An Energy-Efficient Scheduling of Heterogeneous Network Cells in 5G

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***Abstract*—In fifth-generation (5G) wireless communication system, small cell networks (SCNs) are the key technology to provide high Quality of Service (QoS) to the mobile users. However, meeting exponentially increasing data rate of the users demands deploying large number of SCNs which is energy-hungry if they are kept active always. Existing energy-saving approaches offer limited improvement due to considering mere historical data-driven two states system model. In this paper, we assume four states for network cells and design an optimal scheduling of small cells to satisfy user's QoS using minimum number of activated small cells in a network. It optimally schedules a small cell in one of the four states at a given time. Our analysis depicts that proposed system offers significant performance improvement compared to the state-of-the-art work.**

***Index Terms*—Energy-Efficiency, Scheduling, Small Cell, HetNet, Minimize Energy, State Switching Delay, Industry 4.0**

I. Introduction

In network and communication technology, reduction of energy consumption is now a key challenge. According to researchers [1], almost 3% of world electricity production is used by network and communication technology. Around 80-90% of this power is consumed by network base stations (BS) and remaining 10% is consumed by user equipments (UE) [2]. Moreover, communication technology has a great impact on climate. Information and communication technology causes approximately 2% of CO_2 emission in the whole world. Nowadays, the fourth industrial revolution driven smart applications force user demands to increase exponentially and to fulfill this required demand, large number of small cells is being deployed in network area. However, more small cell causes more power consumption. Over the year 2025, energy consumption by the small cells and amount of CO_2 emission will increase by a huge margin because of high dense network technology in 5G. Hence reducing the number of active small cells using an efficient scheduling method will be fruitful to meet the goals of sustainable technology in Industry 4·0.

Initially, we have investigated that network traffic pattern in different areas and at different times varies. Traffic load varies from time to time i.e., in office hours network traffic becomes high in a commercial area whereas at that moment traffic becomes low in the residential area. On the contrary, non-office hour network load pattern changes in reverse way. So, network traffic load depends on region and time. To utilize this behaviour, if SCNs can dynamically make the decision whether it should remain active or not on the basis of load traffic instead of keeping all the SCNs active all the time in a static manner, it will reduce the power consumption with maintaining desired quality of services for the users.

Recent survey of Cisco Visual Networking Index [3] depicts that monthly global mobile data traffic will be 77 exabytes by 2022, which will cause more deployment of small cells and it will result in huge power consumption. To meet this challenge, researchers are working on minimization of energy consumption. Different methods have been addressed in recent literature. In [4], authors proposed a method to schedule the small cells between active and deactive state on the basis of historical load data. Another research work [5], has demonstrated an approach to switch ON/OFF the small cell based on low and high load. However, these existing works didn't perform well in all circumstances. Scheduling considering two states based on historical load data may not be efficient because in two states scheduling method a switched OFF small cell requires some time to turn it ON which may wait the users.

The main objective of our work is to design a scheduling model for the ultra dense multi-tier 5G Heterogeneous Network (HetNet) which can find the minimum number of required small cells those should be kept active in a particular time. This active cells set will change dynamically with the change of traffic load. In our proposed model, a controller will collect load data from small cells in a zone and will schedule those cells based on current load. Our key contributions of this work are summarized as follows:

- We developed an optimization framework to activate minimum number of small cells while satisfying user quality of services.
- We schedule the small cells in such a way that no user can be in void space.
- Our performance analysis depicts that the proposed system outperforms existing methods.

The rest of the paper is organized as follows. Section II reviews the related literature and research contributions. Section III represents the system model for 5G HetNet. In section IV, Optimal Scheduling of SCNs is presented. Performance analysis is presented in section V. Finally, in section VI we draw the conclusion and present our future research direction.

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II. Related Work

Recent survey [3] represents that data demand is increasing rapidly. To fulfill user's requirement, a 5G HetNet architecture with macrocells and different types of SCNs (e.g., microcells, picocells, femtocells) with different protocols is proposed. However, deployment of large number of SCNs increases the power consumption. Researchers are concerned about it and they have demonstrated different approaches to minimize power consumption. Some researches proposed to use multi-tier network [6], [7] and some proposed to switch ON/OFF small cells [4], [5], [8], [9], [10] for energy-efficiency.

