# A Protocooperation-based Sleep-Wake Architecture for Next Generation Green Cellular Access Networks

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*Abstract*—**The rapidly increasing contribution towards global warming from the information communication technology (ICT) sector is a clear indication of the need for energy efficient green communication networks. For instance, in the case of cellular networks, over 80% of the total energy is consumed at the access network. On the other hand, incorporating self-sustainability and autonomy in its operation, control, and maintenance is significantly vital due to relatively larger sizes, higher complexities, and dynamic behaviors of future networks than those of current networks. In this paper, with the inspiration from the ecological principle of protocooperation, a novel energy efficient cellular access network architecture is proposed. With the adoption of the wake-up technology, base transceiver stations (BTSs) are made to protocooperate with each other to achieve higher energy efficiency within a cellular access network. Protocooperation is one of the ecological interactions by which two interacting species gain benefit through cooperation. However, this type of cooperation is not compulsory for the survival of any of these two species. To accomplish less energy consumption and higher self-sustainability at the access network, BTSs cooperatively and dynamically switch between active and sleep modes depending on the current traffic situation. The extent of self-sustainability incorporated in the proposed architecture is studied and analyzed. As per the result, our proposed architecture and algorithm are capable of achieving a significant amount of energy saving, which is an important step towards a self-sustainable green communication system.**

***Keywords-NGMN, ecologically inspired networks, green networks; protocooperation; self-sustainablity***

## I. INTRODUCTION

To meet the continuously increasing subscriber demand for diverse applications, reducing operating costs and increasing the revenue of telecom service providers, communication technologies have been continuously evolving. Hence, the next generation mobile network (NGMN), commonly known as the 4G system, needs to be truly self-sustainable and ubiquitous capable of delivering service guarantees for dissimilar types of data traffic. Therefore the NGMN must support the coexistence and interaction among different heterogeneous technologies for delivering subscribers' and operators' service requirements [1-2].

On the other hand, global warming has recently attracted much attention as it may eventually become a serious threat to the human civilization. $CO_2$ emissions, due to fossil fuel burning, is said to be one of the primary causes. It is estimated that in 2007-2008, 3% of the world energy was consumed by the ICT industry, which accounts to 10% of the world's electrical energy consumption [3] and emitted approximately 2% of the worldwide $CO_2$ emissions. This amount is equivalent to the world-wide $CO_2$ emissions by airplanes or one quarter of the world-wide $CO_2$ emissions by cars [4].

Energy consumption at the cellular access network is also a significant contributor to the total operating expenditure of network operators. Energy consumption in communication networks is increasing exponentially and every four years, the volume of data exchanged over the ICT infrastructure more or less doubles, which corresponds to another 100% increment of the consumption [4]. At present, 37% of the total carbon emission resulting from the ICT industry is from telecom infrastructures and devices, while the remaining 63% comes from end user devices and data centers [5]. Due to the rapid increase in broadband Internet traffic over the next few years, the ratio of the emissions in the network infrastructures to the total ICT emissions will significantly increase. Therefore, the quest for energy efficient future networks or next generation 'True' green communication networks has become one of the top priorities of communication researchers. In addition, to be fully self-sustainable, a network must also be highly energy efficient. A self-sustainable network is self-organizing, self-adapting, self-managing and self-optimizing, and ideally capable of serving its subscribers in any situation.

In this paper, an energy efficient enhanced cellular access network architecture and an algorithm based on the principle of ecological protocooperation is proposed. The cell sites (BTSs, node-Bs and access point (APs)) are made to cooperate with each other for optimizing the energy saving within cellular access networks. From now on, in order to maintain consistency, we will use the general term BTS for all types of cell sites. Wake-up technology is adopted in our proposed system for implementing this particular form of cooperation [6-11]. The proposed sleep/wake-up enabled BTSs are able to operate in any of the following three modes – active, sleep and OFF. A BTS is capable of dynamically switching between active and sleep modes depending on the network traffic situation. OFF mode can only be activated by an operator. According to the argument presented, the proposed architecture is distributed, adaptive and autonomous.

The proposed architecture and algorithm shows that a significant amount of energy can be saved at the cellular access networks level, which will eventually reduce the carbon footprint and network operating cost. This will also be a

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considerable step towards achieving self-sustainability in cellular access networks.

The rest of the paper is organized as follows: Section II provides an extensive literature survey on energy efficient access networks which would clear our motivation behind this proposed system. Section III provides a short overview on ecological system and its sustainability. Section IV presents our proposed system model, followed by the details of our algorithm with a flow chart in Section V. Section VI presents the simulation setup with an evaluation of the results and a discussion, followed by our concluding remarks.

## II. Energy Efficient Cellualr Access Networks

Undoubtedly, ICT will be one of the major carbon contributors in the coming years unless energy efficient technologies, standards and protocols are introduced. By doing so, the ICT industry will also play a key role in reducing $CO_2$ emissions. A list of renowned telecom companies and their own target for reducing carbon emissions by 2020 is available from [5].

