19

SDMN

Industry Architecture Evolution Paths

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19.1 Introduction

Global mobile data traffic is expected to increase at a compound annual growth rate of 61% between 2013 and 2018 [1], which can make the current centralized gateway system a bottleneck. Software defined networking (SDN) [2] based on, for example, the OpenFlow protocol [3] is one suggested solution to dissolve this bottleneck by separating the network into centralized control functions and distributed forwarding switches.

Separating the control plane functions from the user plane elements creates more signaling traffic [4]. However, the network could also see cost savings [5, 6] from capacity sharing and economies of scale benefits from shared cloud platforms. In addition, acquiring and maintaining standardized general-purpose switches are assumed to be cheaper than the costs of proprietary specific-purpose components currently used in mobile networks [5]. Before the net benefit can be quantified, the industry architectures mapping the technical and business relationships between the network elements and the market actors need to be identified.

Industry architectures and business models for virtualized mobile networks are not an entirely new research topic. However, previous studies have typically focused only on one business model or use case. For example, Fischer et al. [7] describe a simple infrastructure-as-a-service business model, where only infrastructure providers, service providers, virtual mobile operators, and virtual mobile providers are considered. Dramitinos et al. [8] discuss video-on-demand use cases over virtualized Long-Term Evolution (LTE) networks and present two industry architectures covering many business roles.

In contrast to the existing studies, this study provides an overview of multiple potential industry architectures for software defined mobile networks (SDMN). The analysis describes how SDN could improve the performance of mobile Internet service provisioning and how the

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industry structure could change due to the introduction of SDMN. The industry architectures are illustrated with Casey et al.'s [9] method that maps the technical components onto business roles and roles further to actors. The industry architectures are based on the current Finnish LTE network structure, and they are identified by interviewing ten technical and business experts representing academia, mobile network operators (MNOs), and network equipment vendors.

New technologies can be sustaining or disruptive [10]; thus, two deployment approaches for SDMN are discussed: (1) evolutionary SDMN and (2) revolutionary SDMN. *In the evolutionary SDMN*, the network elements (i.e., base stations, routers and switches, and gateways) are separated into their control plane functions and user plane elements. The user plane elements are assumed to stay in the same physical locations, though their control plane functions are moved into the cloud. For example, Basta et al. [11] discuss a functional split of Serving/Packet Data Network Gateways (S/P-GWs), where parts of gateway are moved into a cloud platform. *In the revolutionary SDMN*, the control plane functions can be optimized to operate more efficiently or simply by dividing them into subfunctions and forming new functional groups. From the economic perspective, evolutionary SDMN would bring incremental improvements to the operational efficiency of the currently existing industry architectures, whereas revolutionary SDMN could disrupt the current market situation through new industry architectures, where the value is redistributed among the existing and potential new actors in the market.

The rest of this chapter is structured as follows. Section 19.2 gives an overview of the current LTE network and defines the evolutionary and revolutionary SDMN from the technical perspective. The business roles of SDMN are defined in Section 19.3. These roles are used in Sections 19.4 and 19.5 to illustrate the identified industry architectures for evolutionary and revolutionary SDMN, respectively. Finally, Section 19.6 summarizes the findings and discusses the factors that influence which SDMN industry architectures are most likely to succeed.

19.2 From Current Mobile Networks to SDMN

For forming the industry architectures, a thorough understanding of the underlying technical architecture is needed. This section provides the technical background for the work by briefly explaining the technical evolution from the current mobile network to evolutionary and revolutionary SDMN architectures together with the simplifications and assumptions employed in this study. The sources used include the 3GPP specifications 23.002 on mobile networks [12], Pentikousis et al. [13], Penttinen [14], and interviews with technical and business experts in the Finnish market.

Ten semistructured interviews were conducted during spring 2014 with each lasting on average one hour. The interviewees included technology directors from Finnish MNOs, senior research scientists, and business unit representatives from network equipment vendors and senior researchers from academia. Topics discussed covered the current mobile network topology and structure in Finland and how SDN would change the structure.

19.2.1 Current Mobile Network Architecture

A simplified version of the current LTE network is shown in Figure 19.1. The end user's traffic is sent to an evolved NodeB (eNB), that is, an LTE base station, through the radio interface. The eNB contacts the Mobility Management Entity (MME) and Home Subscriber Server (HSS) for subscriber and authentication information. The traffic is then forwarded through the network routers and switches to the S/P-GW, which decides where to route the traffic. P-GW is the point where the traffic leaves the core network and enters the public IP network through the external interfaces (i.e., Internet exchange points, roaming, etc.). Additionally, P-GW acts as a firewall and S-GW serves as the mobility anchor, when the user is changing eNBs. The Policy and Charging Rules Function (PCRF) keeps track of the network usage and handles the billing for each user. In addition, traditional mobility management typically uses the GPRS Tunneling Protocol (GTP) for transporting the IP packets through the mobile network from eNB to P-GW. However, the tunnel is not drawn into the architecture figure, because it is only a logical connection.

As an example of the quantities of each network element, Figure 19.1 shows the numbers for the aggregate Finnish LTE network combining all the MNOs in Finland. Finland has three MNOs with approximately equal number of subscribers. The main challenge is a scarcely populated country with only 18 inhabitants per square kilometer [15], which increases the relative need for eNBs compared to more densely populated areas. For example, all three MNOs in Finland together currently have roughly 10,000 eNBs that serve the 5.4 million population [16], whereas the German mobile operators have 25,000 eNBs serving a customer base of 55 million [5].

In the Finnish LTE network, MME, HSS, and PCRF have already been centralized into data centers. However, virtualization has not happened yet and the elements still run on dedicated MME, HSS, and PCRF servers. In addition, the border between the user plane and the control plane runs through the eNB, S/P-GW, and routers and switches. Routers and S/P-GWs are also running on dedicated hardware in the traditional Evolved Packet Core. This means that the hardware providers have higher control over the market dynamics and they can charge high prices for the maintenance and updating of the network elements.

19.2.2 Evolutionary SDMN Architecture

Figure 19.2 shows the same LTE network with the eNBs, routers and switches, and S/P-GWs split into their control plane functions and user plane elements. The user plane elements are marked with a U, and control plane functions with a C in their names. In addition to the split,

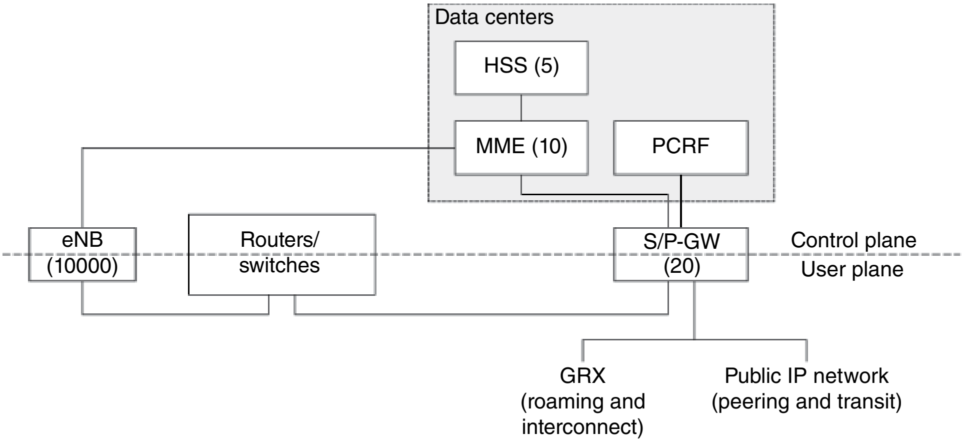

Figure 19.1 Current mobile network architecture.

