BS Switching for Green Cellular Networks Using Energy-Aware Dynamic Traffic Offloading Schemes

[1]Md. Farhad Hossain, [2]Kumudu S. Munasinghe and [3]Abbas Jamalipour
[1]Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology,
Dhaka, Bangladesh, [2]Faculty of Education, Science, Technology and Maths, University of Canberra, ACT 2617,
Australia, [3]School of Electrical and Information Engineering, University of Sydney, NSW 2006, Australia
Email: [1]mfarhadhossain@eee.buet.ac.bd, [2]kumudu.munasinghe@canberra.edu.au, [3]a.jamalipour@ieee.org

***Abstract*—Conventional planning and optimization of cellular networks for supporting the peak-time user demand leads to substantial wastage of electrical energy. Therefore, we propose an energy-aware dynamic network provisioning framework for realizing green mobile cellular systems by reducing energy consumption in access networks. Proposed mechanism allows base stations (BSs) to offload their entire traffic to the neighbors and thus allows some BSs to switch into sleep mode for saving energy. Four different traffic offloading schemes for redistributing users among the neighboring BSs are proposed and investigated. Flexible resource allocation is integrated in the system for maintaining quality of service (QoS) throughout the network. Furthermore, for avoiding the high complexity of the formulated generalized energy optimization problem, a heuristically guided algorithmic framework is developed. System performance is evaluated using extensive simulations demonstrating a substantial energy savings. Impact of the proposed network provisioning framework on the bandwidth utilization is also analyzed.**

***Index Terms*—Green cellular network; dynamic network provisioning; traffic offloading; BS switching; user association**

I. INTRODUCTION

Due to recent unprecedented rise in demand for data applications, cellular mobile networks have been experiencing an exponential increase in energy consumption [1], [2]. In a cellular system, BSs of its radio access network (RAN) are the major energy hungry equipment claiming 60-80% of the total consumption [2], [3], while the accumulated energy usage in user equipment (UE) is around 1% [4]. Consequently, designing cellular network architectures and protocols for reducing energy consumption in RANs, mainly in BSs, has drawn considerable attention of many researchers. On the other hand, tempo-spatial traffic diversity is natural in cellular networks [4], [5]. A typical traffic profile in a BS normalized to its capacity is shown in Fig. 1. Despite substantial diversity, cellular networks are provisioned based on the peak-traffic time leading to a significant wastage of electrical energy, especially during off-peak periods. Consequently, during the recent years, various proposals for minimizing energy consumption by switching off BSs have emerged [2], [4], [6]–[11].

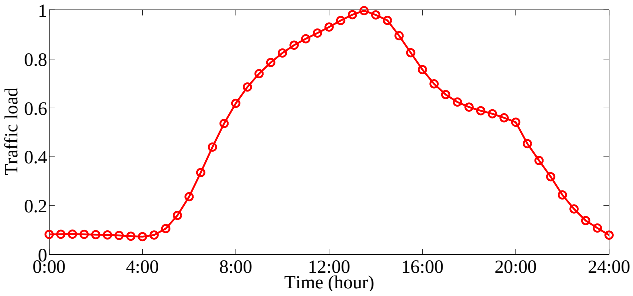

Fig. 1: Typical traffic profile in a BS of cellular networks.

Authors in [6] proposed an energy saving cellular access network by employing distributed cooperation among BSs. On the other hand, authors in [7] employed mutual cooperation among BSs for manually switching BSs. However, the schemes in [7] are applicable only for regular cell layouts. While, [8] proposed algorithms for dynamically shutting down BSs, but provided no mechanism for dynamically switching them back ON. The schemes in [7] and [8] also failed to capture the load-dependent power utilization in BSs. On the other hand, a grid-based traffic profiling scheme for selecting the best BSs to turn off in 3G systems was proposed in [4]. An actor-critic based learning framework for switching BSs into sleep mode was proposed in [9]. Besides, trade-off between energy savings from BS switching and delay for predefined deterministic traffic patterns was analyzed by formulating cost minimization problems [10]. Furthermore, a distributed BS switching framework using a game theory based cooperation technique was presented in [11]. However, the systems in [9]–[11] do not guarantee user data rates leading to the potential degradation of service quality for the users in sleep mode BSs. Moreover, none of these papers considered the diversity in energy efficiency (EE) of BSs, a very common phenomena in real networks, for associating offloaded traffic.

