JCSE Journal of Computing Science and Engineering

Regular Paper

Journal of Computing Science and Engineering,
Vol. 13, No. 1, March 2019, pp. 32-38

Energy and Congestion Management Algorithms of Small Cells in the Cloud RAN (C-RAN)

Ahmed Laguidi* **and Aawatif Hayar**

Smart City team-RITM CEDoc ENSEM, University of Hassan II Casablanca, Casablanca, Morocco

laguidi.ahmed@gmail.com, aahayar@gmail.com

Abstract

In this work, we shed light on the energy consumption profile of small cell deployments in residential and corporate environments. We present new algorithms to manage energy and congestion in small cell networks. We present a comparative study between our work and other similar works. In this paper, we are particularly interested in aspects based on the sleep mode of base stations. Therefore, we propose new algorithms to reduce energy consumption of networks by putting small cells in active or idle mode according to the network status. In addition, we reduced network congestion with this technique.

Category: Cloud Computing / High Performance Computing

Keywords: LTE; 5G; Small cell; Power management; C-RAN

I. INTRODUCTION

Small cells are small base station low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi [1]. There are three types of small cells: femtocells, picocells, and microcells.

The femtocell or Home eNodeB (HeNB) in Long Term Evolution (LTE) is the smallest type of small cells, which represent an important solution to the upcoming demand for high data rate in wireless communication system. It can be used as an ideal solution to ensure good radio coverage in the residential and corporate environments.

The 3GPP provides a standard for HeNB, LTE femtocell, which is one of the best approaches to reduce the operating expenditures (OPEX) for operators as well as to balance the load from the LTE macrocell networks. Femtocells are low-power access points, providing wireless, voice and broadband services to customers primarily at home [2].

Small cells constitute an essential element in the 5th generation (5G) mobile network, and will be soon standardized to satisfy the growing demand for traffic and improve the speed of access to online services.

The energy consumption of small cells, in particular, picocells and femtocells, is not only wasted by cellular network infrastructure and proliferation of mobile device, but also by the cellular networks, which account for more than 50% of the energy consumption by all networks [3]. In this sense, improved energy efficiency of small cells is vital to supply green cellular networks.

Based on different studies and papers reporting the energy efficiency of small cell networks, the following main approaches are mentioned: first, putting a base station (BS) in active or idle mode when necessary or as needed to reduce the energy consumption consumed by the network and second, using the BSs powered by

Open Access http://dx.doi.org/10.5626/JCSE.2019.13.1.32 http://jcse.kiise.org

Received 07 November 2017; **Revised** 16 January 2019; **Accepted** 07 March 2019

*Corresponding Author

pISSN: 1976-4677 eISSN: 2093-8020

renewable energy.

The last approach allows exploitation of the coordinated multipoint (CoMP) transmissions to reduce the energy efficiency of small cell networks.

In this paper, we are interested in the first approach. Specifically, we propose new algorithms to reduce the energy consumed by the networks, by putting the small cells in active or idle modes according to the network status. We are interested in two types of small cells, picocells and femtocells.

Also, our solution can improve network congestion. In addition, we will propose a server to exploit our new algorithms in Cloud Radio Access Network (C-RAN).

II. C-RAN ARCHITECTURE

Here, we present briefly the C-RAN. This architecture will allow us to propose a server to implement our algorithms in C-RAN. C-RAN is a new mobile network architecture designed to confront a few challenges expressed by mobile operators and meet the needs of data volume and fast access to Internet services. The main idea behind C-RAN is to split the base stations into radio and baseband parts and pool the baseband units (BBUs) from multiple base stations into a centralized and virtualized BBU Pool [4].

The functionalities in C-RAN are moved to the cloud computing infrastructure. The remote radio units (RRU) of different cells are connected to the cloud via a high-speed front-haul link, such as a fiber network, unlike classical cellular systems where a baseband processing unit is deployed at each cell site. Moreover, the C-RAN has a central processing system in the cloud [5]. This architecture contains sites and mobile cloud engines and coordinates multiple services operating on different standards. It allows display of two types of RANs: RAN not-real time and RAN real time. The sites that use the real-time RAN require an important number of computing resources. Multi-connectivity is introduced in this facility to enable on-demand network deployment for non-real-time RAN resources [6]. The connection between the cloud and the small cells is done using an IP link.

