VOLUME 10, NO. 1 - 2023
ISSN 2465-7425

FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA
Technology for Empowerment

NIGERIA JOURNAL OF ENGINEERING AND APPLIED SCIENCES (NJEAS)

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Nigeria Journal of Engineering and Applied Sciences – NJEAS (ISSN: 2465-7425) is a publication of the two schools of Engineering: School of Infrastructure, Process Engineering and Technology (SIPET) and School of Electrical Engineering and Technology (SEET) of Federal University of Technology, Minna, Nigeria.

The journal is committed to promoting and publishing original high quality research papers and stresses on academic excellence, knowledge distribution as well as joint scholarly efforts in order to support theoretical, experimental and practical research. Papers for publication are selected through peer review to ensure originality, relevance, and readability.
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Published by:

School of Infrastructure, Process Engineering & Technology and School of Electrical Engineering & Technology, Federal University of Technology, Minna, Nigeria.

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A SURVEY OF TECHNIQUES ON ENERGY SAVINGS FOR GREEN CELLULAR NETWORKS

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ABSTRACT

There has been an increase in the cellular traffic demand in recent times and this will continue in future due to proliferation of mobile devices and Internet-of-things (IoTs), new applications and emerging services, such as multimedia streaming, gaming, and cloud-based computation. The fifth-generation technology, (5G) is an incoming promising cellular network for catering challenges undermining services in previous generation of network services. The 5G is characterized by Base Station (BS) density fixation that is multitude of BSs to meet increase services demand of users, internet of things (IoTs) and other activities. It is obvious that density fixation of BS will improve quality of service (QoS) but it will also raise quantity of carbon emission release to the environment plus operation expenditures (OPEX) due to a raise in energy consumption. This work presents state-of-the-art on energy-saving techniques for BSs in wireless communication. It highlights inherent challenges associated with various schemes and architectures for controlling and minimizing energy consumption of BSs for cellular communications. The paper identified the sleep mode technique as ease-adopt scheme for energy-saving in cellular networks, but still requires the development of algorithms for controlling different stages or state and QoS.

Keywords: Carbon emission; Internet-of-things (IoTs); *OPEX;5G*

INTRODUCTION

Cellular communication technologies have made life easy and convenient for different people across all walks of life. It is now possible at one's finger tips to do things that were impossible a few decades ago. Increase in human population and the expansion of the desire to communicate better and more effectively have led to a significant growth in cellular access networks in the last decade (Hasan *et al*., 2011).The growth in mobile traffic is predicted to increase further in the future, fueled by innovations such as machine-to-machine communications and "Internet of things" (Wu *et al.,* 2011). By 2024, mobile subscriptions are expected to reach 8.9 billion; meanwhile, cellular IoT connections will reach 4.1 billion, with mobile data traffic using approximately up to 136 EB per month, wherein 74% will be utilized for mobile video traffic and 5G networks will carry 25% of global mobile data traffic (Alsharif *et al.,* 2019). Previous generation of mobile communication systems handled the data traffic as effectively as possible, but the exponential increase in data traffic made those technologies obsolete, hence the need for 5G mobile communication systems. 5G mobile communications systems which have been forecasted to be in utilization into the foreseeable future have been designed to handle huge traffic demand using densification of base stations. However, higher traffic induced energy consumption is imminent in 5G network if no energy-efficient methods are employed (Khan *et al.,* 2021).

Considering the components of cellular communication system, BSs consume the lion share of the total energy consumption. Fig. 1 presents the distribution of energy consumption in cellular system (Dutta *et al.,* 2018). BS has nearly 60% of the total power consumption. The following papers also concurred with the distribution of energy consumption (Alsharif *et al*., 2017; Karmokar and Anpalagan 2015; Premalatha and Nisha 2019).

