Dynamic Hardware Resource Provisioning in Hybrid Radio Access Networks

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***Abstract*—This work uses the mobile network operators' knowledge regarding mobile subscriber movement in the current infrastructure, i.e., Decentralized Radio Access Network (D-RAN), to dimension the infrastructure needed for the new generation of mobile infrastructure, i.e., Cloud/Centralized Radio Access Network (C-RAN). We propose a heuristic considering two approaches, one focused on the coverage of users and another focusing on the aggregated throughput. The performance assessment considers that the day is divided into three periods: working hours (morning), leisure hours (afternoon) and home hours (night). Results show that the heuristic allows mobile network operators to properly dimension the number of Small Cells (SCs) needed for a given area, maximizing the multiplexing and efficiency of the BaseBand Units (BBUs).**

***Index Terms*—C-RAN; D-RAN; Heuristic; Small cell; Baseband Processing**

I. Introduction

Ultra-dense deployment of Small Cells (SCs) has been identified as one of the key flavors of the emerging 5G networks [1] for truly addressing the capacity demands of indoor/outdoor environment in a cost-efficient manner [2]. Additionally, Cloud/Centralized Radio Access Network (C-RAN) architecture is another important improvement and has been considered by several operators [3] and service providers [4][5] as a cost-efficient way of realizing SCs. By splitting the Base Station (BS) hardware into Remote Radio Head (RRH) and BaseBand Unit (BBU), C-RAN also improves the flexibility and allows for more dynamic mobile network operation.

However, the deployment of C-RAN introduces some challenges. For instance, RRH deployment [6], BBU-RRH mapping [7][8], BBU-RRH function virtualization [9] and BBU allocation [10]. All these challenges can be aggravated when considering the non-stationarity property of the users in the network, i.e., the so called *tidal effect*, meaning that the BS load changes throughout the day depending on the type of area it serves. In this case, mobile network capacity should follow the user, implying great dynamicity in the mobile network configuration.

In traditional Radio Access Networks (RANs), i.e., Decentralized Radio Access Network (D-RAN), baseband capacity is statically assigned to the cell, meaning that the resources are allocated regardless of the users movements throughout the day. In C-RAN, resources can be dynamically assigned to areas where the load is higher, thereby benefiting from statistical multiplexing gain adapting to traffic fluctuations.

Although the BBUs are decoupled from the RRHs in terms of physical placement, there exists a one-to-one logical mapping between BBUs and RRHs in that one BBU is assigned to generate (receive) a signal (e.g., Long-Term Evolution (LTE) or Worldwide Interoperability for Microwave Access (Wimax) frame) to (from) an RRH (although the mapping can change over time). This one-to-one mapping allows for generating a distinct frame for each SC (deployed in the form of a RRH), which is key for enhancing the network capacity via techniques such as dynamic fractional frequency reuse or coordinated multi-point transmissions [11].

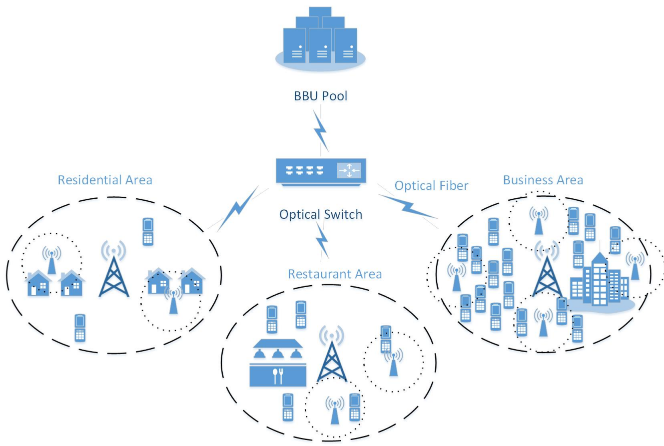
The dimensioning of BBUs poses a major challenge to take the most advantage out of the C-RAN architecture, and has received a major attention from the network community in the last years [12]. However, the dimensioning of BBUs considering the fluctuations on the traffic needs generated by users' movement still requires further research. Therefore, in this work, we develop a heuristic for the dimensioning of BBUs which leverages on the mobile network operator's knowledge regarding users movement in order to maximize the multiplexing potential of the BBU.

