Software-defined cellular networking: a practical path towards 5G

Junyu Lai*

University of Electronic Science and Technology of China,
Chengdu 611731, China
Email: laijy@uestc.edu.cn
*Corresponding author

Lei Jiang and Ming Lei

NEC Laboratories China,
Beijing 100084, China
Email: jiang_lei@nec.cn
Email: ming_lei@nec.cn

Alireza Abdollahpouri

Department of Computer Engineering and Information Technology,
University of Kurdistan,
Sanandaj 66177 15175, Iran
Email: Abdollahpouri@uok.ac.ir

Weiwei Fang

School of Computer and Information Technology,
Beijing Jiaotong University,
Beijing 100000, China
Email: wwfang@bjtu.edu.cn

Abstract: Software-defined networking (SDN) has recently been all the rage. It has already been successfully applied in many practical fields including campus network, wide area network (WAN) and data centre network. As a next step, SDN is expected to be adopted in cellular networks to deal with some most urgent problems faced by carriers, such as ever soaring capacity demands and differentiated quality of service (QoS)/quality of experience (QoE) requirements introduced by emerging services and a large number of exciting applications. This paper first investigates existing proposals and solutions regarding applying SDN in carrier networks from both industry and academia. Then, as the major contribution of this paper, a novel end-to-end (E2E) software-defined cellular network (SDCN) architecture, aiming to the evolution towards 5G, is elaborated with adopting several emerging technologies. The proposed SDCN architecture can provide great flexibility, scalability, agility, and efficiency for carriers to keep profit and sustainability. In addition, some crucial issues for implementing each part of the proposed E2E SDCN architecture, i.e., from radio access network (RAN) to backhaul, and finally to core, are thoroughly discussed, respectively.

Keywords: software-defined networking; SDN; OpenFlow; wireless network; WAN; cellular network; 5G; networking architecture.

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Biographical notes: Junyu Lai received his PhD in Computer Science Department, University of Hamburg, Germany in 2012. He is currently an Associate Professor in the University of Electronic Science and Technology of China. Before this, he was Associate Researcher and Project Manager at NEC Labs China, and his research interests focus on software defined networking (SDN), wireless communications, and live TV delivery via IP networks, specifically emphasising on the QoS and user QoE improvement.

Lei Jiang received her PhD in Electrical and Electronic Engineering from Nanyang Technological University, Singapore, in 2006. From 2006 to 2009, she was a Research Associate with the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, Berlin, Germany. From 2009 to 2011, she was a Research Scientist in Alcatel-Lucent Shanghai Bell. In 2011, she joined NEC Laboratories China. Her research interests include propagation channel modelling, multiple-input-multiple-output communications, SDN and heterogeneous networks.

Ming Lei received his PhD degree from Beijing University of Posts and Telecommunications in 2003. Previously, he worked as Research Scientist in NICT, Japan and as Project Leader at the Communication Technology Laboratory (CTL) of Intel Corporation. Since May 2009, he has been with NEC Laboratories China as the Department Head, managing the research and standardisation projects on wireless SDN, 4G and 5G cellular mobile communications, 60-GHz, mobile backhaul and so on.

Alireza Abdollahpouri is an Assistant Professor of Computer Networks at the Department of Computer and IT Engineering, University of Kurdistan, Sanandaj, Iran. He obtained his PhD degree from University of Hamburg, Germany in 2012. He joined the University of Kurdistan as a faculty member in 2005. His current research interests are in the field of IPTV over WiMAX networks and modelling the behaviour of IPTV users, as well as in the software-defined networking.

Weiwei Fang received his PhD in Computer Science from Beihang University in 2010. Currently, he is an Associate Professor at Beijing Jiaotong University. His current research interests include SDN and cloud computing. He has co-authored one book chapter and more than 30 papers, and served in the Technique Program Committee of more than 30 conferences and workshops.

1 Background and motivation

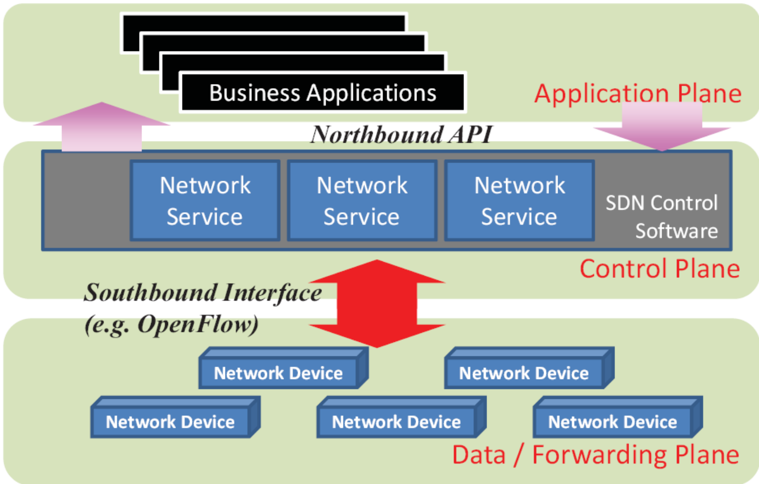
In the past decade, it has been witnessed that cellular network technologies evolve from 2G, 3G to current 4G, mainly driven by the ever soaring network capacity demandings. More precisely, 2G network is voice-oriented, with very limited data communication ability. Typically, it could provide data rates from 56 Kbps up to 115 Kbps by GPRS. 3G is then deployed to support much richer mobile applications, such as web browsing, online chatting, video streaming, etc., with abilities to handle a minimal data rate of 2 Mbps for stationary or walking users. The latest 4G is an essential evolution of its predecessors since it is capable of providing considerably higher data transmission rate, namely peak speed at 100 Mbps for high mobility communication and up to 1 Gbps for low mobility communication (ITU-R, 2007). It is noted that, the increasing popularity of mobile broadband (MBB) and smart terminals introduces unprecedentedly rapid growth of network capacity requirements, and it may never end. However, carriers' revenue growth has meanwhile lagged behind of traffic increasing and investments for network updating, which indicates that it is not sustainable for the entire telecom industry. In fact, carriers are currently struggling to get out of this dilemma.

