Jyväskylän yliopiston julkaisuarkisto
Jyväskylä University Digital Archive
UNIVERSITY OF JYVÄSKYLÄ

This is an electronic reprint of the original article.
This reprint *may differ* from the original in pagination and typographic detail.

Author(s): Chang, Zheng; Zhou, Zhenyu; Zhou, Sheng; Chen, Tao; Ristaniemi, Tapani

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

Year: 2018

Version:

Please cite the original version:

Chang, Z., Zhou, Z., Zhou, S., Chen, T., & Ristaniemi, T. (2018). Towards Service-oriented 5G : Virtualizing the Networks for Everything-as-a-Service. IEEE Access, 6, 1480-1489. https://doi.org/10.1109/ACCESS.2017.2779170

All material supplied via JYX is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.

IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received October 18, 2017, accepted November 22, 2017, date of publication December 4, 2017, date of current version February 14, 2018.

Digital Object Identifier 10.1109/ACCESS.2017.2779170

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

ZHENG CHANG[1], (Senior Member, IEEE), ZHENYU ZHOU[2], (Senior Member, IEEE), SHENG ZHOU[3], (Member, IEEE), TAO CHEN[4], (Senior Member, IEEE), AND TAPANI RISTANIEMI[1], (Senior Member, IEEE)

[1]Faculty of Information Technology, University of Jyväskylä, 40014 Jyvaskyla, Finland
[2]State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, School of Electrical and Electronic Engineering, North China Electric Power University, Beijing 102206, China
[3]Department of Electronic Engineering, Tsinghua University, Beijing 100084, China
[4]VTT, 02150 Espoo, Finland

Corresponding author: Zheng Chang (zheng.chang@jyu.fi)

This work was supported in part by the Academy of Finland under Grant 284706 and Grant 284748, in part by the Nature Science Foundation of China under Grant 91638204, Grant 61571265, Grant 61621091, Grant 61461136004, and Grant 61601181, in part by the Fundamental Research Funds for the Central Universities under Grant 2017MS13, in part by the Beijing Natural Science Foundation under Grant 4174104, and in part by the Beijing Outstanding Young Talent under Grant2016000020124G081.

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 paper, we introduce revolutionary vision of the future 5G wireless networks, in which operating the wireless networks 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 and 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 car, entertainment, manufacturing, healthcare, and agriculture industries. It is envisioned that 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 densificantion 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 advanced platform and functions, such as software defined networking (SDN) and to accommodate the diverse service requirements of the end-users. 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 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 operating the networks is no longer hardware-limited, nor

2169-3536 © 2017 IEEE. Translations and content mining are permitted for academic research only.
Personal use is also permitted, but republication/redistribution requires IEEE permission.
See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

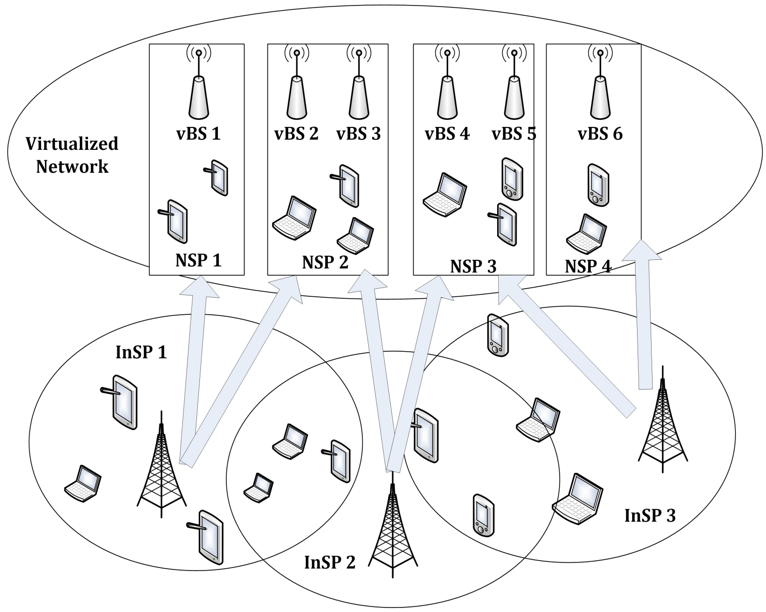


FIGURE 1. An example of wireless network virtualization.

