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Technology Evolution in Mobile Networks

Case of Open IaaS Cloud Platforms

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9.1 Introduction

The current upgrade of mobile networks to LTE technology is a significant technological change that might facilitate an opportunity to introduce novel complementary technologies to the networks. Mobile network operators must invest in new network solutions to remain competitive in terms of mobile data transfer speeds. However, they struggle with the increasing cost of dedicated network hardware and declining revenues. Therefore, there is a clear need for new technologies that, on the one hand, provide increased network performance and value and, on the other hand, lower the overall cost.

One proposed alternative is network function virtualization (NFV). In this approach, the network functions would be implemented in software and provided on top of cheap, generic computing and networking hardware. To support the elastic provision of the virtualized functions, private "telco clouds" are one option. Cloud computing has become the prevalent business model in IT owing to its on-demand flexibility. However, it might struggle with, for example, the latency and fault tolerance requirements of the mobile network operators accustomed to the performance of dedicated hardware.

Despite challenges, NFV and cloud computing hold promise for cost-effective provision of mobile network functions. Initially, virtualized functions could be deployed in parallel with the legacy infrastructure, for instance, to support the growing traffic of machine-to-machine communications. Meanwhile, part of the traffic could be supported by dedicated network hardware.

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It is typical of the high-tech business that possibilities for new technologies continuously open up even though no clear market need exists. Both failures in the commercialization process and unforeseen success stories happen unexpectedly. The technology evolution dynamics are very complicated, as many conditions on success have to be met simultaneously.

This chapter analyzes the factors influencing future evolution of telco clouds controlled by open-source platform software. The employed research methodology is a single-case study. In contrast to an instrumental study of multiple cases, it allows us to understand the market behavior in our specific case [1, 2]. The study itself is based on a review of existing literature and company Web sites. To deal with the volume of information, we define a framework that is based on the theory of generic technology evolution to structure the analysis.

The chapter is organized as follows: First, we describe the theoretical background and the employed framework. Second, we introduce the reader to the basics of cloud computing and its technology, followed by a description of an example open-source cloud platform, OpenStack. Next, we use the framework to analyze the case of open cloud platforms in a software defined mobile network (SDMN). Finally, we discuss the critical factors in this possible evolution and summarize.

9.2 Generic Technology Evolution

Technologies evolve through periods of incremental change interrupted by discontinuous innovations. Competence-enhancing discontinuities complement the existing competences and are initiated by incumbents, because they are unwilling to cannibalize existing products and services. In contrast, competence-destroying discontinuities, typically initiated by new entrants, make the previous competences obsolete [3].

Additionally, incumbents are likely to develop technological performance that finally exceeds even the most demanding customers' needs. Typically at the same time, new cheaper technologies start to gain market share among less demanding customers. These technologies, originally ignored by the incumbents, begin to gain share of the mainstream market. These technologies and the related innovations are called disruptive [4].

Technological discontinuities are likely to cause changes in the existing industry structures and especially in the competitiveness of the incumbents. Expectations of a growing market and high profits encourage new companies to enter the market and challenge the incumbents. The success of many new entrants has led to a phenomenon called the "attackers' advantage." This term refers to the new entrants who are better than the incumbents in developing and commercializing emerging technologies because of their smaller size, limited path-dependent history, and commitment to the value networks of the previous technology [5, 6].

Industries, however, have barriers to entry, which protect the existing profit levels of the incumbents and constrain new entrants from entering the market. Barriers to entry are unique to each industry, and these barriers include cost advantage, economies of scale, brand identity, switching costs, capital requirements, learning curve, regulation, access to inputs or distribution, and proprietary products [7].

In the beginning of the technology evolution, there is a phase called variation, where these technologies and their substitutes seek market acceptance. The speed of change in this phase is slow because the fundamentals of the technology and new market characteristics are still inadequately understood. During this phase, the companies experiment with different forms of technology and product features to get feedback from the market [8]. An important factor affecting technology evolution is the relative advantage and added value over older technologies. Experimentation then relates to the extent to which the technology can be experimented with a low threshold when seeking emerging sources of added value. Easy experimentation possibilities enhance the overall technology diffusion [9].

The standardization and related openness increase the overall market size and decrease uncertainty caused by variation. The competition between several incompatible technologies from the evolving new market is called a “standard war.” New standards change the competition for the market into a more traditional market share battle and from systems into the component level. They also increase price competition and decrease feature variation. Companies can also differentiate their products by promoting an own de facto standard, which provides unique performance. Rival de facto standards have a negative impact on the success of the technologies developed in the formal standardization process. However, a trade-off between openness and control exists: proprietary technologies tend to decrease the overall market size, and the optimum solution lies in between these extremes [10].