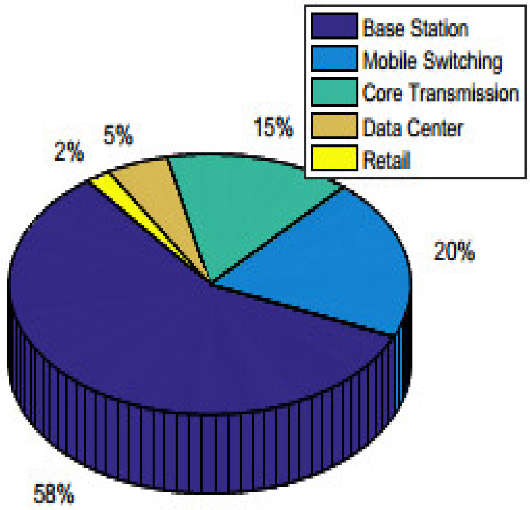

Fig. 1: Cellular network power consumption profile
[Source: Dutta *et al.,* (2018)]

It is envisaged that proliferation of BSs increases the cost of the fossils fuel and carbon emission which results in harming the environment and increasing the global warming. The option of renewable energy is very expensive (Alsharif *et al*., 2017; Aris and Shabani 2015; Hasan *et al.,* 2011). BS is the point at which energy consumption can be curtailed and this has been the focus of researchers. Different algorithms and techniques are being offered to solve this problem. Therefore, this paper focuses on the-state-of-the-art on energy saving techniques in cellular network.

Fig. 2 presents the growth of global mobile subscribers based on cellular generation technologies. It claims that mobile subscribers to LTE increased from 5 billion to 8 billion between 2017 and 2021 hence forth it will be decreasing and this gives way to 5G subscribers from 2021 upwards. It's obvious from this chart that OPEX for 5G will be more than that of previous generations of cellular technologies as 5G requires higher energy consumption due to massive deployment of BSs.

Besides the challenge of higher energy consumption due to the exponential growth in cellular industry, there is also increase in carbon foot print. It has been found that, if unchecked, ICT greenhouse gases (GHGs) relative contribution could grow from roughly 1.6% in 2007 to exceed 14% of the 2016-level worldwide GHGs by 2040 if this upward trend continues (Belkhir and Elmeligi 2018). Furthermore, an increase in carbon emissions has been shown to significantly degrade the environment in recent years (Li and Wei 2021).

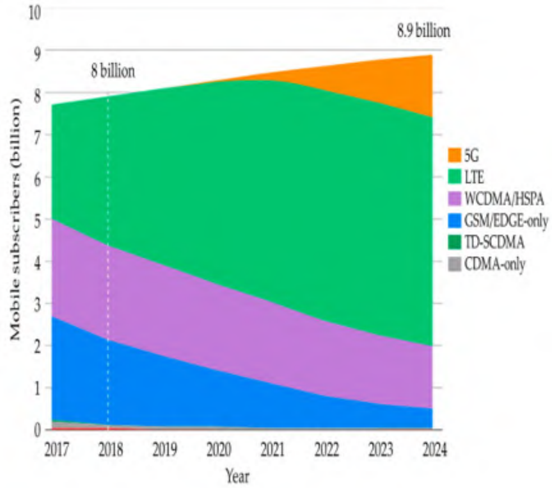

Fig. 2: Expected growth of global mobile subscribers
(Source:Alsharif *et al.,* 2019)

There exist in the literature a number of approaches for improving energy efficiency of BSs but sleep mode Technique is gaining more attention because of its ease of implementation (Wu *et al.,* 2015). Therefore, the main objectives of this paper are to conduct a short survey of techniques of energy savings in cellular networks and present summary of some recent research works that exploited sleep mode technique.

The rest of the paper is organized as follows: Section 2 presents the categories of energy saving techniques for BSs in cellular communication networks. Section 3 discusses structural frame work or architectural structure of sleep mode technology. Section 4 concludes the paper.

METHODOLOGY

Base Station Energy Efficiency Techniques

This section first presents those parts of the base station that consumes most power, which consists of both constant and variable power consumption, it went further to discuss the various techniques employed in literature to reduce power consumed by the BSs

Base Transceiver Station power consumption overview

Base Transceiver Station or simply Base station (BS) is an equipment in the cellular network that connects the mobile terminal to the network. It could come as indoor or outdoor equipment but indoor BS is more energy consuming than outdoor BS in the sense that the indoor BS will have to be confined in a room and expensive cooling systems will have to be provided. The block diagram of Base transceiver station showing main power consuming subsystems is shown in Fig. 3. Irrespective of the technologies, 2G, 3G or even LTE, base stations are made up of three major components; base band unit (BBU) which handles the base band signal processing and management of the whole base station. The radio frequency unit which converts the RF signals to data signal and vice versa. This is also where signal amplification takes place. The third component is an antenna network which contains the cables and antennas that connects the RF unit to the GSM antennas. GSM antennas radiate the signals to the user equipment which can be mobile phones.