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), Security-as-a-service (SaaS) 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. Comparing with the previous works, the main contribution of this work can be presented as follows. First by summarizing and further elaborating some existed works, we discuss the XaaS taxonomy, introduce new definitions in the XaaS and also propose some key enabling technologies towards the mature XaaS framework. Moreover, we also point out some further research directions in this area. 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. 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

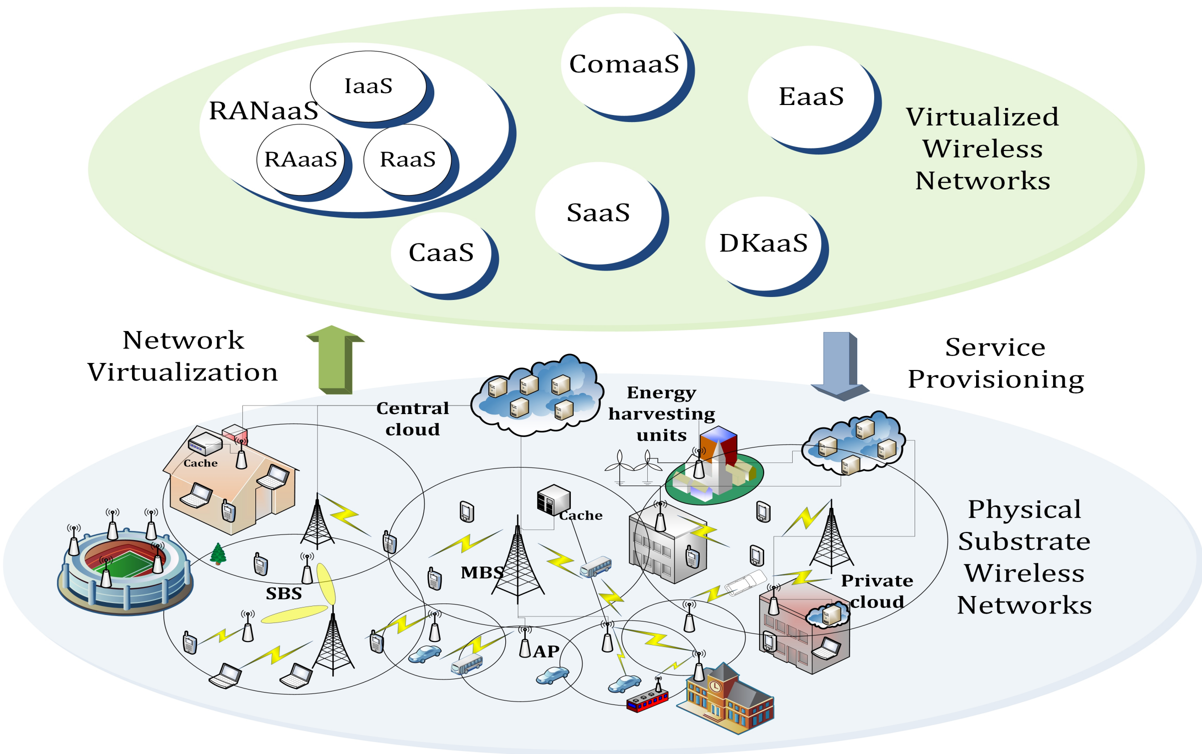


FIGURE 2. Concept of XaaS.

emerging option to efficiently utilize computing units in the wireless networks [4].

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. The owners of these components are the InSPs and the buyers who purchase them are the NSPs. 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. [3]. Extracted from such a concept of anything ‘‘as-a-service’’, we then present an XaaS taxonomy, discuss the enabling technologies and challenges.

A. RADIO-ACCESS-NETWORK-AS-A-SERVICE (RANaaS)

First and foremost, 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 [6], 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) ENERGY SAVING PEFORMANCE OF RANaaS

In Fig. 3, we have evaluated the potential energy saving gain by utilizing the proposed virtualized RAN structure in [7]. In this figure, power consumption comparison between the virtualized BS (VBS) and the conventional BS (CBS) is shown. From the figure we can see that nearly 70% of the energy is saved due to the virtualized BS function when the user packet arrival rate is $0.8s^{-1}$. The reason is that, after function and resource virtualization, the communciation and computing resources can adapt to the traffic variations, while the conventional BS can only provision constant computational resources.

