Resource Sharing in Heterogeneous Cloud Radio Access Networks

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***Abstract*—Heterogeneous Cloud Radio Access Networks (H-CRAN) incorporate Heterogeneous Networks (HetNet) and Cloud Radio Access Networks (C-RAN) concepts for next generation cellular networks. H-CRAN exploits the heterogeneity of macro and small cells from HetNet, enabling cellular networks to achieve a higher spectral efficiency. Meanwhile, concepts from CRAN involving baseband units and remote radio heads enable H-CRAN to insert a centralized point of processing for cellular networks, reducing capital and operational expenditures. In this article, we investigate resource sharing in H-CRAN in three levels: spectrum, infrastructure, and network. For each level, we discuss the benefits and challenges, highlighting key enabling technologies that make resource sharing feasible in H-CRAN, such as software defined radio, virtualization, network function virtualization, and software defined networking. Through these technologies, H-CRAN can be virtualized in an overlay network capable of achieving enhanced infrastructure and spectrum sharing.**

I. Introduction

In this paper, we examine the *sharing opportunities* enabled by the new Heterogeneous Cloud Radio Access Networks (H-CRAN)[1] at the spectrum, infrastructure, and network levels. H-CRAN enables these opportunities through the integration of Heterogeneous Networks (HetNets) and Cloud Radio Access Networks (C-RANs).

From HetNets, H-CRAN inherits the tiered deployment of small and macro cells. Small cells, such as picocells (low power traditional base stations) and femtocells (small area access points, often placed indoors), increase spectrum reuse, resulting in significant gains in network capacity. C-RAN introduces digital functional units, called Baseband Processing Units (BBUs), to handle computing workloads, such as signal processing and resource management. Moreover, C-RAN also inserts radio functional units, called Remote Radio Heads (RRHs), to handle RF translation [2]. Within the BBU, a centralized processing entity, called a central processor, computes workloads, while accounting for Quality of Service (QoS) requirements, *e.g.,* low round-trip time and high bandwidth, as well as resource constraints, *e.g.,* power, time, and frequencies bands. Centralizing processing enables optimized orchestration of the number of users per base station, energy consumption, and interference [3].

H-CRAN was conceived to do a step further in performance by incorporating cloud computing into HetNets to accomplish large-scale cooperative signal processing and network functionalities with increased network capacity [4]. Such a large-scale cooperative signal processing enables H-CRAN to exploit advanced spatial signal processing techniques in the physical layer (PHY), such as centralized massive multiple-input- multiple-output (MIMO) and the distributed large-scale spatial cooperative processing [1]. Whereas the cloudization of network functionalities enables H-CRAN to perform Cooperative Radio Resource Management (CRRM) [5] and Cooperative Self-Organizing Network (CSON) [3] to schedule and reorganize resources to supply huge bit rate demand for ultra-dense communication scenarios.

Integrating of two separate network architectures is not free from challenge [4]. The multi-tiered approach of HetNets increases the complexity of interference avoidance [3]. Separation of functionality into RRHs and BBUs, as suggested by C-RANs, incurs the need for a higher capacity backhaul to avoid delays and service degradation [6]. Fortunately, many of these challenges are offset by the *dynamic resource sharing* enabled by H-CRAN.

We discuss such resource sharing in H-CRAN considering three levels: spectrum, infrastructure, and network [7]. In terms of spectrum sharing, H-CRANs facilitate improved spectral efficiency through distributed multi-antenna use, inter-tier interference mitigation, and dynamic spectrum access. At the infrastructure level, physical entities (*e.g.,* antennas, base stations, backhaul, and access points) can be shared among network operators. At the network level, spectrum and infrastructure from an H-CRAN can be abstracted into network slices defined by higher level metrics (*e.g.,* throughput and processing). At each of these levels, H-CRAN enables resource sharing benefits including a dynamic pool of spectral resources, enhanced infrastructure coverage, and virtual networks tailored to particular service goals [8].

The advantages of resource sharing in the context of H-CRAN are significant, although research on this topic is in its early days. We advance the state of this research through the:

- Systematic investigation of resource sharing in H-CRAN, exploring three levels: spectrum, infrastructure, and network;
- Identification of major challenges in employing dynamic resource sharing in H-CRAN;
- Outlining of research directions to address the major challenges of resource sharing in H-CRAN.

