP SA2) in the definition of the next generation mobile networks is the concept of network slicing. NGMN defines the concept of network slicing as a set of network functions, and resources to run these network functions, forming a complete instantiated logical network to meet certain network characteristics required by the end-user service [27]. Nowadays, resource slicing inside the Core Network is in a more mature stage, and it is already under specification in the 3GPP SA5 working group under the work item OAM14-MAMO-VNF. In this sense, the relationships with ETSI NFV and ETSI MANO standards are of great relevance for the virtualization of the network functions.

Regarding RAN virtualization, the 3GPP RAN TSG proposes different functional splits of the RAN, which are proposed as potential solutions for the Radio Transmission Points (R-TP) [3], which can coexist under a unified management system. Additionally, the pro-

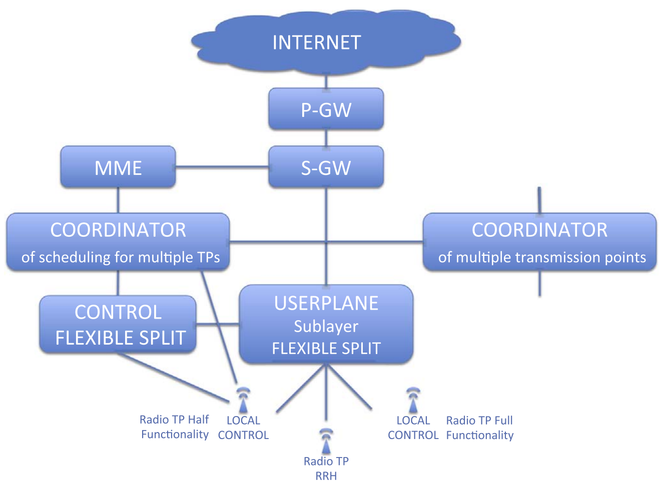

Fig. 8. 3GPP next generation RAN architecture (RAN TSG) based on [3].

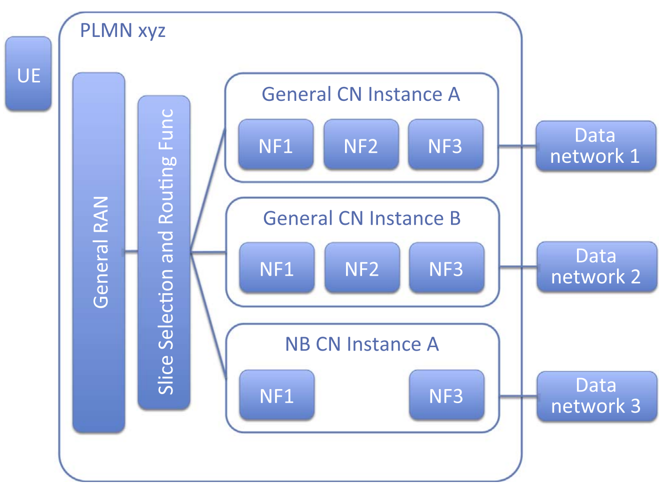

Fig. 9. Network slicing in 3GPP next generation architecture [5].

posed architecture splits the user plane and control plane as shown in Fig. 8. Taking into account the different potential RAN functional splits, the extension of the virtual network slices up to the UE is yet unclear. In this sense, [5] provides an analysis of the implications arising from network slicing, without including the RAN (Fig. 9). In that case, the RAN remains as a common network segment that includes a new element for “slice identification and selection” (similar to the NAS Node Selection Function in 4G).

4.3. Network virtualization

The NFV ISG is the network operator-led working group with open membership created under the umbrella of ETSI to work through the technical challenges of NFV. It is worth mentioning that this ISG does not produce standards, but rather it produces documents that contain guidelines in the form of Group Specifications, which are not in the form of European Norms (EN) or Technical Standards (TS). The outputs are openly published and shared with relevant standards bodies, industry Fora and Consortia to foster a wider collaborative effort. In case of possible mismatches the ETSI ISG NFV will collaborate with other SDOs in order to meet the requirements.