In [6], considering the rapidly raising data traffic, authors proposed heterogeneous network instead of the conventional homogeneous network architecture for 5G to fulfill user demand on data rate and increases energy-efficiency since the small cells of different transmit powers provide required data rates with low energy consumption. However, this model can be more energy-efficient, if some small cells are kept in OFF state during low load period. In [7], authors introduced network architecture using two-tier and three-tier configurations to provide high network capacity as well as energy-efficiency along with better network coverage deploying optimal number of small cells which enhances energy-efficiency of wireless network. However, they have not mentioned how many active small cells will be needed to serve the users. The authors of [8] introduced an idea to switch ON/OFF the small cells to reduce energy consumption. To avoid unnecessary power consumption during the sleep mode, small cells were kept completely shut down during low traffic and assigned an IoT to turn ON the small cells by sending wake-up signal. However, at the time of reactivating a small cell, it takes much time to restart the network, which may affect user service immensely.

In [5], authors introduced an idea of switching ON/OFF the small cells on the basis of high load and low load from energy saving perspective. This work classified the small cells based on load and developed an order to activate those cells whereas deactivation order is reverse of activation order. In [4], authors presented a model in which users' demand and required number of SCNs calculated based on historical load data. They proposed an algorithm to find which small cells should be kept ON and which should be OFF. However, switching off any small cell may need to wake it up next time slot and for waking up a small cell, it takes certain amount of time which will wait the users. So, using these approaches user services may be disrupted. Again calculating the required number of small cells may not be always appropriate because load may fluctuate suddenly.

Comparing with the above mentioned works, we have demonstrated a novel idea to schedule the SCNs in an efficient way so that minimum power is being consumed while satisfying user demands and no user will be in void space.

III. System Model for 5G HetNet

In 5G heterogeneous network many kinds of small cells like micro, pico and femto cells are deployed in each network zone [4]. Each zone in a HetNet architecture of 5G as shown in Fig-1, has a macrocell which works as controller. We assume that the controller collects traffic load information of each small cell through control channel. Then controller schedules all the small cells that is which cell will remain in active or passive state. After evaluating phase, decision will pass to the small cells.

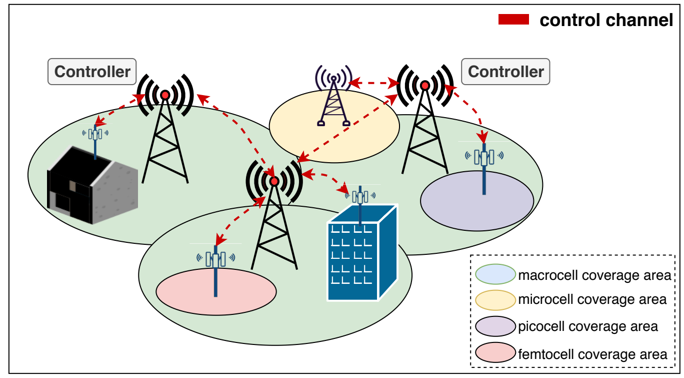
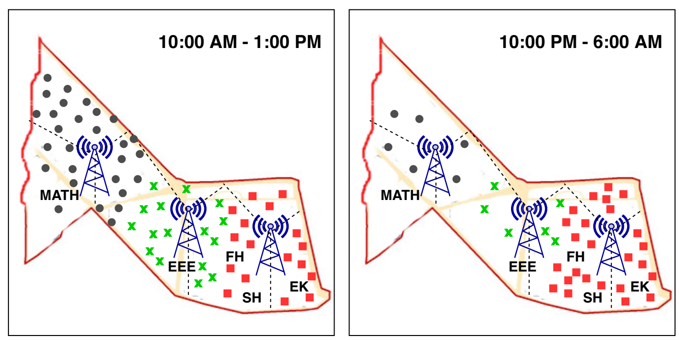


Fig. 1: HetNet Architecture of 5G



(a) Homogeneous Distribution of Load (b) Unequal Distribution of Load

Fig. 2: Load Distribution Over Different Time Period

Network load in a specific zone varies with various hours over the day. It almost maintains a pattern. Using that load behaviour we have investigated that all the small cells in a zone need not to be in active state to serve the users demand. For our research work, we have analyzed load behaviour in Dhaka University area. Here we provide some graphical view of loads in this area in different time periods. In Fig-2(b), network load is unequal as number of UEs in residential hall area (marked using square shapes) is high and in institutional area (marked using crosses and dots) is much low in non-office hour. However in Fig-2(a), at office hour the load is homogeneous in academic buildings and residential hall areas.

In each network zone, there is a load pattern which indicates that in some period all the cells need to be activated but in the other period some cells can be turned off to reduce the energy consumption.

In the following two subsections, we have demonstrated the power consumption and states of small cells.

