Perspectives for 5G Network Sharing for Mobile Small Cells

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Abstract. Ensuring enough network resources for all emerging 5G mobile services, with the advent of 5G will be vital. Network sharing is seen as one of the adopted technologies of 5G, to enhance resource utilization by optimizing resource usage among different operators. A key enabler for network sharing is virtualization. While virtualization of the core network has already been implemented in nowadays mobile networks, the virtualization of the Radio Access Network (RAN) is still an emerging research topic that is currently investigated with the aim of exploiting a fully virtualized mobile network. In this paper, we examine a 5G RAN perspective architecture that has the merit of being a Multi-RAT, Multi band V-RAN and using end user equipment as mobile small cells. We highlight its advantages, and identify how virtualization of RAN can lead to efficient RAN resource sharing. Finally, we anticipate how some virtualization functionalities should be extended to manage the particularity of the perspective RAN architecture.

Keywords: 5G · C-RAN · V-RAN · Multi-RAT

1 Introduction

5G represents the next major phase of mobile communication, which is expected to take over the world starting 2020. 5G radio access network (RAN) system is envisioned to be a true worldwide wireless web (WWWW) [1]. This is because such system will seamlessly and ubiquitously connect everything. Besides addressing IoT deployment on a massive scale, 5G is also expected to satisfy the requirement of applications previously not possible that depend on ultra-reliable and low-latency communications.

In order to meet those requirement, 5G research community along with the main stakeholders and players in the field have collectively agreed on the use of certain technologies in the 5G paradigm. Those technologies include, among

others: The exploitation of the Multi-Rat technology by integrating the evolved existing mobile-broadband RATs (2G, 3G, WLAN, 4G, etc.) and efficiently use the spectrum; the densification of the network with small cells deployment to increase the spectral efficiency and meeting the 1000x challenge. Another potential technology that has existed for decades and need to be revisited for the design of new concepts suitable for the 5G use cases is Network virtualization for RAN and spectrum sharing.

Virtualization used to be related to sharing network resources among different Operating Systems to allow the creation of virtual machines; operators to allow a mobile operator that does not have its own core network resources to share the one available with other operators; or generally speaking among users [2]. A more recent use case of virtualization is Network Function Virtualization (NFV). This use case has emerged in the mobile packet core network as a practical approach to boost the network flexibility along with Software-Defined Networking (SDN). It is expected that 5G push the network virtualization from the core network towards the RAN. In this context, a Cloud RAN architecture exploiting a combination of virtualization (of software), centralization (of hardware) and coordination techniques (between cells and bands) is introduced in order to achieve many benefits, such as: reducing Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).

In this paper, we analyze why each of the three stated above technologies need to be evolved, revisited with new design approaches, after performing a positioning com-pared to the state of the art research works.

2   Densification in 5G

Densifying the network with much big number of small cells is crucial for enhancing the spectral efficiency and meeting the 1000x challenge [3]. Several studies con-firmed that network capacity doubles by doubling the number of small cells. Unlike the deployment of additional macro base station that involves high costs, small cells are low-power nodes that may be installed everywhere indoors and outdoors, operating in licensed band spectrum and referring to an umbrella term for operator-controlled [4]. Small cells can be used to offload the explosive growth of wireless data traffic from macrocells and improve the macro cell's edge data capacity, speed and overall network efficiency. However, the exponentially growing demand for capacity already requires operators to overlay the macro cell large coverage with smaller and smaller cells in the dense areas to achieve more capacity and use spectrum resources more efficiently. Furthermore, the current solution of using Picocells requires radio infrastructure and planning representing significant costs for operators. Most visions [5–8], agree that 5G networks will be an ultra-dense populated by a hybrid combination of heterogeneous cells, including different generations 3G, 4G and 5G, as well as different types of cells such as macro, Pico, and small cells. For instance, in [9] 5G small cells optimized radio design envisioned as a TDD-based system is proposed. In [10], a network architecture where small cells use the same unlicensed spectrum as Wi-Fi has been introduced along with an interference avoidance scheme based on

small cells estimating the density of nearby Wi-Fi access points. Multi-antenna systems such as massive MIMO [11,12] and/or Distributed Antenna Systems (DAS), can also be considered as other method to achieve densification. DAS is functionally similar to picocells from a capacity and coverage standpoint, but is composed of a set of radios deployed in remote locations. Cells in that case are called remote radio heads (RRHs) that have all their baseband processing at a central site and share cell IDs. On a network-wide scale, the cloud-RAN approach extends this as it will be detailed further.

As for 5G with mmWave smalls cells, it is also widely expected that they would be extremely dense in 5G networks to compensate their propagation challenges. In [13] a comprehensive tutorial on the use of millimeter-wave frequencies, notably the 60 GHz band and an analysis of the effect of such cells in coping with the expected growth of this solution is provided.

