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On configuring radio resources in virtualized fractional frequency reuse cellular networks

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ABSTRACT

Virtualization of wireless networks holds the promise of major gains in resource usage efficiency through spectrum/radio resources sharing. Unlike the case in wired networks, achieving high capacity, providing effective isolation, and customization of the network requires intelligent configuration of wireless resources due to the effects of interference. In this paper, we focus on how to configure the "over-the-air" part of virtual wireless networks to enable simultaneous use of radio resources that overlap geographically. A configuration framework is proposed based on an infrastructure cellular network that employs fractional frequency reuse (FFR) and Multiple-input Multiple-output (MIMO) to combat interference. Multiple scenarios are examined that include various network sizes and base station distances. Five radio resources configuration cases are developed and investigated with each of these scenarios for a number of parameter settings (e.g., transmit power, MIMO degree). From the analysis of capacity data obtained from simulations, we observe some general trends in the aggregate spectral efficiency, and more importantly, a variety of tradeoffs between service providers (SPs) or virtual network operators. Based on these tradeoffs, we create configuration maps using which, a network resource manager can select specific network configurations (transmit power, MIMO, etc.) to meet the demand and capabilities of SPs and their subscribers.

1. Introduction

The explosive capacity demand in cellular networks has required network operators to increase capital (CAPEX) and operational expenses (OPEX) in order to improve their networks accordingly. However, operators have to control cost due to the predicted decreasing profit margin [1]. Therefore, *wireless network virtualization* has been proposed recently, with the benefits of increasing resource efficiency, enabling customized applications, and yet providing isolation between services [2]. The premise here is that spectrum, hardware, and network resources in wireless networks can be sliced on demand in a manner similar to CPU, storage, and memory in data center virtualization or network bandwidth in wired network virtualization to support customized services. To facilitate this virtualization, the functions of traditional network operators are expected to be split into two entities – Infrastructure providers (InPs) and Service Providers (SPs). InPs own the spectrum, hardware, and network resources. The "users" are SPs who get slices of these resources dynamically to support the services they provide to their own subscribers [2]. A *resource manager* is responsible for providing the correct configuration of resource slices for various SPs in each time period (see Fig. 1(a)). Spectrum aggregation or pooling [3] is considered as a major feature (pooling together each InP's spectrum for configuration by the resource manager and assignment to SPs) with the potential for large gains in spectrum efficiency.

Wireless network virtualization is a solution that breaks down the old fixed network architecture towards better efficiency, customization, and isolation. Implementing it on an existing physical network implies that we need not physically tear down the existing one and build up a brand new one. Instead, we just remove the "fixed" way of using resources and add a new management entity to dynamically realize multiple architectures on existing physical resources. A core problem is how we should manage the "virtual" resources. Previous work [4,5] on wireless network virtualization assumes "separate spectrum virtualization" (SSV), where spectrum is sliced, but in a completely *separate* or *orthogonal* manner for SPs in any given time period. As shown in the top half of Fig. 2, the spectrum slices allocated to SP_A, SP_B, and SP_C in the same time interval do not overlap, but may change dynamically in time.

However, spectrum is not like CPU resources or wired network bandwidth. Transmit powers, interference, mobility, channel conditions, the use of MIMO (device capability), distances between transceivers, all impact the available *capacity*. To exploit spectrum pooling , the work in [6] introduces "radio resource virtualization" (RRV) that allows a certain overlapping allocation of the spectrum

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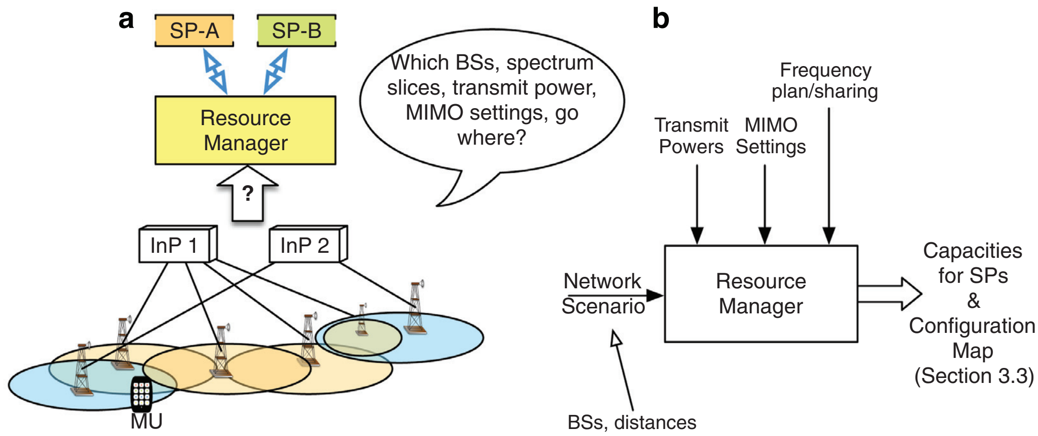

Fig. 1. High level view of wireless network virtualization considered in this paper.