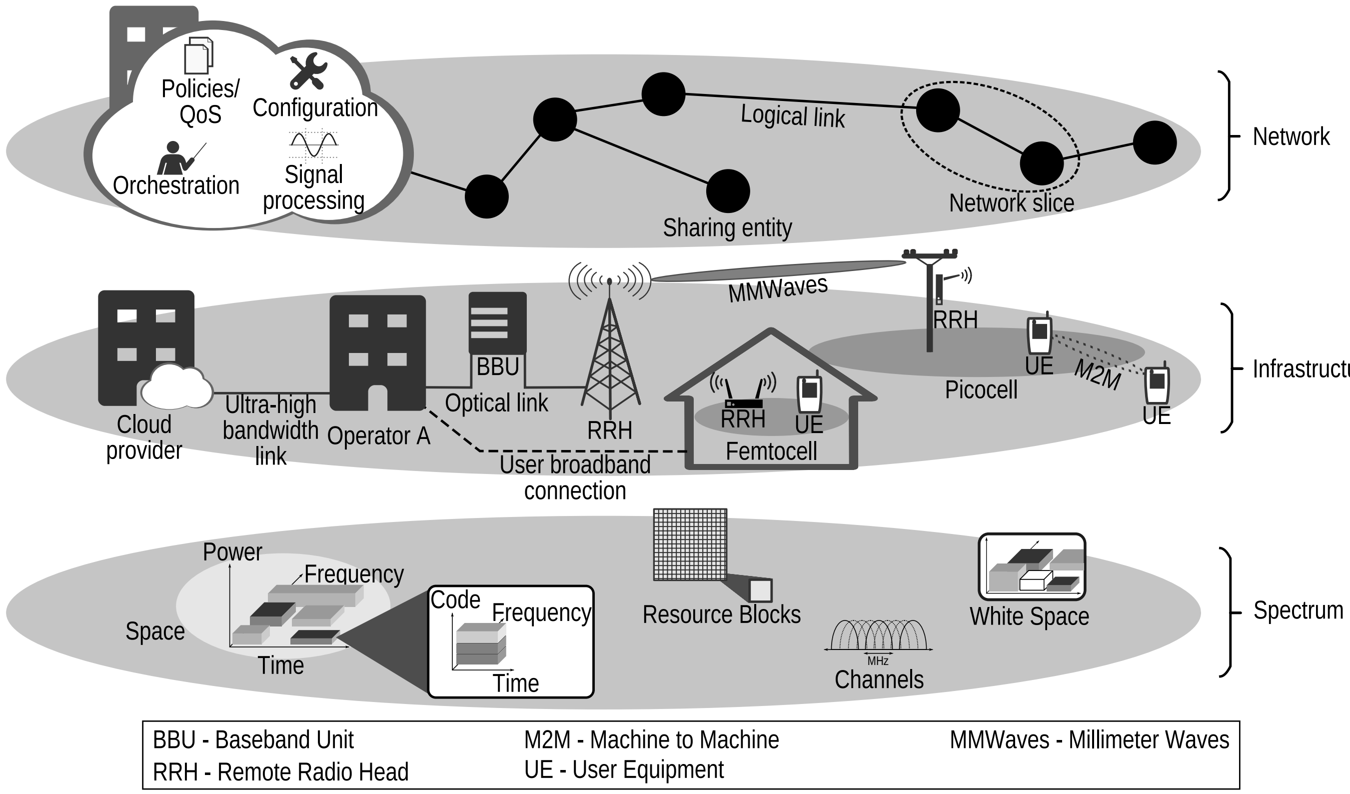


Figure 1: H-CRAN: Resource sharing levels

- A summarization of trending technologies for the conceiving of resource sharing in H-CRAN.
- An experiment to measure the gains of spectral efficiency in H-CRAN through resource sharing.

All of our contributions intend to exploit resource sharing in H-CRAN, investigating the feasibility, opportunities, and challenges, as well as quantifying the benefits of using it in H-CRAN.

The remainder of this article is organized as follows. In the next section, we outline three views of resource sharing in the context of HCRAN, based on spectrum, infrastructure, and network sharing. We then address each of these in more detail in subsequent sections. After, we present results of a preliminary quantitative analysis of the benefits of resource sharing and HCRAN. Finally, we presents our conclusions and directions for future work.

II. Concepts of Resource Sharing in H-CRAN

In this section, we present an overview of resource sharing in H-CRAN. To present this overview, we divided H-CRAN in three sharing levels, depicted in Figure 1.

- **Spectrum sharing** - The radio frequency spectrum is a costly and finite resource bounded by licenses and agreements. Therefore, sharing spectrum among operators becomes an option to extend the pool of available resources [9]. Spectrum sharing may be performed through different allocation units, *e.g.,* channels used on IEEE 802.11.* and Resource Blocks from LTE frames. In addition, unused portions of the spectrum, called white spaces, can be also used as allocation units to be shared through Dynamic Spectrum Access. Each allocation unit can be expressed as power, frequency, time, space, and code, being shared and computed at the BBU.
- **Infrastructure sharing** - With the increasing traffic from mobile devices, operators have to constantly upgrade their radios access and backhaul infrastructure, incurring in additional CAPEX and OPEX [10]. Sharing infrastructure among operators presents a promising solution to reduce costs. Nowadays, a key factor for achieving infrastructure sharing is the virtualization of physical entities by decoupling their functionality from the hardware, through a standardized software programmable layer [7]. Through virtualization in H-CRAN, concepts from HetNet and C-RAN begin to blur, because femtocells and picocells are created by RRHs instead of low power base stations and access points. This means that the infrastructure workload is computed at the BBU, where resource availability as well as overloading of physical entities becomes easier to assess.
- **Network sharing** - Resources of spectrum and infrastructure can be abstracted into sharing entities, network slices, and logical links. A sharing entity represents a set of available resources, *e.g.,* a base station, a set of interconnected base stations, or part of a base station, such as antennas. Network slices, in turn, are the arrangement of available resources among two or more sharing entities.

Furthermore, logical links are sharing entities of link type that connect others. Given this abstraction, network sharing focuses on managing available resources, regardless of their physical representations, *e.g.,* spectrum and infrastructure. At this level, the BBU can be responsible for processing the entire network configuration, orchestration, signal processing, and accounting for policies/QoS requirements.

