Towards Service-oriented 5G: Virtualizing the Networks for Everything-as-a-Service

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Abstract

It is widely acknowledged that the forthcoming 5G architecture will be highly heterogeneous and deployed with high degree of density. These changes over the current 4G bring many challenges on how to achieve an efficient operation from the network management perspective. In this article, we introduce a revolutionary vision of the future 5G wireless networks, in which the network is no longer limited by hardware or even software. Specifically, by the idea of virtualizing the wireless networks, which has recently gained increasing attention, we introduce the Everything-as-a-Service (XaaS) taxonomy to light the way towards designing the service-oriented wireless networks. The concepts, challenges along with the research opportunities for realizing XaaS in wireless networks are overviewed and discussed.

Index Terms

everything-as-a-service; wireless network virtualization; 5G

I. Introduction

The future 5G will be the platform that enables the tremendous growth of many industries, ranging from traditional wireless networks, to the car, entertainment, manufacturing,
healthcare, and agriculture industries. It is envisioned 5G will provide a common core to support multiple radio access technologies (RATs), machine type communications (MTC) and many different coexisting network and service operators. Therefore, 5G must support convergence over traditionally separated network domains and offer greater granularity and flexibility in control signalling and in data transmission. Correspondingly, the architecture is expected to be much more complex than before, in the sense that different network entities, such as relays, small cell base stations (SBSs), massive machines and data centers/cloud, etc, will be widely deployed with ultra densification and taken as close as possible to the end-users. Along with the rapid development of hardware computing units, the BS in wireless networks is expected to be deployed with powerful computing units or data centers to enable the software defined networking (SDN) and accommodated to the diverse service requirements. These changes, however, not only can enable the boost of data rates, but also bring many nontrivial challenges on how to achieve a super-efficient operation from network management point-of-view [1].

In this light, network function virtualization (NFV) is envisioned as one powerful tool to address these aforementioned problems in wireless networks. In the resulted wireless network virtualization (WNV), network infrastructures and functionalities are decoupled from the services that they provide to maximize their utilization, where the differentiated services can co-exist on the same infrastructure [1] [2]. What’s more, due to the fact that the network is expected to be highly heterogeneous and extremely dense, it is natural to consider whether the network infrastructure can be virtualized and provided to whoever wants them and whenever they are acquired, so that the network operator is no longer hardware-limited, nor even software-limited, in the light of both of the hardware and software are owned by different and dedicated network infrastructure operators. By such, every component which used to be essential in the traditional network management can be viewed as a service, and then can be supplied to any (virtual) network operators/service providers (SPs) or even directed to the end-users. Correspondingly, we refer to the resulted system architecture as a service-oriented wireless network with Everything-as-a-service (XaaS) which traditionally is recognized as the service provisioning models in the cloud computing [3]. The new XaaS in WNV will be indeed service-oriented, containing many new elements, such as Data-and-Knowledge-as-a-service (DKaaS), Computing-as-a-service (ComaaS), Radio-Access-Network-as-a-service (RANaaS),
Cache-as-a-service (CaaS) and Energy-as-a-service (EaaS), which could be delivered over the advanced 5G infrastructure.

Despite the potential vision of XaaS in WNV, there are several remaining research challenges to be addressed before its widespread deployment, including control signalling, virtual resource allocation, network management, and some non-technical issues such as business model, etc. Due to the inherent random and broadcast natures of wireless networks, these challenges need to be tackled carefully and broadly by comprehensive research efforts and call for a complete re-design of capabilities, architectures, interfaces, functions, access and non-access protocols of network services.