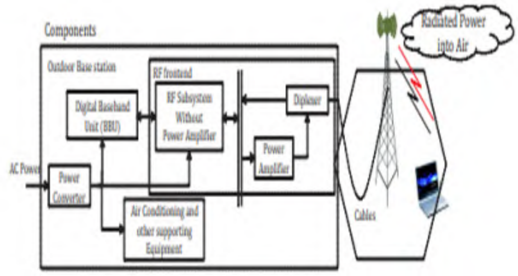

Fig. 3: Block diagram of Base transceiver station showing main power consuming components.

The power consuming components of the BS can be divided into two: the fixed power consumption components and the variable power consumption components, the fixed power consumption components are those that their power consumption are constant as they are not affected by changes in cellular the traffic loads. One example is the power converter unit which is basically the rectifier circuit that converts the dc power that GSM equipment supports. Another example is the base band unit, BBU. The variable power consumption component is the radio frequency (RF) Unit. Although the power amplifier in RF unit is the major source of power consumption at current macro base station transmitters, in future digital baseband will be the major contributor in small cost-effective base stations such as pico cell and femto cell base stations. This is mainly because, in future base stations, the transmission power that will be required is less, while simultaneous processing of various data rate signals from increased number of mobile users will make the digital Baseband Unit (BBU) more power intensive (Boyapati *et al*., 2012)

Review of Energy-Saving Techniques in Cellular Networks

This subsection presents the major categories of techniques that have been considered for energy saving in cellular networks that are currently available in literature. The categories are:

(i) Hardware Component Improvement

In this technique, the hardware of the base stations in terms of the transceivers and the amplifiers which are the basic components and the high energy consuming parts of the BSs are to be improved with the state-of-the-art chips that consumes the least energy. Suarez *et al., (*2012) applied switch mode power amplifier SMPA approach and saved 80 to 90% of energy. SMPA works on the principle that the active device works in saturation mode, therefore it works as a switch, so either current or voltage waveforms are alternately reduced to decrease overlapping. This leads to minimizing power dissipation. If a transistor is considered as an ideal switch, 100% efficiency can be attained by appropriate design of the network. Alsharif *et al*.,(2014), presented hardware components improvement of BS from Alcatel-Lucent – a telecommunication vendor. The paper discusses design of an innovative BSs employed in 2012 that reduces a large amount of energy consumption as compared to the existing radio access network devices. This category of approach requires acquisition of hardware component for reducing energy consumed by BSs. Apart from the cost of acquiring hardware component to minimize energy-consumption, changing of architectural design of BSs are another issue. Hardware improvement is projected as a way-out for minimizing BSs energy-consumption and reduction of gaseous emission. However, there is no significant difference between its cost of implementation and traditional techniques – a factor which vast majority of mobile network operators (MNOs) meticulously consider in operation before initiating hardware replacement (Wu *et al.,* 2015).

(ii) Network Planning and Development

This category of energy saving techniques considered network planning of BSs in cellular networks. It involves combination of different base stations with different levels of power consumption and capacities in a single network which forms an heterogeneous network in terms of macro, micro, Pico and femto-cell deployment in a network The macro BSs provide connectivity and services for high mobility users, while the small cells such as micro, femto and pico BSs serve low mobility users with high data rates (Wu *et al.,* 2015). It has low cost of implementation, user- oriented and high savings. However, it introduces new problems such as radio interference.

(iii) Adoption of renewable energy resources

Here, Adoption of renewable energy resource such as solar, wind and water to power BSs are major considerations. Though this is a long–term solution for off-grid BSs, it is suitable and feasible in a country like Nigeria that has natural renewable energy in abundance. However, it has high initial cost and high replacement cost; and limited gain for existing on-grid BSs.

(iv) Optimization in radio Transmission Process

In this method, optimization in radio transmission process using cognitive radio transmission, cooperative relaying, channel coding and resource allocation for signaling are being considered. These approaches have been proposed to efficiently utilize resources in time, frequency and spatial domains to achieve energy saving. It is not expensive but there is a trade-off between performances and energy savings. Errors due to uncertainty issues such as noise and interference have not yet been well addressed.