This paper proposes a network provisioning technique for dynamically reorganizing cellular RANs for saving energy. In the proposed system, based on the instantaneous traffic, a set of BSs are periodically chosen to switch into low power sleep mode by offloading their entire traffic to the neighbors leading to reduced energy consumption in the network. Based on the the achievable signal quality at UEs and the EE profile of BSs, we propose four different schemes for choosing BSs for offloading traffic. For supporting the guaranteed UE data rates, we integrate flexible resource block (RB) allocation in the system. Other quality of service (QoS) parameters, namely call blocking, outage due to signal quality and network coverage is maintained. We also formulate a generalized energy saving optimization problem. For avoiding the high computational complexity and for the ease of practical implementation, a heuristically guided algorithmic framework is proposed. Extensive simulations are carried out for thoroughly investigating the system performance under various traffic levels, user association policies and BS power models. Evaluation is carried out in terms of percentage of sleep mode BSs, net energy savings and bandwidth utilization.

Organization of the paper: Section II describes the network model. Proposed energy saving framework and the algorithms are presented in Section III. Simulation results with a thorough analysis is provided in Section IV. The paper finally concludes in Section V by summarizing our key findings.

II. NETWORK MODEL

Network model is presented in the context of orthogonal frequency division multiple access (OFDMA) based long term evolution (LTE) networks.

A. Network Layout

We consider the downlink of a cellular network having a set of BSs $\mathcal{B} = \{\mathcal{B}_1, \mathcal{B}_2, ..., \mathcal{B}_{|\mathcal{B}|}\}$ and covering an area $\mathcal{A} = \mathcal{A}_1 \cup \mathcal{A}_2 \cup .... \cup \mathcal{A}_{|\mathcal{B}|} \subset \mathbb{R}^2$, where $\mathcal{A}_i$ is the coverage area of BS $\mathcal{B}_i$. Let $\mathcal{S}_i$ be the number of sectors in BS $\mathcal{B}_i$. Orthogonal frequency bands are assumed for all $\mathcal{S}_i$ sectors in a BS $\mathcal{B}_i, \forall i$.

B. Power Consumption Profile of BSs

Let BS $\mathcal{B}_i$ has total N_T transceiver (TRX) chains. Now, assuming equal maximum operating power P_i^m, equal sleep mode power p_i^s and equal power-load proportionality constant (PLPC) δ_i for all of these N_T chains of $\mathcal{B}_i$, total instantaneous operating power of $\mathcal{B}_i$ can be written as below [9], [10]

$$p_i(t) = \begin{cases} \sum_{j=1}^{N_T} \left[(1-\delta_i) L_i^{(j)}(t) P_i^m + \delta_i P_i^m \right] & \text{(active)} \\ \sum_{j=1}^{N_T} p_i^s & \text{(sleep)} \end{cases} \tag{1}$$

Here $0 \leq L_i^{(j)}(t) \leq 1$ is the load factor (LF) of j^{th} TRX chain, while LF of BS $\mathcal{B}_i$ can be written as $L_i(t) = \frac{1}{N_T} \sum_{j=1}^{N_T} L_i^{(j)}$. The maximum power consumption in a TRX is given by $P_i^m = g_i P_{i,Tx} + h_i$, where, $P_{i,Tx}$ is the maximum transmit power of the chain, and g_i and h_i are constants [10]. PLPC parameter $0 \leq \delta_i \leq 1$ determines the level of dependency of BS power consumption on LF. Thus, based on the value of δ_i, we can model various power profile, i.e., EE of BSs.

C. Link Model

This paper adopts the WINNER+ non line of sight (NLOS) urban macro-cell path-loss model [12]. Thus the path-loss P_L at a distance d in dB is given by

$$\begin{aligned} P_L = {} & (44.9 - 6.55 \log_{10} h_{BS}) \log(d) \\ & + 5.83 \log_{10} h_{BS} + 14.78 + 34.97 \log_{10} f_c \end{aligned} \tag{2}$$

where d is the BS-UE separation in meter, f_c is the carrier frequency in GHz and h_{BS} is the height of the BS in meter. We also consider shadow fading in the channel and modeled as log-normally distributed random variable with a mean zero and standard deviation equal to σ dB.

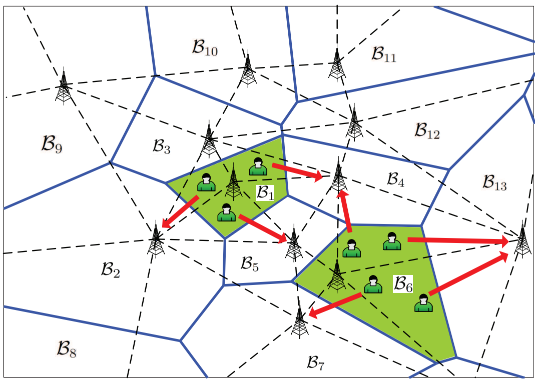

Fig. 2: A simple presentation of the proposed system model.