Resource sharing has been extensively investigated in terms of spectrum sharing [9] [11], infrastructure sharing [7] [10], and network sharing [12] [13]. In such investigations, research focused on topics, such as resource scheduling, fairness, reliability, flexibility, elasticity, energy efficiency, CAPEX and OPEX minimization, and interference management. In this article, we focus on the promise and challenges of resource sharing in the context of H-CRAN.

III. Spectrum Sharing

Combining the centralized computation of C-RANs with the multi-tiered architecture of HetNets presents several opportunities for sharing at the spectrum level. Firstly, this combination simplifies the interference and orchestration processing problems encountered by both approaches. Secondly, secondary use of spectrum – in a Licensed Shared Access (LSA) mode – becomes feasible with the capabilities of H-CRAN. Each of these opportunities is described bellow.

HetNets are already regarded as an effective method for achieving higher spectral efficiency, as evidenced by 3GPP Releases 10 and 11 (and beyond). The main reason for this endorsement is the opportunity for reuse of spectrum at several different network tiers. However, Enhanced Inter-cell Interference Coordination (eICIC) is necessary to deal with interference among network tiers sharing the same spectrum. eICIC reduces interference in the frequency domain by employing Carrier Aggregation (CA), in the time domain with Almost Blank Subframes (ABS), or by using power control [14]. Enabling advanced frequency and time domain techniques in traditional network architectures requires a high degree of base station connectivity in the form of a direct X2 interface between pico and macro cells.

H-CRAN, different from HetNet, directly enables the application of advanced CA and ABS techniques because processing for both pico and macro cells is orchestrated from the same BBU. Moreover, the central processing aspects of C-RAN, combined with the multi-tier architecture of HetNet, enable new methods to handle inter-tier interference [1]. Such an application of interference cancellation, based on the differing power levels among tiers, is discussed in a non-cooperative sense by Learned *et al.* [11]. The centralized nature of an H-CRAN architecture furthers this approach by easing the identification of suitable channels for co-channel inter-tier operation.

The centralized processing provided by the integration of HetNets with C-RANs enables the application of new methods for efficient spectrum use. Eliminating the processing constraint of backhaul by computing base stations workloads

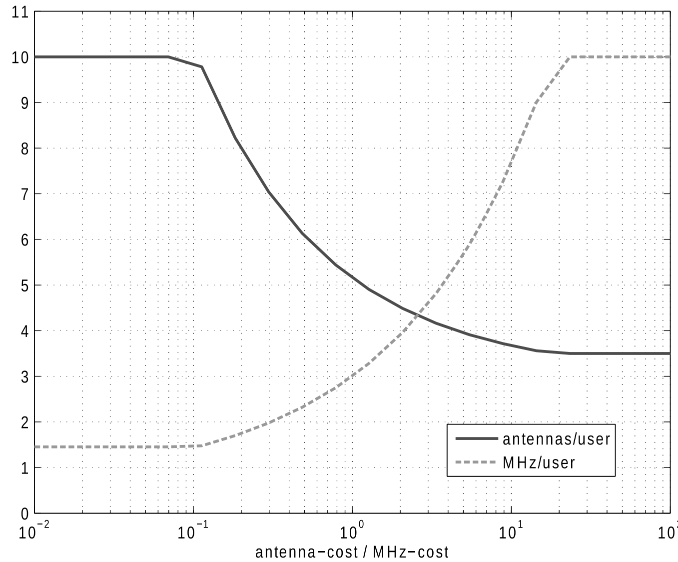


Figure 2: Optimum number of antennas and spectrum per user

with zero delay at BBUs, paves the way for ideal-backhaul interference coordination. Cloud Computing based Coordinate Multi-Point (CC-CoMP) provides an example of such coordinated transmission and reception. A CC-CoMP-enabled H-CRAN resembles a large distributed MIMO system where femto, pico, and macro cells are simply RRHs connected to a centralized baseband processing center in which signals are jointly processed. By eliminating the strict backhaul and synchronization requirements among distributed cells, joint processing becomes practical and economically viable in H-CRAN.

When using CC-CoMP, user rate increases with the number of picocells or antennas involved, even in the case of single-antenna UE. This improvement suggests a trade-off between the number of cooperating cells and spectrum [2]. The impact of the increasing number of picocells and antennas is clearer when considering a virtual network operator, which obtains antennas and spectrum from a pool, and configures the network on-the-fly. The pool of antennas is a feature of H-CRAN, whereas the spectrum pool may come from LSA, for example. The network operator becomes free to use spectral and infrastructure resources, according to leasing cost of each and required performance. In Figure 2, the trade-off is depicted through the optimal number of antennas and spectrum (MHz) required to satisfy a minimum rate constraint of 60 MBps and SINR of 10 dB, as a function of the ratio of the antenna to spectrum costs. The study in Gomez-Miguelez *et al.* [2] outlines scenarios for which more infrastructure and less bandwidth use is better and vice-versa. The inherent flexibility enabled by H-CRAN supports the dynamic tradeoff between infrastructure and spectrum.

The flexibility of the H-CRAN also enables future infrastructure services that go beyond “Infrastructure As A Service”. H-CRANs allow the spectrum to be shared with a much finer granularity than alternative approaches. In LTE, for example, sharing can occur in a resource block or in a subframe, whereas the joint processing enabled by H-CRAN allows sharing at the level of symbols. Finer granularity of sharing enables better adaptation to different operator demands and network heterogeneities, resulting in improved resource utilization. Furthermore, we can also consider spatially multiplexed streams belonging to different operators and sharing the same spectrum, *i.e.,* confining the signals from different operators to different physical locations whilst using the same spectrum. In this scenario, H-CRAN performs signal processing to convert the different streams into a single real signal that will be transmitted through the air, such as shown in Figure 3. These operations may be similar to today's Orthogonal Frequency Division Multiplexing (OFDM) or Filter Bank MultiCarrier (FBMC) modulation and spatial precoding. Each operator's stream of complex samples is modulated and encoded differently, offering vendor variety or service/market/client adaptation, but operating in the same spectrum bands.

