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Reducing Power Consumption in C-RAN Using Switch On/Off of MC-RRH Sectors and Small Cells

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ABSTRACT The evolution toward 5G wireless networks was the result of an exponential growth in data traffic demands and a significant increase in the number of connected devices with stringent quality of services (QoS) requirements. This evolution leads to an increase in the total power consumption and indirectly produces pollution intensive carbon footprints. To overcome 5G challenges in traffic demands and power consumption, Cloud Radio Access Network (C-RAN) architecture is introduced. This paper investigates the energy consumption in 5G C-RAN using switch on/off cell sectors and densification by exploiting Small Cell Remote Radio Heads (SC-RRHs). We develop sector switch on/off algorithms based on reducing the number of underutilized sectors per Macro Cell RRH (MC-RRH). Then, we apply a selective SC-RRHs distribution allowing SC-RRHs to serve users of switched off sectors. Simulations results show that our proposed approaches based on the switch on/off by sector can achieve more than 55% of power saving which makes them more efficient than those based on the switch on/off by cell in terms of power saving.

INDEX TERMS C-RAN, dynamic sectorization, fixed sectorization, power consumption, QoS, switch on/off, small cells, 5G.

I. INTRODUCTION

A. MOTIVATION AND PREVIOUS WORKS

The fifth generation (5G) wireless communication networks deployed in 2020 are designed to offer very high data rates, a low latency, an increased capacity and a good improvement in quality of service (QoS) of users [1]. However, a huge increase in the number of connected devices has been witnessed. According to recent researches, the 5G network serves between 10 to 100 times more number of cellular devices compared to previous generation [2]. This leads to a growth in mobile data traffic demands. Thereby, the amount of mobile data traffic is estimated to reach 77.5 Exabyte per month in 2022 [3]. To accommodate this significant increase in the number of connected devices and the exponential growth of data traffic demands, technologies such as: millimeter wave (mmwave), massive Multiple Input Multiple Output (MIMO), beamforming, new sophisticated radio access techniques, Mobile Edge Computing (MEC) and small cells (SCs) densification were enabled aiming in enhancing network performances in 5G wireless cellular networks [2]. Moreover, splitting each node into sectors is considered as one of the promising approaches that can enhance the radio access network. Replacing the omni directional antenna at the base station (BS) by an intelligent directional antenna represents a solution to boost the system capacity and reduce interference without adding new base stations.

On the other hand, new architectures are deployed to fit with the huge amount of data traffic demand and achieve the required performance metrics. Thus, Cloud Radio Access Network (C-RAN) is considered as an efficient solution to improve load balance and optimize radio resources. As shown in Fig. 1, C-RAN represents a novel centralized architecture based on a wide number of Remote Radio Heads (RRHs). RRHs are connected via fronthaul links called Common Public Radio Interface (CPRI) and served by a centralized Base Band Unit (BBU) pool located in the cloud. More specifically, the combination of BBU and RRH has the same role as the traditional BS. Thereby, RRHs are designed to serve the basic functionalities of signal processing. The trans-

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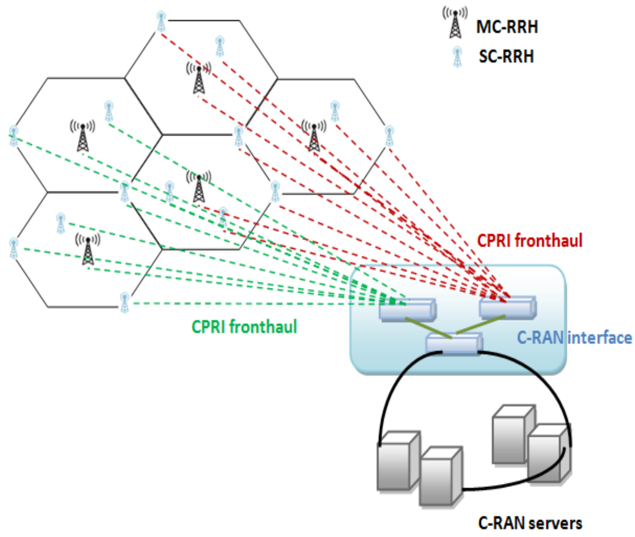

FIGURE 1. Cloud radio access network architecture.

mitted/received signals from RRHs are managed by BBUs which are designed to carry out the main features of baseband processing.

Due to the fact that each set of BBUs settled in the same compartment is sharing the same air conditioning cost and using centralized processing capabilities, a more energy saving can be achieved. Hence, the C-RAN architecture is regarded as an energy-efficient solution by reducing air conditioning cost and decreasing equipment room size [4]. Nevertheless, with the deployment of a dense number of MC-RRHs and SC-RRHs a more energy consumption can arise, since the BS is the most energy-consumer in mobile access networks [5], which consumes approximately between 60% and 80% of the total network energy consumption [6]. Recently, reducing energy consumption in wireless mobile networks has become a major concern not only because of the high cost of operational expenditure of network operators but also because of its indirect impact of environment effects due to the increase of CO2 emissions. In the economic side, according to [7], more than 25 MWh of energy is consumed by mobile cellular networks, costing approximately $3000 worth of power annually. Moreover, Information and Communication Technology (ICT) is responsible for a percentage which varies between 2% and 10% of the annual world-wide energy consumption [8]. In the environmental side, 5% of CO2 emissions is triggered by the ICT sector [5], [8]. In fact, the level of CO2 emissions increases proportionately to the number of connected devices. Furthermore, 100 billions of devices are connected in 2020 [4], this number will be doubled in the next few years. Then, wireless communications systems is been the critical sector to address in reducing ICT-related CO2 emissions. More specifically, decreasing energy consumption in C-RAN has become a major concern for researchers.

Thus, considering the problem of energy consumption in 5G Cloud RAN, several schemes were developed in the literature to improve C-RAN energy efficiency. One important way to reduce energy consumption in C-RAN is to optimize the BBU-RRH allocation, therefore reducing power consumption at fronthaul. In [9], the authors proposed an efficient assignment scheme between BBU and RRH by considering both resource requirement and traffic exchange between the co-located RRHs. For the same purpose, in [10], Shaharan *et al.* proposed a joint RRH selection in 5G C-RAN by employing a low-complexity iterative algorithm combined with the use of coordinated multipoint (CoMP) and user clustering techniques. Besides, in [11], Liu *et al.* were jointly optimizing the RRH selection and computing resource provisioning to reduce energy consumption in a virtual Cloud RAN. Furthermore, a BBU-RRH switching schemes for C-RAN were developed in order to reduce the energy consumption in C-RAN, [12] and [13]. Nambra *et al.* proposed two BBU-RRH switching schemes where the first one is semi-static performed for longer time interval and the second one is adaptive applied for shorter time interval [12]. Moreover, in [13], authors applied a reasonable BBU-RRH switching scheme where considering resource waste and traffic backlog as QoS metrics of network performance.

Other prior works focusing on enhancing energy efficiency in 5G C-RAN networks by applying a dynamic resource allocation in BBU. In [14], an approach depending on the traffic conditions was developed and performed based on a dynamic resource allocation from BBU to RRHs in order to reduce energy consumption. Furthermore, Aqeeli *et al.* proposed an optimal allocation of computational resources in C-RAN [15].

Otherwise, coordinated multipoint technique and cell densification using femtocells can be used to improve C-RAN capacity and also energy efficiency, in [16], Al-Dulaimi *et al.* show that it is possible to reduce power consumption when employing low power neighborhood femtocell networks under the umbrella of a coordinated multipoint macrocell, they proposed a framework for a C-RAN system that can respond to the dynamic changes in the traffic in order to reduce network power consumption.

One more interesting solution used to reduce energy consumption is the switch off algorithm called also the sleeping mode. Switching off some BBUs or RRHs during low-traffic periods is being considered as low cost solution to reduce energy consumption in C-RAN. Thus, in [17], the authors investigated the problem of energy consumption in a two-tier heterogeneous C-RAN composed by macro and picocells. Aiming to reduce energy consumption, Sigwele *et al.* proposed a dynamic switch off of pico BSs based on a utility function [17]. In the cloud side, Sigwele *et al.* also developed a heuristic approximation approach including a genetic algorithm in order to minimize the number of BBU servers. Furthermore, in [18], a dynamic RRH switch off scheme was proposed to save the system power consumption in cloud RAN architecture where the arriving users are modeled as a discrete time queuing network. Other solutions were proposed in the literature aiming to ensure power saving in

C-RAN such as efficient user association policies [19] and renewable energy [20].

In all over mentioned prior work, the main objective was to minimize energy consumption in 5G C-RAN architecture. However, a small rate of power saving can be achieved by applying BBU-RRH allocation schemes, since they only worked on reducing the power of fronthaul network. On the other hand, the switch off algorithms are more efficient in term of power saving. Nevertheless, switching off the entire cell leads to a degradation in the QoS of users, then in network performance. Hence, reducing energy consumption without guarantying a good QoS is considered as an inefficient solution. For that reason, we aim to reduce energy consumption while maintaining a good QoS.