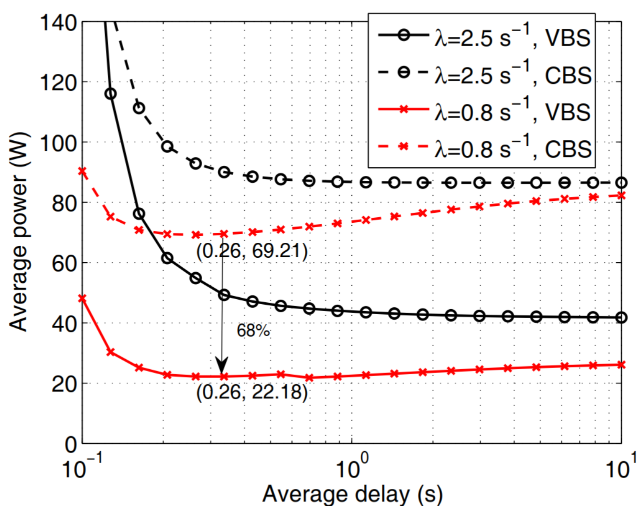


FIGURE 3. Power consumption comparison.

4) 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 [7]. 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)

Due to the decades of exponential growth in data services, it is undoubted that we are entering the big data era [8]. The expansive wireless network is also emerging as a critical data contributor over the air-interface. Big data commonly refers to the data-sets who size is beyond the ability of typical database software tools to capture, store, manage, and analyze and may complex the traditional data processing technique [9]. In wireless networks, the development of big analytic method is critical for efficiently operating the networks and providing diverse and satisfied services to the end-users [8]. 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, is through data visualization. Big data visualization is way-finding, both literally, like the street signs that direct you to a highway, and figuratively, where colors, size, or position of abstract elements convey information. In either sense, the big data can be abstracted, characterized and virtualized to more valuable knowledge, which can offer a shorter route to help guide decision making.

In this sense, 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 knowledge 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 a InSPs in this area and offer the needed information to the NSPs. For example, the data analytic company can provide data mining skills to the NSPs to find the abnormal BSs or to optimize the networks, etc. Another example is that, if allowed, the smart wearable device companies also can transfer relative knowledge, such as location trace or daily behavior of the users to the NSPs in order for them to improve their services. In cognitive networks, the spectrum broker is also a DKaaS provider, in the sense that it can obtain the knowledge of spectrum demands, and then becomes a NSP of spectrum. 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 QoS improvement to the end-users.

C. CACHE-AS-A-SERVICE (CaaS)

To improve the QoS of realtime 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. Nowadays, edge caching at SBS or dedicated caching platform attracts much attention from the community. Due to the development of smart phone industry, today's terminals 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. 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 company-own InSP, can be offered to the NSPs. However, what prevent to realize the CaaS is its distributed and wide deployment nature. Thus, virtualization can provide highly flexible and programmable virtual caching capability to the third party InSPs and NSPs, in order to serve end-users with highly qualified and customized services. In a CaaS platform, cache capability of different entities and the content can be centrally allocated and operated. For example, if we cache a content at a small cell BS (SBS), the path (routing table) for the file can be updated in an optimized way in, e.g., cloud, with less network congestions [11]. By such, the content can be chunked, replicated, distributed, bundled, and redirected flexibly depending on the realistic traffic dynamics, content popularity, and the diversity of user demands.

It is also worth noticing that besides the caching for content delivery, cache can be applied to complement the big data analytic. Caches, in stead of only be deployed at the BSs, can also be placed at the routers and the CPU [8]. Furthermore, distributed caching could also be adopted at MTs to allow mobile users to serve popular contents requested by nearby peer users in a device-to-device (D2D) manner [6]. Moreover, CaaS can be merged with DKaaS, to addresses the questions of what, where, and when to cache in the wireless infrastructure. In this case, accurate knowledge of the end-user demand profiles is key to efficient cache provisioning. The extraction of user demand profiles from mobile data traffic is performed by big data analytic.

