Softwarization and Virtualization

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Management and deployment of 5G technology is greatly simplified by the adoption of a set of complementary technologies enabling flexible usage of deployed hardware and fast provisioning of new functions and services, namely: Software Defined Networking (SDN) and Network Function Virtualization (NFV). These, in turn, are the building blocks for more sophisticated services such as Cloud-RAN, Network Slicing, and Multiaccess Edge Computing (MEC).

1 Software Defined Networking (SDN)

SDN is an umbrella term to indicate a number of protocols and interfaces allowing network programmability. This is achieved by decoupling the control and user plane. In the SDN concept, the user plane is greatly simplified and consists in stateless, distributed forwarding tables performing packet switching at very high speed. The tables are populated by a centralized control plane maintaining end-to-end path information for each service and providing support for advanced functions such as mobility management, policy and subscription control [14].

Figure 1 shows the basic SDN model according to Open Networking Foundation (ONF) [13]. A service consumer exchanges both data and management-control operations with some SDN provider. Service data is ultimately forwarded by some set of resources that are owned by the SDN provider. The service consumer controls them through the SDN controller by invoking actions on a set of virtual resources that it perceives to be its own.

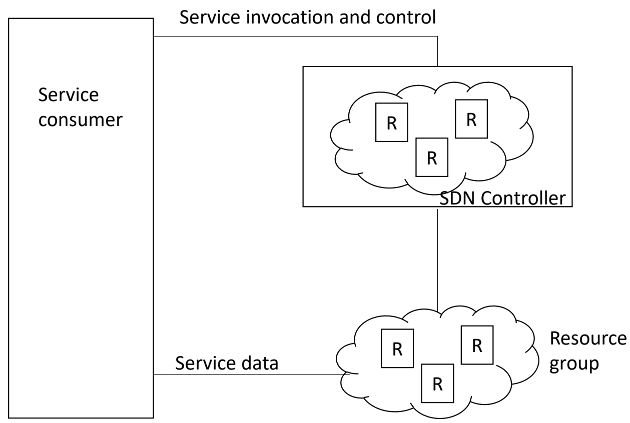

Fig. 1 Basic SDN model according to ONF [13]

2 Network Function Virtualization (NFV)

The NFV architecture defines how software functions can be executed in virtual machines (VMs) and consolidated to share common physical resources in terms of compute, storage, and networking. Multiple functions can be instantiated within the same VM using containers [12]. VMs can be dynamically instantiated to cope with changing network demand in terms of traffic and in terms of offered features and services. Examples of network functions that can be virtualized include:

- Evolved Packet Core (EPC) functions, including the Mobility Management Entity (MME), the Serving Gateway (S-GW), and the Packet Data Network Gateway (P-GW).
- Baseband Processing Unit (BBU) functions
- Switching functions
- Traffic load balancing

With NFV, services are described as sequences of network functions that process end-to-end flows. Figure 2 shows an example forwarding graph for a mobile Internet service provider. Data flows from the evolved eNodeB to the service gateway and to the IP backbone. Mobility management, authentication and other control protocols flow through different network functions. Unlike cellular networks, where a particular feature is activated network-wide, 5G enables the operator to activate a feature on a per-service basis.

NFV and SDN do not require each other, but are related in many ways. SDN provides a natural solution to route packets between the Virtual Network Functions (VNFs) that characterize each service. Additionally, it enables the virtualization of routing functions with a low overhead. Finally, it simplifies the rerouting of traffic flows after a particular VNF is moved from one physical node to another or, similarly, when an additional instance of a VNF is elastically deployed in a new node to cope with increasing traffic demands.