B. AIMS AND CONTRIBUTIONS

Motivated by the above considerations, our main objective in this paper, as previously mentioned, is to minimize power consumption in C-RAN network. Our key contributions are summarized as follows:

- In this paper, we consider a sectorized 5G C-RAN architecture based on SC-RRHs densification, where each MC-RRH is sectorized into six sectors and each sector is served by an mmwave antenna. Adopting this proposed architecture, we are trying to perform two types of sectorization. The first one is a fixed-angle sectorization scheme where the cell is divided into fixed angles sectors and the power is equally distributed between them. Then, the second one is a dynamic sectorization in which the angle varies according to the density of users. We will consider both uniform and nonuniform users distribution patterns.
- We propose a modified power consumption model compatible to our proposed C-RAN architecture, since the traditional power model will be inappropriate. Thereby, the power consumption model includes the power consumed by BBUs, MC-RRHs sectors, SC-RRHs and fronthaul.
- For the purpose to achieve the maximum of energy saving, we will apply a switch on/off algorithm by sector unlike previous works which propose to switch off the whole MC-RRH node. Hence, sectors serving regions with low density of users will be turned off and their powers will be equal to zero. Moreover, we propose to jointly apply the switch off by sector with dynamic sectorization. When applying dynamic sectorization, the switch on/off of sectors depends on users density. Thus, more energy can be saved.
- We highlight the contribution of switch off by sector in term of power saving versus the switch off by cell. Moreover, we show the effectiveness of our proposed approaches for both uniform and nonuniform user distributions unlike the switch off by cell which is efficient only for a nonuniform user assignment.
- Focusing on maintaining an acceptable QoS, we propose a selective distribution of SC-RRHs within the whole MC-RRH area in order to serve the turned off sector users. Further, we consider beamforming because of its ability to overcome the increased loss generated by mmwave antenna with height frequency. Besides, it improves the system performance by reducing interference and power consumption in the cellular system.

C. ORGANIZATION AND NOTATIONS

The rest of this paper is organized as follows: In section II, we describe the 5G C-RAN architecture considered in our work. Section III presents the power consumption model. The proposed approaches are detailed in section IV. In section V, we discuss the simulation results. Finally, section VI concludes the paper and exposes some future works. The principal notations considered in this paper are given in Table 1.

TABLE 1. Table of notations.

Symbols	Designation
N_{BBU}	the number of BBUs
N_{mc}	the number of MC-RRHs
N_{sc}	the number of SC-RRHs
N_u	the number of users
N_s	the number of sectors in each MC-RRH
N_{RB}	the number of resource blocks
P_{total}[dBm]	the total power
P_{Pool}[dBm]	the total power of BBU pool
P_{BBU}[dBm]	the BBU power consumption
$P_{cooling}$[dBm]	the cooling power for BBU
$P_{Fronthaul}$ [dBm]	the total power of fronthaul links
$P_{fh}[dBm]$	the power of one fronthaul link
P_{Radio} [dBm]	the total power of radio part
$P_{MC-RRHs}$ [dBm]	the total power of MC-RRHs
$P_{SC-RRHs}$ [dBm]	the total power of SC-RRHs
P_{mc} [dBm]	the power of one MC-RRH
P_{sc} [dBm]	the power of one SC-RRH
P_{AP} [dBm]	the power amplifier
P_{RF} [dBm]	the radio frequency power
P_{tx} [dBm]	the maximum transmission power of MC-RRH
P^s[dBm]	the transmitted power per sector
P^l [dBm]	the power of links establishing sectors
P_t [dBm]	the power transmitted for user
P_{RB} [dBm]	the power per resource block
P^f [dBm]	the power for fixed sectors
P^d [dBm]	the power for dynamic sectors
P_{rx} [dBm]	the received power
$\theta[°]$	the sector angle for fixed approach
$\theta'[°]$	the sector angle for dynamic approach
λ_u	the density of users
λ_{th}	the density threshold
G [dB]	the antenna Gain

II. SYSTEM MODEL

In this section, we introduce the system model adopted in our work. As shown in Fig. 2, we propose a 5G C-RAN architecture composed by a BBU pool connected via fronthaul links to a set $M = \{1, 2, .., N_{mc}\}$ and $S = \{1, 2, .., N_{sc}\}$ of MC-RRHs and SC-RRHs respectively, where N_{mc} is the number of MC-RRHs and N_{sc} represents the number of SC-RRHs. The fronthaul links can be fiber, microwave, copper connections or a combination of these. In our system model, we consider fiber fronthaul links due to their high bandwidth and low latency characteristics [21]. The RRHs are connected to their

BBU pool using a star topology. In this paper, we are interested in the radio part of the C-RAN architecture, in particular for the downlink transmission. Thereby, we propose a cluster of $N_{mc} = 7$ MC-RRHs where each MC-RRH is sectorized into $N_s = 6$ sectors and each sector is served by a directional mmwave antenna. Since the mmwave antenna can allow a field of view (FoV) of $\pm 45°$, it can cover a maximum angle θ equal to 90° [22], [23]. Hence, to sectorize the MC-RRH area, we need at least $N_s = 4$ sectors. In this paper, we choose to sectorize the cell into $N_s = 6$ sectors [24], aiming to reduce the sector's interference and to enhance the capacity and the coverage. As the beamforming is able to make the transmission between users and the RRH more directional to achieve a more reduced energy consumption and a lower interference, the beamforming technique is implemented in the mmwave antenna [25]. As shown in Fig. 2, MC-RRH are located in the center of each MC area where SC-RRHs are distributed in a predefined manner that we describe bellow.

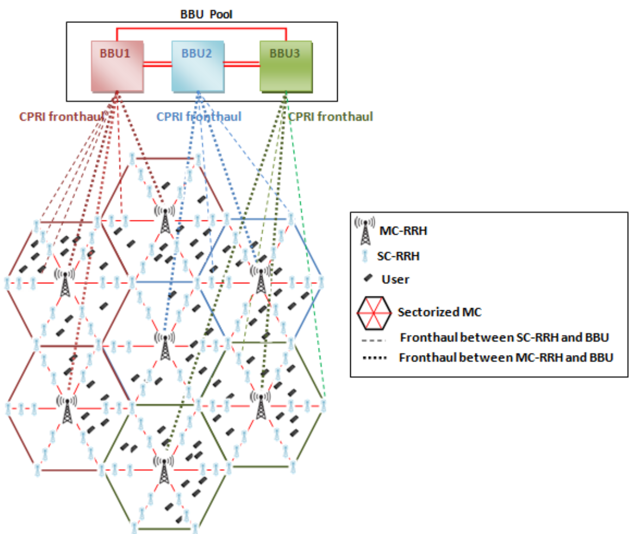

FIGURE 2. C-RAN network topology.

We assume that $U = \{1, 2, .., N_u\}$ is the set of users. In our proposed system model, we consider both uniform and nonuniform distributions of users. For the nonuniform distribution model, the number of users is different from one cell to another and from one sector to another. Users are randomly and nonuniformly distributed and the average of user number in a given area is defined by:

$$N_u = \lambda_u A, \tag{1}$$

where A is the area of the region and λ_u is the number of users per km^2.

On the other side, for the uniform distribution, the number of users is the same in all cells, however, their positions are randomly distributed. Thus, the fixed number of users is given by:

$$N_u^{fix} = \frac{N_u}{N_{mc}}. \tag{2}$$

Our proposed architecture is based on MC sectorization assisted by SC densification which represents the fundamental basis of our developed switch on/off algorithms. In the following subsections, we describe the two types of the deployed sectorization, as well as, how to obtain the total antenna gain. Moreover, we explain the selective method used to distribute the SC-RRHs in the MC area.

A. SECTORIZATION TYPES

There are two types of sectorization investigated in this work, namely fixed sectorization and dynamic sectorization.

1) **Fixed sectorization**
For the fixed sectorization, the MC area is divided into fixed angle sectors and the power is equally distributed between all sectors as shown by the blue plot in Fig. 3. In this type of sectorization, the angle $\theta = 60°$.

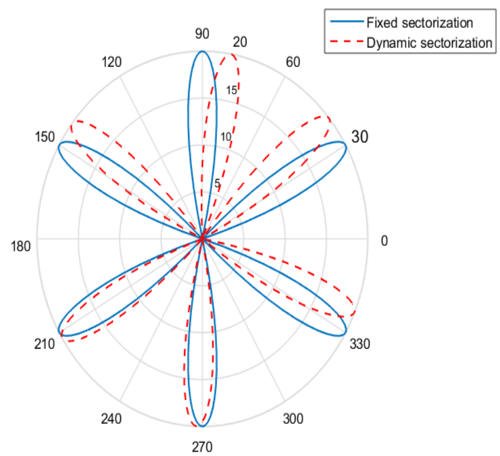

FIGURE 3. Sectorization types.

