

Automatika

Journal for Control, Measurement, Electronics, Computing and Communications



ISSN: 0005-1144 (Print) 1848-3380 (Online) Journal homepage: <https://www.tandfonline.com/loi/taut20>

Energy efficiency based on relay station deployment and sleep mode activation of eNBs for 4G LTE-A network

R. Ratheesh & Pandu Vetrivelan

To cite this article: R. Ratheesh & Pandu Vetrivelan (2019) Energy efficiency based on relay station deployment and sleep mode activation of eNBs for 4G LTE-A network, *Automatika*, 60:3, 322-331, DOI: [10.1080/00051144.2019.1637054](https://doi.org/10.1080/00051144.2019.1637054)

To link to this article: <https://doi.org/10.1080/00051144.2019.1637054>



© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 16 Jul 2019.



Submit your article to this journal [↗](#)



Article views: 117



View related articles [↗](#)



View Crossmark data [↗](#)



Energy efficiency based on relay station deployment and sleep mode activation of eNBs for 4G LTE-A network

R. Ratheesh and Pandu Vetrivelan

School of Electronics Engineering, Vellore Institute of Technology (VIT), Chennai, India

ABSTRACT

The energy efficiency is considered as a major issue due to large power consumption of eNBs in heterogeneous cellular networks. In this paper, a novel relay station (RS) deployment scheme and base station (BS) sleep mode algorithm is proposed to minimize the power consumption of eNBs. The relay stations are deployed to cover the entire transmission area of a cell to provide service when the eNBs are in sleep mode. The network traffic of each cell is considered with Erlang B and C probability measure and sleep mode is activated for eNBs, during the low network traffic intervals which reduces the total power consumption. The network traffic is estimated for each RSs also and the RS without MU association becomes sleep mode in order to reduce power consumption further. The simulation results of proposed work and when it compared with the existing network shows good saving in power consumption. An intra-cell BS-RS handover scheme for our work is also described in this paper. The evaluation results show the efficiency of our proposed work.

ARTICLE HISTORY

Received 25 January 2019
Accepted 29 April 2019

KEYWORDS

Energy efficiency; relay station deployment; network traffic estimation; sleep mode algorithm

1. Introduction

In recent years, the uses of communication and information technologies are developed to enhance the economy of the world. The cellular network plays a major role for the deployment of efficient communication system [1]. The high data rate services are enabled in wireless communication technologies with the key factor of saving energy consumption. In order to realize green communication, less energy requirement is important in the field of wireless cellular communication [2]. When modelling the cellular network, it mainly focuses on lower latency, increased number of active users, enhanced cell edge performance, high data rate and energy efficiency [3]. Renewable energy is one of the main solutions which can be accomplished with the approach of energy harvesting [4].

When the network is powered with green power, the basic issue for the deployment of base station (BS) and relay station (RS) is to efficiently utilize the power to tackle the network traffic requirement of users in the network [5]. If the BS is having less network traffic or no network traffic, more than 90% of its peak energy is consumed by the BS. In order to increase the energy efficiency, there must be coordination among BS and the redundant BS are required to be switched off at the time of low network traffic [6]. Higher data rates are obtained by installing more number of access terminals [7]. The trade-off between power saving and high performance is provided with the design of cellular

network. The macro BSs are mainly designed for largest coverage instead of providing high data rate [8].

The deployment of cellular network based on smaller cells such as pico, micro and femto cells provides benefits in terms of energy reduction, high data rate and cost efficiency [9]. While saving the energy, the researchers analyzed QoS, blocking probability, coverage performance, considerable delay and spectral efficiency [10]. The BSs from the empty cell is prevented from transmitting, as a result the mobile density of the active BS is improved [11]. Furthermore, the power saving operation of BS should not affect the terminals negatively, for example some methods proposed for power saving operation of BSs degrades the QoS. [12].

Switching on/off based dynamic BS operations permits the entire system of BS to turn off at low network traffic periods for significant power saving [13]. When the BS is switched off, the coverage and the service should be provided by the active device. Hence the switching problem of BS is considered as an optimization issue which minimizes the number of active BSs when network traffic occurs [14–15]. From operational perspective, the trade-off between circuit power and transmission power is analyzed with the location and number of BSs [16].

Various algorithmic-based solutions are developed for reducing the power consumption. Deterministic network traffic pattern on daily basis is presented with the predefined BS sleep pattern [17]. Cell zooming

approach adjusts the cell size based on the network traffic load and hence it balances the load and minimizes the energy consumption [18]. When the BS is turned off, the arriving users required to wait for a long period of time and it experiences longer delay [19]. The optimal full network traffic load at the BS is sufficient for reducing the consumption of transmission energy [20].

In this work, the power consumption model is considered as a function of network traffic load which is developed for the macro cell BS. The new deployment scheme for the RS is enabled to enhance the coverage when BS is in sleep mode. The concept of sleep mode is enabled for both BS and RS in order to minimize the total power consumption. This paper investigates the handover approach between the BS and RS.

The outline of the paper is described as follows. Section 2 discusses the related works for minimizing power consumption. Section 3 discusses the proposed concept of relay station (RS) deployment and base station (BS) sleep mode algorithm. Section 4 discusses the simulation results of the proposed work and its comparison. Section 5 discusses the significant aspects of our work and concludes.

2. Related work

Wang et al. investigated user association (UA) algorithms to efficiently utilize the energy in green cellular network. Initially the problem of total energy cost minimization (ECM) is formulated and it is decomposed into UA problem and optimal bandwidth allocation (OBA) problem. The power consumption of each BS was minimized with OBA algorithm with respect to the given UA approach. Near optimal solution for the OBA algorithm was obtained as distributed and centralized UA algorithm. The energy efficiency of this cellular model was improved with the reduction of total energy cost [21].

