A Practical Approach for Small Cell Sharing Using a Time-Multiplexing Scheme

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Abstract. The new requirements for 5G, in terms of latency and bandwidth, demand new technologies such as millimeter-wave small cells, requiring dense deployments to achieve good coverage. Even before the arrival of 5G, small cells were already being deployed to avoid congestion and achieve a good Quality of Service (QoS) in areas with high densities of potential users. These infrastructures require large investments, forcing operators to share them or to use the services of a neutral host, responsible of installation and maintenance. In this paper we present a practical approach for different operators to share a small cell infrastructure, while allowing them to use their respective dedicated frequencies, adjust any parameter, or even deploy any particular radio access technology. This way, each operator can provide a differentiated service that may represent a competitive advantage even on the same physical infrastructure.

Keywords: Small cells · Multi-tenancy · Time-sharing · 5G

1 Introduction

The exponential growth of mobile traffic and the incessant subscriber demand for a better QoS force operators to look for alternatives to increase their network capacity. Furthermore, ITU-R has defined a set of requirements related to technical performance for IMT-2020 networks (5G) including very low latency communications (1 ms) and lower energy consumption [1]. Ultra-dense small cell architectures have proven to be a good choice to address such requirements, as demonstrated in [2–4]. By increasing the density of base stations in an area it is possible to provide higher bandwidths to more users at less power with lower latencies. This holds in areas with high user densities, such as malls, downtown shopping areas, stadiums, factories and enterprise facilities.

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However, although the installation of low power nodes (such as small cells) entails significant lower costs than the installation of macrocells (thanks to their small form factor and simpler power sources), these nodes still require substantial investments. Indeed, “mobile-first” “bring-your-own-device” (BYOD) businesses require very good coverages regardless of the operators providing service to employees, customers or visitors [5]. In such scenarios there are market incentives for multi-operator infrastructure sharing or neutral hosts. Distributed Antenna Systems (DAS) or Wi-Fi hotspots are typical neutral host approaches. Nevertheless, both systems have drawbacks, such as the high cost of DAS deployments and the QoS challenges in Wi-Fi installations.

Nonetheless, there are non-technical issues that slow down the adoption of sharing strategies. For example, some regulators do not permit spectrum sharing because they perceive it as a risk against healthy competition (in Spain this was the case prior to March 2017), and some operators may perceive risks in sharing their infrastructure with their competitors. In this regard, according to [5], a good approach is to combine dedicated and shared cells. Also, recent research projects have considered the “Small Cells as a Service” concept [6], where different operators share a cloud-enabled small cell.

In this paper we present a practical implementation that makes it possible to assign small cells on demand to particular operators in environments with dynamic, high user densities. In this scenario different operators may require more or less resources (small cells) from some moment on. Therefore, a mechanism for fast cell reallocation is necessary. We also present our work-in-progress and the future research lines.

In Sect. 2 we discuss related work in small cell sharing. In Sect. 3 we explain our practical approach. Finally, in Sect. 4 we provide some conclusions and describe our future work.

2 Related Work

In their traditional business model, operators own a network and leverage it to provide better services (in terms of coverage, bandwidth, etc.) than their competitors. Nevertheless, the introduction of new wireless technologies (such as 4G or 5G) is increasingly complex and requires frequent updates. Telecommunications equipment is a commodity and the mere provision of a new technology does not provide a competitive advantage. Operators try to differentiate themselves with specialized services. In this context Radio Access Network (RAN) sharing is a common strategy to increase coverage while keeping costs at bay [7].

3GPP has considered this problem and has provided specifications to share the network [8]. There exist different technical architectures for RAN sharing, ranging from mere location and “tower” sharing (passive RAN sharing) to using exactly the same infrastructure (for example when an operator signs an agreement with another for the users of the first to roam over the infrastructure of the second). Multi-Operator RAN (MORAN) [9] is an interesting intermediate architecture in which operators retain a great level of control over their traffic and capacity because, even though they share the same physical eNodeB, several virtual instances with independent parameters are generated. For example, each operator keeps using its own dedicated frequency bands and controlling its QoS levels. However, at least one independent radio head is required for each operator.

