

# E2CA-SM: an energy-efficient channel allocation with sleep mode for base station in fifth-generation-based cellular network systems

ISSN 2047-4954

Received on 11th March 2019

Revised 14th August 2019

Accepted on 12th September 2019

E-First on 19th February 2020

doi: 10.1049/iet-net.2019.0045

www.ietdl.org

Parimala Venkata Krishna<sup>1</sup>, Vankadara Saritha<sup>2</sup> ✉, Mohammad Salameh Obaidat<sup>3,4,5</sup>

<sup>1</sup>Department of Computer Science, Sri Padmavati Mahila University, Tirupati, India

<sup>2</sup>Department of Computer Science and Engineering, Sri Padmavati Mahila University, Tirupati, India

<sup>3</sup>ECE Department, Nazarbayev University, Astana, Kazakhstan

<sup>4</sup>King Abdullah II School of Information Technology, The University of Jordan, Amman, Jordan

<sup>5</sup>University of Science and Technology, Beijing, People's Republic of China

✉ E-mail: psarithakrishna@gmail.com

**Abstract:** In today's world, power is one of the resources that needs effective utilisation similar to the bandwidth utilisation. As the battery life of the nodes in the cellular networks is not a problem, there is not much extensive research toward energy consumption in the cellular networks. Nevertheless, currently the focus is toward conserving the power being utilised by various components in the cellular network. Hence, an energy-efficient channel allocation (E2CA) procedure for cellular networks with fifth-generation network characteristics is proposed in this study, where the energy consumption is reduced with the concept of sleep mode for base station (E2CA-SM). The SM is more popular in sensor networks when compared with cellular networks. The proposed E2CA-SM algorithm shows low-energy consumption during peak and non-peak hours of cellular traffic. It is shown that the energy consumption per packet is 35.5% less when compared with multi-traffic, with queue, learning automata-based reservation, 32% when compared with E2CA. The system is modelled using single-dimension Markov's model. There will be a trade-off between blocking, dropping probability, and energy consumption, which is tackled in this study.

## 1 Introduction

It is well known that the focus of information and communication technology is to minimise power consumption due to various reasons such as global warming, scarcity of resource etc. Hence, the emphasis of the researches is moved toward energy conservation systems in various fields. In general, there is a scarcity of the available energy resources while handling services in present networks. It needs to be effectively used as it is the basic need for human life. With the introduction of smart devices, the data communication is tremendously increased, and hence, more energy is being consumed in the networks. In the communication process of cellular networks, the most energy consumption is used by the base station (BS) [1, 2]. Hence, there are high chances and also need for reducing the energy being consumed by the BS. The basic methods for minimising the power consumption are by introducing sleep mode (SM) for the BSs [3–8]; the energy can be saved by effectiveness of the hardware machineries [9–13], preparation and organising assorted cells [11, 14], and implementing methodologies to renew the resources of energy [15, 16].

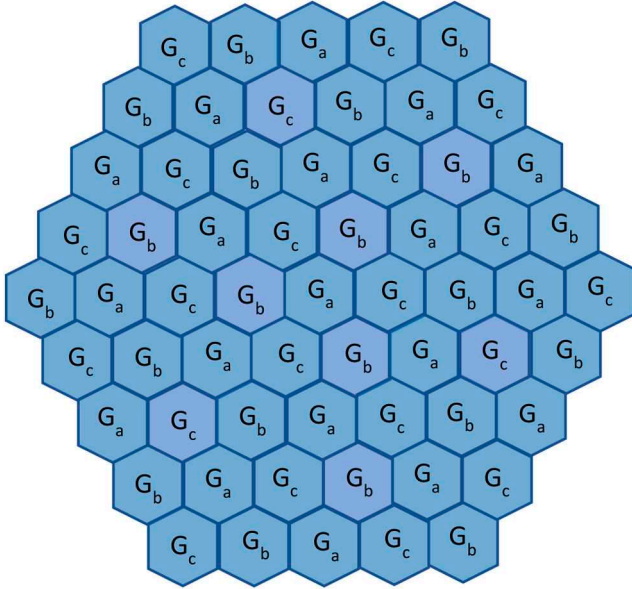
The emphasis of this paper is to diminish the energy consumption of the BS. The researches [3, 4] carried out in this area shows that the load of the BS, which is to be sent to SM is given to other BSs. There are many ways of implementing the SM for the BSs such as co-operation among BSs,  $N$  network, increasing the size of the cell dynamically or cell breathing, estimation of the traffic, and arrangement of the heterogeneity. Nevertheless, the methodology involved in handling the trade-off between the blocking/dropping probability and energy consumption is less emphasised. Furthermore, the existing research [7] considers the issue during non-peak hours (when the traffic is very less/sparse). Hence, the channel allocation procedure where some of the BSs are in SM during peak and non-peak hours is presented in this paper. This procedure also considers the trade-off between blocking/dropping probability and energy conservation.

There is a quick development of wireless cellular networks over recent years. The numbers of mobile users and the movement volume in cell systems have aggressively expanded. System administrators are continually attempting their best to fulfil client needs profitably. The area of the cell is the region, in which the mobile users can hear to the BS and receive the information that it is transmitting. The area and volume of the cell are determined based on the statistics of the network traffic during peak hours. However, the network traffic is not static in the case of cellular networks as the nodes or users in the network move from one location to another [17]. As the traffic in cellular networks is very dynamic, arrangement of cells is a challenging task. When the size of the cell is considered to be big, the dynamic nature of traffic can be handled easily.

When there is an increase in the usage of energy, then there is an increase in the discharge of carbon. Similarly, the cost of energy is rising due to its shortage. Hence, the research is emerging toward new proposals in making the cellular networks green by increasing energy conservation. In cellular networks, the energy is being expended by various components and it is observed that the BS is consuming more energy when compared with the other components. Hence, there is high possibility in reducing the energy consumption of the network by increasing the energy conservation in the BSs [4]. Henceforth, there are many novel proposals from the researchers toward this mode of conserving the energy [18–21].

Applications of fifth generation are high-speed mobile networks, entertainment, and multimedia – everything on cloud, ubiquitous connectivity, intuitive remote access, connecting everything – smart home, smart farming, health care, fleet management, autonomous driving, drone operation, security, and surveillance.

The organisation of this paper is as follows. Basic information required to understand this paper is presented as introduction in Section 1. Section 2 presents the previous related efforts. Energy-efficient channel allocation with SM (E2CA-SM) is presented in Section 3. Section 4 deals with performance analysis, while



**Fig. 1** Network with group assignment using three-colour theorem

performance evaluation results and discussion are reported in Section 5. Finally, Section 6 concludes this paper.

## 2 Related work

Misra *et al.* [22] presented a channel allocation procedure using learning automata concept. Learning automata are used to determine the number of channels to be reserved for the handoff calls. Traffic and queue are considered as two terms. The channels are reserved for handoff calls based on the movement of the nodes and the cell type which may be cold cell, medium cell, or hot cell. Nevertheless, the authors considered only blocking and dropping probabilities as parameters for evaluation and did not consider the energy as a parameter. The work in this paper is compared with the proposed E2CA-SM.