Highly modularized standards will increase the flexibility to adapt to uncertain market needs by providing a larger field of options from which to select and by allowing experimentation and market selection of the best outcomes. Standards should be introduced in an evolutionary way by starting from one that is simple and building it up in complexity as the market uncertainty decreases thus allowing for a staged investment in creating and expanding the standard. Centralized architectures can, however, be used in the technological discontinuities where the market uncertainty related to the end-user needs is low [11].

An incumbent that has a large installed base and locked-in customers can gain a competitive advantage by a controlled migration strategy. The company can prevent backward compatibility for new entrants with its own legacy systems by influencing interface definitions of standards or by introducing an early new generation of equipment with the advantage of backward compatibility [10].

Evolution of compatibility and revolution of compelling performance are distinguishable, and their combinations are also possible. There is a trade-off between these extremes because improved performance decreases customers’ switching costs, while in evolution existing customers can be better locked into the supplier. An ideal solution would be a significantly improved system or product that is also compatible with the existing installed base of the company [10].

In a virtual network of technologies that share a common platform, complementarities influence the value of individual parts of the system. The complementarities between interdependent technologies can have both negative and positive effects on the success of the technology evolution. In a virtual network of complementary goods that share a common technical platform, network externalities arise because a larger availability of the complementary components increases the value of their counterparts [10].

The technology that first creates a critical mass of users simultaneously benefits from the demand and supply sides of economies of scale simultaneously. The diffusion is also accelerated by network externalities, while the value of the subscriptions to the network is increasingly higher as the number of the users of the network increases. The associated process is also called the “bandwagon effect.” These drivers of increasing returns lead to a situation where the winner technology faces an exponential growth of a virtuous cycle, while the loser technology gets increasingly weaker in a vicious cycle [10].

The variation phase is closed when the market selects a dominant design. Typically, the new technology and the related standards do not become the dominant design in their initial form, and the dominant design is not based on the leading edge of the technology. The dominant design does not embody the most advanced features, but a combination of the features that best meet the requirements of the early majority of the market [8]. The emergence of the dominant design leads to the further development of product platforms and related architectural innovations. This also leads to benefits of an increased offer of subsystem products as well as linking different technologies to a bigger system [12].

A dominant design emerges out of the competition between the alternative technological evolution paths driven by companies, alliance groups, and governmental regulators, each of them with their own goals [13]. Especially, regulation has a significant impact on the success of new technologies. Regulation defines the general boundaries of the business, while standardization provides a filtering impact that reduces the uncertainty by increasing predictability [14].

It is assumed that a harmonized market enables the economies of scale and lowers the price levels of telecommunication products and services. The telecommunication industry has been a sector with a strong and broad regulation of the wireless spectrum, technologies, services and competition, and several other aspects. The primary goal of regulation is to balance the sharing of social welfare among the market players, for example, vendors, operators, and consumers [15].

The dominant design tends to command the majority of the market until the next technological discontinuity. Companies now gain a deeper understanding of the technology, and its performance improvement starts to accelerate in an incremental manner [8]. The selection of the dominant design shifts the balance of innovation from product to process in order to decrease the production cost because of the increasing price competition. The product variation decreases and products develop on the basis of incremental evolution. As a result, the industry starts to consolidate because of the increasing number of acquisitions and mergers [7, 16]. At some point, diminishing returns begin to emerge as the technology starts to reach its limits and it is likely to be substituted by a new technology.

9.3 Study Framework

The theoretical background of technology evolution allows us to create a framework with the following 10 dimensions. Next, we describe the dimensions in more detail:

- Openness—the extent of availability of new technologies for all players in the industry
- Added value—the relative advantage over older technologies
- Experimentation—the threshold of end users to experiment with new technology
- Complementary technologies—the interdependence between complementary technologies
- Incumbent role—the product strategy of existing players
- Existing market leverage—the extent of redirection of existing customers to new technologies
- Competence change—the extent of required new competences
- Competing technologies—the role of technology competitors
- System architecture evolution—the extent of new technologies induced to the architecture
- Regulation—the influence of government regulation

Evidently, a number of dimensions correlate with each other. At least three examples emerge. Firstly, increased openness lowers the threshold to experiment. Secondly, contrary to the first example, the required system architecture evolution hinders experimentation via competence change. Finally, the incumbent players leverage the existing markets of their own, possibly to discourage moving to novel technologies.

To speculate the future evolution, the positively and the negatively affecting dimensions must be identified. However, this is highly dependent on the case where the framework is applied. Therefore, these assumptions must be addressed in the analysis.

9.4 Overview on Cloud Computing

Cloud computing is a concept in which a cloud provider offers computational resources remotely as a service. The computational work moves from dedicated servers into a data center of the provider, where a great number of servers perform computation for multiple customers. A cloud customer could, for instance, be a video-on-demand service provider that purchases the content storage and processing capacity as a service from the cloud provider.