D. Resource Block Allocation

Received signal-to-interference-plus-noise-ratio (SINR) $\gamma_u^{i,s}$ at u^{th} UE located in sector s of BS $\mathcal{B}_i$ can be written as

$$\gamma_u^{i,s} = \frac{P_{u,Rx}^{i,s}}{\mathcal{I}_{u,int}^{i,s} + \mathcal{I}_{u,ext}^{i,s} + \mathcal{P}_N} \tag{3}$$

where $P_{u,Rx}^{i,s}$ is the received power, $\mathcal{I}_{u,int}^{i,s}$ is the intra-cell interference, $\mathcal{I}_{u,ext}^{i,s}$ is the inter-cell interference and $\mathcal{P}_N$ is the thermal noise power. In a OFDMA-based BS, zero intra-cell interfrence occurs resulting from the use of orthogonal frequency bands. We also consider adaptive modulation and coding (AMC) scheme. Then $\gamma_u^{i,s}$ can be mapped to the spectral efficiency (SE) given in bps/Hz [13] as below

$$\psi_u^{i,s} = \begin{cases} 0 & \textit{if } \gamma_u^{i,s} < \gamma_{min} \\ \xi \log_2(1 + \gamma_u^{i,s}) & \textit{if } \gamma_{min} \leq \gamma_u^{i,s} < \gamma_{max} \\ \psi_{max} & \textit{if } \gamma_u^{i,s} \geq \gamma_{max} \end{cases} \tag{4}$$

where $0 \leq \xi \leq 1$, γ_{min}, ψ_{max} and γ_{max} are the attenuation factor, minimum SINR, maximum SE and the SINR at which ψ_{max} is achieved. Then, the number of required RBs for the UE can be estimated by

$$\beta_u^{i,s} = \left\lceil \frac{R_u^{i,s}}{W_{RB} \psi_u^{i,s}} \right\rceil \tag{5}$$

where $R_u^{i,s}$ is the required data rate, W_{RB} is the bandwidth per RB. $\lceil x \rceil$ performs the ceiling operation on x.

III. PROPOSED ENERGY-AWARE DYNAMIC NETWORK PROVISIONING

Despite the high degree tempo-spatial diversity in traffic generation, cellular networks are provisioned based on the peak-traffic and all RAN equipment is left into active mode for all time leading to significant wastage of energy. This paper proposes adaptive traffic offloading schemes for switching some of the BSs into sleep mode and thus improves the EE of cellular access networks. The basic concept of the network operation is illustrated in Fig. 2. For instance, BS $\mathcal{B}_1$ is switching into sleep mode for saving energy by offloading (as shown by the arrows) its entire traffic to BS $\mathcal{B}_2$, $\mathcal{B}_4$ and $\mathcal{B}_5$. At the same time, BS $\mathcal{B}_6$ distribute its entire traffic to BS $\mathcal{B}_4$, $\mathcal{B}_7$ and $\mathcal{B}_{13}$, and switches into sleep mode. Proposed traffic offloading from one BS to others is governed by the EE of individual BSs, UE association policies, traffic of BSs, QoS requirements and other design parameters.

A. Optimization Problem Formulation

The goal of the proposed traffic offloading schemes is to minimize network energy consumption by keeping an optimum set of BSs $\mathcal{B}_{ON} = \{\mathcal{B}_1^*, \mathcal{B}_2^*, ..., \mathcal{B}^*_{|\mathcal{B}_{ON}|}\} \subseteq \mathcal{B}$ in active mode and switching $\{\mathcal{B} \setminus \mathcal{B}_{ON}\}$ BSs into sleep mode. QoS is also guaranteed by the active BSs. Thus the optimization problem can be presented as below

$$\underset{\{\mathcal{B}_1^*,\mathcal{B}_2^*,...,\mathcal{B}^*_{|\mathcal{B}_{ON}|}\}}{\arg\min} \sum_{i\in\mathcal{B}_{ON}} \sum_{s=1}^{\mathcal{S}_i} \left[(1-\delta_i)\, L_f^{i,s}(t) P_i^m + \delta_i P_i^m\right] \tag{6}$$

