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Cloud-based Wireless Network: Virtualized, Reconfigurable, Smart Wireless Network to Enable 5G Technologies

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Abstract In recent years, information communication and computation technologies are deeply converging, and various wireless access technologies have been successful in deployment. It can be predicted that the upcoming fifth-generation mobile communication technology (5G) can no longer be defined by a single business model or a typical technical characteristic. 5G is a multi-service and multi-technology integrated network, meeting the future needs of a wide range of big data and the rapid development of numerous businesses, and enhancing the user experience by providing smart and customized services. In this paper, we propose a cloud-based wireless network architecture with four components, i.e., mobile cloud, cloud-based radio access network (Cloud RAN), reconfigurable network and big data centre, which is capable of providing a virtualized, reconfigurable, smart wireless network.

Keywords 5G · Wireless network · Cloud · Virtualization · Big data

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1 Introduction

Mobile communications have been rapidly developing in the recent 20 years. They have brought a huge impact to all aspects of people's lifestyles in terms of work, social, and economy. Human society has entered the information era with the support of big data. The demand for advanced technologies to support future applications and services in all aspects of people's living is continuously increasing. Moreover, with the rapid development of wearable devices, Internet-of-Things and automotive networking technologies, both numbers and types of smart devices to access mobile communications will overwhelm the ability of existing networks. It is predicted that the mobile traffic in 2020 will reach 500 times that in 2010, which imposes new challenges and needs for the development of future mobile communication systems [1]:

- *Connectivity capacity*: Traditional communication technologies mainly provide interpersonal communication. With the rise of Internet of Things and related technologies, more devices can access networks, with the increasing needs for communication between humans and things or things and things. 5G should be able to provide a ubiquitous solution to connect anything, anytime at anywhere in the world.
- *Network performance*: With the new applications accessing the mobile network, people expect easy and fast access to a rich variety of information. In any environment, users can smoothly access multimedia resources, or all kinds of useful information in real time manner through 5G network.
- *Resource optimization*: Traditional communication technologies rely on hardware and infrastructure upgrades to improve their quality of service. However,

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this approach not only increases the service cost, but also easily leads to a waste of resources. 5G networks should be able to intelligently identify the communication scenarios, dynamically allocate network resources and provide the best connectivity and network performance as needed, to improve the efficiency of existing resources.

To address these challenges, research on next generation mobile communication systems, namely 5G, has gradually become the new focus of academia and industry [2]. It is expected that by 2020, 5G will be the leading mobile communication technology to meet the information needs of the human society by interconnecting the wireless world without barriers [3]. With the enhancement of bandwidth and capacity of wireless mobile communication systems and rapid development of the applications of mobile Internet and the Internet of Things for personal usage and business, mobile communications-related industries will have fundamental ecological changes. Wireless communication technology and computer and information technology will be closely and deeply interworked by integrating device technology and software technology to support the development of future 5G mobile broadband industry.

The mobile technology has been developed from the first generation (1G) to the fourth generation (4G), each technique has its typical application scenarios and symbolic techniques for example, time division multiple access (TDMA) and frequency division multiple access (FDMA) for 2G; code division multiple access (CDMA) for 3G; orthogonal frequency division multiplexing (OFDM) and multiple input multiple output (MIMO) for 4G. In recent years, various wireless access technologies are gradually mature and applied in large-scale, while the integrated circuit technology has experienced rapid development, which has also greatly enhanced the capabilities of terminal communications systems. From an ordinary consumer's point of view, the original 1G and 2G cellular communication systems that are expected to provide communication capability for users, need to assure the communication quality; the 3G and 4G cellular communication systems are expected to provide more broadband services, while the goal of future 5G mobile systems is to enhance the user's experience, build a user-centric service model, and allow users to enjoy a new life style of mobile broadband [4].

At present, research on 5G is still at its initial stage, there are already some 5G-relevant documents defining the technical specifications [2, 5, 6]. In addition, although some researchers have discussed how to construct the 5G network from multiple perspectives, such as air interface [7], millimeter wave [8, 9], and energy consumption [10], many of these studies focus on technical details, rarely constructing the whole system from the global perspective. It can be predicted that, 5G cannot be defined by a service or a typical technology. Looking into the future development of computer, network and communication technologies, this paper proposes the future architecture of wireless networks aiming to build a virtual, configurable and intelligent mobile communication systems. Specifically, we design a cloud-based architecture for building the next generation wireless networks. The main contributions of this paper include: 1) a novel virtual cloud-enabled wireless network access architecture; 2) a collaborative scheme between remote cloud and local resources; 3) and a mobile dynamic resource reallocation based on big data.

