Chapter 2
Cloud-Based Networking

Abstract Cloud networking is an novel approach for building and managing secure private networks over the public Internet through the cloud computing infrastructure. In cloud networking, the traditional network functions and services including connectivity, security, management, and control are pushed to the cloud and published as services, such as Network Foundation Virtualization, Cloud Radio Access Networks, and Mobile Cloud Networking (MCN).

2.1 Network Foundation Virtualization

In simplest terms, Network Foundation Virtualization (NFV)[1] is used to migrate the telecommunication equipment from specialized platform to universal x86-based commercial off-the-shelf (COTS) servers. The current telecom networking devices are deployed by the private platforms, within which all the network elements are closed boxes, which cannot utilize the hardware resources mutually. Therefore, the capacity expansion of each devices relies on the additional hardware, while the hardware resources lie idle after the capacity reduction, which is quite time-consuming with poor elasticity and high cost. Through NFV, all the network elements are transformed into independent applications that can be flexibly deployed on a unified platform based on a standard server, storage, and exchange mechanism. As shown in Fig. 2.1, with the decoupled software and hardware, the capacity of every application is available to be expanded rapidly through increasing the virtual resources, and vice versa, which has enhanced the elasticity of the network dramatically.

The technological foundation of NFV is the cloud computing and virtualization techniques in Information Technology (IT) industry. Through the virtualization techniques, the universal resources of computing, storage, and networking provided by COSTS can decompose into a variety of virtual recourses for the use of upper applications. At the same time, the application and hardware are decoupled through the virtualization techniques, while the supply speed of resources has shortened from a few days to a few minutes. Through the cloud computing technology, the

[1]http://www.etsi.org/technologies-clusters/technologies/nfv.

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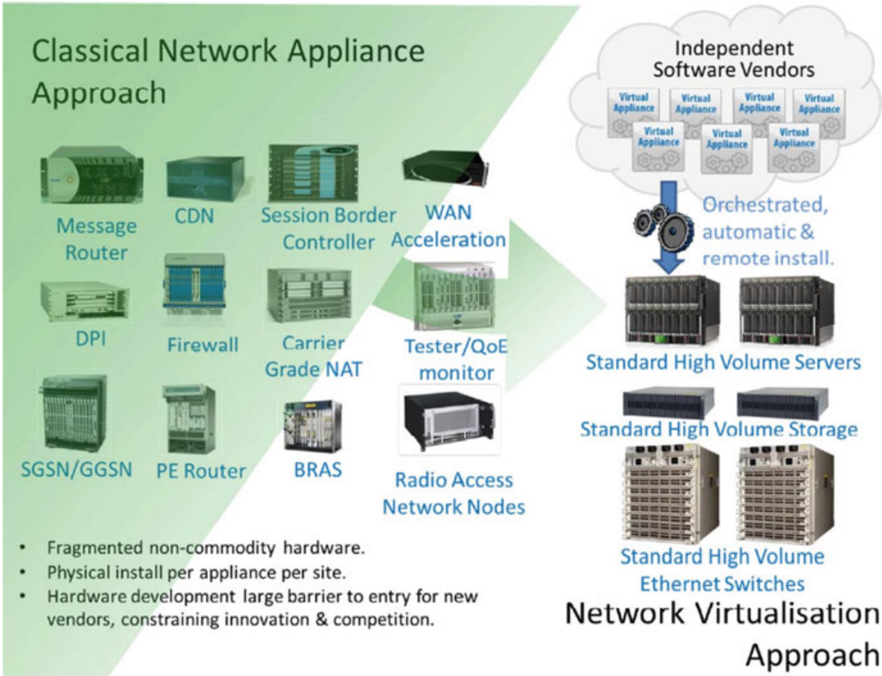

Fig. 2.1 NFV vision (*Source*: ETSI)

flexible expansion and reduction of the applications is accomplished for contributing to the matching of resources and business load, which does not only improve the resource utilization rate but also ensure the system response speed. Specifically, the deployment of NFV brings the following advantages:

- The purchasing, operation and maintenance costs, and energy consumption of the operators are reduced.
- The business deployment is accelerated, while the innovation cycle is decreased. Specifically, the efficiency of testing and integration are improved, the development cost is reduced, and the conventional hardware deployment is replaced with the quick software installation.
- Network applications support multi-version and multi-tenant to enable the different applications, users, tenants sharing a unified platform, so the network sharing is possible.
- The personalized service of different physical domains and user groups are available, while the service modules can be rapidly expanded.
- The network is open, and the business innovation is able to cause new potential profit increasing point.