$$s.t., \quad P_{i,b}(t) \le P_b^{th}, \quad P_{i,out}(t) \le P_{out}^{th}, \forall i \in \mathcal{B}_{ON}, \forall t \tag{7}$$

$$R_u^{(a)}(t) \ge R_u^{i,s}, u = 1, 2, ..., \sum_{i\in\mathcal{B}_{ON}} \sum_{s=1}^{\mathcal{S}_i} U_{i,s}(t), \forall t \tag{8}$$

$$\bigcup_{i\in\mathcal{B}_{ON}} \mathcal{A}_i(t) = \mathcal{A}, \forall t \tag{9}$$

$$\sum_{s=1}^{\mathcal{S}_i} \sum_{u=1}^{U_s(l_i,t)} \beta_u^{i,s}(t) \le \sum_{s=1}^{\mathcal{S}_i} \beta_{Tot}^{i,s}, \forall i \in \mathcal{B}_{ON}, \forall t \tag{10}$$

$$\sum_{s=1}^{\mathcal{S}_i} \sum_{u=1}^{U_s(l_i,t)} P_{u,tx}^{i,s}(t) \le \sum_{s=1}^{\mathcal{S}_i} P_{i,Tx}, \forall i \in \mathcal{B}_{ON}, \forall t \tag{11}$$

where $L_f^{i,s}$ is the LF, $P_{i,b}$ is the session blocking, P_b^{th} is the target session blocking, $P_{i,out}$ is the session outage, P_{out}^{th} is the target session outage, $R_u^{(a)}$ is the achievable data rate, $U_{i,s}$ is the total number of UEs, $\beta_{Tot}^{i,s}$ is the total number of RBs and $P_{u,tx}^{i,s}$ is the transmit power. The subscripts and the superscripts i, s and u used in the symbols represent the i^{th} BS, s^{th} sector and u^{th} UE respectively. QoS parameters session blocking, session outage, UE data rate and network coverage are guaranteed by (7), (8) and (9). Also, (10) and (11) correspond to the limitations of available RBs and transmit power in each BS respectively.

B. Proposed Algorithm

For given sets $\mathcal{B}_{ON}$, the objective function in (6) is convex in $L_f^{i,s}, \forall i, \forall s$. However, for variable $\mathcal{B}_{ON}$, it turns to be non-convex becoming a highly challenging combinatorial problem with a large search space $\mathcal{O}(2^{|\mathcal{B}_{ON}|})$. Therefore, this paper proposes a centralized heuristic algorithm for periodically finding out a set of BSs for switching into sleep mode.

1) BS Switching Policy: Proposed algorithm starts with the initialization $\mathcal{B}_{ON} = \mathcal{B}$ and sorts the BSs according to a preset policy. It then takes one BS at a time (say, $\mathcal{B}_i$) and then using one of the policies explained below in Section III-B2, all UEs of $\mathcal{B}_i$ is distributed by associating them with the neighboring BSs. Following utility function is then evaluated

$$U_i(t) = \sum_{l=1}^{\mathcal{L}} \hat{P}_l^*(t) \Big/ \left\{ \hat{P}_i(t) + \sum_{l=1}^{\mathcal{L}} \hat{P}_l(t) \right\} \tag{12}$$

where $\mathcal{L}$ is the number of BSs to which UEs of $\mathcal{B}_i$ are to be associated, and $\hat{P}_l(t)$ and $\hat{P}_l^*(t)$ are the total operating power of l^{th} neighbors before and after this association respectively. If utility $U_i(t) < 1$ and (7)-(11) are met, then $\mathcal{B}_{ON} = \mathcal{B}_{ON} \setminus \{\mathcal{B}_i\}$. $U_i(t) < 1$ implies that energy savings can be achieved by switching $\mathcal{B}_i$ into sleep mode. The algorithm continues with the next BS, updates $\mathcal{B}_{ON}$ and so on. After finishing with all BSs, final $\mathcal{B}_{ON}$ provides the list of BSs which are left active and the BSs in $\mathcal{B} \setminus \mathcal{B}_{ON}$ are switched into sleep mode.

