# A Distributed Wake-up Scheduling Algorithm for Base Stations in Green Cellular Networks

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## ABSTRACT

Recently, designing energy-efficient techniques in cellular communication has got immense research interest around the world. In this paper, we focus on energy-efficient operation of base transceiver stations (BTSs) in cellular network. We present a distributed wake-up scheduling algorithm (DWS) for the BTSs that use three different modes of operation: *off*, *sleep* and *active*. In DWS, a BTS dynamically takes decision on its operation mode according to the measured traffic load of itself and its neighborhood BTSs in a distributed manner. Our simulation results show that the DWS can save as much as 28% more energy compared to a state-of-the-art Eco-Inspired [6] algorithm.

## Categories and Subject Descriptors

H.4 [**Mobile networking**]: Miscellaneous; D.2.8 [**Mobile networks**]: Energy savings—*Algorithms, performance measures*

## General Terms

Algorithms

## Keywords

Green Cellular Network, Distributed Scheduling Algorithm, Wake-up Scheduling, Traffic Measurement

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## 1. INTRODUCTION

Now a days, the ICT sector is the main contributor for the global warming. One of the studies reveals that in 2007-2010, the ICT industry consumed 3% of the total world-energy and thus contributed to approximately 2% of the worldwide $CO_2$ emission [3]. Obviously, a large portion of this energy is consumed by cellular network infrastructure. Again, in a typical cellular network, the access network part accounts for 80% of the total energy consumed by the entire network infrastructure. It has also been observed that energy consumption in communication networks is exponentially increasing [3]. Hence, the network providers have to pay a huge cost for energy and thus the green communication network has become the hot research topic now a days.

The future networks are becoming larger in size, extremely complex and dynamically changing according to their application requirements [7]. Thus, designing energy-efficient communication technique has become very difficult. In [6], energy-efficient cellular access network architecture is proposed based on the principle of ecological protocooperation, which is a form of cooperation benefitting both the interacting species in an eco-system. In [5] and [6], two modes of BTS operation: *on* and *sleep* have been proposed and scheduling schemes have been developed to increase the energy-efficiency. However, neither of them goes for turning off the BTSs even at zero traffic load.

In this paper, we define three modes of BTS operation: *active*, *sleep* and *off*. In *active* mode, all circuitries of the BTS are fully functional; in *sleep* mode, only the control channel circuitries will be on and all the user traffic channels will be switched off; and in *off* mode, all the communication channel circuitries will be switched off and thus this is the most energy-saving mode of a BTS. To the best of our knowledge, this is the first time three modes of BTS operation are considered in DWS, opening the door of saving more energy.

The key working principle of DWS algorithm is that a BTS estimates its traffic load and collects those of the neighboring BTSs and then dynamically decides its state of operation. Thus, the decision on the operation state of a BTS fully depends on one-hop neighborhood traffic load information and thus DWS is a fully distributed algorithm. The simulation results indicate that our proposed algorithm is capable of saving energy as much as 64% and 28% comared to always-on and Eco-Inspired [6] policies, respectively. Such amount of energy saving greatly reduces the network's operational expense (OPEX) and total energy consumption of the ICT sector will be decreased.

The rest of the paper is organized as follows. In Section 2, we present a number of related works on green cellular communication network. The network model and assumptions are discussed in Section 3, the proposed DWS algorithm is described in detail in Section 4 and the energy consumption analysis are shown in Section 5, performance evaluation is described in detail in Section 6. The Section 7 concludes the paper along with few future research directions.

## 2. RELATED WORKS

Global warming has emerged as a serious threat to the civilization of the Earth, while $CO_2$ emission is being considered as the primary cause for this phenomenon. In addition, the increasing cost of energy has become a major part of network operating cost. For instance, the access network and the core network of a cellular network infrastructure contribute to 80% and 20% of the total energy costs, respectively. More specifically, over 50% of cell operating expenditure is spent to power up BTSs [3]. On an average, a cellular core network consumes approximately 10 kW, whereas a typical universal mobile telecommunication system (UMTS) cell site arrangement consisting of power amplifier, cooling system, signal processors and feeders consume 6 kW. Notably, the power requirement only for the Node-B lies between 500W and 3000W, whereas transmit power of BTSs varies between 1W and 40 W [8]-[1]. Accordingly, reduction of energy consumption in networks has become a key challenge.

