

## AN INSIGHT INTO DEPLOYMENTS OF GREEN BASE STATIONS (GBSS) FOR AN ENVIRONMENTALLY SUSTAINABLE WORLD

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### ABSTRACT

Data traffic and the number of mobile subscribers have increased significantly prompting cellular network operators to install additional mobile cellular base stations (BSs) to meet the increasing demand. This proliferation of BSs has resulted in consequential increase in energy consumption and Green House Gases (GHGs) emission. Several techniques have been deployed to reduce the energy consumption of the base station in what is called a green base station. This paper presents an insight into these approaches and highlights key challenges and potential research directions. It also highlights what environmental sustainability activist, regulators and government can do to incentivize green BSs concept in Nigeria.

**Keyword:** Green base stations, mobile cellular network, base station switching, renewable energy, environmental sustainability, base station sleep mode, greener energy sources.

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### I. INTRODUCTION

#### 1.1. Background

Cellular networks have developed rapidly over the last decade offering more services with high data features. The Cisco® Visual Networking Index (VNI) predicted that data traffic will continue to grow surpassing 80 Exabyte in 2020 [1]. The corresponding increase in unique mobile subscribers indicates an upwardly trending linear growth. In Nigeria, the record shows that there evidence of growth with positive impact on the Gross Domestic Product (GDP). As of the beginning of 2020, the numbers of mobile subscription in the country have exceeded 169 million, with about 85 million of these being internet users [2], [3].

These developments are compelling mobile network operators to expand network capacity by installing additional cellular Base Stations (BSs) to meet the rising demand [4], which have led to higher energy consumption and increased Green House Gases (GHGs) emissions especially for macro BSs. According to Graves [5], the ICT sector contributed 2.5% of global GHG emissions in 2010. If nothing is done, the contribution would be 14% by 2040. The Global System for Mobile communication Association (GSMA) [6] mentioned that the Global e-Sustainability Initiative estimates in 2002 that the cellular network contributed between 43% - 51% of the global Information and Communications Technology (ICT) energy-related emissions and carbon footprint. Going by the study reported in [7], as Nigeria strive towards further economic growth and financial development, a positive growth in the emission of GHGs is to be expected.

A second problem with the rapid deployment of BS is the increase in Capital Expenditure (CAPEX) and Operating Expenditure (OPEX). Developing countries are particularly susceptible because of the low Average Revenue Per User (ARPU). Hence, there has to be a way to reduce costs. Thirdly, green energy source awareness of the society has increased exponentially and governments around the world are more than ever altering their power policies to promote green energy sources [8]. This is due to concerns about climate change and environmental sustainability. These issues have compelled mobile network operators to desire usage of energy in an environmentally sustainable way. But this has posed a challenge to researchers, equipment manufacturers, and mobile operators owing to the expected interplay of techno-economic considerations and the need to protect the environment.

Before now some researchers have directed attention to coming up with solutions for enhancing system capacity and data rate, hence the move from 2G to 3G. Lesser attention was paid to the societal and environmental impacts of mobile network [9]. However, in recent time attention is shifting to the deployment of Green Base Station (GBS). The green wireless communication system is an area of research that aims at improving power efficiency with anticipated contributions to environmental sustainability [4], [9]. Green wireless communication is usually implemented with the adoption of certain energy-saving approaches at an optimal energy cost in the medium to long term, especially because they do not require any change in current network architecture [10].

## 1.2. Previous Review

Some researchers have presented studies on efforts at developing green BSs. These include [4], [10]–[12], [53]. These researchers have looked at the subject from varying perspectives as the next brief overview shows. Alsharif et al. in [4] surveyed the general architecture of BSs, the energy consumption model and the existing potential of renewable energy solutions for cellular BSs. The authors further highlighted emerging trends in green cellular network research with case studies analysis.

Some of these models for describing energy consumption as framed by various authors for evaluating current wireless architecture in terms of how efficiently energy is used were analysed by De Domenico et al. in [11], who also presented green metrics that are utilized as theoretical trade-offs. The authors concluded by discussing enablers of energy efficiency suggested by the green BS research community. And one of such enablers is BS switching. In [10], Shankar examined various research which implemented BS switching for green cellular networking. BS switching involves studying the traffic pattern of BS. Some base stations with lesser load are switched off to reduce their energy consumption. Further analysis of coordinated multipoint transmission and its various parameters in BS switching was done to enhance network operation. Finally, Tala't et al. in [12] examined some methods proposed in the literature for obtaining the optimal solution for the heterogeneous network using a renewable energy source. By definition, the heterogeneous network consisted of a cellular BS and small cell BS. Additionally, the authors suggested some ideas, which can be used to efficiently boost the performance of existing solutions in terms of Quality of Service (QoS).

