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Radio Resource Sharing as a service in 5G: A software-defined networking approach

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ABSTRACT

The rise of heterogeneity in technology, types of services, and coverage area of radio access in the Fifth Generation (5G) wireless communication, opens new challenges in optimising users' access to the networks. To fully utilise the capacity of such rich field of wireless connectivity, mobile devices can not any more be confined with accessing only their previously agreed home operator's infrastructure. On the other hand, and in order to keep up with the agility required to deliver promises in providing new services and applications, virtualization and softwarization are introduced in the 5G. To this end, we propose an on-the-fly Radio Resource Sharing (RRS) scheme between different mobile infrastructures so as to provide mobile devices with the freedom to access all available radio resources around them. Such on-the-fly RRS is empowered by employing the concepts of Software-defined Networking (SDN) and virtualization of radio access resources. We argue that the RRS service is a step forwards in achieving the convergence as foreseen by the 5G: convergence of SDN, virtualization, and wireless control, convergence of heterogeneous wireless infrastructure, and above all, convergence of different operators' infrastructure in a transparent manner.

1. Introduction

While the requirements and details of technologies for the Fifth Generation (5G) wireless communication are not yet defined, it is foreseen that 5G will be a result of convergence, of services, platforms, and standards. Such multi-radio converged network calls for an efficient utilization of the overall available resources to carry user traffic while providing an advanced users' quality of experience (QoE). A question of fundamental importance to the operators and vendors is how to assign and distribute the given traffic within the available wireless radio access network (RAN). The significance of this question is twofold. Controlling of traffic load on various radio access, to ensure well-utilization of all infrastructure on one hand, and delivering the new promised quality (i.e. throughput and latency) as well as meeting users' expectation on the other hand should be addressed.

The concept of virtualization of resources has been studied in mobile networks so as to reuse the infrastructure in a dynamic and flexible fashion. In particular, RAN virtualization and Cloud RAN is well discussed both in research and in industry over the past few years [1]. Since virtualization enables more software-based control in the network, the concept of Software Defined Networking (SDN) in the control plane of mobile networks has been exploited in the literature [2–4]. SDN allows for easier and more cost efficient evolution in the data plane without depending on a slew of management or control protocols, provides centralized control of the overall infrastructure, and delivers a richer feature set based on its programmable nature. One of the advantages of the virtual RANs and the SDN-based mobile network control is the flexibility of accessing different RANs, potentially belong to different operators, depending on the traffic load instead of the traditional access to only home operators.

To this end, and by using the concept of virtual RAN, we present an on-the-fly Radio Resource Sharing (RRS) scheme between different mobile infrastructures so as to provide mobile devices with the freedom to access all available radio resources. In order to support such degree of freedom, we present an SDN-based network architecture that enables instantiations of virtual entities at the radio access network. We propose two different SDN enforcement approaches depending on the trigger and control of the RRS. In the first approach, referred to as the device-centric approach, we consider that trigger and selection of the on-the-

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fly instantiation of virtual attachment points are performed at the user terminals based on (1) their current measurements of the radio and (2) auxiliary information provided by the network. In the second approach, referred to as the network-centric approach, we consider that the SDN enforcement decisions, i.e. trigger and control, are performed at the network based on (1) radio signal measurements provided by the user terminals, and (2) network status updates provided by the network infrastructure elements. We study the performance enhancements in terms of expected figures of merit, and also demonstrate that more dynamic and efficient utilization of resources is accomplished. We further argue that the RRS as a service can pave the path for new revenue models. For example, constructing the global view by means of a logically centralized SDN control, based on the radio and network measurement collected by the network, enables operators to effectively predict the spatiotemporal availability of radio-resources throughout the infrastructure, and allow them to implement real-time spectrum auction schemes.

The remainder of this paper is organised as follows. In Section 2 we summarize the related works. In Section 3, the architecture of mobile networks based on which we propose the RRS service is depicted and details of its elements are explained. The research challenges for accomplishing our proposed RRS service and the associated architecture are discussed in Section 4. In Sections 5 and 6, the device-centric and network-centric approaches are thoroughly explained. Section 7 elaborates the setting in which we examine the performance of RRS service. We analyse results of the two different approaches here. Finally, overview of the highlights are detailed in Section 8.