II. Background

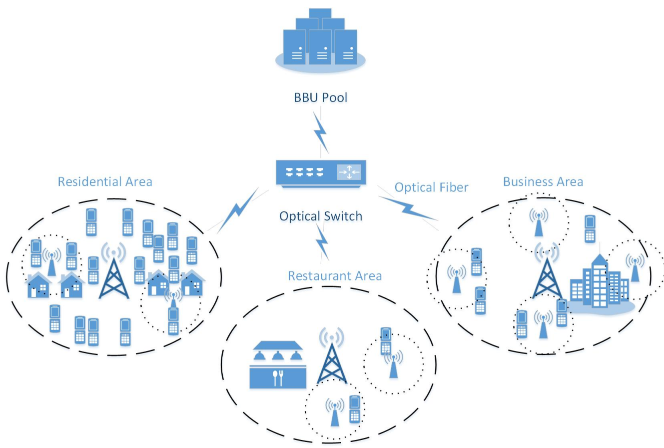
The number of active mobile users at different localities varies depending on the time of the day [13]. This movement of mobile network load based on the time of the day is known as *tidal effect*. Figure 1 illustrates the fluctuations in the BS load throughout the day.

In D-RAN architecture, each macro BS processing capability is only used by the active users associated to it. Static resource provisioning for the peak (worst case) traffic at each cell site leads to grossly underutilized BSs in some areas/times, while provisioning for the average leads to oversubscribed ones. In C-RAN architecture, however, it is possible to implement the demand-aware resource provisioning, in which the BBU resources will be dynamically (re)assigned to meet the fluctuating demands of the mobile network.

Resource allocation and the RRH-BBU mapping problem in 5G C-RAN has been addressed in a number of research works in the literature [11] [7] [14]. Focusing on the Quality of Service (QoS) Key Performance Indicator (KPI) as blocked calls and number of Physical Resource Blocks (PRBs), the authors of [15] developed a dynamic RRH-BBU mapping algorithm in C-RAN architecture. In [16], the authors attempt to solve a joint RRH and precoding optimization problem, which aims



(a) Morning Behavior



(b) Evening Behavior

Fig. 1. Tidal Effect

to minimize network power consumption in a Multiple-input and multiple-output (MIMO) based user-centric C-RAN. Both works focus on load balancing on purely centralized architectures, concerned only with radio capabilities. The work in [17] proposes a model to evaluate the statistical multiplexing gain of C-RAN considering different geographical areas. However, the impact of user movement is not taken into account, which is the main aspect considered in this work.

A. Network Parameters and Throughput Modeling

According to [18], the path loss is generally inversely proportional to the square of the carrier frequency. In mobile network planning, path loss must be estimated for a deployment environment, and cell coverage is determined based on the BS and Mobile Station (MS) antenna gains, Effective Isotropic Radiated Power (EIRP), Radio Frequency Radio Frequency (RF), bandwidth, modulation and coding techniques. Omnidirectional large-scale path loss in urban environments may be estimated from the Hata model and the COST231 extension of the Hata model for carrier frequency (fc) below 2 GHz, and from the Stanford University Interim (SUI) model for fc above 2 GHz.

Therefore, the downlink Signal-to-Interference-Plus-Noise Ratio (SINR) over a given subcarrier N assigned to user k in the SC that it is connected, can be modeled as follows:

$$SINR_k = \frac{P_{k,b(k)}}{\sigma^2 + I_k}, \tag{1}$$

in which $P_{k,b(k)}$ is the received power on subcarrier n assigned to user k by its serving BS $b(k)$, σ^2 is the thermal noise power and I_k is the intercell interference from neighboring SCs. In this work, we assume that all the SCs are transmitting with maximum power PS. The received power at user k from BS $b(k)$ can be calculated by means of (2), which relates the received power of a node as a result of the transmitted power and the fading of the signal, the latter calculated by the SUI model [19]. This can be expressed as:

$$P_{k,b(k)} = \frac{10^{\frac{Pot_{b(k)} - L_{SUI}}{10}}}{1000}. \tag{2}$$

The value of $P_{k,b(k)}$ is a function of the three values calculated by the following equations:

$$L_{SUI} = A + 10\gamma log\frac{d}{d_o} + S, d > d_o, \tag{3}$$

$$A = 20log\frac{4\pi d_o}{\lambda}, \tag{4}$$

$$\gamma = a - bh_b + \frac{C}{h_b}, \tag{5}$$

in which:

- d is distance from the antenna to the measured point, in meters;
- d_o equals to 1 meter, reference distance according to [14];
- λ is the wavelength, in meters;
- γ is the path-loss exponent;
- h_b is the height of base station, which can be between 10 to 80 meters;
- A, B and C are constants dependent on the terrain category (Terrain B was used, A=4, B=0.0065 and C=17.1);
- S is the shadowing effect, which can be between 8.2 to 10.6 dB.