Liu et al. in [53] observed that “highly efficient power amplifiers (PAs) and associated linearization techniques have been developed to accommodate the explosive growth in the data transmission rate and application of massive multiple input multiple output (mMIMO) systems”. Hence, the authors reviewed energy-efficient integrated Doherty power amplifier monolithic microwave integrated circuits and techniques for linearising amplifier outputs for both the sub-6 GHz and millimeter-wave (mm-Wave) fifth-generation (5G) mMIMO systems.

In this paper, a version of which was presented at the third World Environment Conservation Conference [13], an insight into green cellular BSs is presented that could easily be understood by students, environmental conservationist and mobile cellular operators. The sleep mode, switching in heterogeneous base stations and electric load leveling sections of the paper was expanded with more researches in this present discussion. In addition, the conclusion reached and recommendations given were enhanced. In sections 2 and 3, various approaches deployed in the green BSs concept are reviewed and evaluation of energy savings of various approaches in the literature is presented. Section 4 concludes the write up by summarising what was done in the article, highlights ongoing challenges and direction for future research are discussed.

## II. GREEN BASE STATION (GBS) APPROACHES

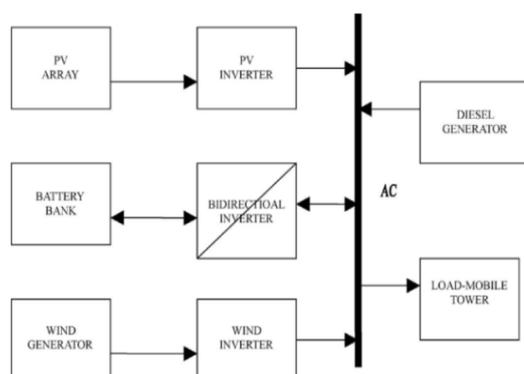
Before reviewing various approaches to ensuring a greener BS, an overview of the components of typical BS and their energy requirements is presented. Components of a typical base station include digital Base Band (BB) unit, Feeder, Power Amplifier (PA), Power supply unit, which includes rectifiers, Battery-backup, antenna & their feeder lines and Cooling system. These components consume energy with a variety of degree [14]. Depending on the size, area of coverage and the technology used, power

consumption in a BS may vary from 0.147 kW to 10 kW. About 80% of these are used in operating the network. There is a positive correlation between the energy consumed for battery-backup macro base stations and both the transmission power and the power of the Base Band signal processor. No battery-backup is required for micro BSs. For BSs with total power consumption less than 0.5 kW, no cooling is required [15]. A bulk of the power consumption in macro BSs are used by the power amplifier, and lesser part of the power is used by antenna feeder, battery backup and cooling system. But in smaller BSs there are usually no battery-backup, feeder losses or cooling requirement [15].

Approaches in GBS include the use of renewable energy sources, and switching on/off of BSs. Other techniques used include: the BS sleep mode control techniques and development of more energy efficient telecommunication hardware, especially with regard to the high frequency radio amplifiers.

### Renewable Energy Sources

The negative impact of fossil fuels used in many BS are well known. In contrast, renewable or green and sustainable energy results in a token impact on the environment when compared with fossil fuels. They also have higher acceptance index socially and economically. out of all renewable energy sources, solar is the most favoured energy source. This is due to the availability of solar radiations worldwide. Also, apart from having a very low environmental impact, solar-powered sites also have the advantage of having very low-maintenance, with a technical lifetime of 20 years or so, and much more reliable than diesel generator-powered systems.



**Figure-1:** Hybrid system schematic diagram for a mobile telephony base station [16]

Other factors driving solar-based sources in hybrid BS powering systems include declining cost of Photovoltaic (PV) panels, decreasing the size of panels and reducing power consumption capacity of increasing energy-lean BS. The typical configuration of the hybrid power system for Remote Base Stations (RBS) is shown in Figure 1.

However, a designer will need to pay attention to load scheduling, and deployment of innovative battery technologies as these are usually the bane of several stand-alone systems. Also, researchers have to address problems associated with the intermittent nature of renewable energy sources [17], [18].

In [16], Nema et al. proposed a stand-alone PV/wind hybrid energy system augmented with a diesel generator for base station sited in an isolated area. This will serve as an alternative to grid power. According to the authors, this will result in more cost-effective operation. An estimate of between 70-80% fuel costs could be saved as opposed to using fossil fuel as the only source of energy. There is also a reduction in GHGs emitted to the environment owing to the scheme proposed by the author.