D. COMPUTING-AS-A-SERVICE (ComaaS)

While early implementations provided each physical BS with its own dedicated computing resources, which resulted in an over-provisioning of computing resources, more advanced implementations permit a dynamic reassignment of processing resources to network infrastructures. As one example, the cloud-RAN networks is an option for efficient network operation that builds upon the idea of co-locating the processing resources of multiple BSs at a cloud-like processing center. Utilizing similar concept, ComaaS emerges as a solution providing immediate and on demand access to computing resources with significant cost savings for NSPs as well as the end-users. Through the virtualization of computing resources, ComaaS can also obtain the cost efficiency for the InSPs, by taking advantage of the cloud's elastic service provisioning model and solely utilizing the needed capacity to satisfy NSP or user's requirement. Meanwhile, 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 be 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, include virtualization, cloud software and cloud management tools, can also be addressed by the ComaaS and other XaaS platforms. he choice of a private cloud is motivated by better control on deployment, security and privacy management. Furthermore, only a private cloud can potentially grant the needed level of performance, network throughput and global Quality of Service, since resource allocation is more deterministically controlled, users are limited in number and capabilities, and load peaks can be managed in a more predictable way. Correspondingly, the end-user experience about cloud computing and future wireless networks can be enhanced as well.

E. SECURITY-AS-A-SERVICE (SaaS)

Nowadays, the security is usually offered by the mobile device companies or network operators. With a large number of intelligent devices/nodes with self-adaptation/context aware-ness capabilities in WNV, security is a big challenge and attracts growing attention. For example, in the WNV, a compromised party can take advantage of the virtualization mechanisms to misbehave in a malicious manner. Therefore, in addition to the vulnerabilities and threats of traditional cellular networks, the involvement of intelligence in future networks present new security challenges and motive the Security-as-a-Service (SaaS). The InSPs in the SaaS can offer the security services of all levels to the NSPs, e.g., the mobile device companies and network operators, or other business vendors, e.g, smart grid providers, while these organizations can concentrate to improve the QoS of end-users. Moreover, the SaaS can cope with induced security issues in the WNV XaaS platforms, such as ComaaS, CaaS, or DKaaS.

F. 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. 4, where 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.

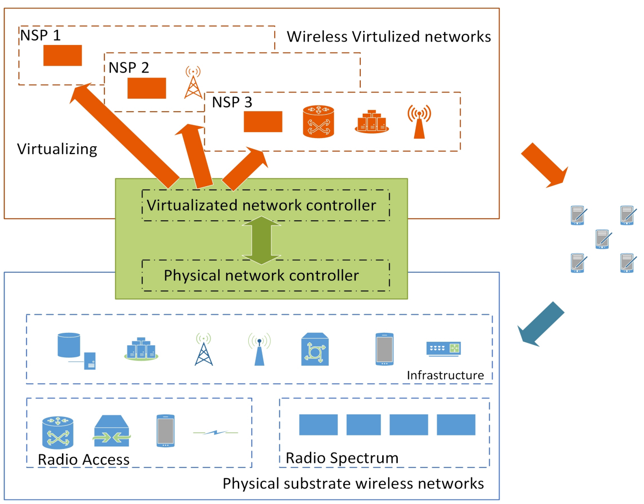


FIGURE 4. An example of virtualizing wireless network for XaaS.

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 negotiations between these two parties can be established and the requirements of the NSPs for resources can be expressed to the InSPs. In addition, 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, 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

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 NSPs 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 assume the connectivity requirement of end-users. 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. Such system operations are able to save the cost of NSPs as well as InSPs and should be reconciled with virtual resource 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.

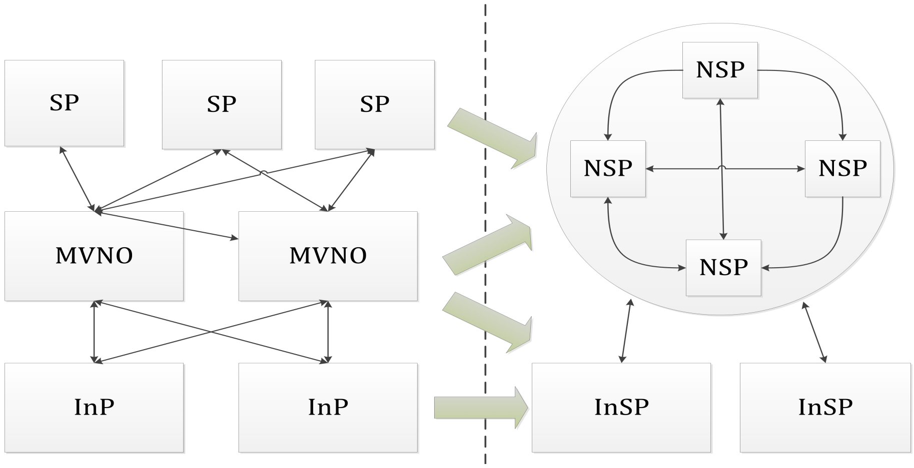


FIGURE 5. Challenges from business model.