RAN sharing becomes especially relevant for deployments that require the installation of a large number of base stations, for example small cell deployments to increase network capacity in very dense areas [2–4]. The number of subscribers per cell decreases with the coverage area, reducing eNodeB congestion. Millimeter bands (30 GHz–300 GHz) have raised a lot of interest for 5G small cells because they are uncongested and allow allocating large channel bandwidths (and thus increasing transmission rates). In fact, as they are subject to higher propagation losses, they are only adequate for dense infrastructures [10].

Although a MORAN architecture provides several advantages, it has been less extended in the small cell ecosystem because of its higher complexity and deployment effort [5] than other architectures such as Multiple Operator Core Network (MOCN) [8], where all RAN elements are shared (including the spectrum). Our solution is similar to MORAN, in the sense that we make it possible to dynamically assign small cells to operators respecting their particular frequencies and configurations. This way, it is possible to cover an area with small cells and dynamically assign them to different operators according to their needs at every moment.

Other authors have also studied solutions for radio resource sharing among operators. The typical approach is based on a Cloud-RAN architecture [11,12] that distributes the implementation of the cellular base stations. Baseband processing is centralized on a cloud server, leaving only the radio frequency functionality in the base stations and, thus, simplifying radio resource sharing. This method reduces the complexity (and therefore, the cost) of radio access network equipment and, at the same time, increases flexibility and efficiency. Cloud-RAN is usually combined with Software Defined Radio (SDR), so that baseband signal processing is performed purely on a general purpose computer (implementing by software elements such as modulators, filters and mixers, which traditionally were implemented by hardware) [13]. Only conversion, channelization and amplification are implemented by hardware at the transmission site.

Most RAN sharing proposals take advantage of OFDMA spectrum division, introduced in cellular communications by the Long Term Evolution (LTE) standard. OFDMA splits spectrum into time and frequency slots (Physical Resource Blocks, PRBs), which are dynamically allocated to the subscribers. In [14] the authors introduce the Network Virtualization Substrate (NVS) concept, which applies a two-step scheduling process for enabling “network slicing” [15] up to the eNodeBs. In this way, the entire physical network is divided into several logical networks specially adapted to provide services with different QoS requirements. On each transmission opportunity, PRBs are firstly distributed among the slices according to their requirements, and then each slice decides how to allocate the received resources among their subscribers. In [16] the authors analyze an extension of NVS that enables partial resource reservation. Each slice is guaranteed a minimum amount of PRBs, but it may also use idle resources of the other slices.

The NVS concept can be extended to enable sharing a RAN infrastructure by multiple Mobile Virtual Network Operators (MVNOs) through the allocation of a set of slices to each operator, as considered in [17]. The authors propose a new scheduler that assigns PRBs to different operators based on the decisions taken by a SDN controller, so that different slices may share a common pool of frequencies according to their requirements.

Considering dense deployments, a finer and more efficient use of the RAN elements can be achieved by centralizing the control plane of the base stations, as proposed in [18,19]. Thus, the interference from adjacent cells can be reduced by considering their location and the interference perceived from other nodes [18] or taking into account the PRBs allocated by the adjacent cells [19].

Although RAN sharing based on a shared scheduler enables efficient spectrum utilization, since MVNOs can use those PRBs that are not assigned to other operators, the control over radio resources is coarse. The operators must agree on parameters such as transmission and reception gains of the radio devices. The radio access technology (RAT) must also be the same for each operator on each radio. In addition, operators have less control over the scheduled PRBs, which limits their choices of slots to improve channel conditions for their subscribers. This fact also hinders the adoption of this approach for multiple independent Mobile Network Operators (MNOs), as control signaling and management is performed in specific PRBs and times in LTE. Finally, spectrum sharing is still forbidden or has been only recently allowed (for example, in Spain), making alternative solutions interesting.

Our proposal provides a simple solution for several independent operators to share a small cell infrastructure, while allowing them to use their respective dedicated frequencies, adjust any parameter, or even deploy any particular radio access technology. To the best of our knowledge, this is an original approach.

3 Implementation

We assume an scenario with a high user density (mall, downtown, stadium, etc.). In it, in order to ensure good QoS, it is necessary to deploy a dense small cell network covering the whole area.

A multi-operator "neutral host" or "infrastructure provider" is in charge of the small cell network, which is shared by different operators. A "neutral host" orchestrator distributes the radio devices among the operators, based on algorithms that seek to maximize the aggregate operator performance and user QoS, under certain Service Level Agreements. Due to the dynamic user location and densities, small cell radios must be configured in the shortest time possible.