Turning off some BTSs during low traffic periods, cooperatively sharing BTSs among operators, use of sectored cells, reducing cell size, improving BTSs requiring less cooling are some of the techniques for improving energy efficiency in cellular access networks[8], [1]-[12]. Scheduling sleep/wake-up periods enables electrical equipments to switch among several low power and high power states depending on instantaneous tasks to be performed. Power requirement varies substantially among these states. Analysis of sleep/wake-up technology for reducing energy consumption has been much explored in diverse fields of communication networks [2]-[10]. Switching-off BTSs in lower traffic situations has been proposed for future long term evolution (LTE) systems [12]. However, the standard so far does not specify implementation schemes.

At present, BTSs work on the 'Always-ON' operating principle irrespective of the total traffic load on it. Keeping their entire equipment set ON at relatively low traffic times, a huge amount of energy is being wasted, which eventually adds to the operating expenditure of the network. In addition, the network capacity remains underutilized during that low traffic period. Therefore, if some BTSs are switched into low power state during low traffic times such that they have no traffic to handle, huge amount of energy could be saved, thus saving a significant portion of operating expenditure (OPEX). In addition, this will improve the efficiency of network capacity utilization[6].

A proposal on switching off BTSs during off-peak periods is presented in [1]. Nevertheless, the proposed scheme is manually operated which is not suitable for sustainable systems. In addition, in case of an emergency arises during switch off period such that the traffic generation increases unexpectedly, many subscribers may experience service interruption. Therefore, solutions capable of making access networks more energy-efficient by reducing the number of active BTSs during off-peak periods and at the same time achieving more autonomy in the network as well as guarranteeing the service availability are indispensable [6]. Fortunately, from the study of practical traffic patterns, it has been realized that for a significant portion of a day, total traffic generation of different classes in a BTS remains relatively low compared to the capacity of it [9]-[4]. Moreover, peak time and off-peak time also varies from area to area. Therefore, this inherent traffic characteristic has in fact been advantageous in implementing wake-up technology in cellular networks.

A wake-up scheduling approach for BTSs in cellular networks has been introduced in Eco-Inspired[6] and it has much similarities with our approach. However, our DWS has the following distinct differences: *first*, Eco-Inspired uses only *sleep* and *on* states, but DWS exploits three states of BTS operation: *off*, *sleep*, and *active*; *second*, BTSs in Eco-Inspired try to form pairs for sharing loads in between them, however in DWS, all BTSs under a cluster (typically 4 or 7 cell cluster) coordinate with other and try to maximize the number of *off* and *sleep* BTSs by sharing loads with others; *third*, Eco-inspired allows a highly-loaded BTS to share its load with others, increasing the burden of the neighboring BTSs which may lead them to have load over higher threshold, whereas, DWS never allows highly loaded BTSs to share their load, rahter it tries to turn off the least-loaded BTS through load-sharing with any moderately loaded BTS.

## 3. NETWORK MODEL AND ASSUMPTIONS

We assume a celluar network with large number of BTSs, where each BTS has the same transmission range, i.e., cells are of equal size. We also consider that cells are organized into clusters and neighboring 7-cells form one cluster. For energy-efficient operation of BTSs, each BTS has threee different modes of operation: *active*, *sleep* and *off*.

- *active* mode: The BTS is fully functional as conventional BTSs. Control and data channel circuitries are powered on and both the transmission and reception continue as usual.

- *sleep* mode: The BTS neither transmits nor receives any user traffic, rather a wake-up module, consuming negligible power compared to *active* mode, located at each BTS remains active to 'hear' any request from other BTSs to switch in to *active* mode in the event of higher traffic arrival rates or sudden failure of a neighboring BTS. It also senses any request of power increment. On hearing the wake-up signal, a BTS is able to switch from *sleep* to *active* mode within a very short time.

- *off* mode: In this mode, the BTS remains disconnected from the power supply. A BTS can switch into *off* mode only if it sees at least one *sleep* BTS in the neighborhood. A timer circuitry is used to trigger the BTS to switch to *active* mode from *off* mode. The circuitry will periodically trigger BTS on after a certain period of time. During this short 'on' period, the BTS checks the existence of any sleep or off BTSs in the neighborhood; if no such BTS exists, it will switch to *sleep* mode, otherwise, it returns back to the *off* mode.

We consider each BTS is covering a uniform hexagon area and periodically shares it's measured traffic load with its one hop neighbor BTSs and thus the neighborhood traffic load knowledge of each BTS is updated.