The NFV ISG also provides an environment for industry to collaborate on Proof of Concept (PoC) platforms in order to demonstrate solutions, which address the technical challenges for NFV implementation and to encourage growth of an open ecosystem. The NFV concept envisages the implementation of Network Functions (NFs) as software-only entities that run over the NFV Infrastructure

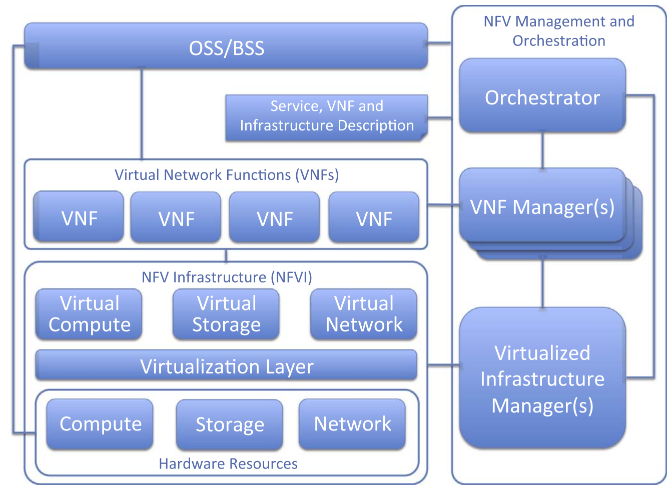

Fig. 10. ETSI NFV reference architectural framework.

(NFVI). Fig. 10 illustrates the high-level NFV framework, as published in October 2013 by the ETSI ISG NFV in its document on global architecture, in which three main working domains can be identified:

- Virtual Network Function (VNF), as the software implementation of a network function which is capable of running over the NFVI.
- NFV Infrastructure (NFVI), which includes the diversity of physical resources and how they can be virtualized. NFVI supports the execution of the VNFs.
- NFV Management and Orchestration (NFV MANO), which covers the orchestration and lifecycle management of physical and/or software resources that support the infrastructure virtualization, and the lifecycle management of VNFs. NFV MANO focuses on all virtualization-specific management tasks necessary in the NFV framework.

The NFV architectural framework handles the expected changes that will probably occur in an operator's network due to the network function virtualization process. Fig. 10 shows this global architecture, depicting the functional blocks and reference points in the NFV framework. This architectural framework focuses on the functionalities that are necessary to support virtualisation but it does not specify which network functions should be virtualized, since that is solely a decision of the owner of the network.

4.3.1. Integration of NFV into mobile networks management systems

Different working groups are studying the integration of NFV management framework with the traditional OSS/BSS management systems. Fig. 11 shows a general overview of this integration effort.

The 3GPP SA5 study item [7] identified the following aspects regarding the management of mobile networks that include virtualized functions (FCAPS): 1) fault, 2) configuration, 3) accounting, 4) performance, and 5) security.

The work in [6] presents the management concept, architecture and requirements for mobile networks with virtualized network functions. The management requirements are organized according to the four management categories extracted from the study item. It also presents a management architecture that provides a mapping between 3GPP and the ETSI NFV-MANO framework (Fig. 11). The management architecture was designed for mobile networks composed of both physical and virtualized network elements.

The Small Cell Forum (SCF) carried out several studies analyzing the introduction of virtualization technologies in small cell networks [28,29]. As a result of these studies, the small cell is separated into two components: a remote small cell, where functions are non-virtualized, i.e. they are Physical Network Functions (PNFs) which are implemen-

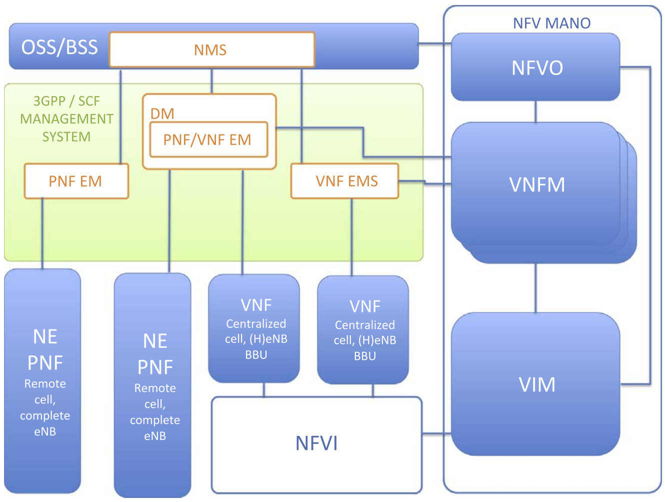

Fig. 11. The mobile network management architecture mapping relationship between 3GPP and NFV-MANO architectural framework based on [6,28].

ted via a tightly coupled software and hardware, and a central small cell, where functions are virtualized, i.e. they are VNFs which are implemented by abstracting the hardware from the software, so that they are executed on a pool of shared computation, storage and networking resources. One central small cell can serve multiple remote small cells. The central and remote small cells are physically connected through the fronthaul link.