In this article, WNV is first briefly reviewed. Then by summarizing some existed work, we discuss the XaaS taxonomy, briefly present some definitions in XaaS and also introduce some key enabling technologies towards the mature XaaS framework. Challenges and research opportunities in these areas are also discussed. This article, we hope, can attract interests from the research and industrial communities on this emerging interdisciplinary field, which is able to boost up the development of the future 5G network infrastructure.
II. Wireless Network Virtualization in 5G

Virtualization have recently moved from traditional server virtualization to wireless network virtualization. In stead of virtualizing the computing resources in server virtualization, in WNV, physical resources need to be abstracted to isolated virtual resources from the infrastructure service providers (InSPs). Then, the virtual resources can be offered to different network service providers (NSPs). In Fig. 1 a simple illustration of WNV is presented. In order to offer services to the users, the NSPs in Fig. 1 will ask the InSPs about the resources. Then, the physical BSs from different InSPs can be virtualized to virtual BSs (vBSs) and provided to different NSPs. Hereinafter, we consider the InSPs as the ones who own the resources, including infrastructures (hardware and software), spectrum and many others, and refer to the NSPs as the ones who do not have own substrate networks and need to acquire the resources from the InSPs and provide services to end-users or other parties. It is also worth mentioning that when the NSP acts as a reseller or broker with respect to the resources, then naturally becomes a InSP for the ones who buy the resources from them. Consequently, a service-oriented wireless architecture which allows flexible and programmable operation can be built upon the proper decoupling of the hardware, software and radio resources. Nevertheless, the inherit properties of the wireless communications make the problem more complicated. Particularly, virtualizing the wireless networks is to realize the process of radio resource virtualization, hardware sharing, virtualization of multiple RATs [1]. Moreover, as the powerful computing units are becoming indiscerptible in communications systems, virtualization of the computing resources is an emerging option to efficiently utilize computing units in the wireless networks [2].

III. Everything-as-a-Service via Virtualization

An example of XaaS is presented in Fig. 2, where different types of cells, such as picocell, microcell, femtocell, and many other types of access points will be deployed and other advances, such as cloud-RAN and energy harvesting units, will be merged and utilized in the 5G physical substrate wireless networks. The densitification of heterogeneous wireless networks, together with WNV, can breakthrough the traditional obstacles on the infrastructure and radio resources towards an efficient network management and operation. By such, naturally, our vision is that the network architecture will be purely service-oriented: every
component, not only BSs and spectrum, but also data, knowledge, computing units, energy, and security, can be viewed as a type of service that can be provided to whoever needs them and whenever they are needed. For several years now, in the cloud computing, researchers have been proposing and discussing many models for defining anything "as-a-service (aaS)"\[3\]. Extracted from such a concept, we then present an XaaS taxonomy, discuss the enabling technologies and challenges.

A. Radio-Access-Network-as-a-Service (RANaaS)

First and foremost, no matter how the network will evaluate, it is still a radio-based network, where the wireless infrastructure and resources are the basis for all kinds of network operations. Therefore, the fundamental of a service-oriented wireless system should be able to offer Radio Access-Network-as-a-Service (RANaaS)\[5\]. It can be noticed that the current proposals usually consider RANaaS is one of the products of cloud-based networks, i.e., cloud-RAN, where all the RAN functionalities are centrally operated. In this part, we
revisit the concept of RANaaS and further decouple the RANaaS to different categories, i.e., Infrastructure-as-a-Service (IaaS), Radio-Resources-as-a-Service (RaaS) and Radio-Access-as-a-service (RAaaS), where the hardware, software and resource can be treated separately and properly towards a flexible and programmable 5G.

1) Infrastructure-as-a-Service (IaaS): Unlike the current BS-dominated 4G system or behind, it is expected that the 5G infrastructure concept will be significantly enriched, due to the massive deployment of different types of BSs and their ultra-density, data caching entities, computing centers, machines, sensors and energy harvesting units. The explosive growth of these network elements can also consequently increase the demands for supporting hardware, such as backhaul, backbone and radio resource control units. In the framework of the IaaS, each or the combination of some of these advanced 5G features can be viewed as one kind of services offered by the InSPs, and then can be virtualized to the NSPs or anyone who needs them.

2) Radio-Access-as-a-Service (RAaaS): When the whole RAN is decoupled, the infrastructure and radio access can be treated separately, which motivates the novel concept of RAaaS, where some RAN functionalities belonging to the protocol stack of the radio interface can be viewed as a service. In light of RAaaS, all the software related components, such as signalling, access and admission control, radio network controller, gateway, and many other protocols in the RAN or core networks, are virtualized. All of these RAN functionalities, or part of them, may then be offered as a service by the RANaaS platform to the NSPs, which adapts, configures, and extends their operation to current traffic demands and keeps up with the backhaul and access network structure requirements.