2) **Dynamic sectorization**
In the dynamic sectorization type represented by the red plot in Fig. 3, the sector antenna angle can be reconfigured to have fewer or larger beam width sectors according to the density and the place of users. Therefore, the sector mmwave antenna changes its angle and its antenna transmitter power. Thus, the power is not equally distributed between sectors. Modifying the angle of the sector allows the antenna's coverage area to be shaped and formed to fit the capacity and coverage requirements of users. Furthermore, due the use of mmwave antenna [23], the new angle θ'_n should verify the following conditions:

$$\sum_{n=1}^{6} \theta'_n = 360°, \quad \text{where } \theta'_n \in [0..90°]. \tag{3}$$

Deploying sectorized MC-RRHs enhances the radio access network capacity and offers a gain that is theoretically equal to the sum of all site sector gains [26]. Therefore, the total

RRH antenna gain $G(j)$ is given by:

$$G(j) = \sum_{n}^{N_s} G_n(\theta_n, \phi_n), \tag{4}$$

where $G_n(\theta_n, \phi_n)$ is the antenna gain per sector, expressed in dB and calculated using the antenna gains in the azimuth direction $A(\theta_n)$ and in the elevation direction $A(\phi_n)$ [27]. Given that (θ_n, ϕ_n) is the pair of horizontal and vertical angles, $G_n(\theta_n, \phi_n)$ is defined as:

$$G_n(\theta_n, \phi_n) = G_{max}(n) - \min[-(A(\theta_n) + A(\phi_n)), A_{max}(n)], \tag{5}$$

where $G_{max}(n)$ represents the maximum directional gain related to the antenna of sector n [27]. A_{max} is the maximum attenuation. $A(\theta_n)$ is the antenna azimuth corresponding to sector n defined by:

$$A(\theta_n) = -\min[12(\frac{\theta_n - \theta_n^{Az}}{\theta_{3dB}})^2, A_{max}(n)], \tag{6}$$

and $A(\phi_n)$ represents antenna elevation of sector n given by:

$$A(\phi_n) = -\min[12(\frac{\phi_n - \phi_n^{tilt}}{\phi_{3dB}})^2, A_{max}(n)], \tag{7}$$

where θ_{3dB} and ϕ_{3dB} represent respectively the 3 dB beam width in the azimuth and elevation beam.

B. SC-RRHs SELECTIVE SCHEME

SCs based technology is one of the key enabling features that is driving the expansion of 5G. It is characterized by a low power consumption [28], [29]. Generally, SCs are distributed along the cell edge to cover users existing there. However, in our model, SCs are located within the MC area using a selective distribution. Thereby, we choose the place of each SC-RRH in order to be able to serve users in the turned off sector when they are out of coverage. The MC is divided into three equal regions R_1, R_2 and R_3 and SC-RRHs are located in the intersection of each region and each sector as shown in Fig. 4. The three regions are equals for the reason to offer the same QoS to users wherever located.

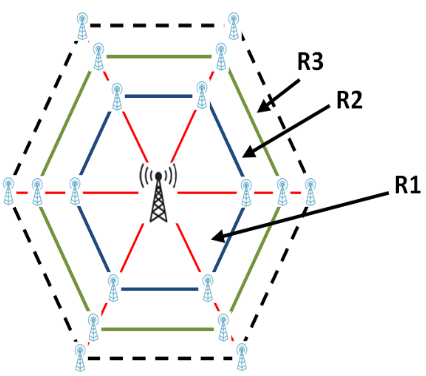

FIGURE 4. Small cell distribution.

III. PROPOSED C-RAN POWER MODEL

Since the BS represents the most consumer of power in mobile access network, an accurate model of the BS power consumption is required to evaluate power consumption in radio access network. In this section, we provide the power calculation model used to obtain the final total power before and after applying the power saving approaches.

In the literature, a traditional power calculation model called Earth model [5] is usually applied in order to calculate power consumption in the traditional BS. However, this traditional power consumption model cannot be adopted by our proposed C-RAN architecture for many reasons. First, in our case, the BS is divided into two different entities RRH and BBU which are spatially separated, so that, the power of BBU and RRH should be calculated separately. Moreover, the set of BBUs existing in the same pool will share the same cooling power. In addition, another amount of power is added to the total BS power consumption which is the power of fronthaul links between RRHs and BBU. For these reasons, we propose another power calculation model dedicated to our proposed C-RAN architecture and based on three principal components: (i) the power of BBU pool, (ii) the power of fronthaul links and (iii) the power of radio part. Therefore, the total power P_{total} is calculated as:

$$P_{total} = P_{Pool} + P_{Fronthaul} + P_{Radio}. \tag{8}$$

In our proposed approaches, we focus on the radio and the fronthaul parts. Thus, we assume that the power consumption of BBU pool is constant and just the power of the radio part and fronthaul links will change according to the state of sectors of each MC-RRH. Thereby, when some sectors of a given MC-RRH will be switched off, the power of MC-RRH will decrease, hence, the power of fronthaul link connecting this RRH to BBU will also decrease.

A. BBU POOL POWER MODEL

The power consumption of BBU pool is composed by the cooling power P_c shared by all pool BBUs and the sum of all BBU power consumption. Thus, P_{Pool} is defined as:

$$P_{Pool}(t) = P_c + \sum_{i}^{N_{BBU}} P_{BBU}(i, t), \tag{9}$$

where N_{BBU} denotes the total number of BBUs existing in the pool and $P_{BBU}(i, t)$ is the power consumed by the i^{th} BBU.

B. FRONTHAUL POWER MODEL

According to our proposed architecture, the power of fronthaul represents the power consumed by fiber cables required to carry out the transmission between BBU and both MC-RRHs and SC-RRHs. Thus, $P_{Fronthaul}$ can be given by [17], [30]:

$$P_{Fronthaul}(t) = \sum_{i}^{N_{BBU}} \sum_{j}^{N_{mc}} P_{fh}(i, j) S_i^{fh,mc}(j, t)$$

$$+\sum_{i}^{N_{BBU}}\sum_{k}^{N_{sc}}P_{fh}(i,k)S_i^{fh,sc}(k,t)$$
$$=\sum_{i}^{N_{BBU}}\sum_{j}^{N_{mc}}[\frac{1}{N_{dl}}P_{sw}(j,t)+P_{dl}(j,t)]S_i^{fh,mc}(j,t)$$
$$+\sum_{i}^{N_{BBU}}\sum_{k}^{N_{sc}}[\frac{1}{N_{dl}}P_{sw}(k,t)+P_{dl}(k,t)]S_i^{fh,sc}(k,t), \quad (10)$$

where $P_{fh}(i,j)$ and $P_{fh}(i,k)$ denote the power consumed by fronthaul link between BBU i and MC-RRH j and the power consumed by fronthaul link between BBU i and SC-RRH k, respectively. N_{dl} is the number of downlink interfaces available at one aggregation switch in the BBU pool. P_{sw} represents the power consumed by the aggregate switch. P_{dl} is the power consumed by one downlink interface in the aggregation switch used to receive the downlink traffic. Finally, $S_i^{fh,mc}(j,t)$ the state of the link between BBU i and MC-RRH j and $S_i^{fh,sc}(k,t)$ the state of the link between BBU i and SC-RRH k are given by:

$$S_i^{fh,mc}(j,t),S_i^{fh,sc}(k,t)=\begin{cases}1 & \text{if ON State}\\ 0 & \text{if OFF State}\end{cases} \quad (11)$$

C. RADIO POWER MODEL

According to our proposed architecture, the radio part is composed by both SC-RRHs and sectorized MC-RRHs. Thus, P_{Radio} is calculated as:

$$P_{Radio}=P_{SC-RRHs}+P_{MC-RRHs}. \quad (12)$$

1) SC-RRHs POWER MODEL

The total power of SC-RRHs is defined as:

$$P_{SC-RRHs}(t)=\sum_{k}^{N_{sc}}P_{sc}(k,t)S_{sc}(k,t), \quad (13)$$

where N_{sc} is the total number of SC-RRHs, $P_{sc}(k,t)$ represents the power consumption of SC-RRH k and $S_{sc}(k,t)$ denotes the state of SC-RRH k at instant t and is defined by (11).