The remainder of this paper is organized as follows. In Section 2, we present the design issues of 5G and introduce our proposed architecture. We introduce mobile cloud, remote cloud, and hybrid cloud for collaborative computation in Section 3. Section 4 presents a novel cloud-based radio access network for collective radio processing. Section 5 describes a reconfigurable network architecture based on network function virtualization and software defined networking. Section 6 shows a wireless networks optimization based on analysis of big network traffic and user behavior data. Finally, Section 7 concludes this paper.

2 Cloud-based wireless network architecture

2.1 Design issues

Along with the ongoing enhancements in bandwidth and capacity of wireless mobile communication system and rapid development of applications of mobile Internet for personal usage and business, mobile communications-related industries are transforming to a diverse ecosystem. 5G is not just an air interface technology providing higher data rates, greater bandwidth and capacity, but is a system to accommodate different business-oriented applications. Specifically, 5G should meet the following requirements and their associated challenges:

- *Sufficiency*: As users rely on mobile applications, the next generation wireless mobile networks should provide sufficient rate and capacity for users. It can be expected, from the current business perspective that most of mobile terminals need to reach 10Mbps data rate to support Full-HD video compression. In some special scenarios, wireless terminals are required to achieve 10 Gbps transfer rate, e.g., for instant and highly fast downloads of files from a nearby access point.
- *Friendly*: Ubiquitous coverage and stable communication quality are basic requirements of a user friendly

communication system. Existing mobile communication systems cover almost all of populated areas but still have blind spots.Wireless communications to fast moving vehicles (e.g., high speed trains) are not stable and reliable yet. Future mobile communication systems will combine a variety of means of communications, to provide users with ubiquitous coverage and reliable communication quality. 5G networks need to provide users with always-on experience to avoid connectionless and information transfer delay. Functionally, in addition to basic communication capabilities coupled with a more colorful video game entertainment, the 5G network is capable of providing richer business applications, bringing convenience to working and improving quality of life.

- *Usability*: Although 5G technology system may become complex, from the user's point of view, it is supposed to be simple and convenient as access technology will be transparent to users and terminals will be seamlessly switching between access technologies.
- *Economy*: 5G systems are supposed to be cost-efficient for users. Cost-efficiency can be achieved as the cost of investment into the infras- tructure will be reduced and network resources will be more efficiently utilized.
- *Personalized*: 5G mobile systems should be people-oriented, and provide user-centric experience. Users can customize their services according to their individual preferences, and enjoy personalized services. According to the user's network environment, network service providers can provide optimal network access functions. Meanwhile, according to the user's physical environment and personal preferences, application service providers can offer personalized recommendation service.

2.2 Cloud-based architecture

Fig. 1 illustrates the architecture of cloud-based wireless networks. The structure consists of mobile cloud, cloud-based radio access network (Cloud RAN), reconfigurable network and data centers.

- *Mobile cloud*: It mainly consists of two parts, the local and remote cloud. Its main function is to migrate the compute-intensive tasks from a mobile device to cloud, in order to overcome the limitation of mobile device computing power, storage capacity, and battery life [11].
- *Cloud RAN*: Its major functions include accomplishing resource sharing, dynamic resource allocation by virtualizing the network access devices, the use of collaborative work mode, improving spectral efficiency while reducing energy consumption, achieving low cost and high performance services of radio access [12].
- *Configurable network*: It can configure the network, by network virtualization and open network control. It aims at centralizing the management and control of network resources, building a flexible network architecture to improve the user experience [13].
- *Big data centre*: Not only it can provide mobile terminals with remote computing and storage capacity, improving the user experience, but it also analyzes the network needs under of different network traffic scenarios, dynamically optimizes allocation of resources, and improves the utilization of network resources [14].