In [23], Wu *et al.* used dynamic programming, 0/1 knapsack problem to introduce SM for the BSs in the heterogeneous networks. The authors claim that the complexity is linear in this method, where it is exponential in the conventional process. However, the algorithm performs better only when the traffic is light, which many researchers focus on. This is also used for comparison with the proposed work E2CA-SM.

Wu *et al.* [24] presented their view of the SM for the BS depending on the traffic and similarity in power. The main aim of the authors is to obtain the best possible trade-off between power consumption and the delay. The BS goes to SM when it is completely idle, which means that there is no mobile station (MS) under the control of it; it is not possible in reality. The BS will become active after some predetermined time or sufficient number of users comes into its range.

In [6], Ashraf *et al.* proposed to minimise the consumption of power with the introduction of SM for BSs whose range of communication is low. The hardware being operated in the BSs are automated such as they are turned off when traffic is nil or negligible and are automatically turned on when more MSs require the services of the BS. The authors proposed three variations of algorithms based on the cell size, network parameters, and equipment in the MSs. It is shown that the energy consumption is reduced to a minimum of 10% and a maximum of 60% in the proposed algorithm with SM when compared with the algorithm without SM.

Another algorithm which is based on the traffic and automatic switching between active and SMs of BS for conserving the energy is proposed in [25]. In this algorithm, required blocking probability is considered in order not to increase the number of calls to be blocked. The time limit is also defined as the minimum duration for which the BS is to be either in active mode or SM.

Cell breathing methodology is used to implement the SM for BSs in [7]. The set of BSs that can be in SM is determined based

on the typical load in the cell for particular duration of time. The number of BSs that can be in SM, and hence the network performance is purely dependent on the predefined threshold value.

In [26], the concept of increasing the size of cell, i.e. cell zooming, is introduced. This is based on the traffic in the cell, the necessities of MSs and situations of the channel. The authors presented both the distributed and centralised process of the algorithm.

There is a trade-off between the delay and the conservation of energy. To obtain optimal trade-off, the key idea is to identify the power matching and sleep control [24]. Two variations of sleep control are presented based on the time at which the BS becomes active and come out of the SM. The two variations are whether the BS needs to become active when sufficient number of nodes are in its range or after a particular time limit. Theoretical analysis is done for the delay, the amount of energy used for the varying rate of service.

In [27], Cili *et al.* proposed the SM for the BSs without raising the height of the BSs which are active to increase the range of communication. Coordinated multipoint (CoMP) transmission radio technology is used in [27] to permit adequate conventional energy from neighbouring BSs every probable time that is probable. The group of CoMP is determined precisely by approximating the status of the channel.

More ideas and suggestions can be found in [28–35].

## 3 Energy-E2CA procedure with SM for BSs (E2CA-SM)

The various types of calls that are employed in the proposed work are the real-time originating calls, non-real-time originating calls, real-time handoff calls, non-real-time handoff calls, real-time transfer calls, and non-real-time transfer calls. The originating calls are the calls, which are initiated in any cell. The call which is transferred from one BS to another is referred as handoff call. The call which is transferred to another BS while in the queue is referred to as transfer call. Example of real-time call is voice communication and example of non-real-time call is data communication. Two different queues  $Q_{RO}$  and  $Q_{NO}$  of sizes  $R$  and  $N$  are maintained for real-time originating calls and non-real-time originating calls, respectively. If the channel is not allocated to the originating call on its request, then it is said to be blocked, and if the channel is not available to allocate to the handoff call, then it is said to be dropped.

In the E2CA-SM, the available frequency is effectively used with the help of frequency reuse concept, and hence the total number of channels are divided into three groups  $G_a$ ,  $G_b$ , and  $G_c$ , which are mutually exclusive to each other. These groups are assigned to each BS according to three-colour theorem. Each BS acquires one group among three groups of channels. The network with channel assignment of three groups is shown in Fig. 1.

The group allocation to the BSs of the cells in the network is described in detail in [1].

The total number of channels in the network is represented as ‘ $G$ ’ which are divided into  $G_a$ ,  $G_b$ , and  $G_c$  and the channels in each BS or each group are represented as ‘ $C_g$ ’ channels, where  $g$  is the group identity, i.e.  $g$  in  $\{a, b, c\}$ .  $C_g$  is divided into subparts as  $C_{gRO}$ ,  $C_{gRT}$ ,  $C_{gNH}$ ,  $C_{gNT}$ , and  $C_{gNO}$ . The division of ‘ $C_g$ ’ channels into subparts is shown in Fig. 2.

The descending order of priority of calls after is the real-time handoff calls, real-time transfer calls, real-time originating calls, non-real-time handoff calls, non-real-time transfer calls, and non-real-time originating calls. The real-time handoff calls are very important and hence highest priority is given to these calls by giving a chance of utilising any of  $C_g$  channels in the cell. Real-time transfer calls will have access from 0 to  $C_{gRT}$  channels, real-time originating calls can access from 0 to  $C_{gRO}$ , non-real-time handoff calls can access from 0 to  $C_{gNH}$  channels, non-real-time transfer calls can access from 0 to  $C_{gNT}$  channels, and finally, non-real-time originating calls can access from 0 to  $C_{gNO}$  channels only.

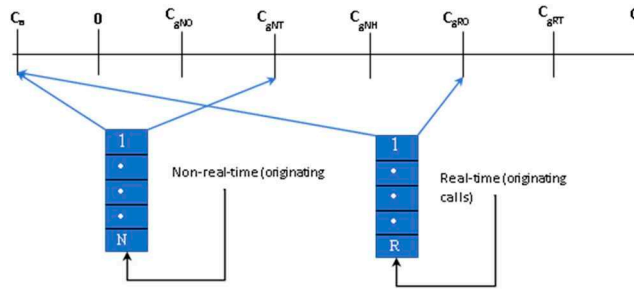


Fig. 2 Distribution of channels among various types of calls in a BS

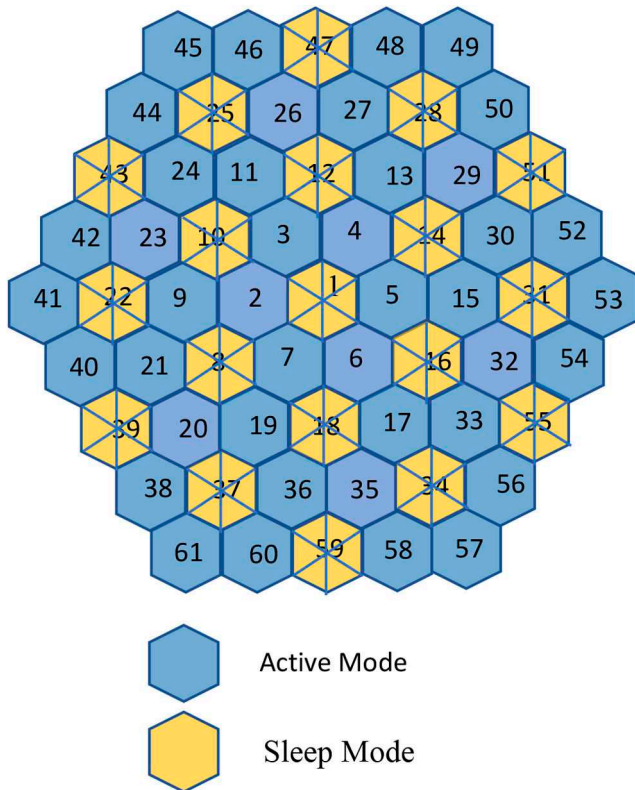


Fig. 3 BS SM during non-peak hours

In this paper, SM for BSs is introduced. Hence, the 24 h time zone is divided into peak hours and non-peak hours. The time from 8:00 AM to 11:00 PM is considered as peak hours and the time from 11:00 PM to 8:00 AM is considered as non-peak hours. The procedure for selecting a particular BS to send into SM is different for both the zones. The system model for the SM of BSs during non-peak hours is shown in Fig. 3. Fig. 4 shows the model for SM of BSs during peak hours.