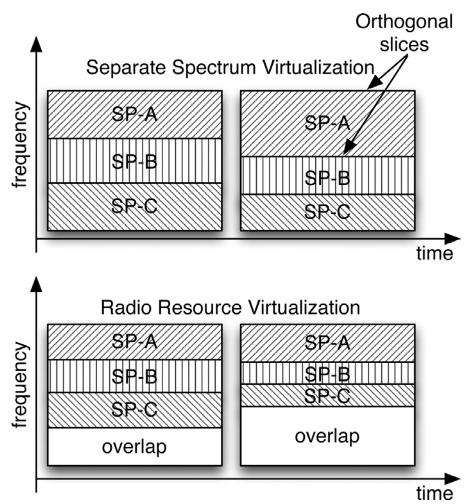

Fig. 2. Separate spectrum virtualization (SSV) vs. radio resource virtualization (RRV).

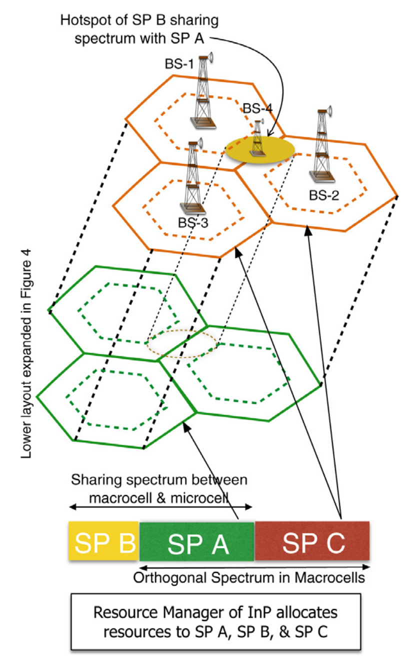

Fig. 3. A multicell virtual system with FFR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

slices to multiple SPs in the same time interval in neighboring or even overlapping geographic coverage areas. As shown in the lower half of Fig. 2, the "overlap" slices could be used by all three SPs with careful planning. In fact, the work in [6] illustrates (albeit in a simple scenario) why spectrum should be considered as a "radio resource" and that RRV often leads to better resource efficiencies compared to SSV [1].

The core problem therefore turns into how we manage cellular networks considering RRV. One question to ask is how can we configure the network to enable RRV to achieve the best resource utilization? Unfortunately, there is no definite or simple answer yet. The configuration problem becomes even more complicated as the network architecture becomes more complicated, such as when frequency reuse is adopted. For example, the resource manager has to decide what power level (in a given slice of spectrum) should be assigned to a given SP in a given cell. It has to determine how many antennas a given SP (or mobile units (MUs)) can use in a given cell. It has to decide how these may change depending on the distances between infrastructure entities such as base stations (BSs)). One example of the results of this paper shows that SPs that are deployed in smaller cells can benefit significantly by using the spectrum of SPs that are deployed over larger cells. However, if such configurations are enabled, the capacity of SPs deployed in larger cells may drop by 20% per subscriber. If the demand in larger cells can tolerate this drop (example during low load periods), this may be a preferred option for the resource manager. If not, more antennas may be used in larger cells to counteract the drop in capacity if the BS and subscriber devices are thus capable.

In this paper, we try to start answering the above questions through a framework examining several scenarios that includes a range of configuration cases. The framework constructs a cellular network with radio resources being shared between two SPs. One SP is deployed in 3 large cells with fractional frequency reuse (FFR) in these cells. The other SP operates in a smaller cell which is a subset of one of the 3 large cells. In practice, it is likely that many SPs may operate in many different sized cells. For example, the three-SP schematic (in Figs. 2 and 3) illustrates the generalized sharing problem. In such

[1] Please note that in this paper, from now unless otherwise specified, we use the word "spectrum" to mean radio resources.