2.1.1 Development Status of NFV

Since founded in October 2012, the European Telecommunication Standards Institute Industry Specification Group for Network Functions Virtualization (ETSI ISG NFV) develops quickly, which has held six plenary sessions and includes the following works:

- Technical Steering Committee (TSC): takes charge of the overall operating of ETSI ISG NFV;
- Architecture of the Virtualization Infrastructure (AVI): takes charge of the architecture of the virtualization infrastructure;
- Management and Orchestration (MANO): takes charge of management and orchestration;
- Software Architecture (SA): takes charge of software architecture;
- Reliability and Availability (R&A): takes charge of reliability and availability;
- Performance and Portability (P&P): takes charge of performance and portability;
- Security: takes charge of security.

Especially, four overall standards, i.e., Use Cases, Architecture Framework, Terminology for Main Concepts in NFV, and Virtualization Requirements, are finalized by TSC, including five working group (WG) under TSC: Evolution and Ecosystem (EVE), Interfaces and Architecture (IFA), Testing, Experimentation, and Open Source (TST), Security (SEC), and Reliability (REL).

Compared with the current network architecture including independent business network and operation support system (OSS), NFV is deconstructed vertically and horizontally. According to NFV architecture illustrated in Fig. 2.2, from the vertical the network consists of the following three layers: NFV infrastructure (NFVI), Virtual Network Functions (VNFs), and Operation&Business Support Systems (OSS&BSS).

- **NFVI** is a resource pool, from the perspective of cloud computing. The mappings of NFVI on physical infrastructures are some geographically distributed data centers connected by the high-speed communication network.
- **VNFs** correspond with various telecommunication service networks. Each physical network element maps with a VNF. The needed resources fall into virtual computing/storage/exchange resources hosted by NFVI. Interfaces adopted by NFVI are still signaling interfaces defined by the traditional network. Moreover, it still adopts Network Element, Element Management System, and Network Management System (NE-EMS-NMS) framework as its service network management system.
- **OSS&BSS** is the operation support layer needing to make necessary revising and adjusting for its virtualization.

By the horizontal view, NFV includes services network and management and orchestration:

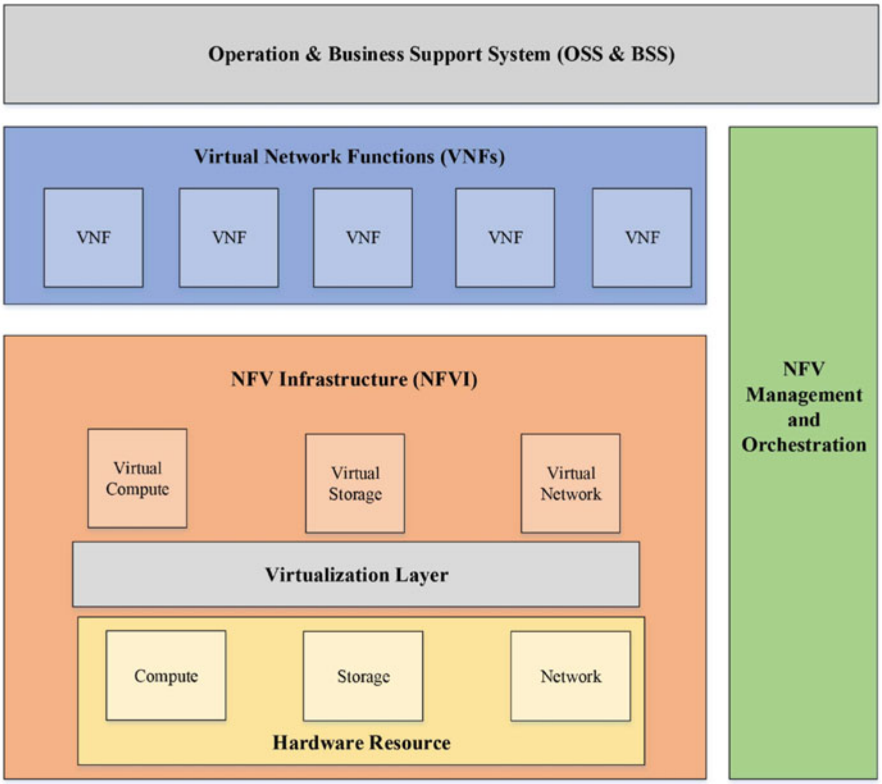

Fig. 2.2 NFV architecture

- **Services network** is the telecommunication service networks.
- **Management and orchestration** is the most significant difference between NFV and traditional network, referred to as MANO. MANO is responsible for the management and orchestration of the overall NFVI resources, business network and mapping and association of NFVI resources, and the implementation of OSS business resource process.

According to the NFV technology principle, a business network can be decomposed into a set of VNF and VNF Link (VNFL), represented as VNF Forwarding Graph (VNF-FG). Each VNF consists of several VNF Components (VNFC) and an internal connection diagram, and each VNFC is mapped to a Virtual Machine (VM). Each VNFL corresponds to an Internet Protocol (IP) connection, which needs link resources, such as flow, Quality of Service (QoS), routing, and other parameters. Thus, the services network can make top-down dissolutions to get distributable resources through MANO. The corresponding VM resources and other resources are allocated by NFVI. In addition, the corresponding VNFL resources need to interact

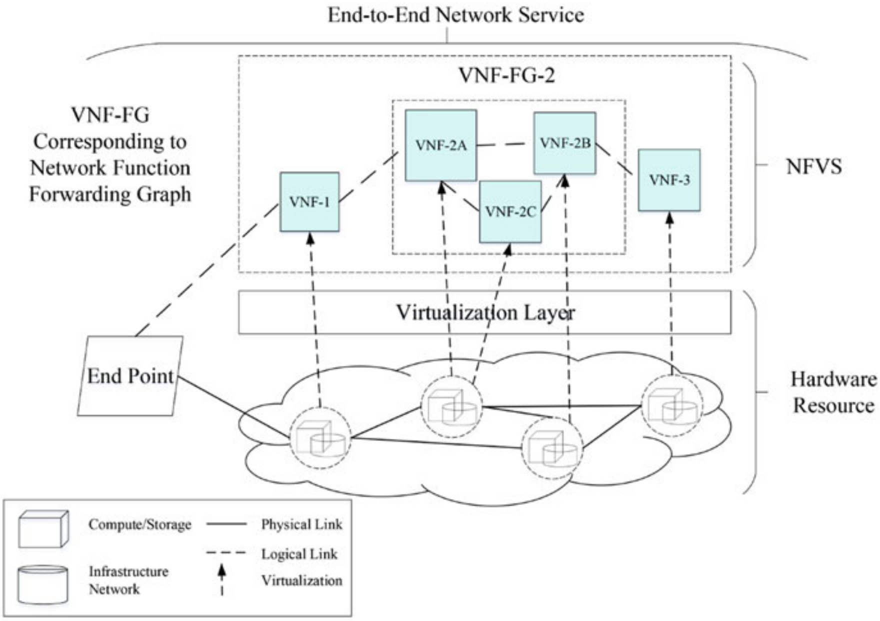

Fig. 2.3 Services network deploying NFV

with the bearer network management system, and to be allocated by IP bearer network. For example, Fig. 2.3 illustrates the services network deploying NFV.

According to the current technical architecture of NFV, many manufacturers have already completed the proof of concept (POC) testing and verification, such as virtual IP Multimedia Subsystem (vIMS) [1], virtualized Evolved Packet Core (vEPC) [7], virtual Customer Premise Equipment (vCPE) [8], and virtual Content Distribution Network (vCDN) [3]. And they have been demonstrated at the annual meeting of the World Radio Communication Conference (WRC) in 2014 to prove that NFV technology is available.