3   Mobile Small Cells

Several research efforts have been devoted to study the optimal static small cell deployment mainly for urban and hot zone environment with respect to different metrics. While authors, in [14], targeted the maximization of the spectral efficiency of the network, maximization of the throughput was the target of [15] to find optimal locations for placing static small cells. These research efforts assumed that the user or traffic distribution is invariant and did not consider that deploying a static small cell in a given hotspot that usually tends to be dynamic will lead to high operational cost.

In order to do so, other recent works have proposed the use of mobile small cells. Most of the research works [16–22] considered deployment scenarios in outdoor hot-spots and public transit vehicles. For instance, in [17,21] mobile small cell deployment in vehicles is investigated. A demonstration of the performance of its gains is given analytically and through simulation considering the outage probability and the error probability as metrics in [17]. Similarly, the authors of [20] studied the deployment problem of mobile small cells, targeting the maximization of the service time provided by mobile small cells for all users. In [21], studies have been performed for small cells environment to understand the gains of proactive cache. The study addressed the wireless backhaul, side-haul and spectrum allocation, but not the impact of spectrum management and mobility in a virtualized network. In [19], the efficiency of deploying moving small cells on the top of buses to offload traffic in the congested macro cell was shown as a beneficial solution, when the small cell is moving near the traffic hotspot and covers a significant proportion of it.

Although several algorithms for the hotspot localization were proposed in the literature [23,24], using moving smalls cells leads to either sporadic gain or to a performance degradation due to the resulting interference, when the mobile small cell is moving away from the hotspot. In addition, resource management schemes for small cells still need more research efforts. A more fresh and efficient way to tackle this problem, is using on-demand mobile small cells that can be dedicated

radio remote heads/units (RRHs/RRUs) or user mobile devices existing in the required location as recently suggested in [25].

Although mobile small cells can potentially provide many advantages, the hyper-densification can pose several challenges. The main challenges for successful UDNs are the management of complexity and inter-cell interference (ICI) coordination, mitigation or management among the macro-cell BSs and the small cells as well as the optimization of network operations, of multi-layer, heterogeneous dense net-works. The emergence of the software-defined networks (SDN), wireless network virtualization (WNV) cloud radio access network (C-RAN) and Self Organizing Networks (SON) provides a promising technological solution for these challenges.

In the following sections we give an overview about the standardization activities related to virtualization for network sharing. Afterwards, we build on this vision of Multi-RAT mobile small cells that take advantages of the Virtualized RAN, describe the overall architecture, the different use case of virtualization for the enablement of the proposed architecture, its benefits and the challenges that it would trigger.

4 Virtualization and Network Sharing

Virtualization concept refers to using an abstraction layers to allow different operating Systems; mobile operators or users to share common underlying physical re-sources and have their own isolated virtual resource. For decades, virtualization of wired resources has been practiced through the creation of Virtual Local network (VLAN) and Virtual Private Network (VPNs). Such virtualization is relatively limited as it involves only few OSI model layers. Recent research efforts have been per-formed with the aim of achieving a service level virtualization applied for mobile networks. Network operators are one of the main key players behind such incentives, as network sharing would allow an operator that does not have infrastructure nor spectrum resources to dynamically share the physical networks operated with other mobile network operators (MNOs). Given this definition, virtualization presents a major enabler for resources sharing among different virtual operators. Recently, some incentives for a fuller RAN virtualization for efficient wireless network sharing are currently gaining strong operator support as a feasible way to accommodate the foreseen increase in mobile traffic, whilst reducing their CAPEX and OPEX.

Lots of attention have also been drawn towards network function Virtualization (NFV), as it would facilitate the creation /management/extension of new services without having to care much about the complexity of the implementation on the physical infrastructure.

The importance of network sharing has been recognized by the 3GPP starting from release 6. In ref. [26], 3GPP defined two architectures of active sharing. In both architectures, the radio access network is shared.

– The Multiple-operator CN (MOCN): In this configuration, each operator has its own CN. And the multiple CN nodes belonging to different operators are connected to the same RNC.
– The Gateway CN (GWCN): In this configuration, the core network is shared in addition to the RAN nodes between multiples operators.

In the following section, we build on the concept promoted in [31] and describe the architecture of the Heterogeneous Cloud RAN based mobile cells, the benefits that it would gain, as well as the main use cases of virtualization, in the context of this architecture.

