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Self-Adaptive Scheduling of Base Transceiver Stations in Green 5G Networks

UZZAL KUMAR DUTTA[1], MD ABDUR RAZZAQUE[1], (Senior Member, IEEE), M. ABDULLAH AL-WADUD[2], (Member, IEEE), MD SAIFUL ISLAM[3], (Member, IEEE), M. SHAMIM HOSSAIN[2], (Senior Member, IEEE), AND B. B. GUPTA[4], (Senior Member, IEEE)
[1]Green Networking Research Group, Department of Computer Science and Engineering, University of Dhaka, Dhaka 1000, Bangladesh
[2]Department of Software Engineering, College of Computer and Information Sciences, King Saud University, Riyadh 11543, Saudi Arabia
[3]Department of Computer Science, College of Computer and Information Sciences, King Saud University, Riyadh 11543, Saudi Arabia
[4]Department of Computer Engineering, National Institute of Technology at Kurukshetra, Kurukshetra 136119, India

Corresponding authors: M. Shamim Hossain (mshossain@ksu.edu.sa) and M. Abdullah Al-Wadud (mwadud@ksu.edu.sa)

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ABSTRACT In this paper, we design self-adaptive scheduling (SAS) algorithms for base transceiver stations (BTSs) of 5G networks to improve energy efficiency, reduce carbon footprint, and develop a self-sustainable green cellular network. In the SAS algorithm, a BTS switches among its operating states (active, turned-off, and sleep), thereby exploiting the traffic loads of the BTS and the single-hop neighbor BTSs thereof. The dynamic settings of traffic thresholds help the SAS system in achieving a high degree of cooperation among the neighborhood BTSs, which in turn increases the energy savings of the network. Each active SAS BTS independently and dynamically decides in determining its operation state, thus make our proposed SAS algorithms fully distributed. Results from a simulation conducted in network simulator version 3 show that BTS scheduling significantly influences cellular networks, and the proposed SAS algorithm can significantly increase the energy savings compared with state-of-the-art protocols.

INDEX TERMS 5G mobile communication, green design, adaptive scheduling.

I. INTRODUCTION

A significant growth has been witnessed in cellular access networks in the last decade [1], [2]. The total number of subscribers and the amount of traffic volume in cellular networks have explosively increased. In 5G networks, the width and depth of user services have also been enhanced significantly [3], [4], [39]. In recent years, the introduction of smartphones and e-book readers and the success of social networking giants, such as Facebook and Twitter, have also led to the demand for increased cellular data traffic. The 5G network [40] operators have been attempting to meet user requirements in a cost-effective manner [3], [5], [6].

Energy expenditure and corresponding CO_2 emissions from base transceiver stations (BTSs) of 5G mobile networks have been increased given the increase in traffic volume. In mobile communications, a typical wireless access network consumes more than half of the total energy required by the whole network. The information and communication technology infrastructure is currently reported to consume 3% of the total energy consumption and 2% of the CO_2 emissions worldwide [7]–[9]. An overview of the typical scenario of energy consumed by the different modules of a cellular operator is presented in Fig. 1 [4]. Nearly 60% of the consumption is associated with the BTS equipment [4]. Thus, the BTSs are the main focus of potential energy savings.

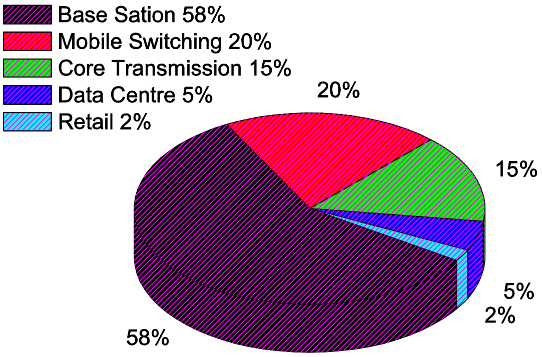


FIGURE 1. Cellular network power consumption profile.

In the literature, several recent works on energy-saving approaches have been proposed for BTSs in 5G networks [10]–[19]. Niu *et al.* [10] and Yu *et al.* [11] propose a cell zooming concept, where cell size is adjusted based on traffic conditions. This concept only attempts to switch off the lightly loaded BTSs, although this technique aims to balance the traffic load among the BTSs and reduce energy consumption. A distributed wake-up scheduling (DWS) algorithm is presented in [13], where a BTS selects its operation state dynamically, following traffic loads and first-step neighbors thereof. However, these protocols have no traffic distribution policy for the BTSs that experience heavy traffic loads. Liu *et al.* [18] develop a dynamic sleeping algorithm (DSA), where user equipment (UE) are classified into clusters based on their spatial features. For each cluster, the closest BTS is selected as a cell to provide access service. In [12] and [19], a completely new energy-saving concept through proto-cooperation has been introduced in which any two neighboring BTSs gain mutual benefits in traffic load sharing and thus switch their operating states from active to sleep, if possible. The sleep mode switching mechanism has been implemented here for the BTSs that experience heavy traffic loads. However, the following issues remain unanswered: (1) the selection of a suitable pair of nearby BTSs to share the traffic load of a highly loaded BTS, (2) the thresholds (lower and upper) of the traffic load of a BTS that can lead load transfer to achieve the maximum energy savings, And (3) the policies of load sharing (full or partial) among the BTSs that can further increase energy savings.

In this work, we design a self-adaptive scheduling (SAS) algorithm for BTSs in green cellular networks, where BTSs cooperate with one another to save energy. The proposed SAS algorithm operates in the following modes: *active, sleep, and turned-off*. A BTS can dynamically decide and switch between *active* and *sleep* modes based on network traffic. Each BTS estimates its own traffic load, collects those of the neighboring BTSs, and then dynamically decides on its state of operation. Thus, the decision on the operation state of a BTS fully depends on its own traffic load and one-hop neighborhood traffic load information. Each lightly loaded BTS in our proposed SAS system aims to switch to *sleep* mode, thereby transferring its load to moderately loaded BTSs. Similarly, a heavily loaded BTS attempts to share a portion of its load with moderately loaded BTSs; in the best case, a BTS may transfer the full load to neighbors and proceed to the sleep state. We use an algorithm for selecting a suitable pair of BTSs that helps in achieving improved load distribution and area coverage.

The contributions of this work are summarized as follows:

--We develop SAS algorithms for BTSs in green cellular networks.

--The algorithms exploit a single-hop neighborhood information only and are fully distributed and self-sustainable.

--Our algorithms switch off a lightly loaded or a heavily loaded BTS, thereby transferring its load to a suitable pair of moderately loaded neighborhood BTSs and thus saving energy.

--The dynamic setting of the lower threshold, T_L, in our algorithms increases the degree of cooperation among the neighborhood BTSs.

--The results obtained from the simulation using network simulator version 3 (ns-3) [20] show that the proposed SAS system achieves considerable improvements in saving energy compared with other proposals in this field.

The rest of this paper is organized as follows: we discuss the existing base station scheduling strategies for energy saving and state the motivation of this work in Section 2. Section 3 presents our network model and assumptions. Section 4 describes the detailed operations of our proposed SAS BTS algorithm. Section 5 provides the simulation and performance evaluation results of our origination. We conclude our paper and present a few future research directions in Section 6.

II. RELATED WORKS

Energy cost comprises a major part of the cost of operating a network [41]. The access network incurs 80%, whereas the core network contributes 20% of the total cost of energy in a cellular network infrastructure; more than half of the cost of cell operation is consumed to power up BTSs [8].

