Motion Sensor-based Small Cell Sleep Scheduling for 5G Networks

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***Abstract*—The fifth generation of mobile systems will rely on a dense deployment of small cells in order to meet its ambitious Key Performance Indicator targets. However, this dense deployment will result in a significant increase in the energy consumption of 5G networks, and thus, OPEX costs. Several small cell sleeping algorithms have been proposed in the literature but they require complex algorithms to decide when to switch on/off the small cells. On the basis of a distributed self-organizing approach, in this paper, we propose a low-cost, low-complexity small cell sleep scheduling algorithm to minimize the energy consumption of small cells in 5G and beyond networks. Our control utilizes a motion detection circuit to toggle the small cell between sleep and active modes based on the presence of a user. We evaluate the performance the algorithm on an experimental testbed and the results show that our algorithm achieves up to 20% reduction in energy consumption when compared to 'always on' approach.**

***Index Terms*—Small cell networks; sleep scheduling, motion sensor, 5G and beyond, Open Air Interface, FlexRAN, NG-SON**

I. Introduction

The fifth generation mobile communication network, 5G, promises to stretch the limits of the Key Performance Indicators (KPIs) of current systems by taking into account several criteria such as latency, resilience, connection density and coverage area, alongside the traditional spectral efficiency and Energy Efficiency (EE) criteria in its design. 5G has performance targets of sub-millisecond latency, 100-fold increase in typical user data rates and connection density and 10 times increase in EE, compared to current systems [1]. These targets are crucial for achieving the three main use cases identified by IMT Vision recommendation ITU-R M.2083-0 as Enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC) and Massive Machine Type Communications (mMTC).

Network densification is one of the keys to meet the demand for higher data rates. It refers to adding more cells by deploying new base stations (BSs) in order to achieve higher capacity within an area of interest. The the Small Cell Forum (SCF) predicts that over 70 million Small Cells (SCs) will be deployed globally by 2025 to support the ever increasing user demands [7]. However, deploying additional BSs implies consuming more energy to run the network, as the energy consumption of a network is directly proportional to the number of BSs it contains. Since BSs constitute the main part of the energy consumption in mobile cellular networks [2], it implies that network densification would have a direct effect on energy consumption of 5G. An effective and efficient network densification can be accomplished by adopting the Control Data Separated Architecture (CDSA) concept as authors underline in [3]. CDSA approach allows a logical separation between signalling and data traffic in the Radio Access Network (RAN). In this architecture, intelligence is partially or completely removed from most of the nodes in the network to be concentrated in fewer central nodes. This results in cost saving, higher performance and resource efficiency [3].

The promotion of CDSA is closely linked to the concept of the Self Organizing Network (SON) which contributes to the flexibility required for 5G. SON was initially identified as a key design principle for LTE, focusing on its distributed approach [4]. However, as shown in [5], a Next Generation (NG)-SON for future 5G networks, designed to maximize automation of all aspects and at all possible levels, depending on the specific use cases is required. In fact, NG-SON provides optimization based on either a higher level (cell cluster scale) scenario, Centralized-SON (C-SON) or on a smaller scale, Distributed-SON (D-SON). Each solution has its advantages and a Hybrid-SON (H-SON) architecture brings together all the advantages of D-SON and C-SON. It is necessary to appropriately choose the degree of centralization in terms of control plane functionalities and SON capabilities, based on the considered scenario. Software Defined Networking (SDN), Network Function Virtualization (NFV) and Cloud-RAN (C-RAN) are regarded as the enabling technologies to realize these enhancements. Accordingly, a hierarchical layered software-defined architecture for future 5G mobile networks has been proposed in [6]. The Master Controllers, which form the upper control layer and are located in remote sites, manage cell clusters, taking into account long-term scale and less fine-grained parameters, while acting as reference entities for the Slave Controllers. Unlike Master Controllers, Slave Controllers form the lower control layer and are located at the edge sites, with highly dynamic features that allow the network to adapt to local changes more quickly.