3) Radio-resources-as-a-Service (RaaS): In the virtualized networks, after abstracting, isolating and slicing, scalable radio resources can be better controlled and optimized, and may be pooled independently of the location, and transparently to the NSPs or directly to the end-users. In the platform of RaaS, the radio resources can be abstracted, isolated, assigned and sliced properly according to the demands and requirements, and then are offered as a service. By such, the available radio resources can be utilized more efficiently by permitting different parties to share the same spectrum.
B. Data-and-Knowledge-as-a-service (DKaaS)

The expansive wireless network is also emerging as a critical data contributor over the air-interface, which makes us entering the big data era [8]. Big data virtualization can be viewed as one of the most valuable means through which to make sense of big data, and thus make it more approachable to the end-users and NSPs. Through virtualization, the big data can be abstracted, characterized and virtualized to more valuable knowledge, which can offer a shorter route to help decision making.

In this context, virtualization becomes a critical tool to convey information in all data analysis, which also induces the the proposal of Data-and-Knowledge-as-a-service (DKaaS). Meanwhile, due to the fact that the delivery of large amount of data over wireless networks truly occupies considerable amount of radio resources, such as spectrum, power, storage, or even backhaul, the data may prefer to be processed locally and only the necessary information can be centrally collected, which open the door for the third parties to join the business. Any local organizations or even person who has the ability to collect data or process the data can become the InSPs in this area and offer the needed information to the NSPs. For example, the data analytic company, spectrum broker, and smart wearable device companies can be the DKaaS provider in this context. As such, when DKaaS can be realized, the responsibility of carrying big data transmission and analytic of the NSPs can be leased to dedicated entities, and the radio resources can be better utilized in order to obtain Quility of Service (QoS) improvement to the end-users.

C. Cache-as-a-Service (CaaS)

To improve the QoS of real-time data services and alleviate the substantial real-time traffic on the backhaul or fronthaul, enabling the storage and cache capabilities of BS is emerging as one of the effective solutions [10]. All these features, as we can predict, can support to realize the concept of Cache-as-a-Service (CaaS), where cache, no matter it is either personal or belonging to the company-own InSP, can be offered to the NSPs. However, what prevents to realize the CaaS is its distributed and wide deployment nature. To address such a problem, virtualization can provide flexible and programmable virtual caching capability to the InSPs and NSPs, in order to serve end-users with QoS guaranteed service [11]. By such, the content
can be flexibly chunked, distributed, and stored based on its popularity, traffic diversity and the user demands.

It is also worth noticing that besides the caching for content delivery, cache can be applied to complement the big data analytic. Consequently, CaaS can be merged with DKaaS, to address the questions of matching between cache and data in the wireless networks, i.e., problems of where, what data and when to cache [8]. Furthermore, due to the development of smart phone industry, today’s terminals also have large storage capacities, which are rapidly growing but typically under-utilized. The highly developed computing units of these devices are also capable of processing much more complicated tasks [12]. To enable the distributed cache provisioning of these devices, accurate knowledge of the end-user demands is crucial.

D. Computing-as-a-Service (ComaaS)

In the traditional networks, the dedicated computing resources are implemented at BS level, which resulted in a networks with an over-provisioning of computing resources [2]. Such distributed nature may prevent the full utilization of computing resources and lead to an energy and cost inefficient networks. Therefore, more advanced implementations should be investigated to permit a dynamic and flexible utilization of computing resources to network infrastructure. Utilizing similar concept as Cloud-RAN, ComaaS emerges as a promising solution to provide immediate and on-demand access to computing resources for the NSPs as well as the end-users with low cost. Through the virtualization of computing resources, ComaaS can also obtain the cost efficiency for the InSPs, by solely utilizing the needed capacity to satisfy NSP or user’s requirement. When computing resources can be viewed as a service, the distributed computing resources, most of which are typically under-utilized, can be exploited as well. The end-users are also able to contribute its computing with proper stimulation.