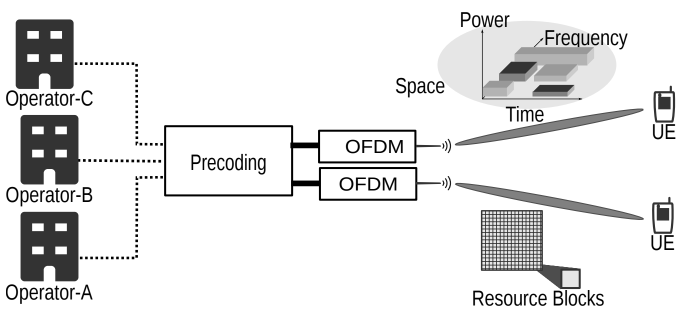


Figure 3: H-CRAN: Spectrum sharing level

Finally, H-CRAN architectures enable the application of cognitive radio techniques for spectrum sharing. H-CRAN can be viewed as a large scale, highly capable cognitive radio, where several distributed radios are connected to a central processing element. The H-CRAN processing unit has a clear picture of spectrum use from its numerous distributed sensor elements, allowing for high confidence when selecting channels. The integration of such a volume of sensing data directly enables the realization of LSA style use of spectrum by providing sufficiently reliable information to respect spectrum rights of a primary user.

At BBUs, central decision making entities, with access to a wealth of information, require less complex techniques for the determination of intelligent actions. Since these techniques are centrally administrated, regulation of autonomous radio action is simplified, *i.e.,* regulators need only to monitor the decisions of one central element, rather than several distributed ones. More than any other aspect, easing the requirements on effective regulation makes H-CRAN architectures an enabling technology for the use of cognitive radio methods for spectrum sharing.

IV. Infrastructure Sharing

According to 3GPP, infrastructure sharing among network operators is classified in two categories: (*i*) passive sharing and (*ii*) active sharing [15]. In the former, operators share their network related entities that are not computational, such as sites, building premises, and masts [7]. For example, in some Brazilian cities, the deployment of new towers in some areas is only granted when all towers in these areas have their capacity exhausted. Therefore, in this case, the passive sharing among operators is mandatory to provide capacity without the need for new towers. Active sharing, in turn, encompasses entities that are directly bound to the network processing, *e.g.,* base stations, access points, backhaul, routers, and switches. Mechanisms that abstract these entities can be used to make them accessible from software, easing their remote management through the network [10]. Such an abstraction can be performed, for example, through the use of virtualization and Software-Defined Networking (SDN) paradigms. Since passive sharing is well exploited and is already provided by third parties [10], in this article we focus on active sharing, which enables massive reduction of CAPEX and OPEX.

In H-CRAN different from HetNets and C-RAN, RRHs replace base stations and access points, among other Radio Access Networks (RAN) devices, as depicted in Figure 4. Through a high capacity backhaul based on millimeter waves and/or optical links, RRHs upload their workload (*e.g.,* modulation and MIMO processing) to be computed at the BBU. Different from a C-RAN environment that focus on macro cell workloads, in H-CRAN the huge amount of processing workload coming from macro and small cells will eventually turn the sharing of BBUs a need, creating BBU pools. Operator resources from macro and small cells can be efficiently shared by having their workload optimally processed at shared BBU pools through Cloud-Computing-based Cooperative Radio Resource Management (CC-CRRM) [1]. For example, by centralizing the workloads, the BBU pool can easily identify a macro cell as overloaded, directing users to handover to a shared underutilized small cell from another operator (*e.g.,* using IEEE 802.21) without the need for additional steps to process the inter-operator handover.

In a recent 3GPP technical report [15], different scenarios of infrastructure sharing are defined for common cellular networks. We have remapped these scenarios to the H-CRAN context. Next, for each remapped scenario, we present a briefly description, and discuss a major open challenge.

In the first scenario, the core of an operator is shared with other operators to handle two or more RANs. In H-CRAN, the sharing of an operator core can be represented by the BBU processing capacity being shared among different RANs. For instance, in Figure 4, let's suppose that BBU-B becomes overloaded by processing heterogeneous cells workloads from RAN-B. Therefore, BBU-B can forward its workload to be processed on the idle BBU-A. In this scenario, a major challenge is how to share the processing capacity among BBUs by distributing the workload without inserting more complexity. The workload distribution can be modeled as an optimal problem that considers the distribution of workloads among BBUs similar to, for example, a bin packing problem considering frequency, time, and space, and the container as