According to this virtualization approach, SCF has studied the functional split between VNF and PNFs, i.e. which small cell functions should reside at the remote small cell and which ones at the central small cell [30]. Considering different layers of the user/control plane protocol stacks, namely Radio Resource Control (RRC), Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), Medium Access Control (MAC) and Physical (PHY) layers, the study follows a top-down approach, in which gradually more layers are virtualized by moving them from the remote to the central small cell, yielding the possible functional splits shown in Fig. 12. For each functional split the study determines the fronthaul latency and bandwidth requirements. Fig. 13.

The impact of small cell virtualization on the management architecture is analyzed in [31], using ETSI-NFV and 3GPP architectures that support a combination of PNF and VNF systems. In particular, Fig. 11 presents one of the options identified in [31] for managing small cells, which include the mentioned PNFs and VNFs. The architecture is aligned with the ETSI-MANO framework of [32] and its adaptation of 3GPP addressed in [7]. In the approach illustrated in Fig. 11, the Element Management System (EMS) is split in two components: the PNF EMS and the VNF EMS, which are in charge of managing the PNF and the VNF, respectively. Besides, Fig. 11 also shows the need to connect the PNF EMS and VNF EMS for coordination purposes, which can be done through the 3GPP defined Itf-P2P interface. Another option identified in [31] for carrying out this coordination is through the Network Management System (NMS) and the Itf-N interface.

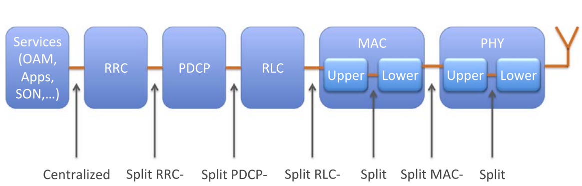

Fig. 12. Functional split between VNF and PNFs.

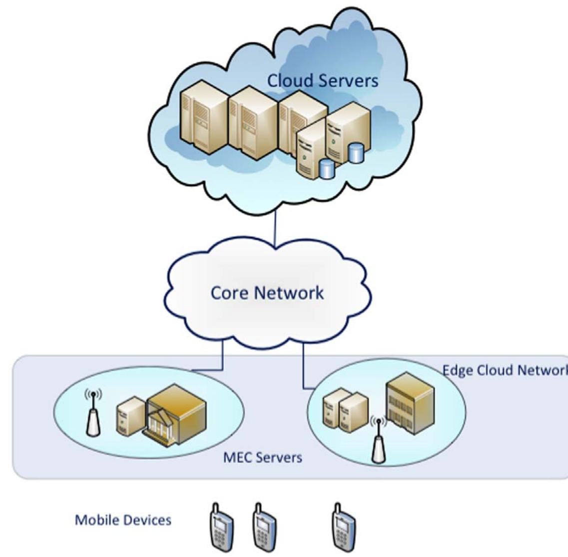

Fig. 13. MEC architecture.

4.4. Mobile Edge Computing (MEC)

The idea of a computing platform located at the mobile network edge is not new and is carried out inside ETSI by the Mobile-Edge Computing (MEC) ISG [9], whose activity started in December 2014. It follows the current trends towards cloud-based architectures operating in an IT environment but with the peculiarity of being located at the edge of the mobile network, within the RAN and in close proximity of the mobile subscribers. MEC platform wants to take advantage from the existing NFV infrastructure - that provides a virtualization platform to network functions enhancing it with new computing/storage resources and creating a virtualization environment for a wide range of applications running at the mobile network edge. Distinctive features of the MEC architecture are low latency, proximity, location awareness, high bandwidth, and real-time insight into radio network information. This facilitates accelerated content delivery services and applications at the edge of the mobile network, closer to the end-users. The mobile subscriber's experience can be significantly improved through more efficient network and service operations, enhanced service quality, minimized data transit costs and reduced network congestion.

The MEC servers provide computing, storage and bandwidth capacity that is shared by multiple virtual machines installed on top of them; being owned and managed by the infrastructure provider, they are directly attached to the base stations. Traditionally, all data traffic originated in data centers is forwarded to the mobile core network. The traffic is then routed to a base station which delivers the content to the mobile devices. In the mobile edge computing scenario, MEC servers take over some or even all of the tasks originally performed in a data centre. Being located at the mobile edge, this eliminates the need of routing data through the core network, leading to lower communication latency.