Cloud providers offer services on three abstraction levels—**software as a service (SaaS)**, **platform as a service (PaaS)**, and **infrastructure as a service (IaaS)**:

- On the highest abstraction level (SaaS), the provider offers the customer applications that are, commonly, accessed via a Web interface. An example of such an application is Gmail, Google's Web-based email application.
- On the PaaS level, which is the middle abstraction level, a customer gets a platform on which they can run their own software. The platform is commonly restricted to one or few programming languages and provides its own services, such as platform-specific storage and databases. One such platform is Heroku.[1]
- The lowest level, that is, IaaS, offers customers access to virtual machines (VMs) that are logical abstractions of physical computers as well as other IT infrastructures such as storage and computer networks. As with physical machines, the customer can install its own software on the machine, beginning with the operating system. An example of an IaaS is Amazon's Elastic Compute Cloud (EC2) and its related services.

The three abstraction levels also require different levels of competence from the cloud customer. For example, a PaaS cloud customer must implement its own software, but the cloud platform manages the service scaling. On the other hand, an IaaS customer is required to handle the scaling features (increasing the amount of VM instances) and the distributed system communication by itself.

An important feature of cloud computing is that the provider typically offers the services on an "on-demand and pay-per-use" basis. Thus, the customer can acquire the required computing resources immediately and release the resources when they are no longer required.

Cloud computing benefits both the cloud customer and the cloud provider. It relieves the former of purchasing own computation hardware, therefore lowering upfront costs, together

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[1] https://www.heroku.com

with removing the need to maintain and administer the own IT infrastructure. The latter, in turn, has economies of scale while providing services to many customers at the same time: hardware is cheaper in large quantities, and the computation tasks can be allocated to the physical machines more efficiently.

Furthermore, cloud computing has three different deployment models. The first model is a **public cloud**, where the customer buys the service from a separate company, for example, Amazon. The second model is a **private cloud**, where the cloud provider is, actually, the customer company itself. The last model is a hybrid cloud, which is a combination of the two previous models. In a **hybrid cloud**, the customer itself provides the base part of the capacity while the remaining required capacity is elastically acquired from a public cloud.

To provide cost-effectiveness, cloud computing bases itself on computer virtualization and extensive use of automation:

- In computer virtualization, the underlying hardware resources of a physical computer are shared by multiple VMs. A piece of software running on the physical machine, the hypervisor, is responsible for sharing access to the physical resources between the VMs and isolating the VMs from each other to provide security. In the context of clouds, an important feature of VMs is that they can be moved from one physical machine to another.
- Automated resource provisioning hastens decisions and execution of configuration changes and provides fault tolerance in the data center. For example, the selection of a physical machine for a new VM instance and VM migration to another physical machine must be automatized to reach sufficient efficiency. Automation is typically provided in the cloud service via its control software, the “cloud operating system.” For example, launching a new VM instance does not require the user to select a physical machine for the VM, for the control software makes the selection.

Multiple cloud platform solutions, both proprietary and open, exist. However, proprietary solutions might lead to vendor lock-ins. To avoid lock-ins, an open solution might be preferred. Such solutions include Apache CloudStack[2] and OpenStack.[3]

9.5 Example Platform: OpenStack

OpenStack is a project that provides open-source software to create an IaaS cloud. Originally, it was created by Rackspace and NASA.

The project is a collection of subprojects that provide functionality for different areas of the cloud platform, such as compute and networking. Furthermore, similarly to other large-scale open-source projects, it is developed and led by a vast community that includes individual and corporate developers, cloud providers, and other project personnel.

This section describes OpenStack as an example of an open cloud platform. First, it details the general design and architecture of the platform. Second, it will describe the community of the project.

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[2] http://cloudstack.apache.org

[3] https://www.openstack.org

9.5.1 OpenStack Design and Architecture

OpenStack is divided to subprojects that implement the different functional parts of a cloud platform. The main idea of the project is to provide well-defined application programming interfaces (APIs) that allow the user to access services providing the actual functionality required to control the hardware infrastructure. The primary APIs are based on Representational State Transfer (REST). Moreover, the project also bundles command line tools to interact with its services.

OpenStack supports numerous infrastructure services via its plug-in-based architecture. For example, support for a novel hypervisor requires implementing a driver plug-in and releasing it for others to use. This flexible nature allows OpenStack to interact with a number of different, proprietary or open, infrastructure technologies.

Figure 9.1 shows the main components of OpenStack. In more detail:

- Compute (code name Nova) controls the virtualized resources, such as virtual CPUs and memory and storage interfaces via interaction with the hypervisors. For instance, cloud users or a dashboard service accesses it to deploy a new VM. The list of supported hypervisors is extensive; Nova also supports other technologies, such as Linux Containers (LXC). Formerly, Nova also provided virtual networking interfaces for VMs. However, that responsibility is nowadays mostly transferred to the networking component Neutron.
- Dashboard (Horizon) provides a Web GUI to access other OpenStack services.
- Networking (Neutron) manages the virtual network connections between the virtual network interfaces of the VMs. It allows the user to create complex virtual network architectures that include virtual routers, load balancers, and firewalls. Its supported network back-end technologies range from Linux bridges to proprietary network control methods and software defined networking (SDN) controllers.