Farooq et al. proposed a hybrid energy sharing framework in which the collection of physical power lines and smart grid was used for energy saving. Based on the average and complete statistics of available RE, the power lines were deployed between BSs. The energy consumption of electricity and RE between BS is estimated with the consideration of energy pricing and battery capacity. The energy management framework was investigated with three cases namely. The reduction in energy cost and energy management between BS was obtained with hybrid energy sharing approach [22].

Huang et al. modelled energy aware cooperation strategies for obtaining energy efficiency based on user demands. Binary integer programming was formulated as a problem for ensuring BS sleep mode and provides cooperation among active BSs. From this formulation, performance lower bound was obtained through Lagrangian Relaxation with search enumeration. Totally 60% of energy was saved with this

algorithm when compared with the energy consumption when all BSs are switched on [23].

Zhang et al. considered the problem of power optimization and joint user allocation which is formulated as a mixed integer programming problem. It was then converted to the convex optimization problem with the user allocation (UA) indicator using Lagrangian dual decomposition. The iterative power allocation and UA was investigated with optimal points rapidly. The complexity of the proposed algorithm was analyzed and its effectiveness was compared with existing methods in the simulations [24].

Niu et al. investigated the problem of reducing energy consumption through power control and concurrent transmission scheduling into a mixed integer nonlinear program (MINLP). The mmWave backhauling and energy-efficient approach were developed in which it has power control algorithm and maximum independent set (MIS)-based scheduling algorithm. The conditions for reducing the power consumption and the options for interference threshold were analyzed [25].

3. Proposed approach for minimizing power consumption of eNBs

In proposed work, the BS is considered as eNBs which are capable of communicating to its neighbouring base station (BSs) and relay stations (RSs) which are deployed in the transmission area of selected BS with a dedicated wireless link. The network traffic prediction and sending corresponding control signals to RSs and BSs in order to change the mode of operation is computed by the control server located at the selected BS. The proposed approach projected a new network model of RS deployment and discusses the techniques such as network traffic estimation, BS and RS sleep mode and handover management for reducing energy consumption. In this section, we first discuss the deployment scheme of BS and RS then the proposed algorithm, and then the remaining part of power saving scheme is discussed.

A. Geographical area of implementation and ideal placement of RS

The practical implementation of the proposed work required a detailed study about the geographical terrain, the density of population and the mobility of mobile stations. With respect to these factors, the suburban and rural areas with periodic peak and off-peak hours of network traffic is more suitable for the implementation of proposed work. In urban areas, the off-peak hours of network traffic is minimum so the BS sleep mode time is also less, also in these areas as the density of human population is very high and to provide service for these high MS density, the transmission

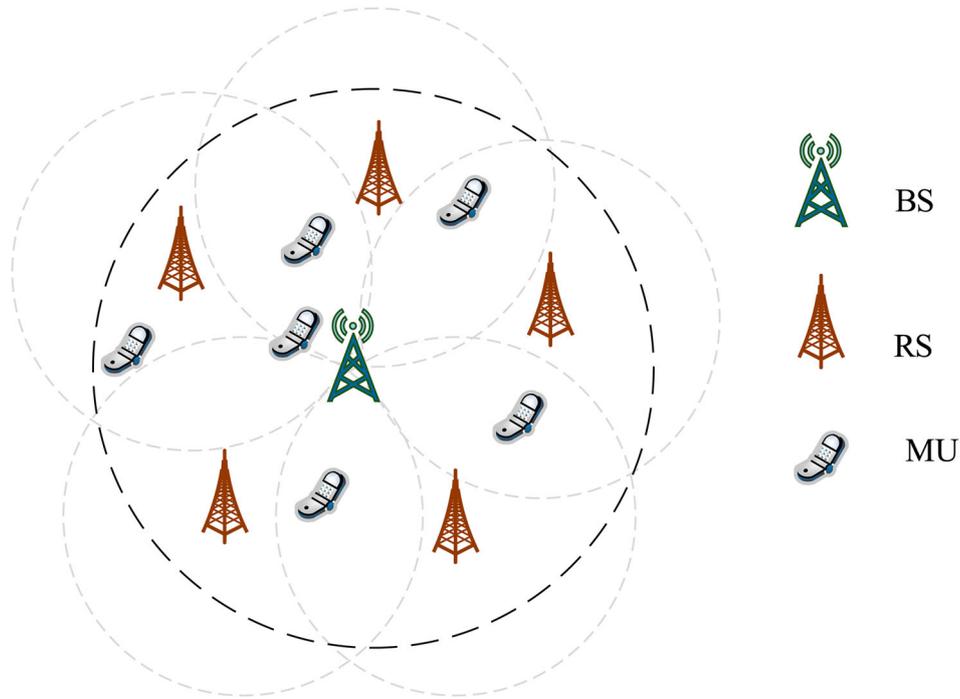


Figure 1. Proposed architecture of cellular network.

area of BS is very less comparing the transmission area of a BS deployed at suburban and rural areas. The number of RS to be deployed is with respect to the size of transmission area of the selected BS provided the whole transmission area of selected BS is covered with number of RS transmission area with minimum overlapping among them. During sleep mode operation of BS, the total power consumed by all the active RS need to be less compared to the power consumed by BS in active mode. This is an important criteria for the selection of area for implementing our proposed work.

B. Network model with RS deployment

The cellular network is designed with cluster size of 7 cells and the deployment scenario of a single cell is shown in Figure 1. Each cell is denoted as C and the BS in cell is denoted as j . Each cell is having J number of BSs. The RS and MS are denoted as j and k . The number of RS and MS in each cell is denoted as K and L . Overlapping circular cells are used in order to avoid the coverage gap. For each cell, the number of available user is varied. The MS and RS in each cell are served with the BS in the corresponding cell. When the network traffic is low, the BS as well as RS is turn in to sleep mode while the others keep active. When BS is in sleep mode, the handoff strategy is used in which all active calls are forwarded to the RS.