3 Mobile cloud

Since the rise of mobile devices, their inherent limited resources have been a major challenge affecting the user experience. Along with the ongoing advances in cloud computing, many researchers began to apply cloud computing for mobile networks[15, 16]. By mobile cloud computing and unloading computing tasks, the performance of mobile devices improves, enhancing the user experience [11, 17–19]. Depending on the location of the data center in the cloud, mobile cloud can be divided into three kinds, namely remote cloud, local cloud, and hybrid cloud.

3.1 Remote cloud

Remote cloud is the traditional cloud computing for mobile network. Mobile devices, acting as a resource consumer, get rich computing and storage resources provided by remote servers through the mobile network, ensuring on-demand, scalable and easy access. Remote cloud model is critical for compute-intensive applications. For example, Apple company has introduced iCloud to support mobile users to upload and share documents, applications, music, and pictures, and expand the storage capacity of mobile devices [20]. However, since mobile devices usually need to upload data or computing tasks to the cloud, or to request large amounts of data from the cloud, the remote cloud model may experience high latency, large communication overhead and other shortcomings, which do not apply to real-time application scenarios.

3.2 Local cloud

Local cloud is not only a resource consumer but also a provider. Its purpose is to organize the local mobile devices into a mobile ad hoc network and to share resources. This approach applies to scenarios whereby user mobility is high, and short response time of applications is important. For example, in [21] Murray et al. proposes