It is easy to understand that, the most urgent challenges presently faced by carriers are directly related to the booming of MBB, which introduces over 100% yearly traffic load increasing. In particular, carriers are mostly annoyed by the following problems:

- *Bandwidth shortage:* Mobile users are currently with powerful smart terminals, e.g., iPhone, requiring considerably larger bandwidth for many bandwidth-hungry applications such as mobile video streaming. Although the current 4G technologies can provide unprecedentedly higher data rate, it still may not be enough as user demands continue to increase, especially in dense urban areas. Besides, the bandwidth shortage problem also holds in backhaul and core networks.
- *Diversity in quality of service (QoS) requirements:* Different applications usually come out with diverse QoS requirements, such as delay, jitter, loss, etc. Since the current carrier networks are generally not flexible, intelligent and agile enough, there exist quite a few challenges for carriers to offer finer-granular end-to-end (E2E) QoS assurance for different types of applications.
- *Operation and maintenance (O&M) complexity:* A typical carrier network consists of tens of thousands of networking nodes, built on dedicated hardwares and manufactured by different vendors. *O&M* in such a network could be extremely complex, that is time-consuming, low-efficient, error-prone and expensive. A well-designed O&M automation mechanism is therefore highly desirable.
- *Revenue loss:* As the major revenue source in the past, the profits brought by voice and SMS services have recently started to diminish. Meanwhile, plenty of over-the-top (OTT) applications operated by internet companies are gaining great momentum. Typically, OTT applications are based on carriers' low value-added data service. What is worse lies in the fact that, many OTT applications (e.g., VoIP) can straightforwardly replace the original services provided by carriers with much lower tariff. Thus, it can further weaken carrier APRU. Consequently, carriers are in danger of becoming 'dump pipes'.

In order to cope with the above problems and to find a practical evolution path toward the next generation of cellular network (i.e., 5G), software-defined networking (SDN) technology has recently been introduced into the carrier network domain. SDN by itself refers to an emerging network architecture evolved from the work done at Stanford University around 2005, which decouples the network control and forwarding (or data) functions. The decoupled control plane, formerly tightly bound in individual network devices, now can be implemented in software in a logically centralised server, while the data plane is implemented in distributed commodity hardwares. The communication between the two plans relies on various southbound Interfaces including OpenFlow. This enables the underlying infrastructure to be abstracted for applications and network services, which can treat the network as a logical or virtual entity. In addition, an application plane exists above the control layer, where business applications operate (via a set of northbound APIs) on an abstraction of the network (i.e., the control layer). Consequently, this architecture enables network services and capabilities to be untied from the details of network implementations. Figure 1 illustrates SDN's principle.

Figure 1 SDN architecture including data plane, control plane and application plane (see online version for colours)



This paper mainly focuses on relevant issues of applying SDN in carrier cellular networks. As the major contribution, a novel software-defined cellular network (SDCN) architecture is elaborated as an E2E solution, dealing with the aforementioned challenges such as better QoS provisioning. The proposed architecture is a generic and forward-looking framework, trying to be aligned with the vision of 5G, leveraging a series of emerging and promising technologies, including SDN, cloud computing, network virtualisation (NV) (Chowdhury and Boutaba, 2009), network functions virtualisation (NFV) (ETSI, 2012), and dynamic service chaining. It is believed that the proposed SDCN architecture can effectively help carriers to keep profits and sustainability. In the meanwhile, it can greatly enhance both capacity and efficiency regarding network O&M, as well as accelerate business innovation to new application fields.

The remaining part of this paper proceeds as follows. Section 2 reviews the state-of-the-art regarding the existing proposals from both industry and academia, as well as the relevant standardisation process. Then, in Section 3, some emerging and promising technologies related to this study have been briefly introduced. After that, a novel and forward-looking SDCN architecture aiming to the evolution towards 5G is elaborated and explained in Section 4. Finally, in Section 5, summary and outlook are given.

2 State-of-the-art

In the wireless cellular network domain, advanced radio resource allocation algorithms are of vital importance for the evolution from 4G to the next 5G. There exist quite a lot of works regarding this topic. Krishana et al. (2009) proposed an efficient approach for distributed dynamic channel allocation with queues for real-time and non-real-time traffic in cellular networks. Misra et al. (2012) also elaborated a learning automata (LA)-based channel reservation scheme to determines the optimal number of reserved channels in cellular networks. The performance evaluation of the systems with the proposed LA scheme shows improvement when compared with legacy systems.