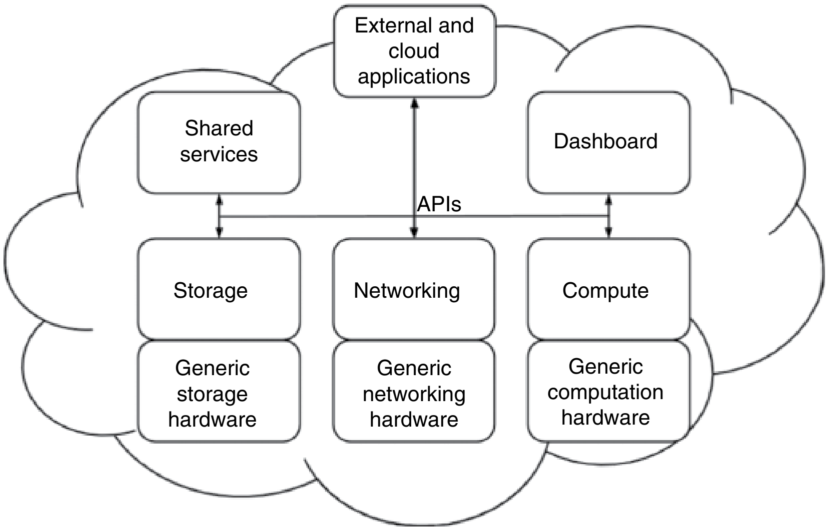

Figure 9.1 OpenStack architecture (Adapted from http://www.openstack.org/software/).

- Storage provides support for block storage, that is, disk volumes via Cinder and distributed object storage via Swift.
- Shared services include the identity service (Keystone), the image service (Glance), the orchestration service (Heat), and the telemetry service (Ceilometer). As the name implies, they serve other services, as well as human users. Keystone is responsible for user authentication and authorization, together with managing user credentials. Glance, in turn, manages the disk and server images. Heat, on the other hand, allows deploying cloud resources in predefined setups using templates. Finally, Ceilometer centrally collects and provides metering data from the cloud.

Additional subprojects have been constantly added to the OpenStack project in each release. The most recent release of April 2014, Icehouse, introduced four new capabilities: database service (Trove), bare-metal service (Ironic), queue service (Marconi), and Hadoop data processing (Sahara).

Today, OpenStack is available in multiple private cloud distributions and public cloud platforms. Private cloud platforms include Red Hat's RDO,[4] Ubuntu OpenStack,[5] and Rackspace Private Cloud.[6] Many cloud providers, such as Rackspace and HP, offer massive OpenStack-based public clouds, as well. In addition, it is already employed in telco systems as well. For example, Ericsson uses OpenStack to power its cloud system product [17].

9.5.2 OpenStack Community

An important part of an open-source project is the community behind it. It consists of people implementing and testing new features, people fixing bugs, and people deciding where the project should be headed.

The OpenStack community consists of the employees of the supporting companies and other interested individuals. In addition to the development, the community has also set up the OpenStack foundation that supports the development and promotes the adoption of the platform. The foundation members also appoint the committees that direct the project. Furthermore, according to a recent community analysis, OpenStack has the largest community of all open-source IaaS platforms [18]. That holds for both the amount of project communication as well as code commits.

9.6 Case Analysis

This section applies our study framework to analyze the possible evolution of open cloud platforms in future mobile networks. Most of the evaluation is based on the authors' own reasoning. Thus, this analysis does not predict the future but pictures several possible evolutionary paths. Furthermore, the analysis is not strictly limited to open cloud platforms: the benefits and disadvantages of NFV are directly related to the success of cloud computing.

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[4] http://openstack.redhat.com

[5] http://www.ubuntu.com/cloud/ubuntu-openstack

[6] http://www.rackspace.com/cloud/private

9.6.1 Openness

We defined openness as the extent of availability of the new technology for all players in the industry. Naturally, open cloud platforms are open by definition: the source code is openly available; they are freely available; they can be deployed to generic hardware; and their development and user communities are open to join.

The open-source code of the platforms is generally distributed via public code repositories using different version control systems. In addition, it is released under a free software license, for example, GNU General Public License (GPL) or Apache License. The biggest differences between the licenses are whether they require changes to be released and whether the license must remain the same in future derivatives.

The platforms are, inherently, provided free of charge. The major Linux platforms also offer it via their packet managers. Furthermore, the platforms support generic commercial hardware. To support the platform deployment, many companies provide paid consultation and training.

Moreover, open cloud platforms are free of the threat of vendor lock-in.

Finally, open platforms of course allow the network functions and other services to be either open or closed solutions. Thus, the adoption of open IaaS cloud software does not limit the network operator's options to choose the solution providers.