2) UE Association Policy: Let $\mathbf{B}_{i,n} = \{\mathcal{B}_{i,1}^n, \mathcal{B}_{i,2}^n, ..., \mathcal{B}_{i,N_{i,b}}^n\}$ be the sequence of neighboring active BSs of $\mathcal{B}_i$ according to which the neighbors are approached for associating a UE located in $\mathcal{B}_i$. Here $N_{i,b}$ is the number of active neighbors of $\mathcal{B}_i$. In addition to the conventional SINR-based strategies, various new neighbor sequencing strategies are outlined here below. On the other hand, for selecting the sequence of BSs, $\mathbf{B}_{seq} = \{\mathcal{B}_1^*, \mathcal{B}_2^*, ..., \mathcal{B}_{|\mathcal{B}|}^*\}$ in which the algorithm proceeds from one BS to another for distributing their UEs, various alternative are considered. Thus, for accounting the level of received SINR at UEs and the possibility of the network having BSs with different EE, following four traffic offloading schemes are proposed.

a) Lower-to-Higher (LH): In this case, BSs of lower EE have the higher priority to distribute first. While, higher efficient neighbors are given the higher priority for accepting offloaded UEs. That means, $\mathbf{B}_{seq} = \{\mathcal{B}_1^*, \mathcal{B}_2^*, ..., \mathcal{B}_{|\mathcal{B}|}^*\}$, $\delta_l^* \ge \delta_m^*, l < m$, and $\mathbf{B}_{i,n} = \{\mathcal{B}_{i,1}^n, \mathcal{B}_{i,2}^n, ..., \mathcal{B}_{i,N_{i,b}}^n\}$, $\delta_{i,p}^n \le \delta_{i,q}^n, p < q$. Here, δ_l^* and $\delta_{i,p}^n$ are the PLPC of $\mathcal{B}_l^*$ and $\mathcal{B}_{i,p}^n$ respectively.

b) Higher-to-Lower (HL): For this scheme, $\mathbf{B}_{seq} = \{\mathcal{B}_1^*, \mathcal{B}_2^*, ..., \mathcal{B}_{|\mathcal{B}|}^*\}$, $\delta_l^* \le \delta_m^*, l < m$, and $\mathbf{B}_{i,n} = \{\mathcal{B}_{i,1}^n, \mathcal{B}_{i,2}^n, ..., \mathcal{B}_{i,N_{i,b}}^n\}$, $\delta_{i,p}^n \ge \delta_{i,q}^n, p < q$.

c) Sequential-Sequential (SS): Under this scheme, no reordering of BSs is done. The algorithm proceeds sequentially from one BS to another according to a predefined order. Thus, $\mathbf{B}_{seq} = \{\mathcal{B}_1, \mathcal{B}_2, ..., \mathcal{B}_{|\mathcal{B}|}\}$, $\mathcal{B}_l > \mathcal{B}_m, l > m$ and $\mathbf{B}_{i,n} = \{\mathcal{B}_{i,1}^n, \mathcal{B}_{i,2}^n, ..., \mathcal{B}_{i,N_{i,b}}^n\}$, $\mathcal{B}_{i,p}^n > \mathcal{B}_{i,q}^n, p > q$.

d) Sequential-to-Better-Signal (SBS): Here, $\mathbf{B}_{seq}$ is same as in the *SS* scheme. However, $\mathcal{B}_{i,n}$ is the set of neighbors sequenced according to the descending order of received SINR, i.e., $\mathbf{B}_{i,n} = \{\mathcal{B}_{i,1}^n, \mathcal{B}_{i,2}^n, ..., \mathcal{B}_{i,N_{i,b}}^n\}$, $SINR_{i,p}^n \ge SINR_{i,q}^n, p < q$. Here, $SINR_{i,p}^n$ is the received SINR at the UE from neighbor BS $\mathcal{B}_{i,p}^n$.

An example of the order of neighboring BSs at which they are approached for associating a UE of BS $\mathcal{B}_1$ is demonstrated in Table I. Pseudo code of the algorithm for *LH* scheme is presented in Table II, which can similarly be written for others. Proposed algorithm has a computational complexity $\mathcal{O}(N_B N_U)$ in place of $\mathcal{O}(N_U 2^{N_B})$ of exhaustive search, while signaling overhead is $(N_U + 2N_B)$. Here, N_B and N_U are the number of BSs and UEs of the network respectively.