Spatio-temporal changes in data traffics of BSs pave the way for green networks by allowing switching unused (or lightly used) BSs off to reduce the energy consumption of the whole network [3]. In other words, since the traffic loads of cells exhibit various patterns over different days of a week and/or time of a day, BSs could be switched off during low traffic (or no traffic) periods. Cell switching strategies based on traffic conditions and/or proximity of SCs to a Macro Cell (MC) have been widely studied in the literature [8]–[11]. In [8], the authors propose a traffic load based cell on/off switching mechanism using actor-critic reinforcement learning. Both centralized and distributed solutions are proposed in [9] by considering BS switching on/off, user association, and power control jointly in order to enhance EE of the system. A mixed integer programming formulation was used for the centralized approach and near optimal solution was obtained. A proximity based SC sleeping technique for Heterogeneous Networks (HetNets) was presented in [10]. SCs that are far from the MC with a certain threshold, are opportunistically switched off and covered by the neighbouring SCs using cell range extension, while the traffic in the SCs closer to the MC is offloaded to the MC in case of switching off. The authors in [11] propose a joint user association and cell switching algorithm where activation states are first determined and then EE is improved by associating users to the cells accordingly. In [12], the authors propose a centralized solution which aims to compute the optimum number of BSs to switch off in order to maximize the energy saving, while maintaining coverage, capacity and Quality of Service through a combination of Grey Relational Analysis (GRA) and Analytic Hierarchy Process (AHP) tools. It adopts AHP and GRA tools in order to include multiple criteria with different priorities in the switch off decision making process. The introduction of multiple decision inputs allows to capture efficiently spatial and temporal traffic fluctuation and, as a consequence, to optimize the set of switched off BSs.

Nonetheless, most of the existing techniques related to BS sleep scheduling rely on complex algorithms, since they often employ centralized approaches to determine which SCs to switch on/off and/or when to do so. These proposals could be classified as C-SON solutions. To cope with all the envisaged scenarios, the C-SON and D-SON solutions will have to coexist and be suitably adopted. However, complex and expensive methods are generally costly in the case of D-SON due to the large number of SCs involved.

In this paper, a low-cost, low-complexity SC sleep scheduling algorithm is proposed for D-SON. An idle SC goes into sleep mode and only wakes up with the presence of a user, which is detected by a motion sensor circuit. After waking up, the SC waits for a certain amount of time to check if the detected user will make a connection with it. If the user does not associate with it, the SC goes back into sleep mode; however, in case there is attachment, the SC remains active and only goes back into sleep mode when the user disconnects. Hence, the proposed SC sleep scheduling algorithm is designed as a distributed (i.e. the decisions are made locally and there is no need for a central entity) and low-complexity (i.e. it is merely a binary decision process, which is triggered by a motion sensor, for an individual SC) algorithm.

The remainder of this paper is organized as follows. Section II describes the system model. In Section III, we propose our motion sensor-based SC sleep scheduling algorithm. Section IV presents the performance evaluation of our algorithm, while Section V concludes the paper.

II. System Model

In this section, we present the experimental setup and the power consumption model of the testbed.

A. Experimental setup

The experimental setup runs on the 5G Self-Organised Network (5GSON) testbed at the University of Glasgow, which is based on OpenAirInterface (OAI). OAI is a software tool enabling an open-source implementation of both the Core Network (CN) and Radio Access Network (RAN) based on 3GPP standards [13]. OAI entities can be either deployed on separate machines or in an all-in-one setting. In this paper, see Fig. 1, both the OAI software entities run on an Intel NUC mini computer. The Radio Frontend (RF) is provided by an Ettus B205mini USRP Software Defined Radio (SDR) platform.

In order to implement the NG-SON concept, we exploit FlexRAN, a Software Defined-RAN (SD-RAN) Controller [14] that also runs on the Intel NUC. FlexRAN supervises the OAI RAN entities, extending the vanilla OAI code to perform control plane functionalities. The FlexRAN controller interacts through specific southbound and northbound APIs to the base stations and the applications, respectively. More specifically, control plane instructions are determined by applications running on top of FlexRAN, each one computing a specific network control algorithm. User plane functionalities are performed by the Agent, embedded in the next generation eNodeB (ng-eNB), which is in charge of executing control plane instructions, e.g. resource allocation, bandwidth and operating frequency. Each Agent sends various network state statistics to FlexRAN which are exploited as input parameters for the network control algorithms.

With inherent features of FlexRAN, it is therefore possible to enable C-SON and D-SON solutions, performing both centralized and distributed control. In a higher-level control (many macro cells) the FlexRAN performs complex controls with a wider overview: traffic loads, user density, etc. While, in a local control (distributed), we can delegate the control logic to the Agents activated only in the first instance by FlexRAN. In the latter case, it needs to apply control strategies with low computational complexity.