C. Network traffic estimation

The BS network traffic is estimated with extended Erlang B and Erlang C. Erlang B computes the blocking probability and Erlang C computes the probability

that the customer waiting in a queue. The step by step procedure of Erlang B is described as follows.

Step 1: Compute the probability of blocking

$$P_b = B(E, m) = \frac{\frac{E^m}{m!}}{\sum_{i=0}^m \frac{E^i}{i!}} \quad (1)$$

where E indicates the total offered network traffic and m indicates the number of identical parallel resources (e.g. server, communication lines, etc.). The total offered network traffic is based on the arrival rate λ which follows Poisson distribution and the average call holding time h . Network traffic E is calculated as

$$E = \lambda h \quad (2)$$

Step 2: Calculate the probable number of blocked calls

$$B_e = EP_b \quad (3)$$

where E indicates the total offered network traffic and P_b represents the blocking probability.

Step 3: Calculate the number of recalls by assuming the recall factor.

$$R = B_e R_f \quad (4)$$

where B_e represents the probable number of blocked calls and R_f represents the recall factor.

Step 4: Calculate the new offered network traffic.

$$E_{i+1} = E + R \quad (5)$$

where E indicates the total offered network traffic and R is the number of recalls.

Return to step 1 until the stable value of E is obtained.

Erlang C for computing the queuing probability

The formula for the computation of queuing probability is described as follows:

$$P_w = \frac{\frac{A^N}{N!} \frac{N}{N-A}}{\left(\sum_{i=0}^{N-1} \frac{A^i}{i!} \right) + \frac{A^N}{N!} \frac{N}{N-A}} \quad (6)$$

where A is the total offered network traffic and N is the number of servers.

For enabling the BS sleep mode, the threshold value δ is fixed for the computed probability. If the probability is less than the threshold, then the sleep mode is activated for the BS.

D. Minimizing power consumption with sleep mode algorithm

The number of MS in the sleeping cell is accessed through active RS. The binary variable is used to indicate whether the MS is served by the BS or not.

$$C_l^j = \begin{cases} 1 & \text{MS}_l \text{ is served by BS}_j \\ 0 & \text{MS}_l \text{ is not served by BS}_j \end{cases} \quad (7)$$

Hence the associated state of BS_j is represented by the vector $C^j = C_1^j, C_2^j, \dots, C_L^j$.

The total power consumed at the BS and RS is described as

$$P_{\text{total}} = \alpha \cdot P_{\text{tx}} + P_{\text{fixed}} \quad (8)$$

where P_{total} denotes the total power consumption, P_{tx} represents the transmitted power, P_{fixed} represents the fixed site power which is consumed independent of average transmit power due to site cooling as well as signal processing, etc. and α represents the power consumption that scales with the average radiated power due to amplifier and feeder losses as well as cooling of sites [26].

The approach of accessing the MS in the sleep cell to the active RS is the key technology of reducing energy consumption. The problem of finding effective offloading scheme for sleeping BS is turned into the effect of minimizing entire power consumption. The optimization problem is formulated as

$$\min (P_{\text{total}}) \text{ s.t. traffic} < \text{threshold} \quad (9)$$

The optimal solution for the problem is obtained with the proposed sleep mode algorithm shown in Figure 2. Initially J numbers of BSs are considered in the proposed cellular network. Then the network traffic is estimated for the first BS ($j = 1$). The result of network traffic estimation is obtained as a probability value from equation (6). The probability value is compared with the fixed threshold (if(traffic < threshold)). If the condition is satisfied, all RS $k(1 : K)$ belongs to the BS j is

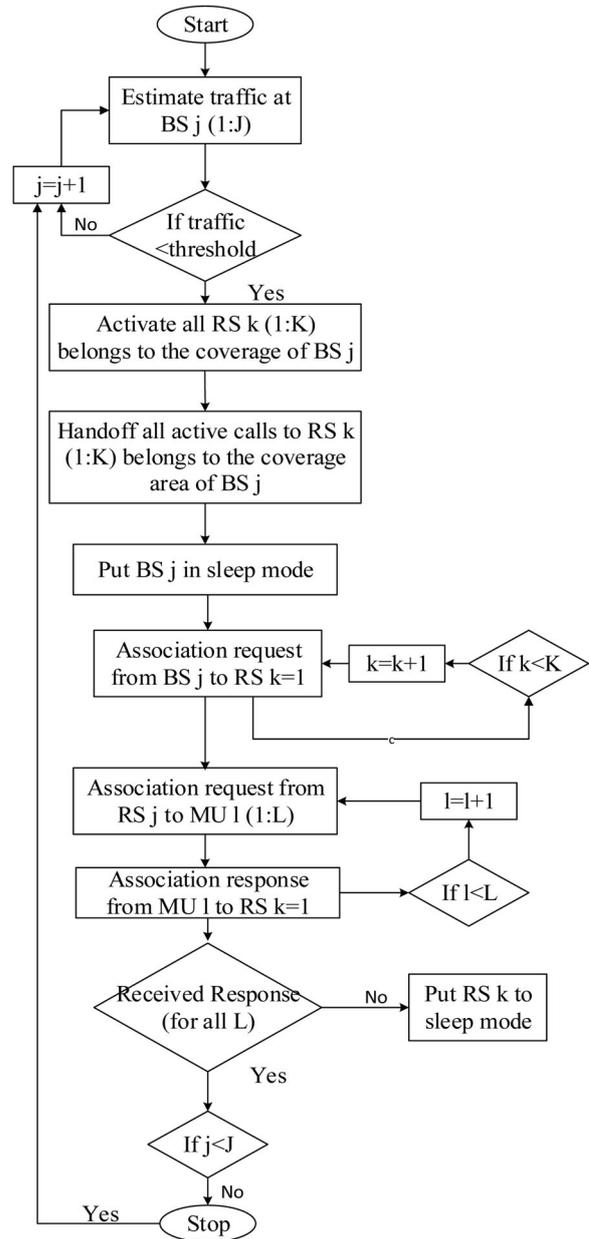


Figure 2. Flow diagram for the BS sleep mode algorithm.

activated and all active calls of the particular BS is handover to corresponding RS. After handover, the BS will go to sleep mode. If the condition is not satisfied, the value of j is increased ($j = j + 1$). Hence, it checks the network traffic of other BSs. The total number of RS per cell is K . In order to make the RS to sleep mode, the BS will send association request to RS. The association request is sent from the RS to mobile user (MU) l . The number of users associated with each RS is L . The response is obtained from the MU until the number of response is less than the total number of MU (if $l < L$). For each request, the response is checked. If all responses are *no*, then the RS will go for sleep mode. Finally, the condition ($j < J$) is checked to ensure that the network traffic is estimated in all BSs. If the condition is satisfied, then the value of j is increased and the network traffic is estimated for the next BS.