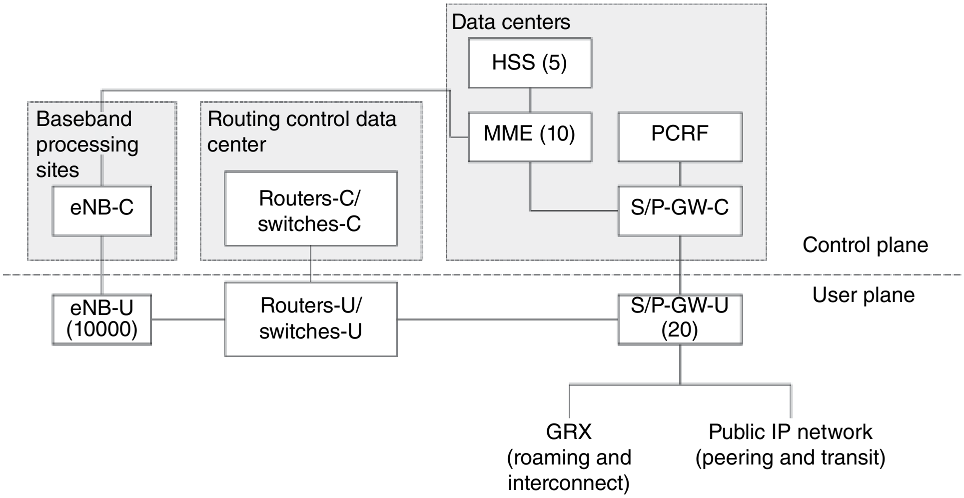

Figure 19.2 Evolutionary SDMN architecture.

the control plane functions of eNBs, routers and switches, and S/P-GWs are also centralized and put into a data center. The degree of centralization depends on the delay sensitivity of the function. For example, eNB-C and routers-C/switches-C cannot be too far away from their user plane equivalents, because it would increase the latency. Thus, eNB-C and routers-C/switches-C are placed in baseband processing pooling sites, which are typically within few kilometers from the user plane equipment (i.e., eNB-U), and the sites have to be connected with a fiber connection [17]. In this evolutionary SDMN architecture, GTP is assumed to function as in the traditional mobile network.

After the control plane functions are stripped from the user plane elements, the user plane can run on general-purpose hardware instead of dedicated servers or routers. This will decrease the costs on building and maintaining the mobile network. In addition, the repair process could potentially be faster, because a malfunctioning user plane element can be replaced with general-purpose hardware and control plane functions can be updated centrally. Moreover, introducing new services should be faster as it would be done by just introducing new pieces of software.

When the control plane functions are moved into data centers and baseband processing pooling sites, more signaling traffic is created between the user and the control plane elements. The separation of the control and user planes also requires more processing capacity in total. This is illustrated in Figure 19.3 and the steps are described below:

1. When the first packet of a flow arrives at a switch-U, the switch-U first unpacks the packet and then repacks it with the switch-C's address.
2. The packet is then sent to the switch-C, which also unpacks and repacks it to add the routing decision and other signaling information.
3. Lastly, the packet is sent back to the switch-U together with the forwarding table, and the packet is then forwarded to the next network element toward its destination.

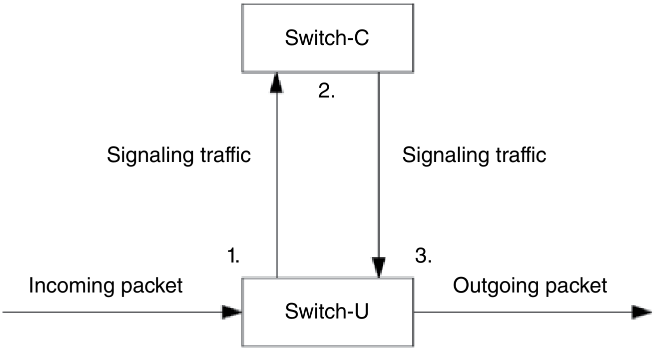

Figure 19.3 First packet processing of a flow and signaling traffic in SDN.

With the traditional switch, the packet would be unpacked and packed only once at the switch and no additional signaling traffic is needed. How much the signaling traffic increases depends on the length of the flows, because only the first packet of a flow is sent to the switch-C. With the following packets of a flow, the switch-U already knows where to forward them. Thus, the scalability of a network with shorter flows is an uncertainty. However, 80–90% of all consumer traffic in the Internet is estimated to be video traffic by 2017 [1], which is a significant optimization opportunity for SDMN. In addition, the amount of the signaling traffic and processing capacity can be decreased with proactive SDN. This means that the switches have predefined routing decisions and rules on how to process certain types of flows. In reactive SDN, each new flow (or its first packet) arriving to a switch-U causes the switch-U to trigger a signaling message, which would cause scalability issues. The number of controllers in the network also affects the performance; the performance decreases with each added controller [4].

On the other hand, the flexibility of the split architecture may reduce the risk of scalability bottlenecks in the mobile networks. In addition, it may also bring cost savings through more efficient resource sharing including both the user plane (spectrum, forwarding) and the control plane (cloud platforms). On the other hand, more advanced resource sharing in the radio access network (RAN) is already under discussion by the 3GPP, for example, the RAN sharing enhancement standards [18], which reduces the resource sharing benefits of SDMN compared to traditional non-SDN mobile networks.

19.2.3 Revolutionary SDMN Architecture

A more radical longer-term step—called revolutionary SDMN—is to reoptimize the control plane elements to function more efficiently. This means that current control plane functions are split further into subfunctions, that is, functional split is performed. These subfunctions can be regrouped into new functional groups, and these new functional groups are marked with a + sign in Figure 19.4, which shows the revolutionary SDMN architecture.