Meanwhile, ComaaS is also one enabler for private cloud or cloudlet, which offers hosted services to a limited number of end-users. This is due to the fact that the use of private cloud can be boosted by the increasing number of InSPs and NSPs. What’s more, additional private cloud expenses, including virtualization, cloud software and cloud management tools, can also be addressed by the ComaaS and other XaaS platforms.
E. Energy-as-a-Service (EaaS)

Energy-as-a-service (EaaS) provides a promising approach to reduce energy costs and improve energy efficiency for both mobile users and telecommunication operators. From the perspective of mobile users, heavy energy consuming tasks can be offloaded to cloud servers with unlimited computing and energy resources to fill the gap between battery capacity limitations and high performance expectation. Furthermore, the emerging simultaneous wireless information and power transfer (SWIPT) technology enables mobile terminals to "recycle" the transmit power to prolong the battery lifetime while receiving data [12].

On the other hand, with the advancing technologies of distributed energy generation (DER) and distributed energy storage (DES) [10], smart BSs with energy harvesting (EH) capabilities enables operators to save excess energy in batteries and sell it back to utility companies during peak periods, or to exploit environmental friendly renewable energies to further reduce electricity prices through smart energy management systems. In addition, BSs with self-generation capabilities can compose a small-scale microgrid and operated in islanded mode during a blackout to ensure safe and reliable service provision. Thus, together with the emerging energy Internet, EaaS is able to motivate the study on fundamental relation between energy and information, and represents a novel marketing paradigm shift from conventional passive energy consumers to active energy prosumers.

IV. CHALLENGES FOR ENABLING XaaS

An example of virtualizing the wireless network for XaaS is shown in Fig. 3. In this example, end-users connect to the virtual network from which they require the services, and they also connect to the cellular network physically to obtain the actual services. In the WNV, a physical network controller and a virtualized network controller need to be deployed between the virtualized wireless networks and physical wireless networks to realize the virtualization process [1]. We can see that enabling WNV for XaaS confronts many challenges from the interaction of two networks, virtual resource allocation, network infrastructure management and involved signalling issues. In the following, we elaborate these challenges and their impact on XaaS development.
A. Signalling

Due to the inherent broadcast nature of wireless communications and randomness character of wireless channel, WNV is more challenging to be realized and provided [1]. In the process of virtualizing the wireless network, connectivity need to be firstly created between the NSPs and InSPs. By such, the communications and negotiation between the NSPs and InSPs can be established and the requirements of the NSPs for resources can be expressed to the InSPs. In addition, in the XaaS framework, virtualization can happen among the InSPs as well. To facilitate the interaction among the InSPs, a standard protocol to express information-sharing and negotiation-handling are also necessary. Thus, proper control signalling considering delays and reliability needs to be explored in a careful manner to enable the connectivity among different parties involved in wireless virtualization. Moreover, NSPs or end-users may have different QoS demands. Therefore, when designing the control signalling and other overhead involved, the diversity of requirements from different parties should be carefully treated.
B. Virtual Resource Allocation

In order to realize the XaaS in the WNV, InSPs or NSPs should discover the available resources in the physical substrate wireless networks. InSPs need to decide what physical resources can be used for virtualization and NSPs can decide what resource to choose based on the end-users’ demands. Since resources will be shared among multiple parties, an efficient resource coordination scheme and interaction model should be investigated. Moreover, the slicing, isolation, customization and allocation schemes are necessary in this case, as different resources needs to be sliced and scheduled based on the provided services to achieve a better service differentiation against different NSPs [13].

In this context, the main focus of virtual resource allocation is to realize the connection between the virtual networks and physical networks. It includes the selection of nodes, radio links, antenna, power, spectrum and other resources, as well as the optimization and combination of them. Unlike wired networks, radio resource allocation becomes much more complicated in the WNV due to the changeability of transmission coverage, frequency channels, user mobility, service demand, interference, transmit power and so on [14]. What’s more, all the parties involved want to maximize their own revenue, so the game theoretic approach should be investigated to maximize the benefits in the XaaS framework.