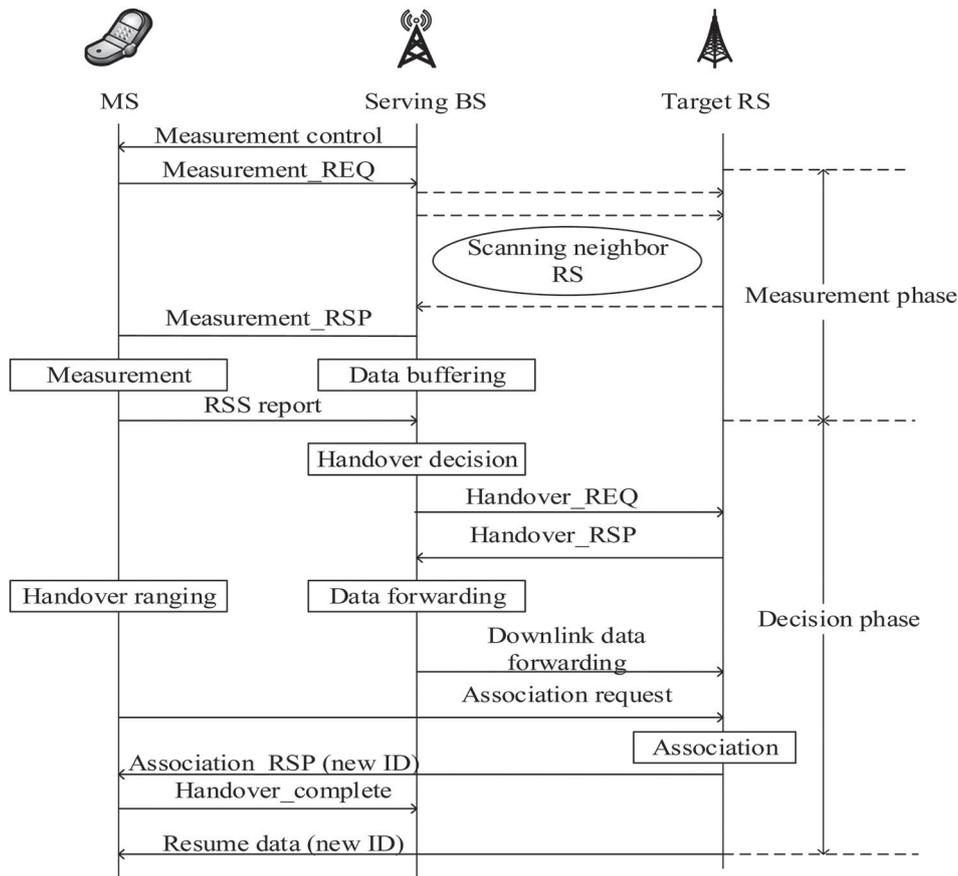


Figure 3. Handover signalling in heterogeneous network.

E. Intra cell BS–RS handover

When the communication node of the mobile station is changed from BS to RS in the same cell it is termed as intracell BS RS handover. The handover process in this stage can be easily handled with BS. The handover procedure signalling is shown in Figure 3. There are two phases in handover process namely measurement phase and decision phase. Initially, the measurement control request is sent to the MS for knowing the RSS from serving BS. In measurement phase, the BS scans the required RS for handover using Measurement_REQ and Measurement_RSP messages. When the number of BS or RS increases, the time required for the scanning process will be increased. It causes network overhead for the scanning process and it affects the QoS. Then the RSS report is sent to the BS. The decision for the handover is based on the RSS measurement. After that, the data forwarding is enabled to connect the MS to the RS. The association_REQ and Association_RSP message is sent between the MS and RS. The connection from the BS is released only after getting the confirmation message of handover completion from the MS.

- (i) *Call switching.* After taking the handover decision, the concept of call switching is enabled to forward active calls to the corresponding RS. Within BS controller (BSC) and BS subsystem (BSS), it

knows the current status of link configurations and it detects the new Base Transceiver system (BTS) from the available channel. Then the MS is requested to switch over the next BTS. When the MS enters into the new location, it is identified and the identification request is sent to available channel.

F. Mobility prediction based on human behaviour

After enabling sleep mode algorithm for RS, the mobility prediction is required for the MU to ensure that the next access point (RS) for the MU is in active mode. If the predicted RS is in sleep mode, then it is activated for avoiding call drops. Here, the mobility prediction used in our work is based on the human behaviour which uses the past history of handoff sequences. The mobility prediction is controlled with BS of each cell and mobility prediction consists of HS table, Group table, Time of the day (ToD) activities of previous MU. It is obtained by finding the handoff history of previous mobile users (MUs) and it can be implemented with the BS of the particular cell.

- (i) *HS table.* The mobility history of the MU is represented with handoff sequence in HS table. The length of the handoff sequence (c_{n-1-l}, \dots, c_n) stored in the HS table is l . Here, c_i indicates the ID for the i th handoff.

Table 1. HS table.

| Past | Current | Next |
|---------|---------|---------|
| C_x | C_w | C_x |
| C_x | C_w | C_y |
| C_x | C_w | C_z |
| \dots | \dots | \dots |
| C_y | C_x | C_w |

Table 1 shows the HS table which contains the mobility pattern history of the network.