Several techniques, including switching certain BTSs when traffic is low, sharing BTSs cooperatively among different operators, decreasing the sizes of cells, using sectored cells, and improving BTSs to require less cooling, may be used to reduce the energy consumption of cellular access networks [8], [10], [12], [19], [21]–[25]. Electrical equipment can be scheduled to switch among different low-and high-power modes. The utilization of such sleep/wake-up technologies to reduce energy consumption is found in different fields of communication networks [10], [12], [19], [22], [26]. The idea of switching off several BTSs when traffic is low is proposed for future long-term evolution (LTE) systems. The implementation schemes, however, have not been specified by the standard [2], [12], [19], [22], [27]. The proposal for switching off BTSs in [28] is manually operated. Moreover, traffic may unexpectedly increase if an emergency arises. Such situations may lead to service interruptions for many users [19]. However, studies show that different classes of traffic generated in a BTS remain relatively lower than its capacity for significant portions of a day [2], [10], [12], [13], [19], [22], [27], [29], [30].

Saker *et al.* [31] propose a dynamic and a semi-static approach to resource provisioning for sleep mechanisms for 2G and HSPA BTSs to switch off different resources when traffic is light. The dynamic method is reported to perform favorably in saving energy, whereas the semi-static method incurs low complexity for an acceptable performance. Kolios *et al.* [27] propose a switch off method for an underutilized base station based on the mobility of relay nodes.

Wu *et al.* [14] exploit daily traffic fluctuation patterns to selectively switch off several lightly loaded base stations to conserve energy. A flexible and effective BTS scheduling based on mealy-type finite state machine has been developed in [15]. The problem of energy saving and quality-of-service to users have jointly been addressed in [16] by enabling small-cell BTSs to dynamically optimize their downlink performances. Zheng *et al.* [17] have developed a fully distributed solution, where nearby BTSs cooperate with each other to find optimized methods for sleeping strategies to reduce energy consumption.

In [10], the concept of cell zooming has been introduced to reduce the energy consumption in the whole network. This network layer technique adjusts the cell size adaptively based on the traffic load. The coverage area of a cell is reduced when traffic is increased, thereby reducing the possibility of congestion; the service gap is addressed by increasing the coverage area of the neighboring cells with minimal traffic. Adhikary *et al.* [13] and Cai *et al.* [42] develop a distributed wake-up scheduling algorithm for the green 5G networks [43]. The algorithm for the BTSs uses three modes of operation, namely, turned-off, sleep, and active modes. The operation mode of a BTS is decided upon based on the traffic load of the corresponding BTS and the other neighboring BTSs. However, this decision ignores the heavily loaded BTSs for load sharing and thus reduces the degree of cooperation among the neighboring BTSs. Moreover, the power consumption of the base station is not modeled as a function of its traffic utilization, and the quality of service of the mobile station (MS) is not guaranteed while achieving energy saving. Liu *et al.* [18] develop a DSA in the LTE-advanced standards for minimizing the energy consumption of the entire network. The UEs are classified into clusters based on their spatial features. For each cluster, the closest BTS is selected as a cell to provide access service. Niu [21] develop a TANGO framework that is aimed at cell planning based on traffic to increase energy efficiency.

Hossain *et al.* [12] and Hossain *et al.* [19] discuss a cellular access network architecture that is based on the ecological protocooperation among cell sites. The participating BTSs gain mutual benefits using cooperation, such as an ecosystem. This kind of cooperation is helpful for increasing the network performance. The wake-up technology is used in this method. A BTS is capable of making cooperative decisions intelligently for changing its power mode.

In this work, we develop new SAS algorithms for BTSs in cellular networks that dynamically change the operation states of BTSs, following their traffic loads, and maximize the number of sleeping BTSs to conserve additional energy. The unaddressed open issues of Eco-Inspired [19] have been accommodated here. *First*, we have developed a BTS pairing mechanism from nearby BTSs for lightly and heavily loaded BTSs and steered away from the traffic load of a highly loaded BTS. *Second*, we have set the lower threshold used in our proposed approach dynamically according to the traffic loads of a single-hop neighborhood BTS, thereby leading to achieving the maximum energy savings. *Third*, we have developed various policies of load sharing (full or partial) among the BTSs that further increase energy savings. We aim to transfer full traffic loads from lightly loaded BTS and release full or a portion of traffic loads from heavily loaded BTSs. *Fourth*, defining the safety and upper threshold of a BTS leads to load transfer to achieve the maximum energy savings. *Fifth*, a BTS can change its state dynamically based on the other nodes in the neighborhood.

III. NETWORK MODEL AND ASSUMPTIONS

A 5G network can be considered a radio network over an area partitioned into several cells, each of which is served by at least one fixed-location BTS. We assume a cellular network with many BTSs, where all the BTSs have the same transmission range, and the cells have equal size. We also consider that cells are organized into clusters, and seven neighboring cells form one cluster.

BTSs can operate in the following modes.

-- *Active mode*: In this mode, the BTS fully functions, that is, typical reception and transmission continue, as a conventional BTS.

-- *Sleep mode*: The BTS neither receives nor transmits any user traffic. Only a wake-up receiver module remains active. This mode consumes minimal power. This module waits for and handles a ''hear'' request from another BTS and can also sense power increment requests. This wake-up receiver module helps a BTS to switch abruptly to active mode. This mode is a semi-power saving mode.

-- *Turned-off mode*: This module is a super power saving mode when a BTS remains disconnected from a power supply. A local timer circuitry is used to turn it on periodically to check the neighborhood network environment at regular intervals.

We assume that a lightly or heavily loaded BTS can transfer its traffic load to its neighbor BTSs for energy saving. The BTS transferring its traffic load to neighborhood BTS can be defined as the *donor* BTS, while the BTS receiving traffic load as the *acceptor* BTS. On the one hand, a *donor* BTS shares its full (or partial) traffic loads among its neighboring *acceptor* BTSs. We also assume that an *acceptor* BTS checks whether it can satisfy the Quality of Service (QoS) requirements of its own users and the newly arrived users following [32]–[34], in which the QoS satisfaction of a user is determined by the achievable data rate under a new BTS.

In addition, the *acceptor* BTS can increment its transmit power dynamically to ensure the coverage of every user. We follow the optimal transmit power selection policy of [25] and [35] that considers instantaneous user traffic and network situations to minimize interference and protect the coverage for all users. It also ensures that the transmission power of a BTS can be made twice the original transmission power at best, by which the effective cell radius becomes the duplicate of the original radius. On the other hand, a *donor* BTS decreases its transmission power within a short time before proceeding to the *sleep* mode, thereby allowing a smooth handover for its users. Thus, no users are allowed to connect a call using the BTS that has switched to the *sleep* state.

We also consider that each BTS covers a uniform hexagonal area and periodically shares its measured traffic load with its single-hop neighbor BTSs, thereby updating the neighborhood traffic load knowledge of each BTS.

IV. PROPOSED SAS SYSTEM

In this section, we describe the detailed operations of our SAS system that comprises two distributed algorithms, that is, algorithms for lightly and heavily loaded BTSs. In the first algorithm, we aim to switch off a lightly loaded BTS, thus transferring its load to a suitable pair of moderately loaded neighboring BTSs. In the second algorithm, a heavily loaded BTS distributes its partial (or full) traffic to a pair of neighbor BTSs. A heavily loaded BTS can switch into the sleep mode only if it can transfer its full traffic to neighbor BTSs. A moderately loaded BTS in our system will not execute any energy-saving algorithm. We also develop a *sleep* state management scheme that increases the energy savings of our proposed SAS algorithm. We present the SAS design components in detail in the following section.