The longer-term revolutionary approach of SDMN technically assumes a standard scalable fiber-based packet network, where control plane processing resides both close to base stations (e.g., cloud RAN) and in large centralized data centers. Mobility anchors can be distributed

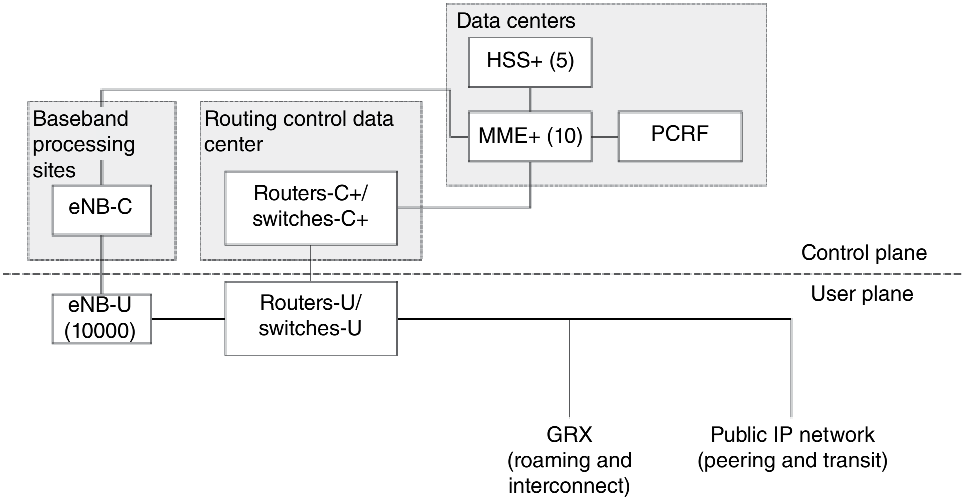

Figure 19.4 Revolutionary SDMN architecture.

and commoditized in all switches, that is, the traditional centralized S/P-GWs can be removed from the architecture. An example of a cloud-optimized control plane function is mobility management based on a standardized tunneling capability in all switching elements, instead of few specialized S/P-GWs. This idea matches with the SDN Enhanced Distributed P/S-GW use case of the Open Networking Foundation's Wireless & Mobile Working Group [19], where distributed S/P-GWs are communicating with a centralized MME to reduce redundant traffic between eNBs and the centralized S/P-GWs.

Removal of centralized S/P-GWs also means changes in GTP. The earlier versions of OpenFlow do not support GTP, but the user plane elements can be realized with different technologies, such as VLAN tagging, or by implementing GTP directly into the OpenFlow switch [20]. The control plane element of GTP could also be moved into the cloud. The role of GTP can be important for a cost-optimized transition from the traditional GTP to a more lightweight mobility management. For example, another use case from the same working group (SDN-based mobility management in LTE [19]) discusses the potential of removing GTP tunneling and, thus, eliminating the signaling traffic and GTP overhead during handovers. The other functionalities of the S/P-GWs are divided between MME+ and routers-C+/ switches-C+.

19.3 Business Roles of SDMN

Introduction of new technology also affects the value networks and business models, that is, the industry architectures, of mobile Internet service provisioning. In order to explore the impact of SDMN systematically, the required functionalities for providing mobile Internet over SDMN are divided into business roles, which are then allocated to different actors. The business roles are identified, and the industry architectures are constructed by using the value

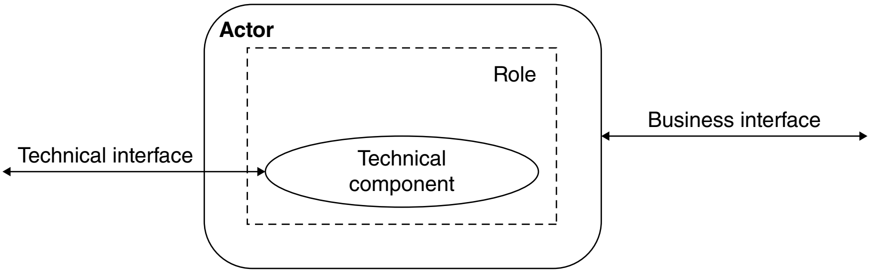

Figure 19.5 Industry architecture notation.

network configuration method of Casey et al. [9]. The components of the notation are illustrated in Figure 19.5 and they are defined as follows:

- **Technical component:** a collection and realization of technical functionalities, including the technical interfaces to other technical components
- **Role:** a set of activities and technical components, the responsibility of which is not divided between separate actors
- **Actor:** an actual market player that takes roles and establishes business interfaces (contracts and revenue models) between other actors

Technical architecture consists of technical components, whereas industry architecture (also value network configuration in the paper of Casey et al. [9]) describes how the roles are divided among actors and how the actors are connected to each other. The notation allows illustration of technical and business architectures in the same figure, which is beneficial for understanding the dependencies between them. Since the technical architectures were introduced already in Section 19.2, from this on, the focus is on industry architectures.

Role analysis forms the basis for constructing and analyzing the industry architectures. Table 19.1 describes the key roles related to SDMN, which can be mapped to the technical components of the traditional mobile network architecture, as is shown in the generic role configuration presented in Figure 19.6. However, the distinct feature of SDMN compared to the traditional mobile networks is the breaking of the tight integration of multiple roles in the same technical components, allowing different actors to control these earlier integrated roles. Therefore, the user plane and control plane functionalities of base stations, routers, and gateways are separated into different roles. Also, the functionalities of S-GW and P-GW are defined separately, even though they are integrated in the existing mobile networks. In order to focus the analysis on the basic functionalities of mobile networks, some advanced functionalities may be missing or they are assumed to be included in the identified key roles.

In addition to the roles related to the internal structure of SDMN, the two key external roles related to network usage and interconnection to other networks are also defined and included in the industry architecture. Even though these two roles are always assigned to end users and interconnection providers, respectively, their inclusion is highly relevant, since a significant amount of revenues and costs are transferred over the business interfaces to these two actors.

Table 19.1 Key roles of SDMN

Roles	Description
Network usage	Accessing the network with a mobile device
Radio network forwarding	Receiving the user traffic in eNBs and forwarding it to the Evolved Packet Core
Radio network routing	Management and operation of the base stations and radio frequencies
Core network forwarding	Traffic forwarding in the Evolved Packet Core network
Core network routing	Traffic routing in the Evolved Packet Core network
Public network forwarding	Traffic forwarding and filtering (i.e., firewall functionality) between the public network and the core network
Connectivity management	Management of connectivity (i) between the public network and the core network and (ii) in the Evolved Packet Core, including situations of inter-eNB handover. Can be divided into (i) public network connectivity management and (ii) mobile network connectivity management, respectively
Mobility management	Management of control plane signaling between the eNB and other network elements like HSS
Subscriber management	Management of the user- and subscription-related information, including user authentication, access authorization, and home network information
Policy and charging	Brokering quality of service and charging policy on a per-flow basis
Interconnection provisioning	Providing the interconnection to public IP networks and other mobile networks through transit, peering, and roaming agreements

Particularly, the business interface to end users, the customers using the mobile networks, is highly valuable as connecting to the source of revenues provides negotiation power against other actors.

19.4 Industry Architectures of Evolutionary SDMN

This section explores the business opportunities of the evolutionary SDMN by analyzing three industry architectures, where SDMN could be introduced. The presented industry architectures are technically feasible with the current technology and existing deployments of the mobile operators in the Finnish market. Since the identified industry architectures already exist in the market, this section focuses on analyzing how SDMN could increase flexibility and improve operational efficiency of the mobile Internet service provisioning.