In this regard, we propose a D-SON algorithm to minimise the energy consumption of SCs by utilizing a motion detection circuit. We utilise an Arduino Uno board and an HC-SR501 PIR motion sensor. The motion sensor is connected to and powered by the Arduino board, which draws its power from the Intel NUC computer via USB. The USRP is also powered by the computer via a USB 3.0 port, with a USB power meter connected between them to measure the energy consumption

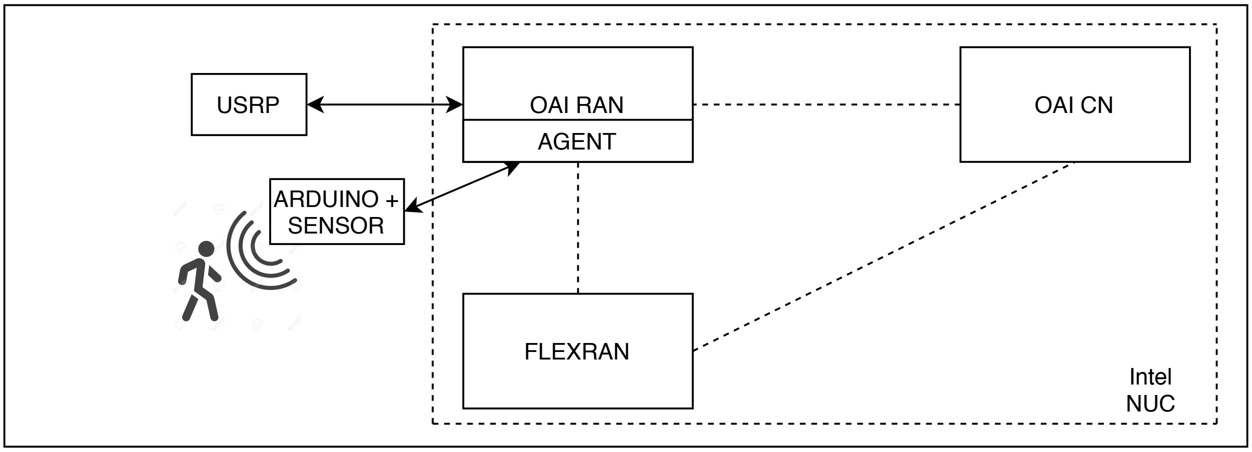

Figure 1. Proposed deployment archtecture

of the USRP. On the other hand, the Intel NUC computer draws its power via a power meter that is connected to the mains to measure the energy consumption of the whole system.

B. Power consumption model

According to [2], the power consumption of a base station with a single transceiver chain can be modeled as

$$P_{\text{in}} = P_0 + \Delta_{\text{p}} P_{\text{out}}, \quad 0 < P_{\text{out}} \leq P_{\max} \tag{1}$$

where P_0 and P_{out} denote the power consumption of the base station at the minimum non-zero output power and the RF output power radiated at the antenna elements, respectively. The parameters Δ_{p} and $P_{\max}$ represent the slope of the load dependent power consumption and the average transmit power of the base station, respectively. It can be deduced from (1) that the power consumption model consists of a fixed part (P_0) and a load-dependent part ($\Delta_{\text{p}} P_{\text{out}}$).

With regards to the SDR platform, the B205mini USRP consists of an FPGA and RF front end. The RF front-end comprises of one transceiver chain that is made up of a power amplifier and an RF small-signal transceiver module. Focusing on active and sleep modes, the USRP has been measured to draw roughly 2 W when the ng-eNB is in sleep mode, while it consumes about 2.5 W when in active mode. Hence, we assume that the FPGA module and the RF front-end denote the fixed and variable parts of the USRP power consumption, respectively. Accordingly, in this paper, P_0 comprises of the power consumptions of the USRP FPGA and the intel NUC mini computer that relates to the CN, FlexRAN and maintaining a connection between the ng-eNB and the CN, whereas the RF front-end, motion sensing circuit and the power requirement for running ng-eNB layers 1-3 on the Intel NUC mini computer make up the variable part.

In the remainder of this paper, we will refer to the Intel NUC mini computer as the ng-eNB machine, unless stated otherwise.

III. Algorithm Design

In this section, we present our proposed D-SON algorithm to minimise the energy consumption of SCs by utilizing a motion detection circuit.

The proposed algorithm has been designed using OAI and FlexRAN to switch off the RF frontend of the ng-eNB SDR without affecting the ng-eNB connection with the CN. The ng-eNB goes into sleep mode by leveraging on FlexRAN functionalities to switch off layers 1 and 2, and Radio Resource Control (RRC) sub-layer of the 3GPP protocol stack and free all resources. Subsequently, the RF front-end of the USRP is turned off. This implies that the ng-eNB always maintains connection with the CN.