C. Network Management and Deployment

Management and deployment of the WNV are important to guarantee the proper and efficient operation of the virtualized wireless networks and the XaaS supported by the WNV. As the XaaS will be based on different physical substrate networks, network management and deployment confront many new challenges. In particularly, the physical substrate network is usually formed by various heterogeneous networks, each of which may have unique and specific properties, thus, careful design for obtain the solutions for efficient network operation and maintenance is required.

More specifically, in the XaaS framework, end-users should be able to smoothly switch to the NSP from which they acquire services. In a perfect case, the end-users should be able to access any NSP offering the best service quality in that location. Thus, the WNV should facilitates this mobility management through infrastructure/resource sharing and protocols development between the InSPs and NSPs to ensure that end-users can successfully connect
with the most appropriate NSP. Moreover, in the system operation perspective, the WNV can require all the InSPs to share their physical resources, which potentially allows certain InSPs to shut down their equipment or put them into sleep when the traffic is low. If several InSPs have overlapped coverage, or the demand is low, it may be possible to save operation cost by carefully choosing one of them and shut down the rest. Such system operations are able to save the cost of NSPs as well as InSPs and should be reconciled with virtual resource allocation, isolation, and slicing, etc. The deployment of the network should be revised as well and will be optimized based on the requirement of the WNV and the features of the XaaS platform. For example, in a certain area, the InSPs may need to consider how to optimally deploy their infrastructures offer reliable services to the NSPs. When the InSPs of certain type of XaaS are sufficient for this area, it is not wise for them to deploy extra experiment or for other InSPs to entering this business. Thus, the corresponding analysis on the network management and deployment calls for proposals from algorithmic and implementation.

D. Data/Knowledge Acquisition and Abstraction

Due to the development of data mining and processing techniques, mobile big data is no longer viewed as a pure burden for the wireless networks. Rather, the big data science can help the mobile network operators to efficiently and effectively manage the future networks with a complex architecture and provide services to massive devices with heterogeneous demands. Meanwhile, both the wireless and fiber-optic link have their own throughput limits, which is considered as an inevitable bottleneck. It can be expected that the adoption of distributed data compression and exploration into 5G may dramatically alleviate the data transmission burden of backhaul/fronthaul link and facilitate big data analysis in the ultra-dense networks. Thus, how to properly acquire, process and abstract the features of data to useful information and knowledge are the breakthroughs on integrating the DKaaS with wireless networks.

Moreover, the SP who directly serves the end-user might be the one who has the most convinces to access the data. However, it is quite common that the SP may not have the data processing capability nor the data is meaningful to them. For example, the data obtained from wireless sensor networks or wearable devices may contain extra information that help
the NSP to provide personalized and flexible services to the end-users. Thus, how to provide these data, compress these data or extract useful information and knowledge from them, can attract interests from different third parties from technique, business or social perspective are the most challenging parts. Beside, the data/knowledge acquisition and abstraction are also absorbing from network operation point-of-view, as the local data processing or introducing professionals of data mining may ease the data transmission over wireless/wired link and abstracted knowledge can help the network operator to run the network in a easier and cost-efficient way. Therefore, addressing these challenges can significantly help to realize the DKaaS concept and also open the arms of wireless networks to embrace the upcoming big data era.

E. Non-technical Challenges

In the technological domain, although facing aforementioned challenges, enabling the XaaS via WNV has the great potential gains from then network point-of-view, and then is able to provide better services to the end-users. Besides, non-technical challenges are brought when designing the models, such as large volume of contextual data, massive connections, new virtual operators, interactions between the InSPs and NSPs etc. As presented in Fig. 4, the interaction and profit models of three layers in the WNV [1], i.e., service provider (SP), mobile virtual network operator (MVNO) and INP, can be simplified to the interaction of InSP and network service operator (NSP). However, as the services can be decoupled and the role of NSP can be easily changed to InSP, different involved parties, such as service descriptions provider and service broker, should be carefully designed and it certainly requires dedicated and long-term research work.

V. Future Research Direction

While we listed some confronted research challenges, in the following, the future research directions are presented in a bigger picture.