In this paper, we propose a server based on the same IP protocol to manage the small cells. This server will be an interface between C-RAN and small cells. The term ‘small cell’ encompasses several types of cells, but we are only interested in the picocell and femtocell.

III. RELATED WORK

In this section, we overview some similar works that reduce the energy consumption of a small cell network. In particular, we present some works similar to our solution.

Han and Ansari [7] have investigated the energy efficiency of the cellular networks, and exploited coordinated multipoint transmissions. Also, they have proposed solutions based on multicellular cooperation.

Han et al. [8] have examined several alternatives of existing cellular network structures in order to reduce energy consumption. In their paper, they studied new techniques that can be used in base stations or handsets to reduce energy consumption by the network. These techniques are based on resource allocation, interference suppression and multi-hop network routing.

Mhiri et al. [9] have proposed a green and distributed algorithm to optimize femtocell coverage while grouping based on adjusted transmitting power in corporate environments and administrative domain.

These studies and others are based on several techniques, which use energy conservation to solve specific energy challenges. However, this does not solve exactly the problems addressed in this paper. In this sense, we focus on a technique proposed by Ashraf et al. [10]. This technique provides a dynamic energy-efficient solution by enabling the idle mode procedure in the femtocell BSs irrespective of the location of the registered users.

IV. ASHRAF’S TECHNIQUE

Here, we provide a brief description of a technique proposed by Ashraf et al. [10], and we present the related flowchart proposed.

We chose to describe briefly this technique because we consider that it contains the necessary elements for logical comparison. For example, it uses logic closest to our work and the same logic is used in several similar techniques.

The authors of this paper have proposed a mechanism to reduce energy consumption by reducing the consumption of one or more network entities. Briefly, this technique is used to reduce the energy consumption by allowing a complete switch-off of femtocell transmissions and associated processing at all times when not supporting an active call [10].

The underlay macrocell coverage is required to enable the idle mode procedure since it relies on detection of transmissions from a user equipment (UE) to a macrocell. When a mobile located inside the coverage range of the femtocell makes a call to the macrocell, the sniffer detects a rise in the received power on the uplink frequency band.

Fig. 1 shows the flowchart proposed by Ashraf involving the idle mode procedure for a femtocell BS.

In our solution, we propose two new algorithms for managing and administering the small cells in the network. Our algorithms propose a mechanism for switching between two modes (idle and active), according to the network status (energy and congestion). Especially, these algorithms can put a small cell in the active mode as

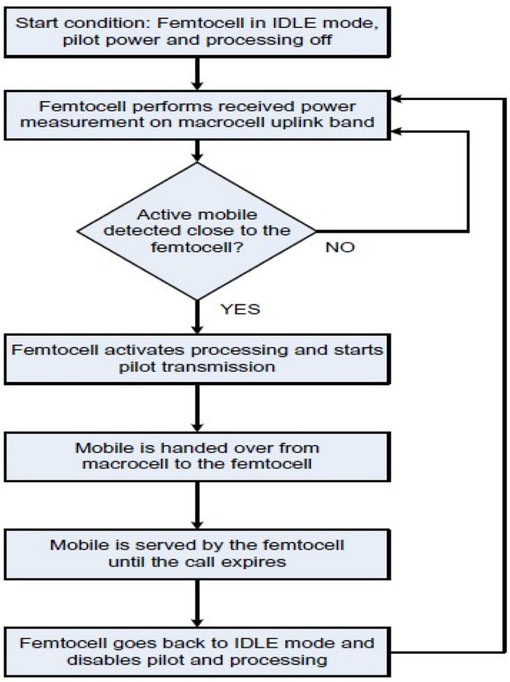

Fig. 1. Ashraf's flowchart outlining the IDLE mode procedure for a femtocell BS.

needed and keep other small cells in the idle mode.