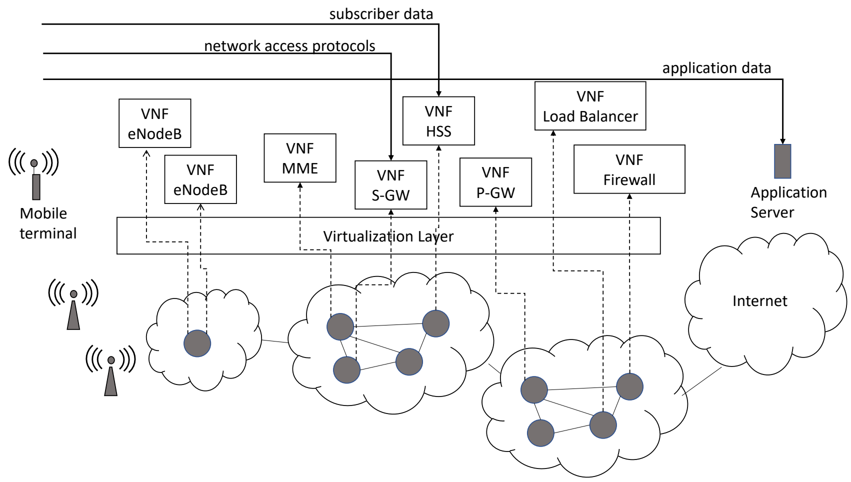

Fig. 2 Example of NFV forwarding graph [8]

The main challenge for NFV solutions is complexity. In order to be cost-effective, many VNFs must be consolidated in a single physical node. As a result, the physical server must be able to manage multiple traffic streams with possibly overlapping addresses while keeping overhead to a minimum.

3 Cloud-RAN

The scenario in which baseband processing is implemented in virtual Baseband Units (BBUs) is known as Cloud-RAN [9]. The virtualized infrastructure manager deploys a pool of virtual BBUs. The cell site simplifies to antennas, Remote Radio Units (RRUs), and switching functions. The switching functions interconnect the virtual BBUs to the RRUs via high-speed optical links to meet latency requirements. According to traffic demand, the VNF Manager allocates BBUs to active cell sites and programs an overlay virtual network to switch traffic flows from the cell site's RRU to the VMs hosting the allocated BBU.

According to [8] Cloud-RAN yields savings over a non virtualized architecture both in terms of CAPEX and OPEX. CAPEX savings stem from the fact that a single virtual BBU can serve traffic from multiple cell sites. Thus, the total number of required BBUs depends on the maximum traffic of the network rather than the maximum traffic of each individual site. OPEX savings stem from the fact that the energy consumption of the whole system depends only on the average number of active BBUs, which depends on the average network traffic rather than on the average number of active cell sites.

Additionally, Cloud-RAN helps the deployment of ultra densified networks. In these deployments, the mobile terminal connects to the network through a cluster of closest cells, which must cooperate to minimize inter-site interference through inter-site scheduling. The consolidation of BBUs in a single physical site makes such cooperation easier and faster.

4 Network Slicing

5G is designed to be a multi-service network supporting multiple verticals with a diverse set of performance requirements. The key to realize this vision is slicing the physical network into multiple isolated logical networks on a per-service basis. Network slicing is the technical mean for allowing the coexistence of different verticals over the same infrastructure.