### 3.1 SM of BS during non-peak hours

The cell numbers given in the system model, shown in Fig. 3, are made in a circular fashion starting at the centre. The non-peak hour duration is considered for 9 h. Initially, when cell 1 is to be sent to SM, its region is divided into six partitions. The cells which are around this cell 1 are responsible for the partition which is nearest to it or toward it. This method of employing the SM for BS will make a particular cell to get the load from three other cells, but still it can be considered that the cell is not overloaded as it is not peak hours and almost all the cells are cold cells during this period. Each BS will be in SM for 3 h. Then automatically, the BS which is in SM comes to active mode, and the other BS will go to the SM. The BSs, which need to go to SM, are selected in a round-robin method. The peak time zone is divided into three slots and the time zone of these slots is represented as  $t_{np1}$ ,  $t_{np2}$ , and  $t_{np3}$ . It can be observed from Table 1 that 17 or 19 cells out of 61 cells are in SM at a time and Fig. 3 illustrates the scenario during time slot  $t_{np1}$ .

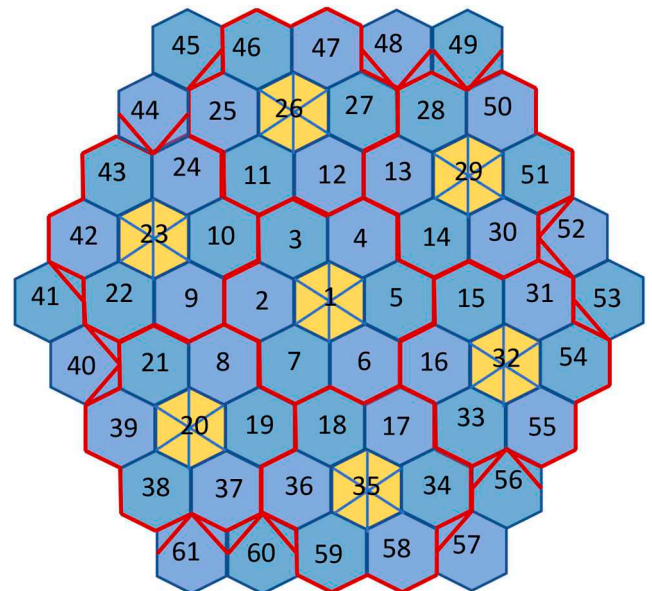


Fig. 4 BS SM during time slot  $t_{p1}$

The list of BSs, which are in SM during the corresponding slot, is shown in Table 1.

### 3.2 SM of BS during peak hours

The cell numbers given in the system model, shown in Figs. 4 and 5, are made in a circular fashion starting at the centre.

The peak hour duration is considered for 15 h. Initially, when cell 1 is to be sent to SM, its region is divided into six partitions. The cells which are around this cell 1 are responsible for the partition which is nearest to it or toward it. This method of employing the SM for BS will make a particular cell get the 1/6th load of another cell, and hence it is considered as overload. Each BS will be in SM for 2 h, 8 min, and 34 s. Then automatically, the BS which is in SM comes to active mode and the other BS will go to the SM.

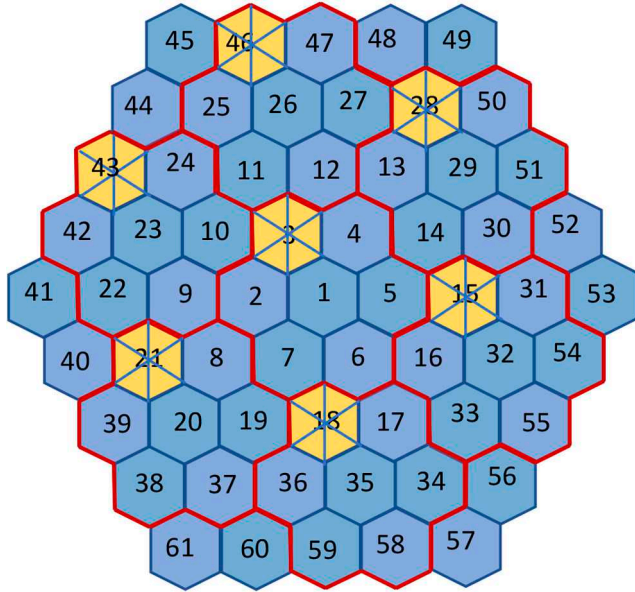
The BSs, which need to go to SM, are selected in a round-robin fashion. The peak time zone is divided into seven slots and are represented as  $t_{p1}$ ,  $t_{p2}$ ,  $t_{p3}$ ,  $t_{p4}$ ,  $t_{p5}$ ,  $t_{p6}$ , and  $t_{p7}$ . The number of BSs in the SM depends on the number of the 7-cell clusters in the network. One BS in a cluster will be in SM at a time. Fig. 4 shows the network with seven clusters, and hence seven BSs go to SM at a time. Fig. 4 illustrates the scenario during time slot  $t_{p1}$  and Fig. 5 illustrates the scenario during time slot  $t_{p3}$ . The list of BSs, which are in SM during the corresponding slot, is shown in Table 2.

### 3.3 Channel allocation with SM for BSs

Channel allocation procedure adopted in this paper is same for both the peak hours and non-peak hours call traffic of different types of calls. The channels used under the control of the BS in SM are divided into two halves. Furthermore, 1/2 is divided into six parts, and the control of corresponding channels is assigned to the BS, which is going to handle the traffic of the BS which is in SM. Another half will be under the control of the BS controller (BSC).

