Part I
Introduction

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Overview

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Future mobile network architectures need to evolve to cope with future demand for high bandwidth, a large and evolving set of services with new specific requirements, high-level security, low energy consumption, and optimal spectrum utilization. Specifically, the increasing number of mobile users and services will result in the increasing capacity requirements for the mobile network. On the other hand, it is expected that mobile data traffic will grow faster than the fixed Internet during the upcoming years. Thus, accommodating this expected traffic growth is an imminent requirement of future mobile networks.

In order to keep up with the traffic growth, mobile networks have not only to go through architecture processes to optimize the current resources but also to add new components/technologies that increase the capacity. However, mobile backhaul networks contain remarkably complex and inflexible devices. Although the interfaces of a cellular network are globally standardized, still most of these devices are vendor specific. Thus, mobile operators do not have flexibility to "mix and match" capabilities from different vendors. In another aspect, the standardization process for mobile networks is a long-lasting process. Although operators find promising concepts, they need to wait years to implement them in their networks. This might bury lots of interesting opportunities due to the lack of support.

On these grounds, software defined networking (SDN) is one of the promising technologies that are expected to solve these limitations in current mobile networks. SDN provides the required improvements in flexibility, scalability, and performance to adapt the mobile network to keep up with the expected growth. Software defined mobile networking (SDMN) is directing the current mobile network toward a flow-centric model that employs inexpensive hardware and a logically centralized controller. SDN enables the separation of the data forwarding plane from the control planes (CP). The SDN-enabled switches, routers, and gateways are controlled through an SDN

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controller/network operating system (NOS) and are seen as virtual resources. The CP of the mobile networking elements can be deployed onto an operator cloud for computing.

In this paradigm, each operator has the flexibility to develop his own networking concepts, optimize his network, and address specific needs of his subscribers. Furthermore, software-programmable network switches in SDMN use modern agile programming methodologies. These software methodologies can be developed, enhanced, and upgraded at much shorter cycles than the development of today's state-of-the-art mobile backhaul network devices.

The acquisition of virtualization into Long-Term Evolution (LTE) mobile networks brings the economic advantage in two ways. First, SDMN requires inexpensive hardware such as commodity servers and switches instead of expensive mobile backhaul gateway devices. Second, the introduction of SDN technology to mobile networks allows entering new actors in the mobile network ecosystem such as independent software vendors (ISV), cloud providers, and Internet service providers (ISP) that will change the business model of mobile networks.

Thus, the concept of SDMN would change the network architecture of the current LTE 3rd Generation Partnership Project (3GPP) networks. SDN will also open up new opportunities for traffic, resource, and mobility management as well as impose new challenges on network security. Many academic and industrial researchers are working on the deployment of SDMNs. We believe that ideas stemming from design and experiments with SDMN provide indispensable knowledge for anybody interested in next-generation mobile networks.

The overview chapter starts with Section 1.1, which contains a discussion on the limitation of the present mobile network. The SDMN architecture and its components are presented in Section 1.2. The key benefits of SDMN architectures are described in Section 1.3. Section 1.4 contains the conclusion.

1.1 Present Mobile Networks and Their Limitations

The mobile communication was introduced in the 1980s. The first generation of mobile networks supports only the voice call services and the connectivity speed up to 56 kbps. However, the mobile network technology achieved a tremendous development during the last four decades. Today's mobile networks support various network services such as amended mobile Web access, Internet Protocol (IP) telephony, gaming services, high-definition mobile television (TV), videoconferencing, 3D television, cloud computing, and high-speed broadband connectivity up to several Gbps [1].

With inbuilt mobility support, these services fuel the attraction toward the mobile broadband networks instead of wired Internet. It is expecting that the mobile data traffic will be exceeding the wired data traffic in the near future. On the other hand, mobile networks have to provide carrier-grade high-quality services for their subscribers even while copping with these traffic demands.

It is challenging to satisfy all these requirements by using present-day mobile network architecture. Present-day mobile networks are facing various limitations, and they can be categorized as below [2, 3]:

- *Scalability limitations* – The rapid increment of mobile traffic usage is projected due to new bandwidth-hungry mobile services such as online streaming, video calls, and high-definition mobile TV. The existing static overprovisioned mobile networks are inflexible and costly to scale to keep up with the increasing traffic demand.