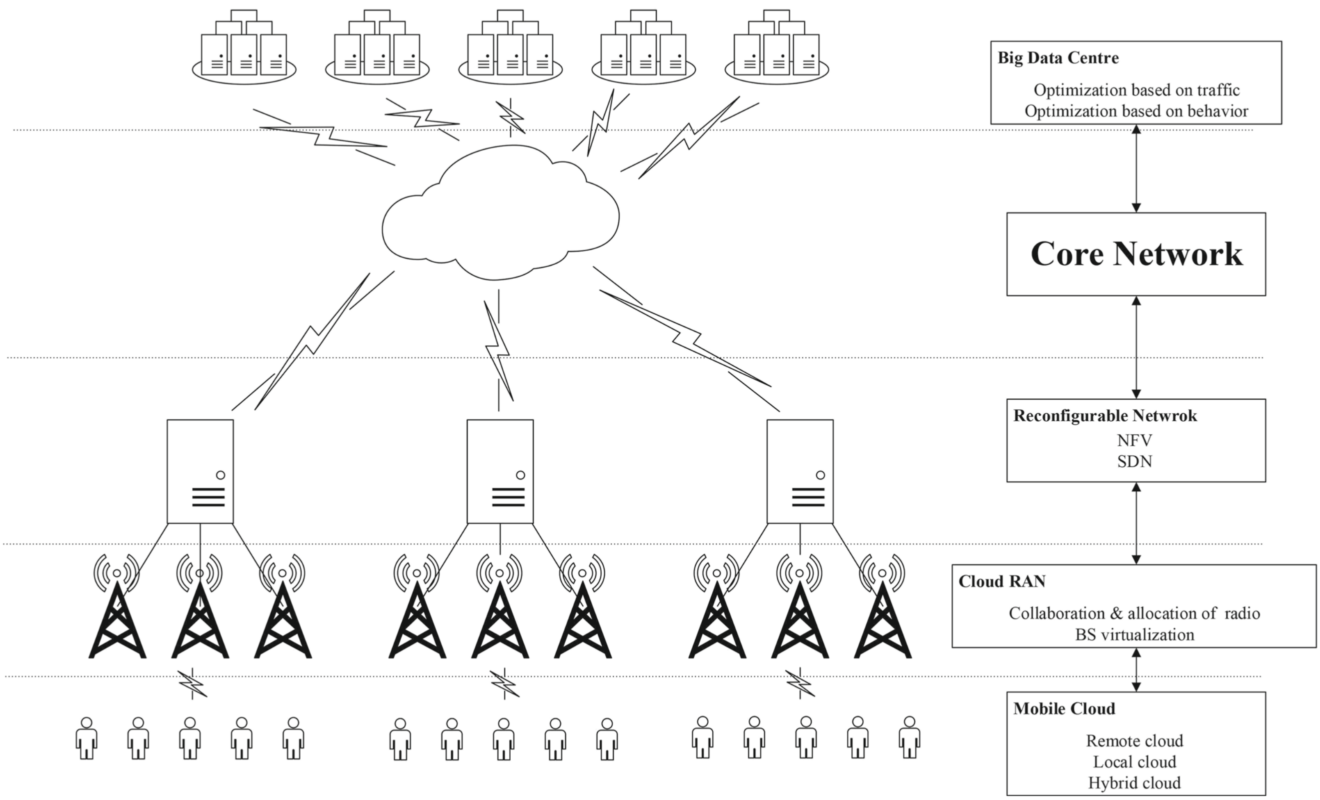

Fig. 1 Cloud-based wireless network architecture

crowd computing to complete large-scale distributed computing with a local cloud resources. With the development of virtualization technology, other local static devices can provide richer resources for mobile devices over a wireless network, such as computers, network equipment, and household appliances. Local cloud supports diverse applications, such as smart home [22] and multi-screen interaction [23].

3.3 Hybrid cloud

In hybrid cloud, a mobile device may offload computing tasks to a local cloud. The local cloud offloads in turn computing of highly complex tasks to a remote cloud. A hybrid cloud may also include Cloudlet which has a direct link to the remote cloud. Traditional Cloudlet consists of a number of static computers [24]. However, with the improvement of virtualization technologies, mobile network devices may become capable of running a computing function which can provide access to remote cloud, similar in fashion to Cloudlet. Thus, regardless of users' locations, mobile devices can self-organize to form a local connection to a remote cloud.

4 Cloud RAN

Radio access network (RAN) is an important part of mobile communication system. Traditional RANs have the following disadvantages:

- *Limited capacity*: a base station with limited number of sectors antenna can only cover and deal with the transmission and reception signals in a same transmission range, and is difficult to improve spectrum efficiency.
- *Insufficient expendability*: the traditional way of extending coverage areas requires the construction of new base stations. During the expansion and upgrade process, it is also critical to ensure the compatibility of newly installed base stations with existing ones.
- *Low utilization*: the actual utilization of existing base stations is low, the average load of the network load is often lower than busy period, and the handling capacity cannot be shared between different base stations.

Cloud RAN offers solutions to the above mentioned limitations. As shown in Fig. 2, the base band unit (BBU), separated from the radio access unit (RAU), forms a pool