Thus, the corresponding analysis on the network management and deployment calls for proposals from algorithmic and implementation.

D. DATA/KOWLEDGE 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 a 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. Besides, 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 wirless/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. DATA OFFLOADING AND TASK ALLOCATION

Data offloading and task allocation are not new to the server virtualization and cloud computing, but still facing many challenges. However, in the considered XaaS paradigm, as the combination of computing units and communications units, new obstacles emerge and calls for a contiguous development from the research community. Thew data offloading and task allocation are no longer only limited to the P2P structure and computing resources allocation, but also have many other constraints on location, route, availability and security etc. For instance, in a typical cloud computing scenario, a user who have data offloading requirement will contact with the cloud provider and then, the tasks of the user will be allocated inside the data center. While in the presented XaaS, as the existence of multiple InPs, the data, signalling, tasks, resources and security concerns can be decoupled and optimized. The user may obtain the nearest computing resources with certain level of security with low latency and without causing any network congestion or overload of any computing units. To reach such a goal, considerable efforts on the algorithm design need to be dedicated to address the confront challenges.

F. 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. 5, 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

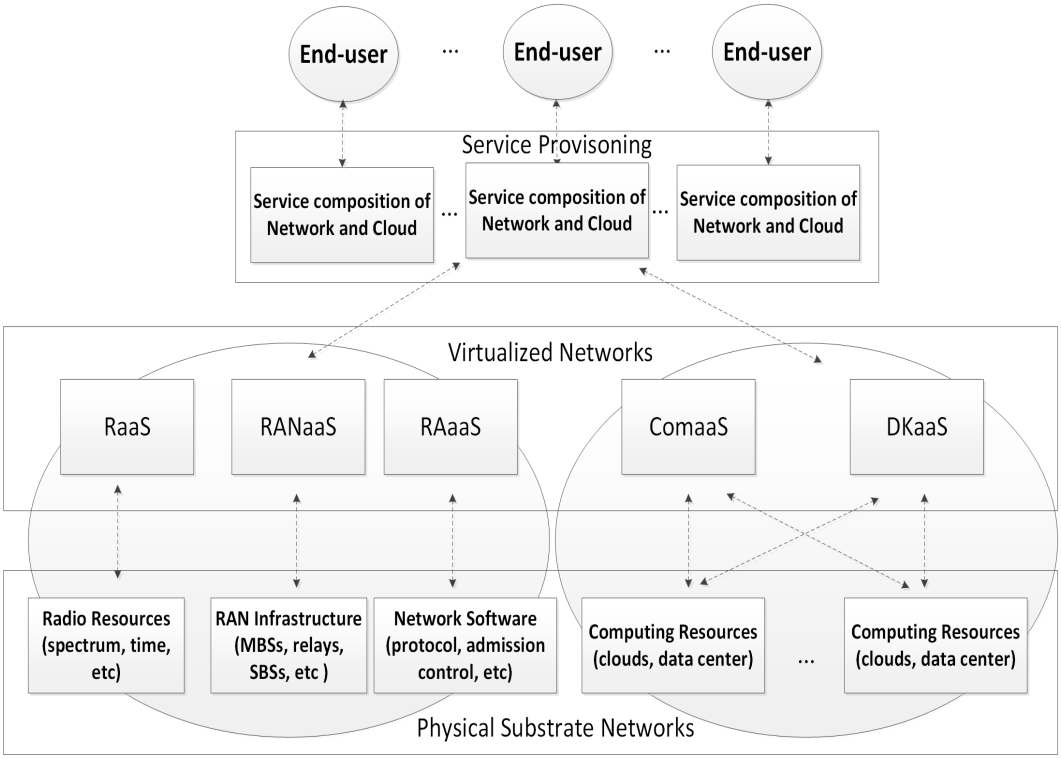


FIGURE 6. Convergence of network and cloud.