In 2007, cellular network infrastructure around the world consumed a total energy of 60 TWh. The radio access networks consumed 80% of this energy. For example, a large portion of this energy is used for cooling infrastructure of BTSs. More than 50% of cell-site operating expenditure is spent to power up base stations [4]. On the other hand, the average consumed power at a cellular core network (CN) is 10 kW. A typical universal mobile telecommunication system (UMTS) cell site arrangement consisting of a low noise amplifier (LNA), air conditioner (AC), digital signal processor (DSP) and feeder from radio network controller (RNC) to Node-B consumes an average of 6 kW power. Notably, the power requirement only for the Node-B lies between 500 W and 3000 W, while transmit power of carriers of BTSs varies from 1 to 60 W [12-16]. As a result, improving the cellular network infrastructure in such a way for reducing the energy consumption has recently gained a significant attention. For example, shutting down some BTSs during low traffic time, high efficiency transmission scheduling, decreasing the size of the cells, design of improved BTSs which requires less cooling, sharing BTSs among different operators, using sectored cells, using renewable energy sources are some of the techniques for improving energy efficiency in access networks [12, 16]. In this paper, wake-up technology is identified as a potential solution applicable for the aforementioned power consumption problem.

Wake-up technology has shown a great potential to reduce energy consumption in diverse fields of applications. This technology makes electrical and electronic devices capable of operating in multiple power modes so that they can switch to a low power state when devices need not keep all the sections in power mode and then wake-up with the reception of a special data packet to go to active mode for transmission and/or reception. The power requirement varies substantially among operating modes. For example, a desktop personal computer (PC) can generally be operated in four different modes – active, idle, sleep and hibernate at which the typical power consumption is 140 W, 100 W, 1.2 W and 1.0 W respectively. Similarly, typical Wi-Fi user equipment (UE) consumes 400 mW, 1000 mW and 1100 mW in connected/idle mode, searching mode and active transmission/reception mode respectively [17].

Applicability and possible incentives of introducing the wake-up technology for communication networks have been investigated for the last few years [6-11]. Different wake-up scheduling algorithms for increasing the life time of sensor networks as well as for maintaining the required quality of service (QoS) have been proposed [6-7]. For Ethernet, power saving mechanisms by deactivating some links and routers during the lower traffic time has been studied in [8]. Few analyses of sleep mode and wake-up technology for Wi-Fi APs and battery powered end user devices are also available from [9-10]. Further energy saving through switching between wireless and wired networks in office environments based on the data rate requirement by allowing the unused network to go into sleep mode is investigated in [11]. All the aforementioned published results have established the great promise of this technology by significantly increasing the life time of battery operated isolated devices and substantially reducing the energy consumption in these networks.

Switching-off BTSs in lower traffic situation has already been proposed for future long term evolution (LTE) systems [18]. Switching off schemes for some BTSs during off-peak periods to enhance the energy efficiency in the access networks have also been proposed in [15-16]. The assumptions of same traffic with similar patterns in all BTS and the use of simplified smooth traffic model made the proposed system as a theoretical one. Switching off is a hard decision and this is critical as the response time of many other related equipment such as ACs and computers are crucial. Moreover, in case, an emergency condition arises during switch off time and the traffic generation increases unexpectedly, many users may experience service interruption. However, solutions capable of making access networks more energy efficient by reducing the number of active BTSs during off-peak periods as well as guarantying the service availability are indispensable. This has driven us to this proposed scheme.

To the best of our knowledge, wake-up technology has not been applied to a cellular scenario. Nevertheless, we believe that by applying this technology in BTSs will not be as straight forward as in the case of previous applications. For example, highly dynamic nature of the network due to roaming users between BTSs, unpredictable mobility pattern and channel holding times of users, maintaining QoS of the services, wide coverage area per BTS, limited BTS capacity, time variant channel characteristics are some of the key factors to be considered in such a scenario. Therefore, a careful design and analysis is required before deploying wake-up technology in cellular networks.

## III. Ecological Balance and Sustainability

An ecosystem is a system in which all types of living organisms and non-living physical components (both homogeneous and heterogeneous types) such as human, animal, plants, climate, landscapes, water etc. of a particular geographical area interact constantly with each other - directly or indirectly [19]. In a self-sustainable ecosystem, for example, Earth's ecosystem, all of its components can survive for an indefinite time.

Despite natural changes and instability in the Earth's ecosystem, the entire system regains its stability; hence it is arguably in a highly balanced and stable state. Self-organizing, self-managing, self-adapting and self-optimizing capabilities are the fundamental properties of the Earth's ecosystem which still maintains it in a highly self-sustainable state after millions of years. A self-organizing system consists of many small components, which works based on some basic local rules. Systems of this class, starting from an initial random state, with no guidance or help from any external body, emerge spontaneously in a well-organized structured system [20]. On the other hand, a self-adaptive system, consisting of a large number of interacting components, is capable of adjusting its parameters to the changes in the environment preserving its essential organization. Besides, a system capable of managing its resources and organization, in either optimal or non-optimal way, is a self-managing system. However, a self-optimizing system always attempts to optimize the utilization of its available resources.

Different types of interactions among large number of homogeneous and heterogeneous components in an ecosystem play a key role in maintaining its sustainability. Mutualism/ cooperation, competition, altruism, predation, parasitism, coopetition, protocooperation, commensalism and detritivory are the main interactions observed in the Earth's ecosystem [19, 21]. An interacting species either gets benefits, or loses something, or neither gets benefits nor loses anything from the interaction.

The Earth's ecosystem, which comprises of different heterogeneous components, can be considered analogous to the environment of an NGMN. Therefore, if the NGMN is considered as an ecosystem, then different networks connected to the NGMN can be thought to be analogous to different components of the Earth's heterogeneous ecosystem. Therefore, solutions based on the principles of the ecosystem can be appropriately applied for an NGMN. If communication networks are developed based on the principle of sustainability of the ecosystem, we believe that those networks would be also self-sustainable.