Unlike several solutions proposed, our approach allows management of the entire network to achieve the same objective: reduced energy consumption. In addition, our algorithms contribute to effective management of the congestion in the network under specific conditions (as mentioned in this paper).

However, as discussed in the next section, additional details of this technique and the benefits of this proposition are needed.

V. ENERGY AND CONGESTION MANAGEMENT OF SMALL CELLS

A. Motivation

The rapid evolution of small cells to improve radio coverage in the residential environment and small businesses or other areas raises challenges involving management, energy consumption and administration of small cell networks in different types of mobile networks: 3G, 4G, and 5G. Therefore, we would like to reduce energy consumption in the network by improving the management of small cells in the network, in particular, picocells and femtocells. Microcells are not studied here because we are mainly interested in improving indoor coverage. Microcells are used especially for outdoor coverage.

B. Problematic Formulation and Description

In this section of the paper, we present different challenging situations modeled by simple equations. In order to better understand our algorithms, we use the general mathematical formula of energy:

$$E = P * T,$$

wherein P denotes small cell power, and T represents time.

1) Energy Not Exploited in Idle Mode

In this picture (Fig. 2), several UEs attempted to connect to the same small cells but without results. However, a number of UEs attempt to connect to a single small cell and a few stations are in idle mode.

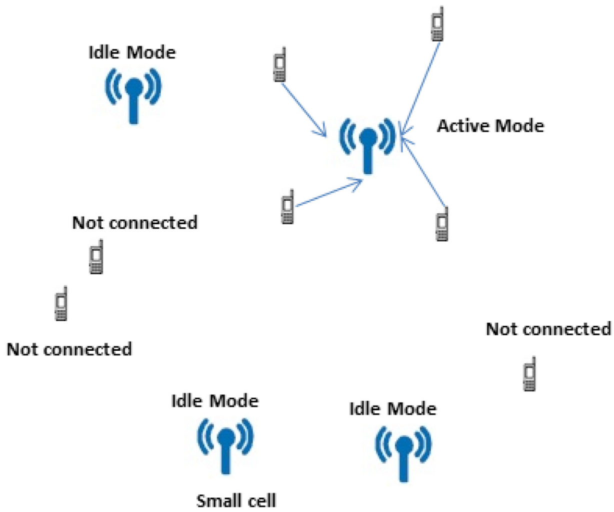

Fig. 2. Energy not exploited in idle mode.

We note that a quantity of energy is, therefore, wasted by some stations. During a period T, the energy not exploited can be modeled by the following equation:

$$E_{idle} = \sum_{i=1}^{Ni} P_{Fidle} * T \quad (1)$$

where Ni is number of small cells in the idle mode and T is time.

2) Wasted Energy Exceeds the Energy Needed

In Fig. 3, we observe that all small cells are in the active mode; however, all UEs can be supported by a single small cell. Therefore, the energy used exceeds the needs.

This energy can be modeled by the following equation:

$$E_{Used} = \sum_{i=1}^{Na} P_{Factive} * T \quad (2)$$

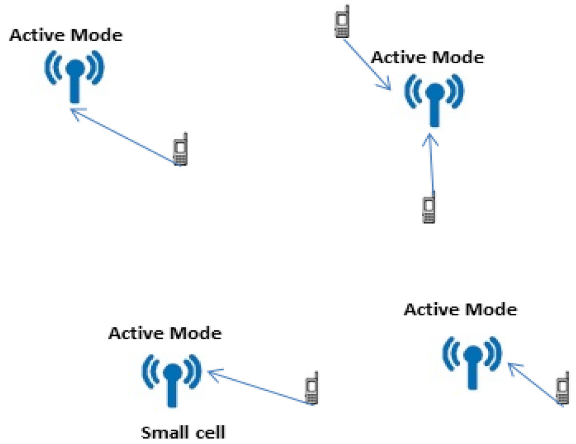

Fig. 3. Energy used exceeds the energy needed.

where Na is number of small cells in active mode and N is total number of small cells in the network. In this case, $Na = N$.

