Efficient Resource Allocation and Spectrum Trading for Virtualized Multi-tenant 5G Networks

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***Abstract*—The huge increase of mobile devices and user data demand has initiated efforts for more efficient mobile network solutions. To this direction, virtualization has attracted much attention as a promising solution for higher resource utilization and improved system performance. Therefore, basic on-demand wireless resource allocation approaches among multiple tenants are investigated. Taking also into consideration two contrasting terms, the spectrum scarcity and the spectrum underutilization, this work proposes spectrum trading among frequency owners and tenants, enabling dynamic spectrum access and optimal management.**

***Keywords*—wireless network virtualization, multi-tenancy, wireless resource allocation, spectrum trading.**

I. INTRODUCTION

Currently, mobile networks are a key element of society, enabling communication, access and information sharing. In future, mobile networks need to address the proliferation of mobile devices and the predicted growth in mobile traffic volume, mainly due to video and web applications. According to [1], the demand for mobile data usage grows at a rapid pace, resulting in 61% growth in data traffic in 2015 compared to 2014. It is also predicted that due to the concept of the Internet of Things (IoT), the number of connected devices will expand to somewhere between 20 and 46 billion by 2020, and the data quantity transfer will be 1000 times higher than today. Therefore, current wireless and mobile networks should evolve to become more intelligent, efficient, secure and scalable to meet the future stringent communications data requirements.

In order to cope with this huge increase in data traffic without deteriorating the quality and reliability of the provided services, network operators started to consider the introduction of new access technologies or the efficiency improvement of the existing ones. This challenge led to examples like heterogeneous networks (HetNets), the combination of different Radio Access Technologies (RATs) and the cognitive radios, which can increase the efficiency of wireless networks, but they will also increase the costs of network operators (CapEx and OpEx), by requiring the deployment of more infrastructure, and consequently making network management more complex. Such pressure has pushed mobile operators to reconsider their investments and research efforts directing towards achieving more cost efficient mobile network solutions.

Recently, the Wireless Network Virtualization (WNV) concept has appeared as a new alternative to help on the achievement of this goal, effectively reducing capital and operational costs [2]. Whereas in the past, a single physical machine was used just as a single processing or storage machine, nowadays thanks to virtualization, it can host multiple virtual machines, each dedicated to its own task. This has the advantage of separating the physical infrastructure from its services and providing the service independent from its physical underlying hardware [3]. Virtualization promises to bring a similar revolution to wireless networking as well.

Presently, one of the major concerns of wireless networks comes from the spectrum scarcity in combination with the constantly increasing demand of traffic from the end users. In fact, wireless spectrum resources are typically the scarcest and most expensive resources in mobile wireless networks and their effective slicing is crucial for successful active Radio Access Network (RAN) sharing. Furthermore, studies show that spectrum resources owned by a single operator are often underutilized. For instance, work in [3] shows that macro-cell utilization is typically around 20-40%.

One of the main benefits of resource virtualization is the fact that it enables efficient resource utilization in a network. This can be achieved through an entity called hypervisor, which is added on top of the physical resources and is responsible for allocating these resources among different tenants running on top. It could be also achieved by dynamically sharing radio resources from the under-loaded virtual network segments to the overload ones. Both ways are presented in this work.

II. WIRELESS NETWORK VIRTUALIZATION

A. Virtualization advantages

Generally, with WNV, physical mobile network infrastructure resources, such as RANs, core networks (CNs), and physical radio resources (licensed spectrum), can be abstracted and sliced into virtual cellular network resources, and shared by multiple tenants through isolating each other. As a result, network infrastructure can be decoupled from the services it provides, and customized services can share the same physical infrastructure.