**Table 1** List of BSs in the SM for various time slots

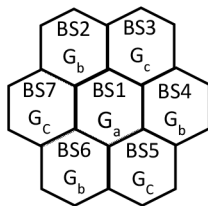
Time slot	BSs in the SM
$t_{np1}$	1, 8, 10, 12, 14, 16, 18, 22, 25, 28, 31, 34, 37, 39, 43, 47, 51, 55, 59
$t_{np2}$	3, 5, 7, 9, 13, 17, 20, 24, 26, 30, 32, 36, 40, 42, 45, 48, 50
$t_{np3}$	2, 4, 6, 11, 15, 19, 21, 23, 27, 29, 33, 35, 44, 46, 49, 52, 54



**Fig. 5** BS SM during time slot  $t_{p3}$

**Table 2** List of BSs in the SM for various time slots

Time slot	BSs in the SM
$t_{p1}$	1, 20, 23, 26, 29, 32, 35
$t_{p2}$	2, 13, 16, 25, 36, 39, 42
$t_{p3}$	3, 15, 18, 21, 28, 43, 46
$t_{p4}$	4, 8, 17, 24, 31, 47, 50
$t_{p5}$	5, 10, 19, 27, 34, 51, 54
$t_{p6}$	6, 9, 12, 30, 37, 55, 58
$t_{p7}$	7, 11, 14, 22, 33, 38, 59



**Fig. 6** Various groups assigned for BSs in a sample network

The channels of the BS which is in SM will be utilised for the calls in the corresponding range only, but not for the calls in the range of BS, which takes control of the channels of sleeping BS. Hence, no kind of co-channel interference problem is going to rise.

Consider that the BS1 in Fig. 6 is going to SM. Channels of Group  $G_a$  are assigned for BS1. Assume that there are  $C_a$  channels in group  $G_a$ . Then, the  $C_a$  channels are divided into two halves.  $C_a/2$  channels are under the control of BSC. The control of other  $C_a/2$  channels is given to BS2–BS7, each  $C_a/12$  channels.

When a call request arrives at BS, first it verifies the current location of the MS with the help of mobile switching centre, which maintains the visiting locations of the MS in visitor location register. If the current location of the MS is in its range, then the channel is allocated from its group of channels. Otherwise, it will verify whether the free channel is available in the group of channels of the BS which is in SM. If the free channel is available,

then it is allocated; otherwise, the request for free channel is forwarded to BSC. If free channel is available at BSC, then the channel is allocated; otherwise, it is blocked (if originating call) or dropped (if handoff call). The complete process of channel allocation for a particular BS is divided into three parts. This process is after the assignments of group of channels to the BSs (Fig. 7).

#### 4 Performance analysis

Poisson distribution is considered for modelling the arrival process of the calls. The assumptions made that cannot be exactly modelled are [1]:

- Speed and the direction of the movement of MSs is random.
- MSs are enabled with global positioning system.
- Arrival rate of the real-time originating calls is  $\lambda_{RO}$ .
- Arrival rate of the real-time handoff calls is  $\lambda_{RH}$ .
- Arrival rate of the real-time transfer calls is  $\lambda_{RT}$ .
- Arrival rate of the non-real-time originating calls is  $\lambda_{NO}$ .
- Arrival rate of the non-real-time handoff calls is  $\lambda_{NH}$ .
- Arrival rate of the non-real-time transfer calls is  $\lambda_{NT}$ .
- Arrival rate of all the calls from the range of the BS in SM is the same and is represented as  $\lambda_a$ .
- Service rate of the real-time originating calls is  $\mu_{RO}$ .
- Service rate of the real-time handoff calls is  $\mu_{RH}$ .
- Service rate of the real-time transfer calls is  $\mu_{RT}$ .
- Service rate of the non-real-time originating calls is  $\mu_{NO}$ .
- Service rate of the non-real-time handoff calls is  $\mu_{NH}$ .
- Service rate of the non-real-time transfer calls is  $\mu_{NT}$ .
- Service rate of all the calls from the range of the BS in SM is the same and is represented as  $\mu_a$ .
- Dwell time of MS in the range of BS is  $T_{c-dwell}$ .
- Dwell time of MS in the handoff region is  $T_{h-dwell}$ .

Let  $P(i)$  be the probability of  $i$  channels is busy. The state transition diagram shown in Fig. 8 is used to determine  $P(i)$ .

The state balance equations obtained are as shown below:

$$i\mu_{NO}P(i) = (\lambda_{NO} + \lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})P(i-1), \quad 0 \leq i \leq C_{gNO} \quad (1)$$

$$i\mu_{NT}P(i) = (\lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})P(i-1), \quad C_{gNO} < i \leq C_{gNT} \quad (2)$$

$$i\mu_{NO}P(i) = (\lambda_{NO})P(i-1), \quad C_{gNT} < i \leq N \quad (3)$$

$$i\mu_{NH}P(i) = (\lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})P(i-1), \quad C_{gNT} < i \leq C_{gNH} \quad (4)$$

$$i\mu_{RO}P(i) = (\lambda_{RO} + \lambda_{RT} + \lambda_{RH})P(i-1), \quad C_{gNH} < i \leq C_{gRO} \quad (5)$$

$$i\mu_{RT}P(i) = (\lambda_{RT} + \lambda_{RH})P(i-1), \quad C_{gRO} < i \leq C_{gRT} \quad (6)$$

$$i\mu_{RO}P(i) = (\lambda_{RO})P(i-1), \quad C_{gRO} < i \leq R \quad (7)$$

$$i\mu_{RH}P(i) = (\lambda_{RH})P(i-1), \quad C_{gRT} < i \leq C_g \quad (8)$$

$$i\mu_aP(i) = (\lambda_a)P(i-1), \quad C_g < i \leq C_a \quad (9)$$

**Input:**

Number of channels obtained from the group of the channels of the base station which is in sleep mode –  $C_a$

**Output:**

Status of the channel allocation

**Begin**

```

A new call arrives at BS
If Current location of MS in the range of BS then
    If call is real-time call then
        Call "Real-Time Process"
    Else
        Call "Non-Real-Time Process"
Else
    If free channel available in  $C_a$  then
        Channel is allocated
    Else
        Request is forwarded to the BSC
        If channel available at BSC then
            Channel is allocated
        Else
            Call is blocked/dropped

```

**END****Real-time Process**

When Real-time call arrives at the BS then, this process is executed.

**Input:**

Number of channels in a group assigned to the base station –  $C_b$

Number of channels in  $C_{bRT}, C_{bRO}$

**Output:**

Status of the channel allocation

**Begin**

```

If handoff call then
    If (number of busy channels <  $C_b$ ) then
        Channel is allocated
    Else
        Call is dropped
        Number of real-time handoff calls
        dropped is incremented
    Else if call is transfer call then
        If (number of busy channels <  $C_{bRT}$ ) then
            Channel is allocated
        Else
            Call is blocked
            Number of real-time transfer calls blocked
            is incremented
    Else if call is originating call then

```

```

If any calls waiting in the queue then
    Call is queued
Else If (number of busy channels <  $C_{bRO}$ ) then
    Channel is allocated
Else If queue is full then
    Call is blocked
    Number of real-time originating calls
    blocked is incremented
Else
    Call is queued

```

**END****Non-Real-Time Process**

When Real-time call arrives at the BS then, this process is executed.