For the past years, SDN has been the buzz of the networking world. It was originally proposed to accelerate networking innovations in legacy campus networks which comprise of a number of closed networking boxes with diverse functionalities such as routing, switching, firewall, etc. (McKeown et al., 2008). It is observed that plenty of emerging networking problems appeared in the era when cloud computing meets big data applications, and SDN seems to be extremely suitable for solving those problems in respect of networking efficiency, scalability, flexibility, agility, as well as O&M complexity. Therefore, cloud data centre networking (DCN) became an essential application field for SDN. Substantial research efforts were conducted on DCN-related topics such as architecture evolution (Chiba et al., 2010; Yu et al., 2011) and modern SDN stack implementation (Voellmy et al., 2012; Wang et al., 2012). In addition, SDN has also been used in the domain of wide area network (WAN). Taking Google's G-scale as an example, by introducing the OpenFlow technology (i.e., an emerging southbound protocol), the network utilisation has been greatly improved from 30% to nearly 100% (Google, 2012), which leads to significant cost saving. In terms of SDN's application in enterprise networking, interested readers can refer to the latest use case in Kanazawa University Hospital reported by NEC (2013) as an example.

Carriers and vendors now rush to introduce SDN into telecom networks, hoping to reduce capital expenditure (CAPEX) and operational expenditure (OPEX), while enhancing service quality and network efficiency. Huawei has recently unveiled its SoftCOM strategy for applying SDN and cloud computing in carrier networks. SoftCOM is regarded as a holistic approach to network architecture, and organises a series of solutions into three groups, namely SoftMobile, value growth, and operational excellence. Ericsson also published its service provider SDN approach, aiming to extend virtualisation and OpenFlow with three additional key enablers: integrated network control, orchestrated network and cloud management, and service exposure. Juniper has developed JunosVContrail SDN product line, which includes SDN controller and the ability to deliver complete virtualisation in carrier networks. NEC was the first vendor announcing commercial SDN/OpenFlow controller and switches, and has also released its carrier SDN architecture, mainly focusing on infrastructure, management and orchestration, and service provisioning. Besides, the trend of carrier network evolution towards SDN provides tremendous opportunities for many start-ups, such as Tellabs, Taif-f Systems, Accedian, Elephant Talk, who are usually partnered with different carriers or some major vendors, leveraging their unique technical advantages.

It is also worth noting that, the topic of carrier SDN is not just getting more attention in industry, but also in academia. Quite a few research efforts have been carried out or are ongoing. Bansal et al. (2012) from Stanford established OpenRadio project, targeting for a programmable wireless network data plane that provides modular and declarative programming interfaces across the entire wireless stack. Li et al. (2012) sketched out a SDCN architecture called CellSDN, which enables four main extensions to the existing SDN architecture, namely flexible policies on subscriber attributes, scalability through local switch agents, flexible switch patterns and actions, and NV on subscriber attributes. Naudts et al. (2012) conducted a techno-economic analysis of SDN as architecture for the virtualisation of a mobile network. They indicated that SDN and virtualisation of the first and the second aggregation stage network infrastructure leads to substantial CAPEX reductions. Gudipati et al. (2009) recently focused on solving efficiency problems emerging in radio access network (RAN), and proposed a SoftRAN concept based on SDN technologies. Yang et al. (2013) also proposed a software-defined RAN architecture called OpenRAN. According to the authors, OpenRAN can achieve complete virtualisation and programmability vertically, and can benefit the convergence of heterogeneous network horizontally. Pentikousis et al. (2013) present their MobileFlow architecture for software-defined mobile networks, the authors believe MobileFlow enables operators to capitalise on a flow-based forwarding model and fosters a rich environment for innovation inside of mobile network.

The industrial standardisation process for SDN is currently also ongoing among different standard definition organisations (SDOs), such as Open Networking Foundation (ONF), IETF, ETSI, ITU, Broadband Forum (BBF), as well as Optical Internetworking Forum (QIF). ONF is the SDO for the most widely adopted OpenFlow standardisations, and therefore is regarded as the leader for SDN standardisation. As the competitor to ONF SDN, IETF mainly focuses on extending existing protocols for SDN without OpenFlow. ETSI has led Telco operators to establish ISG NFV, and has carried out pre-standardisation study on SDN for carrier networks. ITU has also just started the discussions on transport SDN. QIF mainly works on SDN for the optical. Besides, there are also some open source societies (OSS) working like SDO. The most famous one is the OpenDaylight project, which is under the Linux Foundation with the goal of furthering the adoption and innovation of SDN through the creating of a common industry supported framework including the SDN controller.

3 Some key technologies towards 5G

In the past, most technologies adopted in communication industry (i.e., *communication technology*, CT) are quite distinguished from *information technology* (IT). However, starting from the last decade, there was an irreversible trend of IT and CT convergence, reflected by the new term ICT (i.e., information communication technology). This is mainly owing to the fact that IT industry has experienced unprecedentedly rapid development, many of which can also be adopted in communication industry and can help carriers to cope with many urgent problems introduced by ever growing and changing subscriber demands. Currently, it is believed that the next generation cellular network after 4G (i.e., 5G) will also follow the same technology convergence path. Some promising technologies are expected to be the key leading to the success of 5G.