2.1.2 Technical Issues of NFV

Although the criterion defined by NFC is technically feasible, there is still a long way to realize its commercial application with the following issues [4–6]:

- **Maturity**: Due to its too large target, only four specifications have been completed after the first phase, while many relevant specifications defined by other groups estimate to complete. Many problems have been postponed to the second phase, so there is still a long way to go to meet its mature standard.

- **Compatibility**: Architecture defined by NFV is quite huge with many new interfaces, dividing the closed telecom equipment manufacturers into several levels: hardware equipment suppliers, virtualization management software suppliers, virtualization software vendors, NFV Orchestrator (NFVO) software vendors, NFV system integrator, etc. Thus, the telecom network is transferred from a integration of hardware and software managed by one manufacture into a series integrations of hardware and software managed by several manufactures, so the complexity increases greatly. However, NFV only defines the architecture levels, while the detailed definition and implementation of the corresponding interfaces are to be coordinated by other technical organizations. Therefore, compared with the existing standard, the technical standards are not so strict. It is a great challenge to ensure the equipment compatibility among various manufactures in the future.
- **Flexibility**: The lagging Self-Organization Network (SON) technology affects the expansion and deduction of service level. According to the NFV architecture, although the needed resources of a new VNF are automatically deployed by MANO, its business network operational architecture still relies on the traditional EMS/NMS mechanism, and the connection between VNF and traffic routing is still deployed manually and the VNF plug and play is not available.
- **Reliability**: Traditional telecom applications often require the reliability of 99.999 %, which should not be decreased after its virtualization. Due to the special design, the reliability requirements of traditional telecom hardware are relatively high. However, the reliability of COTS equipment adopted by the virtualization is relatively lower, demanding compensation by raising the software reliability.
- **Integration**: The current telecommunications equipment often uses special chips to realize user plane. Considering the packet mangling, x86 has lower cost performance. Therefore, its virtualization will lead to the reduction of equipment integration. Currently there are several ways to solve this problem: (1) the Software Defined Network (SDN) is implemented to separate the control and operation of user plane equipment and offload the forwarded packet to the SDN switch; (2) the Intelligent Ethernet Card including packet processing module is implemented to offload packet processing burden.
- **Virtualization**: Compared with computing and storage virtualization, network virtualization technology is relatively backward. Although the current network virtualization technology has various types, it is a critical issue to integrate them into the NFVI. Telecommunication network is usually a distributed network needing sufficient network resources, which are decomposed to local network resource within data center, the bearer network resources among the data center, the bearer network resources between the service network and access network, etc. The allocation of the bearer network resources may involve the transport network resources allocation, which needs virtualization and automation. Currently the allocation still needs to fulfil through bearer network and transport network management, which is a long way to reach the automation.

- **Systematicity**: NFV is expected to solve the problem of automatic deployment of business network, which is a giant Information and Communication Technology (ICT) integration project from the perspective of architecture. NFV can be decomposed into NFVI integration, VNF integration, and business network integration, involving a number of systems, manufactures, areas, and interfaces, which makes the engineering more difficult than the current public/private cloud. Despite its automatic deployment, every link of the telecom network deployment (planning, implementation, testing, upgrade, optimization, operations, etc.) is involved and implemented. Therefore, it is a complicated issue to implement the deployment in the future, because the technical requirement for the integrator is very high.

After the implementation of NFV architecture, automatic management and agility of the telecom network should ascend dramatically. The deployment cycle of a telecommunications device is decreased from a few months to a few hours, the expansion cycle is decreased from a few weeks to a few minutes, and the new business deployment cycle of the telecommunications network is decreased from a few months to a few weeks.

2.2 Cloud Radio Access Networks

Cloud Radio Access Networks (Cloud-RAN) is a new type of wireless access network architecture based on the trend of current network conditions and technological progress. As a type of clean system, C-RAN is based on the Centralized Processing, Collaborative Radio, and Real-time Cloud Infrastructure. Its essence is to cut down the number of base station and reduce the energy consumption, adopt the collaboration and virtualization technology to realize the resources sharing and dynamic scheduling, improve the spectrum efficiency, and achieve low cost, high bandwidth, and flexible operation. C-RAN's overall goal is to address the various challenges brought by the rapid development of mobile networks, such as energy consumption, construction and operation and maintenance costs, and spectrum resources., pursuing a sustainable business and profit growth in the future [2].