4.5. Software Defined Networks (SDN)

SDN introduces support for dynamic programmability of network nodes in the process of data forwarding. For this aim, SDN proposes to separate the control and data planes, enabling centralized control of all the data flows and data paths in the network domain. Apart from traditional routing functions, in SDN the central control element, or SDN Controller, carries out the networking decisions and sends the resulting forwarding rules to the data plane nodes. As a result, the data plane of network nodes is less complex, which implements fast forwarding mechanisms leading to enhanced data plane performance

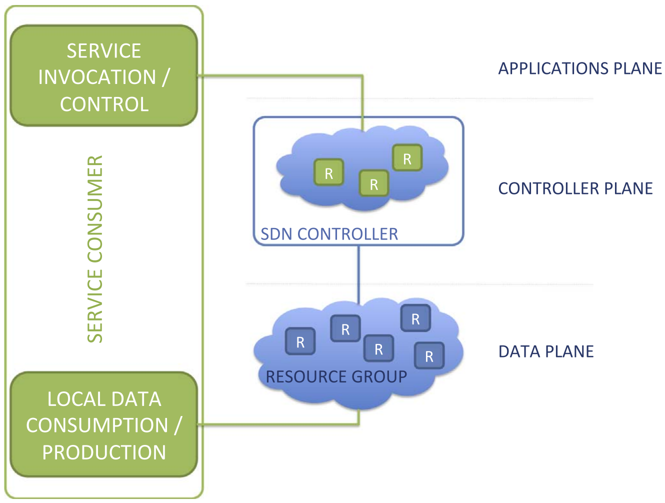

Fig. 14. SDN basic model based on [34]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

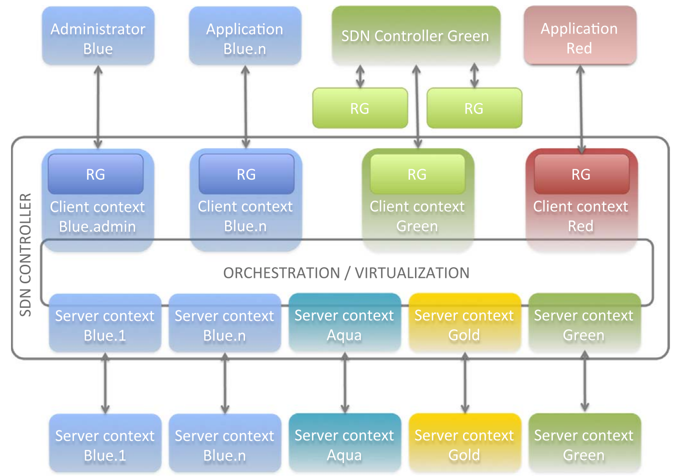

Fig. 15. SDN architecture based on [34]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and enabling the use of programmable general-purpose hardware as well.

Although SDN has been traditionally associated with the OpenFlow protocol, Open Flow is just one candidate protocol to implement the communication between the SDN Controller and data plane nodes. The main attempt to provide a standardized architecture for SDN is performed by the ONF in the form of Technical Recommendations. The first version of the SDN architecture was released in June 2014 [33] and has been updated in February 2016 to the SDN Architecture 1.1 [34]. The latest ONF SDN Architecture is aimed to provide a knowledge synthesis of the discussions across the ONF working groups, standard development organizations (SDOs), and open-source communities. In particular, this document is further extended and elaborated in the following three ONF technical papers: TR-522: SDN Architecture for Transport Networks, TR-518: Relationship of SDN and NFV and TR-523: Intent NBI - Definition and Principles.

Fig. 14 depicts the basic model proposed by the ONF. It consists of two main entities: (1) a Service consumer in charge of controlling the data and management plane service by exchanging operations with (2) the SDN controller and invoking actions on a set of owned virtual resources (Green). The user data is processed by the set of resources (Blue) owned by the SDN controller. The SDN controller is the main instigator in orchestrating virtual resources and services on the top of own processing resources. This architecture illustrates the coexistence of Consumer and Control roles in separate business domains to stress the importance of segregation in a scenario where traffic isolation, information hiding, security and policy enforcing on the interface points are essential Service Level Agreements (SLAs) clearly defined in the contract specification.