3.1 Software-defined networking

As already explained in Section 1, SDN is an approach to decouple the control layer and the data/infrastructure layer of a network (i.e., switches, routers, etc.). In conventional network, when a packet arrives at a switch, rules built into the switch's proprietary firmware tell the switch where (i.e., which port) to forward the packet. The switch sends every packet with the same destination address along the same path, even if the path is not globally optimal. The goal of SDN is to allow the network respond quickly to changing business demands. In a software-defined network, a network administrator can shape traffic from a logically centralised controller without having to touch individual network equipment. More precisely, SDN technology enables the administrator to change any network node's (e.g., router) rules when necessary, such as prioritising and blocking specific types of packet flows in a very fine-granular level. All these can be just done by simply programming at the controller. Consequently, the network can be much more flexible, agile, and efficient by adopting SDN. Essentially, this allows the network to be much cheaper and less complex than ever before.

3.2 Cloud computing

In the past decade, cloud computing became a popular term appearing everywhere across the globe. It refers to distributed computing over a network and means the ability to run a program on many connected computers at the same time. Cloud computing relies on sharing of resources to achieve coherence and economies of scale similar to a utility over a network. At the foundation of cloud computing is the broader concept of converged infrastructure and shared services. A cloud can be private, public, community or hybrid. A public cloud sells services to anyone on the internet. For example, *Amazon Web Services* (AWS) is currently the largest public cloud provider. A private cloud is a proprietary network or a data centre that supplies hosted services to a limited number of users. A community cloud shares infrastructure between several organisations from a specific community with common concerns (i.e., security, compliance, jurisdiction, etc.). Hybrid cloud is a composition of two or more types of clouds (private, public, or community) that remain unique entities but are bound together, offering the benefits of multiple deployment models.

The services provided by cloud computing can be broadly divided into three categories, namely *infrastructure-as-a-service* (IaaS), *platform-as-a-service* (PaaS) and *software-as-a-service* (SaaS). In particular, the IaaS model provides virtual server instance API to start, stop, access and configure their virtual servers and storages; the PaaS model delivers a computing platform, typically including operating system, programming language execution environment, database, and web server; the SaaS model installs and operates application softwares in the cloud and cloud users access the software from cloud clients.

A cloud service has three distinct characteristics that differentiate it from traditional hosting. Firstly, it is sold on demand, typically by the minute or the hour; secondly, it is elastic, i.e., users can have as much or as little of a service as they want at any given time; last but not the least, it is fully managed by the provider, and the consumer needs nothing but a personal computer and internet access.

3.3 Network virtualisation

Conceptually, virtualisation is a basic action of decoupling an infrastructure service from the physical assets on which that service operates. By means of virtualisation, the service to be consumed is not described on, identified by, or strictly associated to any physical asset. Instead, the service is described in a data structure, and exists entirely in a software abstraction layer reproducing the service on any physical resource running the virtualisation software. The life-cycle, identity, location, and configuration attributes of the service exists in software with API interfaces, thereby unlocking the full potential of automated service provisioning.

More specifically, NV decouples and isolates virtual networks from the underlying network hardwares, similar to server virtualisation which decouples and isolates virtual machines from the underlying computers. Once virtualised, the physical network is used only for packet forwarding and treated as an IP backplane. Virtual networks are then programmatically created and operate completely decoupled from the underlying hardwares, offering the same features and guarantees of a physical network; yet with the operational benefits and hardware independence.

There are two forms of NV, external and internal. External virtualisation generally combines multiple networks – or parts of networks – into a single virtual entity. Internal virtualisation provides system-wide sharing and other network functionality to the software containers, which act as hosting environments for the software components of the network, on a single physical system. The external variety is the most commonly used method to create virtual networks. Vendors that distribute these virtualisation tools generally offer either one form or another.

3.4 Network functions virtualisation

Telecommunications software typically runs on standard server computers directly, on dedicated computer appliances, or on virtual machines. Network operators and service providers have problems managing a variety of (proprietary) hardware-based appliances. Launching new network services could require yet another hardware appliance and accommodating such boxes is becoming increasingly difficult (finding space and power), in addition to the complexity of integrating and deploying these physical devices in a network. Another challenge is when these hardware-based appliances reach their end-of-life, as hardware life-cycles are becoming shorter with concomitant acceleration in innovation, thus reducing the return on investment, requiring disruptive upgrades while it can become inherently harder to deploy new services.

In October 2012, aiming to address and solve issues mentioned above, an industry specifications group was formed under the ETSI (2012), calling itself NFV. NFV aims to address these problems by leveraging standard IT virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in data centres, network nodes and in the end user premises. NFV can be applicable to any data plane packet processing and control plane function in fixed and mobile network infrastructures, and is highly complementary to and mutually beneficial with SDN.

According to NFV's white paper (ETSI, 2012), the benefits can be offered by NFV include:

- reduced equipment costs and reduced power consumption
- increased speed of time-to-market

- availability of network appliance multi-version and multi-tenancy
- targeted service introduction based on geography or customer sets is possible
- enables a wide variety of eco-systems and encourages openness.

3.5 Dynamic service chaining

Service chaining is another SDN-related topic recently gain much attentions from both carriers and vendors. Currently, for providing inline services, such as network address translation (NAT), deep packet inspection (DPI), firewall, and load balancing, carriers use different physical or virtual machine-based middle boxes or appliances to manage or manipulate network traffic. This is a quite crude method since separated devices are physically connected by e.g., Ethernet cables, and each device must be individually configured to establish the service chain. There are no protocols or tools available for carriers to perform flexible, dynamic, traffic steering. Solutions currently available are either static or inefficient.