(ii) **Group table.** The group table contains different groups based on the time of the day characteristics of MU. Different groups are represented with the group IDG_j . If p numbers of groups are available in the group table, then the group ID is represented as G_0, G_1, \dots, G_{p-1} .

(iii) **ToD activities.** The mobile users (MUs) belongs to the same group may show an analogous handoff behaviour which is considered for T duration. The default period for time of day is set to T . The periodic behaviour of handoff is separately modelled as $ToD_i = \{\tau_0, \tau_1, \dots, \tau_{q-1}\}$, where τ_j denotes the time group, q represents the number of time segments and $\sum_j \tau_j = T$.

For mobility prediction, the information such as {ID, HS, Duration} are received by the BS from the MU. The BS performs the prediction for next access point of RS. The priority order for the next handover prediction is based on HS table and ToD activities. The last k handoffs from the handoff sequence are utilized for searching the matching entries from HS table. The ID is used to detect the group based on the time of the day characteristics of different group of MUs. By matching the ID with the group table, the ID belonging to the MU group is determined. From the detected group, the ToD activities for T duration is obtained. The current handoff sequence and time duration is matched with the HS table entries and the ToD of the specific group for obtaining the prediction list. After mobility prediction, the predicted RS is activated and the handoff sequences are updated in the hash table. The human behaviour-based mobility prediction (BMP) improves the prediction accuracy by using the mobility behaviour of user.

4. Simulation results and discussion

The performance of the proposed scheme is evaluated with MATLAB tool. The performance of the proposed scheme is compared with the energy consumption without sleep mode. The simulation is performed with 7 BSs and 35 RSs. Fixed power consumption P_{fixed} at the BS and RS is set to 68.8 W and 20 W [26]. The implementation parameters are listed in Table 2. The amplifier used in the heterogeneous cellular network or the feeder loss causes some power consumption. It is

Table 2. Implementation parameters.

| | |
|--|---------|
| Coverage range of BS (km) [27] | 3.2 |
| Coverage range of RS (km) [27] | 1.9 |
| Total power allocated (W) for BS [27] | 40 |
| Total power allocated (W) for RS [27] | 8 |
| Fixed power consumption at the BS P_{fixed} [26] | 68.8 W |
| Power consumption due to amplifier or feeder loss (BS) α [26] | 3.8 W |
| Fixed power consumption at the RS | 20 W |
| Power consumption due to amplifier or feeder loss | 2 W |
| Arrival rate, λ | (0–13) |
| Average call holding time, h | 15 min |
| Number of identical parallel resources, m | 5 |
| Number of servers, N | 5 |
| Recall factor, R_f | 0.5 |
| Number of BS [27] | 7 |
| Network traffic threshold, δ | 23.9896 |
| Deployment cost (BS) (units) [27] | 9 |
| Deployment cost (RS) (units) [27] | 3 |
| Deployment budget T_{DB} (units) [27] | 40 |

denoted as α and it is set to 3.8 W for BS and 2 W for RS. The system bandwidth is set to 10 MHz and the energy factor P/N_0B is set to -4 dB.

The RS deployment location is shown in Figure 4. There are five RSs deployed for each cell. The RSs are deployed in a way to enhance the total coverage of cell. It avoids the issue of coverage hole because of its overlapping structure and the numbers of RSs used are sufficient to cover the entire cell area. The proposed scheme achieves 99% coverage with slight increase of deployment cost.

The deployment pattern of RS and sleep mode activation is shown in Figure 4 and Figure 5. In Figure 5, BS is active and all five RSs are in sleep mode. This is the consideration of state before network traffic estimation. It contains several number of MSs and all are associated or within the coverage of BS. In Figure 5(a), BS in sleep mode, all the RSs are active and the numbers of MSs are associated with the nearest RS. In Figure 5(b), the BS is in sleep mode and two RS also in sleep mode based on the estimated network traffic. If RS, sleep mode is activated it does not contain any MSs. When the sleep mode is activated for BS and RS, the sleep mode power consumption is only 15% of the total power consumption.

A. Deployment cost

The deployment cost [27] for the proposed network topology considering the simulation parameters is calculated by Equation (10).

$$\sum_{j=1}^J DC_{\text{BS}} \cdot \beta_j + \sum_{k=1}^K DC_{\text{RS}} \cdot \gamma_k \leq T_{\text{DB}} \quad (10)$$

where DC_{BS} and DC_{RS} denote the deployment of BS and RS, number of BS and RS are denoted as J and K ,