## IV. PROPOSED ARCHITECTURE

In this section, the details of our proposed system architecture and cooperation mechanism have been presented.

### A. *Cellular Access Networks: An Overview*

A typical cellular network mainly consists of two components – an access network and a core network. A cellular network can be interconnected with other public land mobile networks (PLMNs), public service telephone networks (PSTNs) and/or Internet through the core network. The access network and the core network together form the cellular network infrastructure. The access network mainly consists of several cell sites and cell sites controllers. A controller controls a group of cell sites. The cell site is known as a BTS in GSM/GPRS/EDGE and Node-B in UMTS, whereas the controller is termed as base station controller (BSC) and RNC in GSM/GPRS/EDGE and UMTS respectively. A simple view of typical cellar network is shown in Fig. 1.

At present, a BTS works on the 'Always-ON' operating principle, which means a BTS remains always ON irrespective of the traffic generation level to that BTS. Since the energy consumption of the currently used macro sites is effectively independent of traffic load, under any significantly lower traffic situations, keeping the entire equipment set ON requires a huge amount of energy [22], which eventually adds to the operating expenditure of the network operators. In addition, the network capacity also remains underutilized during the low traffic. Therefore, if some BTSs are switched into low power mode during low traffic times, considerable amount of energy can be saved, thus saving a significant portion of operating expenditure. More importantly, the network will become more energy efficient which in turn will facilitate the telecom industries to reduce their carbon footprint and achieve the committed target of carbon emission reduction. The network utilization can also be improved.

Fortunately, from the study of practical traffic patterns, it has been realized that for a significant portion of time in a day, user traffic generation remains relatively low compared to the capacity of a BTS. Besides, irrespective of the random fluctuation of user traffic, average traffic of each BTS of different classes also follows a particular pattern [23-24]. 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.

### B. *Sleep/Wake-up Enabled BTS*

As mentioned before, currently deployed BTSs remain ON 24 hours a day. In our proposed model, BTSs will be capable of operating in three different modes – active, sleep and OFF.

- Active mode: BTSs will remain fully functional as the conventional BTSs. Both transmission and reception would continue as usual.

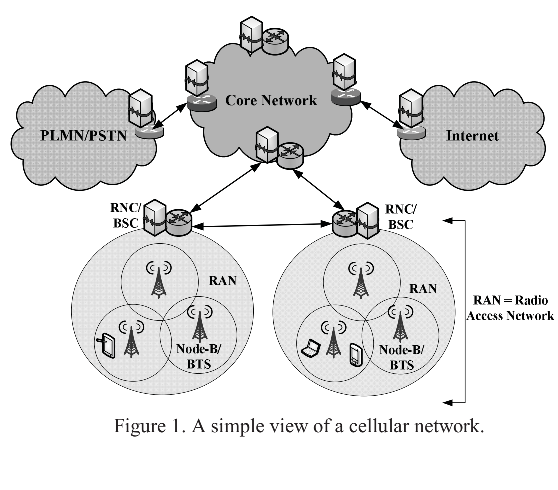


Figure 1. A simple view of a cellular network.

- Sleep mode: BTSs will neither transmit nor receive any user traffic, rather a small 'wake-up module' located at each BTS will remain active to 'sense' or 'hear' any request from other BTSs to switch in to active mode in the event of higher traffic arrival rates or the sudden failure of a neighboring BTS. It also sense any request of power increment. Low-power milliwatt range wake-up modules are currently being used in WLANs. Research on further improvements in terms of energy consumption (microwatt range) and size of these modules are currently underway [10, 25]. The power consumption in sleep mode will be negligible compared to active mode and if necessary, the BTSs will be able to switch to active mode from sleep mode within a very short time.
- OFF mode: The BTSs will remain disconnected from the power supply. This mode can only be initiated by an authorized human controller.

### C. *Protocooperative Cellular Access Networks*

Currently deployed BTSs work individually with no form of interaction with each other. However, there exist proposals for future generation LTE BTSs to be interactive and cooperative [26-27]. This cooperation can happen through traffic sharing, bandwidth sharing, intelligent handovers, exchange of information on channel conditions and network loading and so on, which will eventually make the access network self-sustainable.

In our proposed system, the BTSs interact with each other based on the principle of ecological protocooperation. In ecological protocooperation, two species cooperate with each other in such a way that both of them gain benefits through their cooperation. However, this type of cooperation is not mandatory for their individual survival. In our proposed system, BTSs do not necessarily need to interact and cooperate with each other for delivering quality services to its subscribers, but if they cooperate, they can save a significant amount of energy in addition to achieving a certain amount of autonomy and hence improve sustainability at the access network level.

Each BTS will be equipped with an extra functional block named the 'sleep/wake-up module', which will have two segments. The first segment named as the 'decision maker', which will make the decision of when to go to sleep, when to request other sleeping BTSs to wake-up, and whether any power increment is necessary. The second segment termed as 'wake-up module', is further mentioned in section IV. This sleep/wake-up module can also be set up in BSC in which case all BTSs will send their information to the controlling BSC and based on the information, the BSC will make the decision and command the BTSs as required. In this paper, we have not considered this BSC based option.