The WNV is a promising solution that will allow for realizing the vision of 5G, including many advantages [2, 4]:

- *Enabling slicing and multi-tenancy*: virtualization and slicing are two concepts so coupled that virtualization becomes the principal technology enabler for slicing. Nowadays, all slicing proposals consider each slice as some kind of virtual network in order to achieve the objectives behind wireless network virtualization. Such kind of objective is the infrastructure sharing among several operators.
- *High resource utilization*: network operators will perform dynamic adaptation of resources across slices. In this way, efficient resource utilization is achieved and their revenue is maximized, by keeping the scarce wireless channels occupied as much as possible. Utilization of base stations can be maximized by allowing usage of unused resources by one entity to other entities.
- *Improved system performance*: customized services within the different slices will be provided to achieve greater service differentiation against competitors and enhance the Quality of Service (QoS) management. Customization provides flexibility to the different entities in order to program the base station and optimize their service delivery. Also, isolation among slices will prevent the deterioration on the performance of one slice due to any change on another slice, like the number of end users, channel conditions, etc.
- *Reduced CapEx and OpEx*: virtualization enables the hostage of multiple virtual base stations on a physical one, so there is no need to deploy new infrastructure and avoid expenses for constructing new base stations and their maintenance.

B. Business model

The virtualization concept is directly applied to the business models of the wireless network. In general, a business model provides a description of the roles and relationships of a company, its customers, partners and suppliers, as well as the flows of goods, information and money between these parties. Hence, the business model of the virtualized wireless network can be decoupled into specialized roles. Two main players are identified [5]:

- *Infrastructure providers (InPs) or Mobile Network Operators (MNOs)*, which own and manage the physical cellular network infrastructure resources and physical radio resources. Most of the time, they implement the virtualization. They are responsible for slicing the physical mobile network resources into virtual resources.
- *Service providers (SPs) or Mobile Virtual Network Operators (MVNOs)*, do not own any physical resources such as base stations (BSs) and wireless spectrum, but lease the virtual network resources from InPs based on the requests from clients, operate them over the virtual topology and assign them to clients. MVNOs deploy their networks by assembling the virtual slices and creating a virtual topology in this way. They use this virtual network to offer their fully differentiated end-to-end services to their subscribers. These services include VoIP, video telephony, live streaming, along with traditional voice services.

C. Network slicing

As mentioned, wireless virtual resources are created by slicing wireless network infrastructure and spectrum into multiple virtual slices. Another aspect of the definition of a slice is related to up to what level slicing should be applied. A good classification of the different levels of slicing are detailed in [2]:

1) *Spectrum-level slicing:* The spectrum can be sliced by time, space or frequency and assigned to tenants (MVNOs or SPs). It can be roughly stated that spectrum-level slicing is an application of spectrum sharing and dynamic access in the virtualization environment.

2) *Infrastructure-level slicing:* It is the slicing of physical network elements, such as antennas, base stations (BSs), processors, memory, routers, which are virtualized to support sharing by multiple tenants.

3) *Network-level slicing:* It is the slicing of the entire network infrastructure and appears as the ideal case. For example, a BS is virtualised to multiple virtual BSs, and then the radio resources are also sliced and assigned to the virtual BSs. Then, the core network (CN) entities are virtualized too.

4) *Flow-level slicing:* The slice is here defined as the set of flows belonging to an entity. The slices can be bandwidth-based like data rate, or resource-based like time slots. A typical example is an MVNO that does not have physical infrastructure and spectrum resource (but has its own customers) to serve video calls to its customers. This MVNO may request a specific slice based on certain data rate (bandwidth-based) from the MNO who actually operates the physical networks.

III. Resource Allocation

This work focuses more on RAN virtualization and ways to efficiently share the available spectrum among multiple tenants. In fact, when implementing slicing on a wireless network, the main issue is how to assign resources to the different slices [2]. This is known as the resource allocation problem.

As mentioned, the WNV concept can be applied at different layers and degrees, from only virtualizing the core network to virtualizing the radio spectrum and physical layer of BSs.

One option for the implementation of spectrum virtualization could be to share the RF front end and antenna of the BS [6], where the flexible slicing of a radio into multiple slices, each operating on different spectrum fragments, is enabled. Modifying the scheduling software in use is another option. In fact, the vast majority of approaches modify the frame scheduler to assign Physical Resource Blocks (PRBs) to the slices [7, 8]. The PRB structure is described in [7]. As a result, BS virtualization can allow each tenant to have its own customized schedulers over its slice, assigning wireless resources intelligently based on the actual need [9].