Dimitriou et al. [17] investigated a model to evaluate the performance of a BS wholly powered by renewable energy sources. The BS was modelled as a three-queue system with two of them coupled. The first model the stored energy; the second described the data queue and finally, the third model represented the reserved energy queue. This smart base station was able to control the traffic intensity by dynamically adjusting coverage and to generate signals to the reserved energy queue that trigger

the movement of energy units to the main energy buffer. Owing to the intermittent nature of these energy supplies and the internal traffic intensity control, the queuing model was operated in a finite state random environment.

In [19], Nakamura and Takeno advanced a power control technique that achieves a long-term autonomous operation using PV and lithium-ion batteries (LiB) and regeneration operation by only PV for when commercial power is lost during a power outage. Meanwhile, LiB batteries are preferred for this kind of operations because they have high “voltage capacity”, “energy density”, and “stability” with multiple recharge capability.

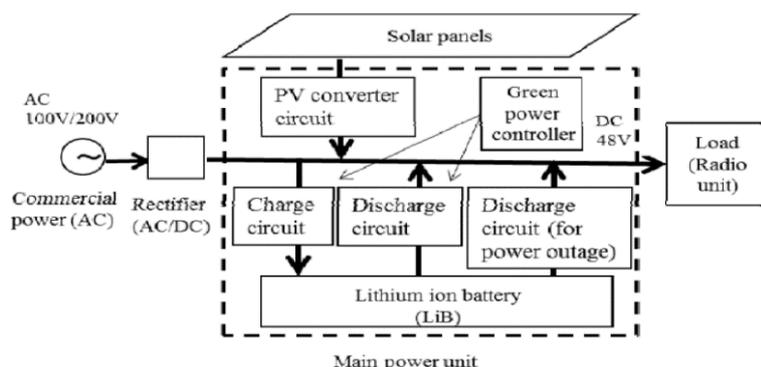


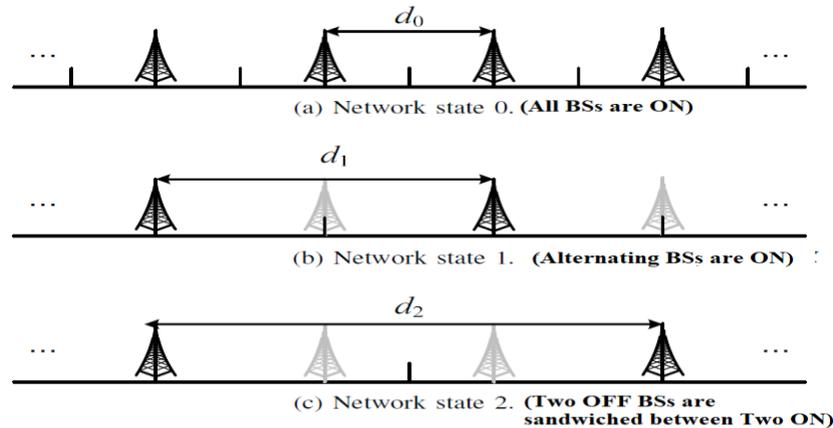
Figure-2: Block diagram of a green base station [19]

They equally have low “self-discharge rate”. These qualities make LiB batteries better than other battery types [20]. The architecture of the autonomous operation is as shown in Figure 2, which is a modification of the basic regulated power supply circuitry. Kong and co [21] introduced a power peak load shifting mixing with solar energy solution for the hybrid energy system of telecom BS. This solution can help telecom operators reduce investment and OPEX when compared with traditional power supply solution. Other than minimizing the usage of fossil fuels and increasing the usage of ecologically friendly renewable energy sources, some have considered the concept of BS switching on and off.

### 1.3. On-Off Base Station Switching Technique

One potential green BS strategy is the BS on-off technique. The approach involves switching off a selected number of lightly-loaded BSs during off-peak hours. Researchers have shown that 90% of the mobile cellular traffic is carried by only 40% of BSs even under peak traffic demand. The implication of this is huge. The 60% of the BSs responsible for 10% traffic is largely wasting energy with consequential unnecessary OPEX and GHGs emission. With an optimized switching and traffic redirection systems, these underutilized BSs can be switched off. Therefore, switching off underutilized base stations for saving power is gaining momentum with the increasing awareness of operators of their environmental responsibilities and the need to improve their profit margin in the long run [22].