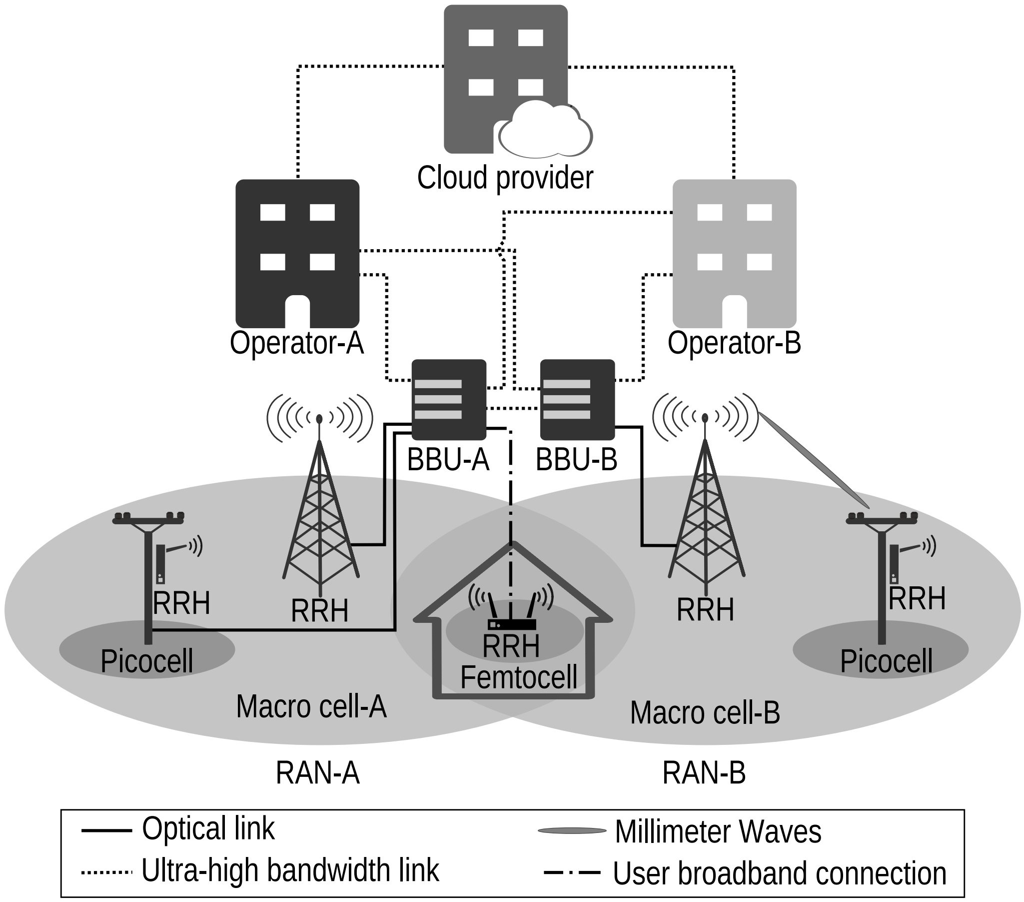


Figure 4: H-CRAN: Infrastructure sharing level

the BBU. It means that the workload distribution is an NP-hard problem that must be processed without compromising BBUs to meet strict performance requirements. For example, according to a white paper from China Mobile Institute Research [5], BBUs have a time restriction for processing workloads of $5\mu s$ for 8 antennas using 10∼20 MHz per carrier in LTE/LTE-A. According to the strict performance requirements, heuristic solutions must be explored to solve the problem of workload distribution.

In the second scenario, a RAN from an operator is shared with other operators without mixing spectrum resources. In H-CRAN, the same scenario would be represented by BBUs processing workloads from a RAN without mixing their spectrum resource pool. BBUs may exploit Cloud-Computing based Cooperative Self Organization Networking (CC-CSON) techniques to orchestrate all the RAN connected to the BBU pool. Using CC-CSON, the BBUs exchange information to allow subscribers from different operators to use the same RRHs and gain access to the network. However, the isolation of spectrum resources of each operator is kept, *i.e.,* frequencies of both operators are not shared. In Figure 4, RAN-A could have its workload divided between Operator-A and Operator-B to be forwarded and processed by their respectively BBUs. This forwarding can be performed directly, between BBU-A and BBU-B, or indirectly, through a Cloud provider. In this scenario, the main open challenge is how to provide the workload exchange among BBUs. The workload exchange requires the definition of a new interface and stack of protocols among BBUs, whereas there already exist interface definitions for communication between BBUs and RRHs, such as the Common Public Radio Interface (CPRI) and the Open BBU-RRH Interface (OBRI) [5].

The third and fourth scenarios refer to the sharing of coverage area among operators, being performed partially and fully respectively. Partial sharing means that RANs from different operators can be shared within a small geographic area. Full sharing, in turn, combines RANs from different operators completely to enlarge their coverage in a country. BBUs could accept access from subscribers of different operators inside their own infrastructure to expand the coverage area. In addition, BBUs can share their workload, as well as their RANs, with other operator's BBUs, considering all the entities shown in Figure 4. In this scenario, a partially shared H-CRAN has the challenge to provide a policy mechanism to grant permission to or restrain operators from using other RANs. For fully shared H-CRANs, scalability becomes a major challenge because there are physical limitations to moving workloads among a huge number of BBUs as well as