With this scenario in mind we have implemented a LTE small cell sharing proof-of-concept using OpenAirInterface (OAI) [20]. OAI is an open source platform developed by the OpenAirInterface Software Alliance (OSA), which allows running a 3GPP-compliant LTE testbed on a general purpose computer and an SDR device. It provides all the necessary network entities in an LTE architecture (eNodeB, MME, HSS, SGW and UEs). The OAI front radio is compatible with some popular SDR devices, such as Ettus Research USRPs and Lime Microsystem's LimeSDRs. Specifically, in our proof-of-concept we have used a LimeSDR device, a low cost software defined radio which is able to operate in frequencies ranging from 100 kHz up to 3.8 GHz, and handle up to 61.44 MHz channels [21].

3.1 Initial Tests

Each small cell would be implemented on an embedded computer running the basebands selected by each operator (in our experiment OAI's eNodeB). The small cell would be connected to an operator Core Network (CN) by decision of the neutral orchestrator. However, OAI is not designed to be "plugged" and "unplugged" from the SDR device, so our first step was a procedure for disabling the eNodeB that is using the radio up to a certain moment and launching a new eNodeB for the new operator. This procedure takes setup times of approximately 16.3 s with a USRP SDR device and 10.2 s when using a LimeSDR.

These times may be quite large for highly dynamic scenarios, so we analyzed the different stages completed during the setup of an OAI eNodeB in order to decrease them. Successively, the eNodeB:

1. starts the set up for each protocol stack layer on independent threads,
2. requests the SDR device,
3. configures the SDR device with the appropriate radio parameters,
4. starts the transmission.

As all the stack processes are independent of the radio, a first possibility to reduce this delay is forcing those processes to be ready before the radio is allocated to the eNodeB. Therefore, we modified the eNodeB to complete all internal start up tasks and then keep waiting for a grant message to use the radio device. Thereby, the transition delay is reduced to the time it takes to configure the SDR device. We estimated this delay running multiple independent executions, and the results show that, on average, it was reduced to 2.81 s.

3.2 Abstracting the Radio from the eNodeBs

We then analyzed other possibilities. We found that by introducing a new element, exclusively in charge of all the transceiver tasks, we are able to keep the previous transceiver configuration state. This way, on each radio reallocation, it is only necessary to modify the parameters that differ from those in the previous session, so the transition time is reduced. We called this new element "transceiver coordinator".

Figure 1 shows the proposed system architecture. The transceiver coordinator and operator's base station processes run on an embedded computer on which the SDR device is connected. In our experiment, both processes are connected

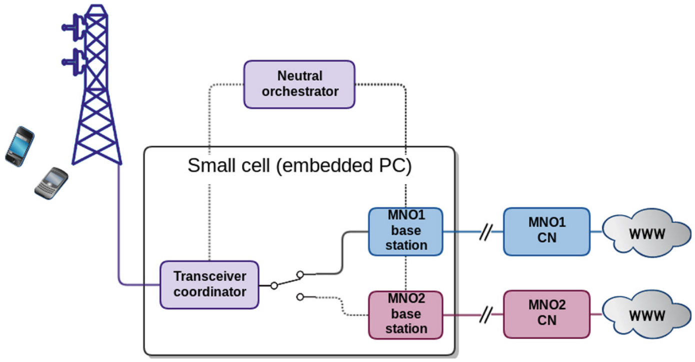

Fig. 1. High-level system architecture.

through UNIX sockets. All the operator's core networks are reachable from this computer. The base station processes susceptible to take the radio are kept ready for being deployed and to inform the neutral orchestrator about the radio parameters they need. When a radio reallocation takes place, the orchestrator informs the transceiver coordinator and notifies the new radio parameters, which are compared with the previous configuration and set only if they are different. Then, the transceiver coordinator notifies the radio availability to the implied base station processes. From that moment on, the new base station process may begin transmitting and receiving IQ samples.