In [23], Bousia and co developed an algorithm for BS that utilize the information about the distance between the user equipment and the base station they are linked to for LTE/A wireless network. This approach was intended to reduce BS energy requirement without sacrificing the specified QoS. The authors' scheme achieved a significant power saving since under-utilized BS were switched during off-peak hours in the Long Term Evolution (LTE)-Advanced mobile cellular network. In contrast to the aforementioned approach, wherein BS were deployed by considering peak traffic loading, the scheme proposed in [24] was premised on the entire traffic variation dynamics. They considered a linear mobile network as shown in Figure 3 and subscribers are uniformly distributed. The authors analyzed the power consumption of the system to derived “the energy optimal base station density” for a given network traffic dynamism and specified performance. The outcome of the research indicated that in comparison with peak load BS deployment approaches, the power drawn by the present method is reducible by at least 20% but what could potentially be achieved will depend on how the network traffic is changing.



**Figure-3:** Linear cellular network model and different network states [24].

On their part, Oh et al. [25] and Son et al. [26] formulated a general energy minimization problem concerning BS switching, which is a combinatorial problem and demands high computational power owing to its complexity. The energy minimization problem is also characterized by large signaling overhead, which increases the modelling complexity. The Oh et al. developed a simplified energy-saving algorithm for a BS switching scheme. This algorithm had a much lower computational complexity. A major feature of the algorithm is the switching off of BS one at a time and as such the impact of under-utilized BS being switched off and their traffic transferred to a neighbouring BS is minimized. Other algorithms were formulated, which assisted in minimizing the system signaling and execution energy requirement. These BS switching algorithms were based on heuristic techniques and made use of “approximate values of network-impact as their decision metrics”. Oh et al. further described the manner of execution of proposed algorithms in a real-life scenario as to protocol and also estimated the quantity of energy conserved under a most basic scenario by at least 50% and even getting to 80% on an actual network “traffic profile” of a modern urban environment. The authors in [26] used greedy-on and greedy-off algorithms which were inspired by sub-modularity maximization problem. Additionally, other heuristic algorithms, which considered the activities of BS and the distances between them were proposed. These algorithm did not impose extra signalling cost making them simple to execute in reality. Robust simulations under a variety of realistic scenarios demonstrated that the proposal can substantially decrease power drawn by the networks.

In [27], Yang et al. elucidated on the process of choosing the minimum group of operative BS without sacrificing the specified user data rate. The resolution of this resulted in the formulation of energy consumption minimization problem, which involves integer programming (IP) and is NP-hard in complexity characterization [22]. According to the authors in [28], this is “due to the fluctuations of the on-grid energy prices, the harvested renewable energy, and the network traffic loads over time, as well as the BS coordination to hand over the traffic offloaded from the inactive BSs to the active BSs”. The authors in [27] thus proposed two approximation algorithms that ensured QoS was not traded-off. These algorithms, which are not as complex as existing algorithms are iterative in nature for determining the smallest or biggest BS group coverages. They further established the performance limits of the iterative maximal coverage algorithm by leveraging the sub-modularity theory. The numerical results showed that the proposed algorithms outperform the conventional counterpart in terms of efficiently selecting the minimal group of BS in operation with QoS retention in view.

In [29], Lee et al. investigated BS turning-off operation capable of running without global knowledge of Spatio-temporal distribution of traffic. A green self-organizing network based on an overlay network using Delaunay triangulation (DT) was proposed, which allows the switching off to be determined by meeting a defined threshold for reliable and operator-friendly operation. Conceptually, this triangulation technique seeks to maximise the smallest angle of the entire triangles’ angles involved in the

triangulation, while avoiding sliver triangles. It is the group of lines that join a collection of points side-by-side in such a way that every point is adjoining its closest neighbours. The proposed algorithm can be readily implemented and complied with standard, the existing architecture such as may be used with little modification. A robust simulation using a realistic urban BS topology was performed leading to the confirmation that the development is can of decrease energy consumption by at least 60%.

The authors in [30] and [28] proposed a Binary Social Spider Algorithm (BSSA) to control the switching off of BS and jointly designed two policies. One was for optimal BS On/Off execution and the other was for “on-grid energy purchase” from the perspective of network-level to reduce the “on-grid energy cost in a large-scale green” mobile network respectively. In the implementation Yu and Li, a penalty function was used to frame the problem thus bypassing several constraints associated with the usual optimisation problem. Several cellular networks arbitrarily spawned were used for the implementation of the algorithm. The work of Che et al. showed that the algorithm has superior performance metric for time-dependent loading in the wireless network. The results of the reported scheme were closed to that obtainable from an optimal model with the usual complexity avoided.