19.4.1 Monolithic MNO

A very natural evolution path would be one, where an MNO drives the SDMN deployment due to their ownership of the current network infrastructure and the business relationship with the end users (Fig. 19.7). Thus, in the first scenario, MNO operates its own mobile cloud platform and runs the control plane functions on it. The MNO also negotiates with the interconnection providers for the roaming, transit, and peering agreements.

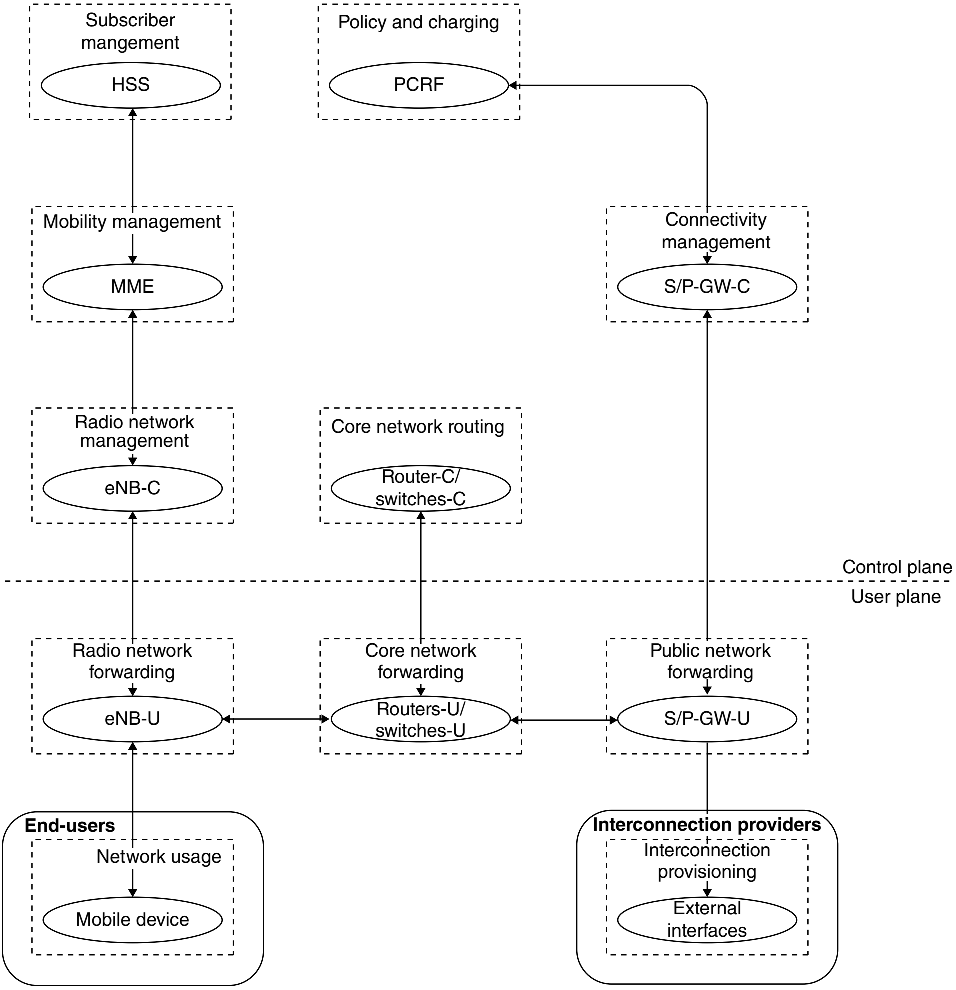

Figure 19.6 Generic role configuration of SDMN.

This scenario's benefit lies in the potential cost reduction from using general-purpose and standardized hardware in both the user plane and in the control plane cloud platform. For example, Naudts et al. [5] show that an SDN-enabled mobile network in Germany presents substantial capital expenditure savings, especially in the preaggregation sites (i.e., the routers). In addition, network configuration can be handled more dynamically, which enables new services to enter the market faster.

However, cost savings from future capital expenditure as the only incentive are not enough for the MNOs to switch to SDMN immediately. The SDMN deployment would most likely happen only when the existing network infrastructure is being renewed. For immediate deployment, SDMN should show more benefits, for example, a decrease in operational expenditure or new revenue potentials, which remain to be determined.

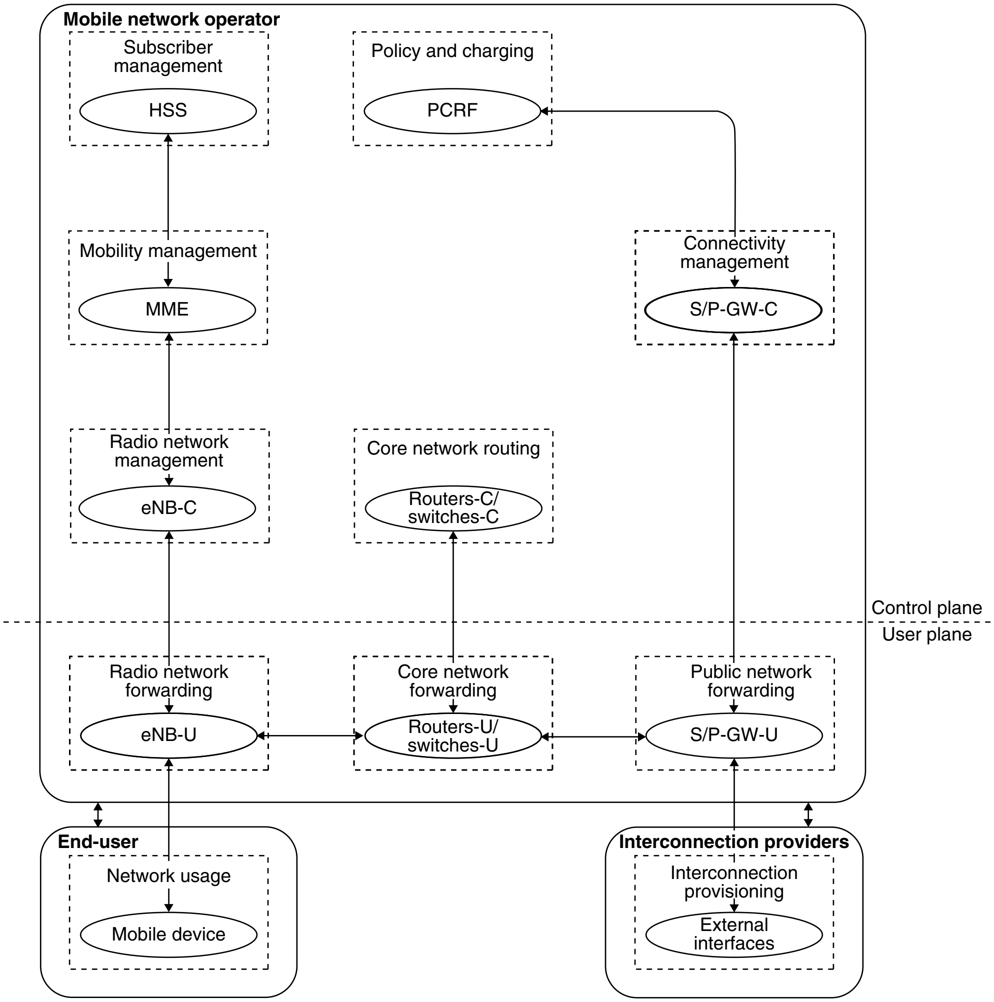

Figure 19.7 Evolutionary SDMN with monolithic MNO.