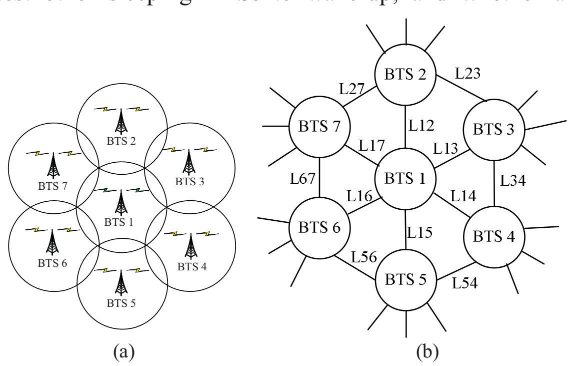


Figure 2. (a) 7-cell configuration, (b) Interacting model.

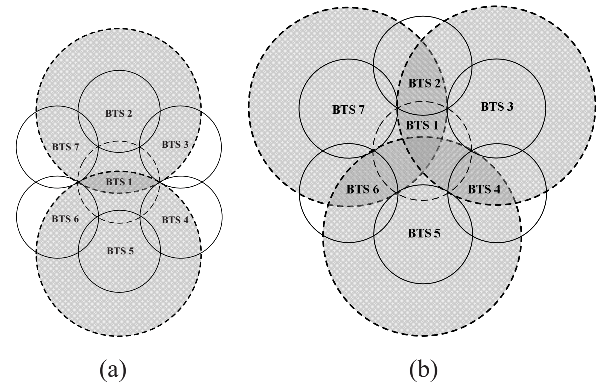


Figure 3. BTS 1 is in sleep mode, (a) BTS 2 and BTS 5 are acceptor BTSs, and (b) BTS 3, BTS 5 and BTS 7 are acceptor BTSs.

We have considered a standard 7-cell configuration where one cell is surrounded by six cells as shown in Fig. 2(a). Each cell directly interacts with its surrounding six cells and indirectly with other cells in the network via its surrounding cells. The interacting model is illustrated in Fig. 2 (b). Here, $L_{mn}$ is the link through which $m^{th}$ and $n^{th}$ BTS interacts with each other.

Suppose, the center base station, BTS 1 falls asleep, there must be an appropriate combination of surrounding BTSs which could support the traffic of BTS 1. For example, BTS 2 and BTS 5; BTS 3 and BTS 6; and BTS 4 and BTS 7 are the three 2-cell candidate combinations, which can share the load of BTS 1. There are also several other candidate combinations of 3 BTSs, 4 BTSs, 5 BTSs and 6 BTSs. In order to optimize the energy saving, the best, i.e., the best combination has to be chosen. For demonstration purpose, two candidate combinations of 2 BTSs and 3 BTSs are shown in Fig. 3. The extended coverage area is shown as shadowed and it is drawn assuming isotropic antennas at the BTSs.

A slight increment in transmit power of an acceptor BTS may require to support a larger coverage. A BTS is termed as acceptor BTS when it shares traffic of other BTS. For example, as shown in Fig. 3(a), BTS 2 and BTS 5 are acceptor BTSs. Power increment requirement of an acceptor BTS depends on its instantaneous traffic situation. If the total transmit power of an acceptor BTS is distributed among its current traffic (current traffic equals own users' traffic plus transferred users' traffic from other BTSs) and its total traffic is lower than a predefined threshold, it would not require to increase transmit power [16]. We assume that the transmit power in a particular sector of a BTS can be double at best so that the effective cell radius can be twice of the original radius. Nevertheless, any of the suitable available radio propagation models can be used to estimate transmit power requirement.

However, if only a slight increment in transmit power is required, it will not contribute a significant amount to the total energy consumption since the transmit power is very low compared to the total power requirement of an active BTS. Rather, more energy can be saved by allowing an active BTS to go to sleep with a slight increment in the transmit power of the acceptor BTS. Fortunately, most of modern BTSs have the capability of programmable transmit power. In our proposed system, the transmit power is programmable only when a BTS acts as an acceptor BTS. It can be speculated that the interference problem may not be much crucial for these power increments as an active BTS goes to sleep. In addition, if we use sectored cells and directional antennas, interference can be easily managed and kept under QoS limit.

## V. PROPOSED ALGORITHM

In our proposed algorithm, every active BTS makes its own decision independently; i.e., when to go to sleep, and when to request other sleeping BTSs to share its traffic based on the current traffic information and operating modes of its own and other BTSs. If the requested BTSs are ready to cooperate by accepting the transferred traffic, then the requesting BTS can implement its decision. However, a sleeping BTS cannot request other BTSs to wake-up or to sleep as only wake-up module will be in active mode.

As illustrated in Fig. 4, our proposed Sleep-Wake (SLAKE) algorithm is as below:

- Each BTS activates its decision maker after every particular interval. This particular interval can vary from network to network. If the total traffic in a BTS falls below a threshold $\lambda_{Low}$ (Fig. 4(a)) or increases above another threshold $\lambda_{High}$ (Fig. 4(b)), the decision maker runs its algorithm to make a decision whether to go to sleep or to request other BTSs to wake-up for sharing its traffic. In order to distribute the traffic, the traffic of the acceptor BTS (i.e., existing own traffic plus transferred traffic) should be below than another predefined threshold $\lambda_{Surr}$. Numerous trials or an optimization technique can be used to find out these threshold values which are network and operator specific.
- As per Fig. 4(a), if the total traffic is lower than $\lambda_{Low}$, a BTS searches for the best combination among the candidate combinations of surrounding BTSs, which could handle its full traffic and allow it to go to sleep. Candidate combinations are the combinations of only active BTSs. A BTS does not request other sleeping BTSs surrounding it to wake-up to take its traffic since this does not increase the number of sleeping BTSs in the network. If there is no candidate combination to share the traffic, this BTS continues to operate with its lower traffic.
- As per Fig. 4(b), if the total traffic equals or rise above $\lambda_{High}$, a BTS tries to distribute its traffic to other BTSs. This distribution is important to restrict the loading of a BTS within a reasonable value such that the blocking probability in that BTS does not go beyond the accepted limit. In the proposed architecture, a BTS experiencing high traffic has four options to distribute its traffic. In the descending order of priority the options are: a) entire traffic distribution among the active BTSs surrounding it and then switching to sleep mode, b) partial traffic distribution among the active BTSs surrounding it so that its own traffic goes below $\lambda_{High}$ and then continuation to operate in the active mode, c) requesting other sleeping BTSs surrounding it to wake-up and distribution of the full traffic to them, and then switching to sleep mode, and d) requesting other sleeping BTSs surrounding it to wake-up and distribution of partial traffic among them so that its own traffic goes below $\lambda_{High}$ and then continuation to operate in the active mode. Through this priority order, the sleeping BTSs are allowed to sleep more unless it is absolutely necessary to wake them up. If none of the four options can be made, this BTS continues to operate with its higher traffic.
- If transmit power increment is necessary to provide the coverage, the acceptor BTSs may increase as necessary. Nevertheless, transmit power is programmable only when a BTS operates as acceptor BTS.
- Before going to sleep mode, each BTS decreases its transmit power within a short interval, which allow smooth handover for its users.
- After making the decision of going to sleep, no new user is allowed to connect a call with that BTS.

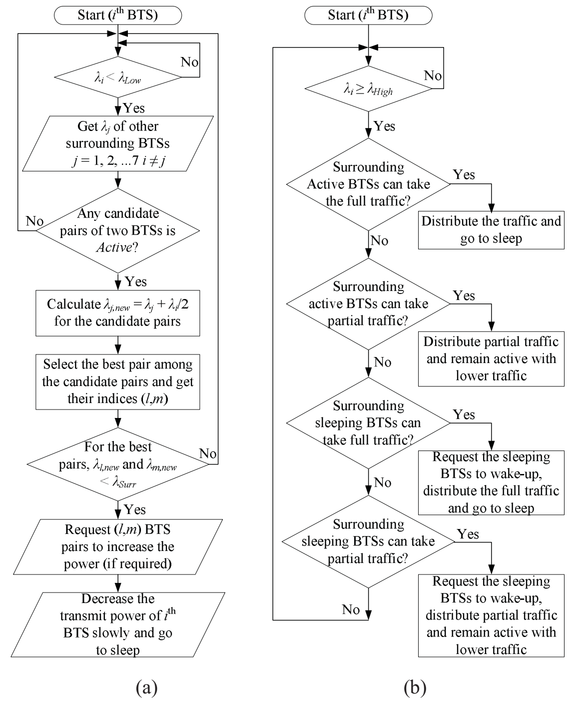


Figure 4. Flow diagram, a) sleeping procedure when the traffic is lower than $\lambda_{Low}$, b) traffic distribution procedure when the traffic is above $\lambda_{High}$.

## VI. SIMULATION, RESULTS AND DISCUSSION

### A. Simulation Setup

We have used MATLAB for simulating our proposed system. In our simulation, we have considered a geographical

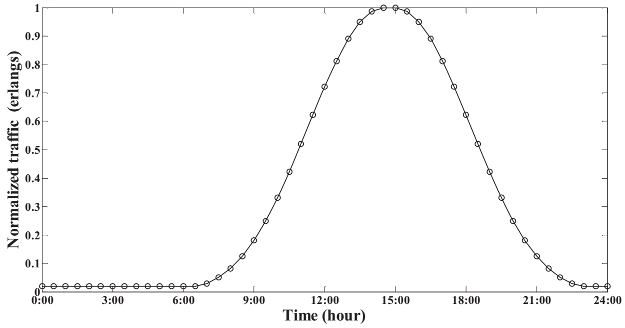

Figure 5. Sinusoidal traffic pattern of BTSs.

area covered by 180 overlapping macro cells having equal capacity of circular shape such that there are no dead zones.

Daily traffic pattern of a BTS can be approximated by a sinusoidal profile [23] as shown in Fig. 5. Although, this pattern is close to the practical patterns, it is a simplified model and we consider it as a theoretical model. We also believe that the presented analysis using this simplified model does not cause any harm to evaluate the prospect of the proposed sleep-wake architecture. However, in this paper, we have used the pattern with little modification to make it more practical which is given by,

$$a(t) = \frac{1}{2^b}\left[1+\sin(\pi t/12+\varphi)\right]^b + n(t) \qquad (1)$$

where, $a(t)$ is the instantaneous normalized traffic in erlangs; $\varphi$ is a uniform random variable in the interval $[0, 2\pi]$ which determines the distribution of traffic pattern among the BTSs; $n(t)$ is a Poisson distributed random process with parameter $\lambda_{mean}$ which models random fluctuations of the total traffic; and $b$ = 1, 3 which determines the abruptness of the traffic profile. Normalized traffic patterns $\lambda(t)$ are then generated for all the serving 180 BTSs by using equation (1).