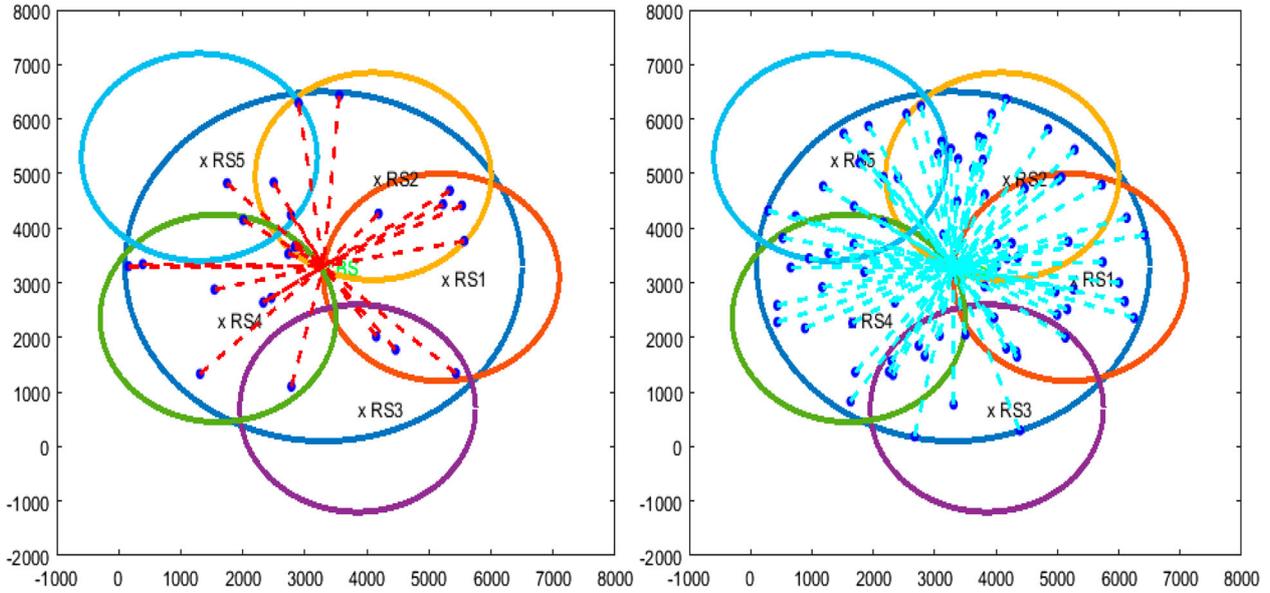


Figure 4. Deployment of the BS and RS: the BS is active and all RS are in sleep mode and all the MSs are connected with the BS.

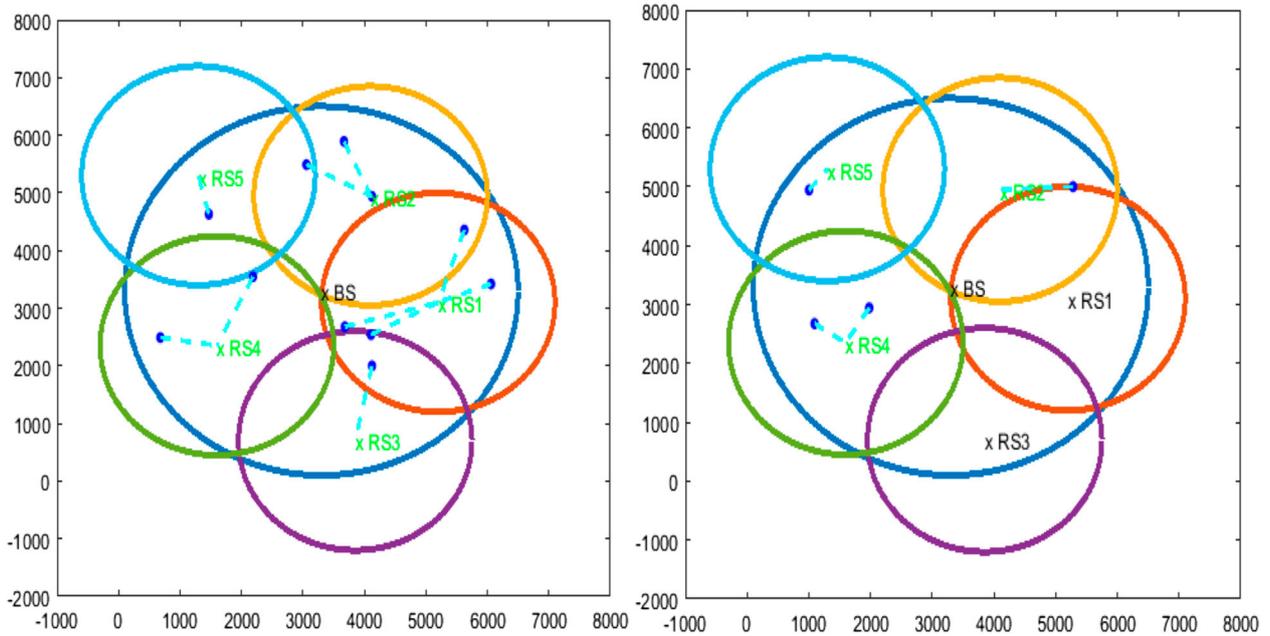


Figure 5. Deployment of BS and RS: (a) BS, sleep; 5RS, active; (b) 3RS, active; 2RS, sleep; BS, sleep.

β_j and γ_k are binary variables.

$$\beta_j = \begin{cases} 1, & \text{if BS is deployed in the } j\text{th} \\ & \text{candidate position} \\ 0, & \text{otherwise} \end{cases}$$

$$\gamma_k = \begin{cases} 1, & \text{if RS is deployed in the } k\text{th} \\ & \text{candidate position} \\ 0, & \text{otherwise} \end{cases}$$

For the single BS, the binary variable used for deployment cost computation is 1. Hence the deployment cost for a BS is 9 units. The number of RS used is 5 units and the value for the binary variable is 1. The deployment cost of a single RS is 3 units and for a single cell,

the deployment cost of RS is 15 units. Hence for the single cell combined with both BS and RS requires the deployment cost of 24 units.

B. Power consumption

The power consumption model for 24 hours duration is shown in Figure 6. Initially for the time interval between 12.00 am to 3.00 am (0–3.00), the power consumption is very low. Because, in this time there is less number of MSs and the BS and selected RS are in sleep mode. Since, it consumes less amount of power when it is in sleep mode. There is a slight increase in the power consumption up to 5.00 am. After 5, the increase in power consumption shows that all RS are active due

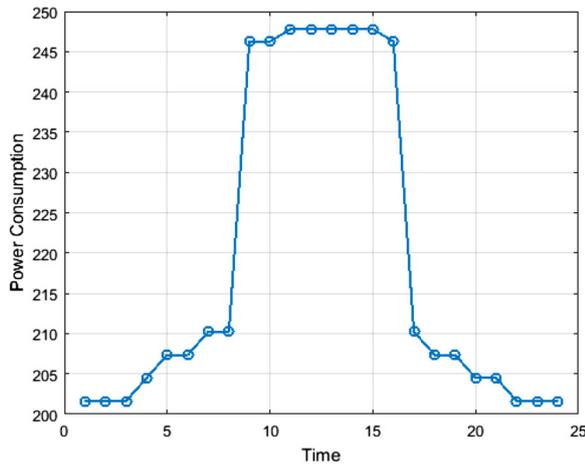


Figure 6. Power consumption for various time intervals.