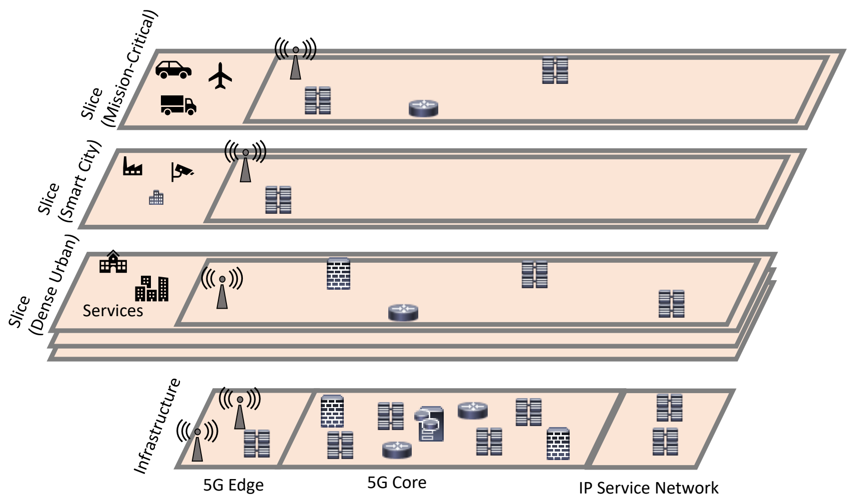

Fig. 3 Example of 5G network supporting multiple network slices

According to the Next Generation Mobile Networks (NGMN) Alliance, a network slice is a set of network functions, and the resources to run these functions, forming a logical network that meets the requirements of a given service[11]. Figure 3 exemplifies the NGMN definition of network slice.

Network Slicing opens the way to a model in which multiple stakeholders cooperate to provide the final service. The 5G-PPP identifies three such roles [7]:

- The **tenant** offers an end-to-end service to the final users and expresses the requirements of the network slice.
- The **Mobile Service Provider (MSP)** brokers the resources, either internally or from the external Infrastructure Providers, manages the network slices, and is responsible of ensuring that each network slice meets the tenant's requirements.

It may operate as a Network-as-a-Service (NaaS) or as a Platform-as-a-Service (PaaS) provider.
- the **Infrastructure Provider** provides the resources, which can be either physical resources or virtualized resources in a shared network or data center.

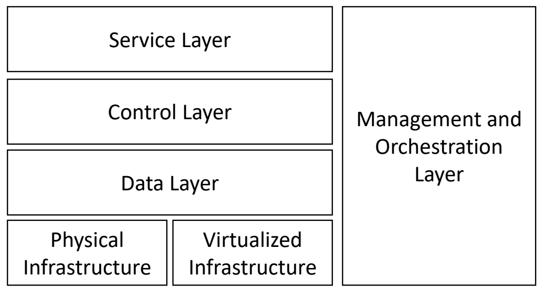

Fig. 4 Layers of the 5G architecture [7]

5G-PPP architectural vision is depicted in Figure 4 and reflects the existence of different business roles and business relationships. It comprises different layers:

- The **Service Layer** comprises the functions for the creation of value, namely the logic and data of the various applications using the 5G infrastructure. It also comprises the tools for analyzing big data and making predictive decisions in real-time.
- The **Management and Orchestration Layer (MANO)** includes the functions for the management of the life cycle of Virtual Network Functions (VNFs) and allocation of resources. It transforms customer-oriented service descriptions into resource-oriented service description.
- The **Control Layer** transforms service requests into configurations and commands to Physical and Virtual Network Functions. It is responsible of routing decisions and of ensuring that the service meets the performance requirements.
- The **Data Layer** comprises the Physical and Virtual Network Functions responsible for value enablement. It includes common networking functions such as user authentication, resource accounting, or network security and dedicated, value-added or mission specific services such as video delivery, state prediction, facility monitoring, or machine control.
- The **Physical Infrastructure** includes assets such as compute, network, and storage, which are distributed in the back-end data centers, in the core network infrastructure, and radio access network.
- The **Virtualized Infrastructure** consists of compute, network, and storage resources reserved in a shared network or data center.

This architecture yields several options for the design of network slices. Figure 5 shows some of these options: standalone slices with own hardware, slices with own spectrum, which share only RF and antenna equipment, slices with shared resources

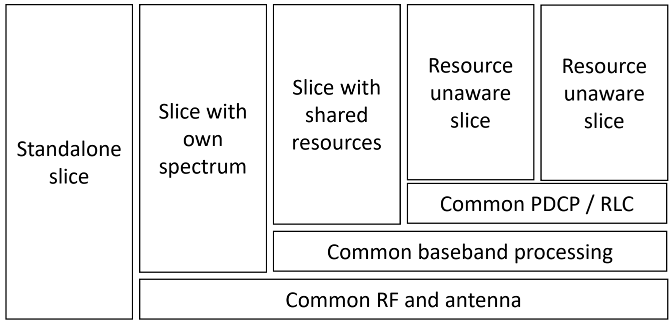

Fig. 5 Options for slice multiplexing

up to the baseband processing, and resource-unaware slices, which have no control over the assigned resources.