**Input:**

Number of channels in  $C_{bNT}, C_{bNO}, C_{bNH}$

**Output:**

Status of the channel allocation

**Begin**

```

If call is handoff call then
    If (number of busy channels <  $C_{bNH}$ ) then
        Channel is allocated
    Else
        Call is dropped
        Number of non-real-time handoff calls
        dropped is incremented
    Else if call is transfer call then
        If (number of busy channels <  $C_{bNT}$ ) then
            Channel is allocated
        Else
            Call is blocked
            Number of non-real-time transfer calls
            blocked is incremented
    Else if call is originating call then
        If any calls waiting in the queue then
            Call is queued
        Else If (number of busy channels <  $C_{bNO}$ ) then
            Channel is allocated
        Else If queue is full then
            Call is blocked
            Number of non-real-time originating calls
            blocked is incremented
        Else
            Call is queued

```

**Fig. 7** Algorithm

Equations (1)–(9) are used recursively in addition to the probability rule that the sum of all probabilities is equal to 1,  $P(i)$  is obtained as shown in the equation below: (see (10)), where

$$W = \frac{(\lambda_{NO} + \lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{C_{gNO}}}{i! \mu_{NO}^i} \quad (11)$$

$$X = \frac{(\lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{C_{gNT} - C_{gNO}}}{i! \mu_{NT}^i} \quad (12)$$

$$Y = \frac{(\lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{C_{gNH} - C_{gNT}}}{i! \mu_{NH}^i} \quad (13)$$

$$Z = \frac{(\lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{C_{gRO} - C_{gNH}}}{i! \mu_{RO}^i} \quad (14)$$

where  $P(0)$  is given as in the equation below: (see (15)). The blocking/dropping probability of all the calls in the BS due to additional load of SM BS is given as

$$B_{\text{sleep}} = \sum_{i=0}^{C_a} P(i) \quad (16)$$

The blocking probability of non-real-time originating calls is given as

$$B_{NO} = \sum_{i=C_{gNO}+1}^{C_a} P(i) \quad (17)$$

The blocking probability of non-real-time transfer calls is given as

$$B_{NT} = \sum_{i=C_{gNT}+1}^{C_a} P(i) \quad (18)$$

The blocking probability of non-real-time Handoff calls is given as

$$B_{NH} = \sum_{i=C_{gNH}+1}^{C_a} P(i) \quad (19)$$

The blocking probability of real-time originating calls is given as

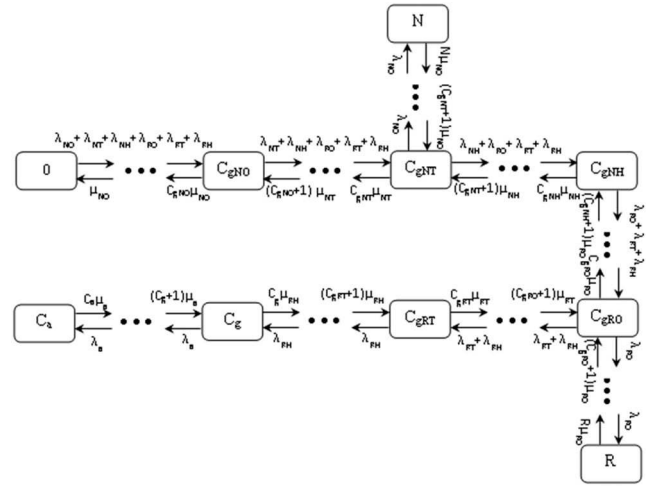
$$B_{RO} = \sum_{i=C_{gRO}+1}^{C_a} P(i) \quad (20)$$

The blocking probability of real-time transfer calls is given as

$$B_{RT} = \sum_{i=C_{gRT}+1}^{C_a} P(i) \quad (21)$$

The blocking probability of real-time handoff calls is given as

$$B_{RH} = \sum_{i=C_g+1}^{C_a} P(i) \quad (22)$$



**Fig. 8** State transition diagram for Fig. 2

#### 4.1 Energy model

If energy consumed by the BS in active mode is considered as  $E_{active}$ , in SM it is considered as  $E_{sleep}$ , and for switching the load as  $E_{switch}$ .

Then, total energy consumed =  $E_{active} + E_{sleep} + E_{switch}$ .

$$P(i) = \begin{cases} \frac{(\lambda_{NO} + \lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^i}{i! \mu_{NO}^i} P(0), & 0 \leq i \leq C_{gNO} \\ W \times \frac{(\lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{i-C_{gNO}}}{i! \mu_{NT}^{i-C_{gNO}}} P(0), & C_{gNO} < i \leq C_{gNT} \\ W \times X \times \frac{(\lambda_{NO})^{i-C_{gNT}}}{i! \mu_{NO}^{i-C_{gNT}}} P(0), & C_{gNT} < i \leq N \\ W \times X \times \frac{(\lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{i-C_{gNT}}}{i! \mu_{NH}^{i-C_{gNT}}} P(0), & C_{gNT} < i \leq C_{gNH} \\ W \times X \times Y \times \frac{(\lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{i-C_{gNH}}}{i! \mu_{RO}^{i-C_{gNH}}} P(0), & C_{gNH} < i \leq C_{gRO} \\ W \times X \times Y \times Z \times \frac{(\lambda_{RT} + \lambda_{RH})^{i-C_{gRO}}}{i! \mu_{RT}^{i-C_{gRO}}} P(0), & C_{gRO} < i \leq C_{gRT} \\ W \times X \times Y \times Z \times \frac{(\lambda_{RO})^i}{i! \mu_{RO}^i} P(0), & C_{gRO} < i \leq R \\ W \times X \times Y \times Z \times \frac{(\lambda_{RT} + \lambda_{RH})^{C_{gRT}-C_{gRO}}}{i! \mu_{RT}^{C_{gRT}-C_{gRO}}} \times \frac{(\lambda_{RH})^{i-C_{gRT}}}{i! \mu_{RH}^{i-C_{gRT}}} P(0), & C_{gRT} < i \leq C_g \\ \frac{(\lambda_a)^i}{i! \mu_a^i} P(0), & C_g < i \leq C_a \end{cases} \quad (10)$$

$$P(0) = \left[ \sum_{i=0}^{C_{gNO}} \frac{(\lambda_{NO} + \lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^i}{i! \mu_{NO}^i} + \sum_{i=C_{gNO}+1}^{C_{gNT}} W \times \frac{(\lambda_{NT} + \lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{i-C_{gNO}}}{i! \mu_{NT}^{i-C_{gNO}}} \right. \\ + \sum_{i=C_{gNT}+1}^N W \times X \times \frac{(\lambda_{NO})^{i-C_{gNT}}}{i! \mu_{NO}^{i-C_{gNT}}} + \sum_{i=C_{gNT}+1}^{C_{gNH}} W \times X \times \frac{(\lambda_{NH} + \lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{i-C_{gNT}}}{i! \mu_{NH}^{i-C_{gNT}}} \\ + \sum_{i=C_{gNH}+1}^{C_{gRO}} W \times X \times Y \times \frac{(\lambda_{RO} + \lambda_{RT} + \lambda_{RH})^{i-C_{gNH}}}{i! \mu_{RO}^{i-C_{gNH}}} + \sum_{i=C_{gRO}+1}^{C_{gRT}} W \times X \times Y \times Z \times \frac{(\lambda_{RT} + \lambda_{RH})^{i-C_{gRO}}}{i! \mu_{RT}^{i-C_{gRO}}} \\ + \sum_{i=C_{gRO}+1}^R W \times X \times Y \times Z \times \frac{(\lambda_{RO})^i}{i! \mu_{RO}^i} + \sum_{i=C_{gRT}+1}^{C_{gRH}} W \times X \times Y \times Z \times \frac{(\lambda_{RT} + \lambda_{RH})^{C_{gRT}-C_{gRO}}}{i! \mu_{RT}^{C_{gRT}-C_{gRO}}} \times \frac{(\lambda_{RH})^{i-C_{gRT}}}{i! \mu_{RH}^{i-C_{gRT}}} \\ \left. + \sum_{i=C_g+1}^{C_a} \frac{(\lambda_a)^i}{i! \mu_a^i} \right]^{-1} \quad (15)$$