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 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. 6, 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

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.

REFERENCES

[1] C. Liang and F. R. Yu, "Wireless virtualization for next generation mobile cellular networks," *IEEE Wireless Commun.*, vol. 22, no. 1, pp. 61–69, Feb. 2015.

[2] P. Rost *et al.*, "Benefits and challenges of virtualization in 5G radio access networks," *IEEE Commun. Mag.*, vol. 53, no. 12, pp. 75–82, Dec. 2015.

[3] Y. Duan, G. Fu, N. Zhou, X. Sun, N. C. Narendra, and B. Hu, "Everything as a service (XaaS) on the cloud: Origins, current and future trends," in *Proc. IEEE 8th Int. Conf. Cloud Comput.*, New York, NY, USA, Jun. 2015, pp. 621–628.

[4] H. Wen, P. K. Tiwary, and T. Le-Ngoc, *Wireless Virtualization*. Springer, 2013.

[5] D. Sabella *et al.*, "Energy efficiency benefits of RAN-as-a-service concept for a cloud-based 5G mobile network infrastructure," *IEEE Access*, vol. 2, pp. 1586–1597, 2014.

[6] Z. Chang, K. Zhu, Z. Zhou, and T. Ristaniemi, "Service provisioning with multiple service providers in 5G ultra-dense small cell networks," in *Proc. IEEE PIMRC*, Hong Kong, Sep. 2015, pp. 1895–1900.

[7] S. Zhou, T. Zhao, S. Zhou, and S. Zhou, "Software-defined hyper-cellular architecture for green and elastic wireless access," *IEEE Commun. Mag.*, vol. 54, no. 1, pp. 12–19, Jan. 2016.

[8] S. Bi, R. Zhang, Z. Ding, and S. Cui, "Wireless communications in the era of big data," *IEEE Commun. Mag.*, vol. 53, no. 10, pp. 190–199, Oct. 2015.

[9] J. Wu, D. Liu, X.-L. Huang, C. Luo, H. Cui, and F. Wu, "DaC-RAN: A data-assisted cloud radio access network for visual communications," *IEEE Wireless Commun.*, vol. 22, no. 3, pp. 130–136, Jun. 2015.

[10] S. Zhou, J. Gong, Z. Zhou, W. Chen, and Z. Niu, "GreenDelivery: Proactive content caching and push with energy-harvesting-based small cells," *IEEE Commun. Mag.*, vol. 53, no. 4, pp. 142–149, Apr. 2015.

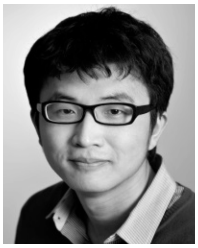
[11] X. Li, X. Wang, C. Zhu, W. Cai, and V. C. M. Leung, "Caching-as-a-service: Virtual caching framework in the cloud-based mobile networks," in *Proc. IEEE INFOCOM*, Hong Kong, Apr. 2015, pp. 372–377.

[12] Z. Chang, J. Gong, T. Ristaniemi, and Z. Niu, "Energy-efficient resource allocation and user scheduling for collaborative mobile clouds with hybrid receivers," *IEEE Trans. Veh. Technol.*, vol. 65, no. 12, pp. 9834–9846, Dec. 2016.

[13] N. Nikaein *et al.*, "Network store: Exploring slicing in future 5G networks," in *Proc. 10th Int. Workshop Mobility Evol. Internet Archit.*, Paris, France, 2015, pp. 8–13.

[14] Z. Chang, Z. Han, and T. Ristaniemi, "Energy efficient optimization for wireless virtualized small cell networks with large-scale multiple antenna," *IEEE Trans. Commun.*, vol. 65, no. 4, pp. 1696–1707, Apr. 2017.

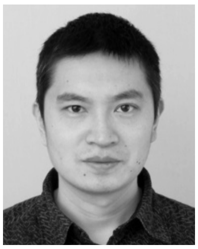
[15] Q. Duan, Y. Yan, and A. V. Vasilakos, "A survey on service-oriented network virtualization toward convergence of networking and cloud computing," *IEEE Trans. Netw. Serv. Manage.*, vol. 9, no. 4, pp. 373–392, Dec. 2012.