A. SELF-ADAPTIVE CELLULAR ACCESS NETWORKS

The BTSs in the proposed system cooperate with each other to save power and improve sustainability. We develop this cooperation at the BTS level, where each BTS can cooperate with neighbor BTSs for sharing its traffic loads, thereby developing a green cellular network. Each BTS runs a SAS algorithm to decide on switching to the *sleep* state, requesting any other sleeping BTS to wake up, and notifying this BTS about the requirement for any power increment. A BTS might transfer its full traffic to other neighbor BTSs and can switch to *sleep* mode when a BTS is lightly loaded (e.g., 30% loaded). If a BTS is highly loaded (e.g., more than 90% loaded), then this BTS cannot handle its own traffic during a sudden surge of new traffic. Thus, this highly loaded BTS can share a certain portion of traffic with neighbor BTSs for this highly loaded BTS to operate with moderate traffic load. The chance of transferring its full traffic to other neighbor BTSs and switching to the *sleep* state is minimal.

We consider a standard seven-cell cluster configuration, where each cell directly interacts with the surrounding six cells, as illustrated in Fig. 2. Each BTS identifies the IDs and traffic loads of neighbor BTSs by interacting with surrounding BTSs. In our proposed system, the BTSs are categorized into three types given their traffic loads, that is, highly, moderately, and lightly loaded. The lightly loaded region can be defined as 0%–50%, moderately loaded area as 51%–90%, and the highly loaded area is more than 90%. A BTS constantly selects a pair of moderately loaded BTSs from the neighborhood when a BTS must switch to sleep mode through transferring its traffic to neighbor BTSs. We discuss the motivation of using pairs and a scheme for pairing BTSs in the succeeding section.

B. PAIRING BTSs

We use a BTS pairing technique for traffic distribution among the neighbor BTSs. This technique has a twofold advantage. *First*, this technique is useful because a single neighbor BTS is frequently unable to receive full traffic from a lightly loaded BTS [19]; thus, a pair of BTSs from the moderately loaded list can take over the traffic easily. *Second*, the required amount of extension of the coverage area by the acceptor BTSs will be nearly half in case of using paired BTSs compared with that of single BTS, thereby reducing the amount of interference significantly.

An example of pairing BTSs is illustrated in Fig. 2. If BTS 1 is lightly loaded and wants to switch to sleep mode by distributing its traffic, then BTS 1 must find a pair of neighboring BTSs, which can take over its traffic. BTSs 2 and 5, 3 and 6, and 4 and 7 are examples of the best possible pairings depicted in Fig. 2. We select a suitable BTS pair among the single-hop neighborhood BTSs. Fifteen BTS pairs are available because each BTS is surrounded by six BTSs. In the best case, we attempt to pair opposite BTSs. Furthermore, we select two other suitable BTSs in case the two opposite BTSs are not found for load sharing. We must select the best pair to optimize the energy savings, which is determined by the energy-saving scheduling algorithms discussed in Section IV(D).

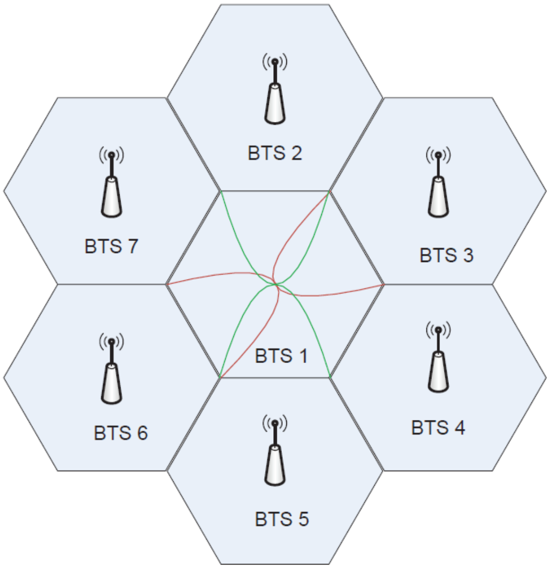


FIGURE 2. Standard 7-cell configuration and load-sharing technique.

C. TRAFFIC LOAD DISTRIBUTION

A lightly or heavily loaded BTS can transfer its full traffic load to a pair of neighboring BTSs. If transferring the full load is infeasible for a heavily loaded BTS, then it can transfer the partial load to the neighbors.

1) FULL LOAD DISTRIBUTION

We distribute the traffic load of the donor BTS among the pair of acceptor BTSs, following their proportionate traffic loads. If BTS 1 is lightly loaded and wants to share its traffic with BTSs 2 and 5, and the current traffic loads of BTSs 1, 2, and 5 are $T_1 = 30\%$, $T_2 = 55\%$, and $T_5 = 65\%$, respectively. For traffic distribution, we use proportional weights of their corresponding traffic loads, and the shared amounts are calculated as follows:

$$ST_2 = \left\lfloor \frac{T_5}{T_2 + T_5} \times T_1 \right\rfloor, \tag{1}$$

$$ST_5 = T_1 - ST_2 \approx \frac{T_2}{T_2 + T_5} \times T_1, \tag{2}$$

where ST_2 and ST_5 are the shared amount of traffic loads by BTSs 2 and 5, correspondingly. In this example, Eqs. 1 and 2 produce $\mathrm{ST}_2 = 16\%$ and $\mathrm{ST}_5 = 14\%$, respectively. The total traffic of an acceptor BTS must be less than a safety threshold, T_S after receiving traffic from donor BTS 1, that is,

$$T_2 + ST_2 < T_5, \tag{3}$$

$$T_5 + ST_5 < T_5. \tag{4}$$

Thus, each *donor* BTS node must check whether the selected *acceptor* BTSs satisfy the above two constraints or not before transferring traffic.

Algorithm 1 Algorithm 1 Energy-Saving Algorithm at Each Lightly Loaded BTS, $i \in S$

```
INPUT: Traffic load of neighborhood BTSs.
OUTPUT: Decision on BTS operation mode.
1. Collect traffic loads from active neighbor BTSs
2. Let the active BTSs make a set BTSactive
3. for each pair of BTS (a, b) from BTSactive, do
4.     if (Eqs. 3 and 4 are satisfied by (a, b)), then
5.         Request a BTS pair (a, b) to take users;
6.         Transfer traffic load to (a, b);
7.         Switch to sleep mode;
8.         break;
9.     end if
10. end for
```

2) PARTIAL LOAD DISTRIBUTION

The full traffic load of a highly loaded BTS is non-transferrable to any pair of neighboring BTSs; thus, this full traffic load selects the partial load distribution. A heavily loaded BTS (> 90%) shares its partial traffic between a pair of neighboring *active* BTSs in which its own traffic load becomes less than or equal to the safety margin, TS = 80%, after transferring the traffic. We follow Eqs. 1 and 2 for distributing the traffic to the neighbors. In the worst scenario, the highly loaded BTS will wake a sleeping BTS, if any, and transfer this amount of partial load when no active pair is found to take the said amount.

D. BTS SCHEDULING ALGORITHMS

We have developed separate algorithms and used distinct scheduling policies for lightly and heavily loaded BTSs. The energy-saving scheduling algorithm for a lightly loaded BTS runs when the traffic load of a BTS falls below a lower threshold, T_L, and that for a heavily loaded BTS runs when the traffic load increases above a predefined higher threshold, T_H. Therefore, every BTS with traffic loads below T_L or above T_H attempts to share its traffic load with a pair of neighboring BTSs. In particular, a lightly loaded BTS transfers its traffic load to a pair of neighbor BTSs and switch to the sleep mode; a heavily loaded BTS shares part of its traffic load with a pair of neighbor BTSs to balance the traffic loads and satisfy the user QoSs.