9.6.2 Added Value

A new technology must provide a fair amount of added value to be accepted to the market. Open cloud computing platforms, together with virtualization, have several advantages and drawbacks compared to the current solutions.

In general, virtualization offers flexible allocation of computation capacity provided by generic, commercial off-the-shelf (COTS) hardware. Moreover, the automatized allocation introduced by the cloud platform offers increased utilization of the hardware. Increased utilization, in turn, allows greater energy efficiency. Therefore, this approach would also reduce overall expenses.

The benefits of open cloud platforms include modifiability and constant access to the novel features and updates on the platform together with lower cost. The first means that anyone can make changes to the platform code to support their own needs. The second fact promises that the progress the community makes is available to all members. Finally, the open platforms are free, thus lowering the total cost of the network.

Introduction of cloud computing in the mobile operator's core network also facilitates several novel business models. First, the operator could rent computing capacity from the telco cloud to third-party providers. Furthermore, the third-party services provided in the operator cloud could be offered similar control of spare capacity of the underlying infrastructure (i.e., reserve network tunnels with given quality of service). Therefore, this approach would transform the operator from a bit pipe into a computing and networking infrastructure provider.

In contrast to dedicated hardware devices, the software-based approach provides significant advantages. Compared to hardware development, software development allows a faster development cycle. The shorter development time also means that new services and technologies can be deployed more often.

However, there are a number of drawbacks, including decreased performance. A virtualized network function is supposedly slower than its dedicated counterpart. Thus, the same work must be distributed to multiple virtualized instances, which leads to modified architecture and functionality. For example, a distributed network function might require an additional aggregation layer solution.

The introduction of open cloud technologies to the mobile networks would open a new market for virtualized network function solutions. This allows new players to enter the networking business, which in turn could lead to competition resulting in faster development times and lower prices.

9.6.3 Experimentation

The threshold of experimenting with open cloud platforms is minimalistic. Usually, a cloud platform can be entirely installed to a single commodity computer. Since the platforms can be installed on top of free operating systems, usually with their package managers, beginning to experiment is easy, indeed.

Furthermore, the whole existing architecture is not required to change. The LTE core network, for example, is already fully IP based. Therefore, the network providers can start by virtualizing a single network function and replacing the corresponding dedicated machine with a virtual instance run on a cloud. Another approach could be to separate some traffic, such as machine-to-machine communication, to be served by virtual network functions [19].

Open cloud platforms also power numerous public cloud services, such as Rackspace's public cloud. An alternative approach to study a specific cloud platform is to try a publicly available instance in the beginning.

To stay up-to-date with current computing trends, the academia is also researching and experimenting on different, most likely open, cloud platforms. This benefits the whole community since a lot of innovation is also done at the universities and the results are published to the community.

9.6.4 Complementary Technologies

The complementary technologies of open cloud platforms include generic COTS computing hardware and SDN together with its related technologies.

Cloud platforms are typically run on standard hardware, that is, x86 servers, instead of proprietary dedicated hardware. Moreover, they might support other computing architectures. For example, OpenStack also runs on ARM-based hardware.

Currently, the idea of openness is also reaching hardware. For example, the Open Compute Project[7] aims to provide open schematics and designs of cloud computing infrastructure. In the future, open cloud platforms might be optimized to utilize open hardware or vice versa.

The other main complementary to cloud computing in mobile networks is SDN. Data center networking has been one of the main drivers for SDN. Therefore, it is logical to integrate the control of an SDMN to the cloud platforms to allow advanced network control, such as traffic

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[7] http://www.opencompute.org/

engineering. Open cloud platforms provide drivers for both proprietary and open back-end technologies. Alternatives as the network controller include the OpenDaylight[8] or the OpenContrail.[9]

9.6.5 Incumbent Role

The incumbent players of the mobile network market comprise of hardware vendors, network providers, and network operators. In the center of the market are the network providers that manufacture the networks using devices from the hardware vendors and their own products, finally selling them to the mobile network operators.

In the past, network operators preferred multivendor solutions and possessed significant skills in system integration. However, modern networks are usually provided as a whole by a single provider since operators have reduced their effort in network construction and maintenance.

Massive increase in mobile data traffic and operator business demands highly developed solutions. Previously, network providers have based their solutions on top of hardware providers' proprietary products. The results have been expensive dedicated hardware devices that are designed to support the vendors' other products. However, the recent interest in more flexible solutions forces the network providers to consider their future strategy.

The open cloud platform approach would separate the hardware and the software business of mobile networks, thus allowing new players to enter the network business. The economies of scale would make the IT hardware providers the logical choice to provide the generic computing and networking infrastructure. In the software side, the development of network functions does not, anymore, require massive resources. Therefore, the network function market opens to both incumbent network providers and newly entering software companies.