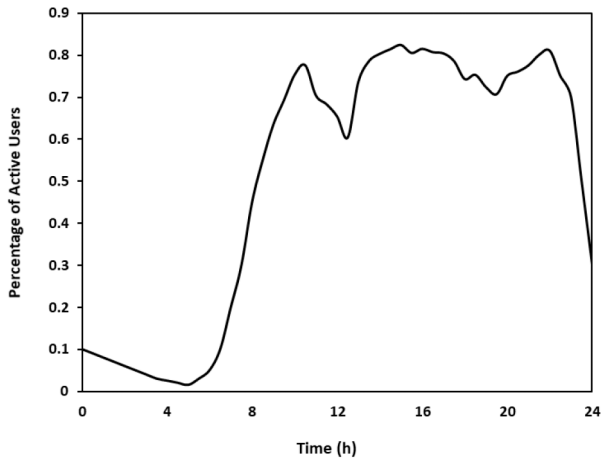


Fig. 9 Percentage of active users versus time

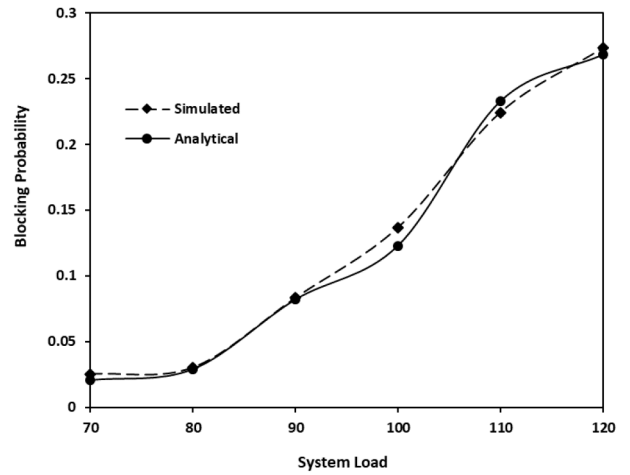


Fig. 12 Comparison of simulated versus analytical results in terms of blocking probability

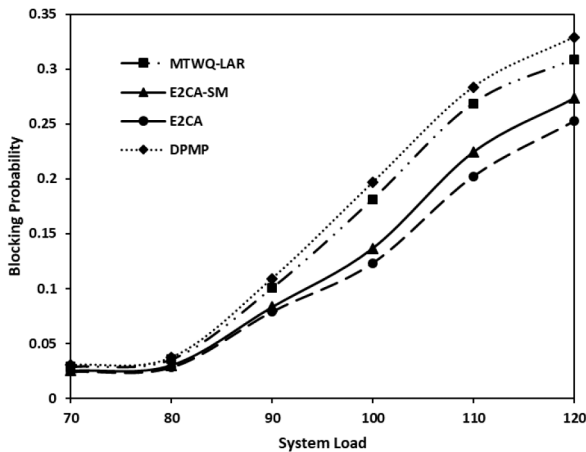


Fig. 10 Blocking probability versus system load

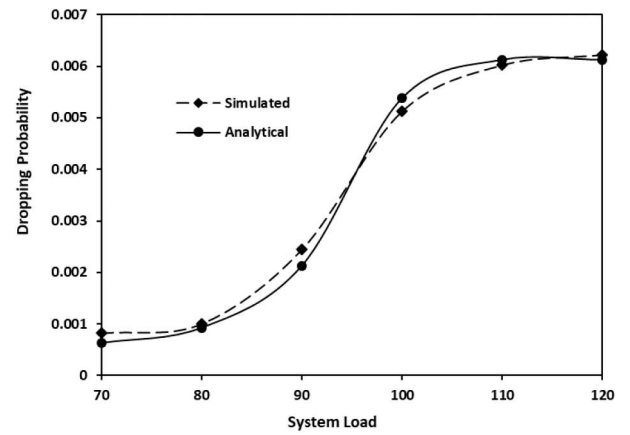


Fig. 13 Comparison of simulated versus analytical results in terms of dropping probability

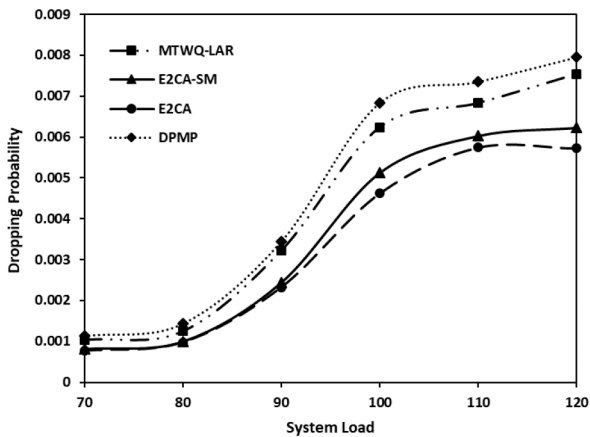


Fig. 11 Dropping probability versus system load

When the energy consumed during SM and energy consumed to switch the control of the channels to the neighbouring BSs is considered to be negligible. Then, the amount of energy consumed is only the energy consumed during active mode.

## 5 Results and discussion

The performance evaluation metrics considered for the evaluation of the E2CA-SM are blocking probability, dropping probability, and energy consumption.

The average of 25 runs of the simulation is considered for plotting the graph. The proposed system with SM of BSs (E2CA-SM) is compared with the same algorithm, but without SM for the BSs (E2CA). Moreover, it is compared with multi-traffic, with queue, learning automata-based reservation (MTWQ-LAR) and dynamic programming algorithm for minimising power

consumption (DPMP). The percentage of active users during 24 h time slot for 1 day is shown in Fig. 9.

Observe that the percentage of active users from 8:00 AM to 11:00 PM is above 50%, which is considered as peak hours and the rest of the time as non-peak hours, where active user's percentage is <50%.

It can be observed from Figs. 10 and 11 that the blocking probability and dropping probability of the proposed system, E2CA-SM, is less when compared with MTWQ-LAR and DPMP.