# 4. PROPOSED ALGORITHM

## 4.1 Basic Idea

In DWS, every *active* BTS can make its own decision, such as, when to switch to *sleep* or *off* mode and when to be in *active* mode. A BTS can dynamically decide its operation mode whenever it has updated traffic knowledge of itself and the neighborhood BTSs. An *active* BTS, now covering any other BTS's area (i.e., sharing traffic loads of others), will not be able to switch in *sleep* or *off* mode till it releases others load (even though its selfload decreases to very low value). A BTS having least traffic load in its neighborhood will try to transfer its load to another BTS and, if possible, will go to *off* mode if there exists at least one *sleep* BTS in its neighborhood; otherwise, it will switch to *sleep* mode.

## 4.2 Load Sharing Technique

Every underloaded BTS tries to share its traffic with one of its neighbor BTSs carrying moderate traffic load. The most underloaded BTS within its neighborhood will first get chance to share its load with others and then switch to *sleep* or *off* mode. If the BTS finds at least one *sleep* BTS in its neighborhood, then it will go to *off* mode; otherwise, it will move to *sleep* mode. Following the same rule, the other underloaded BTSs will also try to switch to *off* mode if load-transfer is possible.

Lets term the BTS transferring its full load to another BTS as the "Reluctant BTS" and the load receiving BTS as the "Carrier BTS"; and, we call the other BTSs as "Typical BTS". When a "Typical BTS" wants to share its load to its surroundings, at first it will try to share its load to the highly loaded "Carrier BTS" and if not possible then it will look for the 2nd highly loaded "Carrier BTS" and thus it will continue its steps. If there is no such "Carrier BTS" then the "Typical BTS" will share its load to another "Typical BTS" whose load is higher. In this case, the former "Typical BTS" will be termed as "Reluctant BTS" and the later one as "Carrier BTS".

We must ensure that no "Carrier BTS" will go to *sleep* or *off* state unless it removes its sharing and thus return back to a "Typical BTS". When a "Carrier BTS" sees that the traffic has become higher than its capability in its covered area, then it will pass a wake-up signal to the *sleep* BTS within its surroundings. After getting this signal, the *sleep* BTS will turn on and will act as a "Typical BTS". After that the "Carrier BTS" will remove its extra load and give it to the "Typical BTS" which has recently turned on. We also must ensure that after a certain time period an *off* BTS will turn on and checks whether there exists at least one BTS in *sleep* mode in the neighborhood, if true, it will then go to *off* mode again; otherwise, it will switch to *sleep* mode.

In figure 1 let BTS 1 has minimum load and it will now try to share its own load to its neighbor BTSs. At first, BTS 1 makes a sorted list of neighborhood BTSs in descending order of their loads; and, then it sums up the remaining traffic loads (i.e., full capacity of a BTS - current load) for all the neighbor BTSs. If the remaining load < BTS 1 load, then it will not take any further decision; otherwise, it will continue to the next step.

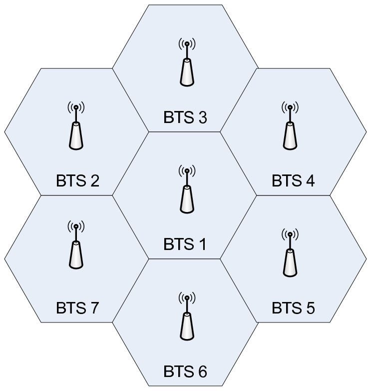


**Figure 1: 7-Cell Configuration**

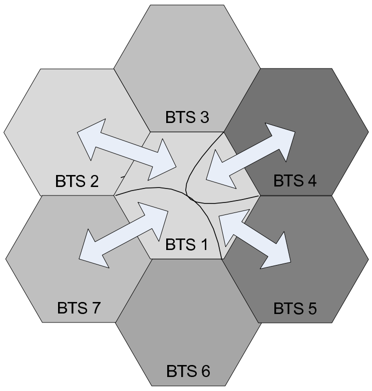


**Figure 2: Load-sharing technique**

Now, BTS 1 tries to transfer its full load to the first BTS of the sorted list, if fails, a partial load is shared and then it tries to share its load with the second BTS of the list and continue this process till its load becomes zero. The process is shown in figure 2. When BTS 1 shares its full load, it checks if at least one sleep BTS is present in its surroundings. If it finds a sleep BTS then it moves to *off* mode; otherwise, it switches to *sleep* mode.