TABLE I: Neighbor sequence for associating a UE of $\mathcal{B}_1$

Neighboring BS ID	$\mathcal{B}_2$	$\mathcal{B}_3$	$\mathcal{B}_4$	$\mathcal{B}_5$
δ_i	0.2	0.8	0.5	0.4
SINR (dB)	8	4	10	12
LH	I	IV	III	II
HL	IV	I	II	III
SS	I	II	III	IV
SBS	III	IV	II	I

TABLE II: Pseudo code of the algorithm for *LH* scheme

```
1:  Initialize: $\mathcal{B}_{ON} = \mathcal{B}, T, L_i(t) \forall i$, SINR data of UEs
2:  Determine $\mathbf{B}_{seq} = \{\mathcal{B}_1^*, \mathcal{B}_2^*, ..., \mathcal{B}_{|\mathcal{B}|}^*\}$,
        s.t., $\delta_l^* \geq \delta_m^*, l < m$
3:  for $i = 1 : |\mathcal{B}|$
4:      Determine $\mathbf{B}_{i,n} = \{\mathcal{B}_{i,1}^n, \mathcal{B}_{i,2}^n, ..., \mathcal{B}_{i,N_{i,b}}^n\}$,
            s.t., $\delta_{i,p}^n \leq \delta_{i,q}^n, p < q$
5:      Associate all UEs of $\mathcal{B}_i^*$ with BSs in $\mathbf{B}_{i,n}$
6:      Calculate $U_i(t)$ for $\mathcal{B}_i^*$ using (12)
7:          If (7)-(11) are met and $U_i(t) < 1$
8:          Set $\mathcal{B}_{ON} = \mathcal{B}_{ON} \setminus \{\mathcal{B}_i^*\}$ and $i = i + 1$
9:          Else Set $i = i + 1$, End If
10:             If $i \leq |\mathcal{B}|$, Go to Step 4
11:             Else Stop the algorithm, End If
12: End for
```

IV. SIMULATIONS, RESULTS AND ANALYSIS

A. Simulation Setup

We evaluate the proposed energy saving framework through extensive simulations. Simulated network is served by 64 BSs deployed using hexagonal layout with an inter-site distance of $\sqrt{3} \times 500$m and uniformly distributed UEs. Carrier frequency = 2GHz, channel bandwidth per sector = 5MHz (i.e., 25 RBs), number of sector per BS = 6, BS transmit power per sector = 40dBm, BS antenna gain = 18 dBi, attenuation due to non-uniform radiation pattern = 3 dB, $h_{BS} = 25$m, $h_{UE} = 1.5$m and shadow fading parameter $\sigma = 8$dB are used. AMC code set parameters $\xi = 0.75$, γ_{min} = -6.5dB, γ_{max} = 19dB and ψ_{max} = 4.8bps/Hz are chosen [13].

Without losing the generality, we assume that all subscribers are of real-time constant bit rate type requring a data rate equal to 512 kbps. New sessions arrive following a Poisson process with parameter λ and a constant session duration of 3 minutes. Variable number of RBs, calculated using (4)-(5), is allocated to the sessions for maintaining data rates, which remains dedicated for the session duration. Unless otherwise specified, $P_b^{th} = 1\%, P_{out}^{th} = 1\%$, $\delta_i = 0.7$, $\mathcal{S}_i = 6$, $p_i^s = 0$, $\{g_i = 21.45, h_i = 354.44\}$ [6], $\forall i \in (1, 2, ..., |\mathcal{B}|)$ are used.

B. Results and Analysis

Percentage of sleep mode BSs with the session arrival rate is illustrated in Fig. 3. For all the schemes, values of δ_i for BSs are drawn from a uniform distribution $U[0.4, 1.0]$ for modeling the existence of BSs with different EE. An additional case of the *SS* scheme with $\delta_i = 0.7, \forall i$ (i.e., all BSs are of equal EE) is also included in the figure. As expected, with the increase of session arrival, number of sleep mode BSs decreases. For this particular parameter settings, a higher number of BSs switch into sleep mode under the *SS* scheme compared to that in both *LH* and *HL* schemes. However, nearly equal number of BSs sleeps under *LH* and *HL* schemes. Whereas, since the average of $U[0.4, 1.0]$ is 0.7, for the two cases of *SS* scheme with $\delta_i \sim U[0.4, 1.0]$ and $\delta_i = 0.7$, almost equal number of BSs switch to sleep mode. On the other hand, though *SBS* scheme allows a lower number of BSs to sleep in the lower traffic scenario, it outperforms the others in the higher traffic case. Since *SBS* scheme associates UEs to BSs offering higher SINR, UEs require less number of RBs. Consequently, compared to the other cases, active BSs are lightly loaded allowing more BSs to switch into sleep mode.