To keep up with the competition, the existing mobile network providers have two options. On the one hand, they can continue with the dedicated device path and improve the existing solutions to support increased traffic and flexibility. On the other hand, they can seek for novel solutions from the virtualization domain via software development. Naturally, the approaches can be combined. This makes sense since virtualized and hardware solutions are interoperable. At least two examples of such a hybrid approach exist: First, Ericsson already provides the LTE core network in both virtualized and dedicated hardware solutions [20]. Second, Nokia Solutions and Networks (NSN) offers a telco cloud solution that supports both hardware and virtualized network functions together with multiple cloud platforms [21].

In general, we believe that the existing network vendors will offer virtualized solutions in parallel with dedicated devices. And, with increasing emphasis, the network solutions will become software based.

Another new market business opportunity to hardware and network providers is to design and provide the computing infrastructure for the mobile operators. The incumbent players are familiar with the requirements of mobile networks, which give them initial advantage.

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[8] http://www.opendaylight.org/

[9] http://opencontrail.org/

9.6.6 Existing Market Leverage

The existing market is filled with dedicated offerings. Mobile operators have heavily invested to existing networks and devices. These investments must be amortized, which discourages moving totally to cloud-based network solutions.

The future of cloudified networks lies in future network investments. The technological disruption in LTE adoption requires the operators to invest in new networks. Fortunately for cloud approach, the interoperability of hardware and virtualized network functions allows operators to choose this approach.

Overcoming the existing leverage of hardware solutions requires positive experiences of virtualized solutions. Such experiences may be obtained via trials in test and production networks. Positive opinion on virtualized solutions could also affect the ongoing design of future, 5G and later, networks.

Another market leverage is the possible preference for proprietary solutions. However, the success of open approach in the IT business could provide an incentive to employ such technologies in mobile networks, as well.

9.6.7 Competence Change

Moving to cloud solutions requires significant change in both development and operating competences.

Developing virtualized solutions is, first and foremost, a software development effort. The main idea is to exploit generic hardware and differentiate with software products. Therefore, the network providers would have to integrate and implement software components instead of designing novel products from hardware components.

Another major change in cloudification is that network operators must become cloud service providers and administrators. Although cloud computing relies on automation, the operator must, nevertheless, have experienced cloud administrators configure, update, and troubleshoot the infrastructure and platform software. Furthermore, cloud computing bases itself to a different idea of fault tolerance: the massive amount of commodity hardware makes it bound to fail at some point, thus requiring the platform to tolerate failures instead of resisting them with custom high-availability hardware.

Moreover, the operators must be capable of selecting and integrating together different virtualized solutions. Otherwise, they must rely on providers for complete network solutions.

Hardware manufacturers typically provide training for the users of their proprietary technologies. In turn, training is also available for open cloud platforms. A number of networking and cloud computing companies offer consultation, training, and support for installing and using open cloud technologies.

9.6.8 Competing Technologies

Open cloud platforms face competition from three directions: traditional dedicated hardware, proprietary cloud platforms, and public clouds.

While virtualized products reach the market, the dedicated hardware solutions continue to evolve. Although the performance and benefits of these dedicated products may not increase significantly, the network operators are familiar with the technology and other aspects of the approach. Thus, continuing to invest in dedicated technologies might attract the operators unwilling to take risks.

Another competitor for open cloud platforms is the commercial, proprietary platforms, such as VMware vSphere[10] and Microsoft System Center.[11] These platforms might lock the user in certain technologies and providers. On the other hand, they might offer superior support because the provider controls the whole platform.

9.6.9 System Architecture Evolution

Cloudification of the mobile core networks requires the addition of generic computing capability. Two approaches exist: the first option is to add data centers, that is, facilities that house hundreds or thousands of servers to the core network infrastructure. Another possibility is to distribute the computation devices across the network.

The data center approach is the current de facto way in IT systems. Therefore, it could benefit from the experiences of administering IT cloud services. However, it only provides a small number of sites for the execution of network functions.

On the other hand, distributing computation across the core network would allow, for example, more flexible spatial allocation of network functions and other services. The idea has already been realized by NSN whose product portfolio includes NSN base stations that include computing capacity [22].

In the distributed approach, the latencies to the nearest network function instances could be lower. However, maintaining the hardware would be more difficult. For example, a server residing in a base station is harder to replace quickly than a server in a rack in a data center. Another question is network speed and latency from a remote location to supporting systems, such as database servers, and other virtualized instances.

Independent of the architecture choice, the existing legacy networks and their devices will not disappear. Therefore, the backward compatibility of novel solutions is also important. However, the virtualization of legacy network elements is also possible. Thus, the operators could, for example, in the case of device failure, replace the device with a virtualized solution.

Finally, it remains to be seen whether virtualized solutions and cloud computing affect the future 5G and later networks and become the dominant solution. Without question, the experiences of virtualization and cloudification of parts of 4G networks will affect their design.