(v) Sleep mode Techniques

This technique selectively turns radio transceivers or BSs to sleep mode in order to save energy. The idea here is that idle times of BSs are being sought for, at such times, BSs are switched off or put in sleep mode. Furthermore, BSs with lesser traffic are put to sleep mode while their traffic are being taken care of by other BSs in such a way that quality of service is still maintained. It is easier and less costly for testing and implementation. There is a trade-off between performance and energy savings. Current model is not accurate enough (Alsharif *et al.,* 2019).

Some research works that used this technique will be discussed in detail in the next section. These categories of base station energy saving techniques, their merits and limitations are summarized in Table 1

Table 1: Summary of Energy-Saving Schemes in Cellular Network

	Techniques	**Strength**	**Weakness**
1	Hardware Component improvement	Reported to have largest energy savings	High cost of implementation
2	Network Planning & deployment	Low cost of implementation with high potential energy saving	New problems such as radio interference are introduced
3	Renewable energy sources	Long term solution for off grid BSs	High cost of implementation and replacement
4	Radio transmission optimization	Low cost of implementation	Tradeoff between energy saving and QoS, error due to uncertainties issues
5	Sleep mode	Moderate energy savings and does not require change of system architecture	Tradeoff between energy saving and QoS

RESULTS AND DISCUSION

Sleep mode Technologies

This section presents various research works using sleep mode technologies:

Bousia *et al.,*(2012) proposed a sleeping algorithm in 'Green distance –aware base station sleeping algorithm in LTE- advanced Networks' in order to save energy consumption and still maintain quality of service in a homogenous 4G Networks. The scheme attempted to improve on the work of Marsan *et al.,*(2010) that considered only 3G networks and based their switching off decision on the traffic load only. For the switching off Mechanism in this work, it considered, apart from low traffic load, the average distance between the eNodeBs and their UEs; unlike in the random switch off scheme where half of the eNodeBs are switched off. It proposes to switch off cells that have greater average distance between themselves, the UEs and their neighbor UEs relative to them as this will lead to greater transmission power if they are to be switched ON. Fig. 4 presents the architectural structure with which Bousia developed his algorithm.

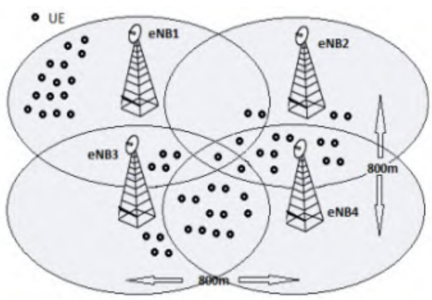

Fig. 4: Adopted architectural structure for sleep mode algorithm
(Source: Bousia *et al.,* 2012)

In Fig. 4, the UEs of eNB1 are gathered at its cell edges and it will not be good if it were to be switched off because the other three cells will have to increase their transmission power to handle these UEs. So the algorithm switches off eNB3 and the two cells closer to it (eNB1 and eNB4) zoom out to serve the UEs of the switched-off eNB3. The proposed scheme thus intelligently selects the eNBs to switch off to save energy by considering the distance of the UEs to their eNBs and their neighbors.

During switch off session, total energy consumption of the eNodeBs that remains active is as shown in equation (1):

$$E_{\text{total new}} = E_{\text{total}} + \Delta E \quad (1)$$

where E_{total} is the energy consumption of the eNB taking into account only its traffic and its constant energy consumption while ΔE in equation (1) is the expression for the extra energy consumed due to the additional traffic of the switched off cell.

$$\Delta E = \sum_{i=1}^{N} \left(P_{max} \cdot min\left\{\frac{1}{N_{RB}}, max\left[R_{min}, \left(\frac{l + 37.6 \cdot \log_{10} R_i}{L}\right)^{a}\right]\right\} \cdot t_{\text{transi } i} \right) \quad (2)$$

The simulation results reveal that up to 29% of the power consumed to operate the network can be saved by decreasing the number of active eNBs during low traffic periods. The shortcoming is that quality of service is not considered in this work

Prithiviraj *et al.* (2013) developed and implemented a sleeping scheme for a 3G network. Their model is able to save energy in homogeneous five-cell micro cellular network using cell zooming technique. The system structure comprises five cells arranged in such a way that one of the cells is in the middle and the coverage areas of the neighboring cells overlap as shown in the Fig. 5.