For the acceptor pair of BTSs, we introduce a new threshold, that is, safety threshold, T_S, which determines the upper limit of traffic level after taking over the traffic load of others. This threshold also determines the level of protocooperation among the BTSs. Thus, this threshold helps in maintaining the stability of the network in catastrophic conditions, such as accommodating the sudden surge of data traffic generated from additional MSs under its coverage area.

1) SCHEDULING FOR LIGHTLY LOADED BTS

The energy-saving scheduling algorithm of a lightly loaded BTS runs when its traffic load falls below the lower threshold, T_L. Initially, the algorithm searches for two opposite BTSs for load sharing. If such a pair is not found, the BTS searches for the pair from a list of surrounding active moderately loaded BTSs. To do so, these BTSs are first sorted in non-increasing order of their total traffic loads. The BTS selects the first two BTSs from the list and checks whether they can take over its traffic load, thereby satisfying the safety threshold, T_S, constraint, as mentioned previously. If not found, then the BTS will check the same for the next two BTSs from the list. The procedure ends once a feasible pair is found or the list is ended. The BTS transfers its traffic load to the selected pair of BTSs and switches to *sleep* mode. If no feasible pair is found from the list, then the BTS continues its operations.

The detail of our proposed scheduling for lightly loaded BTS is depicted in Algorithm 1. A lightly loaded BTS in our proposed SAS algorithm does not request for waking up any sleeping BTS, hence increasing the amount of energy savings.

2) SCHEDULING FOR HEAVILY LOADED BTS

Heavily loaded BTSs remain active to concentrate on traffic, and many works in the literature follow this approach. In this work, we explore the means of increasing the degree of cooperation among the neighboring BTSs. We allow a heavily loaded BTS to share its full or partial load with the neighbors. In the case of full load sharing, the incumbent BTS can go into the sleep state to conserve energy; for partial load sharing, the BTS can change its state from heavily loaded to moderately loaded, thereby facilitating the stable operation of the network system. The energy-saving scheduling algorithm of a heavily loaded BTS starts running when the total traffic of a BTS elevates above $\mathrm{T_H}$. Initially, the algorithm searches for two opposite BTSs for load sharing; if not found, then the BTS attempts to distribute its traffic among a pair of moderately loaded BTSs in the neighborhood. The neighborhood BTSs are sorted in non-decreasing order of the traffic loads. The BTS then selects the last two BTSs from the list and checks whether they can take over its full or partial traffic load, thereby satisfying the safety threshold, T_S, constraint, as mentioned previously. If possible, the BTS transfers its full traffic load to the selected pair of BTSs and switches to the *sleep* mode. Otherwise, the BTS will share partial traffic load to the selected pair of BTSs and switches to the moderately loaded state. Thus, the traffic loads of neighboring active BTSs are high. The active BTSs are unable to share additional traffic from a heavily loaded BTS, which then requests a sleeping BTS to wake up and share its traffic. The details of our proposed scheduling for heavily loaded BTS are presented in Algorithm 2. This BTS scheduling ensures that the sleeping BTSs will not be awakened unless crucial. In the worst case, if none of the abovementioned scheduling approach is applicable for a certain network environment, then the heavily loaded BTS continues its operations with the current traffic.

Algorithm 2 Energy-Saving Algorithm at Each Heavily Loaded BTS, $i \in S$

```
INPUT: Traffic load of neighboring BTSs.
OUTPUT: Decision on the BTS operation mode.
Collect traffic load from neighboring active BTSs;
Let the set of active and sleep BTSs to be $BTSpair$;
for each pair of active BTS $(a, b)$ from $BTSpair$, do
    if (Eqs. 3 and 4 are satisfied by $(a,b)$), then
        Request BTS pair $(a, b)$ to take users;
        Transfer traffic load to $(a,b)$;
        Switch to sleep mode;
        break;
    else
        if (Pair $(a,b)$ can take 20% load), then
            Distribute partial traffic;
            BTS $i$ remains active;
            break;
        else
            if (Any sleeping BTS can take the load), then
                Request to wake up;
                Transfer 20% traffic;
                BTS $i$ remains active;
                break;
            end if
        end if
    end if
end for
```

E. BTS STATE MANAGEMENT

In this section, we present an energy-efficient state management scheme for the BTSs of the cellular network. An active BTS checks whether at least one *sleep* BTS is in the neighborhood when an active BTS determines that it can switch to any of the energy-saving modes, *sleep* or *turned-off*, by transferring its traffic loads to neighbor BTSs. If found, then the BTS can switch into the *turned-off* mode; otherwise, the BTS switches to *sleep* mode. We opt for maintaining at least one node in the *sleep* state in the neighborhood for this node to quickly share traffic loads that are suddenly arriving from the MSs in that neighborhood.

A *turned-off* BTS uses a timer circuitry to periodically check the neighborhood network environment. The circuitry triggers the BTS "ON" after a certain period of time. During this short period, the BTS checks for existing *sleep* BTSs in the neighborhood. If any such sleeping BTS is found, then it returns to the *turned-off* mode; otherwise, this BTS switches to *sleep* mode.

F. DYNAMIC THRESHOLDS

The performance of the proposed SAS system significantly depends on the optimal determination of threshold parameters, namely, T_H, T_L, and T_S. A heavily loaded node is defined as when the traffic load of a BTS crosses the higher threshold, T_H. In our energy-saving algorithm, a heavily loaded node attempts to share (or distribute) its traffic load with the neighborhood BTSs. Therefore, providing a predefined fixed value for the higher threshold T_H will meet the requirement; we set $T_H = 90\%$ in our algorithm. Similarly, we use 80% traffic load for safety threshold, T_S, and keep an extra 10% traffic for a BTS to easily accommodate sudden traffic arrivals from its MSs.

The optimal value of the lower threshold, T_L, significantly influences the performance of any energy-saving algorithm, and we have selected the value dynamically. The value of the lower threshold T_L should be slightly less than the mean traffic load of the neighboring BTSs because the lower threshold T_L determines the candidate nodes in a neighborhood that can go to low-power sleep or *turned-off* state by transferring loads to others. Therefore, the T_L value, unlike the value of T_H and T_S, of each node will be different from others as their single-hop neighbor BTSs will be different. In the SAS algorithm, we subtract the standard deviation (σ) of the traffic load values for neighboring BTSs from the arithmetic mean to calculate the value of T_L as displayed in Eq. 5. This setting does not guarantee the optimal selection of the value. However, it increases the degree of cooperation among the neighboring BTSs by allowing additional lightly loaded nodes to switch to low-power sleep states, thereby saving additional energy.

$$T_L = \bar{x} - \sigma, \tag{5}$$

where $\bar{x}$ is the arithmetic mean of the traffic loads of BTSs in a single-hop neighborhood, and the standard deviation σ can be calculated as

$$\sigma = \sqrt{\frac{1}{N_{neigh}} \sum_{i=1}^{N_{neigh}} (x_i - \bar{x})^2} \tag{6}$$

where x_i is the traffic load of BTS i, and N_{neigh} is the number of BTSs in each neighborhood; typically, $N_{neigh} = 7$ for the seven-cell clusters. The traffic loads of the neighboring BTSs are 11%, 60%, 91%, 39%, 87%, 34%, and 79%. According to