- *Complex network management* – Significant expertise and platform resources are required to manage the present mobile network. In most cases, backhaul devices are lacking of common control interfaces. Therefore, straightforward tasks such as configuration or policy enforcement also require a significant amount of effort.
- *Manual network configuration* – Most of the network management systems are manually intensive, and trained operators are required [4–7] to achieve even moderate security [8]. However, these manual configurations are prone to misconfiguration errors. Also, it is expensive and taking a long time to troubleshoot such errors. According to the Yankee Group report [4], 62% of network downtime in multivendor networks happened due to human errors. Furthermore, 80% of IT budgets are spent on maintenance and operations of the network.
- *Complex and expensive network devices* – Some of the mobile backhaul devices have to handle extensive amount of work. For instance, Packet Data Network Gateway (PDN GW) is responsible for many important data plane (DP) functions such as traffic monitoring, billing, quality-of-service (QoS) management access control, and parental controls in LTE networks. Thus, the devices are complex and expensive.
- *Higher cost* – Mobile operators do not have flexibility to "mix and match" capabilities from different vendors' devices. Therefore, they cannot build their network by using the cheap equipment from different vendors. It directly increases the CAPEX of the network. On the other hand, the manual configuration and inflexibility increase the OPEX of the network.
- *Inflexibility* – The standardization process for mobile networks is a long-lasting process. It requires many months or years to introduce new services. Furthermore, the implementation of new service also takes weeks or months due to the manually intensive service activation, delivery, and assurance.

Apart from these key issues, future mobile networks will face critical network congestion issues. Regardless of the limited radio bandwidth, the demand for mobile data is increasing rapidly. Therefore, mobile network operators have to use smaller cells to accommodate the traffic growth, which ultimately increases the number of base stations in the network. It is predicted that the global number of cellular sites will reach up to 4 million by the end of 2015. It was only 2.7 million by the end of 2010 [1]. Therefore, mobile backhaul networks will face congestion in a manner similar to data center networks due to the increment of mobile broadband traffic and the number of base stations as a solution.

1.2 Software Defined Mobile Network

The adaptation of SDN and virtualization concepts to the mobile network domain will solve the previously mentioned issues. The SDN concepts not only solve these issues but also improve the flexibility, scalability, and performance of a telecommunication network. SDN is originally designed for fixed networks. However, mobile networks have different requirements than fixed networks such as mobility management, precious traffic transportation, efficient protection of the air interface, higher QoS, the heavy use of tunneling in packet transport, and more. Therefore, SDMN concept is proposed as an extension of SDN paradigm to support mobile network-specific functionality. Furthermore, SDMN has a greater degree of service awareness and optimum use of network resources than original SDN concepts.

The least telecommunication architectures such as the 3GPP Evolved Packet Core (EPC) explained the advantages of the separation of the CP from the DP. EPC supported this separation to some extent. However, SDN enables the complete separation of the CP from the data forwarding plane. Furthermore, standardization organizations such as the Internet Engineering Task Force (IETF) and the European Telecommunications Standards Institute (ETSI) are interested to utilize network function virtualization (NFV) concepts in telecommunication networks. The SDN concepts help to adapt the NFV functions as well. Basically, the NFV concepts facilitate on-demand provision and online scale-up for mobile networks.

The SDMN architecture is now directing the current mobile network toward a flow-centric model that employs inexpensive hardware and a logically centralized controller. SDMN is basically an approach to networking in which the CP is decoupled from telecom-specific hardware and given to a software application called the controller. The SDN-enabled switches, routers, and gateways are controlled through the SDN controller and NOS. The CP of the mobile networking elements can deploy in an operator cloud as virtual components. Furthermore, the modern agile programming methodologies can be used to program and upgrade the performance of software-programmable network switches in SDMNs. These software methodologies can be developed, enhanced, and upgraded at much shorter cycles than the development of today's state-of-the-art mobile backhaul network devices. In this paradigm, each operator has the flexibility to develop his own networking concepts to address specific needs of his subscribers and optimize his network to achieve better performance. During the past few years, many academic and industrial researchers are working on the deployment of SDMNs. The integration of SDN in mobile networks is proposed in various papers [3, 9–11].

Figure 1.1 illustrates the basic architecture of SDMNs [2, 12].

Basically, SDMN splits the CP and the DP of the mobile network. It allows centralizing all the controlling functionalities. The DP now consists of low-end switches and links among them.