We also assume that each user achieves the Shannon capacity, i.e., the data rate for user k is expressed in (6) as:

$$C_k = B * log_2(1 + SINR_k), \tag{6}$$

in which B is the bandwidth.

Figure 1 (a) and (b) depicts an example of the reference scenario, where according to the traffic demand fluctuation at different hours, a set of RRHs corresponding to macro BS covers large areas, and a set of SCs' RRHs covers smaller areas for capacity management. The next section discusses the problem of selecting RRH to BBU ports to satisfy demands at any time for all cells.

III. Upgrading from D-RAN to C-RAN

Our problem can be divided into two steps. The first step determines the number of ports required to cover a given

Algorithm 1: UE-RRH Assignment

Data: list of RRHs (S_t)
Result: aggregated throughput A for each $A_r | r \in S_t$

forall $r \in S_t$ **do**
    allocate UEs closest to r;
end
forall $u \in UE$ **do**
    update SINR of u according to (1);
    calculate Shannon capacity of u according to (6);
end
forall $r \in S_t$ **do**
    calculate aggregated throughput A_r;
end
return aggregated throughput A;

aggregate flow capacity. For this, we propose a heuristic described in Algorithms 1 and 2.

Algorithm 1 describes the process of allocating UEs to the closest RRHs (where S_t is the list of possible RRHs). After this phase, the maximum capacity of each UE is calculated (interference between RRHs and RRHs and UEs is calculated at this stage) considering the resources available in each RRHs (i.e., PRBs), which are divided evenly (regardless of the channel quality of the UE). At the end of this phase, a list of RRHs with their maximum aggregated capacities is generated, which will serve as input to Algorithm 2.

In Algorithm 2, in addition to the list (S_t), a maximum percentage of aggregated throughput is given as input (A). In this algorithm, different UEs positions are used and the number of RRHs required to offload that percentage of aggregated throughput as input is accounted. The tests are repeated several times, until an average number of ports is obtained (equivalent to the average number of RRHs needed to offload). To determine which RRHs should be counted, two criteria were used: *(i)* the throughput-based approach, where RRHs with higher aggregated throughput are prioritized; *(ii)* the user-based approach, where the RRHs with the highest number of users are prioritized. Both approaches should respect the limits of PRBs existing in RRHs.

Algorithm 2: Setting the Maximum Number of Ports

Data: list of RRHs (S_t), Max aggregated throughput (A)
Result: output

repeat
    UE-RRH Assignment;
    sort S_t by A in descending order;
    sort S_t by number of User Stations (UEs) associated to it in descending order;
    while $(RRHAggregatedThroughputTEMP < \%AggregatedThroughputDefined)$ **do**
        NUM-RRH = NUM-RRH + 1;
        RRH-Aggreg-throughput-TEMP = RRH-Aggreg-throughput-TEMP + RRH-Aggreg-Throughput(St);
    end
until *NUM-PORTS is equal to NUM-RRH*;
return NUM-PORTS;

Algorithm 3: RRH Selection

Data: S_t, NUM-PORTS
Result: output

repeat
    Generate UEs distribution;
    UE-RRH Detection (St);
    forall *all RRH E St* **do**
        Calculate Aggregated Throughput;
    end
    Sort St by Aggregated Throughput (Max down to Min);
    Sort St by Number of UEs (Max down to Min);
    Select RRH (St, NUM-PORTS);
    UE-RRH-Macro Detection (St, Sm);
until *this end condition*;

The second step is outlined in Algorithm 3, with the number of ports and the scenario to be studied being given as input. Here, all the RRHs are deployed and the UEs are allocated to these RRHs. Based on the number of ports given as input, the RRHs with the highest number of users or with higher aggregated throughput are selected, the RRHs are eliminated and a new allocation of UEs and RRHs is done. UEs not covered by RRHs should be covered by the macro BS.

IV. Simulation Results

In this section, the performance of the proposed dimensioning and resource allocation scheme is evaluated through numerical simulation that was implemented in MATLAB. A hybrid C-RAN with one macro BS was considered. The network simulation parameters are listed in Table I.

The UEs are randomly positioned over a $4km^2$ area, and the proposed approach is simulated considering different numbers of UEs offloaded for the SC RRHs (depending of the approached used). The simulation area is divided into business, restaurant and residential areas. It is also assumed that the UEs are homogeneous, which means different UEs have the same QoS requirement.