With the introduction of SDN to service chaining, networks can be reconfigured on the fly, and can be allowed to dynamically respond to the needs of the business. In particular, SDN service chaining can offer carriers greater control over network traffic and the use of subscriber-based selection of inline services can provide subscribers access to products such as virus scanning, firewalls, and content filters through an automatic selection and subscriber portal, and consequently lead to the creation of new ways to monetise the production networks for the carriers.

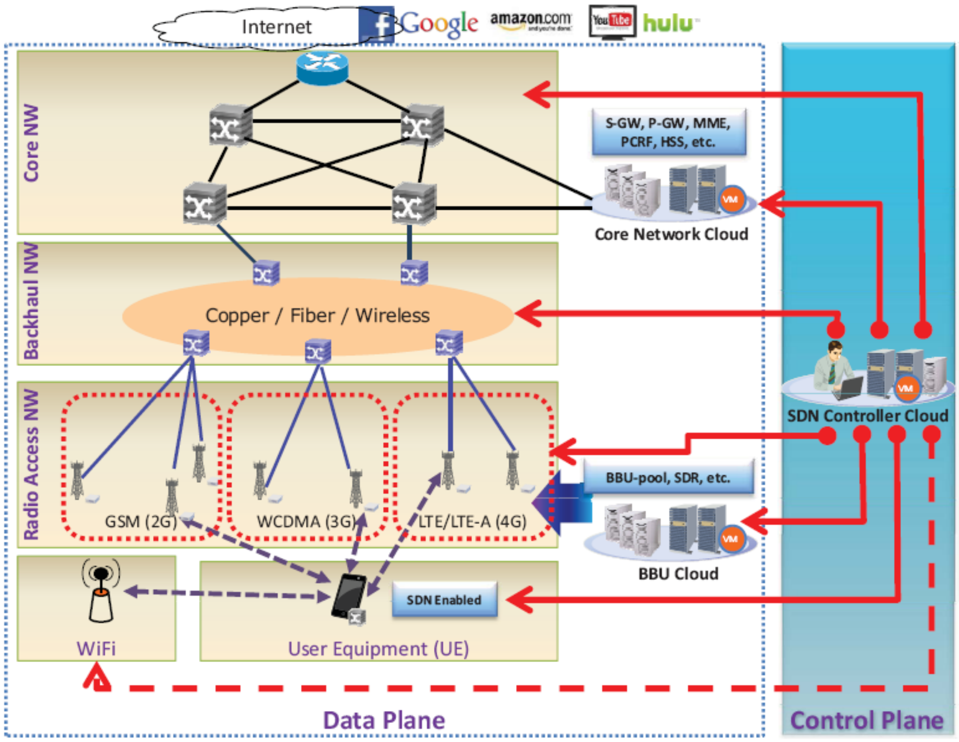
4 A novel SDCN architecture

The explorative journey towards 5G has just started, i.e., several relevant SDOs and research projects, such as METIS (2012), are recently kicked off. Although there have already been a few solutions and strategies with respect to 5G networking architecture designing from both industry and academia. Most of them are just visions which are quite general and abstract. Furthermore, few of them pay sufficient attention to the importance of a smooth evolution for carriers to protect the investments on existing infrastructures. In order to bridge the gap, a novel and forwarding-looking SDCN architecture towards the future 5G is elaborated in this section, accompanied with detailed explanations of key implementation issues.

4.1 An E2E cellular networking architecture towards 5G

A SDCN architecture has been derived and is illustrated in Figure 2. The SDCN architecture is an E2E strategy covering all the three parts of a typical cellular network, i.e., RAN, backhaul network, and core network. In other words, SDCN touches almost all the networking elements from user equipments (UEs) to the packet data gateway (P-GW) in core network.

Figure 2 An E2E SDCN architecture (see online version for colours)



As shown in Figure 2, the most revolutionary characteristics of the proposed SDCN architecture (distinguished from the current cellular network) encompass the following four points:

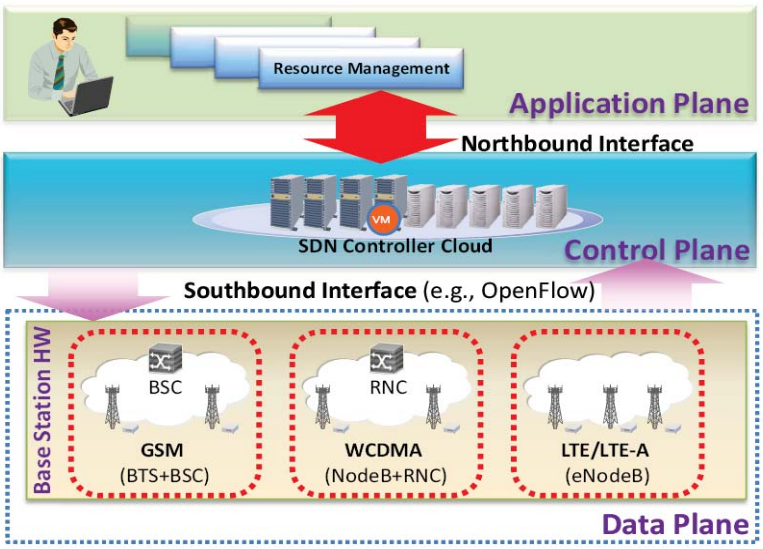
- decoupling the control plane and the data plane for the networking nodes in accordance with the SDN concept
- cloud computing technology is widely used in the SDCN architecture
- NFV and dynamic service chaining are integrated in the SDCN architecture
- NV is enabled in the SDCN architecture.