19.4.2 Outsourced Subscriber Management

Another common business arrangement in the current mobile market is such that a mobile virtual network operator (MVNO) handles the business relationship with the end users and partially or fully uses the MNO's network infrastructure [21]. For example, Virgin Mobile in the United States is a MVNO running over a network provided by the Sprint Network [22], and Lycamobile is a United Kingdom-based MVNO operating in 17 countries and partnering with local MNOs in each country [23].

When a MVNO is entering the market, it can choose different levels of investment into the network equipment [21]. Figure 19.8 shows a scenario, where a service provider MVNO manages a front-end HSS and PCRF. The MNO in this scenario retains control of the critical

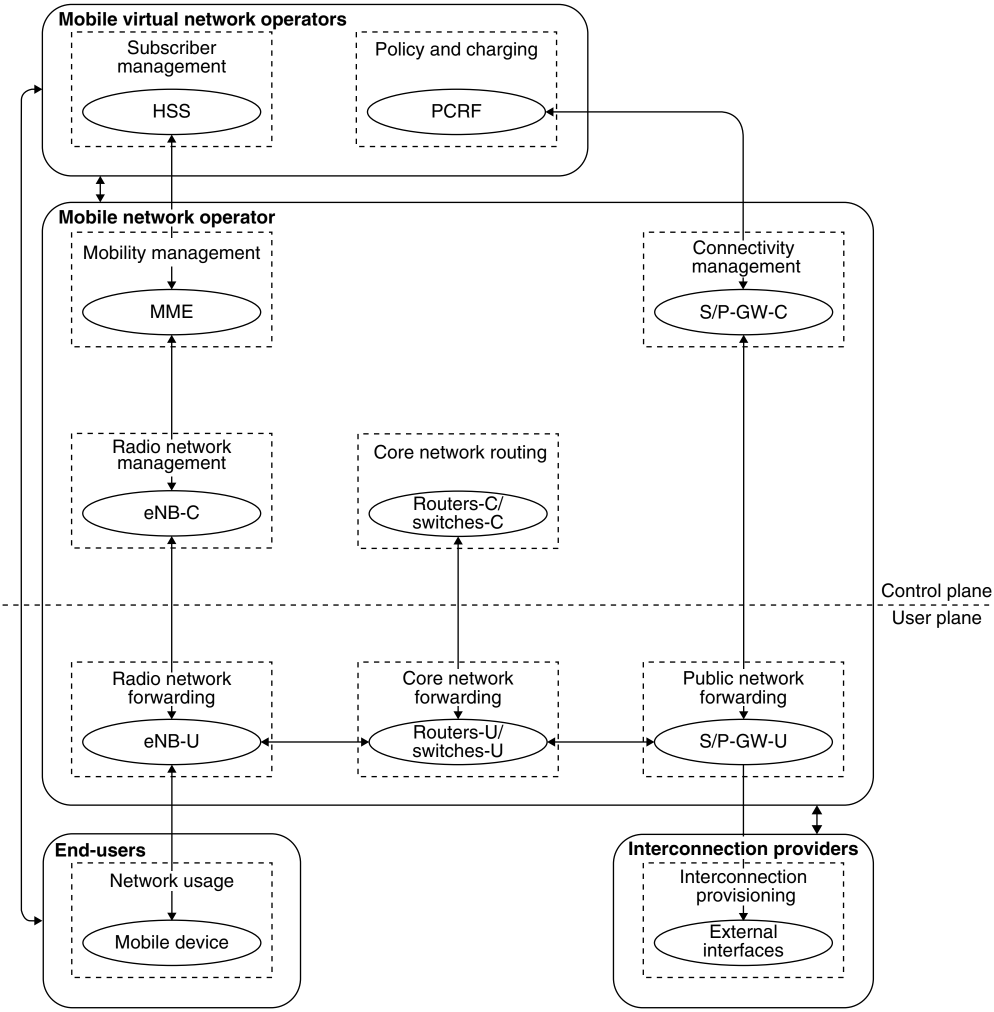

Figure 19.8 Evolutionary SDMN with outsourced subscriber management.

functions of the network, such as MME, S/P-GW, and HSS database. In addition, the service provider MVNO might not wish to own any infrastructure and could be managing the operations of the subscriber management and policy and charging over a leased cloud provided by, for example, a data center or a mobile infrastructure provider.

The SDN-related benefits and challenges for the MNO in this industry architecture are the same as in the monolithic MNO industry architecture. Some additional benefits could be obtained if the MNO would charge the MVNOs the same price as before but still enjoy the cost savings from SDN. In addition, a more agile network could potentially enable the MVNOs to offer better services to the end users and the MNO could use this argument to charge more from the MVNOs.

19.4.3 Outsourced Connectivity

In the third evolutionary SDMN industry architecture illustrated in Figure 19.9, the traditional monolithic MNO is divided into the mobility, connectivity, and service parts. MVNOs manage the subscription, service, and charging-related functions toward the end users, as in the outsourced subscriber management industry architecture. In addition, the core network connectivity is outsourced to a connectivity provider, but the connectivity management and radio network functions are still in the hands of the MNO. Interconnection negotiations and business agreements with the transit, peering, and roaming partners are still taken care by the MNO.

This division enables economies of scale for the connectivity provider, because the same transport network could carry the traffic of several MNOs. However, this study takes the