9.6.10 Regulation

Rationally, regulation should not present obstacles for employing open cloud technologies in the mobile networks. Regulation might even encourage the opening of the network function market and, thus, require operators to seek multiprovider solutions, where multiple vendors provide the virtualized network elements.

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[10] http://www.vmware.com/products/vsphere/

[11] http://www.microsoft.com/en-us/server-cloud/products/system-center-2012-r2/

On the other hand, regulation might affect the possible business cases of telco clouds and its complementary technologies. For example, net neutrality might become an issue when some over-the-top (OTT) services are offered dedicated network slices in the form of virtual private networks (VPN).

9.7 Discussion

As Section 9.2 pointed out, the path from a novel technology to a dominant design includes many surprising events. However, the possible evolutionary paths can be speculated.

This section will tie together the case-by-case analysis presented in the previous section and, based on that, discuss the future of open cloud platforms in mobile core networks. We separate the framework dimensions to enablers, neutral factors, and inhibitors based on the case analysis. Furthermore, we will point out the relations between the dimensions in this specific case.

As the enablers for the success of open cloud platforms in future networks, we identify the following dimensions: openness, added value, experimentation, and complementary technologies.

Firstly, high openness is a clear enabler for open cloud technologies. The technology and the communities are fully available to all, both existing and future, players in the industry. Thus, the mobile network industry would gain immediate access to the advances of the IT industry that are based on the success of cloud computing model. Furthermore, the virtualized network element market possibly attracts new players from the IT industry and open-source communities to develop products that compete with the new and the old solutions of the incumbent players. Thus, the development speed increases and solution prices would possibly decrease.

In the big picture, openness is clearly related to the threshold of experimentation and added value. Open platforms are available to everybody, making them easy to try and study. They also create a market for applications that employ the platform.

Secondly, open cloud platforms also offer added value. The value proposition of open platforms, including price, modifiability, and access to the whole development effort of the community, is attractive to the network operators and providers. Moreover, virtualization and the cloud computing approach would address many challenges present in modern networks.

Network providers have already realized the benefits of open cloud platforms and employ them in their products. Thus, the added value of such platforms already affects the incumbents and their role in the evolution of mobile networks. Furthermore, the value increase promotes the architecture evolution to integrate cloud computing to the networks.

The third enabler is the low threshold to experiment with the technology that is boosted by the increased openness. Different industry players can study the employment of the platforms to their benefit. Furthermore, openness attracts the academia to study the platforms. Altogether, the combined experimental efforts might lead to new value propositions via creative ways of using the technology.

Finally, the complementary technologies of open cloud platforms support the evolution toward cloudified mobile networks and open platforms as well. For instance, network providers see SDN as an important technology to expand the capabilities of modern mobile networks. In turn, the open cloud platforms quickly support novel technologies via the community development effort. Thus, the novel networking features would be promptly supported by the network platform.

The complementary technologies also affect the added value of open cloud platforms, the architectural evolution of mobile networks, and the required competence change. The complementary technologies introduce generic hardware to the core network and should thus lower the costs. However, the required competences of the network administrators and designers are significantly different.

Next, we identify the neutral dimensions, that is, the dimensions that do not seem to clearly resist nor promote the evolution toward the inclusion of open cloud platforms to the mobile networks. These three factors consist of the role of the incumbent players, system architecture evolution, and regulation.

Firstly, the incumbent players have a significant but uncertain role in the success or failure of the employment of open cloud platforms in mobile networks. To date, network providers have already included them to their product portfolios. On the other hand, they have not abandoned the dedicated solutions business either. Therefore, it is evident that network providers are unsure of the future dominant design. Thus, the success of open cloud depends on the reactions of the network operators in the live deployments. In summary, the effect the incumbents have on the evolution is uncertain.

Secondly, system architecture evolution is actually the end result of technology evolution. Therefore, we identify it as a neutral dimension. On the other hand, an extensive change in the system architecture leads to significant change in required competences.

Thirdly, regulation is also seen as a neutral factor. For instance, it might favor the use of open cloud platforms in the core networks. On the other hand, it might limit many of the possible new business models, such as dedicated network slices and quality of service differentiation. Regulation might also lead to multiple network function and service providers joining the market, thus affecting the future system architecture as well.

The final three dimensions, that is, existing market leverage, competing technologies, and competence change, seem to restrict the adoption of open cloud platforms.

Firstly, the competing technologies, including dedicated solutions and proprietary cloud platforms, could hinder the employment of open cloud technology. Some industry players will definitely resist change and continue to offer and employ dedicated solutions in their networks. However, dedicated and virtualized solution can and will coexist. In turn, the competition between open and closed cloud platforms will probably exist similar to the corresponding competition in the IT sector. Altogether, the market share between the competing solutions will also affect the future system architecture.