2) MC-RRHs POWER MODEL

The total power of MC-RRHs represents the sum of power consumption of all sectorized MC-RRHs given by:

$$P_{MC-RRHs}(t)=\sum_{j}^{N_{mc}}P_{mc}(j,t), \quad (14)$$

where N_{mc} is the total number of MC-RRHs and P_{mc} represents the power consumption of MC-RRH j. Generally, the total power consumption of MC-RRH that is based on two main contributors: the power amplifier P_{AP} and the radio frequency power P_{RF} is defined as [14], [17]:

$$P_{mc}(j,t)=P_{AP}(j,t)+P_{RF}(j,t)=\frac{P_{tx}(j,t)}{\eta}+P_{RF}(j,t), \quad (15)$$

where η denotes the power amplifier efficiency and $P_{tx}(j,t)$ is the maximum transmission power of MC-RRH j at instant t. However, according to our proposed architecture, each MC-RRH is sectorized into N_s sectors. Thus, the transmitted power of each MC-RRH is the sum of sectors power consumption:

$$P_{tx}(j,t)=\sum_{n}^{N_s}[P_j^s(n,t)+P_j^l(n,t)]S_s(n,t), \quad (16)$$

N_s is the total number of sectors by MC-RRH, $P_j^s(n,t)$ is the transmitted power of sector n existing in MC-RRH j, P_j^l is the power required for establishing links and signaling per sector and $S_s(n,t)$ denotes the state of sector n at instant t defined based on (11).

Since we propose two types of sectorization in our proposed switch on/off algorithms, the sector power $P_j^s(n,t)$ is calculated with two different equations according to the employed sectorization type:

1) **Fixed sectorization**
For the case of fixed angle sectorization, all sectors share the same power. When the sector power $P_j^s(n,t)$ is fixed, it is denoted by $P_j^f(n,t)$ and equal to:

$$P_j^s(n,t)=P_j^f(n,t)=\frac{P_{tx}(j,t)}{N_s(j,t)}, \quad (17)$$

where $N_s(j,t)$ is the number of sectors in MC-RRH j and $P_{tx}(j,t)$ is the transmitted power of MC-RRH j at instant t given by:

$$P_{tx}(j,t)=\sum_{m}^{N_u^j}P_t(m,t), \quad (18)$$

where N_u^j is the number of users existing in the cell j and $P_t(m,t)$ represents the transmitted power to user m calculated as:

$$P_t(m,t)=N_{RB}(m,t)P_{RB}(j,t), \quad (19)$$

where $N_{RB}(m,t)$ denotes the total number of resource blocks allocated to user m and $P_{RB}(j,t)$ represents the power transmitted per resource block for MC-RRH j. $P_{RB}(j,t)$ is given by the following equation:

$$P_{RB}(j,t)=\frac{P_{tx}(j,t)}{N_{RB}(j,t)}, \quad (20)$$

where $N_{RB}(j)$ is the total number of resource blocks attributed to MC-RRH j.

2) **Dynamic sectorization**
For the dynamic sectorization, the power and the antenna angle of different sectors change according to user's density. Thereby, when the sector power $P_j^s(n,t)$ is variable, it is denoted by $P_j^d(n,t)$:

$$P_j^s(n,t)=P_j^d(n,t)=(1-\alpha_j(n,t))P^f, \quad (21)$$

where $\alpha_j(n,t)$ is defined as:

$$\alpha_j(n,t) = (1 - \frac{g(\theta_j(n,t))}{g(\theta'_j(n,t))})_+, \quad (22)$$

where g is the linear gain, θ represents the angle related to the fixed sectorization, θ' denotes the new angle after the dynamic sectorization and $(y)_+ = max(y,0)$ is the max function. According to (22), the new angle allocation of sectors will lead to a lower power consumption.

Finally, the total power can be expressed as:

$$\begin{aligned} &P_{total}(t) \\ &= P_c + \sum_{i}^{N_{BBU}} P_{BBU}(i,t) + \sum_{i}^{N_{BBU}} \sum_{j}^{N_{mc}} P_{fh}(i,j) \\ &\times S_i^{fh,mc}(j,t) + \sum_{i}^{N_{BBU}} \sum_{k}^{N_{sc}} P_{fh}(i,k) S_i^{fh,sc}(k,t) \\ &+ \sum_{k}^{N_{sc}} P_{sc}(k,t) S_{sc}(k,t) + \sum_{j}^{N_{mc}} [\frac{1}{\eta} \sum_{n}^{N_s} [P_j^s(n,t) + P_j^l(n,t)] \\ &\times S_s(n,t) + P_{RF}(j,t)] S_{mc}(j,t). \end{aligned} \quad (23)$$

IV. POWER SAVING APPROACHES

In this section, we detail our two proposed power saving approaches. The first one is based on a fixed sectorization and the second is based on a dynamic sectorization. Both of our proposals are based on the concept of switch on/off by sector. Then, we propose an approach that combines our two proposed schemes.

A. SWITCH ON/OFF BASED ON FIXED SECTORIZATION (SOOFS)

In this approach, we apply our power saving algorithm in a 5G C-RAN architecture based on a fixed sectorization, where sectors have the same angle width and the same transmitted power. The switch on/off is performed according to the density of users in each sector. The principle is to turn off the MC-RRH's sector when its density of users λ_u is lower than a given threshold λ_{th}. Turning off the MC-RRH sectors with low density represents an efficient solution to reduce energy consumption in C-RAN. However, it can reduce the QoS of users by reducing the coverage. Therefore, to achieve coverage continuity, users of turned off sector will be served by SC-RRHs existing in its coverage range. SC-RRHs are distributed as we described in Section II. We assume at first that all sectors are actives and all SC-RRHs are in off state.

Switch on/off based on fixed sectorization (SOOFS) scheme is composed by four principal phases which are described in Fig. 5.

More details are presented in the following steps.

- **Step 1**
  The first phase consists of taking the decision of switch on/off. The decision to turn on or off a sector n is performed when the density of users in sector n, $\lambda_u(n,t)$, is lower than the density threshold λ_{th}.

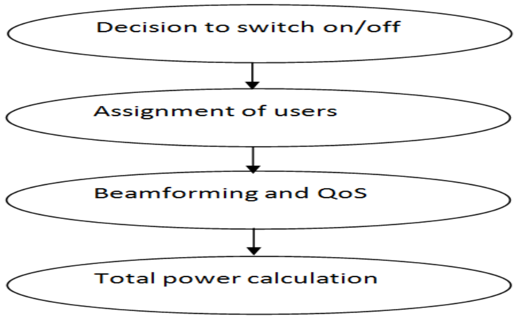

FIGURE 5. Principal phases of SOOFS scheme.

- **Step 2**
  Once the condition of switch on/off is confirmed, a verification of the state of sector n at instant $t-1$, $S_s(j,n,t-1)$, is carried out to decide if the sector will be turned on or off. Steps 1 and 2 are more explained in algorithm 1:

Algorithm 1 Decision to Switch On/Off

```
Input Parameters N, N_s, λ_th
for j = 1 : N_mc do
  for n = 1 : N_s do
    Input Parameters λ_u(j, n, t), S_s(n, t − 1)
    if λ_u(j, n, t) > λ_th then
      if S_s(j, n, t − 1) = 1 then
        S_s(j, n, t) ← 1 {sector n still ON}
      else if S_s(j, n, t − 1) = 0 then
        S_s(j, n, t) ← 1 {switch on sector n}
      end if
    else if λ_u(j, t) ≤ λ_th then
      if S_s(j, k, t − 1) = 0 then
        S_s(j, n, t) ← 0 {sector n still OFF}
      else if S_s(j, n, t − 1) = 1 then
        S_s(j, n, t) ← 0{switch off sector n}
      end if
    end if
  end for
end for
```

- **Step 3**
  The next step is the allocation of users. Thus, when a sector n is switched off, user m existing in its coverage area will served by the best SC-RRH k that send him the maximum power:

$$\widetilde{sc} = \arg\max_{k \in N_S}(P_{rx}(k,m)), \quad (24)$$

  where $P_{rx}(k,m)$ represents the received power of user m from SC k. More details of step 3 are described in algorithm 2.

- **Step 4**
  Activated SC-RRHs will perform with beamforming technique in order to enhance QoS of users after the switch on/off process.