The SDMN architecture can be divided into three layers [2, 12, 13]:

1. **DP layer**
   The DP layer is also known as the infrastructure layer. It consists of the network elements such as switches and other devices. These switches support packet switching and forwarding functions. Base stations are connected to DP switches at the border. However, the SDMN architecture is transparent to the existing radio technologies. Similarly, border switches at the core network are connected to the Internet to off-load the mobile subscriber traffic.
2. **Network controller**
   The logically centralized controller provides the consolidated control functionality of the DP switches. The control protocol (e.g., OpenFlow [14], Beacon [15], Maestro [16], and DevoFlow [17]) is used by the controller to communicate with the DP elements. Basically, the controller uses the control protocol to install flow rules in each DP switch to route the traffic along the mobile network DP. The boundary between the network controller and the DP layer is traversed by the southbound application programming interface (API).
   The NOS is run on top of the controller to support the control functions.
3. **Application layer**
   The application layer consists of all the controlling and business applications of the mobile network. The traditional mobile network elements such as Policy and Charging Rules Function (PCRF), Home Subscriber Server (HSS), Mobility Management Entity (MME), and Authentication, Authorization, and Accounting (AAA) are now software

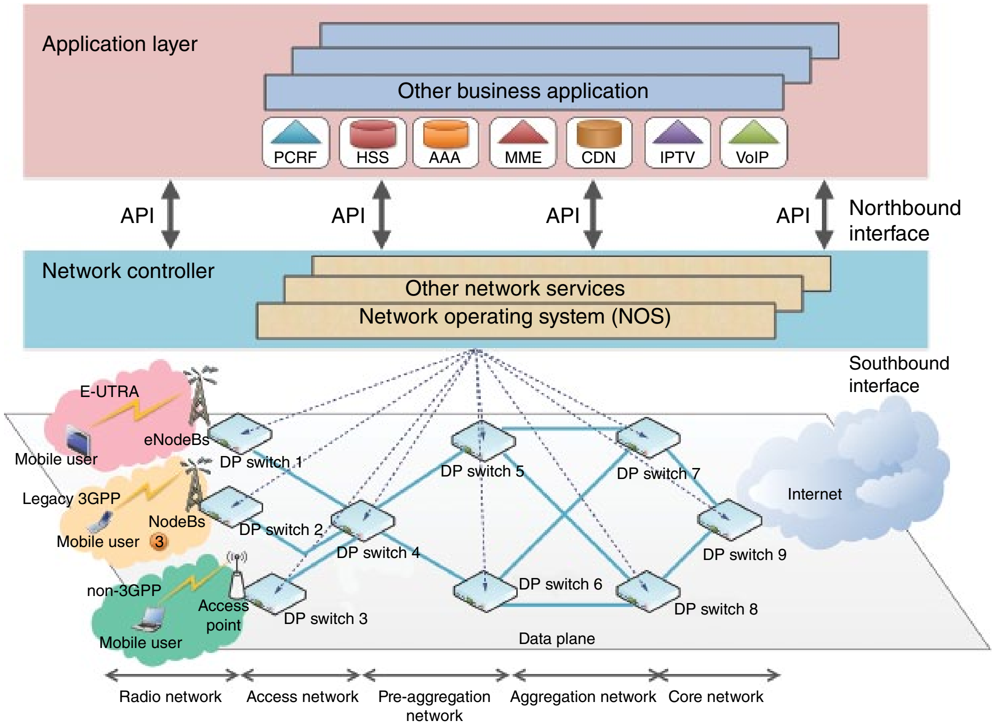

Figure 1.1 SDMN architecture.

applications that are running on top of NOS. The boundary between the application layer and the network controller is traversed by the northbound API.

Control elements perform the traditional functionalities and assist NOS to handle mobile network functionalities such as mobility management, resource management, and traffic transportation.

Thus, the adaptation of SDN changes the network architecture of the current mobile networks. Moreover, SDN will also open up new opportunities in various sections in the mobile network. Especially, it provides various benefits for traffic, resource, and mobility management as well as imposes new challenges on network security.

1.3 Key Benefits of SDMN

The adaption of SDN concepts offers various benefits for the entire mobile networks including wireless access segments, mobile backhaul networks, and core networks. Here, we present the key benefits of SDMNs [2, 11–13]:

- *Logically centralized controlling* – A centralized controller can take control decision based on the global view of the network. These decisions are more accurate, optimum, and efficient than the existing autonomous system-based mechanisms.