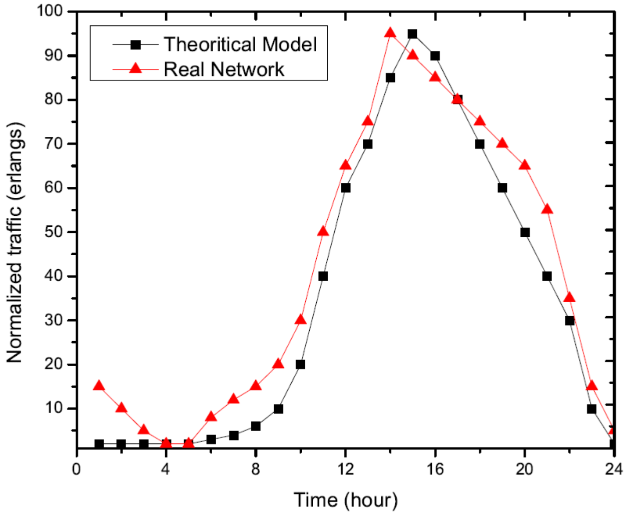


FIGURE 3. **Daily traffic pattern of a BTS.**

this traffic load, we calculate the mean value as 57.28571429, the variance as 14.56738793, and the lower threshold $T_L = 42.71832636$. Therefore, three lightly loaded and one heavily loaded BTSs are determined to run the energy-saving algorithms 1 and 2, respectively, in the first round. The other nodes might also obtain the opportunity in the next round. We can enforce the most lightly loaded BTSs to switch into the turned-off state first and the remaining BTSs afterward, thereby increasing the number of sleeping BTSs and saving additional energy.

V. ANALYSIS AND SIMULATION RESULT

A. TRAFFIC PATTERN ANALYSIS

The daily traffic pattern of a BTS varies significantly on an hourly basis as presented in Fig. 3. The first pattern [36] can be approximated by

$$X(t) = \frac{1}{2^b}\left[1 + \sin\frac{rt}{12}\right]^2 + \alpha, \qquad (7)$$

where $X(t)$ represents the instantaneous normalized traffic in Erlang, α is a constant, and $b\epsilon \{1, 3\}$ determines the abruptness of the traffic profile. The second pattern [37] is expressed as

$$X(t) = \sum_{i=1}^{n} x_i(t)\sin(y_i t - z_i), \qquad (8)$$

where x_i, y_i, and z_i are constants. In this work, n is set to 5.

The measurement of the traffic load of a BTS is required by our SAS algorithm to determine the BTS mode of operation. Different types of traffic may originate from different MSs and produce data packets of varying traffic rates. We have used EWMA (exponentially weighted moving average) method for estimating the traffic load of a BTS. Data packets with varying sizes and speed are exchanged between the MSs and the BTSs. The algorithm for measuring the traffic load of a BTS is described here. The estimated traffic load TL_{est} is the time average traffic load of a node. The current traffic load TL_{cur} represents the measured traffic load during a time interval T. Therefore, the estimated traffic load is calculated using EWMA [13], as follows:

$$TL_{est} = (1-\beta) \times TL_{est} + \beta \times TL_{cur}, \qquad (9)$$

where β $(= 0.2)$ is the weight factor, which adds weight to the previously observed loads and deducts weight to the current load. Here, the current traffic load is measured during a predefined time interval T as follows:

$$TL_{cur} = \sum_{k=1}^{K} DT_k \times AC_k, \qquad (10)$$

where DT_k represents the data transfer rate of the traffic category $k\epsilon K$, and AC_k is the number of active users of such category under the incumbent BTS. We have considered voice, text, and video traffic categories, K, during simulation.

B. ENERGY CONSUMPTION ANALYSIS

The total energy consumption per day considering N BTSs is calculated and provided by [13], as follows:

$$P_{total} = \sum_{i=1}^{N}\int_{t=0}^{24hrs} st_i \times (P_{control} + P_{trans})dt, \qquad (11)$$

where st_i is a binary variable; $st_i = 1$ for active or sleep mode, and $st_i = 0$ for the off-mode operation of any BTS i. The average energy consumption by a BTS in a day in the proposed network can be calculated as the sum of the energy for powering up the BTS components and control signaling and for data packet transmission or reception. Therefore, the controlling power can be expressed as follows:

$$P_{control} = P_{on} + \gamma \times P_{control}, \qquad (12)$$

where P_{on} is the power required for keeping the BTS components on, and $P_{control}$ is caused by the exchange of control messages between BTS and MSs. For a non-energy saving BTS, $\gamma = 1$, and for an acceptor BTSs controlling power, $\gamma = \frac{k \times p_{inc}}{6}$, where p_{inc} is the amount of additional power required for covering the area of other BTSs, and k is the total number of BTSs that have been shared.

The power consumed for transmission of user information can be calculated as

$$P_{trans} = \sum_{j=1}^{m} P_{self_i} + \sum_{k=1}^{m} p_{ext_k}, \qquad (13)$$

where P_{self_i} is the transmission power for MS j in its own area, and P_{ext_k} is the transmission power for MS k in the extended area.

C. SIMULATION ENVIRONMENT SETUP

We have used ns-3 [20] to evaluate the performances of the proposed SAS system. We have considered an area covered by 49 equal-sized cells. The simulation layout is 7 × 7 hexagon cells wrapped up to avoid a boundary effect. The cell radius is set to 200 m, and each BTS can extend its coverage to 400 m at most. The BTSs have an equal capacity. The coverage areas overlap, thereby ensuring no dead zone. Normalized traffic patterns $X(t)$ are generated for the 49 BTSs using Eq. 8. A Poisson distributed random process has been added to the traffic pattern to achieve random fluctuations. Different data rates from different types of traffic from MSs have been considered for calculating the total traffic load of a BTS using Eq. 10. The estimated traffic load over time is measured using Eq. 9.

The proposed dynamic SAS algorithms are evaluated in a scenario with time-varying traffic distribution. The power consumption is 400 W for BTSs in *active* mode, 10 W for BTSs in *sleep* mode, and 0 W for BTSs in *turned-off* mode [10], [38]. All nodes have an equal initial energy of 100 J. The simulation parameters are listed in Table 1. A single simulation run is performed for 1000 s, and graph data values from the average of the results of 10 simulation runs are plotted.

TABLE 1. **Simulation parameters.**

Parameter	Value
Number of BTSs	49
Deployment layout	7×7 hexagonal
Cell radius	200 m
Cell radius for acceptor BSTs	400 m
Power consumption for active BTS	400 W
Power consumption for sleep BTS	10 W
Initial energy	100 J
Cluster size	7
Lower threshold	Select Dynamically
Safety threshold	0.8
Higher threshold	0.9
Traffic pattern	Poisson Arrival
Simulation time	1000 s