In [31], Arvaje and Ghahfarokhi noted that existing research on cell switching usually does not address the spectrum efficiency and QoS of users at the same time in their methods. Hence, a cell switching method was proposed based on a baseline method which considers the spectrum efficiency and QoS of users in the reallocation of radio resources after switching off a base station. The simulation results demonstrated that the presented method is capable of lowering the system drawn power. It also improved spectral efficiency when compared with the baseline method.

#### **Base Station Switching for Heterogeneous Cellular Network**

Heterogeneous cellular network (HCN), which by and large comprises of micro and macro BS, is proposed as a promising system capable of improving cellular network capacity. Nonetheless, huge power requirements by the densely deployed micro BS is an issue that deserves resolution to attain the potential benefits of HCNs. Therefore, the researchers in [32] attempted to decrease the overall power drawn by the HCNs through jointly designing an energy-efficient system that can efficiently link users with Small Base Station (SBS) switching, hitherto a complex problem. They developed a suboptimal algorithm that resolve the problem. For this, an efficient local search methodology was framed to limit the aggregated power requirement of the HetNet by controlling the states of every micro base station dynamically, whether active or not. Obtained results demonstrated that the presented technique reduces the power requirement of the HetNet substantially when juxtaposed with some selected methods.

In [33], the problem of energy efficiency in HetNets was examined using radio resource and power management combined with the base station (BS) on/off switching. The objective was to decrease the total power demand of the HetNet and satisfy QoS specifications of each connected user simultaneously. The authors further investigated the case of coexisting macrocell BS, small cell BS, and private Femtocell Access Points (FAPs) under various scenarios. Furthermore, a unified framework was proposed to concurrently allocate spectrum resources to subscribers in an energy-efficient manner and turnoff redundant micro base stations.

In [34], Feng and co investigated the problem of a base station (BS) on/off switching, user association, and power control in a heterogeneous network with massive Multiple Input Multiple Output (MIMO), aiming to switch off idle to less-used BS's and maximize the system energy efficiency. With a mixed integer programming problem formulation like we seen in the previous discussion, Feng et al. first developed a centralized scheme to derive the near-optimal BS on/off switching, which is an iterative framework with proven convergence. Then they further proposed two-game theory-based distributed schemes with a bidding game between users and BS's and a pricing game between the wireless service provider and users. Both games were shown to achieve a Nash Equilibrium. The obtained results verified that the developed schemes met expectations. This was not the first time game theory was applied to BS switching. For instance, an interaction graph was defined in [35] to assess the impact of the BS switching

activity on the cellular network. Then, the authors formulated the problem of power conservation as a graphical game; every base station acts as a player and traffic loading modelled as the constraint. The best generalized Nash Equilibrium coincided with the global solution of overall power consumption minimization problem, which was obtained using a decentralized iterative algorithm. In the decentralized iterative algorithm, the global exchange of information among neighbouring base stations is not needed. The results illustrated that the solution of the developed algorithm can converge at an optimal point.

Ameer et al. [36] reported a framework that examined both Energy Consumption and Efficiency stated as two sub-problems. These are dynamic deployment of base station and dynamic small cells switch on or off technique capable of reducing energy consumption of idle or underutilized cells. The article also compared current frameworks, modified or unmodified with energy consumption, efficiency, complexity and cost as bases. Simulation results show that efficiency can be increased to 87.5% and energy consumption can be lowered by up to 14%.

In [37], Herrería-Alonso et al. reported a technique to regulate the sleep mode of base station, which are designed with energy awareness in view. With this development, hyper-cellular or heterogeneous networks, "can be put to sleep without causing undesired coverage holes, thus preserving the cellular service over the whole coverage area". The sleep mode is activated immediately the base station have no traffic to send. By means of "a coalescing algorithm", the length of the sleeping periods is adjusted dynamically to enhance the power saved while simultaneously maintaining the average service delay within a threshold. On the other hand, The researchers in [38] investigated the energy efficiency optimization of the "Macro-Femto heterogeneous cellular network". The sleep process of the Femto Base Stations (FBSs) was modeled as a Semi-Markov Decision Process while taking note of the network users dynamics to save power consumed.

Some researchers do not outrightly switch off a BS but instead, they put it to sleep. The concept of BS sleeping and some studies on it will be examined in the next subsection.