A. Power Consumption of Small Cells

In a small cell, there are various components that consume different amount of powers. However, power consumption of a small cell can be divided into four major parts [11] as follows:

- **Rectifier:** It converts AC signal to DC signal consuming approximately 7.5% of total power [6].
- **Signal Processor**: According to [12], this signal processing circuit consumes around 10% of total power.
- **Power Amplifier and Feeder**: Power amplifier and feeder consumes the major portion of power [6], which is around 50-80%, since it depends on total load and user equipment's distance. Long distance user equipment needs greater amplified signal, which consumes high power.
- **Cooling System**: It consumes almost 10-25% of total power [6]. This amount is also environment and load dependent. If temperature of the surroundings is high, then cooling system consumes more power to balance the temperature. Moreover, high traffic load needs more processing operation that leads to increment in temperature.

B. Working States for Small Cells

We have classified a small cell's state into four states to minimize power consumption as well as reduce the time delay to restart a completely shut down cell. If we only use ON and OFF states, then sudden increase of load will need to restart a switched off small cell. However, a switched off small cell takes around 30 seconds to wake up [13]. To reduce this delay, we have used two intermediate states (e.g., $Waiting$, $Deep$ $Sleep$ State). Description of each state is given below-

- ***ON State*:** All the components of base stations is in working mode. It consumes almost 100% power, but it can be varied depending on traffic load.
- ***Waiting State*:** In this state, an SCN is not in full processing mode. According to [13], Rectifier and TCXO heater are being switched off. A TCXO is a temperature-compensated crystal oscillator with a correcting voltage for temperature variation. However, an SCN can be waken up quickly within around 0.5 seconds, when needed. So using this state around 15-20% power can be saved.
- ***Deep Sleep State*:** In *Deep Sleep* state, only power supply, back end connection and core CPU remain active. Power amplifier, transmitter, receiver is being switched off. So, in this state, an SCN consumes around 15% power, rest of the power (around 80%) will be saved. However, it takes a small amount of time around 10 seconds to wake up [13].
- ***OFF State*:** Full operation of an SCN is being turned off in this state. So no power will be consumed. However, it takes almost 30 seconds to turn on [13].

IV. Optimal Scheduling of SCNs

The main objective of this work is to minimize the total power consumption while maintaining the minimum required quality of services for the users. To fulfill this goal, we have designed an optimization model. Notations used in our model are listed in Table-I.

TABLE I: Notations

Notations	Description
$\mathbb{C}$	Set of all small cells in a certain zone.
$\mathbb{U}$	Set of all user equipments(UE) in a certain zone.
$\mathcal{S}$	Small cell's working state set. $S \in \{ON, Waiting, Deep\ Sleep, OFF\}$
$\mathcal{R}_c$	Maximum service capacity of small cell $c \in \mathbb{C}$.
N	Number of antennas in each cell
$\mathcal{P}_a$	Power consumption by power amplifier
$\mathcal{P}_{tx}$	Power consumption by transmitter
$\mathcal{P}_{rx}$	Power consumption by receiver
$\mathcal{P}_r$	Power consumption by rectifier
$\mathcal{P}_{cs}$	Power consumption by cooling system
$\mathcal{P}_b$	Power consumption by back end system
λ_c	Coverage range of a small cell $c \in \mathbb{C}$
P_c^s	Power consumption of small cell $c \in \mathbb{C}$ which is in state $s \in \mathcal{S}$.

Firstly, we have to calculate the demand for each small cell network. If d_u is the demand of each user equipment and α_u^c is a binary variable defines user equipment's association under small cells. Then, total demand of small cell $c \in C$ can be calculated as,

$$D_c = \sum_{u \in \mathbb{U}} d_u \cdot \alpha_u^c, \tag{1}$$

For a small cell $c \in \mathbb{C}$ in ON state, total power consumption can be calculated as,

$$\mathcal{P}_{ON}^c = N(\mathcal{P}_a + \mathcal{P}_{tx} + \mathcal{P}_{rx} + \mathcal{P}_r) + \mathcal{P}_{cs} + \mathcal{P}_b, \tag{2}$$

In $Waiting$ state, $\mathcal{P}_{tx} = 0$ and $\mathcal{P}_r = 0$ and thus its power consumption is,

$$\mathcal{P}_{WA}^c = N(\mathcal{P}_a + \mathcal{P}_{rx}) + \mathcal{P}_{cs} + \mathcal{P}_b, \tag{3}$$

In *Deep Sleep* state, $\mathcal{P}_{tx} = 0$, $\mathcal{P}_r = 0$ and $\mathcal{P}_a = 0$ and thus we have,

$$\mathcal{P}_{DS}^c = N \cdot \mathcal{P}_{rx} + \mathcal{P}_{cs} + \mathcal{P}_b, \tag{4}$$

and in OFF state, consumed power is approximately zero that is, $\mathcal{P}_{OFF}^c \approx 0$.