3) Network Congestion Situation

Also, we note that a few UEs are not connected to any small cell, even if other cells are available. The number of UEs that are not connected N_{NC} is obtained by the following equation:

$$N_{NC} = N_T - N_C$$

where N_T is total number of UEs attempting to connect to a small cell; N_C, number of UEs connected; and N_N, total number of UEs supported by the small cells in the network.

$$\text{With } N_N \geq N_T \geq N_C .$$

Thus, the total network capacity is not exploited. Therefore, we propose our new algorithms for management of small cells and UEs. According to the network status, we put a few small cells in the idle mode or in the active mode depending on the number of UE. Thus, we derive the following equation:

$$N_T = N_C \qquad (3)$$

$$\text{With } N_{NC} = 0.$$

As soon as possible, we connect the total UEs (if technically feasible) to the network.

In some cases, the number of UEs wanting to connect to the network exceeds the network capacity. This topic is not the objective of this paper.

Based on an analysis of the algorithm proposed by Imran Ashraf, we note that the femtocell is in the idle mode where a UE is detected. In this case, all femtocells are connected in the active mode to resolve the problem mentioned in Fig. 2. We will demonstrate this observation in the next section based on numerical results.

In the next section, we propose our new algorithms for management of small cell network energy and congestion.

C. New Algorithms

Our algorithms solve the network challenges presented in this article, to possibly reduce the energy and network congestion. These algorithms facilitate the management of the total energy of the small cell network, according to the general flowchart (Fig. 4).

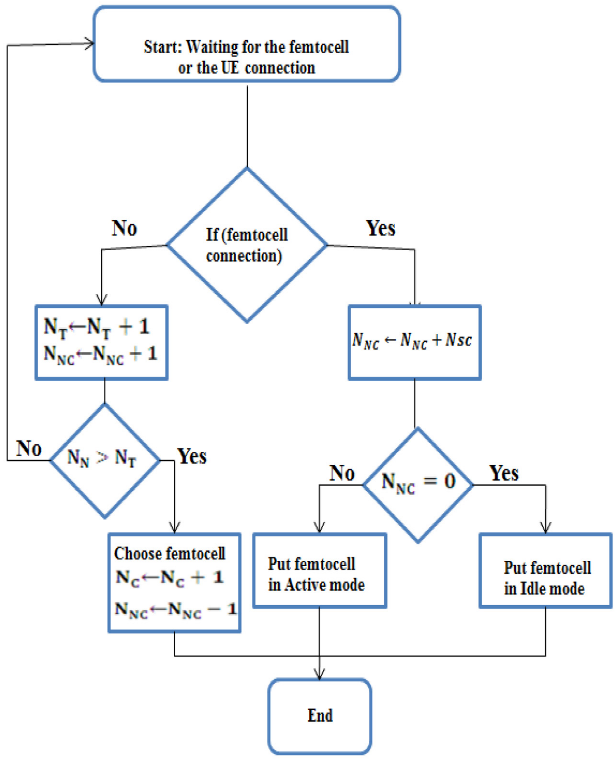

Fig. 4. Flowchart of the small cells and UEs connection management.

Fig. 4 presents the flowchart of the small cells and UEs management. It puts the small cells in the idle or active mode network as needed.

Here, we describe briefly the algorithm 1 associated with the flowchart (Fig. 4).

In the beginning, the algorithm requires UEs or small cell connection. Then, upon small cell connection, the small cell server performs the following operation:

$$N_N \leftarrow N_N + N_{SC}$$

where N_{SC} is number of UEs supported by each small cell.

Subsequently, if $N_{NC} = 0$ (number of the UEs that are not connected is zero), the server puts the small cell in the idle mode, else the server puts the small cell in the active mode.