- *Flexibility* – SDN architecture defines a common standard among the backhaul devices. Therefore, the controller can control any SDN-enabled mobile network component from any vendor. It allows the network operator to mix and match the network elements from different vendors.
- *Higher rate of innovation and opportunity for new services* – The network programmability and common APIs accelerate business innovation in mobile networks. The operator has the flexibility to quickly innovate and test various novel controlling applications on top of the NOS. The deployment of these software-based novel applications is faster than today's hardware-based application deployment.
- *Automatic network management* – The centralized controller help to deploy, configure, and manage the backhaul devices rapidly. Automatic network management allows deploying new network services and network capabilities in a matter of hours instead of days. Also, it is possible to dynamically fine-tune the device configurations to achieve better resource utilization, security, and lower congestion than static configurations. For instance, mobile operators can adaptively apply off-loading policies based on actual traffic patterns. Today's static policies do not adapt to changing network conditions. Furthermore, troubleshooting is very fast due to the global view at controllers.
- *Low-cost backhaul devices* – The SDN architecture removes the CP from the backhaul devices. Now, these devices are needed to do only very basic functions. Therefore, SDN switches do not need to employ with high processing hardware, and low-cost, low processing switches can be utilized at the DP.

  On the other hand, SDN architecture further reduces the size of a flow table by several orders of magnitudes than the forwarding table in an equivalent Ethernet switch. The traditional Ethernet switch has static or distributed algorithm-based flow tables that are not optimized. Therefore, even small wiring closet switches typically contain a million entries. However, the flow-based traffic routing and centralized controlling will optimize the flow rules in the switches, and these rules can be dynamically revoked or added. Therefore, SDN switches now have much smaller flow tables that need to keep track of flows in progress. In most of the cases, the flow tables can be small enough to be held in a tiny fraction of a switching chip. Therefore, SDN switches now contain low-capacity memory, and the cost of the devices is drastically decreasing. Even for a campus-level switch, where perhaps tens of thousands of flows could be ongoing, it can still use on-chip memory that saves cost and power [18].
- *More granular network control* – The flow-based control model in SDN architecture allows applying the flow control policies at a very granular level such as the session, user, device, and application levels. Also, it is possible to dynamically change these control policies based on observed network behaviors. For instance, the operator is able to provide priority for high-revenue-producing corporate customers than lower-yielding consumers.
- *Heterogeneous network support and interoperability* – The flow-based traffic transport model in SDN is well suited to provide end-to-end communications across heterogeneous network technologies, such as Global System for Mobile Communications (GSM), 3G, 4G, Wi-Fi, code division multiple access (CDMA), and more. Also, it provides compatibility for future 5G-like network technologies.
- *Efficient segmentation* – SDN architecture supports efficient network segmentation. The software-based segmentations can be used to provide services for extremely popular mobile virtual network operator (MVNO) services. For instance, FlowVisor and language-level isolations can be used here.

- *Efficient access control network* – The centralized controlling allows deploying efficient intercell interference management algorithms. It allows taking efficient and optimal resource management decisions and improves the utilization of scarce radio-frequency (RF) spectrum. In addition, computational-intensive processing can be off-loaded to cloud devices by reducing the costs and increasing the scalability.
- *Path optimization* – The network controller can optimize the end-to-end path by considering the global view of the network. In a mobile environment, fast and efficient path optimization mechanisms are important as they support millions of mobile subscribers who change their locations rapidly. The centralized path optimization procedures are more efficient, faster, and optimum than the existing distributed path optimization mechanisms.
- *On-demand provision and online scale-up* – The SDN concepts enable adaptation of network virtualization. The virtualization of network devices offers the on-demand provisioning of resources when needed and scaling up of resources whatever demands are requested.

1.4 Conclusion

The growing traffic demand and new bandwidth-hungry mobile services increase the strain on present mobile networks. Thus, many academic and industrial researches are currently underway exploring different architectural paths for future mobile networks. The development of beyond LTE architecture is presently in its early research stages. Researchers are seeking new architectural paths that not only increase the network capacity but also solve the existing limitations in present LTE architecture.