To evaluate the RRH-BBU port mapping, we considered a typical mobile network, in which the overall network traffic

TABLE I
Summary of Network Parameters.

Parameter	Value
System Bandwidth (B)	180 kHz
Path Loss for Macrocell User	COST231
Path Loss for Smallcell User	SUI-TYPE A
Maximum Macrocell Transmission Power	43 dBm
Maximum Smallcell Transmission Power	23 dBm
Confidence Interval	95%
Number of Simulation Experiments	30

TABLE II
NUMBER OF SMALL CELLS SELECTED

Approach	% of Aggregated Throughput				
	20%	40%	40%	80%	100%
Users	4	10	19	34	86
Throughput	5	12	23	39	88

fluctuates during the time of the day. For this, as previously mentioned, the UEs were statically positioned and change positions in 3 different scenarios. We divide our analysis in 3 times of the day: morning, afternoon(happy-hour) and night. For morning, 60% of the users are positioned in business area, and 40% in the rest of the area. In happy-hour, some users from business area (about 30%) move to the restaurant area and the rest for the residential area. In the night, 80% of users are in the residential area.

We now put together the elements from the analysis methodology and evaluate the performance of our RRH-BBU mapping ports allocation scheme.

A. *Number of RRH-BBU ports*

First, it is important to define how many BSs are needed to cover the network users. In this way, one can analyze the current behavior and conjecture whether there is a need for greater investments in BBU expansion of a given BBU pool. Table II shows the average number of antennas required to cover 20%, 40%, 60%, 80% and 100% of the total capacity of the scenario.

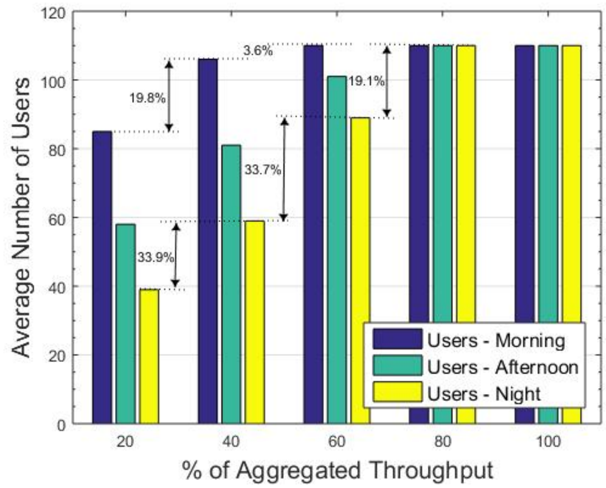
As the traffic load for different cells fluctuates greatly over time, when a RRH is under high traffic condition, more BBU resources are required; however, the number of ports in the BBU is limited. When the traffic load is low, the free ports could be dynamically reassigned to other RRHs with a higher traffic load at that moment. Through adaptive hardware resource allocation, the network traffic *tidal effect* can be effectively solved, and the hardware resource efficiency can be maximized.

Starting with the 20% of aggregated throughput, we obtained the same amount of RRHs to cover the area during all day (morning, happy-hour and night). Folowing, we obtained a difference of 16.67% for 40%, 9.09% for 60%, 10.53% for 80% and only 1.12% for 100%. In users-based approach we obtained a smaller number of RRHs, this fact was expected because of the densified network, it is easier to cover more users in the same RRH. Note the higher increase in the number of RRHs between 20-40 (40%) and 80-100 (74.07%).

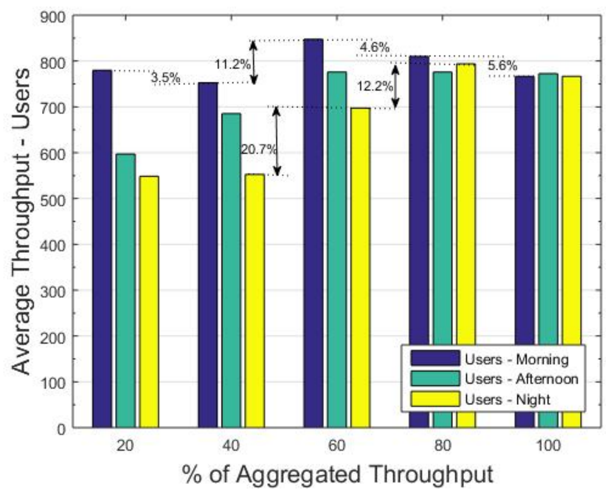
The aggregated throughput increases linearly, but the same does not occur with the number of SCs. There are specific cases of significant increases, which need to be studied on a case-by-case basis, since it depends strongly on the behavior of the users and the tidal effect phenomenon.