As shown in Fig. 2.4, C-RAN architecture mainly consists of the following three components:

- Distributed network consisting of a Remote Radio Unit (RRU) and an antenna.
- Optical transmission network with high bandwidth and low latency which connects the RRU and the Bandwidth-Based Unit (BBU).
- Centralized base band processing pool consisting of high performance general processor and real-time virtual technology.

C-RAN architecture includes the following advantages:

- The centralized approach can greatly reduce the number of base stations and the energy consumption of the air conditioning systems.

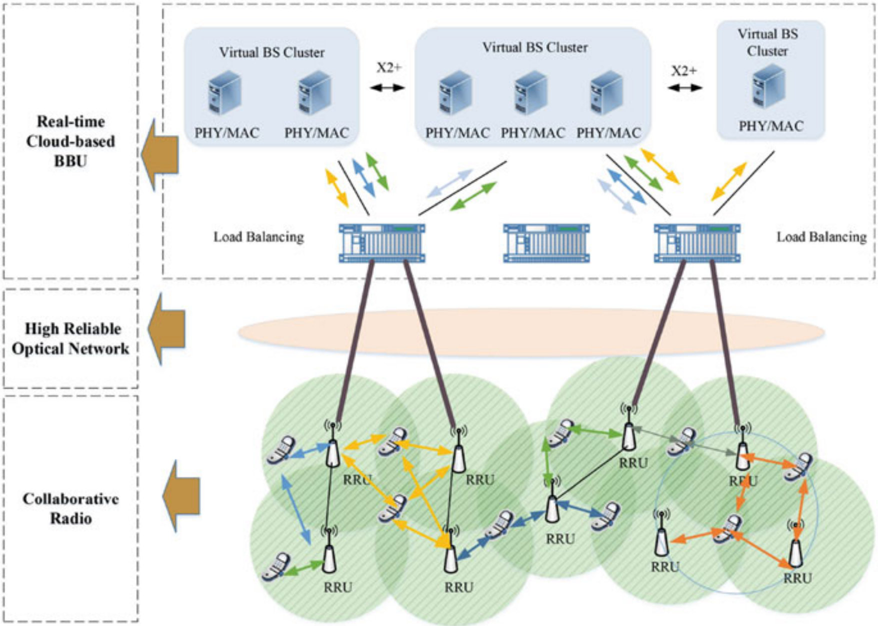

Fig. 2.4 C-RAN architecture

- Due to the high-density RRU, the distance from RRU to the users is shortened for reducing the emission power without affecting the overall network coverage. Low transmission power means that the terminal's battery life will be longer and the power consumption of wireless access networks will be reduced.

Different from the traditional distributed base station, C-RAN breaks the fixed connection relationship between RRU and BBU that each RRU does not belong to any BBU. Sending and receiving signals in RRU is in a virtual BBU, while the processing capacity of the virtual base station is supported by the assigned processors in the real-time virtual allocation base band pool.

In the C-RAN architecture, the sites of BBU can be reduced by one to two orders of magnitude. Centralized base band pool and related auxiliary equipment can be placed in some key central machine room for simple operation and management. Though the number of RRU is not reduced in C-RAN, due to the small size and low power consumption of these devices, they can be easily deployed in a limited space with the power supply system and without the frequent maintenance. As a result, it can accelerate the speed of the operational network construction.

2.3 Mobile Cloud Networking

Mobile cloud networking (MCN)[2] is a large-scale integrated project funded by the European Commission EP7, focusing on the implementation of cloud computing and network function virtualization to achieve the virtual cellular network. It is designed as a completely cloud-based mobile communication and application platform. More specifically, it aims to investigate, implement, and evaluate the LTE mobile communication system's technology base. This mobile communication system provides atomic level of service based on the mobile network and decentralized computing and intelligent storage, in order to support atomical services and flexible payment.