We assume that the transmit power of carrier frequencies of acceptor BTSs is programmable, therefore power increment will be allowed if necessary. It is also assumed that the cells are sectored and hence the BTSs are equipped with directional antennas such that any power increment can be accomplished only in the specified direction for eliminating any deteriorating interference problems. To choose the best combination, we specifically considered two cell combinations. For clarity and convenience of the carried out simulations in this paper, normalized values for thresholds in erlangs are chosen as: $\lambda_{Low}$ = 0.5, $\lambda_{High}$ = 0.9 and $\lambda_{Surr}$ = 0.7 (these values are network and operator specific). The simulation time represents 24 hours of a day, which has been performed for three different cases: a) similar traffic pattern for each BTS, i.e., peak time and off-peak time coincides in all the BTSs, b) moderate variations in traffic patterns, i.e., peak time and off-peak time varies moderately among the BTSs., and c) relatively high variations in traffic patterns, i.e., peak time and off-peak time varies relatively high among the BTSs. This variation in peak period and off-peak period among the traffic patterns of the BTSs is induced through the random variable $\varphi$. All the evaluated results are presented and discussed below.

### B. Results and Discussion

Figure 6 illustrates the traffic pattern of a randomly taken BTS out of the 180 BTSs. Before the application of our algorithm, all BTSs are in active mode through 24 hours of the day. After the application of our algorithm, this BTS goes to sleep mode at 0:00 hrs and remains in sleep mode until 12:15 hrs. Then it wakes up and remains active until 18:45 hrs, and later on again sleeps from 18:45 hrs to 24:00 hrs amounting the total sleeping time for this BTS equals to 17 hours 30 minutes. Thus by sleeping, this particular BTS saves 72.9% energy consumption in comparison to always active operating mode. It is also observed that for a certain period (14:00 hrs to 18:30 hrs) of its active time, it carries more traffic than it would have been carried out in an 'Always-ON' cellular system.

In Fig. 7, the percentage of BTSs in sleep mode is plotted against time. Three lines in the figure correspond to three different pattern distributions as shown in the legend. It is evident from the plot that in a similar pattern scenario, for a certain period (from 0:00 hrs to 9:45 hrs), around 52% BTSs sleeps while the others remain active. The reason behind this is that this period corresponds to the off-peak period of the day and hence the aggregated traffic to the BTSs is very low compared to other part of a day. As the traffic pattern is similar in each BTS, off-peak time of all BTSs coincides, and hence less than half of the BTSs are enough to carry out the network total traffic. But, during the peak period, from 12:00 hrs to 18:00 hrs, many BTSs wake up to handle the increased traffic. This is obvious as the total traffic soars to reasonably high values at around 10:00 hrs (Fig. 5), sleeping BTSs starts

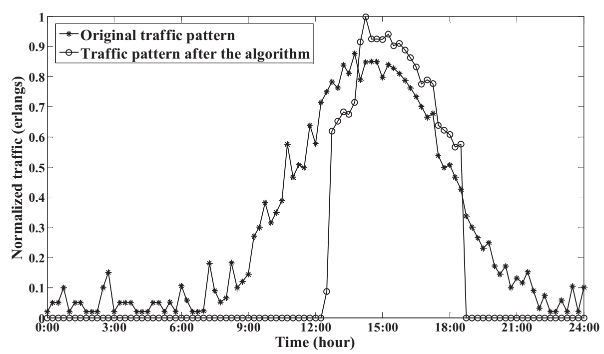

Figure 6. Traffic pattern of a randomly taken BTS.

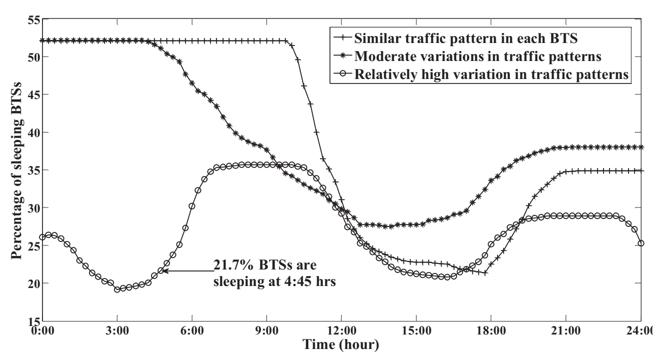

Figure 7. Percentage of BTSs in sleep mode.

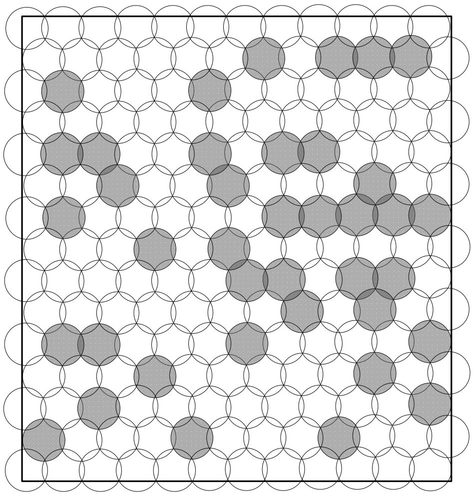

Figure 8. Geographical representation of BTSs in sleep mode (shadowed) and active mode at 4:45 hrs (corresponding to the point marked by arrow in Fig. 7)

to wake-up and hence percentage of sleeping BTSs decreases first rapidly and then gradually until the minimum reaches to 21.4% at 17:45 hrs (Fig. 7). From 17:45 hrs onwards, percentage of the sleeping BTSs again starts to climb up (Fig. 7) due to the declining total traffic (Fig. 5). For the other two scenarios, the percentage of sleeping BTSs fluctuates more over the entire day. Maximum fluctuation is observed in relatively highly different traffic pattern scenarios, which is obvious as the traffic pattern varies from BTS to BTS, so the off-peak periods of all the BTSs do not coincides and hence the fluctuation in percentage.