5 Architecture of Heterogeneous Cloud-RAN Based Mobile Small Cells

5.1 Architecture

The combination of multi-tier HetNet and Cloud architecture is referred to as Heterogeneous Cloud Radio Access Network (H-CRAN). This concept was driven by greater needs for coordination, as well as techniques to increase resource efficiency and advances in network visualization. Cloud RAN appeared as a disruptive concept in cellular network aiming to exploit a combination of centralization, virtualization, and coordination techniques. Traditionally, radio and baseband processing functionality (responsible of coding, modulation, fast Fourier transform, etc.) are integrated inside the BS, while the inter-BS coordination performed over X2 interface. RAN used also to be connected to the rest of the network with backhauling segments. With C-RAN the new concept of front hauling is adopted. As shown in Fig. 1, and in contrast to the traditional approach, with front hauling, the baseband resources are pooled at baseband processing units (BBUs) situated at remote central office. A BBU pool serves a particular area with a number of remote radio heads (RRHs) of macro and small cells for a centralized signal processing and management.

5.2 Benefits

As can be seen from the architecture, the envisioned scenario refers to a Multi-RAT, Multi-band C-RAN based mobile small cells, provides multiple potential ad-vantages, for instance, in terms of providing high-speed services, with dense deployment of mobile small cells, allowing the service of increased number of connected wireless devices. The flexibility provided by the C-RAN based architecture also helps with the adaptation of the network to the highly variable environment envisioned in future networking, especially with the vast adopting of Internet of Things (IoT).

The flexibility of the reference scenarios also enables the network to address the different use-cases envisioned for 5G paradigm. The proposed network structure can provide high speed service (high data rates) to use-case 1 of 5G, namely
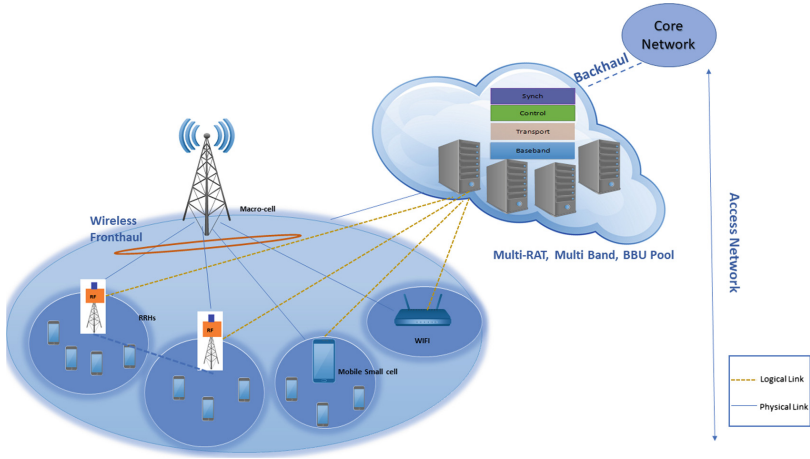
Fig. 1. Perspective Architecture: Multi-RAT, Multi-band C-RAN based mobile small cells with wireless front-haul

Enhanced Mobile Broadband (eMBB). In this case, the wireless fronthaul has to be high-speed link, providing the required high data rate broadband. On the other hand, the second use-case of 5G, the Massive Machine-Type Communications (mMTC), which re-quires a high number of connected devices, can be supported, but with lower data rates. The envisioned scenario can address such use-case through the dense deployment of mobile small cells, which can be easily achieved through the multiple-RAT multiple-band C-RAN, especially that the wireless fronthaul probably does not re-quire high capacity nor high speed. In the next subsection, we analyze the use cases of virtualization that can be fulfilled within this prospective architecture.

5.3 Use Cases of Virtualization within the Proposed Architecture

– *USE CASE 1: Virtualization for Computational Ressource Sharing(V-RAN)*
  This virtualization is embodied through the BBU pool definition within the C-RAN. Based on [27,28], pooling or statistical multiplexing, allows an execution platform to perform the same tasks with less hardware or capacity as the C-RAN capitalizes on the diversity of traffic peaks, hence, improves the utilization efficiency of the infrastructure. That also leads to fewer handover failures and less network control signaling in complicated heterogeneous radio network environments, as well as energy efficient operations and resource savings. Virtualization can also be used to simplify the management and deployment of the RAN nodes, provide isolation, scalability and elasticity, among other things, for the Radio Resource Control (RRC) protocol layer. It has also the potential of providing greater flexibility to the mobile network operator and reducing the network costs. Virtualized BBU Pool can be shared
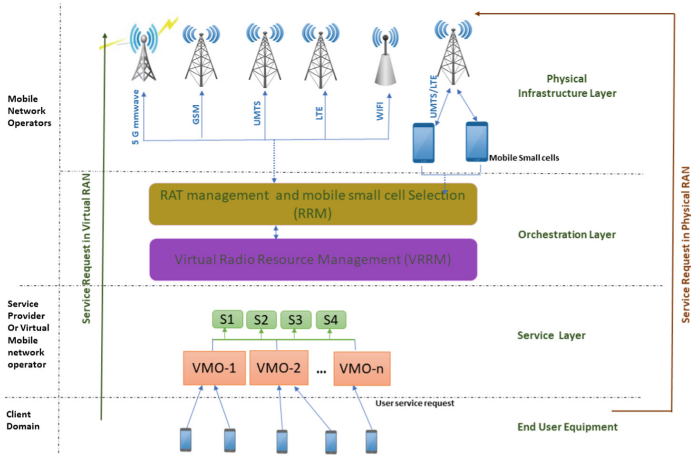
Fig. 2. Virtualization for radio resources efficient sharing