In the case where a UE attempts to connect, the server performs the following operations:

$$N_T \leftarrow N_T + 1$$

$$N_{NC} \leftarrow N_{NC} + 1$$

Finally, if $N_N > N_T$, the server chooses a small cell to connect the UE and performs the following operations:

$$N_C \leftarrow N_C + 1$$

$$N_{NC} \leftarrow N_{NC} - 1$$

Conversely, the server waits for a small cell or UE connection.

Also, we describe the algorithm 2 associated with the flowchart (Fig. 5).

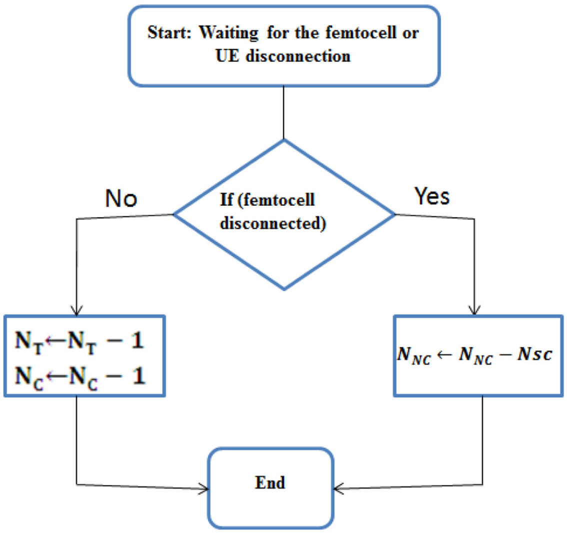

Fig. 5. Flowchart of the small cells and UEs disconnection management.

In the beginning, the small cell server waits for the UEs or small cell disconnection and when a small cell attempts to connect to the network, the server performs the following operation:

$$N_N \leftarrow N_N - N_{SC}$$

Conversely, the server performs the following operations:

$$N_T \leftarrow N_T - 1$$

$$N_C \leftarrow N_C - 1$$

These algorithms can efficiently manage the network, especially, network congestion and energy consumption.

In addition, the amount of energy saved increases over time. For example, the amount of energy saved is also important for systems that require a lot of energy over time.

We use this solution to manage the total energy of small cell network, and use the energy only when needed. Thus, we can minimize the energy used in small cell networks.

D. Experimental Procedure

To implement our algorithms, we introduced a server in the C-RAN architecture. The small cell servers (picocells and femtocells) represent an interface between the C-RAN and the small cell site. This server facilitates the management of the entire site according to the proposed algorithms.

The connection between the small cell server and the other entities can be of different types: Optical, Fiber, Wave, VPN, etc. The connection between the C-RAN and the server is performed by an IP link (Fig. 6).

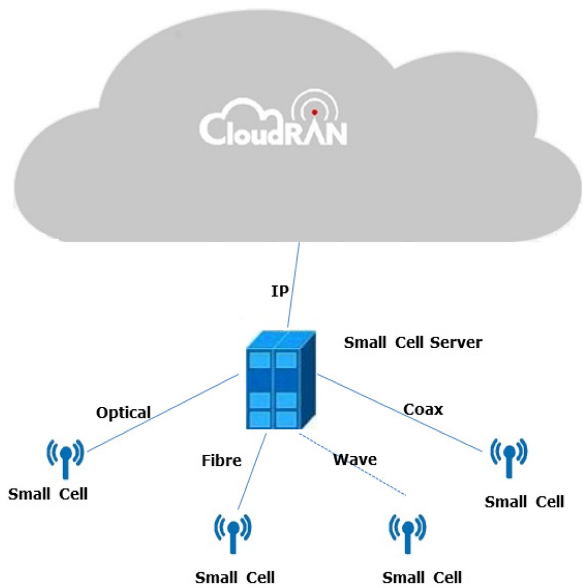

Fig. 6. Small cells server management in the C-RAN architecture.

This approach allows the management of energy and network congestion, and avoids problems related to heterogeneous media involving small cells: VPN, Fiber, etc. This strategy facilitates communication by switching to the all IP mode.