ZHENG CHANG (S'10–M'13–SM'17) received the B.Eng. degree from Jilin University, Changchun, China, in 2007, the M.Sc. (Tech.) degree from the Aalto University, Espoo, Finland, in 2009, and the Ph.D. degree from the University of Jyväskylä, Jyväskylä, Finland, in 2013. Since 2008, he has held various research positions with the Aalto University, University of Jyväskylä, and Magister Solutions Ltd., Finland. He was a Visiting Researcher with Tsinghua University, China, in 2013, and the University of Houston, TX, USA, in 2015. He has been honored by the Ulla Tuominen Foundation, the Nokia Foundation, and the Riitta and Jorma J. Takanen Foundation, the Jorma Ollila Grant for his research excellence. He is currently an Assistant Professor with the University of Jyvaskyla. His research interests include IoT, cloud/edge computing, security and privacy, vehicular networks, and green communications. Prof. Chang has also served as a TPC member for many IEEE major conferences, such as Globecom, ICC, INFOCOM, PIMRC, and VTC. He serves as an Editor of the IEEE Access, the *Springer Wireless Networks*, and the IEEE MMTC Communications Frontier, and the Guest Editor of the IEEE Access, the *IEEE Communications Magazine*, the IEEE Internet of Things Journal, and the *Wireless Communications and Mobile Computing*.

ZHENYU ZHOU (S'06–M'11–SM'17) received the M.E. and Ph.D. degrees from Waseda University, Tokyo, Japan, in 2008 and 2011, respectively. Since 2013, he has been an Associate Professor with North China Electric Power University. His research interests include green communications and smart grid. Prof. Zhou was a recipient of the Beijing Outstanding Young Talent in 2016 and the IET Premium Award in 2017. He is an Editor of IEEE Access and the *IEEE Communications Magazine*.

SHENG ZHOU (S'06–M'12) received the B.E. and Ph.D. degrees in electronic engineering from Tsinghua University, Beijing, China, in 2005 and 2011, respectively. Since 2010, he was a Visiting Student with the Wireless System Laboratory, Department of Electrical Engineering, Stanford University, Stanford, CA, USA. From 2014 to 2015, he was a Visiting Researcher with the Central Research Laboratory, Hitachi Ltd., Japan. He is currently an Associate Professor with the Department of Electronic Engineering, Tsinghua University. His research interests include cross-layer design for multiple antenna systems, mobile edge computing, and green wireless communications.



TAO CHEN (M'10–SM'13) received the Ph.D. degree in telecommunications engineering from the University of Trento, Italy, in 2007. Since 2007, he has been with the VTT Technical Research Centre of Finland, where he is currently a Senior Researcher in the connectivity research area. He is also currently the Docent (Adjunct Professor) with the University of Jyväskylä, His current research interests include software defined networking for 5G mobile networks, massive IoT in 5G, dynamic spectrum access, energy efficiency and resource management in heterogeneous wireless networks, and social-aware mobile networks. Dr. Chen is the Project Coordinator of the EU H2020 COHERENT Project, and the Board Member of the EU 5G PPP Steering Board.

TAPANI RISTANIEMI received the M.Sc. degree in mathematics in 1995, the Ph.Lic. degree in applied mathematics in 1997, and the Ph.D. in wireless communications in 2000 from the University of Jyväskylä, Jyvaskyla, Finland. In 2001, he was appointed as a Professor with the Department of Mathematical Information Technology, University of Jyvaskyla. In 2004, he moved to the Department of Communications Engineering, Tampere University of Technology, Tampere, Finland, where he was appointed as a Professor in wireless communications. In 2006, he moved back to University of Jyvaskyla to take up his appointment as a Professor in computer science. In 2013, he was a Visiting Professor with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. He is currently an Adjunct Professor with the Tampere University of Technology. He has authored or co-authored over 150 publications in journals, conference proceedings, and invited sessions. He served as a Guest Editor of the IEEE Transactions on Wireless Communications in 2011. His research interests are in the areas of brain and communication signal processing and wireless communication systems research. Besides academic activities, he is also active in the industry. In 2005, he Co-Founded a start-up Magister Solutions Ltd, Finland, specializing in wireless system research and development for telecom and space industries in Europe. Prof. Ristaniemi is currently a Consultant and a member of the Board of Directors of Magister Solutions Ltd. He is currently an Editorial Board Member of *Wireless Networks* and *International Journal of Communication Systems*.