In OFF state, a small cell consumes insignificant amount of power, since a small IoT device is being used to receive wake-up signal and turn on the small cell when it is needed. Our main objective is to classify small cells among four states in a particular time in order to minimize power consumption, to reduce wake-up delay and to ensure minimum required services.

Main objective is to schedule small cells in such a way so that minimum number of small cells remain in ON state. For scheduling purpose we have designed a MINLP optimization model which is represented as follows-

Minimize :

$$E = \sum_{c \in \mathbb{C}} \sum_{s \in \mathcal{S}} (P_s^c \cdot \beta_s^c) \tag{5}$$

Subject to :

$$\beta_s^c \in \{0,1\}; \quad \forall c \in \mathbb{C}, \forall s \in \mathcal{S} \tag{6}$$

$$\sum_{s \in S} \beta_s^c = 1; \quad \forall c \in \mathbb{C} \tag{7}$$

$$\alpha_u^c \in \{0,1\}; \quad \forall u \in \mathbb{U} \tag{8}$$

$$\sum_{c \in \mathbb{C}} \alpha_u^c \cdot \beta_s^c = 1; \quad where, s = ON; \forall u \in \mathbb{U} \tag{9}$$

$$D_c \leq \mathcal{R}_c; \quad \forall c \in \mathbb{C} \tag{10}$$

$$\alpha_u^c \cdot \delta_u^c \leq \lambda_c; \quad \forall u \in \mathbb{U} \tag{11}$$

$$D_c \cdot \beta_s^c \leq \mathcal{R}_c \cdot L_{th}^s; \quad \forall c \in \mathbb{C}, \forall s \in \mathcal{S} \tag{12}$$

Equation (5) is used to calculate a feasible set of states that is which small cell should enter in which state. In constraint (6), β_s^c is a binary variable, which is 1 for the current state for an SCN; 0 otherwise. Constraint (7) ensures small cell's state atomicity, that is a small cell can exist in only one state in a particular time. This constraint restricts the model from making ambiguous decision.

In constraint (8), α_u^c is a binary variable, which 1 for only one cell to which it is associated and 0 otherwise. Constraint (9) ensures user equipment's association atomicity, that is an user equipment can be associated to only one small cell. And this constraint also ensures that the cell to which an user is associated must be in ON state.

Constraint (10) is a capacity constraints, i.e., it ensures that each small cell's demand must be less than or equals to the capacity of that cell so that it can ensure the minimum quality of services to the users.

In constraint (11), δ_u^c is the distance of user $u \in U$ from the small cell $c \in C$ to which it is associated. This constraint ensures that any user must be associated to a small cell $c \in \mathbb{C}$ which minimum coverage area λ_c is greater than the user's distance. In this optimization model coverage are of each small cell (λ_c) is given as input. Small cells coverage area λ_c is varying between 10m to 2km.

Using constraint (12), a small cell can find the all possible states on the basis of traffic load. However, objective function will choose the best possible state for the small cells to minimize power consumption as well as no users equipment can be in void space. L_{th}^s is the threshold for each state. For our proposed model we used a set of thresholds which is L_{th}^s= {0.95, 0.70, 0.50, 0.30}. This set represents that when load of any small cell is less than 95% of its maximum capacity, it can remain in any of the four states, but model will choose the best state (i.e., ON as load is higher). On the contrary, when load is less than 30% of its capacity it can only remain in OFF state.

When current working states of all small cells fail to serve the user's demand controller will run the proposed model and re-schedule the small cells.

V. Performance Analysis

We have performed numerical evaluation of our proposed model in NEOS optimization server [14]. For simulation, we assume a network zone with homogeneous distribution of load. According to [15], we assume that a small cell can serve up-to 128 users for evaluating our optimization model. Rest of the parameter is represented in Table II.

TABLE II: Simulation Parameters

Parameter	Value
$\lvert\mathbb{C}\rvert$	5-25
$\lvert\mathbb{U}\rvert$	100-1000
P_{micro}	2-10.0W
P_{pico}	0.25-2.0W
P_{femto}	0.02-0.10W
λ_{macro}	10-40km
λ_{micro}	2km
λ_{pico}	200m
λ_{femto}	10-50m

Our performance analysis is represented in the following subsections.