As shown in Fig. 2.5, MCN is expected to achieve the following goals:

- MCN is expected to provide the basic network infrastructure and platform software as a service for solving the resources waste problems (energy, bandwidth, etc.) facing the inflexible traditional network, and supporting payment on demand, self-service, flexible consumption, remote access, and other services.
- The structure of cloud computing is unable to support the integration with the mobile ecosystem. Therefore, MCN attempts to extend the cloud computing concept from data center to the mobile terminal users. Specifically, the new virtualization layer and monitoring system is designed, the new mobile platform is developed for the future mobile services and application supporting cloud, and the end-to-end MCN services are provided.

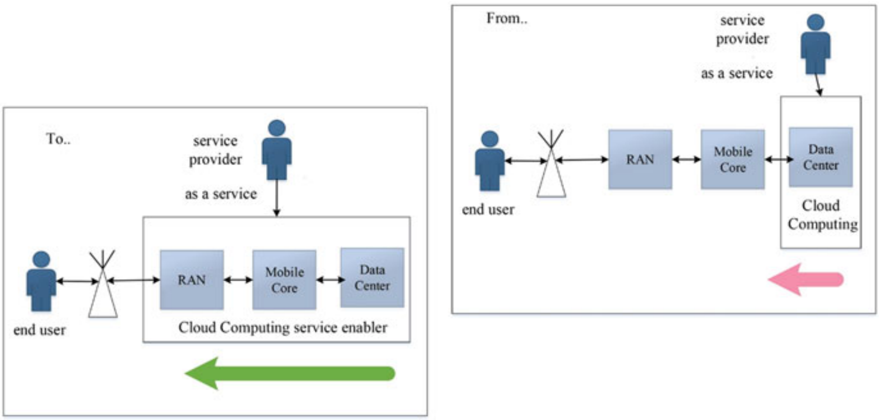

Fig. 2.5 The goals of MCN

[2] http://www.mobile-cloud-networking.eu/site/.

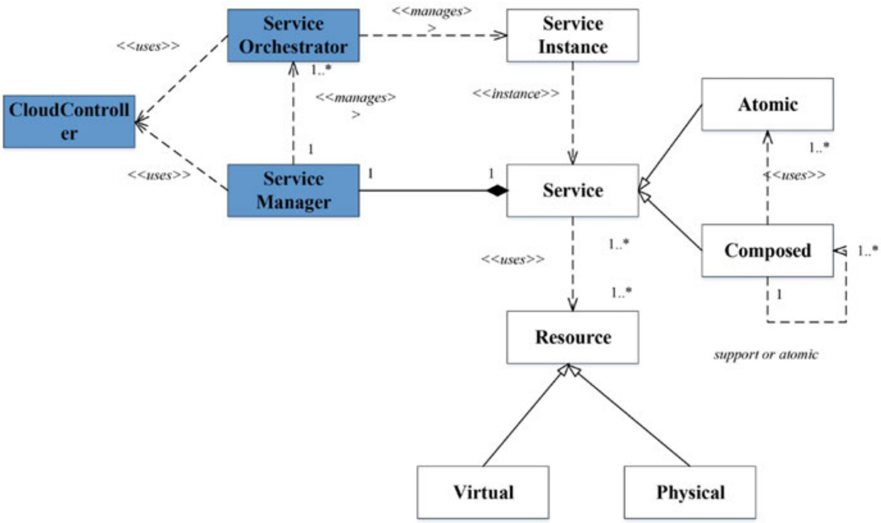

Fig. 2.6 The crucial entities and relationships in MCN architecture

MCN focuses on two main principles: (1) the cloud computing service must illustrate the resource pool, (2) the architecture is service-oriented. The related work of MCN mainly consists of the following components: cloud computing infrastructure, wireless cloud, mobile core network cloud, and mobile platform services.

MCN architecture is service-oriented, in which the functional elements are modularized into service. The services provided by MCN are derived from the resources that can be both physical and virtualized. The MCN service is divided into two kinds: atomic-level service and composite service.

Figure 2.6 illustrates the following crucial entities and relationships in MCN architecture:

- **Service Manager (SM)**: provides an user-oriented visual external interface and supports multi-tenant services.
- **Service Orchestrator (SO)**: provides the actual services.
- **Cloud Controller (CC)**: supports for the deployment and configures SOs.

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