Algorithm 2 Assignment of Users

```
for m = 1 : N_u do
  for k = 1 : N_sc do
    Input Parameters N_u, N_sc, S_sc(k, t − 1)
    if max(P_rx(k, m)) then
      {turn on the best SC-RRH k sending the maximum
      power for user m}
      if S_sc(k, t − 1) = 1 then
        S_sc(k, t) ← 1
      else if S_sc(k, t − 1) = 0 then
        S_sc(k, t) ← 1
      end if
    end if
  end for
end for
```

- **Step 5**
  Once the user allocation procedure has been completed, a little amount of power, returns to activated SC-RRHs and their fronthaul links connecting them to BBU, is added. on the other hand, an amount of power relative to switched off sectors and their fronthaul links is subtracted. Hence, according to (23) and based on fixed sectorization P_{total} is calculated as:

$$\begin{aligned} P_{total}(t) &= P_c + \sum_{i}^{N_{BBU}} P_{BBU}(i,t) + \sum_{i}^{N_{BBU}} \sum_{j}^{N_{mc}} \\ &\times P_{fh}(i,j) S_i^{fh,mc}(j,t) + \sum_{i}^{N_{BBU}} \sum_{k}^{N_{sc}} P_{fh}(i,k) S_i^{fh,sc}(k,t) \\ &+ \sum_{k}^{N_{sc}} P_{sc}(k,t) S_{sc}(k,t) + \sum_{j}^{N_{mc}} [\frac{1}{\eta} \sum_{n}^{N_s} [P_j^f(n,t) + P_j^l(n,t)] \\ &\times S_s(n,t) + P_{RF}(j,t)] S_{mc}(j,t). \end{aligned} \tag{25}$$

B. SWITCH ON/OFF USING DYNAMIC SECTORIZATION (SOODS)

Contrary to the switch on/off based on fixed sectorization where the sector angles are fixed, in this approach, the sector angle can be increased or decreased according to the density of users and their locations. Thus, for dynamic sectorization, the switch on/off is performed when there is a sector n verifying the condition of switch off ($\lambda_u(n) \leq \lambda_{th}$) and its users are located in the sector extremity or distributed in the half region of the sector. We assume that users should not exceed the half of the sector region for the reason that mmwave antenna cannot exceed an angle of 90° [22]. More details of our proposal are depicted in the following flowchart in Fig. 6.

Steps of the SOODS approach are:

- **Step 1**
  As shown, in the flowchart, the first step consists on checking the density of users of sector n and verifying the condition of switch on/off.

TABLE 2. SINR user requirement [31].

User position	SINR [dB]
around the antenna sector	≥ 13
middle of the sector	[0..13]
extremity of the sector	≤ 0

- **Step 2**
  The second step is to check the state of sector n at instant $t-1$. If the sector is on, we can continue our switch off process.
- **Step 3**
  This step consists of verifying users position of sector to be switched off. If users are located in the sector extremity or in the half of the sector region we can continue our algorithm. Thus, this verification is performed based on user's SINR value. As explicated in Table 2, according to the SINR value of user, we can define its position:
  The SINR of user m from sector n is calculated using the following expression:

$$SINR_j(n,m) = \frac{P_{rx}^j(n,m)}{\sum_{m' \neq m}^{N_s} P_{rx}^j(n,m') + \sum_{j' \neq j}^{N_{mc}} P_{rx}(j',m) + P_{noise}}, \tag{26}$$

where $P_{rx}^j(n,m)$ denotes the received power at user m from antenna sector n of MC-RRH j, $\sum_{m' \neq m}^{N_s} P_{rx}^j(n,m')$ is the intercell interference average power from other sectors in the same cell, $\sum_{j' \neq j}^{N_{mc}} P_{rx}(j',m)$ represents the intracell interference average power from other MC-RRHs and P_{noise} denotes the AWGN power calculated using the following formula [19]:

$$P_{noise} = -174 + 10\log_{10}(B), \tag{27}$$

where B represents the bandwidth.
Thereby, the received power at user side m is calculated as [32]:

$$P_{rx}(m,\theta) = P_{tx} g(\theta) d^{-\gamma}, \tag{28}$$

where P_{tx} is the transmitted power, $g(\theta)$ represents the linear antenna gain defined in dB in (5), d is the distance between the MC-RRH and user and γ is the propagation exponent selected depending on the type of propagation medium.

- **Step 4**
  Once previous steps are verified, we can start the switch on/off process. Thereby, according to users position and state of neighboring sectors we have two possible cases:
  1) **Case 1: increasing the sector angle**
     The first case consists on increasing the sector angle of switched off sector's neighbor. This increase is performed when users of switched off sector are located in its extremity or in its half region and the neighbor sector is in ON state. In this case, when the received power of users in

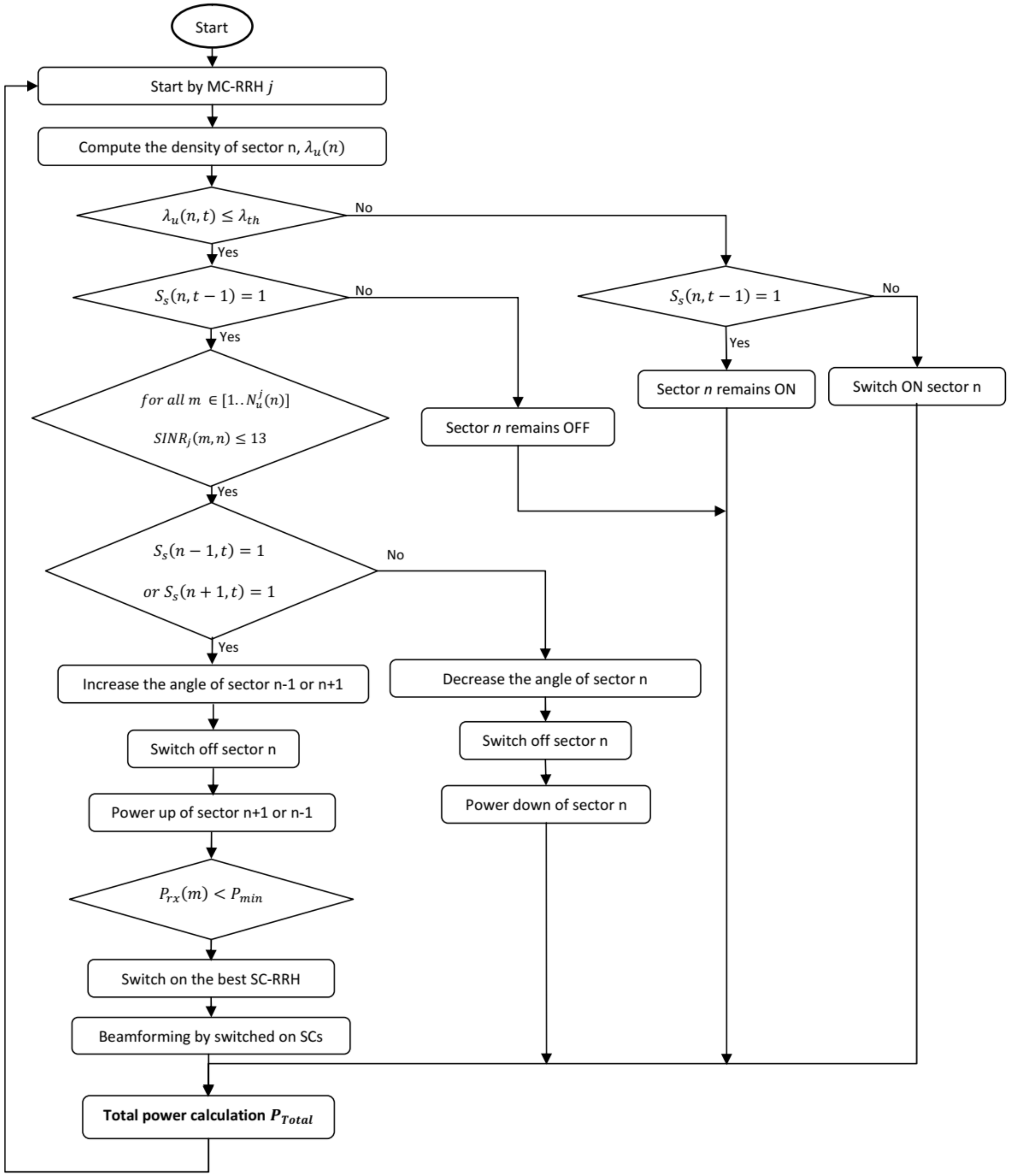

FIGURE 6. **Flowchart of SOODS algorithm.**

the switched off sector is lower than the power sensitivity P_{min}, an activation of the best SC-RRHs is performed in order to offer a good signal to users.

$$P_{rx}(m) < P_{min}. \quad (29)$$

In order to offer a good signal to users of the switch off sectors, activated SC-RRHs will operate with beamforming technology.

2) **Case 2: decreasing the sector angle**
In this case, a decrease of the sector angle is executed when its users are concentrated on a part of its region and there is no neighboring sectors in on state to serve them.