The SDN controller is a central independent component within the SDN architecture, (Fig. 15). SDN exemplifies the client-server relationship between SDN controller and other entities/SDN controllers. There is a dual perspective of the entity SDN controller, represented through the role of SDN-server - as an element that offers services to clients, and the SDN-client - an element that can request service invocation from other services, including the SDN-server. The idea behind providing complementary SDN components from both, customer-provider and resource owner/administrator viewpoint, is to grant an overview of the different resource types. Fig. 15, the SDN controller offers services to Green, Red and its own Blue clients. Moreover, the boxes separate the associated Client contexts from the Resource groups with respect to ownership and isolation enforcement policies. For instance, an administrator in the Blue organization could have unrestricted view and privilege over the SDN controller including all client and server contexts.

As a collaborative organization, ONF has sent the aforementioned SDN architecture for consideration to multiple SDOs, including 5G-related activities and liaison statements. For example, ETSI NFV and ONF are in the process of drafting a comprehensive collaboration agreement with several liaisons across various areas of each organization, including both the Migration and Market Education work groups. Besides, ONF is working with IEEE on their 802.16r proposed protocol efforts within ONF's wireless and mobility working and discussion groups. Additionally, ONF has created formal liaisons with various subgroups of ITU and is also currently discussing with IETF regarding mobile and wireless standards and SDN.

5. Convergence of NFV, MEC and SDN in 5G systems

As mentioned above, operation and management of the network infrastructure have evolved with the introduction of SDN controllers. SDN helps virtualization of the network infrastructure, since it paves the way for isolation, abstraction and sharing of network resources. Another outstanding advancement which has significantly changed networking and service provisioning is NFV. The idea is to migrate network functions, such as gateways, proxies, firewalls, and transcoders traditionally deployed over specialized hardware (i.e. middle-boxes) to software-based applications, implemented and executed over standard high volume servers. Such migration provides several benefits such as: 1) efficient management of hardware resources, 2) rapid introduction of new functions and services to the market, 3) ease to upgrade and maintenance, 4) exploitation of existing virtualization and cloud management technologies for VNF deployment, 5) reduction of CAPEX and OPEX, 6) enabling a more diverse ecosystem, and 7) encouraging openness.

Despite the abovementioned benefits of NFV, the interconnection of VNFs (or traffic steering) is a challenging task, especially under the MEC environment, where VNFs are deployed in the C-RAN with ultra-low latency and high bandwidth requirements. In this context, SDN has been considered as a complementary technology to improve the flexibility and simplicity on delivering the network service (NS). This vision triggered a huge effort to evolve the NFV architecture from SDN-agnostic to fully SDN-enabled [35,36]. The ultimate goal is to build up a system in which NFV technology focuses on the creation, configuration and management of VNFs used in the NS instances. Furthermore, SDN helps VNFs interconnection and NS organization. To fully realize SDN-enabled NFV architectures, the main integration approach is to include the SDN controller in the Virtualized Infrastructure Manager (VIM) and let the NVF Orchestrator (NFVO) to orchestrate/manage the SDN operation [37,38]. In a service chain procedure, the NVFO first

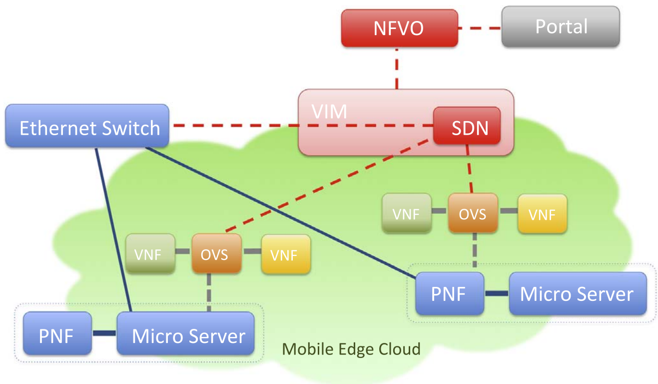

Fig. 16. Service instantiation from the VIM perspective.

tries to logically combine different NSs, considering their interdependencies. That is upon receiving a NS request, the NFVO is free to chain the functions in the best possible way to fulfill the requirements of the end users while optimizing resource utilization. Such an optimal resource allocation may include VNF sharing and reuse among NSs. After the service chaining, the second challenge is to find the best placement for the VNFs, considering: 1) available resources, 2) requirements of the requested NS, and 3) possible impact on the other running NSs. These challenges can be modeled whereby NP-hard optimization problems, such as Location-Routing Problems (LRP) [39] and Virtual Network Embedding (VNE) [40]. The solution to this problem will be passed to the embedded SDN controller in the VIM to instantiate the NS.