B. *RRH Selection – User-based Approach*

Figure 2 gives the average number of users connected to all selected RRHs that match with the number of ports defined based on the percentage of aggregated throughput. It can be observed that for users' behavior during the morning period,



(a) Average Number of UEs (Tidal Wave Behavior)



(b) Average Throughput (Tidal Wave Behavior)

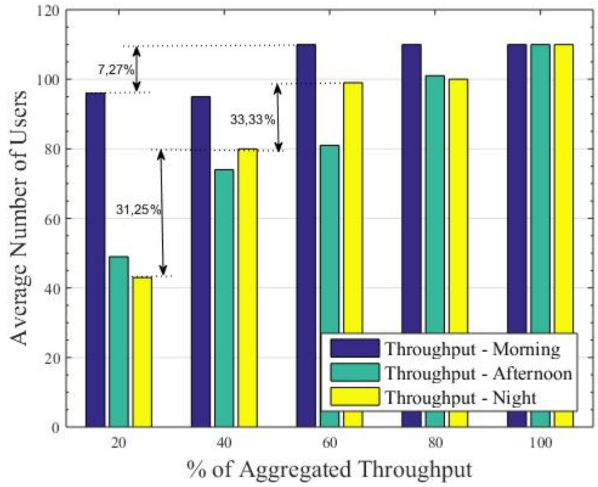
Fig. 2. Performance measures for the user-based approach

UEs are more concentrated near dense regions (business areas) and therefore, a larger number of UEs area covered with higher average throughput. It is worth noting that due to this concentration, with the growth in the number of ports, the increase in the number of users does not follow the same trend, as can be observed in Figure 2 (a) and (b).

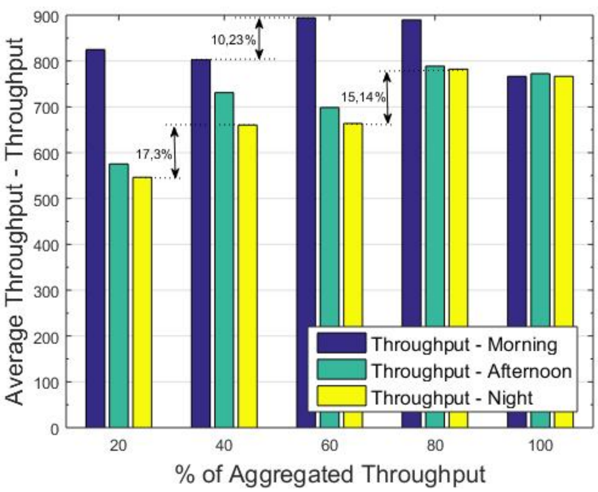
As previously mentioned, this approach selects antennas in the areas of higher concentration of users, those UEs in areas of lower concentration end up connecting to antennas with smaller capacity and those that cannot get any signal from SCs are routed to macro BS. For situations of lower UEs density (night-time period), with the dispersion of the UEs, the selected RRHs will be sparser too, which allows for a better distribution of the antennas and with this a smaller variation of the throughput.

C. *RRH Selection – Throughput-based Approach*

The average number of users connected to all selected RRHs that match with the number of ports defined based on the



(a) Average number of UEs connected (Tidal Wave Behavior)



(b) Average throughput (Tidal Wave Behavior)

Fig. 3. Performance measures for the throughput-based approach

percentage of aggregated throughput is presented in Fig. 3 (a) and (b).

In this approach, the selection of RRHs was more dispersed, which provided a better coverage of the UEs and with higher rates. In the periods of the day with higher concentration of UEs (morning), the increase in the percentage of aggregate throughput slightly affects the increase of covered users. In the times of less density period (afternoon and night), due the higher number of RRHs, there is a significant increase in the number of users and the disparity between the maximum and minimum throughput tends to increase (attributed to the distances from the users to the RRHs which they were connected).

V. Conclusion

The migration process from D-RAN to C-RANs architecture will trigger hybrid scenarios to coexist, and to cooperate in order to meet the UEs' needs. The hardware resource allocation is especially important in this phase. To this end, we proposed heuristic approaches focusing on the dimensioning of BBU resources considering the movement of users throughout the day. Results obtained show that it is possible to dimension the number of SCs that need to be activated at the same time, and therefore the number of BBU ports required, maximizing the multiplexing and efficiency in the use of baseband processing.

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