However, there is minimal variation between E2CA and E2CA-SM due to the new BS which is not able to provide services for the MSs in the range of the BS, that is, in the SM. However, this increase in blocking or dropping probability of E2CA-SM can be neglected as the percentage of improvement in terms of energy or power is remarkably good. The blocking probability of E2CA-SM is only 7.7% higher than E2CA, but it is 19.56 and 27.6% reduced when compared with MTWQ-LAR and DPMP, respectively. In the case of dropping probability, E2CA-SM is 6.8% higher than E2CA, and 20.7 and 32.3% reduced when compared with MTWQ-LAR and DPMP, respectively. Figs. 12 and 13 show the comparison of simulated and analytical results in terms of blocking and dropping probability.

This is because the proposed system deployed SM is during peak hours also. As the average of both the peak and non-peak hours is considered to plot the graph, the blocking probability of the E2CA-SM is more than the blocking probability of E2CA. However, deploying the SM during peak and non-peak hours helped in reducing the energy consumption of the system to a great extent. The graph is plotted for energy consumption per packet and is shown in Fig. 14. The energy consumption per packet is 35.5% less when compared with MTWQ-LAR, 32% when compared with E2CA as there is no SM in these methods when compared with

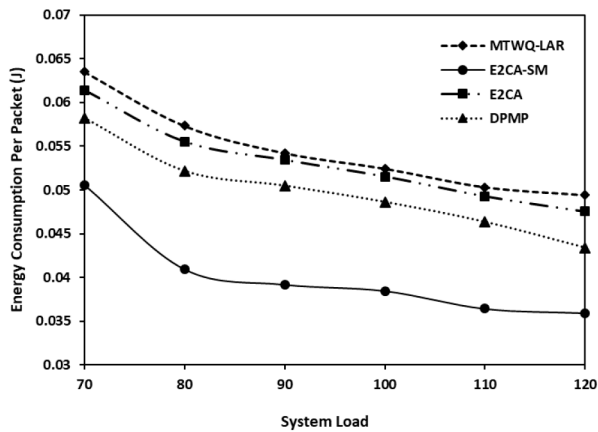


Fig. 14 Energy consumption per packet versus system load

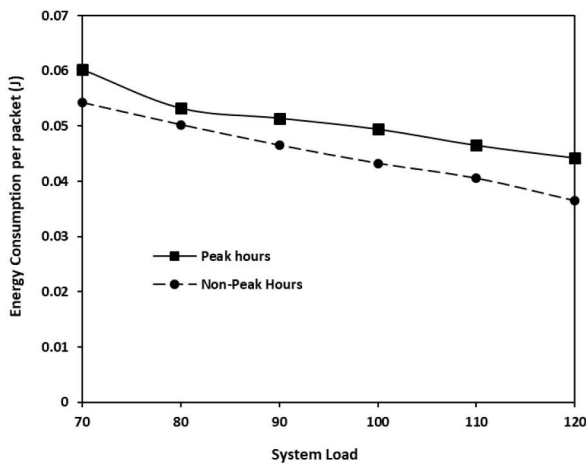


Fig. 15 Comparison of energy consumption per packet during peak and non-peak hours

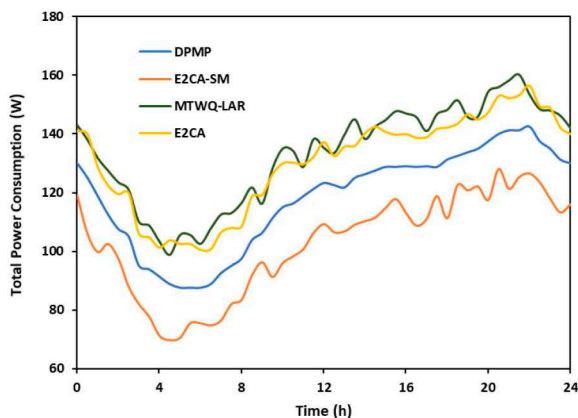


Fig. 16 Total power consumption concerning time

DPMP. The energy consumption per packet is measured during peak and non-peak hours as shown in Fig. 15.

The energy consumption during non-peak hours is less than the energy consumption during peak hours as the traffic will be much lower during non-peak hours. The main advantage of the proposed work E2CA-SM is the deployment of SM during peak hours also without overloading the other BSs, which enables energy conservation to a great extent. Finally, the total power consumption for 1 day with 200 nodes is shown in Fig. 16. It can be observed that the power consumption during peak hours is more than during other hours. The power consumed according to E2CA-SM algorithm is 14.9% less than DPMP, 29.82% less than MTWQ-LAR, and 26.9% less than E2CA. The channel allocation procedure designed here helped in maintaining the blocking and dropping probability to the required level and improving the performance in terms of power saving.

## 6 Conclusion

In today's world, power is a very valuable resource, and hence it is required to conserve it as much as possible. At the same time, the usage of mobile devices is also increasing, where the BSs are required to provide service to them. Nevertheless, the disadvantage of increasing the number of BSs will require more power consumption. Hence, to make it win-win situation, i.e. no compromise in the number of mobile users and the power consumption, the power needs to be conserved even when more BSs are used which is the main objective of this paper. An energy-E2CA procedure with SM for BSs (E2CA-SM) is proposed in this paper. The 24 h duration of a day is divided into peak and non-peak hours. Both originating and handoff calls are considered along with the type of traffic as real time and non-real time. Also, transfer calls are considered. The channel allocation by the BS is done by verifying the location of the user. The proposed work E2CA-SM is evaluated in terms of blocking probability, dropping probability, energy consumption per packet, and total power consumption.