### **Sleeping Base Stations**

Closely related to BS switching on/off is BS sleeping. Base station sleeping is among the recently proposed solutions for *greening* a cellular networks base station, consequently lowering the network carbon footprint. It saves power by selectively turning BS not used to a certain set threshold to a low power consumption mode, called the *sleep mode* during low traffic condition while transferring BS associated traffic to neighbouring turned on BS. But in the process of conserving energy, the overall network capacity is reduced. More so, the coverage radius is decreased, which is similar to what was observed during BS switching. All these may result in Grade of Service (GoS) being degraded, necessitating a trade-off between the amount of power-saving and performance of the network for good user experience [39]. So the goal of BS sleeping researches as a green energy solution is to come up with appropriate schemes that can optimally put BS to sleep with no performance degradation. The different cellular network may have a different sleeping pattern [40].

In [41], dynamic and semi-static schemes based on radio resource management for optimizing network power consumption while preserving the users' perceived QoS were developed. In the dynamic scheme, resources were either activated or deactivated in real-time depending on the system loading. Whereas, in the semi-static case resources are left unchanged for at least an hour. The proposed schemes were applied to 2G and High-Speed Packet Access (HSPA) systems. The result proved that the dynamic scheme achieved larger energy-saving than the semi-static one. But the semi-static scheme still produces good performance with lower complexity than the dynamic scheme. Related to the aforementioned research, is [42] where the authors studied a power matching and a base station sleeping scheme that was aware of the traffic profile.

Real-life BSs sleep mode implementation challenges were examined in [43]. One of such challenges is the ping pong effect, which causes needless on/off oscillations capable of the stability of the network. Owing to the inadequacy of offline based optimization techniques is for a large-scale network, the authors

advanced an online controller based on a simple  $\epsilon$ -greedy algorithm, which obtain optimal policy for activating or deactivating of network resources depending on cell users dynamics. However, the sleep control algorithm proposed in [38] was for Femto Base Stations (FBS) and based on the value iteration of Semi-Markov Decision Process.

A sleeping mode control with time-varying traffic load awareness for Pico Base Station (PBS) in heterogeneous networks was advanced in [44] to reduce the cost of energy with. "By formulating the sleep mode control problem into the framework of a standard 0/1 knapsack problem, then a dynamic programming scheme for solving the sleeping on/off mode for PBS in heterogeneous networks was investigated". This approach lowered the complexity of the suggested. The complexity of conventional schemes are exponential but that of this research was linear, representing an improvement.

### **Base Station Sharing**

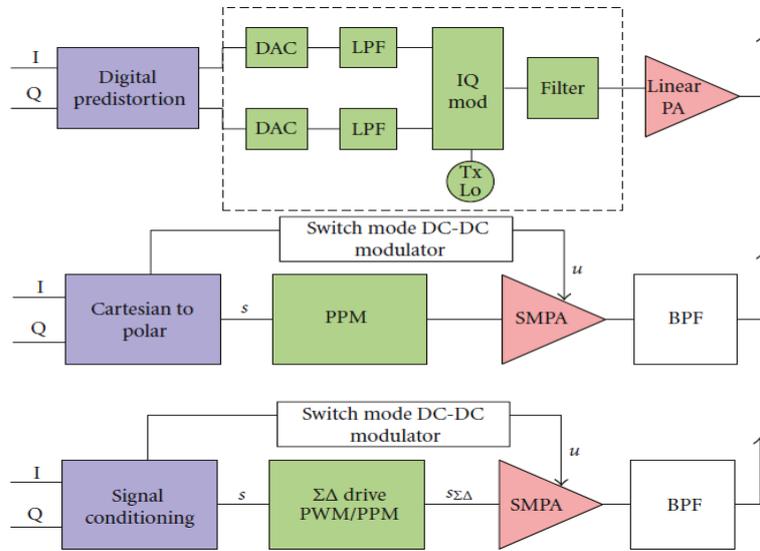
Cellular networks can be operated more energy efficient if operators agree to share base-stations resources during off-peak hours under a well formulated pricing and penalty policy. The general motivation for base station sharing was reviewed in [14]. In this session, we focused on energy sharing among operators.