While in sleep mode, the ng-eNB machine periodically scans its serial port every y seconds for updates from the motion detection circuit to wake up. The moment motion is detected, the Arduino board writes the binary value "1", denoting "ON", to the serial port of the ng-eNB machine for w seconds before writing binary "0" to reset the serial port and then waiting for the motion to be detected again for the process to repeat. The length of w is set such that the ng-eNB does not miss any event between successive probes of the serial port, that is $w \geq y$. Once the ng-eNB reads this ON value, it wakes up for x seconds and waits for users to connect to it. If no users connect within this time, the ng-eNB goes back to sleep and starts scanning the serial port again. However, if there is a user connected, the ng-eNB will not go to sleep and will periodically check every z seconds until no user is connected before going back to sleep. Fig. 2 gives the flowchart of the proposed algorithm.

Given that the goal of this paper is to reduce energy consumption of SC networks, it is important to minimise the energy consumption of the motion detection circuit so as not to undo the gains of this algorithm. Accordingly, we put the Arduino board in sleep mode and utilise its interrupt pins to power it up whenever motion is detected. Once motion is detected, the Arduino board is powered on and it writes to the serial port of the ng-eNB machine and goes back to sleep.

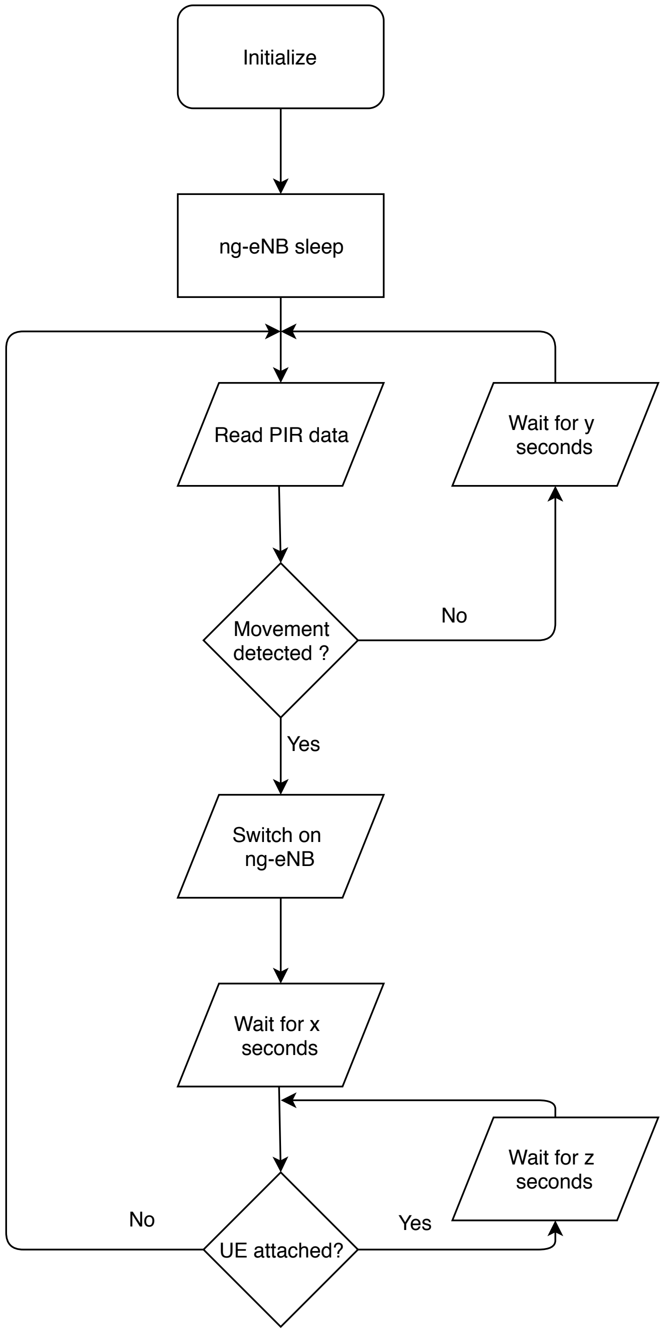

Figure 2. Proposed motion sensor-based sleep scheduling flowchart.

This results in about 45% reduction in power consumption of the motion detection circuit compared to when the Arduino board is always on.