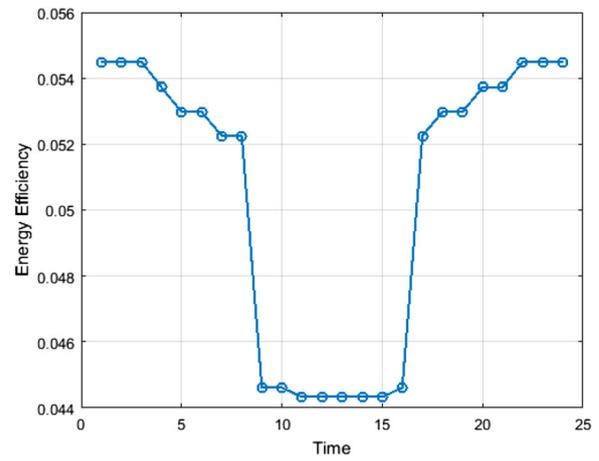


Figure 8. Energy efficiency for various time intervals.

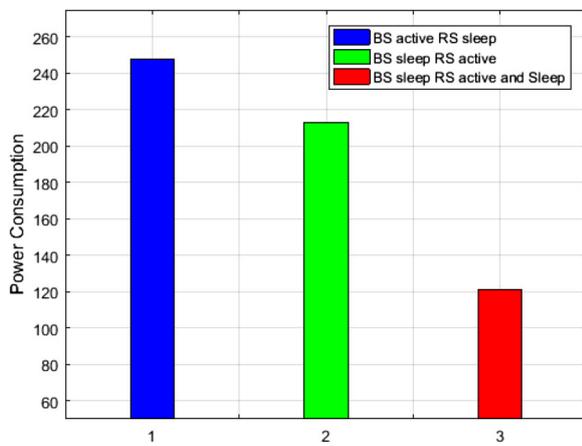


Figure 7. Power consumption comparison for varying the sleeping status of the BS and RS.

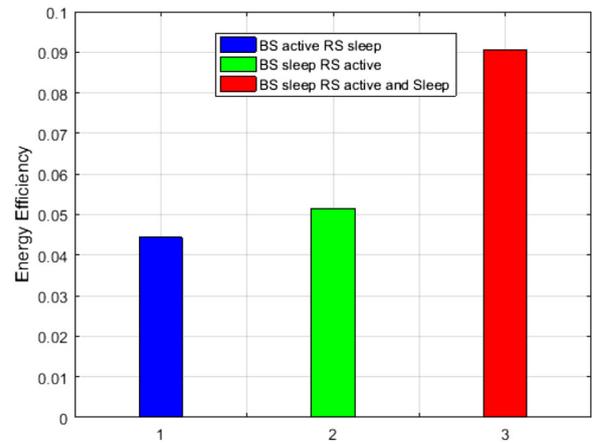


Figure 9. Energy efficiency comparison for varying the sleeping status of the BS and RS.

to increase in the number of UA. When the time is 10.00 and 15.00, it consumes high power since the BS is activated at this time. After this peak power consumption, again the value is reduced to the previous level. The comparison of power consumption for various statuses is shown in Figure 7. When the BS is active above 240 W power is consumed for the single cell. When the BS is in sleep mode, the power consumption is between the range of 200W–220W. The power consumption is further reduced to 120 W, by making the RS to sleep mode.

C. Energy efficiency

The energy efficiency [29] for the proposed network model is calculated by Equation (11)

$$\eta_{tee} = (B \log_2 (1 + \frac{P_{tx}}{N_0 \mathbf{B}})) / P_{total} \quad (11)$$

where P_{tx} is the transmit power, B is the system bandwidth, P_{total} denotes the power consumption and N_0 is

the power spectral density of AWGN. The energy efficiency for 24 hours duration is shown in Figure 8. The energy efficiency is high when the power consumption is low and the energy efficiency is low when the power consumption is increased [28]. The energy efficiency comparisons with various modes are shown in Figure 9. The proposed method achieves energy efficiency up to 0.09. The obtained energy efficiency is high when compared with the active BS.

When the BS is active for certain period of time, there is constant power consumption and energy efficiency also less. It can be mitigated with our proposed sleep mode concept. Here, the activation of BS and RS is based only on the estimated network traffic. The implementation parameters used in this work is suitable for suburban areas where the network traffic is low in a specific period of time. The power consumed by the control server in this work is assumed as consumed system power during simulation. The simulation time in MATLAB is obtained by tic, toc function, which is multiplied with the total power rating of the system. The simulation results show the reduced power consumption of our proposed technique.

5. Conclusion

In this paper, the power consumption of eNBs is reduced using proposed RS deployment and BS sleep mode scheme. Initially, the numbers of RSs are deployed within the coverage of total cell area. The blocking probability of each BS is estimated based on the number of users. The estimated probability is compared with the network traffic threshold for enabling sleep mode for BS. It is accomplished by intra cell hand-off of active calls to the corresponding RSs. The network traffic in the RS is also measured with number of mobile station associated to each RSs and sleep mode is activated for the RS if there is no MU associated to it. We also proposed a human behaviour model mobility prediction to switch modes of RSs. The performance of our propose work is evaluated considering power consumption, energy efficiency and deployment cost as parameters. The performance results show that the RS deployment and sleep mode activation scheme and the proposed algorithm of BS sleep mode reduced the total power consumption of eNBs in 4G LTE-A network. Our future work focuses on spectrum utilization and call switching in addition with our proposed work.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