4.2 Software-defined RAN

Cellular network carriers may simultaneously operate several different types of RANs with different radio access technologies (RATs), such as GSM, WCDMA or LTE as demonstrated in Figure 2. Separated operations and maintenance are typically quite complex, low efficient and expensive in the state-of-the-art manner. A unified O&M platform, as well as lower-cost implementation of base stations, e.g., by means of software-defined radio (SDR) technology, are highly desirable. Meanwhile, carriers' existing investments should be protected. In that sense, the evolution of base stations should be comprised of the following three phases.

In the first phase, the SDN concept is introduced into the legacy base stations. Generally, the control plane of a base station is defined as the functionalities to conduct tasks such as radio resource scheduling, hand-off, paging, interference management, etc.; the data plane refers to the baseband and radio portions conducting the data forwarding tasks. The control plane is split from the data plane, and then moved to a logically centralised location, and is recommended to be implemented with IT clouding technologies, such as the SDN controller cloud in Figure 2. The southbound interface between the data plane and the SDN controller cloud is envisioned to be standardised. The application plane on top of the control plane consists of a number of application modules, each conducting a specific function such as radio resource management. Essential advantages are brought by this centralised control plane for implementing many newly proposed advanced features in 3GPP standards, such as CoMP, self-organising networking (SON), and 3D-MIMO. Taking an UE at the edge of two neighbouring cells as an example, thanks to the global view from the perspective of the centralised control plane, it will be much easier to coordinate radio resources of the two cells, so as to achieve higher resource utilisation and cell capacity, as well as better service quality for the UE. Figure 3 illustrates the aforementioned evolution.

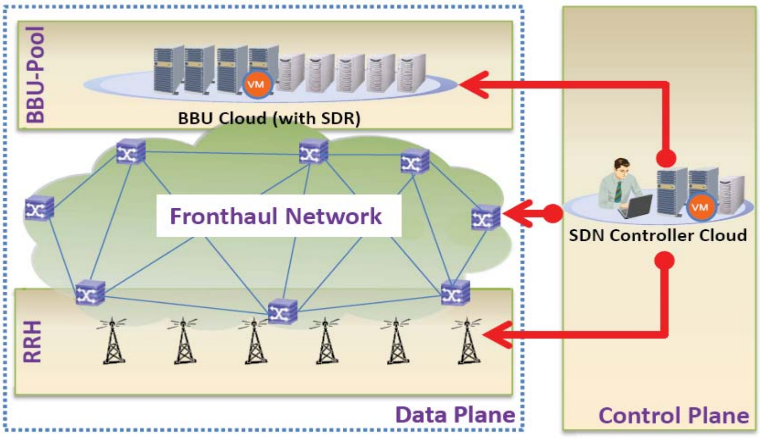
Figure 3 RAN evolution according to the proposed SDCN solution (see online version for colours)



In the second phase, aiming to further decrease the cost and increase the flexibility, the data planes of base stations in different RATs can be (fully or partially) implemented by means of SDR on commodity off-the-shelf (COTS) hardwares. For example, functional components of GSM, WCDMA, and LTE which are typically implemented in dedicated hardwares (such as mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) can instead be implemented by means of software on high-volume computers with general purpose processors (GPP). Consequently, the flexibility of software and the adoption of COTS hardwares can significantly reduce CAPEX and OPEX.

Recently, cloud-RAN (C-RAN) became eye-ball attractive due to its potential for cost saving. Briefly, C-RAN splits base station into baseband unit (BBU) and remote radio head (RRH), responsible for baseband processing and radio related transmission, respectively. All the BBUs of a certain scale (typically several hundreds) of neighbouring base stations are then centralised, forming so-called BBU-pool. To the contrary, the RRHs are still installed at the original sites, yet with much lower environmental condition requirements (no need for cooling systems and cheaper rental), as well as being much easier for maintenance. Therefore, C-RAN is adopted in the third phase. More precisely, BBU-pool can be implemented by using SDR and IT cloud computing technologies, which implies that the data plane (referring to the data forwarding functionalities) of the BBU-pool can also be software-based, and resides in either physical or virtual computers in the BBU cloud. In the meanwhile, the links connecting the BBU-pool and the RRHs form another network called fronthaul network, which generally requires high bandwidth capacity and extremely low transmission latency. It is believed that SDN can also be essential and promising in this fronthaul network, depending on concrete topologies and technologies adopted. The architecture mentioned above is presented in Figure 4, which can be regarded as an extension of the RAN architecture given in Figure 2.

Figure 4 SDN-based C-RAN architecture (see online version for colours)

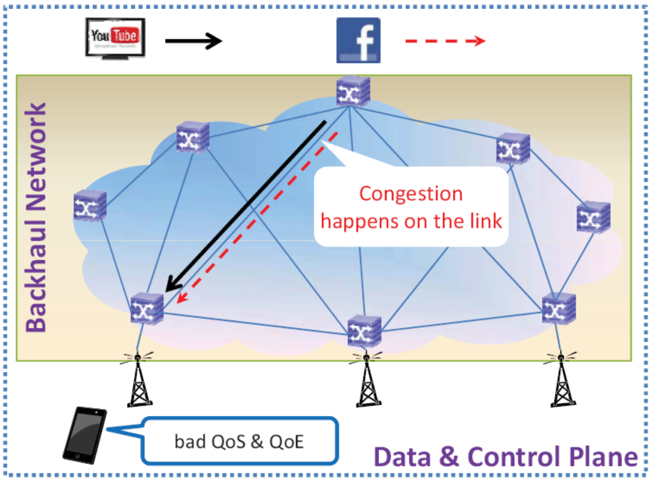


Note that UEs can also be included in the SDCN architecture. For example, a virtual switch (e.g., Open vSwitch) can be integrated into each single UE, and the control plane of the switch is split from the data plane and moved to the network side, i.e., SDN controller cloud. By doing so, carriers can further enhance user quality of experience (QoE) by implementing better flow control mechanism, and offload to the WLAN networks when it is necessary.