2. Related works

Mobile network operators need to face the even increasing demand of data traffic in a cost effective manner. As the spectrum is a scarce resource, mobile operators are stressed to devise solutions for leveraging additional capacity across multiple radio access technologies (Multi-RATs). To this end, there is a big interest in the research community in designing architectures that aggregate different radio technologies and offer a multi-radio converged network to the end user in a transparent manner. The cellular standardization community, a.k.a. Third Generation Partnership Project (3GPP), has made a big effort in developing specifications that address inter-working among cellular and Wireless LAN (WLAN) technologies, e.g. solutions for enabling trusted access to 3GPP services with WLAN devices and for supporting the access network discovery and selection function (ANDSF) [5]. Moreover efficient network selection algorithms are needed to enable users to connect to the best RAT in an efficient manner. The network selection algorithms for Multi-RAT can be classified in two groups [6]: 1) user-centric approaches where the users are continuously monitoring the link quality with all the neighboring base stations and steer traffic to the access point with the best quality and 2) RAN assisted approach: where the users combine their signaling measurements with additional knowledge of the loading information from the network infrastructure. Although the latter approach ensures better performance, it is more complex.

The aim of our paper is to apply an SDN approach for enabling a less complex network selection process [7]. We believe that the proposed RRS service can improve the radio resource management (RRM) operation in a Multi-RAT scenario due the larger knowledge of the network state that can be achieved by employing the SDN technology. One the most candidate technology for enabling Multi-RAT 5G architectures is the C-RAN technology proposed in [1]. Even though the benefits of C-RAN are clear its integration into the existing cellular architecture requires a smooth transition between prominent 3GPP systems (e.g. LTE-A) and forward-thinking 5G architectures. Some hybrid approaches are needed to enable a soft transition from the current mobile architectures to the future 5G system. SDN and Network Virtualization (NV) are envisaged as the key enabler technologies for that purpose, as they can be used to improve scalability and enable service oriented-management in the current architectures in a less invasive manner. To this end, a plethora of works have risen in the literature to exploit the potential benefits of SDN/NV in future 5G networks. In [8] the authors discuss the key benefits and the key challenges of applying SDN in wireless and mobile networks, describing the main features of the SDN-based mobile architectures. The authors in [9] propose an SDN architecture specific for the Long-Term Evolution (LTE) system, which enables infrastructure sharing among different RAN technologies. Network sharing in the context of 5G and network slicing has also been discussed in [10]. Even though this work is clearly a first attempt towards an SDN-enabled RAN, several open issues are yet to be solved, e.g. how to deploy the proposed solution in the current mobile network architecture in a non-invasive manner.

Other research works are focusing on the design of SDN-Controller architectures for wireless networks with the aim to enable flexible sharing of network resources among multiple operators, referred to as tenants. In [11] authors propose a two-tier dynamic SDN-Controller architecture for wireless backhaul networks that aims at balancing the tradeoff between scalability and system performances in shared wireless networks. In [12] authors propose an SDN controller architecture for controlling multi-tenant slices in a shared RAN. Different from [11,12], in this paper we focus more on evaluating the impact of the proposed RRS service in the current mobile architectures. Moreover in this paper we provide our vision on how to enable dynamic sharing of the network resources among multiple operators in a Multi-RAT scenario in a less invasive manner. Furthermore, how an abstraction of mobile network topology can be shaped within the SDN-Controller and allow for selection of RAN during handover, is presented in [13].

It is worth to note that dynamic and flexible network sharing is a key requirement of future 5G networks as it can enable operators to face the increasing demand for traffic in a cost effective manner, by maximizing the resource utilization efficiency. 3GPP has recently outlined a suite of requirements and guidelines for network sharing [14], specifying the architecture and procedure to enable different operators to share the RAN and proposed two different approaches for RAN sharing, named Multi Operator Core Network (MOCN) and Gateway Core Network (GWCN) respectively. In the MOCN approach the RAN is shared among multiple operators, while each operator owns an independent core network. In the GWCN approach, in addition to RAN, the operators share the Mobility Management Entity (MME). Note that the MOCN is considered more flexible than the GWCN approach as it can be used to enable inter-networking with legacy networks and mobility among multiple radio access technologies.

The concept of RAN sharing has been analyzed in our previous work [15] where we propose a framework that permits the flexible sharing of virtualized LTE evolved Node Base station (eNB) among multiple operators. In this framework the virtualization of the eNBs is dynamically handled in an SDN fashion, enabling one operator to offload traffic on-demand to the base stations owned by other operators. In another work [16] we propose an SDN-based framework for enabling elastic spectrum sharing in multi-operator environment of Frequency Division Duplex (FDD) macro eNBs and Time Division Duplex (TDD) pico-eNBs. The aim of this framework is to enhance flexibility and the resource management efficiency by enabling an SDN-based coordination of network resource management process. Different from [15,16], in this paper we focus more on the resource sharing aspects in multi-domain environment consisting of cellular base stations, femtocells and WiFi access points (APs).