For a scenario of relatively high variation in traffic patterns, Fig. 8 illustrates which BTSs are in sleep and active modes at 4:45 hrs of a day. At this particular instance of a day, 39 out of 180 BTSs are in sleep mode. The BTSs in sleep mode are shown as shadowed. Therefore, at this time, around 21.7% BTSs are in a sleeping state and consuming minimal amount of energy barely sufficient for keeping wake-up module ON. This instance of time corresponds to the arrow marked point as shown in Fig. 7. This sleeping pattern of the BTSs changes from time to time. If the traffic decreases on the overall system, the number of sleeping BTSs increases and vice versa.

Number of hours spending in the sleep mode by the 180 BTSs is shown in three plots embedded in Fig. 9. Each plot in the figure represents a different traffic distribution scenario. The first one for similar traffic pattern in all the BTSs, the second one is for moderate variation in traffic patterns and the third one for relatively high variation in traffic patterns. From all these graphs, it can be observed that some BTSs may never go to sleep mode (viz., BTS 1-12, 169-180 and so on). Such BTSs are located in the border of the geographical area, where there are no appropriate BTS combinations to handover their traffic and hence cannot go to sleep at all. Remaining BTSs are able to spend a certain portion of daily time in sleep mode. There may be multiple times of a day that a BTS can go to sleep, which is not quite evident from Fig. 9. Average sleeping hours per BTS varies in these three scenarios – BTSs in similar pattern scenario can stay longer time in sleep mode compared to other scenarios. As evaluated, average sleeping time for the three scenarios is 10.2, 9.7 and 7.2 hours respectively and hence, energy savings are 42.5%, 41.0% and 30% respectively.

### C. *Sustainibility*

Our proposed access network is autonomous in decision making where BTSs decide themselves when to switch to sleep mode or when to switch back to active mode. BTSs are enabled with built-in intelligence for making decisions and cooperating with each other. No operator assistance is required for making such switching decision. Hence, we argue that the proposed architecture is self-organizing and self-adapting in nature. Depending on the traffic situation, the network reconfigures itself to serve its subscribers.

The proposed architecture is self-managing and self-optimizing in terms of energy saving. Despite the fact that BTSs can serve their subscribers independently, they protocooperate with each other to reduce energy consumption in the network. The network switches some of its BTSs to

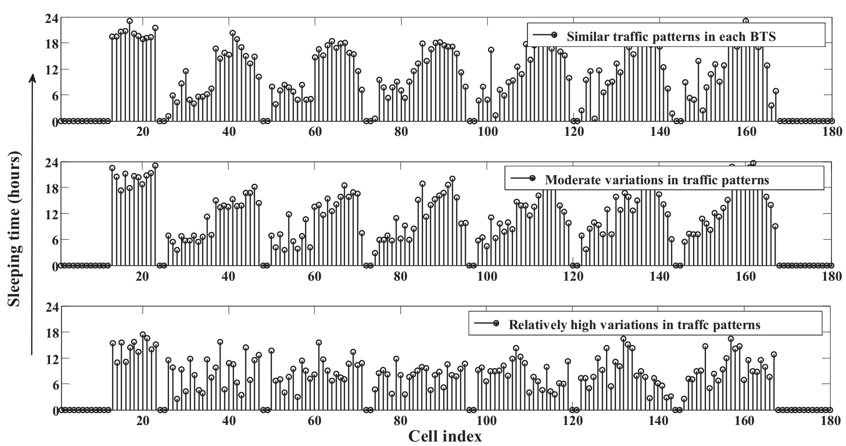


Figure 9. Average sleeping times of the BTSs.

sleep mode for saving energy when they are not required for serving subscribers. Selection of appropriate combinations of BTSs for distributing traffic is made based on the principle of optimizing the energy saving and improved network capacity utilization.

Since the BTSs exchanges information, if in any case a BTS fails due to unwanted causes like a natural disaster or a power failure, other BTSs will soon be aware about the failed BTS as they will not receive any signal from the failed BTS. By extending our proposed architecture, remaining BTSs can take care of the area left uncovered by the failed BTS. Thus the proposed access network has a high potential of assuring uninterrupted services to its users in the event of any service disruptions.

## VII. CONCLUSIONS

We have proposed an improved cellular access network architecture inspired by the principle of ecological protocooperation. BTSs are equipped with more intelligence enabling them to make decisions by cooperating with each other for reducing energy consumption and also for achieving a self-sustainable access network. Depending on the traffic situation, any BTS may switch to a low power sleep mode whereas other BTSs would take its traffic. Similarly, some other BTSs may switch from sleep mode to active mode. No operator assistance is required for making decisions and switching. This architecture is suitable for both homogeneous networks as well as next generation heterogeneous networks. We have also shown that our proposed architecture and algorithm can save a substantial amount of energy at the access networks, which is very important for achieving a self-sustainable green communications future.

## REFERENCES


[1] F. Dressler and O. B. Akan, "A survey on bio-inspired networking," Elsevier Journal of Computer Networks, vol. 54, no. 6, pp. 881-900, 2010.

[2] C. Kappler, P. Poyhonen, M. Johnsson and S. Schmid, “Dynamic network composition for beyond 3G networks: a 3GPP viewpoint,” IEEE Magazine of Network, vol. 21, no. 1, pp. 47- 52, January-February 2007.

[3] L. Chiaraviglio, D. Ciullo, E. Leonardi, M. Mellia, “How much can the Internet be greened,” in Proceedings of Workshop on Green Communications in conjunction with IEEE GLOBECOM, Hawaii, USA, pp. 1-6, December 2009.