## 7 References

- [1] Krishna, P.V., Misra, S., Obaidat, M.S., *et al.*: 'An efficient approach for distributed dynamic channel allocation with queues for real-time and non-real-time traffic in cellular networks', *J. Syst. Softw.*, 2009, **82**, (7), pp. 1112–1124
- [2] Wu, J., Zhang, Y., Zukerman, M., *et al.*: 'Energy-efficient base-stations sleep-mode techniques in green cellular networks: a survey', *IEEE Commun. Surv. Tutor.*, 2015, **17**, (2), pp. 803–826
- [3] Wu, J., Zhou, S., Niu, Z.: 'Traffic-aware base station sleeping control and power matching for energy–delay tradeoffs in green cellular networks', *IEEE Trans. Wirel. Commun.*, 2013, **12**, (8), pp. 4196–4209
- [4] Louhi, J.: 'Energy efficiency of modern cellular base stations'. Proc. 29th INTELEC, Rome, Italy, October 2007, pp. 475–476
- [5] Frenger, P., Moberg, P., Malmolin, J., *et al.*: 'Reducing energy consumption in LTE with cell DTX'. Proc. IEEE 73rd VTC Spring, Linköping, Sweden, May 2011, pp. 1–5
- [6] Ashraf, I., Boccardi, F., Ho, L.: 'Sleep mode techniques for small cell deployments', *IEEE Commun. Mag.*, 2011, **49**, (8), pp. 72–79
- [7] Micallef, G., Mogensen, P., Sch, H.: 'Cell size breathing and possibilities to introduce cell sleep mode'. Proc. European Wireless Conf., Lucca, Italy, April 2010, pp. 111–115
- [8] Li, R., Zhao, Z., Chen, X., *et al.*: 'TACT: a transfer actor-critic learning framework for energy saving in cellular radio access networks', *IEEE Trans. Wirel. Commun.*, 2014, **13**, (4), pp. 2000–2011
- [9] Jeong, J., Kimball, D.F., Kwak, M., *et al.*: 'High-efficiency WCDMA envelope tracking base-station amplifier implemented with GaAs HVHBTs', *IEEE J. Solid-State Circuits*, 2009, **44**, (10), pp. 2629–2639
- [10] Cho, K., Kim, J., Stapleton, S.: 'A highly efficient Doherty feed-forward linear power amplifier for W-CDMA base station applications', *IEEE Trans. Microw. Theory Tech.*, 2005, **53**, (1), pp. 292–300
- [11] Arnold, O., Richter, F., Fettweis, G., *et al.*: 'Power consumption modelling of different base station types in heterogeneous cellular networks'. Proc. Future Network Mobile Summit, Dresden, Germany, June 2010, pp. 1–8
- [12] Wei, Y., Staudinger, J., Miller, M.: 'High-efficiency linear GaAs MMIC amplifier for wireless base station and femtocell applications'. Proc. IEEE Topical Conf. PAWR, Tempe, AZ, USA, January 2012, pp. 49–52
- [13] Han, C., Harrold, T., Armour, S., *et al.*: 'Green radio: radio techniques to enable energy-efficient wireless networks', *IEEE Commun. Mag. Spec. Issue: Green Commun.*, 2011, **49**, (6), pp. 46–54
- [14] ElSawy, H., Hossain, E., Haenggi, M.: 'Stochastic geometry for modelling, analysis, design of multi-tier and cognitive cellular wireless networks: a survey', *IEEE Commun. Surv. Tutor.*, 2013, **15**, (3), pp. 996–1019
- [15] Rowlands, I.H., Parker, P., Scott, D.: 'Consumer perceptions of green power', *J. Consum. Market.*, 2002, **19**, (2), pp. 112–129
- [16] Chia, Y.K., Sun, S., Zhang, R.: 'Energy cooperation in cellular networks with renewable powered base stations'. Proc. IEEE WCNC, Shanghai, China, April 2013, pp. 2542–2547
- [17] Willkomm, D., Machiraju, S., Bolot, J., *et al.*: 'Primary user behavior in cellular networks and implications for dynamic spectrum access', *IEEE Commun. Mag.*, 2009, **47**, (3), pp. 88–95
- [18] Marsan, M.A., Chiaraviglio, L., Ciullo, D., *et al.*: 'Optimal energy savings in cellular access networks'. Proc. IEEE Int. Conf. Communications Workshops, Dresden, 2009, pp. 1–5
- [19] Chiaraviglio, L., Ciullo, D., Meo, M., *et al.*: 'Energy-aware UMTS access networks'. Proc. 11th Int. Symp. Wireless Personal Multimedia Communications, Lapland, Finland, September 2008
- [20] Zhou, S., Gong, J., Yang, Z., *et al.*: 'Green mobile access network with dynamic base station energy saving', *ACM MobiCom*, 2009, **9**, (262), pp. 10–12
- [21] 3GPP R3-100162: 'Overview to LTE energy-saving solutions to cell switch off/on'. 3GPP RAN3 Meeting, Valencia, Spain, January 2010
- [22] Misra, S., Venkata Krishna, P., Saritha, V.: 'An efficient approach for distributed channel allocation with learning automata-based reservation in cellular networks', *Simul. Sage J.*, 2012, **88**, (10), pp. 1166–1179

- [23] Wu, G., Dong, L., Qin, Z., *et al.*: 'Dynamic programming-based pico base station sleep mode control in heterogeneous networks', *Int. J. Commun. Syst.*, 2017, **30**, (2), p. e2967
- [24] Wu, J., Zhou, S., Niu, Z.: 'Traffic-aware base station sleeping control and power matching for energy-delay tradeoffs in green cellular networks', *IEEE Trans. Wirel. Commun.*, 2013, **12**, (8), pp. 4196–4209
- [25] Gong, J., Zhou, S., Niu, Z., *et al.*: 'Traffic-aware base station sleeping in dense cellular networks'. IEEE 18th Int. Workshop on Quality of Service (IWQoS), Beijing, China, 2010, pp. 1–2
- [26] Niu, Z., Wu, Y., Gong, J., *et al.*: 'Cell zooming for cost-efficient green cellular networks', *IEEE Commun. Mag.*, 2010, **48**, (11), pp. 74–79
- [27] Cili, G., Yanikomeroglu, H., Richard Yu, F.: 'Cell switch off technique combined with coordinated multi-point (CoMP) transmission for energy efficiency in beyond-LTE cellular networks'. Proc. IEEE Int. Conf. Communications, Ottawa, Canada, 2012, pp. 5931–5935
- [28] Celebi, H., Güvenç, I.: 'Load analysis and sleep mode optimization for energy-efficient 5G small cell networks'. Proc. IEEE Int. Conf. Communications Workshops (ICC Workshops), Paris, 2017, pp. 1159–1164, doi: 10.1109/ICCW.2017.7962815
- [29] Wu, H., Xu, X., Sun, Y., *et al.*: 'Energy efficient base station on/off with user association under C/U split'. Proc. IEEE Wireless Communications and Networking Conf. (WCNC), San Francisco, CA, 2017, pp. 1–6, doi: 10.1109/WCNC.2017.7925662
- [30] Della Penda, D., Abrardo, A., Moretti, M., *et al.*: 'Distributed channel allocation for D2D-enabled 5G networks using potential games', *IEEE Access*, 2019, **7**, pp. 11195–11208, doi: 10.1109/ACCESS.2019.2891823
- [31] Dighiri, M., Saeed Dayem Alfoudi, A., Myoung Lee, G., *et al.*: 'Resource allocation scheme in 5G network slices'. Proc. 32nd Int. Conf. Advanced Information Networking and Applications Workshops (WAINA), Krakow, 2018, pp. 275–280, doi: 10.1109/WAINA.2018.00098
- [32] Huo, L., Jiang, D.: 'Stackelberg game-based energy efficient resource allocation for 5G cellular networks', *Telecommun. Syst.*, 2019, **72**, pp. 1–12. Available at <https://doi.org/10.1007/s11235-019-00564-w>, accessed February 2019
- [33] Ning, Z., Wang, X., Rodrigues, J.J.P.C., *et al.*: 'Joint computation offloading, power allocation, and channel assignment for 5G-enabled traffic management systems', *IEEE Trans. Ind. Inf.*, 2019, **15**, (5), pp. 3058–3067, doi: 10.1109/TII.2019.2892767
- [34] Ma, B., Shah-Mansouri, H., Wong, V.W.S.: 'Full-duplex relaying for D2D communication in millimeter wave-based 5G networks', *IEEE Trans. Wirel. Commun.*, 2018, **17**, (7), pp. 4417–4431, doi: 10.1109/TWC.2018.2825318
- [35] Lien, S.Y., Tseng, C.C., Moerman, I., *et al.*: 'Recent advances in 5G technologies: new radio access and networking', *Wirel. Commun. Mob. Comput.*, 2019, **2019**, pp. 1–2