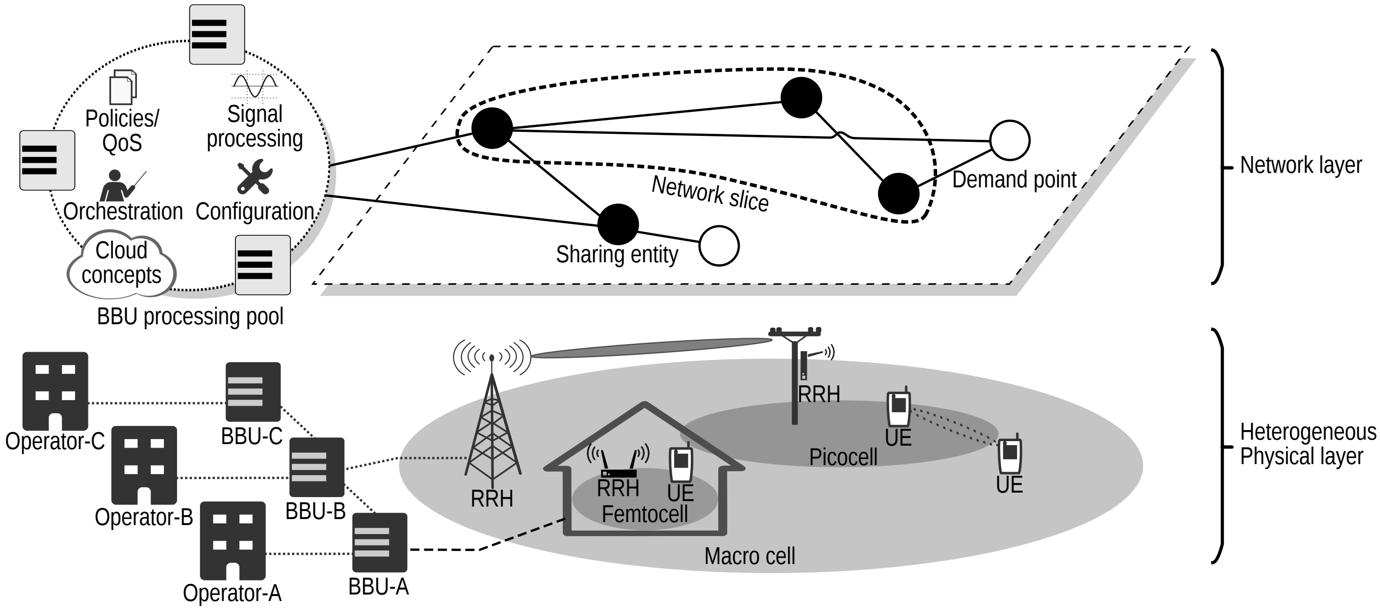


Figure 5: H-CRAN: Network sharing level

managing them. The workload moving can be modeled as a shortest path or minimum spanning tree problem, where BBUs represents nodes connected by optical links that presents the edges. The weight of each edge can be measured in terms of a weighted sum that considers the quantity, the delay, and the processing time needed to process the workload being exchanged. Different solutions can be explored, for example, Dijkstra's algorithm for shortest path or Bernard Chazelle soft heap for spanning tree problem.

V. Network Sharing

Integrating spectrum and infrastructure belonging to different operators using H-CRAN requires the careful orchestration of resources to preserve bilateral agreements among operators. To this end, the state-of-the-art indicates solutions based on the abstraction of heterogeneous physical layer to an overlay [7] [10] [12], which is called the network layer, depicted in Figure 5. At the network layer, sharing is performed according to high level network metrics, *e.g.,* throughput and processing. To achieve such sharing, we highlight four fundamental key enabling technologies: (*i*) SDR for RF processing decoupling in a software layer [5]; (*ii*) virtualization for physical layer complexity abstraction and isolation [7]; (*iii*) Network Function Virtualization (NFV) for scalability and network functionalities isolation [10]; and (*iv*) Software Defined Network (SDN) for centralization and improved orchestration of network control and management [13]. Below, for each of these technologies, we provide a brief description as well as a discussion of their employment in H-CRAN and major open challenges.

SDR refers to technologies where the baseband processing is performed by software modules running digital processors [5]. In H-CRAN, the use of software modules enables the baseband processing by a software layer in BBUs. As a consequence, operations, such as coding, modulation, signal processing, and radio parameter configurations, can be easily computed by the processing pool. Currently, an open challenge for SDR in H-CRAN is to provide an optimal solution to split radio functionalities between RRH and BBUs to avoid performance degradation in terms of latency aggregation and higher energy consumption [16].

Virtualization enables network entities to have their heterogeneous physical complexity abstracted to a homogeneous virtual sharing entity. Also, this technology avoids mixing workloads from different operators, isolating resources from the physical network in self contained virtual machines [12]. In H-CRAN, BBUs and RRHs can be virtualized in sharing entities having their physical resources (*e.g.,* frequencies and backhaul capacity) homogenized in higher network metrics. Sharing entities can be linked, creating an overlay network, also called network layer, as depicted in Figure 5. Within a network layer, UEs that generate traffic can be represented by demand points. Network slices can then be created to combine resources from sharing entities to meet the requirements of demand points. However, the dynamicity of wireless environments imposes challenges for virtualization in H-CRAN. It means that virtualization must be performed over a dynamic resource pool that must be frequently recalculated to guarantee the correct operation of sharing entities [7].

NFV encapsulates network functionalities into software packages that can be distributed through the network to be performed in an homogeneous environment, for example, a virtualized network [13]. In H-CRAN, NFV provides scalability for the sharing among operators that involves a huge number of BBUs and RRHs, creating large network domains [5]. NFV also provides isolation of network functionalities by creating packages that have their execution life cycle completely independent from others. The definition of a standard platform to manage the life cycles of packages is an open challenge for the realization of NFV in H-CRAN.