Technically, the validation of the work of this article was carried out under a platform specially designed for this purpose. In fact, several free or open source simulation tools did not allow the validation. We designed this platform to address this limitation. The platform consists of a central server implementing our new algorithms and several nodes. These nodes are specially designed to play the role of small cells studied in this article. This platform enabled simulation of reality (Note that the platform runs on the Linux operating system).

VI. RESULTS AND DISCUSSION

In this section, we illustrate concrete cases to elucidate our work, and present specific results graphically and as a table.

Toward this end, we used two conditions. First, we consider a network of 8 femtocells and 8 UEs and use results obtained in [11], especially femtocell power in the idle or active modes (Table 1). Second, we consider a network of 8 picocells and 8 UEs, and use specific results obtained in [12] (Table 1). Thus, we compare the situation modeled by Eq. (1) and the results of our solution.

Table 1. Energy consumed by picocell and femtocell

Small cell	Power (W)	
	Active mode	Idle mode
Femtocell	10.2	6
Picocell	70	49

We have chosen a picocell that consumes 70 W, and have calculated the energy value in the idle mode.

Here, we suppose that the 8 UEs are supported by a single small cell.

Under these conditions (Figs. 7 and 8), we found that the energy consumed by our solution was lower with

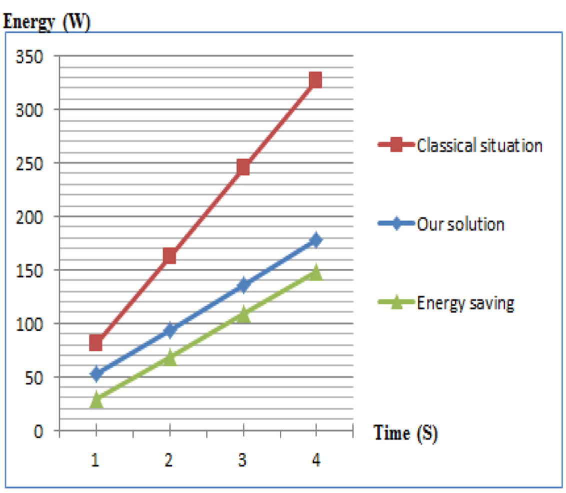

Fig. 7. The situation shows the energy consumed by our solution (femtocell).

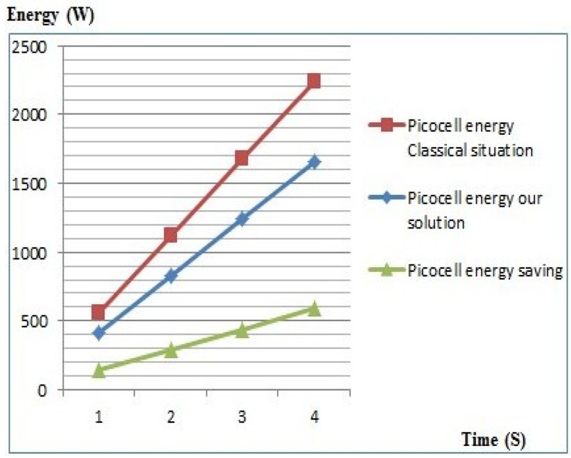

Fig. 8. Energy consumed by our solution (picocell).

respect to the energy modeled by Eq. (1).

According to Fig. 7, during 4 seconds we conserved 148.2 J, which is 45.40% in the case when 8 femtocells are in the active mode. In the Ashraf's technique, the energy saved is of the order of 41.2% [10].

According to Fig. 8, during 4 seconds we conserved 588 J, which accounts for 26.25%, when 8 picocells are in the active mode (Note these numbers vary according to the number of picocells or femtocells set in the idle or active mode).

VII. CONCLUSION

In this paper, we have presented an overview of different studies. We have provided a brief description of Ashraf's technique, and proposed our algorithms for small cell management in the last section. These algorithms reduce the energy consumed by the network. Under several scenarios, our solution also improved the management of congestion in the network.