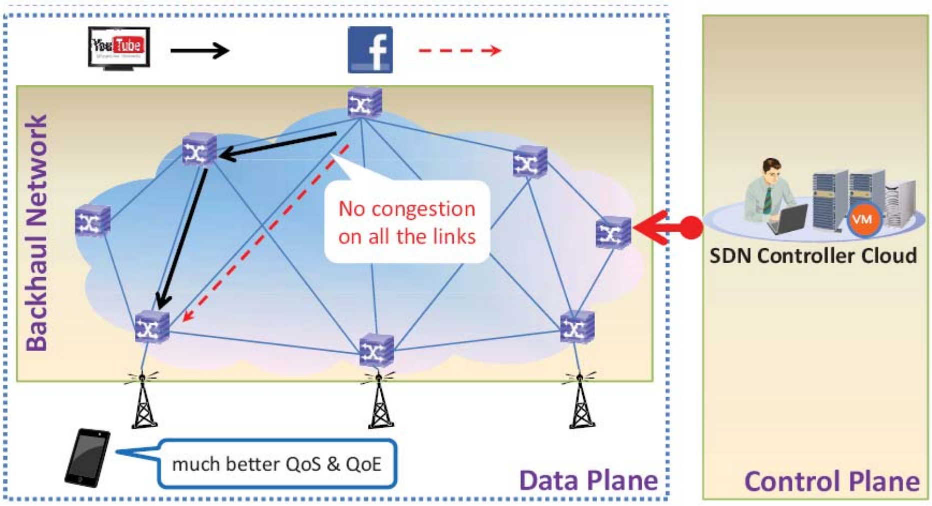
4.3 Software-defined backhaul

Backhaul in cellular network generally comprises the intermediate links connecting core network and RAN. It appears most often that, backhaul network is hierarchically implemented with access and aggregation layers; the topology of backhaul network could be ring, mesh, tree, or hybrid; the physical transmission media could be copper, fibre or wireless. To cater for the upcoming MBB era and to provide considerably greater data rates, 4G RATs induce smaller cell size and consequently a lot more base stations in dense urban areas. Therefore, the capacity and scalability requirements on the backhaul network are soaring; legacy backhaul networks may become bottlenecks of the entire cellular network.

Figure 5 Example to illustrate the advantages of adopting SDN in backhaul network, (a) without using SDN (b) adopting SDN (see online version for colours)



(a)



(b)

The proposed SDCN solution evolves current backhaul networks with SDN technology. The control planes of all the networking nodes (i.e., routers and switches) are decoupled from their data planes, and then moved to the SDN controller cloud. This can introduce finer-granular flow control capability, along with higher efficiency of bandwidth utilisation. Accordingly, This can avoid link congestion, enhance E2E QoS and provide differentiated QoE for subscribers. Figures 5(a) and 5(b) demonstrate an example where the backhaul network is Ethernet based with mesh topology. Two different applications (i.e., video streaming on YouTube and photo sharing on Facebook) with non-identical QoS requirements are simultaneously used by a subscriber on the same UE. In the legacy backhaul network shown in Figure 5(a), congestions may happen on some certain intermediate links, since all the packets to the same destination will always go though the same path. In contrast, SDN technology is adopted in Figure 5(b). Based on the networking global view, the SDN controller can dynamically and intelligently steer the flows of the two different applications to be transmitted through different intermediate links in the backhaul network. This can significantly enhance QoS/QoE, namely smoother video playing and faster photo sharing. In addition, SDN is essential for network O&M which are now becoming increasingly complex and expensive, as the scale of legacy backhaul networks continuously expands. The SDCN solution implements backhaul network O&M functionalities by a set of unified application modules running on top of the control plane, and therefore can significantly reduce CAPEX/OPEX.