- [1] Wang C-X, Haider F, Gao X, et al. Cellular architecture and key technologies for 5G wireless communication networks. *IEEE Commun Mag.* 2014;52(2):122–130.
- [2] Gong J, Thompson JS, Zhou S, et al. Base station sleeping and resource allocation in renewable energy powered cellular networks. *IEEE Trans Commun.* 2014;62(11):3801–3813.
- [3] Sambo Y, Shakir M, Qaraqe K, et al. Expanding cellular coverage via cell-edge deployment in heterogeneous networks: spectral efficiency and backhaul power consumption perspectives. *IEEE Commun Mag.* 2014;52(6):140–149.
- [4] Sawy E, Hesham E, Alouini M-S. Analytical modeling of mode selection and power control for underlay D2D communication in cellular networks. *IEEE Trans Commun.* 2014;62(11):4147–4161.
- [5] Han T, Ansari N. ICE: Intelligent cell breathing to optimize the utilization of green energy. *IEEE Commun Lett.* 2012;16(6):866–869.
- [6] Bu S, Yu F, Cai R, et al. When the smart grid meets energy-efficient communications: green wireless cellular networks powered by the smart grid. *IEEE Trans Wireless Commun.* 2012;11(8):3014–3024.
- [7] Cho S-r, Choi W. Energy-efficient repulsive cell activation for heterogeneous cellular networks. *IEEE J Sel Areas Commun.* 2013;31(5):870–882.
- [8] Mclaughlin, Steve, Grant, P.M., Thompson, J.S., Haas, H., Laurenson, D.I., Chadi Khirallah, Hou, Y Wang, Rui. (2011). Techniques for improving cellular radio base station energy efficiency. *IEEE Wirel Commun.* 18(5):10–17.
- [9] 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):803–826.
- [10] Peng J, Hong P, Xue K. Stochastic analysis of optimal base station energy saving in cellular networks with sleep mode. *IEEE Commun Lett.* 2014;18(4):612–615.
- [11] Lee S, Huang K. Coverage and economy of cellular networks with many base stations. *IEEE Commun Lett.* 2012;16(7):1038–1040.
- [12] Holtkamp H, Auer G, Bazzi S, et al. Minimizing base station power consumption. *IEEE J Sel Areas Commun.* 2014;32(2):297–306.
- [13] Oh E, Son K, Krishnamachari B. Dynamic base station switching-on/off strategies for green cellular networks. *IEEE Trans Wireless Commun.* 2013;12(5):2126–2136.
- [14] Han T, Ansari N. On optimizing green energy utilization for cellular networks with hybrid energy supplies. *IEEE Trans Wireless Commun.* 2013;12(8):3872–3882.
- [15] Wang Z, Zhang W. A separation architecture for achieving energy-efficient cellular networking. *IEEE Trans Wireless Commun.* 2014;13(6):3113–3123.
- [16] Xiang L, Ge X, Wang C-X, et al. Energy efficiency evaluation of cellular networks based on spatial distributions of network traffic load and power consumption. *IEEE Trans Wireless Commun.* 2013;12(3):961–973.
- [17] Zhang X, Yu R, Zhang Y, et al. Energy-efficient multimedia transmissions through base station cooperation over heterogeneous cellular networks exploiting user behavior. *IEEE Wirel Commun.* 2014;21(4):54–61.
- [18] Ho, Keong, C., Yuan, D., Lei, L and Sun, S. (2015). Power and load coupling in cellular networks for energy optimization.” *IEEE Trans Wireless Commun* 14, no. 1 509-519.
- [19] Chen X, Wu J, Cai Y, et al. Energy-efficiency oriented network traffic offloading in wireless networks: a brief survey and a learning approach for heterogeneous cellular networks. *IEEE J Sel Areas Commun.* 2015;33(4):627–640.
- [20] Niu Z, Guo X, Zhou S, et al. Characterizing energy–delay tradeoff in hyper-cellular networks with base station sleeping control. *IEEE J Sel Areas Commun.* 2015;33(4):641–650.
- [21] Wang B, Kong Q, Liu W, et al. On efficient utilization of green energy in heterogeneous cellular networks. *IEEE Syst J.* 2017;11(2):846–857.
- [22] Farooq MJ, Ghazzai H, Kadri A, et al. A hybrid energy sharing framework for green cellular networks. *IEEE Trans Commun.* 2017;65(2):918–934.
- [23] Huang P-H, Sun S-S, Liao W. Green CoMP: energy-aware cooperation for green cellular networks. *IEEE Trans Mob Comput.* 2017;16(1):143–157.
- [24] Zhang H, Huang S, Jiang C, et al. Energy efficient user association and power allocation in millimeter-wave-based ultra dense networks with energy harvesting base stations. *IEEE J Sel Areas Commun.* 2017;35(9):1936–1947.
- [25] Niu, Y., Gao, C., Li, Y., Su, L., Jin, Zhu, Y and Wu, D.O. (2017). Energy-efficient scheduling for mmWave backhauling of small cells in heterogeneous cellular networks. *IEEE Trans Veh Technol.* 66(3), 2674-2687.
- [26] Wang W, Shen G. (2010). Energy efficiency of heterogeneous cellular network. In *Vehicular Technology Conference Fall (VTC 2010-Fall)*, IEEE 72nd, IEEE. 1–5.

- [27] Arthi M, Arulmozhiarman P. Power-aware fuzzy based joint base station and relay station deployment scheme for green radio communication. *Sustain Comput Inform Syst.* 2017;13:1–14.
- [28] Zhang Q, Chen H, Zhao F. Energy-efficient joint BS-RS sleep scheduling based on cellular automata in relay-aided cellular networks. In *International Conference on Wireless Communications & Signal Processing (WCSP'15)*, 2015, IEEE, 1–6.
- [29] Mahapatra R, Nijsure Y, Kaddoum G, et al. Energy efficiency tradeoff mechanism towards wireless green communication: a survey. *IEEE Commun Surv Tutor.* 2016;18(1):686–705.