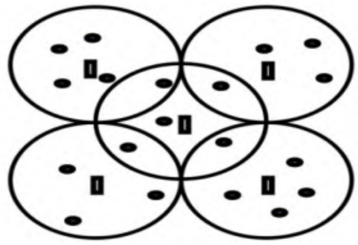

Fig. 5: Cell with original size
(source: Prithiviraj *et al.,* 2013)

When the traffic load of the cell in the middle of the network is low, it will be switched off because considering its geographical region, it is easy for the neighboring cell(s) to increase their transmitting power so that they zoom out as in Fig. 6 to take care of the switched-off cell users. The choice of neighbor cells that will zoom out will be decided by comparing the distances between the switched-off cell users and the centers of the neighbors. The neighboring cell with the smallest distance is chosen. In this scheme, the chosen BS is assumed to have adequate channels to handle the users in the switched-off cell.

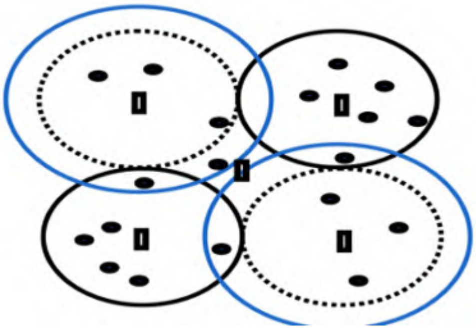

Fig. 6: Central cell switched off while neighboring cells zoom out
source: (Prithiviraj *et al.,* 2013)

The amount of energy saving is then determined by finding the difference between the total amount of power consumption of the BS before and after cell zooming. The total power consumption before cell zooming is given in equation (3) while total power consumption after the cell zooming is given in equation (4).

$$P_{\text{net-Bz}} = (P_{tx-Bz}, L_t + P_{\text{fixed}}) \cdot N_b \qquad (3)$$

Where P_{fixed} is the constant power consumption of the BS, which includes the power required for signal processing and power resources used for running the BSs, L_t denotes the total losses due to fading, penetration loss, shadowing loss of the signal and P_{tx-Bz} is the total transmit power of the BS before cell zooming. Similarly, P_{tx-Az} is the total transmit power of the BS after cell zooming

$$P_{\text{net-Az}} = (P_{tx-Az} L_t + P_{\text{fired}}) \cdot N_b \qquad (4)$$

Simulation results show that 20% of power consumption of the network can be saved when compared to all active BS scenarios. However, the quality of service of the network is not considered or analyzed.

In Morosi *et al*. (2013), the authors proposed the management of a BS in sleep mode in a cellular network through a forecasting algorithm known as Holt winter forecast method, which made predictions based on daily and weekly periodic behavior of traffic in 2G and 3G networks. It is a kind of predictive analysis that forecasts the value of a variable in future occurrences based on history. The prediction is then used to determine the points where there are low traffic loads at which certain BSs can be switched off to save energy. Also, the required or predicted channels of a GSM cell is obtained by using earlang B formula which is given in equation (5).

$$P_B = \frac{\frac{F^n}{n!}}{\sum_{k=0}^{n} \frac{F}{k!}} \qquad (5)$$

where F is the considered traffic, n is the number of available channels and P_B is the drop call rate whose value is a target defined by operator policies

For the switching off procedure, if it happens that the network capacity or channels at a given time is much greater than the predicted number of channels required, then the BSs with the lowest traffic load can be switched off after handing over of its users to the neighboring BSs.

Lower power consumption was observed in the morning hours for both forecasting based sleep mode algorithm (FBSMA) and Real time measurement sleep mode algorithm (RTMSA) algorithms. However, their performance was less than the theoretical optimum.

A stable increase in area power consumption (APC) was observed for FBSMA and RTMSA algorithms with increase in traffic. They outperformed the theoretical optimum which showed an abrupt increase in APC as the traffic increased. FBSMA and RTMSA algorithms have 15% on average savings on energy Wu *et al.* (2017) modeled Base Stations (BS) as a processor-sharing queue with vacations and investigated the performance of three BS sleeping schemes – isolated scheme, cooperative scheme, and the combination of sleeping and cooperative scheme.