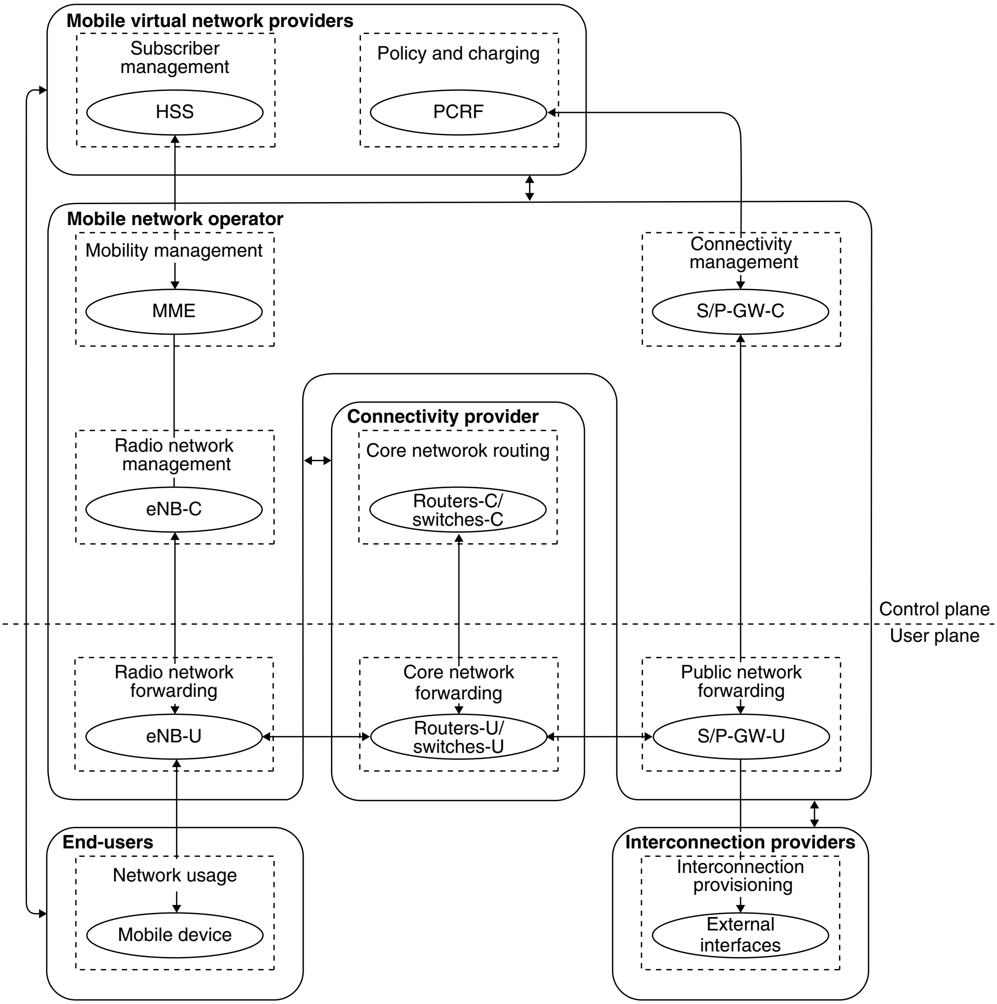

Figure 19.9 Evolutionary SDMN with outsourced connectivity.

perspective of one MNO; thus, only one MNO is illustrated in Figure 19.9. Consequently, the MNO loses some control of the transport network and behaves rather like an overlay network operator. Whether the cost savings from not owning a transport network are enough to compensate the lost control remains to be determined by market forces.

In addition, the performance of a virtualized network is assumed to be weaker due to more signaling and longer distance between the control plane functions and user plane elements. However, to decrease latency and improve service quality, for example, caching can be deployed at the centralized baseband processing sites.

From the MNOs' perspective, the capital expenditure savings from SDMN in this industry architecture are not significant, because according to Naudts et al [5], substantial cost savings come from preaggregation sites, which are now owned by the connectivity provider. Thus, MNOs need more incentives to deploy SDMN, when it outsources its connectivity. On the other hand, the connectivity provider may have an incentive for bringing SDN into its own network.

19.5 Industry Architectures of Revolutionary SDMN

This section explores the potential industry architectures for the drafted revolutionary architecture. The scenarios of evolutionary SDMN have their continuations in the revolutionary phase, but the focus here is on discussing the changes in the market structure due to SDN as well as new actors taking the roles. A big change that revolutionary SDMN enables is the outsourcing of the different network elements, which reduces the control of the MNO. On the other hand, as MNOs control the radio frequencies and the base station infrastructure, their position in the market is still strong. The three revolutionary scenarios discussed are (1) MVNO (2) outsourced interconnectivity, and (3) outsourced mobility management.

19.5.1 MVNO

On the other end of the MVNO spectrum, a full MVNO manages the whole mobile core network and leases just the frequency and connectivity from the MNO, as is shown in Figure 19.10. This scenario is enabled by the division of user plane and control plane. The actor that takes the MVNO role in this scenario has to be big enough to accommodate all the network elements and potentially act internationally to enjoy economies of scale benefits.

The public network forwarding and, as a consequence, the interconnection agreements are also controlled by the MVNO in this scenario. This makes sense for a global MVNO, whose users are highly mobile and who wants to control its own roaming agreements instead of relying on the MNO's roaming partners. In addition, the MVNO could operate on different MNO's networks in different countries. For example, Volvo's connected cars service enabled by Ericsson [24], which offers data connection to Volvo's new cars in any country, could benefit from a more flexible SDMN architecture. Ericsson would then be taking the MVNO role in Volvo's case.

In this scenario, the MNO loses control over the network operations and becomes a mere radio network and connectivity provider. In addition, giving up the management of the baseband processing pooling sites (i.e., eNB-C) means losing control over access management

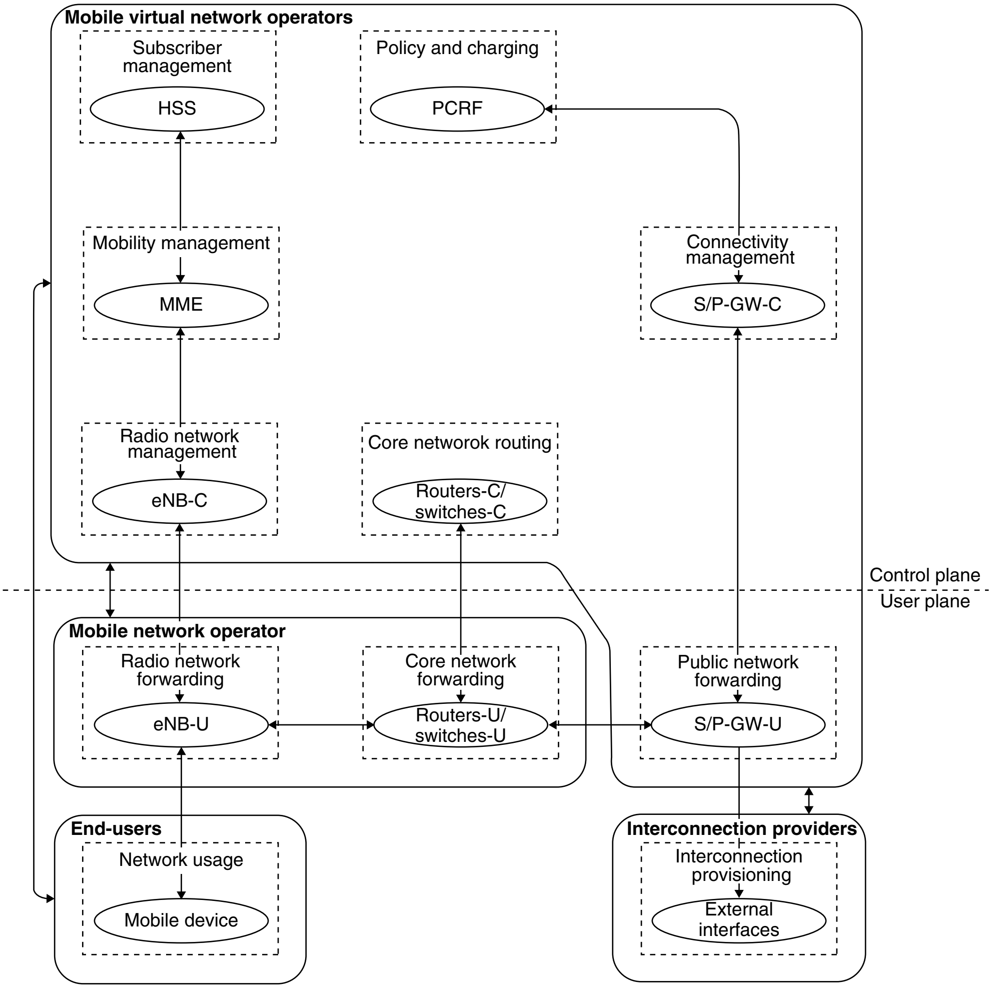

Figure 19.10 Revolutionary SDMN with mobile virtual network operator.

and resource optimization in the radio and core network, which might not be for the best interest of the MNO. However, if the MVNO is a subsidiary of the MNO and targets a different market segment, this industry architecture could be more feasible.