The BS is the entity responsible for accessing the radio channel and scheduling the air interface resources between the users. In order to effectively allocate resources, these should be virtualized first. Therefore, the BS has to be virtualized first, before the virtualization of the air interface takes place. Virtualizing the BS is similar to node virtualization. The physical resources of the node (e.g., CPU, memory, I/O devices) are shared between multiple virtual instances. A hypervisor, which is a well-known virtualization solution, is added on the top of the physical layer of the BS and is responsible for virtualizing the BS and the spectrum as well. In summary, the hypervisor accomplishes two tasks:

1) Hosts several virtual BSs onto a physical BS.
2) Schedules the wireless resources (PRBs) among the different virtual BSs.

Following this way, two different versions of the hypervisor exist [10]:

1) *Static version*: the hypervisor allocates the PRBs among the different tenants just once at the beginning. The number of the allocated PRBs for each tenant is equal, where each virtual BS will get the exact same amount of PRBs and keeps it regardless if it is being actually used or not.

2) *Dynamic version*: the PRBs are allocated to the different tenants in a dynamic manner at equal time intervals. The amount of the allocated PRBs will depend on the load that each tenant is experiencing during the last time instance. In this way, each operator will only get his required share of the PRBs and less waste of resources will occur.

Decades of experience with Internet has reinforced a general rule of thumb: it is nearly always more preferable to dynamically allocate resources over static resource allocations. Dynamic resource allocation can allow for more efficiency and flexibility in situations where the demand on scarce resources is not predictable. The multi-tenant model defines that each tenant is dynamically assigned and reassigned all the physical and virtual resources according to its consumers' demand [11].

This solution uses the PRB as the minimum resource granularity that can be allocated, and assigns PRBs among the different virtual nodes, and not among the users (as typically done by a scheduler). The PRBs are scheduled to the different virtual BSs based on previously arranged contracts (Service Level Agreements), which specify different guarantees for the operator owning a virtual BS. After the hypervisor allocates PRBs to the virtual BSs, each virtual BS allocates the PRBs to the attached users. In other words, the hypervisor is responsible for scheduling the air interface resources.

IV. Spectrum Trading

As mentioned in Section I, it has been observed that the radio spectrum allocated to some MNOs remains largely unoccupied in terms of time or space. The same time, the radio spectrum allocated to other MNOs is fully utilized by their customers and the impossible further spectrum provision results in low QoS or even worse in customer churn. Therefore, in order to improve spectrum management and frequency allocation, the spectrum trading among frequency owners (or MNOs) and service providers (or MVNOs) is proposed [12].

Generally, the MNOs can be considered as the spectrum owners of different mobile bands, and the MVNOs can be considered the entities that access these bands. It is worth saying that MVNOs can be independent content service providers (CSPs) (e.g. Viber, Facebook, Google) that do not own infrastructure resources, but they can be also related to specific frequency owners (MNOs). In the dynamic exclusive-use model [13], MVNOs grant the right of spectrum access to MVNOs. Another approach could be the case that MVNOs opportunistically access the free MNOs' bands without interfering with them. However, this approach would make the provisioning of performance guarantees more difficult. Furthermore, the cognitive network should be able to detect and change operating bands dynamically, something which increases the complexity of the system in this way.

In the case that CSPs are involved as MVNOs, same services can be offered by different MVNOs and the client has the option to select the most suitable one to him according to the cost and provided quality or performance. However, this work is focused on the case that some time, one MNO has offered all available spectrum to its clients and needs more frequency resources to serve additional requests. As a result, a related-to-MNO MVNO requests some frequency bands from different MNOs that sell their available spectrum, if any. It has to be also noted that, regarding the MVNOs, the estimation of the portion of requesting spectrum on each MNO is affected by the number of the users (their customers) in the different service regions. The MVNO buys the unused spectrum owned by other MNOs and is temporally hosted there (MNO BS) in order to provide the required services to related customers. In this case, MVNOs can decide if they further charge their clients for the offered service or not. If not, this procedure remains invisible to customers. However, in general, MVNOs choose appropriate service prices to charge users so that their profits are maximized.

A framework for spectrum trading is presented, where a double auction [14] is established to model the trading of unused bands among multiple MNOs (with free spectrum) and MVNOs who sell and buy the radio spectrum, respectively. So, when the frequency bands are underutilized, the owners of the free spectrum bands (MNOs) can sell these bands to MVNOs. In this way, MNOs may help MVNOs serve their own clients more effectively, and the same time gain some money. Since the value of the spectrum bands can vary due to the time-varying demand, an auction can be used for the selling and buying processes. MVNOs must obtain the spectrum by bidding for free bands made available by MNOs. After the radio spectrum is obtained, MVNO's clients can access the spectrum. With the frequency band auction, an optimal spectrum bidding strategy is required for a MVNO. Obviously, the MVNO aims to gain the optimal number of frequencies (enough to serve its clients) at the lowest possible cost.