by different network operators, allowing them to rent Radio Access Network (RAN) as a cloud service (RAAS).

– *USE CASE 2: Virtualization for radio resources efficient sharing*

The requirement in this use case is of a network with virtualized RAN supporting the Multi-RAT, Multi Band technologies. The first aim of using the Multi-RAT HetNet approach is to efficiently exploit the unlicensed spectrum by having a 5G RAN system integrating the evolved existing mobile-broadband RATs (2G, 3G, WLAN, 4G, etc) and operating in different configurations. Virtualization will play here a major role to provide abstraction, convergence and sharing of the available multi-RAT re-sources between several service providers. The efficiency of the network can be maximized through the choice of the optimal access technology to be used at given time for each service request/operator, for the communication between end users and mobile cells, as well as for the front-haul between small cells and the backhaul. Given this requirement, the virtualization functionalities need to be further extended with the feature of eventually assigning an optimal mobile small cell/ RAT and technology to be used between to relay the communication to and from an end user equipment.

Figure 2 illustrates the different physical and virtual components involved in this use-case. As it can be shown from the figure, end users equipment solicits the network with different service requests. In the virtual RAN, these service requests are passed to the service layer. At this layer, the virtual mobile operator, also referred to as service provider, operates. Depending on the request, the offered service is classified into one of the offered differentiated services and then relayed to the orchestration layer. This layer, as well as the infrastructure layer, are governed by the traditional mobile opera-tors who owns the

physical infrastructure. The orchestration layer is divided into two function-
alities: The virtual radio remote management (VRRM) and the RAT man-
agement and mobile small cell selection. The VRRM is a functionality that
appeared within the concept of virtual-RAN (V-RAN), which is in charge of
the creation management and optimization of a set of virtual radio resources,
for each of the MVNO, on top of a set of available physical resources. In
other words, through the VRRM task, the virtual resources required by the
MNOs are mapped onto physical ones, optimized, and monitored. On Top
of the VRRM, the traditional entities in the heterogeneous common network
for radio remote management (RRM), which are CRRM for common RRM
and LRRM for local RRM, operates. In the context of the use-case stipu-
lated by the detailed architecture, these two management schemes have to be
extended by the mobile small cell selection schemes. Within this functional-
ity, the decision about whether a multi-hop communication is needed through
one or more optimum existent mobile small cells, before being passed to the
end physical radio station is made. It is worth noting that mobile small cells
are considered here as one of the underlying physical resources.

5.4   Open Research Challenges

The advantages discussed in the previously detailed architecture can be achieved
but with some arising research challenges. Some of the identified research chal-
lenges, related to the general discussed architecture, are listed below:

– Meeting the requirement of very low latency (1 ms end-to-end) for the
  5G Ultra Reliable and Low Latency Communications (URLLC) or critical
  Machine-Type Communications (cMTC) Use Case is one of the main chal-
  lenges in the presented architecture. The challenge could be addressed accord-
  ing to the particular use-case, by paying attention to the particular design of
  front-haul link.
– Managing and controlling the interference induced in the architecture would
  also be a challenge with the adoption of the multi-RAT multi-band and mobile
  small cells set-up on demand concept. The question would be determining
  the optimal set of mobile cells that can offload the traffic and which set of
  the available RAT would be chosen for the communications, based on some
  attributes such as (number of devices, used applications and mobility, etc.).
– A third important challenge would be determining the optimal operating
  point of the network considering the context of highly mobile users/devices.
  This should be done continuously and automatically which drives the need
  for the investigation of self-organizing networking (SON) algorithms for the
  optimization of the multi-RAT, multi-band V-RAN based mobile small cells.

6   Conclusion

In this paper, we analyzed the architecture of Multi-RAT, Multi-band V-RAN based mobile small cells with wireless front-haul. We highlighted two main uses cases of the virtualization within the architecture, and concluded that the virtualization functionality in the V-RAN should be evolved to meet the architecture particularity.

Our future work will concentrate on proposing a set of new algorithms for the identification of the optimal set of mobile small cells and RAT selection for a given hotspot zone.

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