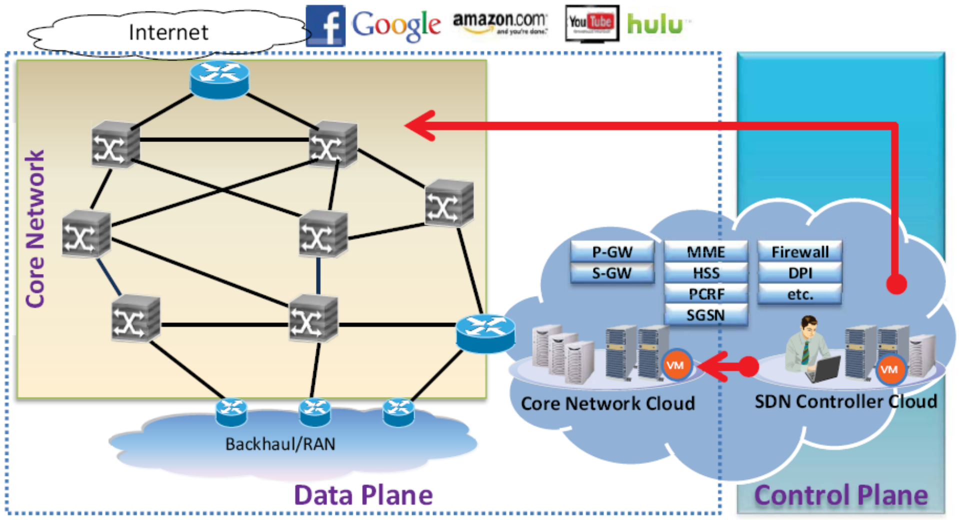
4.4 Software-defined core

The cellular core network contains the gateway to the internet. There usually exist many different types of logical nodes with variable data plane/control plane functions together forming the core network. For example, in the 3GPP EPC architecture, some nodes are dedicated for control plane, including mobility management entity (MME), home subscriber server (HSS), policy control and charging rules functions (PCRF), etc.; the others operate in both data and control planes, including service gateway (S-GW) and P-GW. Similar to the backhaul network, the performance of the core network is also heavily impacted by the soaring traffic loads.

The legacy architecture suffers from three major limitations in the upcoming MBB era. Firstly, these logical nodes are implemented on dedicated and vendor-specific hardwares, which are quite expensive and complex to interoperate for creating innovative services. Secondly, since the traffic load in control plane may be quite distinguished from that in data plan, the integrated data and control planes may weaken networking scalability. Thirdly, lack of intelligent caching mechanism for popular contents inside of the core network tends to put extra load pressure on the gateways to internet.

To solve the first two challenges, the proposed SDCN solution adopts SDN, NFV, cloud computing, and dynamic service chaining technologies. The legacy core networking architecture remains without radical modification, and Figure 6 demonstrates the proposed evolution. Two different types of logical clouds are introduced, namely SDN controller cloud and core network cloud. In particular, the SDCN solution at first virtualises all the core networking nodes (by means of NFV), such as 3GPP-defined nodes (S-GW, P-GW, MME, etc.), as well as other service nodes (firewall, DPI, etc.), by means of implementing them in COTS computers in the core network cloud. Subsequently, the control planes of these virtual nodes are decoupled from their data plan, and are shifted to the SDN controller cloud, with each of them implemented by a separate application module (in the application plane). To mitigate the third limitation, efficient content cache system deployed in carrier cloud data centres are required. The control plane of the cache system is decoupled and implemented in the SDN controller cloud, and finally is integrated into a unified O&M platform. In addition, the SDCN solution adopts dynamic service chaining technology for providing more flexible and differentiated services on subscriber attributes and application characteristics.

Figure 6 Evolved software defined core networking architecture (see online version for colours)



4.5 Advantages and benefits

In order to provide a smooth evolution path towards the next 5G, the proposed SDCN consolidates SDN, cloud computing, network virtualisation, NFV, and dynamic service chaining technologies into an organic whole. the major advantages and benefits of the SDCN solution for carriers can be simplified as enhancing service quality while reducing costs. To sum up, the proposed SDCN infrastructure can:

- *Cut down the CAPEX:* Network virtualisation, NFV, cloud computing technologies relying on COTS hardwares can effectively decrease the networking cost. Further cost reduction attributes to the extended life-cycle of network gears based on generic hardwares, namely, by using SDN, the control and application planes may only need software replacement or upgradation.
- *Reduce the OPEX:* The SDCN solution relies on centralised control planes and network orchestration. This can simplify the complex O&M tasks (e.g., software updating for a new application on distributed networking nodes of different types and from different vendors) in current cellular networks, and accordingly can lower the OPEX.
- *Shorten time-to-market:* Innovative business models and services are keys for carriers to achieve new revenues. The SDCN solution can enhance network agility to fit and accommodate newly appearing services. Accordingly, it can accelerate service time-to-market and ensure better network monetisation.

- *Ensure better QoS/QoE:* The SDCN solution is capable of providing flexible and fine-granular flow control. It can steer the flows based on subscriber attributes and application characteristics, leveraging SDN technology. As a result, enhanced bandwidth utilisation efficiency, better E2E QoS, and improved user QoE can be easily achieved.

5 Conclusions

The recent blossoming of MBB, smart terminals, and bandwidth-hungry mobile OTT applications has introduced cellular network carriers a planarity of challenges. On the one hand, rapidly growing traffic loads put unprecedentedly large pressure on the underlying communication networks; network QoS and subscriber QoE are getting increasingly harder to be satisfied. On the other hand, carrier revenues are not proportionally increased against the investments; the legacy telecom ecosystem are not sustainable. This paper elaborates a holistic and forward-looking SDCN architecture, with adopting several promising technologies including SDN, cloud computing, NV, NFV, and dynamic service chaining. The proposed SDCN architecture can help carriers to accelerate time-to-market, to enhance network capacity, flexibility, agility, scalability, and to increase revenues. Further, the SDCN architecture is designed to be a bridge for the gap between the current cellular network and the future 5G.

A demonstrative system on COTS hardwares for the proposed SDCN architecture is currently under developing, and is indispensable for the verification and demonstration of SDCN's advantages. Therefore, the demo developing work should possess the highest priority in the near future. Besides, considering the importance of openness and standardisation, the SDCN architecture may need to be dynamically adjusted and further detailed, so as to be always aligned with future industrial standards.

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