A scenario example of the two cases is described in Fig. 7. We assume that the density threshold is $\lambda_{th} = 10$. For the first case, we suppose that users of

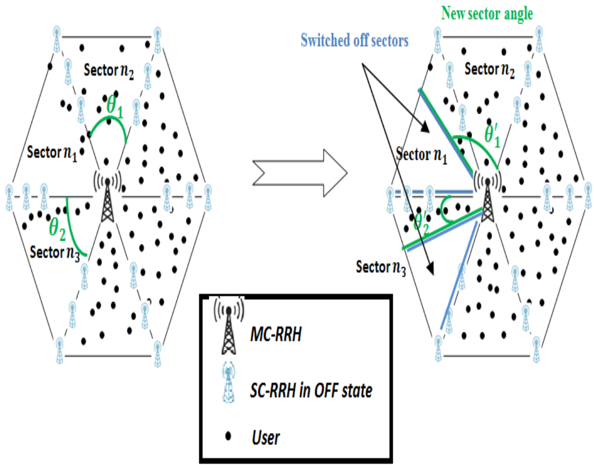

FIGURE 7. Scenario example of SOODS.

sector n_1 exist in the extremity of sector n_2 and verify the condition $\lambda_u(n_1) \leq \lambda_{th}$. Therefore, sector n_1 will be turned off and the angle coverage of sector n_2 will be increased to be able to serve users of sector n_1. For the second case, we assume that sector n_3 verify the condition $\lambda_u(n_3) \leq \lambda_{th}$ and its users are situated in the sector extremity but there is no neighboring sector able to serve them. In this case, the sector angle of n_3 will be decreased.

- **Step 5**
  The final step is to calculate the total power based on (23):

$$P_{total}(t) = P_c + \sum_{i}^{N_{BBU}} [P_{BBU}(i,t)] + \sum_{i}^{N_{BBU}} \sum_{j}^{N_{mc}} P_{fh}(i,j) \times S_i^{fh,mc}(j,t) + \sum_{i}^{N_{BBU}} \sum_{k}^{N_{sc}} P_{fh}(i,k) S_i^{fh,sc}(k,t) + \sum_{k}^{N_{sc}} P_{sc}(k,t) \times S_{sc}(k,t) + \sum_{j}^{N_{mc}} [\frac{1}{\eta} \sum_{n}^{N_s} [(1-\alpha_j(n,t))P^f + P_j^l(n,t)] S_s(n,t) + P_{RF}(j,t)] S_{mc}(j,t) \quad (30)$$

C. COMBINATION OF SOOFS AND SOODS

By reducing the number of sectors for both SOOFS and SOODS algorithms, an amount of power saving is achieved. For that, the combination of the two approaches will reduce more the amount of power consumption in the radio part of C-RAN. Thus, we combine the two proposed approaches. In this case, the total power is calculated using (30). In the flowchart presented in Fig. 8, we describe the behavior of the algorithm based on the combination of the two above proposed methods. In fact, according to received users SINR values, which determine positions of users of the sector to be switched off, we decide which approach to be performed. Thus, if users are distributed in all the surface of the concerned sector, the switch on/off based on fixed sectorization (SOOFS) will be applied. On the other hand, if users of the sector to be switched off are located in the sector edge and/or not exceed the sector's half, the switch on/off based on dynamic sectorization (SOODS) will be performed. Further, SOOFS is applied for long time interval of switch off, however, SOODS is dedicated for short time interval.

V. SIMULATION RESULTS

In this section, we present the simulation results of our proposed schemes to investigate their effectiveness in reducing power consumption and compare them with other schemes as the switch off by cell methods.

A. SIMULATION SCENARIO

To assess performances of our proposed techniques, we deploy a 5G C-RAN architecture based on sectorization and small cell densification using MATLAB as implementation software. We are interested by the radio part of cloud RAN topology which is composed by $N_{mc} = 7$ MC-RRHs. The distance between MC-RRHs is $d = 500m$, and the MC-RRH user distance is computed through their positions in the map. Each MC-RRH is sectorized into 6 sectors and in each sector we disposed a set of SC-RRHs. At instant $t = 0$, all SC-RRHs are in OFF state. For user's distribution, we start by simulating our proposed approaches for a nonuniform distribution model where the average number of users served by a MC-RRH is fixed to 100 users. Then, for the purpose to show the effectiveness of our proposed strategies even for uniform distribution pattern, we investigate the uniform users assignment model. Fig. 9 represents our proposed architecture for both uniform and nonuniform user distribution patterns. The network parameters used in our simulation scenario are presented in Table 3:

TABLE 3. Simulation parameters [33].

Parameter	Value
Number of MC-RRHs	7
Number of SC-RRHs per MC	18
Bandwidth[MHz]	400
Frequency [GHz]	28
Propagation model	Pathloss model
Distribution of user	uniform and nonuniform
Transmitted power for MC-RRH [dBm]	$46 - 43$
Transmitted power for SC-RRH [dBm]	$21 - 17$
Distance between MC-RRH[m]	500
Number of resource blocks (RBs) in MC-RRH	100
Number of resource blocks (RBs) in SC-RRH	20
Max number of users per MC	100
Max number of users per SC	8
MC-RRH antenna height [m]	30
SC-RRH antenna height [m]	6
Path loss model [dB]	$32.9 + 19.2\log_{10}(d) + 20.8\log_{10}(f)$

B. SIMULATION RESULTS

Our aim in these subsections is to evaluate the performance of our proposed switch on/off by sector schemes in term of power consumption, power saving and quality of service.

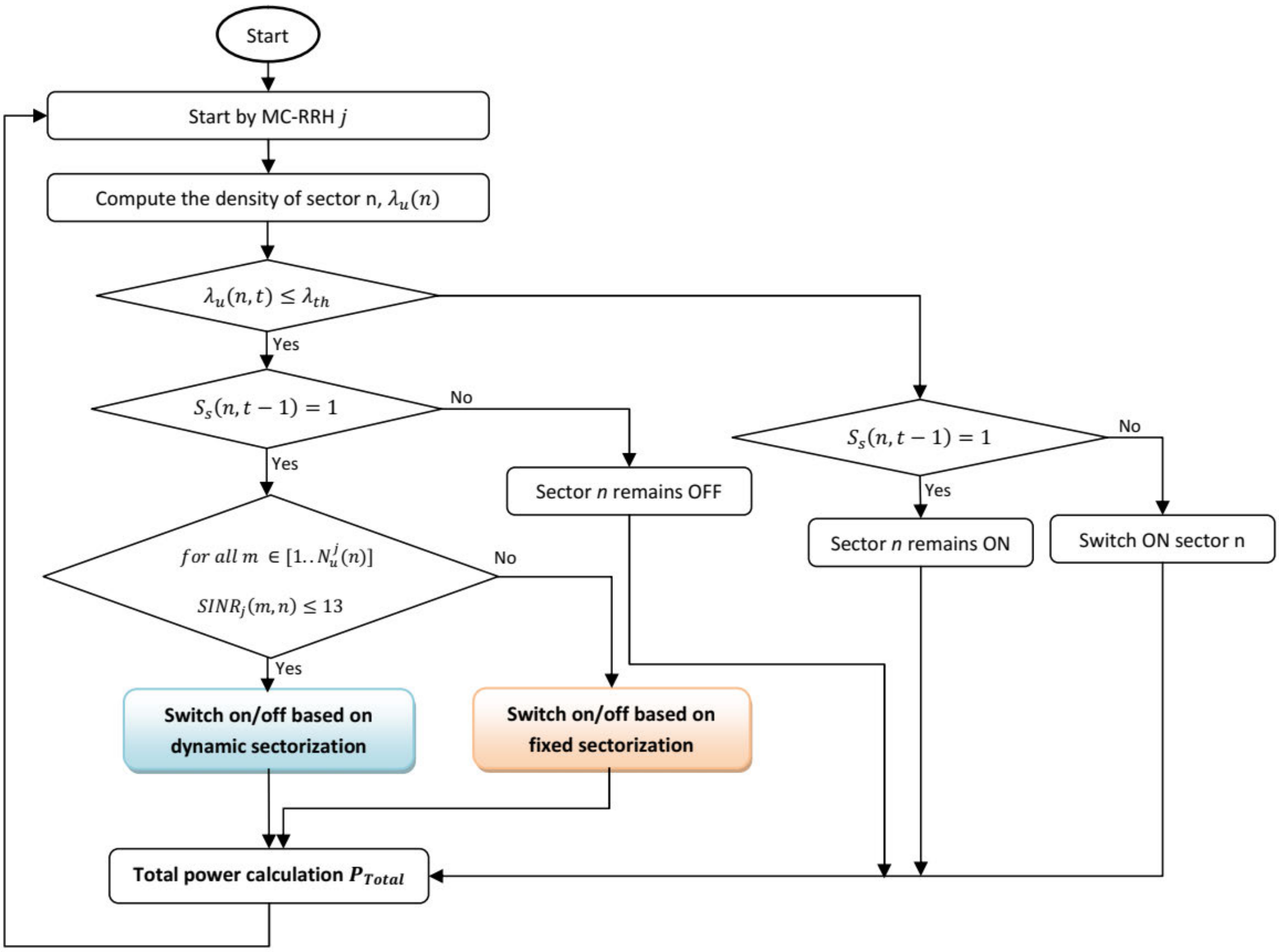

FIGURE 8. Flowchart of the combination of SOOFS and SOODS schemes.