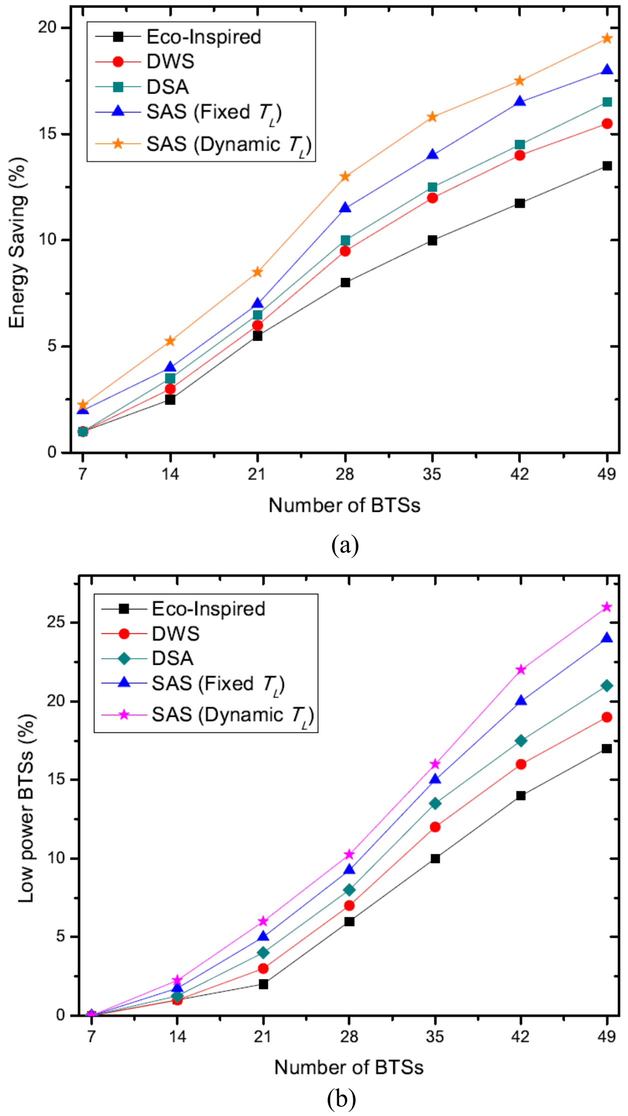
D. PERFORMANCE METRICS

The following metrics have been used to study the comparative performance of the energy saving algorithms: eco-inspired [19], DWS [13], DSA [18], and the proposed SAS algorithms.

-- *Percentage of Energy Saving* We measure the total amount of energy expenditures by all the BTSs for a studied energy-saving algorithm and calculate the amount of energy saved compared with a non-energy-saving algorithm. We then calculate the average percentage of energy saved per BTS. A high value indicates a favorable performance of the associated protocol.

-- *Percentage of Low-power BTSs* We calculate the ratio of the average number of BTSs in the sleep and turned-off modes to the total number of available nodes in the network and then express it in percentage.

-- *Scheduling Efficiency* We measure the ratio of energy savings to the average number of switching of BTSs (between active and sleep states) that are experienced by a scheduling algorithm during the simulation period. The high value of scheduling efficiency represents a favorable stability and increased energy savings.



(a)

(b)

FIGURE 4. **Effect of the number of BTSs. (a) Percentage of energy saving. (b) Percentage of low-power BTSs.**

E. PERFORMANCE METRICS

1) EFFECTS OF THE NUMBER OF BTSs

In Fig. 4 (a), we observe that the percentage of energy savings gradually increases with the number of BTSs in the network in all the studied algorithms. This increase is caused by the increase in availability of neighboring BTSs to share traffic loads. However, our proposed SAS systems achieve as much as 2.5% and 4.5% more energy savings than the DWS and eco-inspired algorithms, respectively. The results also show that changing the lower threshold dynamically helps the SAS system in achieving a better performance than its static counterpart. Our in-depth analysis of the simulation trace file data values reveals that the dynamic setting of the T_L and selecting acceptor pair from the list of moderately loaded BTSs in our proposed SAS system provide added versatility to save additional energy.

In Fig. 4 (b), we observe that the average percentage of the BTSs in low-power sleep and turned-off modes increases

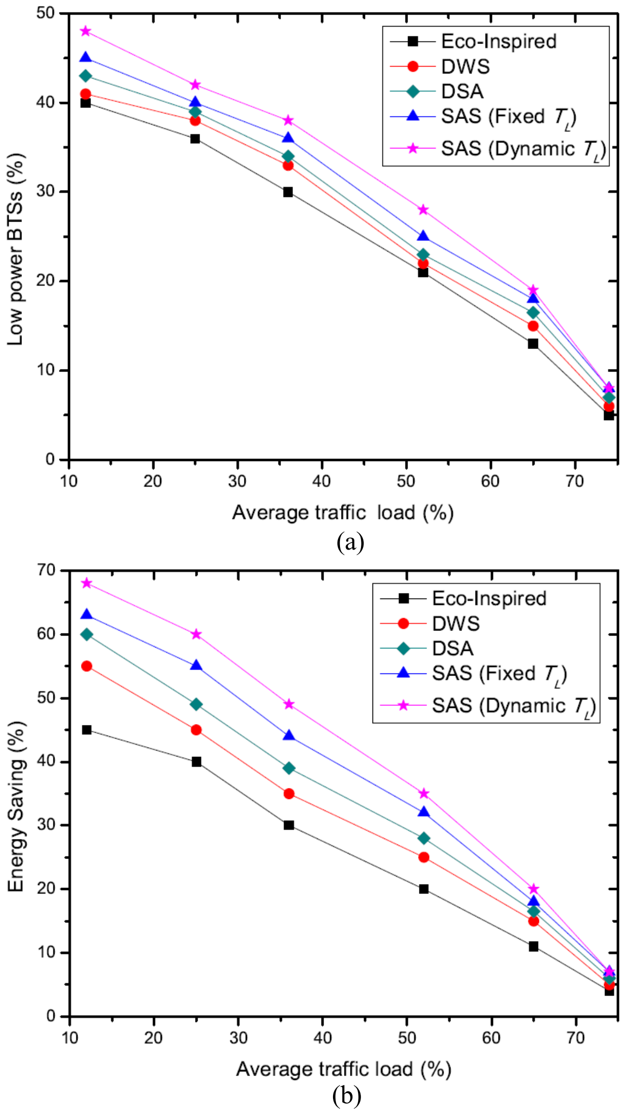


FIGURE 5. **Effects of average traffic load on energy saving. (a) Percentage of energy saving. (b) Percentage of low-power BTSs.**

with the number of BTSs in the network for all the studied energy-saving algorithms. The availability of the neighboring BTSs and sharing of traffic loads increases. However, our proposed SAS algorithm has sent a higher percentage of BTSs to low-power sleep and turned-off modes than the state-of-the-art systems. Specifically, approximately 5% and 8% improvements have been observed over DWS and eco-inspired algorithms, respectively.

2) EFFECTS OF AVERAGE TRAFFIC LOAD

The effects of average traffic load on energy-saving are depicted in Fig. 5 (a). The average traffic load per BTS is calculated simply by dividing the total traffic load of the network by the total number of BTSs, and the simulation is conducted for increasing the average amount of traffic loads per BTS. We observe that our SAS algorithm at 12% traffic load can achieve 9% more energy savings than DWS and 21% than eco-inspired. The maximum number of BTSs with an average lower traffic load can execute the energy-saving algorithm for lightly loaded BTSs because we can place additional BTSs in the turned-off state by selecting the T_L dynamically. The graph reveals that the energy-saving gap between the algorithms gradually decreases, as expected theoretically when the traffic load increases. We also notice that energy saving cannot be achieved in both algorithms when the traffic load level increases to very high values and crosses a certain saturation level (for example, 80%) because the process of traffic sharing becomes infeasible at high traffic loads. The percentage of the BTSs operating in low-power *sleep* and *turned-off* states also decreases with the increase in traffic loads, as presented in Fig. 5 (b). The results also show that approximately 5% additional energy savings are possible when we dynamically vary T_L compared with keeping it fixed.