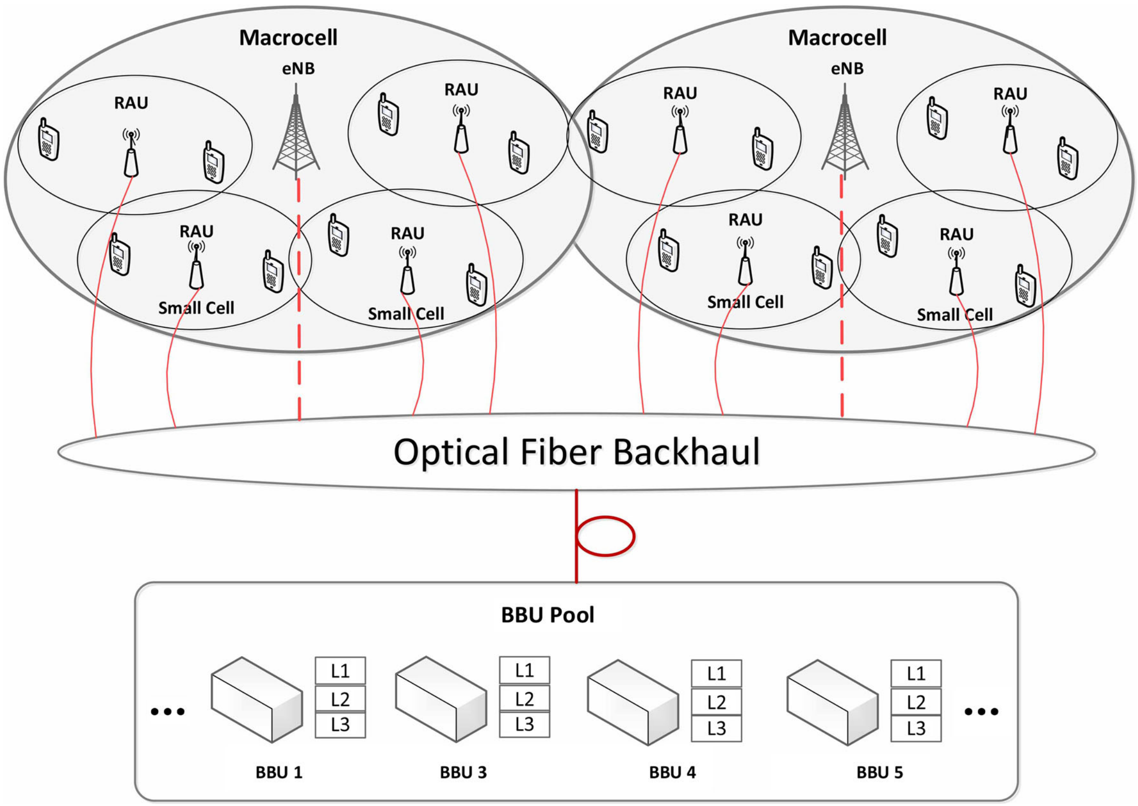

Fig. 2 Cloud RAN architecture

BBU to achieve centralized digital processing and management [25]. Cloud RAN breaks the intrinsic connection between RAU and BBU, each sending or receiving signal from RAU is finished at a virtual base, and the processing capacity of the virtual base station is assigned by BBU in real-time, which can achieve global optimum utilization of physical resources. Nowadays, research on cloud RAN mainly focuses on the following aspects: i) dynamic resource allocation and collaborative wireless processing; and ii) base station virtualization.

4.1 Dynamic resource allocation and collaborative radio processing

A major goal of cloud RAN is to significantly improve the spectral efficiency and the cell edge user's throughput. However, due to the presence of severe inter-channel interference between cells, we need to employ techniques, such as coordinated multi-point (CoMP) [26] and multiple-input multiple-output (MIMO) [27, 28], to build effective multi-cell joint dynamic resource allocation and collaborative wireless processing mechanisms.

To further reduce the complexity of Cloud RAN network architecture and scheduling processes, collaborative processing and scheduling mechanism should be restricted inside the cell clusters. The complexity of the scheduling in the cell clusters is determined by the moving speed and the number of mobile terminals and RRU. Therefore, how to choose the best cell clusters in the system will be a tradeoff considering the system gain, capacity requirements of return link and the complexity of scheduling.

The user terminal can be serviced by multitude cells of a cell cluster. Based on the monitoring of the user terminal and the feedback channel information, we can statically or semi-statically select and organize the cell cluster. The cells in the cluster provide business services to the terminal user in the coordinated transmission mode. To further reduce network complexity, one can limit the number of terminals in the scheduling collaboration services, also one can define and select the terminals based on the signal strength from the terminal point of view. The activation/deactivation process of cells in a cluster can be controlled by a master station, and can be flexibly configured according to the feedback of the user experience.

4.2 Base station virtualization

The current BBU processing board is designed based on some kind of specific communication standards and can only support a fixed number of loads. The following issues then emerge:

- *Low-compatibility*: If the computational load of new standard is not compatible with the existing hardware configuration, the same hardware platform is also difficult to support other different standards.
- *Inefficiency*: the demand for computing resources of the physical layer or MAC layer changes with the traffic load, number of users and the type of air interface configuration, but in the traditional system, computing resources cannot be effectively re-allocated, resulting in poor efficiency of the hardware.
- *Inelastic*: in a collaborative MIMO and other new algorithms, dynamic virtual MIMO group needs to dynamically coordinate each base station's physical layer, which is difficult to achieve in the traditional mechanisms.

These problems can be solved by abstracting the computer resources of base stations, and building a base station baseband pool based on real-time virtualization technologies [29]. As shown in Fig. 3, the processing resources provided by the physical hardware can be divided into four layers according to their properties: the physical layer, MAC layer, the accelerator control and management layer. With virtualization technology, for a given standard, you can determine the needs of the four resource pools of processing resources. Thus, through a flexible combination of resources can construct a virtual base entity.

When the physical load of the virtual base station changes, the system can determine whether to adjust the allocation of resources. In such case, one can re-allocate resources to construct base stations to support different standards through software. Since resources can be dynamically allocated at a global scope, resource utilization can be significantly improved.

5 Configurable network

At present, many studies suggest that an important challenge is to build the next generation of wireless networks that can redefine a network architecture, in order to increase the flexibility of the network [30–32]. Among them, the core but also the most basic concept and technique, is undoubtedly Network Functions Virtualization (NFV) and Software Defined Network (SDN) [33, 34].