Figure 4 presents the energy savings under the proposed schemes. As seen, although equal number of BSs sleep in *LH* and *HL* schemes, energy savings is much higher in *LH* scheme. This is because, unlike *HL* scheme, *LH* scheme prioritizes BSs of lower EE to switch to sleep mode by distributing their traffic to BSs of higher EE. Thus the network leaves BSs in active mode having relatively higher EE leading to higher savings. Furthermore, for the same reasons explained in Fig. 3, *SBS* scheme outperforms the others in terms of energy savings in the higher traffic region.

On the other hand, daily energy savings under the proposed schemes in a cellular network having traffic profile shown in

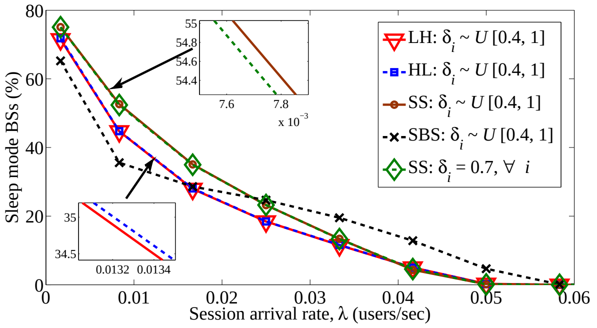

Fig. 3: Sleep mode BSs under the proposed schemes.

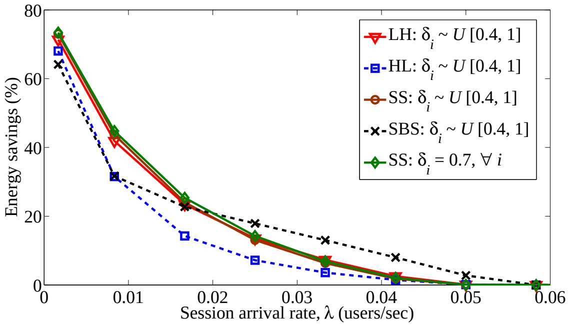

Fig. 4: Energy savings under the proposed schemes.

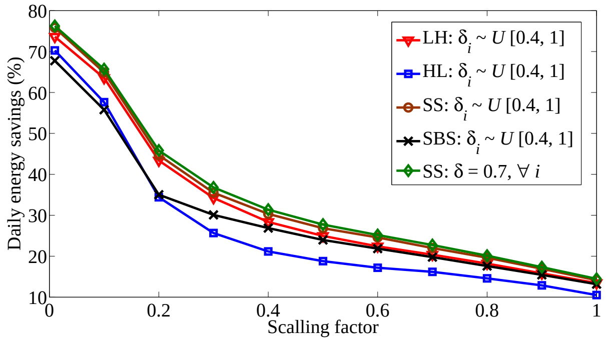

Fig. 5: Daily energy savings under the proposed schemes.

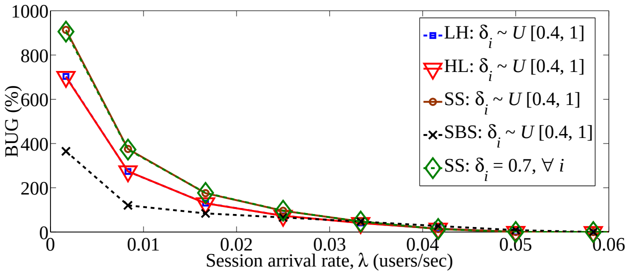

Fig. 6: Bandwidth utilization gain by the proposed schemes.

Fig. 1 is presented in Fig. 5. The parameter in the x-axis represents the scaling factor by which the traffic profile is shaped for simulating various level of loading of BSs. For instance, scaling factor 0.5 implies that the the traffic load over the entire 24 hours is multiplied by 0.5 and thus the peak-time traffic load of the BSs is 0.5. As expected, with the increase of the scaling factor, as the traffic load increases, daily savings decreases. The highest daily savings is achieved by *SS* scheme which is as high as 75%. While, the lowest daily savings is achieved by *SBS* and *HL* schemes for lower and higher loading scenarios respectively, which is also supported by Fig. 4. However, the gap between the savings from *SS* and *SBS* schemes diminishes with the increase of scaling factor as *SBS* scheme becomes better energy efficient with the increase of traffic load as also seen in Fig. 4.

Figure 6 demonstrates the bandwidth utilization gain (BUG) of a network under the proposed schemes compared to that of the conventional cellular network with no BS switching. BUG is calculated using $(LF_p/LF_c - 1) \times 100\%$, where LF_p and LF_c are the average LF of the active BSs in the proposed network and the conventional network respectively. For smaller λ, many BSs are switched into sleep mode and their UEs are associated with the other active BSs. This results in higher number of RBs in use in the active BSs resulting in higher bandwidth utilization. With the increase of λ, fewer number of BSs switch into sleep mode leaving higher number of BSs in active mode. This leads to higher number of under utilized BSs resulting in lower values of BUG implying inefficient use of bandwidth.