In addition, we have proposed a small cell server in the C-RAN architecture for management of small cells and implementation of our algorithms. Based on our solution, we can reduce the energy consumption up to 45.40% in some cases.

Compared with the existing techniques, our strategy allows management of energy resources via a collective and collaborative approach.

REFERENCES

1. Small Cell Forum, "Small cell definition," http://www.smallcellforum.org/about/about-small-cells/small-cell-definition/.
2. H. Zhang, X. Wen, B. Wang, W. Zheng, and Y, Sun, "A novel handover mechanism between femtocell and macrocell

for LTE based networks," in *Proceedings of 2010 2nd International Conference on Communication Software and Networks*, Singapore, 2010, pp. 228-231.
3. S. Carlaw and C. Wheelock, "Femtocell market challenges and opportunities: cellular-based fixed mobile convergence for consumers, SMEs, and enterprises," ABI Research Report, 2007.
4. A. Checko, "Cloud radio access network architecture: towards 5G mobile networks," Ph.D. dissertation, Technical University of Denmark, Kongens Lyngby, Denmark, 2016.
5. Aalto University, "Cloud Radio Access Networks (C-RAN)," 2018; https://www.aalto.fi/5g-research/cloud-radio-access-networks-c-ran
6. Huawei Technologies, "5G network architecture: a high level view," 2016; https://www.huawei.com/minisite/5g/img/5G_Network_Architecture_A_High-Level_Perspective_en.pdf.
7. T. Han and N. Ansari, "On optimizing green energy utilization for cellular networks with hybrid energy supplies," *IEEE Transactions on Wireless Communications*, vol. 12, no. 8, pp. 3872-3882, 2013.
8. C. Han, T. Harrold, S. Armour, I. Krikidis, S. Videv, P. M. Grant, et al., "Green radio: radio techniques to enable energy efficient wireless networks," *IEEE Communications Magazine Special Issue: Green Communications*, vol. 49, no. 6, pp. 46-54, 2011.
9. F. Mhiri, K. S. B. Reguiga, R. Bouallegue, and G. Pujolle, "A power management algorithm for green femtocell networks," in *Proceedings of the 10th IFIP Annual Mediterranean Ad Hoc Networking Workshop*, Sicily, Italy, 2011, pp. 45-49.
10. I. Ashraf, L. T. W. Ho, and H. Claussen, "Improving energy efficiency of femtocell base stations via user activity detection," in *Proceedings of 2010 IEEE Wireless Communication and Networking Conference*, Sydney, Australia, 2010, pp. 1-5.
11. Y. S. Chen and C. Y. Wu, "A green handover protocol in two-tier OFDMA macrocell–femtocell networks," *Mathematical and Computer Modelling*, vol. 57, no. 11-12, pp. 2814-2831, 2013.
12. L. Saker, G. Micallef, S. E. Elayoubi, and H. O. Scheck, "Impact of picocells on the capacity and energy efficiency of mobile networks," *Annals of Telecommunications*, vol. 67, no. 3-4, pp. 133-146, 2012.

Ahmed Laguidi

Ahmed Laguidi received the Master's degree in computer science and engineering from the Faculty of Sciences and Techniques (FSTE), Errachidia, Morocco, in 2005 and the D.E.S.A. degree in Telecommunications and Networks, from the Faculty of Sciences and Techniques (FSTG), Marrakech, Morocco, in 2008. He is currently pursuing the Ph.D. degree in network, C-RAN at the High National School of Electricity and Mechanical (ENSEM), Casablanca, Morocco. His research interests include 5G network, C-RAN, small cells, green computing and efficiency energetics.

Aawatif Hayar

Aawatif Hayar is IEEE Senior Member, Chair of Casablanca IEEE Core Smart City project, and Professor at University Hassan II Casablanca Morocco-GreenTIC-ENSEM, Co-founder of e-Madina. She was selected in 2015 by the African Innovation Foundation as one of the Top-10 innovative African women. She is currently leading R&D projects in smart cities with the City of Casablanca, IRESEN, CNRST, Lydec, GIZ and HBS Foundation.