A microeconomic analysis for a single-cell-two-operator scenario in the examination of the circumstances that will encourage a selfish operator to make resources available for sharing was done in [45]. The authors considered two cases. First, what happens if the rates of payment are determined by external factors? Second, what happens if the rates of payment are determined the operators? The quality of the equilibria obtained either when payment are set by others or operators as compared with the optimized solution was investigated. In [46], Bao et al. considered ways to incentivized operators to willingly disclose their private particulars cooperatively to enhance the overall system utility in a game-theoretic formulation, which is also called social efficiency in mechanism design. Simulation results indicated that there is a positive correlation between the similarity of profile reflecting operators' traffic load and their willingness to cooperate. According to Leng and co, factors such as penalties, capacity, load, energy price, revenues and payments will determined whether or not a selfish operator will share resources. In [47], optimal green energy sharing was the focus. The excess energy generated by the base station is shared with other BS.

### **Hardware Enhancement Based Approaches**

#### *2.6.1 Radio Architecture Design*

In [48], Bassoo et al. noted that current power amplifiers used in 3G base stations draw high power contributing to a higher OPEX and unfavourable environmental consequences. To reduce on the power amplifier, one direction is to work on the radio modulation stage to generate the appropriate drive signal that is optimized for efficiency and linearity by coming up with appropriate architectures such as Envelope Elimination and Restoration (EER), Linear Amplification With Nonlinear Components (LINC) and Pulse Width Modulation (PWM). The authors proposed a promising radio architecture for wireless BS as shown in Figure 4. The architecture used a combination of Envelope Elimination and Restoration (EER) and Pulse Width Modulation (PWM)/Pulse Position Modulation (PPM) modulations to develop a digital transmitter (Tx) with an efficiency of 57%.

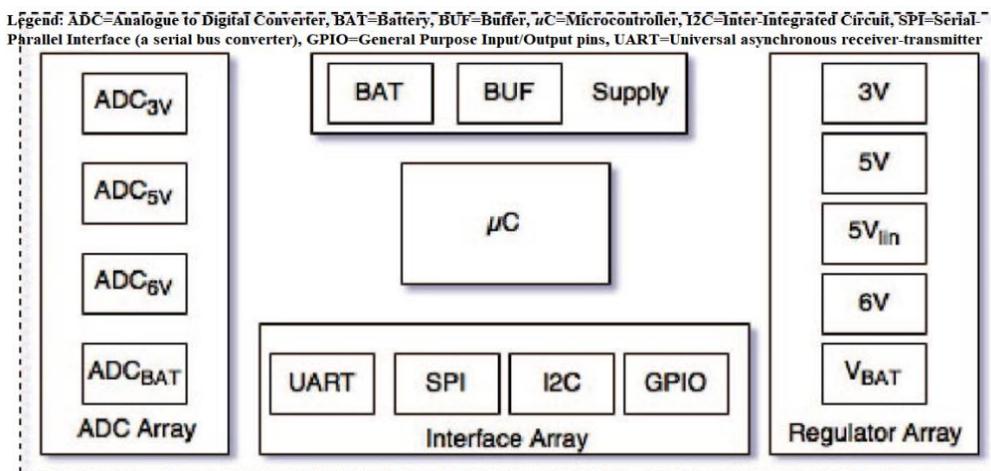


**Figure-4:** Traditional (top), EER (middle), and proposed (bottom) Tx architectures [48].

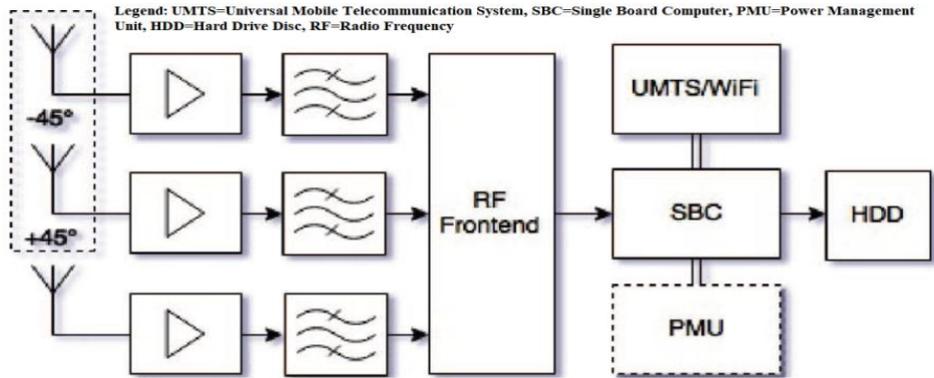
A radio resource management algorithm that reduced the base station power requirement for a multi-user Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system was proposed in [49]. An algorithm was developed to optimize the trade-off between three basic power-saving mechanisms: antenna adaptation, power control and discontinuous transmission. To do this, the number of transmit antennas, the RF transmission power per resource unit and spatial channel, the number of discontinuous transmission time slots, and the multi-user resource allocation was determined by the proposed algorithm, to minimize power consumption. Simulation results showed that the proposed algorithm was capable of reducing the supply power consumption by at least 25% and up to 40%, depending on the system load.