V. CONCLUSION

This paper have proposed a framework for improving EE of cellular RANs by employing energy-aware traffic offloading. Four different schemes for offloading traffic of BSs to their neighbors have been outlined. Using the proposed schemes, access networks have been dynamically provisioned by switching some of the BSs into sleep mode for saving energy, while QoS is maintained. The schemes have been developed by considering SINR at UEs and the power profile of BSs. For reducing computational complexity, a heuristically guided algorithmic framework has been proposed. System performance has been evaluated thorough extensive simulations demonstrating the impact of traffic offloading schemes, BS power profiles and traffic levels. Among all the four schemes, the lowest energy savings has been achieved by *HL* scheme, which offload traffic from higher energy efficient BSs to those of lower EE. On the other hand, *SBS* scheme that offloads traffic to BSs offering better SINR has been found as more energy efficient for heavily loaded conditions, whereas the better options for lower traffic scenarios are *LH* and *SS*.

REFERENCES

[1] R. Mahapatra, Y. Nijsure, G. Kaddoum, N. Ul Hassan and C. Yuen, "Energy Efficiency Tradeoff Mechanism Towards Wireless Green Communication: A Survey," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 1, pp. 686-705, First quarter 2016.

[2] M. Ismail, W. Zhuang, E. Serpedin and K. Qaraqe, "A Survey on Green Mobile Networking: From the Perspectives of Network Operators and Mobile Users," *IEEE Communications Surveys and Tutorials*, vol. 17, no. 3, pp. 1535-1556, Third quarter 2015.

[3] M. F. Hossain, "Traffic-Driven Energy Efficient Operational Mechanisms in Cellular Access Networks," *PhD Thesis*, The Univ. of Sydney, 2014.

[4] C. Peng, S. Lee, S. Lu, H. Luo and H. Li, "Traffic-Driven Power Saving in Operational 3G Cellular Networks," *Proc. Int. Conf. on Mobile Computing and Networking (MobiCom)*, Nevada, USA, pp. 121-132, Sep 2011.

[5] U. Paul, A. P. Subramanian, M. M. Buddhikot and S. R. Das, "Understanding Traffic Dynamics in Cellular Data Networks," *Proc. IEEE Int. Conf. on Computer Comm. (INFOCOM)*, pp. 882-890, China, Apr 2011.

[6] M. F. Hossain, K. S. Munasinghe and A. Jamalipour, "Distributed Inter-BS Cooperation Aided Energy Efficient Load Balancing for Cellular Networks," *IEEE Transactions on Wireless Communications*, vol. 12, no. 11, pp. 5929-5939, Nov 2013.

[7] M. A. Marsan, L. Chiaraviglio, D. Ciullo and M. Meo, "Optimal Energy Savings in Cellular Access Networks," *Proc. Workshop on Green Comm. in conjunction with IEEE ICC*, Dresden, Germany, pp. 1-5, Jun 2009.

[8] E. Oh and B. Krishnamachari, "Energy Savings Through Dynamic Base Station Switching in Cellular Wireless Access Networks," *Proc. IEEE Global Communications Conf. (GLOBECOM)*, pp. 1-5, Dec. 2010.

[9] R. Li, Z. Zhao, X. Chen and H. Zhang, "Energy Saving through a Learning Framework in Greener Cellular Radio Access Networks," *Proc. IEEE Global Communications Conference (GLOBECOM)*, pp. 1574-1579, Anaheim, USA, 2012.

[10] S. Kyuho, K. Hongseok, Y. Yung and B. Krishnamachari, "Base Station Operation and User Association Mechanisms for Energy-Delay Tradeoffs in Green Cellular Networks," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 8, pp. 1525-1536, Sep 2011.

[11] J. Zheng, Y. Cai, X. Chen, R. Li and H. Zhang, "Optimal Base Station Sleeping in Green Cellular Networks: A Distributed Cooperative Framework Based on Game Theory," *IEEE Transactions on Wireless Communications*, vol. 14, no. 8, pp. 4391-4406, Aug 2015.

[12] Wireless World Initiative New Radio WINNER+, "D5.3: WINNER+ Final Channel Models," Jun 2010.

[13] 3GPP TR 36.942, Rel. 11, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios," *Technical Report*, Sep 2012.