The non-deterministic communication delay between the base stations and the transceiver coordination processes does not affect the radio frequency transmission. Most of the commercial SDRs exchange signals by blocks labeled with

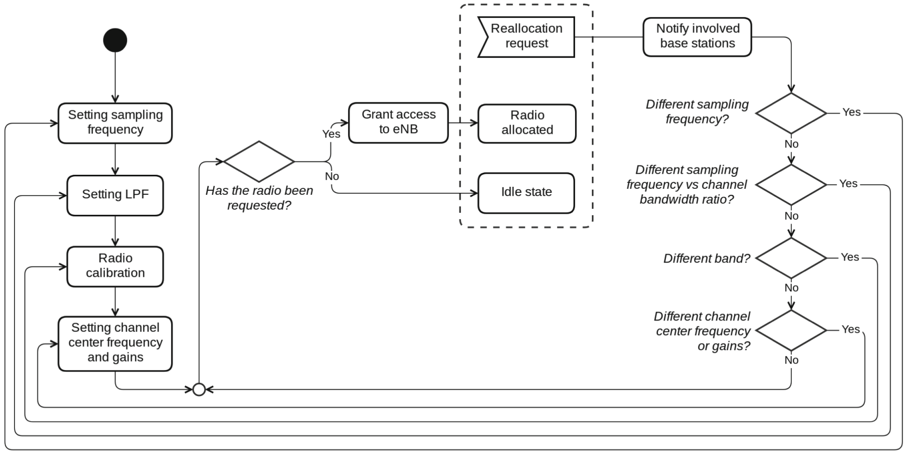

Fig. 2. Flow diagram of transceiver coordination processes.

time stamps, identifying the instants in which they must be transmitted or were received, according to the radio clock. The margin between the moments when the samples are generated and when they must be transmitted is large enough to allow the transceiver coordinator to receive them on time.

Figure 2 shows the flow diagram of the transceiver coordination process. Specifically, for reallocating the radio to another operator, it:

1. is notified to allocate the radio to a new operator,
2. notifies both base station processes involved in the reallocation procedure,
3. sets those radio parameters which must be modified from the current session,
4. starts using the new base station sockets for exchanging the IQ samples with the radio.

3.3 Results

Some minor tasks performed during the radio initialization (which take up to 710 ms) can be avoided, as they only need to be run once. The exact time to reassign a small cell to a new operator will depend on the parameters that must be modified given the ones used by the previous operator:

- Changing the sampling frequency takes only 225 ms on average, but it requires reestablishing the baseband low pass filter.
- Setting the baseband low pass filter consumes about 1.10 s. Once established, the filter may not need to be modified until the bandwidth/sampling frequency ratio changes.
- The radio calibration task introduces a delay of about 0.73 s. This task should be performed when the channel central frequency, the channel bandwidth or the sampling frequency are modified. However, the calibration may be reused for adjacent channels without noticeable signal degradation. Within LTE band 7, we were able to keep signal quality by calibrating the radio once at the band center frequency and then using different channels along the band (sharing the rest of the parameters).
- Finally, modifying the reception and transmission RF frequencies and gains takes 43 ms on average.

If both operators share the same parameters, the transition delay will only be the time to grant the communication to the new operator and the time to synchronize the base station with the radio clock (which in our tests was always 1 ms). If it is necessary to change the channel frequencies and gains, this delay increases by about 43 ms.

A new sampling frequency or channel bandwidth leads the transition to slow down for up to 0.96 s. However, setting the low pass filter and the sampling frequency could be avoided by digitally resampling and filtering the baseband signals at the transceiver coordinator, so that the sampling frequency and filter on the radio remain unchanged.

Considering all the aforementioned optimizations, it would be possible to switch operators in just 44 ms in the worst case, and in less than 1 ms when both radio services use the same parameters. This is a great improvement from the 10.2 s we achieve when we do not preserve the radio configuration state. Therefore, it should be possible to deploy a small cell infrastructure in which an "infrastructure provider" would assign small cells dynamically to the different operators according to their instant needs in up to 44 ms.

4 Conclusions and Future Work

In this paper we have presented a practical approach for different operators to share a small cell deployment. Each small cell is assigned exclusively to one operator at a time. Thus, such operator may keep a tight control of traffic and capacity, as it continues using its own dedicated frequency bands and controlling its QoS levels. It may even use a different RAT. If one operator requires more resources at some moment, it may be granted more small cells that were initially assigned to other operators. According to our analysis, this reallocation can be performed in less than 1 ms in optimum circumstances and up to 44 ms in the worst case.

An LTE proof-of-concept has confirmed the viability of our approach, which is akin to the MORAN concept. We are currently exploring other mechanisms to share small cells. For example, how to transmit different waveforms in different frequencies of a small cell at the same time, even when they use different RATs.

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