19.5.2 Outsourced Interconnection

Compared to the first revolutionary industry architecture, also, the scenario in Figure 19.11 has outsourced the management of the interconnection agreements but to the connectivity provider. This move of responsibilities is the result of the removal of the S/P-GW technical components from the network (see empty role boxes in Fig. 19.11), which enables a more flexible division of the control plane functions. The roles related to S/P-GWs are divided

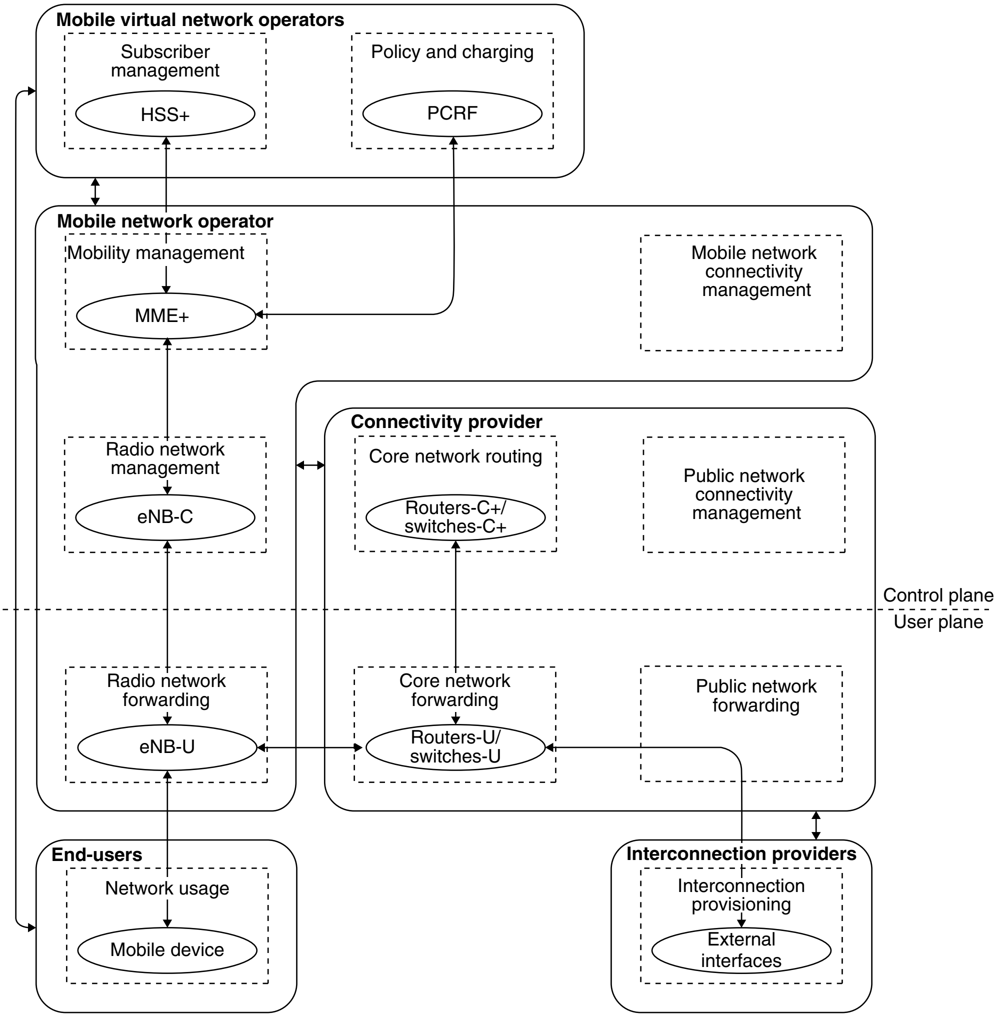

Figure 19.11 Revolutionary SDMN with outsourced interconnection.

between the MNO (mobile network connectivity management role) and the connectivity provider (public network connectivity management role). In addition, the functionalities are now performed by the MME+, HSS+, and routers-C+/switches-C+, which are collections of functionalities rather than traditional technical components.

As a consequence, mobility management could be done in a simpler and lighter way. For example, if the MVNO is big enough (e.g., Google) or has a trustworthy reputation (e.g., banks), it could partner with several MNOs in different countries and local breakout could be handled more efficiently. Mechanisms for local breakout are defined already in the current mobile network; however, due to the lack of trust and inequality in sizes between the MNOs in different countries, its popularity still remains low [25]. In addition, the lowering roaming fees in Europe [26] may become a driving force for simpler mobility management.

As the connectivity provider is serving several MNOs, it might have a higher bargaining power when negotiating with interconnection providers, which could be reflected in roaming and transit prices. In addition, as a bigger network player, it may have higher chances of peering with other big players instead of buying transit from them.

The technical feasibility of removing the S/P-GW from the network is not tested and could still pose challenges. In addition, roaming brings significant revenues for MNOs [27]. Thus, it is uncertain whether they would really give up control of the roaming agreements to connectivity providers. This could be feasible within EU, if the European Commission passes the regulation that abolishes roaming fees across EU [28]. However, European MNOs' subscribers still need to roam, when they travel outside EU.

19.5.3 Outsourced Mobility Management

The third revolutionary SDMN industry architecture outsources also the mobility management and radio network management to a mobility provider, as is shown in Figure 19.12. Potential mobility providers could be network equipment vendors, such as Ericsson and Nokia, who instead of selling the network infrastructure to MNOs could offer the service to run the mobility management and radio network management on their cloud platform. The mobility provider could serve several MNOs and, thus, gain economies of scale benefits, which could potentially be reflected in the operational expenditure of the MNO. Similar services exist already in the current network, for example, Ericsson's Network Managed Services [29] handles the planning, implementation, and day-to-day operations of an MNO. SDMN could bring more flexibility to the existing services due to the separation of the control plane from the user plane. For example, in the current Network Managed Services, Ericsson could not take full responsibility of the radio network management, because it is integrated with the radio network forwarding.

Despite giving up the control of radio network management, MNOs still own the frequency licenses and would, thus, control the radio-related resources. Figure 19.12 shows a separate MVNO, who manages the subscriber, service, and charging-related functions. However, these roles can also be taken by the MNO itself, which might be more feasible, because the MNO might not wish to lose control of the business interfaces to the end users in a network, where everything else is outsourced.