A simple example is given for better understanding. In Fig. 1, a system with 3 MNOs is considered. Each MNO owns one band (i.e., a total of 3 bands). Of course, all of these spectrum bands are non-overlapping and hence there is no co-channel interference among different BSs (owned by different MNOs). It is defined that a service region is composed of multiple service areas, and each service area contains at least one BS. In Fig. 1, the service region consists of 3 service areas. It is highlighted that all of them are more or less overlapping. Note that in some part of the green service area, wireless access service for users is available from MNO-1, MNO-2 and MNO-3. Since there are multiple MNOs (BSs) owning multiple frequency bands, there is the chance for multiple MVNOs to be hosted in MNO's BSs too. If one specific MNO has obtained all its frequencies to its active users and needs more resources to serve more customers (for high definition video, real time applications, higher QoS), then it "transforms" into a MVNO that pursues spectrum from other MNOs. In this example, if MNO-1 cannot serve all its users due to lack of spectrum, a MVNO hosted by MNO-2 or MNO-3 will do this job instead (given that this user belongs to the service area of MNO-1 or MNO-2). Thus, a double auction can be applied to this multiple-seller multiple-buyer market structure.

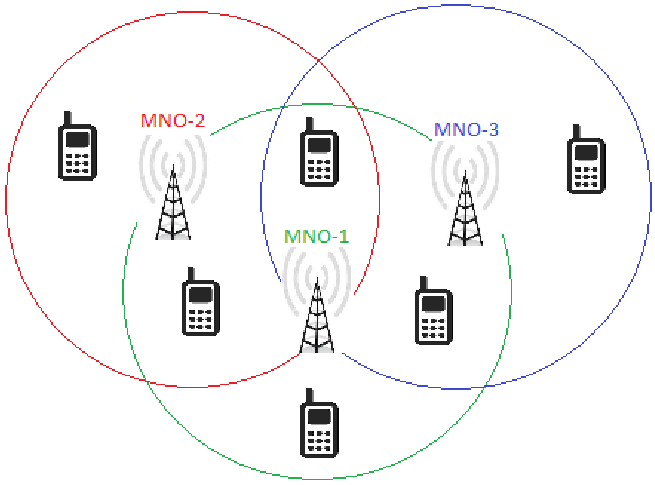

Figure 1. Service region with three overlapping service areas

V. CONCLUSION

Cellular technology is expected to be a critical tool for future connectivity. In 5G cellular networks of the future, virtualization is expected to be on the frontline, and it is a challenge to find ways to optimize the network and handle the vast data increase. Thus, it is imperative for the future 5G architectural models to be designed having in mind the IoT data explosion.

As described throughout this work, the next wireless virtualization solutions can be implemented at different parts of the network and also different levels: flow level, sub-carrier level, time slot level, or even at the lowest level of hardware components. There have been recent efforts to introduce wireless network virtualization, explain its performance requirements, architecture, uses cases and potential approaches to challenges. Although virtualization in future wireless access networks is expected to support the anticipated vast increase in the number of mobile devices, the heterogeneity in devices, requirements, and usage scenarios, leaves many hurdles yet to be taken. There are important unexplored research challenges such as resource management, inter-operability, instantiation, heterogeneity support, which should be addressed in order to realize an a virtualized 5G network that facilitates efficient resource allocation and multi-tenancy.

Regarding the spectrum trading, a future work could jointly consider the end users in the game as well. Assume the scenario where different CSPs, as MVNOs, offer their services hosted by one specific MNO. After the spectrum bands are obtained through double auction, the MVNO can determine the spectrum price to be charged to its users that maximizes its profit. In a service area where multiple MVNOs are present, users can choose the MVNO that provides the best payoff in terms of allocated bandwidth and service price. Therefore, MVNOs must competitively determine their spectrum bidding and pricing strategies so that their profits are maximized.

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