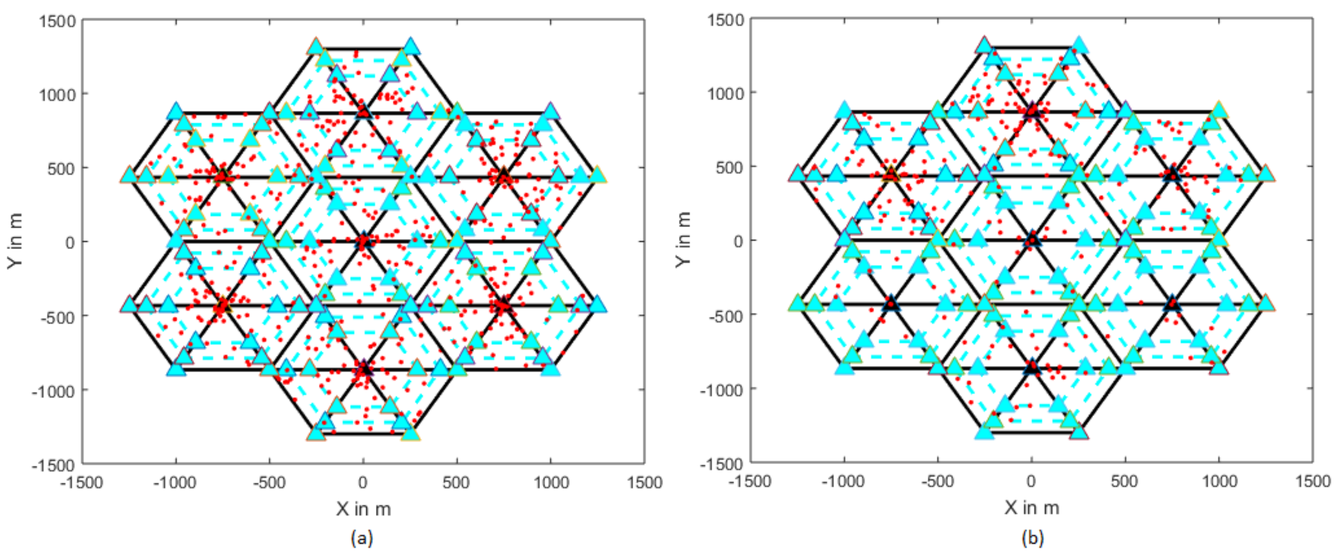

FIGURE 9. Simulation scenarios: (a). Uniform users distribution, (b). nonuniform users distribution.

1) POWER CONSUMPTION

In order to show the effectiveness of our proposed approaches in reducing power consumption, we compare them by algorithms based on the switch on/off by cell. Accordingly, the power consumption and the power saving versus the number of users for our proposed schemes and for those based

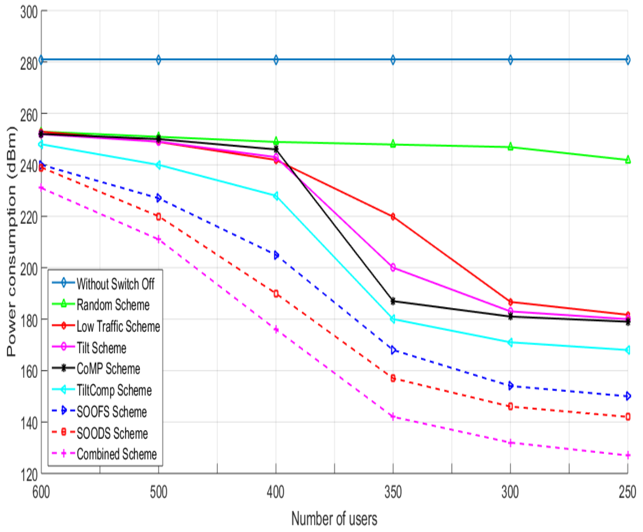

FIGURE 10. Power consumption versus the number of users.

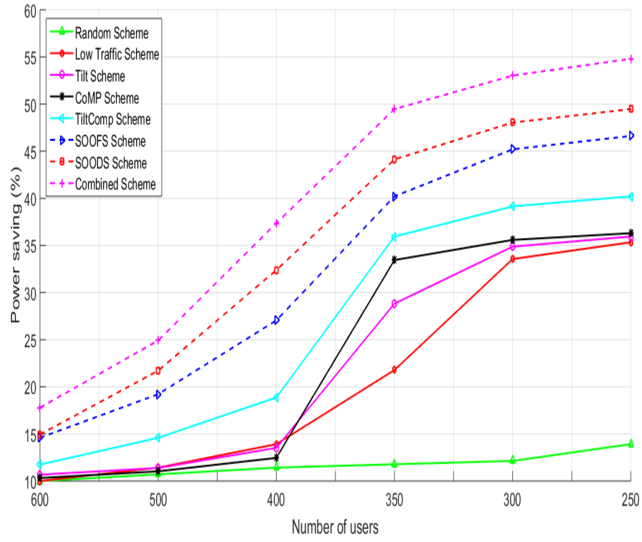

FIGURE 11. Power saving (%) versus the number of users.

on switch on/off by cell are presented in Fig. 10 and Fig. 11, respectively.

Observing Fig.10 and Fig. 11, the dotted line curves represent the power consumption and the percentage of power saving after applying our proposed schemes. Thus, the dotted blue, red and magenta plots represent the simulation results after applying the SOOFS, the SOODS and their combination, respectively. On the other hand, others curves with continuous lines represent different approaches applying the switch on/off by cell. Thus, the cyan plot represents the simulation results after applying the switch off by cell deploying jointly a tilt variation procedure and coordinated multipoint technology [34]. For the black curve, the switch on/off by cell is performed jointly with coordinated multipoint and femtocells [35]. Switch on/off by cell is carried out combined with a tilt variation procedure using femtocells for the magenta curve [36]. For the red plot, the switch on/off by cell is applied only for low traffic periods [37]. Then, the curve in green describes the random switch on/off approach [38] where 1/3 of MC-RRHs are turned off randomly. Finally the blue plot denotes the case when no switch on/off algorithm is executed.

1) **Switch on/off by sector versus switch on/off by cell**
Comparing our proposed approaches based on the switch on/off by sector by those based on the switch off by cell, we observe in Fig. 11 that the SOOFS and SOODS schemes and their combination achieve a better percentage of power saving than those based on switch on/off by cell strategies. In particular, a percentage of power saving reaching 55% is achievable by deploying switch on/off by sector schemes. Nevertheless, it is lower than 30% when applying switch on/off by cell. In fact, as shown in Fig. 10 and Fig. 11, the switch on/off by cell algorithms are efficient only for low number of users. however, our proposed schemes are effective for either big or little number of users. In particular, for a big number of users N_u equal to 600, the switch on/off by sector saves more than 20% than the switch off by cell scheme labeled TiltComp. Further, for a little number of user $N_u = 250$, a difference of 25% of power saving is achieved by the switch off by sector algorithms than those by cell. Accordingly, we conclude that the switch off by sector is more efficient to the benefit that it reduces more number of underutilized regions unlike the case of turning off the entire cell.

2) **SOOFS versus SOODS**
By comparing in Fig. 11 the performance metrics achieved by our proposed schemes, it is quite evident that the SOOFS and the SOODS behave similarly and provide a good amount of power saving. Nevertheless, the SOODS offers a percentage of power saving a little bit better than the SOOFS. In fact, the SOOFS strategy is dedicated for long time interval of switch off, however, the SOODS approach is effective for short time interval. Thus, thanks to the dynamic sectorization, the sector angle can be increased or decreased to offer more deactivated regions and then more power saving especially for short time interval. On the contrary, for long time interval and when the sector angles are fixed, switch off the entire sector is more appropriate.

3) **Combination between SOOFS and SOODS**
Since each switch on/off algorithm achieves a significant amount of power saving, the combination of the both improves more this amount. Indeed, we observe in Fig. 10 that the less amount of power consumption is obtained by the algorithm combined the SOOFS and the SOODS schemes which is represented by the magenta discontinuous curve. Another interesting result disclosed in Fig. 12, which represents the number of active sectors versus the number of users, that the combined scheme achieves the lower number of active sectors than the SOOFS and SOODS techniques.