As the number of N policies increased, the power consumption decreased, and the blocking probability decreased. The analytical approximation showed much better computational efficiency (0.2s) than the simulation approximation which took 3 hours. Analytical results for blocking probability and mean delay in the isolated scheme were very accurate. Also, Nahas *et al.* (2017) proposed an energy saving system by using the user's location and speed as determinants in the formation of BS- user association algorithm so as to optimize the power consumption and the number of the needed handovers.

Simulation results show that the proposed algorithm, compared to 'Nearest Algorithm', which connects each MS to the nearest BS (macro, micro or pico) regardless of the MS's speed or direction, achieved good reduction in power. Also Number of handovers are reduced with Pico cells, femto and microcells included in the network compared to when the network is homogenous.

On the negative side, the proposed scheme emphasizes on reduction of power consumption due to unnecessary hand off calls while reducing much power that could be obtained through the small cell sleeping is not exploited.

In 'Greener RAN operation through machine learning' by (Vallero *et al.,* 2019), Machine Learning techniques are used to predict the future traffic demand, PV and RES power production in a cluster of a network comprising of one macro cell base station and six micro cell base stations as shown in Fig. 7. Based on the prediction, some resource management strategies were applied to determine the maximum number of BSs to be in sleep modes in order to save energy and reduce the CO_2 emission produced by the brown energy supply from the power grid. The network management system operation for achieving the power reduction is in two steps as shown in Fig. 8. The result shows that energy savings of up to 40% and never below 10% were achieved. Also, only small amount of power, between 8% and 23% is purchased from the grid hence low CO_2 emission. The metrics considered are the accuracy and effectiveness of the traffic prediction algorithms, the energy savings considering the resource management techniques.

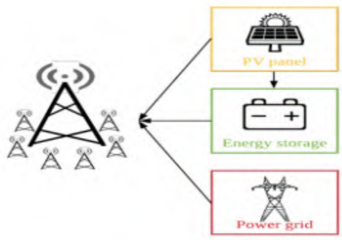

Fig. 7: A cluster composed by one macro BS and a few micro BS is powered by the PV panel, the battery and the power grid

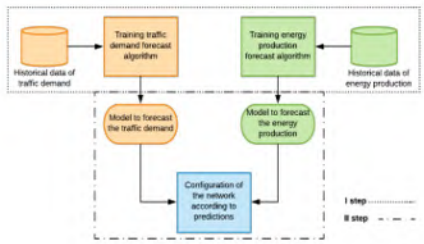

Fig. 8: Flowchart of the two-step network operation

On comparing the effectiveness of the different algorithms, results show that, with all the considered traffic forecast algorithms, except for the Baseline with and without ANN, energy consumption is very close to the ideal case (where we assume perfect knowledge of future traffic demand). The Baseline with and without ANN show the highest and the lowest energy consumption drops, respectively. However, the energy reduction is achieved at the cost of QoS deterioration. With the exception of the Baseline with ANN, the other ML algorithms have equivalent performance within each zone, with QoS deterioration that depends on the area but is usually below 5%.

In 'Donevski *et al.* (2019), the authors proposed an artificial neural network-based system for energy saving and reduction of CO_2 emission. Specifically, two different approaches, unified and two-step approaches were proposed and each of the approaches used Dense Neural networks (DNN) and Recurrent neural network (RNN) algorithms to predict the future traffic demand and as well determine the best combination of SBSs to be in sleep modes in order to save energy and still maintain quality of service. The power consumption model used is as shown in equation 6

$$P_{\text{in}} = \begin{cases} N_{TRX}(P_0 + \Delta p P_{\text{out}}), & 0 < P_{\text{out}} \leq P_{\max} \\ N_{TRX} P_{\text{sleep}}, & P_{\text{out}} = 0 \end{cases} \quad (6)$$

where P_{out} is defined as

$$P_{\text{out}} = \rho P_{\max}, 0 \leq \rho \leq 1$$

where N_{TRX} is the number of transceivers in the BS; P_0 is the idle power consumption per transceiver; Δp is the slope of the load dependent elements; P_{out} is the instantaneous transmission power of the transceiver; $P_{\max}$ is the maximum possible transmission power of a transceiver; ρ is the BS traffic load normalized to 1; P_{sleep} is the amount of energy spent in sleep mode, which we assume negligible.