[4] A. J. Fehske, F. Richter and G. P. Fettweis, “Energy efficiency improvements through micro sites in cellular mobile radio networks,” in Proceedings of Workshop on Green Communications in conjunction with IEEE GLOBECOM, Hawaii, USA, pp. 1-5, December 2009.

[5] The Climate Group, “SMART 2020: Enabling the low carbon economy in the information age,” http:// www.theclimategroup.org, 2008.

[6] R Cohen and B. Kapchits, “An optimal wake-up scheduling algorithm for minimizing energy consumption while limiting maximum delay in a mesh sensor network,” IEEE/ACM Transactions on Networking, vol. 17, no. 2, pp. 570–581, April 2009.

[7] F. Wu and Y. Tseng, “Distributed wake-up scheduling for data collection in tree-based wireless sensor networks,” IEEE Communications Letters, vol. 13, no.11, pp. 850–852, November 2009.

[8] H. Imaizumi1, T. Nagata, G. Kunito, K. Yamazaki and H. Morikawa, “Power saving mechanism based on simple moving average for 802.3ad link aggregation,” in Proceedings of Workshop on Green Communications in conjunction with IEEE GLOBECOM, Hawaii, USA, pp. 1-6, December 2009.

[9] M. A. Marsan, L. Chiaraviglio, D. Ciullo and M. Meo, “A simple analytical model for the energy efficient activation of access points in dense WLANs,” in Proceedings of International Conference on Energy-Efficient Computing and Networking (e-Energy), Passau, Germany, pp. 159-168, April 2010.

[10] E. Shih, P. Bahl and M. J. Sinclair, ‘Wake on wireless: an event driven energy saving strategy for battery operated devices,” in Proceedings of Annual International Conference on Mobile Computing and Networking (MobiCom), Georgia, USA, pp. 1-12, September 2002.

[11] N. P. Le, T. Morohashi, H. Imaizumi, and H. Morikawa, “A performance evaluation of energy efficient schemes for green office networks,” in Proceedings of IEEE Green Technologies Conference, Texas, USA, pp. 1-9, April 2010.

[12] J. T. Louhi, “Energy efficiency of modern cellular base stations,” in Proceedings of IEEE International Telecommunications Energy Conference (INTELEC), Italy, pp. 475 – 476, September 2007.

[13] HUAWEI base station datasheets, http://www.huawei.com.

[14] Node-B datasheets, http://www.motorola.com/, 2008.

[15] L. Chiaraviglio, D. Ciullo, M. Meo and M. A. Marsan, “Optimal energy savings in cellular access networks,” in Proceedings of International Workshop on Green Communications in conjunction with ICC 2009, Dresden, Germany, pp. 1-5, June 2009.

[16] L. Chiaraviglio, D. Ciullo, M. Meo and M. A. Marsan, “Energy-efficient management of UMTS access networks,” in Proceedings of International Teletraffic Congress (ITC), Paris, France, pp. 1-8, September 2009.

[17] R. Gupta, “Collaborative heterogeneity for energy efficient systems,” in Proceedings of Workshop on Green Communications in conjunction with IEEE GLOBECOM, Hawaii, USA, December 2009.

[18] 3GPP TR 36.902 version 9.1.0 Release 9, “LTE; evolved universal terrestrial radio access network (E-UTRAN); self-configuring and self-optimizing network (SON) use cases and solutions,” Technical Report, April 2010.

[19] P. H. Longstaff, “Competition and cooperation: from biology to business regulation,” A Publication of the Program on Information Resources Policy, Centre for Information Policy Research, Harvard University, pp. 1–57, October 1998.

[20] S. Camazine, J. Deneubourg, N. R. Franks, J. Sneyd, G. Theraula and E. Bonabeau, Self-Organization in Biological Systems. Princeton Press, 2002.

[21] W. R. Engels, “Evolution of altruistic behaviour by kin selection: an alternative approach,” in Proceedings of National Academy of Sciences, USA, pp. 515–518, October 1982.

[22] F. Richter, A. J. Fehske and G. P. Fettweis, “Energy Efficiency Aspects of Base Station Deployment Strategies for Cellular Networks,” in Proceedings of IEEE Vehicular Technology Conference. (VTC), Alaska, USA, pp. 1-5, 2009.

[23] M. A. Marsan and M. Meo, “Energy efficient management of two cellular access networks,” in Proceedings of GreenMetrics Workshop in Conjunction with ACM SIGMETRICS Conference, Washington, USA, pp. 1-5, June 2009.

[24] P. E. Heegaard, “Empirical observations of traffic patterns in mobile and IP telephony,” in Proceedings of International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN), St.Petersburg, Russia, pp. 26-37, September 2007.

[25] N. M. Pletcher, S. Gambini and J. M. Rabaey, “A 2 GHz 52 μw wake-up receiver with -72dBm sensitivity using uncertain-IF architecture,” in Proceedings of IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, USA, pp. 524–525, 2008.

[26] 3GPP TR 25.912 version 9.0.0 Release 9, “Universal mobile telecommunications system (UMTS); LTE; feasibility study for evolved universal terrestrial radio access (UTRA) and universal terrestrial radio access network (UTRAN),” Technical Report, October 2009.

[27] Y. Shen, T. Luo, and M. Z. Win, “Neighboring cell search techniques for LTE systems,” in Proceedings of International Conference on Communications (ICC), Cape Town, South Africa, pp. 1-6, May 2010.