A. Network and Cloud Convergence

The proposed XaaS paradigm relies on the convergence of traditional cellular networks and cloud computing platform. From RAN perspective, the role that cloud computing plays
Fig. 4. Challenges from business model

Fig. 5. Convergence of network and cloud

in networks calls for a holistic vision that allows control, optimization and management of both network and computing resources in a cloud-based environment. Virtualization can be viewed as a profound enabler for the convergence of networks and cloud. As shown in Fig. 5.
radio resource and computing resources can be effectively, flexibly and efficiently virtualized into services. Then, both resulted XaaS in communication and computing domains should be properly combined for service provisioning to the end-users.

Indeed, the previous research on the RAN optimization usually focus on the radio resource allocation, such as spectrum or power, based on the channel state information, without considering the computing resource and other contextual information, while most of the research of cloud computing concentrate on the computing resources allocation [15]. The limitation of previous work will motivate the research on a joint consideration of radio and computing resources. The challenges, in this respect, may come from the design of a metric to measure the radio and computing platform and to propose corresponding optimization methods. Moreover, the protocols design between the computing resource providers and radio resource providers in the XaaS framework also call for research efforts. In addition, mobility issues also course challenges in a converged network and cloud environment. Two dimensional mobility in both physical and virtualized wireless networks, should be taken into consideration for service provisioning. The problem can become more serious when the mobile devices are the resources to offer the services, which may make the service discovery and provisioning more complex.

B. Big Data Analytic

Both proposed XaaS and WNV heavily rely on effective development of big data processing technologies. At the moment, the traditional cellular networks and recent cloud-RAN are not designed for the incoming big data era and needs sufficient revision to enhance the capabilities for big data analytic. To realized the XaaS, various features of networks should be either improved or total renovated. Exploring advanced big data analytical tools, such as stochastic modelling to capture the dynamic features of big data, development of data mining and machine learning algorithms, distributed optimization and dimension reduction. In addition, some features should be developed and brought into the current cellular networks to future explore their capabilities for handling vast volume of data, such distributed caching, computing, quantization and compression, investigation of the utilization of cloudlet and mobile cloud processing, etc, which can help to reduce traffic amount on the fronthaul or backhaul, also release the abundant on central data processing units.
C. Service Composition

In order to run a network or provide QoS-guaranteed services directly to the end-users, a NSP needs to acquire from different InSPs in the XaaS framework. Such a inherit nature of XaaS essentially requires to enable the service composition. For example, when a end-user needs to watch a stream, different InSPs may be asked from the NSPs to provide caching capability, radio resource, infrastructure, and network functionality. Accordingly, the proposal and investigation for energy and cost efficient service composition will play a central role in supporting and coordinating the XaaS framework.

Specifically, as loose-coupling among services is one of the critical concepts in the XaaS and there are a large number of services involved in the XaaS, scalability emerges as one topic with research significance for service composition design. Accordingly, how to take into consideration of different needs to compose multiple services and maintain QoS requirements of different parties are of research importance. Besides, heterogeneity is another challenging issue to service composition. The services that are provided to the end-users in the XaaS platform, commonly comprise of heterogeneous services offered by different InSPs. For example, the combination of computing and radio resources, heterogeneous infrastructures (different types of BSs or other network elements), each of which has its own characteristics that may result in different technical approaches and solutions. In addition, the on-demand, programmable and flexible features of the XaaS framework also require dynamic and adaptive service composition. By predicting and overseeing the service performance and the user’s satisfaction level along the time, adaptation to QoS requirements will be beneficial for supporting elasticity of XaaS provisioning [15]. Thus, balance between system scalability, QoS awareness, user satisfaction, and service composition is a significant research issue.

VI. Conclusions

As one of the main concept enables infrastructure sharing and radio resources abstraction, wireless network virtualization emerges as a solution to reduce operation and management expenses of wireless networks. In this article, we introduced a revolutionary vision of the future 5G wireless networks, in which the network is no longer limited by hardware, radio resources or even software. Specifically, based on the idea of virtualizing wireless networks, the Everything-as-a-Service (XaaS) concept was presented and elaborated to light the way
towards designing a service-oriented wireless architecture. Some important research challenges as well as future research directions in designing the XaaS framework were discussed and presented.

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