The key metrics for measuring the performance are coverage loss and efficiency loss. The coverage loss measures the percentage of available traffic that is lost due to SBS in sleep modes hence it measures the quality of service. The efficiency loss measures the percentage of extra energy spent relative to the whole potential energy saving in the optimal scenario (where future traffic is known).

The results show that the overall average performance metrics obtained with two-step DNN when considering the 11 clusters are EL 1.58% and CL= 1.03% while for the two step RNN, the overall averages of the performance metrics are EL =1.24% and CL = 0.84%.

Considering unified DNN, the overall average performance with offset of 0.9 is EL = 37.48% and CL = 0.02% while with unified RNN, with offset equal to 0.9, the average across all scenarios is below 0.1%; indeed, we get: EL = 26.7%, CL = 0.05%.

All the considered options proved quite effective, but with the second class of ANNs we achieved the goal of saving a substantial amount of energy with minimal QoS deterioraton. In particular, the amount of served traffic is at least 99.9% of the requests, while achieving 63% of the energy savings

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In Energy Efficiency and coverage Trade-off in 5G for eco-friendly and sustainable cellular networks by Alsharif *et al.* (2019), the authors proposed a Particle Swarm Optimization (PSO) based algorithm which exploits the co-existence between LTE BS and 5G BS in order to achieve a balance in the energy efficiency and the quality of service.

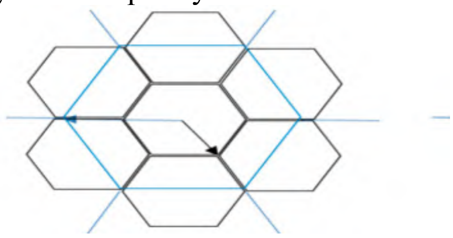

Fig. 9: A cluster of six 5G BSs and one LTE BSs

In the system which comprises of a cluster of six small BSs (5G BSs) and a large LTE BS arranged as shown in Fig. 9, 5G BSs are put into sleep mode during the low traffic period on daily basis to save energy while the LTE BSs take care of the subscribers in the 5G BS coverage. PSO is used to determine the optimum values of the constraints; transmission power, total antenna gain, channel bandwidth and signal-to-interference-plus-noise ratio (SINR) that achieve the maximum coverage for the entire area during the switch off period of 5G BSs.

The simulation results show that Energy savings of 3.52kW per day is achieved and at the edge of the cell where SINR was the lowest, maximum coverage could still be achieved. However, for very high data rate users, full coverage is not guaranteed hence there is a compromise between energy savings and network performance.

In Yunusa *et al.* (2020), the authors developed a sleep mode algorithm on heterogeneous networks (pico cells and macro cells) that reduces energy consumption and still delivers data rate that is within the 3GPP standards for both rural and urban environments.

The data rate model used here was Khirallah *et al.* (2014) which is in equation (7)

$$SINR = PTX + GTX + GRX - N - I - SF(d) - PL(d) - PLN \quad (7)$$

where: PTX is the eNodeB transmission power (per cell sector); GTX and GRX are the eNodeB and UE antenna gains respectively. N and I are the noise and the inter-cell interference (ICI) power from all the interfering eNodeB at the UE location respectively. PLN is the wall penetration loss for signals received by indoor UE. Finally, PL (d) and SF(d) are the path loss and shadow loss in dB respectively measured at different UE position.

If the estimated average user data rate of the overall network is greater than the set threshold value, the pico cell will remain in sleep mode otherwise it will become active. As traffic increases (greater than 10 user equipment per macro area coverage) and the average user data rate goes below the threshold value, the algorithm will dynamically change the operating state of the pico eNodeB cells to active.

Based on this review, some of the authors laid emphasis on energy saving however, the main problem of these schemes is lack of emphasis on the quality of service. Even though some of the authors considered the performance in terms of data rate and coverage loss, one of the important metrics to be considered is added delay which is not considered. Not many users are willing to subscribe to networks whose quality of service is bad. Network operators are aware of this and would not want to risk losing their customers just for the sake of reducing power consumption of their BSs.

CONCLUSION

In this paper, we presented a survey on techniques for energy savings in cellular networks. These techniques fall within the five categories which are classified based on their features, ease of implementation, and the amount of energy savings. Sleep mode technique is given attention by researchers because it does not require change of the architecture of the cellular network.

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