SDN has been proposed as a solution for improved orchestration of networks [13]. This orchestration is achieved through centralized controllers that provide a clear separation between control and data planes. In H-CRAN, the controller can be maintained at BBU processing pools. Data flows are established as rules to be deployed in sharing entities, providing rescaling of available resources without compromising the network [12]. A major challenge to realize SDN in H-CRAN is the creation of an SDN interface that supports wireless network operations, *e.g.,* controlling handover and managing mobility across heterogeneous RANs.

VI. H-CRAN RESOURCE SHARING ANALYSIS

In this section, we summarize the trending technologies in H-CRAN and we present the simulation results for the spectrum and infrastructure sharing considering an H-CRAN environment.

A. Trending technologies

We highlight some trending technologies that will be indispensable for the conceiving of resource sharing in H-CRAN. In Table I, we classified each technology according to the H-CRAN level and its application. In addition, different shareable resources are also presented as well as the Pros and Cons for each technology.

Considering Table I, we can related each technology of different levels in the conceiving of resource sharing in H-CRAN. One of the major features of H-CRAN resides in its capability to reconfigure itself at each different level. Through CC-CRRM, H-CRAN has the potential to exploit the shared pool of spectrum, using different techniques, *i.e.,* FDD, TDD, and biding. In addition, combining CC-CRRM and SDR can enable H-CRAN to change its way to access shared frequencies bands, *i.e.,* DSA or LSA, adapting itself to different operators policy of spectrum access. Moreover, using CC-CSON, the infrastructure of H-CRAN can become self-managed, which combined to virtualization enable the integration of multi-operator infrastructures under an abstracted shared entity. For each shared entity, NFV technology can quick distribute network services and functionalities to be executed and supply different operators subscribers. Finally, SDN can help in the network flows orchestration to improve the performance of shared entities intercommunication achieving QoS and improved users experience.

B. Simulation results

We claim that resource sharing is fundamental for achieving higher spectral efficiency in H-CRAN environments. To quantify the resulting efficiency gains (in b/s/Hz), we designed two experimental H-CRAN scenarios. For both scenarios, we placed a macro cell on the middle of a 1 km^2 area, representing one sector of a cellular network. UEs are spread randomly in this area. In addition, inside the same area, small cells are randomly placed varying in number [50, 100, 250, 500]. For the macro cell (*m*), we calculated the mean spectral efficiency (M) according to distances of the UE to the RRH (D). This calculation was done based on a Single-input and Single-output operational mode of a base station from 3GPP LTE-Advanced.

$$\begin{cases} D_m < 300m & M_m = 3.75b/s/Hz \\ 300m \leq D_m \leq 600m & M_m = 1.875b/s/Hz \\ 600m < D_m < 1000m & M_m = 0.9375b/s/Hz \end{cases}$$

For the small cell (*s*) the calculation was based on the draft of IEEE802.11 ac 3.0. Each small cell was designed to support 20 UEs and the macro cell has no support limit.

$$\begin{cases} D_s < 50m & M_s = 9.75b/s/Hz \\ 50m \leq D_s \leq 75m & M_s = 4.875b/s/Hz \\ 75m < D_s < 100m & M_s = 2.4375b/s/Hz \end{cases}$$

We also considered that UEs will always try to connect to the RRH with the best received signal strength indicator (usually the closest one). The results of more than 1000 repetitions of Monte Carlo simulations are depicted in Figure 6.

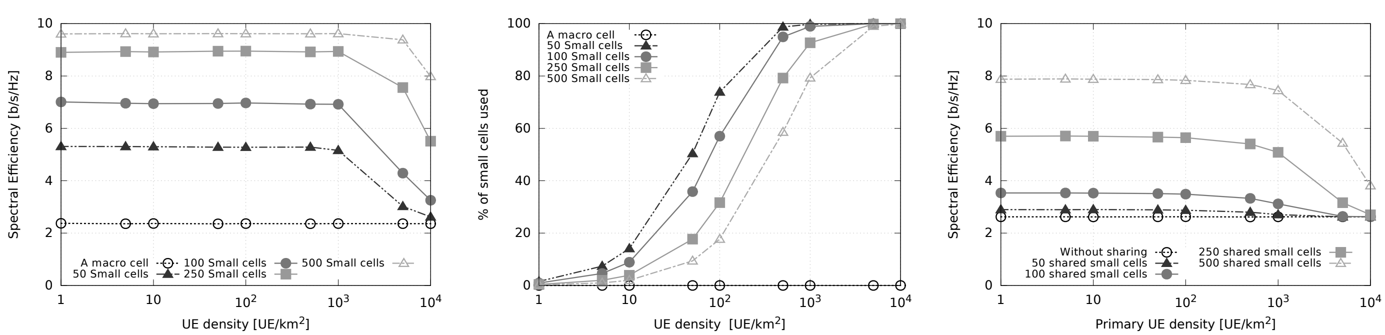
In the first H-CRAN scenario, we investigated the maximum spectral efficiency reached by deploying small cells without resource sharing, being depicted in Figure 6a. As a baseline, we measured the average spectral efficiency reached by a solo macro cell of 2.134 b/s/Hz, which remains constant because we did not limit the macro cell capacity. By deploying 50 small cells, the average spectral efficiency grows reaching 5.235 b/s/Hz on average; nevertheless, as soon as the number of UEs per km^2 exceeds 1000 the efficiency degrades significantly, down to 2.423 b/s/Hz. With the deployment of 250 to 500 small cells, the average spectral efficiency almost reaches the maximum of 9.75 b/s/Hz, but both efficiencies degrade in the presence of 1000 UEs or more.