Many IT professionals consider them as two exclusive technologies. In fact, both of them have complementary advantages, they will promote development of configurable networks.

5.1 NFV

NFV is derived from telecom operators who hope to virtualize network infrastructure and tools, rather than increasing physical devices to realize the functions in terms of routing, switching, content filtering, spam filtering, load balancing, WAN acceleration, optimization and unified threat management, to deploy new network services. These participants have established the European Telecommunications Standards Institute (ETSI) NFV group, whose members include most of the major global operators and providers [35].

The purpose of the organization is to define requirements and architecture for the virtualization for network functions defined requirements and architecture. The long-term goal is to help customers to reduce the cost of operating the network, while accelerating the marketing of software services for industry-standard server hardware components and providing a flexible and agile solution.

NFV's ultimate goal is to virtualize IT resources in a soft way to make virtualization development providing important network functions, rather than the physical demands of professional equipment. These virtual devices in the network will work as a physical device, and can achieve a variety of specialized functions without a specific device [36–39]. Currently, NFV mainly focus on the following issues.

- Virtual exchange, or physical ports and virtual ports on the virtual server connection. Here virtual router can use the virtual IPsec and SSL VPN gateway.
- Virtual network tools. This makes the need to deploy a dedicated network device functions which can be deployed by virtual tools that are able to achieve a variety of specialized functions.
- Virtual network services. It can provide traffic analysis, network monitoring and alarm, load balancing, quality of service or level, including software-based network monitoring and management services.
- Virtual application. It can provide network optimization framework and API for cloud applications to support the growing number of mobile or Bring Your Own Device (BYOD) user groups.

5.2 SDN

SDN has come from the Stanford campus network project OpenFlow, when researchers carrying out scientific research

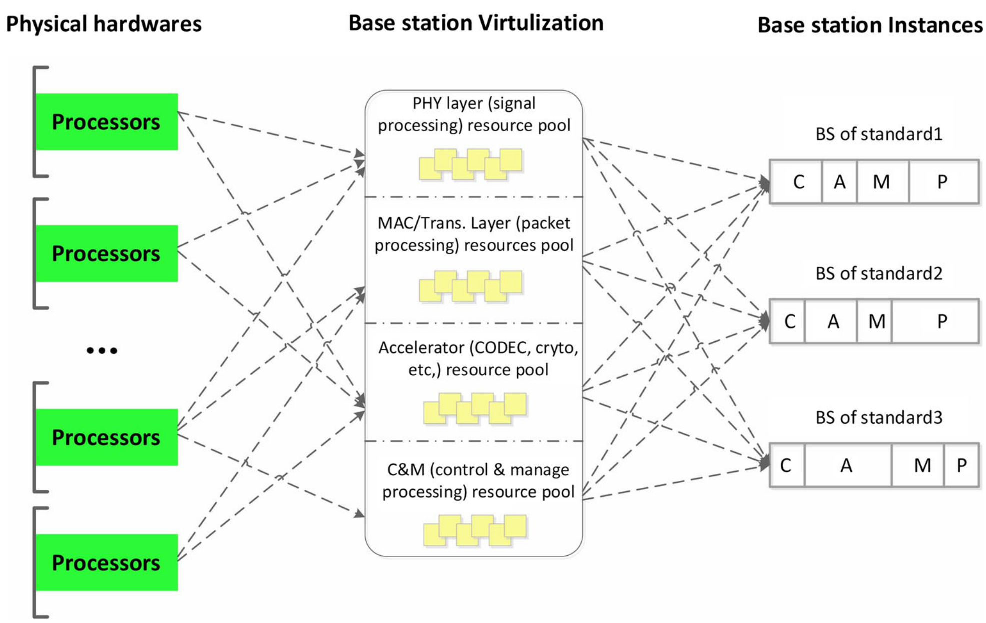

Fig. 3 Base station virtualization

found that every time when deploying new agreement, we need to change the network device software, so they began to consider a network with programmable hardware devices and centralized control and management, which give birth to the basic definition of SDN and its important features [40]: i) separation of control and dispatching functions; ii)centralized control; and iii) use of a broad definition of (software) interface.

In SDN, network control and management is somewhat centralized and takes the form of a software.