## 4.3 Traffic Load Measurement

Measurement of traffic load of a BTS is needed by our DWS algorithm for determining the BTS mode of operation. There may have different types of traffic originating from different mobile stations (MSs) and producing data packets of varying traffic rates. We have grouped all types of traffic into six major categories. They are shown in table 1.

The multimedia traffic transfer uses the highest data rate and the lowest data rate is used for text messaging. Device type also has an affect in user workloads. The size and resolution of the display varies considerably in laptops, PDAs and data-phones, and the amount of data received is correlated with the display capabilities [11]. Four simplex channels are needed to exchange synchronization and data

**Table 1: Traffic Classification**

| Category | Content |
|---|---|
| Voice call | Audio |
| Video call | Audio and video |
| Internet browsing | Usual web surfing, chatting |
| Multimedia | Text, Image, Video, Hologram Annimation, Graphics |
| Voice search | Audio and browsing |
| Online game | Audio and video, Graphics |

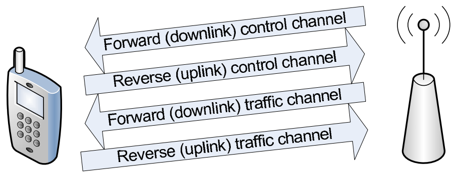


**Figure 3: Uplink and downlink channels**

between BTS and MS. Such an action is shown in figure 3.

The amount of traffic load in uplink and downlink channels depends on application and device. We have considered the uplink and downlink traffic load separately. We have used EWMA (Exponentially Weighted Moving Average) method for estimating the traffic load of a BTS. Data packets of varying sizes with varying speed are exchanged between the MSs and the BTSs. There are six states and changing of these states is responsible for traffic load variation in a BTS. The states are:

- Register with a Base Station (BS): Each MS must need to be registered to a BS.
- Unregister from a BTS: When a registered MS moves out of a BTS the BS unregister that MS.
- Switch to active mode: When a registered MS starts to receive or send Data, it's state switches to active mode.
- Switch to inactive mode: When a registered MS stop to receive or send Data, it's state switches to inactive mode.
- Handoff as active user into a BS: Handoff refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another. Here handoff performs handing over an active MS from a BS to another BS.
- Handoff as active user from a BS: During handoff, an active and registered MS becomes unregistered from its previous BS.

The algorithm for measuring the traffic load of a BTS is described here. The estimated traffic load $TrafficLoad_{est}$ is the time average traffic load of a node. The current traffic load $TrafficLoad_{cur}$ represents the measured traffic load during a time interval $T$. Therefore, the estimated traffic load is calculated using the Exponentially Weighted Moving Average (EWMA) formulae as follows:

$$\begin{aligned} TrafficLoad_{est} &= (1-\alpha) \times TrafficLoad_{est} \\ &+ \alpha \times TrafficLoad_{cur}, \end{aligned} \tag{1}$$

where, $\alpha$ is the weight factor, which gives more weight to the previously observed loads and less weight to the current load. Here, the current traffic load is measured during a predefined time interval $T$ as follows:

$$TrafficLoad_{cur} = \sum_{k=1}^{traffic.type} M_k \times N_k, \tag{2}$$

where, $M_k$ represents the data transfer rate of the traffic category $k$ and $N_k$ is the number of active users of that category under the incumbent BTS. The traffic measurement procedure is detailed in Algorithm 1.

**Algorithm 1** Traffic Measurement Algorithm, *for each BTS*

**INPUT**: M: *set of data rates of different traffic types*, N: *set of active users*;
**OUTPUT**: $TrafficLoad_{est}$

```
while True do
   if Timer Expires then
      TrafficLoad_cur = Σ_{k=1}^{traffic.type} M_k × N_k;
      TrafficLoad_est = (1 − α) × TrafficLoad_est + α × TrafficLoad_cur;
      Start timer T;
   else
      Wait for the timer to expire;
   end if
end while
```

## 4.4 Distributed Wake-up Scheduling Algorithm

In algorithm 2, we present our distributed wake-up scheduling algorithm, DWS. Here, *Selfload* represents the traffic load of the BTS that is applying the algorithm. $Load_n$ is the set of traffic loads of its adjacent BTSs sorted in descending order of their traffic loads. Each BTS considers its adjacent BTSs numbered from 1 to 6. Also, $\beta$ is the load sharing safety margin used for network security purpose. For instance, $\beta = 10$ means that a BTS can share traffic loads of other underloaded BTSs till its load reaches to 90% (=100-10) of its capacity. Thus, it helps in maintaining sustainability of the network in catastrophic condition, for example, sudden surge of data traffic generated from more MSs under its coverage area.