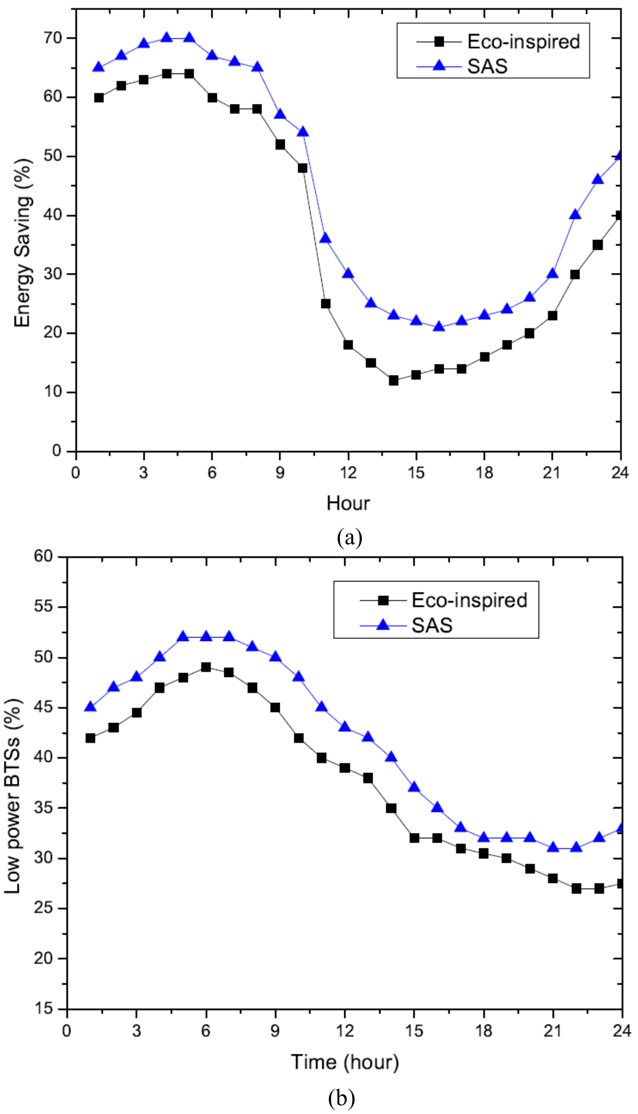
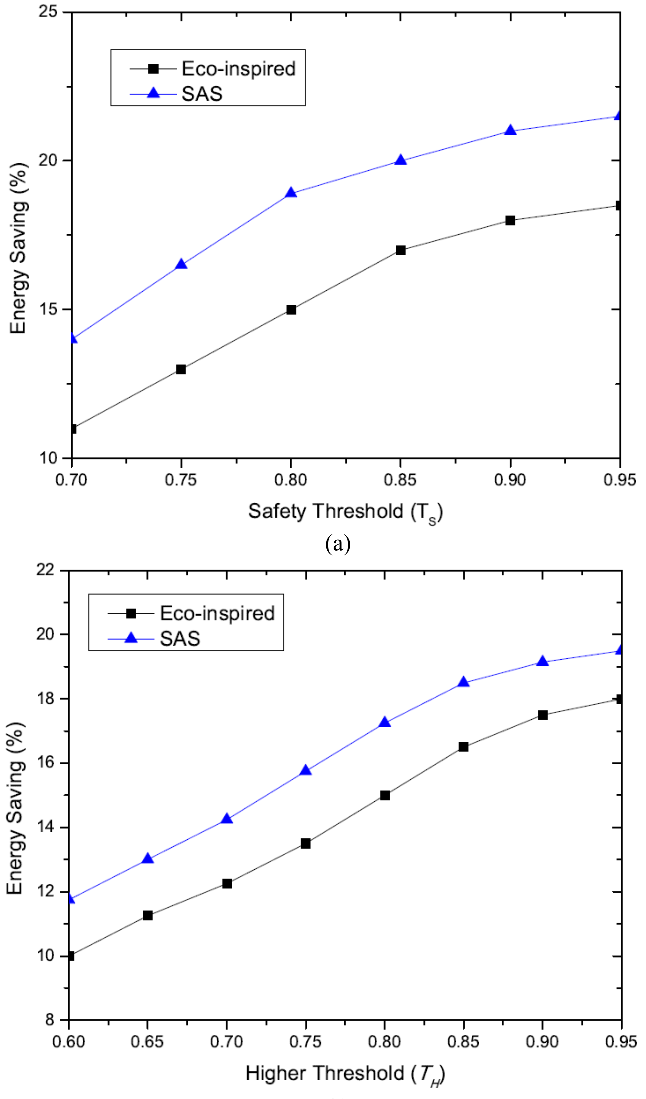


FIGURE 6. **Daily energy-saving pattern. (a) Percentage of energy saving. (b) Percentage of low-power BTSs.**

3) EFFECTS OF DAILY TRAFFIC PATTERN OF BTSs

The percentage of average energy savings per BTS and the percentage of low-power BTSs on an hourly basis in a day



(a)

(b)

FIGURE 7. **Effects of thresholds on energy saving. (a) Safety threshold. (b) Higher threshold.**

are plotted in Figs. 6 (a) and (b), respectively. The plot shows that the percentage of the sleeping BTSs begins to increase at 00:00 hours and reaches 52% at around 5:00 hours. This phenomenon is explained by being on the off-peak period when the traffic to the BTSs is low. The BTSs are awakened to support the increased traffic during the peak period. The sleeping BTSs begin to wake up, and the percentage of sleeping BTSs decreases sharply until 18:00 hours. Afterward, the percentage of the sleeping BTSs begins to increase from nearly 22:00 hours. In Fig. 6 (a), the energy savings is at the minimum during 11:00 to 18:00 hours because this time interval is super peak hours, and the BTSs are sufficiently loaded, thereby obtaining least chances to switch to low-power modes.

4) EFFECTS OF THRESHOLD

Fig. 7 (a) illustrates the energy savings with respect to safety threshold, T_S. For this result analysis, we kept T_H fixed and calculated T_L dynamically. The graph reveals that the energy savings increases up to $\mathrm{T_S}$ value 85% of the full traffic load and becomes stable afterward. The reason is that minimal acceptor BTSs can take traffic from other BTSs with a low value of T_S. Therefore, a few BTSs are in sleep mode, thereby resulting in minimal energy savings. Energy savings does not increase further with T_S values at a certain stage (in this case, when $T_S > 85\%$); a BTS has no space to accommodate the traffic load of others.

In Fig. 7 (b), the percentage of energy savings is plotted for the increase in values of T_H, while the T_L is selected dynamically. The graph shows that the energy savings increase with respect to T_H until the latter reaches 90%. The number of moderately loaded BTSs at low values of T_H and the scope of the energy savings decrease.

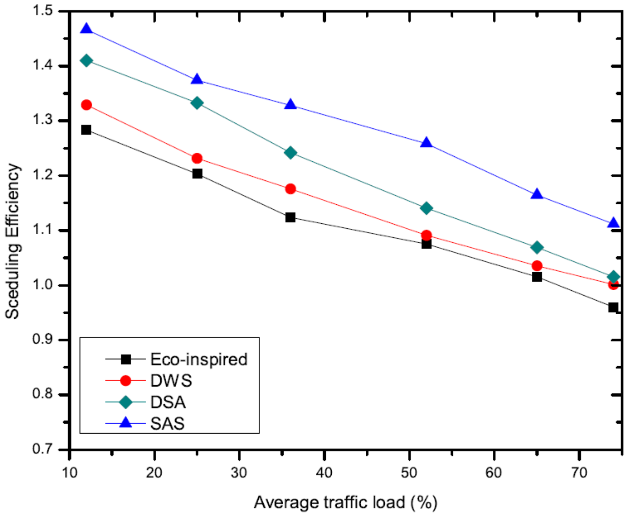


FIGURE 8. **Scheduling efficiency for varying traffic loads.**

5) SCHEDULE EFFICIENCY

In this section, we conduct a separate simulation experiment to study the scheduling efficiency of the studied systems. Fig. 8 demonstrates that the scheduling efficiency gradually decreases with the increase in traffic loads for all the approaches because the energy savings is decreased at high traffic loads as discussed previously. We also observe that the proposed SAS system achieves better scheduling efficiency than the state-of-the-art works. The dynamic threshold-driven state management of BTSs in our proposed SAS system helps it to save additional energy and avoid unnecessary state transitions. Thus, the SAS system exhibits high stability (i.e., reduced average number of switching between the states of BTSs) to changes in network traffic loads and can achieve a favorable level of trade-off between energy savings and network stability.