To better understand what mentioned above, let's focus on the service instantiation process from the VIM (OpenStack) perspective on an example presented in Fig. 16. To deploy a service with on the presented MEC environment, one needs to take two main steps: 1) create a network, i.e. a specific and isolated VLAN (assuming that all required plugins are available on OpenStack) for the network service - NS, and 2) launch instances, i.e. virtual machines (VM) with appropriate images on them, i.e. VNF. Let's take a closer look at each; in the first step, some items like the network name, access permission, subnet name, network address (range of available IPs), version of IP protocol (IP4/IP6), subnet Gateway IP, Enable/disable DHCP server, etc. are determined. In the second step, instances will be launched, i.e. we will determine the name of instance, its availability zone, flavor, its boot source (image to run on it - which turns a VM to VNF), instance count, security and access to it, network which it belongs, etc.

Let's name the abovementioned steps the network service creation. The role on NFVO in this phase is to make it automated. It means that instead of doing all these steps one by one and manually (as one does in OpenStack) an orchestrator sits between the end user (human being) and VIM and make the process user friendly and automated. That is, it generates a complete network descriptors (NSD) from the virtual network operator (VNO) high level inputs, e.g. on a GUI, and then translate the NSD to a complete and understandable template for the OpenStack (i.e. heat template) with all required information mentioned above (e.g. range of available IPs, etc.). This is useful especially for wide deployments where many services needs to be instantiated and keeping track of all records manually is difficult. To guarantee the isolation between instantiated NS and multi-tenancy, a separate VLAN is dedicated to each NS and the access permission is passed to the right VNO. It means that if a VNO requests two NSs, NFVO ask for the creation of two separate VLANs each for one NS and passes the access permission to VSCVO. Remember, it is a logical VLAN (in other words a range of IPs or ports) which can be hosted over a single vSwitch instance.

In addition to what explained above as the network service creation, there is another important missing point to change the instantiated network into a complete network function chain. This important step is the network configuration. In this process which happens in the same time as the network service instantiation (though via a different logical path), NFVO configures the network, i.e. dictates the data flow between VNFs and identifies how data packet will travel from one VNF to another. Based on the received NSD (which contains VNFFGD and VNFFPD), NFVO generates a template (heat template) which will be communicated to a SDN controller (inside or on the same level as VIM) who makes decisions for data packets. It helps SDN controller to determine the destination of data packet on run time. In simple words, before departing from a port the data packet asks the SDN controller about the destination and the controller determines it (southbound interaction of SDN controller). To do the configuration correctly, based on our previous experience, a set of extra APIs and software (e.g. the software kit developed by ZHAW - Netfloc) is needed on top of a conventional SDN controller (e.g. OpenDayLight - ODL). NFVO with the help of Netfloc communicants with the ODL and configures the service network in an automated manner. It means that the end user (i.e. VNO) does not need to be worried about the details of such configuration because NFVO will take care of it based on the extracted data from the NSD. In addition to the benefits on the instantiation process, NFVO plays an important role on the automated service monitoring, scaling and reconfiguration, etc.

After all, Telecom operators need to guarantee end-to-end QoS and adequate user experience over a network that belongs to various operators, which encompass different technologies [41]. An SDN-enabled NFV architecture in this scenario needs to take care of the composition of network slices and services over multiple domains. The other challenge is to extend NFV and SDN capabilities to support more layers of the RAN protocol suite, e.g. to support new control plane mechanisms such as RRC or Information-Centric Network (ICN). Introducing protocol agnostic forwarding methods such as Protocol Oblivious Forwarding (POF) is another important progress towards a network untied to specific implementations.

6. Conclusions

Numerous groups of industry stakeholders, vendors, researchers, standard developing organizations, certification bodies and other institutions are currently involved in the development of the 5G ecosystem. This paper has provided extensive overview of the expected role and activities undertaken by 5G stakeholders, since this is fundamental for the success of the next generation of communication technologies. This paper showed several use cases, scenarios and emerging vertical sectors foreseen to have a role in the 5G ecosystem. In addition, system requirements have been identified and the key design principles highlighted. Driven by service requirements and innovative technological trends applied to the mobile network, such as SDN, NFV and mobile edge computing, the 5G communication system will be capable of accommodating multiple radio access technologies, meet end-to-end user requirements and provide compelling solutions for flexible network deployment and timely network operations.

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