Each BTS checks whether there is a neighboring BTS that has traffic load density less than itself. If it finds such a neighboring BTS, it stops running the algorithm. The most underloaded BTS then calculate the *Shareable Load (SL)*, which is the aggregation of the amount of traffic loads that the neighboring BTSs can share, see line no. 6 in algorithm 2. If $SelfLoad > SL$, it means that the load-sharing is not possible and thus the algorithm stops (lines 7 to 9).

Now, the underloaded BTS tries to share it's traffic load with it's neighbor BTSs in order of their decreasing traffic load. It first tries to share it's load with a "Carrier BTS" that has higher load than others. If it can share it's fulload, its $SelfLoad$ is updated to zero and the control exits from the loop (lines 11 to 14); otherwise, it starts to share partial load and goes for the second highest loaded BTS. This process continues till its full load is being shared (lines 16 to 17). After sharing the full load, the "Reluctant BTS" checks if there exists at least one *sleep* BTS in the neighborhood area, if true, it moves to *off* mode of operation; otherwise, it switches to *sleep* mode.

**Algorithm 2** DWS Algorithm, *at each BTS*

**INPUT**: $SelfLoad$ : *Current total traffic load of this BTS in percentage of the its maximum capacity,*
$Load_n$ : *Total traffic load of all neighbor BTSs sorted in descending order of their loads*
$SafetyMargin(\beta)$ : *Traffic load percentage of the maximum capacity of a BTS that can not be shared with other BTSs*
**OUTPUT**: *Decision on BTS operation mode*

```
for each BTS i ∈ Load_n do
  if SelfLoad > Load(i) then
    return;
  end if
end for
SL = Σ_{i=1}^{6} {100 − (Load(i) + β)};
if SelfLoad > SL then
  return;
end if
for each BTS i ∈ Load_n do
  if SelfLoad ≤ 100 − (Load(i) + β) then
    Load(i) = Load(i) − SelfLoad;
    SelfLoad = 0;
    exit();
  else
    SelfLoad = SelfLoad − {100 − (Load(i) + β)};
    Load(i) = 100 − β;
  end if
end for
if at least one adjacent sleep BTS present then
  Go to off mode;
else
  Go to sleep mode;
end if
```

# 5. POWER CONSUMPTION ANALYSIS

Total power consumption per day in our network can be calculated as the sum of the energy for powering up the BTS components and control signalling and that for data packet transmission or reception. Therefore, the controlling power

$$P_{control} = p_{on} + \alpha \times p_{control}, \tag{3}$$

where, $p_{on}$ is the power required for keeping the BTS components on and $p_{control}$ is due to the exchange of control messages in between BS and MSs. For typical BTSs $\alpha = 1$ and for carrier BTSs $\alpha = k \times p_{inc}/6$, where, $p_{inc}$ is the total power required due to covering additional 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

$$P_t = \sum_{j=1}^{m} p_{self_j} + \sum_{k=1}^{m} p_{ext_k}, \tag{4}$$

where, $p_{self_j}$ is the transmission power for MS $j$ in it's own area and $p_{ext_k}$ is the transmission power for MS $k$ in the extended area. Therefore, combining the Eq. 3 and Eq. 4, the total energy consumption per day considering $N$ BTSs is calculated as

$$P_{total} = \sum_{i=1}^{N} \int_{t=0}^{24hrs} \{st_i(p_{on} + \alpha p_{control} + \sum_{j=1}^{m} p_{self_j} + \sum_{k=1}^{m} p_{ext_k})\} dt \tag{5}$$

where, $st_i$ is a binary variable; $st_i = 1$ for *active* or *sleep* mode and $st_i = 0$ for *off* mode operation of BTS $i$.

Moreover, transmission power $p_t$ for a MS is a function of receiving signal power $p_r$ as:

$$p_r = \frac{A_e G_t p_t}{4\pi d^2} \tag{6}$$

where, $A_e$ is the effective area covered by the transmitter, $G_t$ is the transmitting antenna gain and $d$ is the distance between MS and BTS. The value of $P_t$ is directly proportional to the square of the distance the signal travels. The value of $p_t$ should be such that, $p_r \geq$ minimum required signal power. In summary, the amount of saved energy using DWS algorithm is huge compared to a traditional network.