In the same scenario, to better understand why the spectral efficiency degrades for densities larger than 1000 UEs per km^2, we measured the percentage of saturated small cells, *i.e.,* small cells that cannot provide communication to any additional UEs, shown in Figure 6b. The number of saturated small cells grows quickly between UE densities of 10 and 1000 per km^2. The average spectral efficiency decreases in proportion to the number of saturated small cells. Therefore, a massive number of small cells is required to reach better average spectral efficiency in some densely populated areas. In this case, exploiting the sharing of small cells becomes inevitable.

The second scenario was created to assess the benefits of resource sharing in an H-CRAN environment. From the first scenario, let us assume a density of 10000 UEs/km^2 with 50 small cells deployed, and average spectrum efficiency of 2.434 b/s/Hz, which notionally represents the infrastructure of an operator that lease infrastructure (receiver) from another (donor). According to an LSA methodology [2], shared cells must prioritize the communications of UEs that belong to the donor, *i.e.,* primary UEs, rather than UEs from the receiver. In addition, we must consider that the donor leased both

Table I: H-CRAN trending technologies

Trending Technology	Level	Resource Sharing	Pros	Cons
FDD, LTE-FDD	Spectrum level	• Frequency bands pool	• Symmetric data traffic • Free from interference	• Asymmetric data traffic • No reconfigurable link capacity • High cost • Need of guard band
TDD, LTE-TDD	Spectrum level	• Time slot	• Asymmetric data traffic • No need of paired spectrum • Reuse of frequencies • Reconfigurable capacity	• Symmetric traffic • Inter-tier interference • Complex processing • Synchronization with UEs
Biding [17]	Spectrum level	• Time slot • Frequency bands • Resource blocks	• Priority insertion	• Need of an auction system
Dynamic Spectrum Access	Spectrum level	• White space	• Unused frequency bands • Cognition • Sharing functionality	• Complex radio functions • Intermittent use • Restrict bands
Licensed Shared Access	Spectrum level	• Frequency bands	• Sub-leasing • Unused frequency	• Secondary use • Primary UE priority • Spectrum Broker
CC-CRRM	Spectrum level	• Frequency bands • Time slot • Space	• Cooperatively management • Interference estimations • Radio resources recalculation • Optimal objectives	• Insertion of delays • Higher complexity used/shared • Need of BBU pool
CC-CSON	Infrastructure level	• BBU • RRH	• Self-configuration • Self-healing • Self-control • Autonomic management	• Insertion of delays • High complexity • Need of BBU pool • Need of handover technologies
Virtualization	Infrastructure level	• BBU • RRH	• Abstracted level • High level network metrics • Resource flexibility	• Insertion of delays • Hard to guarantee QoS • High complexity
Network Function Virtualization	Network level	• Network Functionalities	• Software bundle • Scalability • Interchangeability of network service	• Hard to Manage • Need of Orchestrator
Software-Defined Networking	Network level	• Network Flows	• Control/Data flow separation • Centralized flow control • Reconfigurable network • Ease the network management	• No support wireless substrate • No accounting for wireless conditions



(a) Small cells without resource sharing (b) Saturation of small cells (c) Small cells resource sharing

Figure 6: Spectral efficiency and cell saturation for spectrum and infrastructure sharing

spectrum and infrastructure resources, allowing its BBUs to exchange and process the receiver workload freely through CC-CRRM and CC-CSON [1]. Finally, we measured the spectral efficiency gain of the receiver operator according to the number of shared small cells in use, such as depicted in Figure 6c.

By exploiting 100 shared small cells, the receiver may reach the spectral efficiency of 3.87 b/s/Hz for its 10000 UEs with a low primary UE density (less than 1000 UE/km^2). When the receiver uses 250 shared small cells, its 10000 UEs reach 5,845 b/s/Hz, more than double of the spectral efficiency without sharing. For the use of 500 shared small cells, the receiver's UEs can achieve 7.9 b/s/Hz, more than triple of the spectral efficiency without sharing. However, when the density of primary UEs exceeds 1000, the receiver's UEs spectral efficiency gradually degrades for all the considered deployments of small cells. It means that the receiver can improve its spectral efficiency by taking advantage of shared resources in areas where primary UEs are not fully dominant. Finally, by taking advantage of resource sharing in H-CRAN, receivers can duplicate or triplicate their spectral efficiency by leasing small cells.

VII. Conclusions

In this article, we have discussed the benefits and challenges of employing resource sharing in H-CRAN architecture. To address these challenges, we exploited three sharing levels: spectrum, infrastructure, and network. At the spectrum level, H-CRAN enables spectral efficiency gains through coordination and interference avoidance, and facilitates dynamic spectrum sharing. Meanwhile, at the infrastructure level, we map the four sharing scenarios from 3GPP to discuss how H-CRAN can potentially reduce CAPEX and OPEX. At the network level, the integration of SDR, virtualization, NFV, and SDN enables the creation of an overlay network to achieve enhanced sharing and orchestration. Also, we summarized trending technologies for the conceiving of resource sharing in H-CRAN. Finally, we simulated resource sharing scenarios and measured the gains of spectral efficiency for H-CRAN.

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