VI. CONCLUSION

The primary focus of the green 5G Network is to save energy in operating BTSs. In this work, we have developed the SAS algorithm for BTSs in a distributed way by exploiting their single-hop traffic loads. The SAS BTSs cooperate to optimize the energy savings within the green 5G networks. The SAS BTSs can dynamically switch between active, sleep, and turned-off modes, depending on the network traffic situations. Evaluation through simulations have shown that the SAS BTSs can autonomously determine their operating modes, and the proposed architectures and algorithms can significantly reduce the energy consumption in the access networks, thereby helping the SAS algorithms in achieving a self-adaptable green communication network.

In the future, we aim to study the optimal strategies of the dynamic power control for BTSs and the effects of the increase in transmission power on interference and network capacity.

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UZZAL KUMAR DUTTA received the B.Sc. and M.Sc. degrees in computer science and engineering from the University of Dhaka, Bangladesh, in 2009 and 2011, respectively. He has over six years of software industry experience. His research interests include wireless networks and communications, green cellular networks, and next-generation technologies.

MD ABDUR RAZZAQUE (M'08–SM'12) received the B.S. and M.S. degrees from the University of Dhaka, Bangladesh, in 1997 and 1999, respectively, and the Ph.D. degree in computer engineering from the School of Electronics and Information, Kyung Hee University, South Korea, in 2009. He was a Research Professor with Kyung Hee University from 2010 to 2011 and a Visiting Professor with Stratford University, USA, in 2017. He is currently a Professor with the Department of Computer Science and Engineering, University of Dhaka, where he is the Group Leader of the Green Networking Research Group. He has published 112 research papers in international conferences and journals. His research interest is in the area of modeling, analysis, and optimization of wireless networking protocols and architectures, wireless networking, sensor data clouds, Internet of Things, cognitive radio networks, 5G Networks, and so on. He is a TPC Member of the IEEE HPCC, ICOIN, ADM, and NSysS. He is a member of the IEEE Communications Society, the IEEE Computer Society, the Internet Society, the Pacific Telecommunications Council, and KIPS. He is an Editorial Board Member of the IEEE Access and the *Journal of Network and Computer Applications* (Elsevier). He is a General Co-chair of the IEEE R1HTC.

M. ABDULLAH AL-WADUD (M'13) received the B.S. degree in computer science and the M.S. degree in computer science and engineering from the University of Dhaka, Bangladesh, in 2003 and 2004, respectively, and the Ph.D. degree in computer engineering from Kyung Hee University, South Korea, in 2009. He served as a Faculty Member with the Department of Industrial and Management Engineering, Hankuk University of Foreign Studies, South Korea, from 2009 to 2014. He also served as a Lecturer with the Faculty of Sciences and Information Technology, Daffodil International University, Bangladesh, in 2003, and with the Faculty of Sciences and Engineering, East West University, Bangladesh, in 2004. He is currently an Associate Professor with the Department of Software Engineering, King Saud University, Saudi Arabia. His research interests include pattern recognition, optimization, computer vision, cloud computing, recommender systems, sensor, and wireless networks.

MD SAIFUL ISLAM (M'08) received the B.Sc. degree (Hons.) in computer science and engineering from Khulna University, Bangladesh, in 1999, and the Ph.D. degree in computer engineering from Nanyang Technological University, Singapore, in 2007. He was a Research Fellow with the School of Computer Engineering, Nanyang Technological University. He was an Assistant Professor and a Lecturer with the Dhaka University of Engineering and Technology, Bangladesh, from 2006 to 2009 and from 2000 to 2006, respectively. He was also an Adjunct Faculty Member with the Islamic University of Technology, Dhaka. He has been an Assistant Professor with the College of Computer and Information Sciences, King Saud University, Saudi Arabia, since 2010. He is also a permanent Research Member of the Advanced Laboratory for Intelligent Systems Research. His current research interests include machine learning, biometrics (heartbeat biometrics, multimodal biometrics, and liveness), and biomedical signal analysis (ECG feature extraction and classification). He is a referee for several international journals.

M. SHAMIM HOSSAIN (SM'09) received the Ph.D. degree in electrical and computer engineering from the University of Ottawa, Canada. He is currently a Professor of software engineering with King Saud University, Riyadh, Saudi Arabia. He has authored and co-authored about 165 publications, including refereed the IEEE/ACM/Springer/Elsevier journals, conference papers, books, and book chapters. His research interests include serious games, social media, IoT, cloud and multimedia for healthcare, smart health, and resource provisioning for big data processing on media clouds. He served as a member of the organizing and technical committees of several international conferences and workshops. He is a member of the ACM and ACM SIGMM. He was a recipient of a number of awards including, the Best Conference Paper Award, the 2016 *ACM Transactions on Multimedia Computing, Communications, and Applications* Nicolas D. Georganas Best Paper Award, and the Research in Excellence Award from King Saud University. He has served as a co-chair, general chair, workshop chair, publication chair, and a TPC for over 12 IEEE and ACM conferences and workshops. He currently serves as a Co-Chair of the 1st IEEE ICME workshop on Multimedia Services and Tools for Smart-health MUST-SH 2018. He served as a Guest Editor of the IEEE Transactions on Information Technology in Biomedicine (currently JBHI), *International Journal of Multimedia Tools and Applications* (Springer), *Cluster Computing* (Springer), *Future Generation Computer Systems* (Elsevier), *Computers and Electrical Engineering* (Elsevier), and the *International Journal of Distributed Sensor Networks*. He currently serves as a Lead Guest Editor of the *IEEE Communication Magazine*, the IEEE Transactions on Cloud Computing, the IEEE Access, *Future Generation Computer Systems* (Elsevier), and *Sensors* (MDPI). He is on the Editorial Board of the IEEE Access, IEEE Multimedia, *Computers and Electrical Engineering* (Elsevier), *Games for Health Journal*, and the *International Journal of Multimedia Tools and Applications* (Springer).

B. B. GUPTA (SM'17) received the Ph.D. degree in information and cyber security from IIT Roorkee, India. He has published over 90 research papers (including 03 book and 14 chapters) in International Journals and the Conferences of high repute, including the IEEE, Elsevier, ACM, Springer, Wiley Inderscience, and so on. He has visited several countries, i.e., Canada, Japan, China, Malaysia, and Hong Kong to present his research work. His biography was selected and publishes in the 30th Edition of Marquis Who's Who in the World, in 2012.

He was a Visiting Researcher with Yamaguchi University, Japan, in 2015. He is a principal investigator of various research and development projects. He is currently guiding ten students for their master's and Ph.D. research in information and cyber security. His research interest includes information security, cyber security, mobile security, cloud computing, Web security, intrusion detection, computer networks, and phishing. He is member of the ACM, SIGCOMM, the Society of Digital Information and Wireless Communications, the Internet Society, the Institute of Nanotechnology. He is a Life Member of the International Association of Engineers and the International Association of Computer Science and Information Technology. He served as a Technical Program Committee Member of over 20 International conferences worldwide. He is a Reviewer of the Journals of the IEEE, Springer, Wiley, and Taylor & Francis. He is serving as a guest editor for various reputed Journals. He is currently serving as an Associate Editor for the IEEE Access and IJICS (Inderscience), and an Executive Editor for IJITCA (Inderscience), respectively. He is also an editor of various International Journals and magazines.