5 Multiaccess Edge Computing

The idea of a computing platform located at the network edge is not specific to the world of cellular networks. This is the reason why ETSI choose the name Multiaccess Edge Computing (MEC) for its working group in charge of standardizing such platforms. A MEC platform follows the trend towards cloud-based architecture, but exploits the advantage of being located in close proximity to the end users. In the case of 5G, this means in the RAN. MEC architectures take advantage of the existing NFV infrastructure but are further characterized by low latency, proximity, location awareness, high bandwidth, and real-time insight into radio network information. Exploiting real-time location and radio conditions can create a context for a new ecosystem of use cases with an improved user experience.

In order to support Cloud-RAN (see Section 3), operators will deploy small datacenters at the edge. These IT infrastructures will make it possible to deploy applications and VNFs at the edge without investing additional resources. As a consequence, MEC will become cheaper and more appealing. Those operators that also have fixed subscribers will find natural to concentrate mobile and network operations at the same Points-of-Presence (PoPs), making these locations candidates for providing edge computing for all customers. The MEC platform at each data center will allow third party applications to activate traffic offloading at the edge while also enabling access to other information provided by the operator.

6 Software Platforms

There are several efforts for implementing a NFV-capable platforms, often based on the ETSI MANO specifications [10]. A growing number of such frameworks are being released with an open source licence, either because they are the result of a publicly-funded research project, or they were commercial projects later donated to the community in an attempt to stimulate the adoption. We briefly discuss the most relevant projects in this class.

- *OSM – Opensource MANO* is an ETSI-hosted project aiming at being the reference implementation of the ETSI MANO specifications.[5]
- *ONAP – Open Network Automation Platform* is a Linux Foundation project that is rapidly growing and has strong industrial support. The initial release includes two blueprints: Voice over LTE, and Residential vCPE.[2]
- *Open Baton* is an implementation of ETSI MANO provided by Fraunhoefer FOKUS.[3]
- *SONATA* is the output of an EU-funded research project and provides an SDK for developing VNFs.[6]
- *OPNFV* is another Linux Foundation project. OPNFV aims at building an ETIS MANO platform by integrating components from upstream projects [4]
- *M-CORD* is an ONF hosted project and provides both virtualization of RAN functions and a virtualized mobile core (vEPC) to enable mobile edge applications and innovative services using a micro-services architecture.[1]

7 Conclusion

Communication networks are quickly adopting the cloud model that revolutionized the IT world, providing both flexibility and cost reduction through consolidation of the infrastructure. 5G is adopting network virtualization as a key technology both in the RAN and in the core network.

Operators will deploy small data centers in the RAN, at the edge of the network. These data centers will enable virtualization of the baseband processing, resulting in significant savings. They will also support MEC, which will enable new services for the end user characterized by low latency and location awareness.

Network slicing, which virtualizes both the radio access and core networks, will enable per-service performance levels and isolation. It will support a model in which the mobile service operator operates as a resource broker, which pools resources from different infrastructure operators and provides network slices. Each slices is then operated by a tenant, which offers the service to the end-user.

In addition to 3GPP, several organizations are standardizing network softwarization and virtualization protocols and interfaces, most notably ETSI and ONF. In parallel to standardization activities, several projects are releasing components under an open-source licence. These components are accelerating the adoption of newer technologies and are becoming reference implementations, thus improving interoperability.

There are many issues still open and which require more operational experience to be fully understood. Some of these issue are: how to distribute network functions over different execution platforms by different vendors; how to efficiently and reliably translate service requirements into resource requirements; how to provide a trusted execution environment for third party services over shared resources; how to manage the operational complexity of a large network with multiple stakeholders.[15]

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