In common terms, SDN is considered as “the radical new idea in networking.” It has provided various benefits for fixed and wired network. Thus, SDN is considered as one of the promising technologies that can solve limitations in current mobile networks. SDN provides the required improvements in flexibility, scalability, and performance to adapt the mobile network to keep up with the expected growth. Therefore, SDN will likely play a crucial role in the design phase of beyond LTE mobile networks. A deep understanding of this emerging SDMN concept is necessary to address the various challenges of the future SDN-enabled mobile networks. The book will provide a comprehensive knowledge for researchers who are interested in SDMN concepts. Moreover, it covers all the technical areas such as virtualized transport and network management, resource and mobility management, mobile network security, and technoeconomic modeling concepts.

References

[1] M. Liyanage, M. Ylianttila, and A. Gurtov. A case study on security issues in LTE backhaul and core networks. In B. Issac (ed.), *Case Studies in Secure Computing—Achievements and Trends*. Taylor & Francis, Boca Raton, FL, 2013.

[2] K. Pentikousis, Y. Wang, and W. Hu. Mobileflow: Toward software-defined mobile networks. IEEE Communications Magazine, 51(7):44–53, 2013.

[3] L. E. Li, Z. M. Mao, and J. Rexford. Toward software-defined cellular networks. European Workshop on Software Defined Networking (EWSDN). IEEE, Darmstadt, Germany, 2012.

[4] Z. Kerravala. *Configuration management delivers business resiliency*. The Yankee Group, Boston, MA, 2002.

[5] T. Roscoe, S. Hand, R. Isaacs, R. Mortier, and P. Jardetzky. Predicate routing: Enabling controlled networking. SIGCOMM Computer Communication Review, 33(1):65–70, 2003.

[6] A. Wool. The use and usability of direction-based filtering in firewalls. Computers & Security, 26(6):459–468, 2004.
[7] G. Xie, J. Zhan, D. A. Maltz, H. Zhang, A. Greenberg, and G. Hjalmtysson. Routing design in operational networks: A look from the inside. In Proceedings of the SIGCOMM, Portland, OR, September 2004.
[8] A. Wool. A quantitative study of firewall configuration errors. IEEE Computer, 37(6):62–67, 2004.
[9] A. Gudipati, D. Perry, L. E. Li, and S. Katti. SoftRAN: Software defined radio access network. In Proceedings of the Second ACM SIGCOMM Workshop on Hot Topics in Software Defined Networking. ACM, Chicago, IL, 2013.
[10] X. Jin, L. E. Li, L. Vanbever, and J. Rexford. CellSDN: Software-defined cellular core networks. Opennet Summit, Santa Clara, CA, 2013.
[11] X. Jin, L. E. Li, L. Vanbever, and J. Rexford. SoftCell: Taking control of cellular core networks. arXiv preprint arXiv:1305.3568, 2013.
[12] K. Christos, S. Ahlawat, C. Ashton, M. Cohn, S. Manning, and S. Nathan. OpenFlow™-enabled mobile and wireless networks, White Paper. Open Network Foundation, Palo Alto, CA, 2013.
[13] Y. Liu, A. Y. Ding, and S. Tarkoma. *Software-Defined Networking in Mobile Access Networks*. University of Helsinki, Helsinki, 2013.
[14] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner. OpenFlow: Enabling innovation in campus networks. ACM SIGCOMM Computer Communication Review, 38(2):69–74, 2008.
[15] OpenFlowHub. BEACON. http://www.openflowhub.org/display/Beacon (accessed January 17, 2015).
[16] Z. Cai, A. L. Cox, and T. E. Ng. Maestro: A system for scalable OpenFlow control. In Rice University Technical Report, 2010. Available at: http://www.cs.rice.edu/~eugeneng/papers/TR10-11.pdf (accessed January 17, 2015).
[17] J. C. Mogul, J. Tourrilhes, P. Yalagandula, P. Sharma, A. R. Curtis, and S. Banerjee. DevoFlow: Cost-effective flow management for high performance enterprise networks. In Proceedings of the ninth ACM Workshop on Hot Topics in Networks (HotNets). ACM, New York, 2010.
[18] M. Casado, M. J. Freedman, J. Pettit, J. Luo, N. McKeown, and S. Shenker. Ethane: Taking control of the enterprise. ACM SIGCOMM Computer Communication Review 37(4):1–12, 2007.