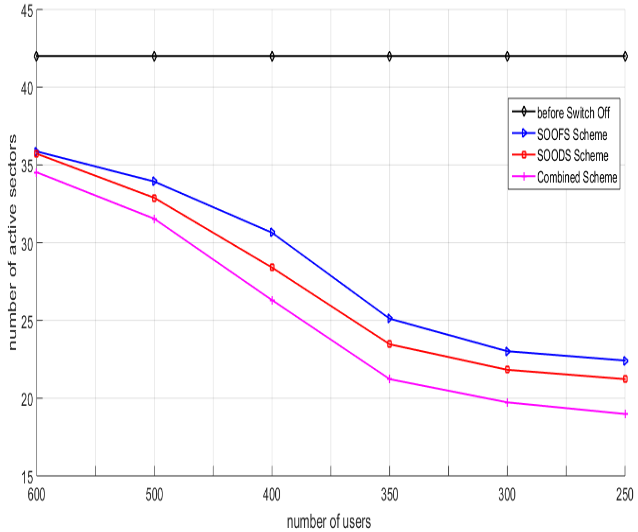

FIGURE 12. Number of active sectors versus the number of users.

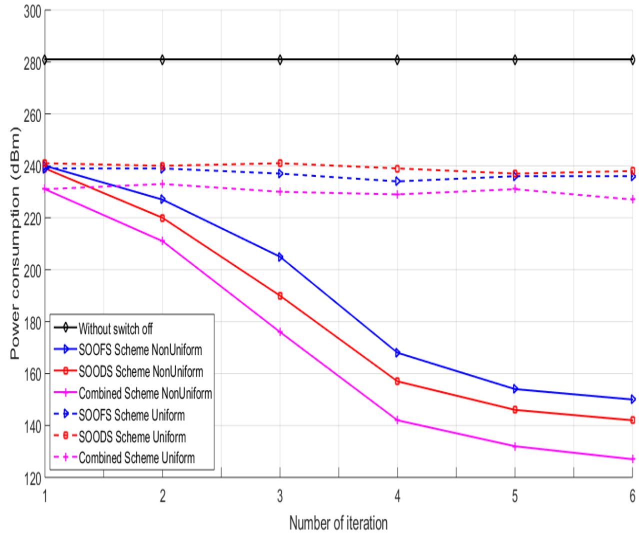

FIGURE 13. Uniform distribution versus nonuniform distribution of users: power consumption.

Actually, Deploying the SOOFS scheme for long time interval jointly with the SOODS for short time interval increases the number of switched off sectors then the amount of power saving.

4) **Uniform versus nonuniform distribution of users**
In this paragraph, we aim to show the effectiveness of our proposed schemes for both uniform and nonuniform user distribution patterns. Moreover, we compare the power simulation results of the proposed algorithms in the uniform case by the nonuniform one. Fig. 13 and Fig. 14 represent respectively the power consumption and the power saving for both uniform and nonuniform distribution of users for different iterations after applying our proposed schemes. For the uniform distribution case, we choose to simulate a fixed number of users by cell equal to 80. Thus, the number of users is fixed, however, their positions vary from iteration to another and from one sector to another.
As depicted in Fig. 14, we observe that the SOOFS scheme is more efficient in term of power saving than the SOODS method for the case of uniform user distribution. However, the SOODS technique is more energy efficient than the SOOFS approach for the nonuniform distribution model. In fact, for uniform distribution, the number of users is fixed in all cells and changes from one sector to another, for that, the switch off will be for long time interval and switching off the whole sector is more suitable than changing the sector angle. In contrary, for nonuniform distribution, the number of users varies from one cell to another and from one sector to another, thus, the switch off is for short time interval and the dynamic switch off is more adequate in this case.
On the other side, and contrary to the switch on/off by cell which is possible only for nonuniform user distribution model, our sector switch on/off algorithms are effective also for uniform case. As shown in Fig. 14, when applying our proposed power saving approaches for uniform user distribution, approximately an average percentage of 15% of power is saved.

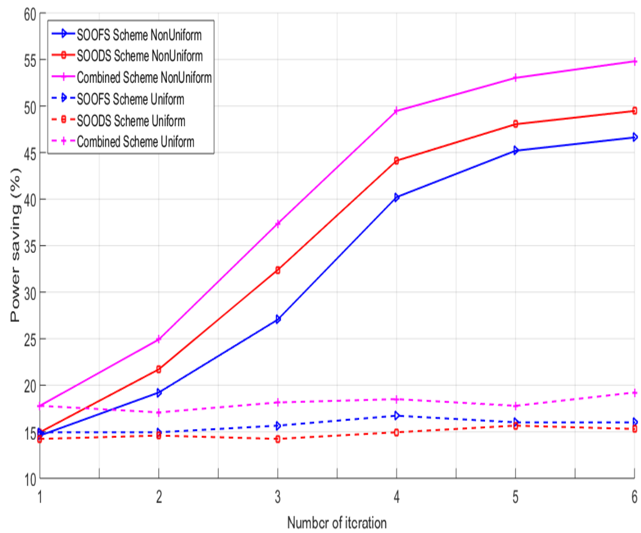

FIGURE 14. Uniform distribution versus nonuniform distribution of users: power saving.

2) QUALITY OF SERVICE

Few mobile users will be impacted by the sector switching off and their QoS will degrade. However, the deployment of distributed SC-RRHs, which aims to improve signal coverage after sector switch on/off process, and by virtue of the dynamic sectorization, an acceptable QoS can be guaranteed. Hence, in order to show the effectiveness of our proposed approaches for maintaining a good QoS after applying the switch on/off, we choose to simulate the SINR values of

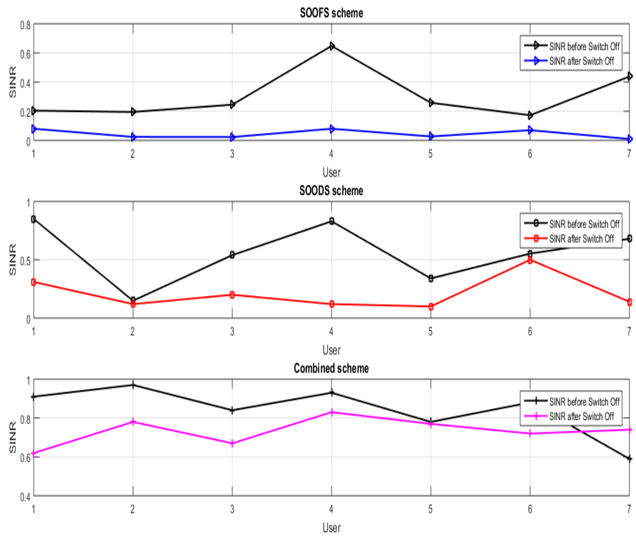

FIGURE 15. **SINR comparison before and after the switch ON/OFF process.**

some users of switched off sector for the three proposed approaches. The simulation results of SINR values are shown in Fig. 15. We observe that for the three schemes the QoS remains almost the same as before the switch off. Thus, as depicted in Fig. 15 the mean value of SINR after applying the sector switch off schemes still stable. Thereby, we deduce that our proposed switch on/off by sector schemes offer a good network performance.

VI. CONCLUSION AND FUTURE DIRECTIONS

A. CONCLUSION

In this paper, we have investigated the power consumption problem in 5G Cloud RAN architecture based on sectorized MC-RRHs and densified SC-RRHs deploying uniform and nonuniform assignment of users. In order to improve the amount of power saving in C-RAN, we proposed to switch off the MC-RRH sectors when their user density is lower than a density threshold. Based on both fixed and dynamic sectorizations, our proposed approaches were implemented. Then, a scheme based on a combination of these two approaches was introduced to offer more energy saving. When switching off a sector, the QoS can be decreased. Hence, we deployed a selective distribution of SC-RRHs within the sector area in order to guarantee a good QoS after the switch on/off process. Moreover, a beamforming technique was adopted by the mmwave antenna of both MC-RRH and SC-RRH to enhance more network performance and reduce interference.

Simulation results have proved that our proposals effectively improve network power saving while maintaining the required QoS. In fact, the two proposed approaches SOOFS and SOODS and their combination can achieve a significant percentage of power saving up to 55%, more especially when the user density is low. Furthermore, our proposals reduce more than 25% of power consumption compared with the switch off by cell. In addition, unlike the switch off by cell schemes which are efficient only for the nonuniform user distribution, our proposed switch on/off by sector techniques are efficient for both uniform and nonuniform user distribution patterns. Moreover, an acceptable QoS for users of switched off sectors has been revealed by evaluating SINR values of users after the switch off process. The resulted QoS returns to the use of the selective distribution of SC-RRHs and the dynamic sectorization deployment.

B. FUTURE DIRECTIONS

A promising extension of our proposed work is to implement a prediction of traffic behavior of users and dynamic allocation of resources to prevent exhaustive power consumption. According to this prediction, the switch on/off process can be dynamically deployed.

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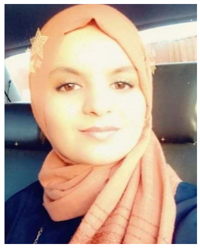

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