Secondly, the leverage of the existing market inhibits the future cloudification. Network operators have a large installed base of dedicated hardware solutions, and the dedicated products are proven to work. Furthermore, the existing network vendors are not likely to welcome new entrants to the network business.

Finally, we think the most notable resistance to open cloud technologies emerges from the required competence change. Cloud computing is a revolutionary approach to offer mobile connectivity. Therefore, the operators must reeducate the network administrators and technicians or recruit new employees with the required skills. The amount of change might also increase the attractiveness of continuing with existing approach. Moreover, it also affects the role of incumbent vendors: the failure of existing vendors to transform themselves to provide virtualized solutions and clouds will offer a chance for new players to enter the market.

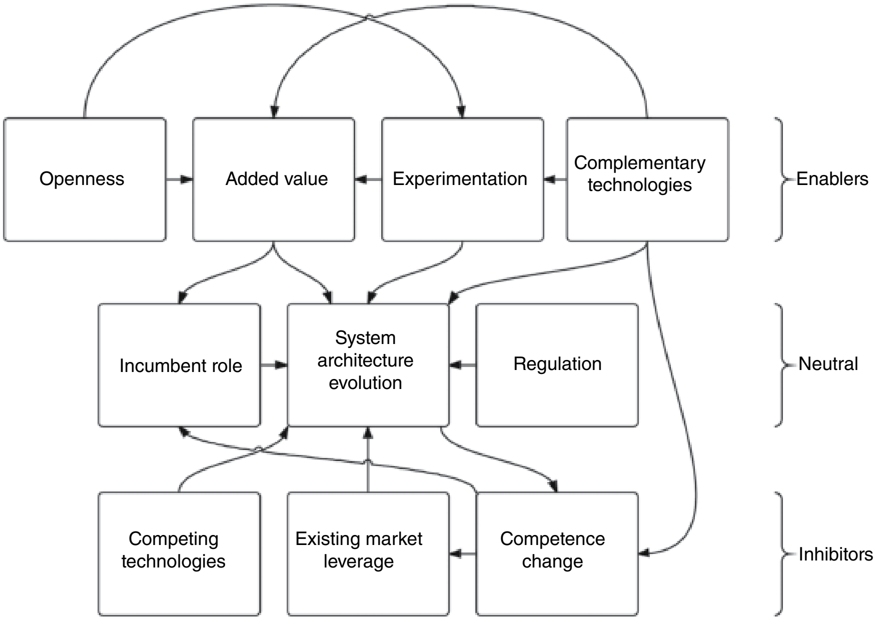

Figure 9.2 Identified roles and relations of the framework dimensions in the technology evolution of open cloud platforms in mobile networks.

Based on the discussion in this section, Figure 9.2 summarizes the roles and relations of the dimensions of the employed framework. It is evident that in this case the future system architecture evolution depends on success in a number of areas. Open cloud approach addresses many present challenges of mobile network business, such as vendor lock-ins, flexibility, and cost. It also supports the other key developments, such as NFV and SDN. On the other hand, cloudification is a major technological disruption that requires significant changes in competence and solution methods.

We believe that the cloud approach will be first trialed in some specific use cases, such as machine-to-machine communication. If the performance seems appropriate, new networks will be increasingly built from virtualized components running in operator clouds that are run on generic hardware. In that case, the virtual network function market opens and new players enter the business. However, the dominant cloud design may consist of either open or proprietary platforms. Differences in price and hardware support promote open solutions. In turn, the vendors have a long history of using proprietary technologies. Solutions of both types have room in the market, but the dominant type cannot be foreseen.

9.8 Summary

This chapter discussed the technology evolution in mobile networks in the specific case of open cloud platforms. We provided an analysis based on a framework drawn from the theory of generic technology evolution.

Generic technology evolution theory suggests that in a market of numerous players and solutions, a dominant design emerges as a product of legacy product evolution and novel disruptive solutions. The actual reasons for the success of one technology over others are difficult to identify exactly. However, common features in successful technology allow us to analyze possible evolutionary paths. In this case, we selected 10 dimensions for our analysis framework.

The chapter also briefly introduced the concepts of cloud computing, including the division to different service abstraction levels (SaaS, PaaS, and IaaS) and deployment models (public, private, and hybrid). We also presented OpenStack as an example of an open cloud platform project.

Based on the analysis, open cloud software addresses some problems present in the modern networks that are provided with dedicated hardware. It also supports the modern network developments, such as NFV and SDN. However, complete cloudification is not possible due to large installed base of dedicated hardware and sudden competence change. Therefore, we predict that cloud technology, open or proprietary, will be introduced gradually to the network. For example, it could be initially deployed to face the increasing machine-to-machine traffic. The possible positive experiences from the initial trials and development cloud technologies would lead to wider usage and the birth of the virtual network function market. The competition between the developers of such functions would drive the virtualization of mobile networks forward. However, the final selection between open and closed cloud platforms depends on the network provider or operator preferences.

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