19.6 Discussion

This chapter discussed the evolution path from the current mobile network to SDMN and identified three evolutionary industry architectures and three revolutionary industry architectures. The analysis shows that in the first phase, the SDMN improves the flexibility and operational efficiency of the industry architectures already existing in the market. For example, evolutionary SDMN sees improvements in network management including faster maintenance as well as more efficient and easier software updates, which enable faster entrance of new services into the market. In addition, an SDN-enabled mobile network introduces cost savings due to the use of general-purpose hardware. In the outsourced connectivity industry architecture, the connectivity provider may also experience economies of scale, if it serves several MNOs. However, the deployment of evolutionary SDMN can be slow, because cost

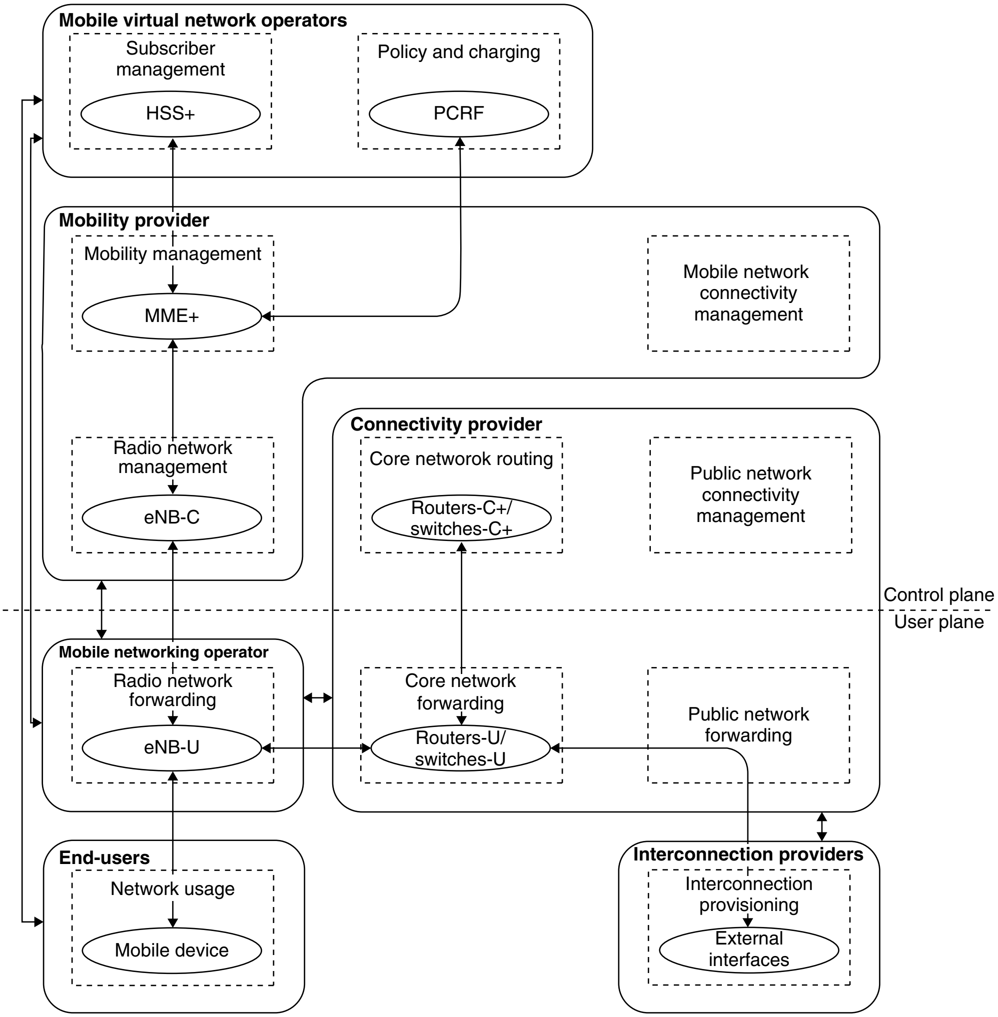

Figure 19.12 Revolutionary SDMN with outsourced mobility management.

savings from future capital expenditure mean that the MNO would implement SDN into the mobile network only when the current infrastructure is at the end of its lifecycle. More incentives, such as lower operational expenditure or additional revenue enabled by SDMN, are needed for faster deployment of SDMN.

However, SDMN also enables new, disruptive industry architectures, where the MNO outsources more functions and new industry actors enter the market. The main benefit from outsourcing is the more efficient operation of the network by more specialized actors. For example, in the outsourced mobility management industry architecture, the mobility provider enjoys economies of scale, which may be reflected in the pricing toward MNOs. At the same time, the connectivity provider, due to its large scale, potentially does more peering than a single MNO and has higher bargaining power over transit and roaming agreements, which may also be reflected in the operational expenditure of the MNO. SDMN also enables easier network sharing. Thus, MVNOs have the option of managing the whole control plane and, as a consequence, offer more varied services. Removal of the S/P-GWs in the revolutionary architecture enables lighter and more flexible mobility management, which together with global MVNOs improves the efficiency of data roaming. However, this case requires the MVNO to be operating in several countries and have a trustworthy reputation.

Mobile networks are going toward cloudification and virtualization due to more flexibility and new service potentials, and this can be seen from the offerings of the network equipment vendors, for example, Nokia's Liquid Net [30], Ericsson's Cloud System [31], and Huawei's Agile Network & SDN Solutions [32]. Thus, even without SDN, the Evolved Packet Core (i.e., MME, HSS, PCRF, and S/P-GW) is likely to be operating on cloud platforms in the near future. In addition, if the majority of the content is available from an MNO's cloud, operating the core network in the same cloud platform seems rational due to savings in traffic volumes. With this in mind, the evolutionary industry architectures are very likely to become reality.

On the other hand, the revolutionary industry architectures' realization depends heavily on the MNO's willingness to give up its control of the key network functions. For example, radio network management (eNB-C) is a role that the MNO might not wish to give up. However, according to a recent research [33]—based on brainstorming sessions with representatives from European mobile operators, network equipment vendors, and academics—actors, who typically are hidden from the end users, could take bigger roles in the future. This would drive the industry architecture, where mobility management is outsourced to a network equipment vendor. In addition, regulators may require more resource sharing in the future, which might force MNOs to at least lease part of its network to other actors, if not fully outsourcing.

A general limitation to the analysis is the immaturity of the SDMN technology. As a consequence, the technical implementations of the revolutionary industry architectures are not discussed. For example, how the allocation of radio network management and radio network forwarding roles to different actors can be done technically is not discussed. In addition, the technical challenge of removing GTP is identified, but no solution is offered. Moreover, due to the scope and nature of the chapter, the net gain from the economies of scale, the resource sharing, and the increased processing could not be determined. Thus, technoeconomic modeling should be adopted in future research to quantify the costs and benefits of SDMN.

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