A. Working State Analysis of Small Cells

Firstly, we have observed the small cell's working states by increasing the number of user equipments in a certain zone within a range of 200 to 1000 and the number of small cells is 15. Obtained result is given in Fig-3 which represents that

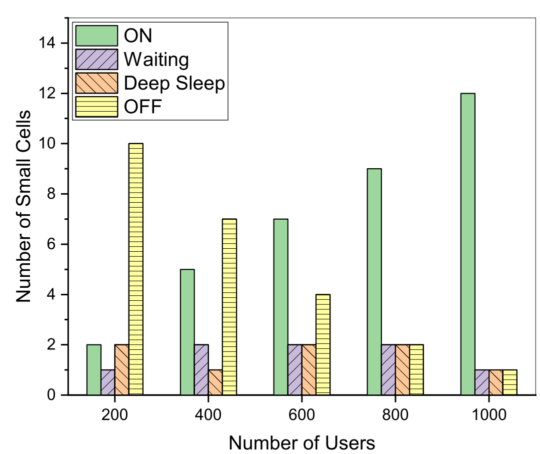


Fig. 3: Impact of number of users on working state of small cells

when the number of users is increasing, the number of active small cells is also increasing proportionally, but all the small cells don't need to be kept ON. A certain number of small cells remain in other three states and thus power consumption decreases. When the number of users is 400-800, 2 small cells are in waiting state, because sudden increment of traffic load will put these small cells into ON state which will take around 0.5 sec [13] and thus it ensures that users don't need to wait much for getting services.

B. Comparison Based on Number of Activated Small Cells

We have simulated our optimization model multiple times using different combination of the number of users and small cells. We analyzed that how many small cells need to be activated to serve the users by increasing the number of small cells from 5 to 25 and the number of users from 200 to 1500. After simulating 20 times, we have calculated the average percentage of number of activated small cells. We have compared our obtained result with existing two states method (ON/OFF) [5]. Our analysis depicts that according to our proposed method, less number of small cells need to be kept in active state comparing to existing literature, multi-tier network without any ON/OFF system [7] and two states method [5]. Fig-4 represents the obtained result.

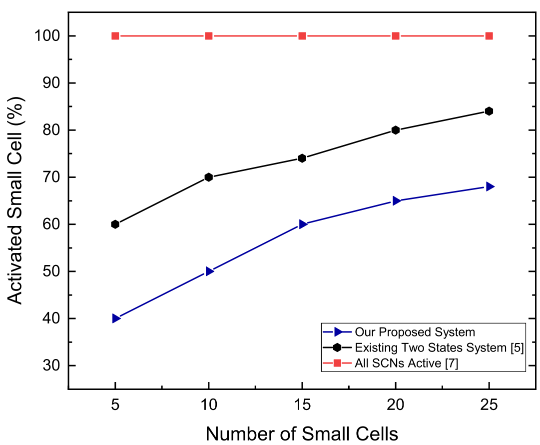


Fig. 4: Comparison of the activated small cells

C. Power Consumption Analysis

After simulating our optimization framework, we have found the number of small cells need to be activated and using that result, we have analyzed power consumption using various number of small cells. Fig-5 shows that our proposed system outperforms the existing systems, multi-tier network without any ON/OFF system [7] and two states method [5] in terms of power consumption. Our designed framework saves around 10% power consumption than the existing approaches.

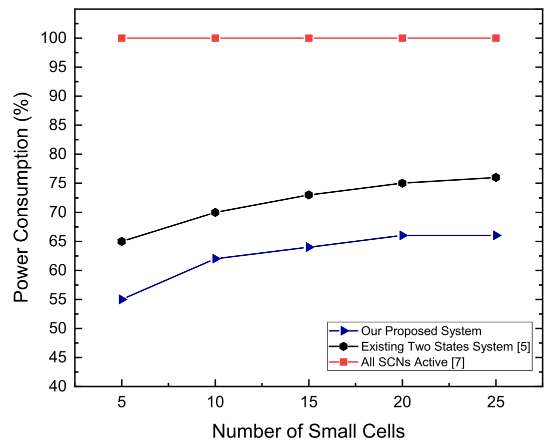


Fig. 5: Power consumption comparison of small cells

VI. CONCLUSION

Sustainable technologies aim to minimize the waste and maximize the efficiency and also the goal of the fourth industrial revolution (Industry 4.0) is to provide human's demand without affecting the climate. To obtain this goal, we have designed an optimization model to schedule the small cells using four states in order to minimize the power consumption through maintaining minimum required quality of services for the users. We have simulated our model and the obtained results depict that our proposed model outperforms the existing method by reducing the percentage of the number of activated small cells thus reducing the power consumption to around 10%. As optimization model would be an NP-hard (non-deterministic polynomial-time) problem for large number of users and cells, we will provide a greedy or heuristic solution to solve this problem in our future work.

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