IV. Performance Evaluation

In this section, we present the performance results of our motion sensor-based SC sleep scheduling algorithm against the no sleep scheduling approach, whereby the SC does not employ any form of energy saving and is always active. The experimental setup was deployed in a 16 m^2 room and the ng-eNB was toggled between active and sleep modes based

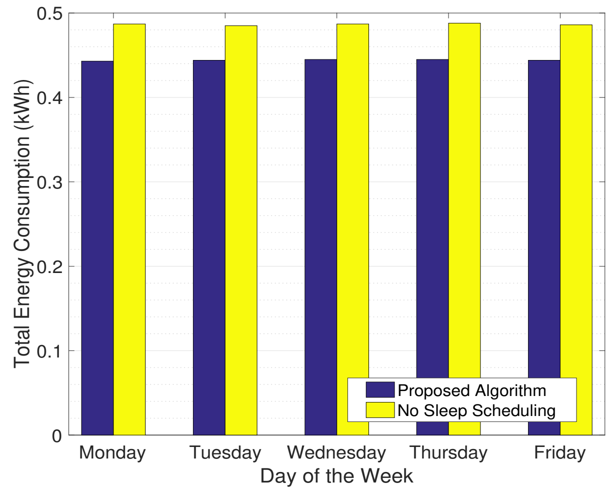

Figure 3. Total energy consumption comparison of our proposed SC sleep scheduling algorithm versus the no sleep scheduling approach.

on movements in the lab. No user equipment was allowed to connect to the network during the experiments in order to mimic a deployment location that experiences low-to-medium user activity such as staircases, areas around toilets or even office rooms. In this paper, we assume $w = y = 1$ second, $x =$ 60 seconds and $z = 30$ seconds such that there is instantaneous reading of the motion detection circuit enough time for the user to connect to the network after waking up the ng-eNB.

Fig. 3 shows the total energy consumption comparison of our SC sleep scheduling algorithm versus the benchmark no sleep scheduling approach. For both approaches, the energy consumption of the full setup, including the Intel NUC mini computer and USRP was measured at 24 hour intervals over 5 days, from Monday to Friday. However, in the case of our proposed algorithm, the motion detection circuit is also considered when computing the total energy consumption of the full setup. It can be seen that our approach achieves an average of 8% energy saving compared to the no sleep scheduling approach due to no or low user activity at certain times in the lab which results in the ng-eNB going into sleep. Note that this energy saving performance is highly dependent on the power rating of the computer used as a computer with high power consumption rating would overshadow the energy gains of using our proposed algorithm.

Fig. 4 shows the USRP energy consumption comparison of our algorithm against the no sleep scheduling approach. It can be seen that the no sleep scheduling approach has a constant USRP energy consumption across the days of the week as it is always in the active mode irrespective of user presence. On the other hand, there is a slight variation in energy consumption of our proposed algorithm across the days of the week. This is because the lab sees different levels of user presence and activity across different days of the week and the effect of switching off the RF fron-end is more pronounced when only the USRP is considered as it constitutes a fifth

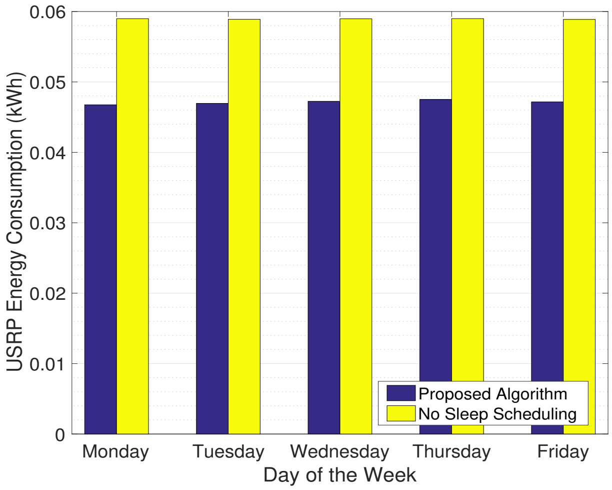

Figure 4. USRP energy consumption comparison of our proposed SC sleep scheduling algorithm versus the no sleep scheduling approach.

of the USRP power consumption. Accordingly, our algorithm achieves about 20% reduction in energy consumption when compared to the no sleep scheduling approach. It is worthy of note that the energy consumption of the USRP does not reach zero as the FPGA consumes about 80% of the power consumed by the USRP, even when the USRP is not transmitting.

V. Conclusion

In this paper, we have proposed and implemented on a real testbed, a low-cost, low-complexity SC sleep scheduling algorithm to minimise the energy consumption of SCs in 5G and beyond networks. Our algorithm is based on the D-SON approach and it leverages on a motion detection circuit to instantaneously toggle the SC between sleep and active modes based the presence of a mobile user, without the need for complex traffic prediction algorithms. Experimental results show that our algorithm can achieve up to 20% USRP energy consumption saving when compared to the no sleep scheduling approach.

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