As per Open Network Foundation, SDN is a framework that is able to transfer control logic to the underlying infrastructure that can be separated from the specialized computing devices used to access applications and network services, and to see the network as a set of logically independent virtual entities.

In essence, this means that SDN control software located on the top of the network equipment consisted of physical infrastructure layer, and so on to achieve communicate through OpenFlow control layer interface. This concept allows the network to become a platform with the flexibility and programmability to optimize resource utilization and achieve better cost savings and scalability. By providing an API for commercial applications and services, SDN integrates cloud services with features and high-speed networks as computing architecture, reshaping the IT technology.

6 Big data centre

With the popularity of mobile devices, it is easier to collect and analyze user data, such as users' location and their behavior. Data analysis companies can provide users with more accurate and personalized services through analysis and prediction based on big data. In addition, with the development of reconfigurable wireless network, it is possible to dynamically optimize wireless networks. According to the wireless network performance based on the analysis of big data from physical layer, such as measurement and signaling information, operators can provide a more accurate and effective optimization. Therefore, by analyzing big data, wireless networks can be more intelligent.

6.1 Optimization based on wireless network traffic data

Wireless network optimization is the procedure to identify the factors affecting the quality of service (QoS), maximize the performance with existing resources, and provide users with a high reliable network. Usually, the basis of optimization includes traffic statistics, performance report analysis, multi-network element interface data acquisition, parameter analysis, and hardware inspection. Moreover, parameter change, network structure adjustment, and device reconfiguration are other approaches to optimize wireless networks.

With the implementation of big data, we can extract more valuable information from wireless network traffic data to improve the efficiency of optimization through the following aspects.

- *Coverage analysis*: Traditionally, we evaluate wireless network coverage according to the downlink signal obtained from mobile terminal road test. This sampling test-based coverage analysis is often limited by the selection of test area, i.e., it cannot test in unreachable area, such as indoor, and street corners. Instead, with the analysis of network traffic data, we can construct a global network coverage map to identify the weak or blind zones according to user's location and traffic.

- *Resource reallocation*: With the foundation of cloud and virtualization technologies, we can detect the resources usage of each virtual BS and dynamically reallocate resources according to user distribution and traffic. Furthermore, we can evaluate the possibility of resource shortage, and reallocate more resources in advance to avoid performance degradation.
- *Device upgrade and fault detection*: Through the analysis of big traffic data, we can determine whether the running devices can meet the current demands, and even predict which device may be faulty. These results can help us for wireless network maintenance, renovation and upgrade.

6.2 Optimization based on user network behavior data

Currently, many application services provide mobile users with personalized services according to their behavior, such as location-based services [41] and context-aware personalized recommendations [42]. Conversely, although operators have big data about user behaviors in the network, they have not taken full advantage of its potential value. For a better network monitoring, wireless network can be optimized in terms of terminals and network devices according to the data of user's network behaviors.

- *Terminal optimization*: Carry out real-time collection on user network behaviors at terminals, and set up a personal model for users according to the data collected. Analyze and predict user's behaviors at the next stage as per the model; access the corresponding network resources in advance and cache them locally when the wireless network utilization rate is low. In this way, the network load can be reduced to improve user experience at the peak period of network use.
- *Local optimization*: Carry out staged statistics and analysis on the user network behavior models collected at all terminals in local area, to figure out the behavior trend of user groups in the corresponding network segment. Then, cache the corresponding data in advance as per the probability of occurrence of the behaviors at the next stage. Thus, not only the network use level of users is optimized within the network segment, but also the visitor volume of entire network is reduced at the peak time.

7 Conclusion

In this paper, we proposed a cloud-based approach merging advanced computation, communication and control technologies, for construction of virtualized, reconfigurable, and smart next generation wireless network. In essence, to cope with the new requirements of 5G, such as higher capacity and data rate, support of high number of connected devices, higher reliability, larger versatility and support of application-domain specific topologies, new concepts and design approaches are needed. Some existing techniques can be implemented for increasing bandwidth and ensuring more efficient transmission, for interference management and also for interworking with other systems. In addition, advances in terminals and receivers will be needed to optimize network performances. Cloud-based architecture is an interesting paradigm for 5G, together with cloud computing, CoMP, MIMO, NFV, SDN, and big data.

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