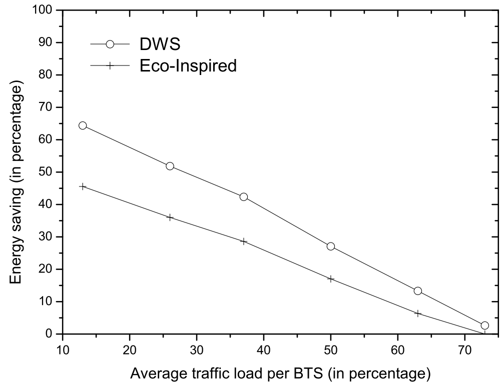


**Figure 4: Energy saving vs. traffic load**

# 6. PERFORMANCE EVALUATION

We have considered a geographical area covered by 35 uniform hexagonal shaped macro cells having equal capacity and placed side by side such that there are no dead zones. A Poisson distributed random process is used to generate traffic of different types in the area which models the random fluctuations of the total traffic. Different data rates for different types of traffic, multiplied with the number of MS of that type, generated total traffic of a particular type and total network traffic is calculated by adding the total traffic of different types. The traffic is measured for different patterns considering traffic fluctuations over time (i.e. peak hour, off-peak hour). The simulation is done considering total time as 24 hours and the values presented in the graphs are found by taking average of 10 simulation results.

Figure 4 shows the amount of energy savings in percentage for varying traffic loads per BTS. The value of load sharing safety margin ($\beta$) is kept at 10%. Average traffic load is found by dividing the total traffic load of the network by the total number of BTSs. It shows the amount of energy that can be saved for different traffic loads for two different schemes: our proposed DWS and Eco-inspired[6]. We

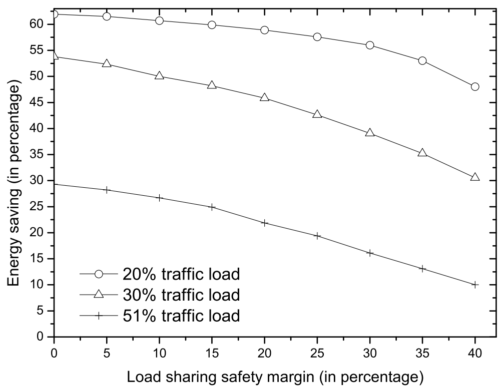


**Figure 5: Energy saving vs. load sharing safety margin**

observe that for 12% traffic load, our DWS algorithm can achieve 28% more energy saving compared to Eco-inspired and as the traffic load increases the energy saving gap between the two algorithms gradually decreases. We aslo notice that when the traffic density level increases to higher value and crosses some saturation level (e.g., 73%), there remains no room for acheiving energy saving in both the algorithms. This is because the process of traffic sharing becomes impossible for higher traffic load.

An in-depth look into the obtained numerical results also reveals that the sustainability of DWS algorithm is higher than Eco-inspired. More accurate measurement of BTSs' traffic loads and judicious decisions on their traffic load sharing makes it more robust. Consideration of three operation modes including *off* mode in DWS helps to acheive substantial energy saving difference with Eco-inspired.

Figure 5 shows the energy saving achieved by three distinct average load levels of BTSs for different load sharing safety margin ($\beta$) values. As the value of safety margin increases, the percentage of energy saving decreases slowly. This is because the scope of load sharing shrinks. We also observe that, at 0% safety margin, the amount of energy saving when the network is with 20% traffic load is almost double of that when it is 51% loaded. Interesting fact is that as the safety margin increases the above energy saving difference also pronlogs (e.g., 2.5 times at 20% margin, 4.8 times at 40% margin). This result goes with the theoretical expectation since the scope of sharing load of others diminishes when the network is in moderate to high load. On the otherhand, at low network traffic load there is much room for energy saving as more number of BTSs can be turned off through transferring the traffic load to underloaded BTSs.

The obtained data values also states that if we increase the value of load sharing safety margin at higher values, at some point the energy saving will not be possible because BTSs will not be able to share others load.

# 7. CONCLUSIONS

In this paper, we have developed a distributed sleep/wake-up scheduling algorithm (DWS) for BTSs in cellular network and also developed a traffic measurement algorithm for estimating the current traffic load of a BTS. The algorithm increases the energy saving of a BTS by dynamically changing its modes of operations: *off, sleep, active* based on its estimated traffic load and neighborhood load conditions. Simulation results state that the DWS can save as much as 28% more energy compared to a state-of-the-art approach Eco-Inspired [6].

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