2.6.2 Power Management Unit

In [50], the software aspect and architecture of a Power Management Unit (PMU) was reported. The architecture is as shown in Figure 5. This BS used in telemetry in the “BATS” project. Preliminary results of a field trial in Berlin, Germany was reported, demonstrating the possibilities for further improvements. The placement of the PMU unit in the BS framework is shown in Figure 6.



**Figure-5:** Functional diagram of the proposed Power Management Unit (PMU). Adapted from [50].



**Figure 6:** Schematic representation of the base station’s essential hardware components. Adapted from [50].

2.6.3 Electric Load Leveling

A green base station offloading model was developed in [51] by Wei et al. The scheme was based on green energy prediction and storage with energy saving as a key objective. By predicting the value of green energy collected by the BS and updating the residual energy of each BS, the researchers obtained the theoretic maximum number of users that each green base station can offload. Moreover, the authors also computed the optimum number of users to achieve different network performance as may be desired.

In [52], Nakamura et al. demonstrated that it is possible to lowered energy usage during peak loading by an electric load-leveilling method. This approach was implemented in the Green Power Controller designed for green BS. Evaluation of the controller proved that the control proposal is adequate in reducing energy consumption by suppressing the peaks in electric power consumption.

**III. EVALUATION**

From the analysis in Table 1, it will be noticed that the base station switching off during off-peak period seems to be the most preferred green BS solution. It constituted about 50% of green BS solutions seen in the literature.

**Table-1:** Analysis of selected green base station research

Research	Green energy sources	BS switching	BS sleeping	Hardware redesign	Energy Saving cost
[16]	☑				70-80%
[17]	☑				NA
[18]	☑			☑	
[24]		☑			20%
[25]		☑			50-80%
[26]		☑			NA
[28]		☑			NA
[29]		☑			60%
[30]		☑			NA
[36]		☑			14%
[40]			☑		72%

[41]	<input checked="" type="checkbox"/>	NA
[42]	<input checked="" type="checkbox"/>	NA
[49]	<input checked="" type="checkbox"/>	25-40%
[51]	<input checked="" type="checkbox"/>	NA
[52]	<input checked="" type="checkbox"/>	NA

#### IV. CHALLENGES AND FUTURE DIRECTIONS

##### Conclusion

In this research, the following methods for reducing the carbon footprints of telecommunication base stations were reviewed and analysed. They include: the use of renewable energy sources, optimised base station switching or sleeping. Another method is to redesign hardwares such as radio frequency transmitters that are more energy efficient.

The factors that must be given considerations are approach specific. In the use of greener sources of energy; quantification of available sources of energy within the locality, location, cost of acquisition of innovative technology based long lasting battery bank and effective system load scheduling must be factored in. Network coverage, interference, quality of service and battery life of mobile device have to be investigated in the deployment of switching and sleep mode based GBSs. When radio frequency power amplifiers are to be replaced, the cost of replacement must be consider. In addition, technical matters like the amplifier’s efficiency, peak to average power ratio and linearity need to be evaluated.

Switching off of base stations during off-peak period seems to be the preferred green BS solution. The authors proposing this solution constituted about 50% of the reviewed green base station solutions researches. The use of renewable energy sources is also a promising method of greening base stations. Solar energy is the most exploited of the energy sources and this is followed by the use of wind turbines in combination with diesel powered generators.

##### Challenges, Future Directions and Recommendations

Even though BS have different system loads and communication ranges, researchers for simplicity usually assumed that the base stations considered in their studies consume the same amount of energy. But in a realistic implementation, both the loads and communication ranges will influence the energy consumption model. When these are taken into consideration, the problem will become more complex. Another future research will be to consider the diversity and heterogeneous nature of base stations as against the assumption of homogeneity. Future research can study the effect of adopting different types of base stations on energy-saving performance. Furthermore, how to mitigate the impact of the inherent uncertainty associated with unconventional sources of energy on a cooperative green base station resource sharing scheme should be the subject of future studies.

Currently, parasitic capacitances, which increases at high frequencies is among the challenges limiting the development of highly efficient completely digital Tx operating at a high carrier frequency. How this parasitic capacitance could be minimized to improve transmitter efficiency in terms of energy consumption may yet draw the attention of future research.

It is recommended that environmental sustainability organizations develop a comprehensive green energy compliant scoring system for mobile cellular operators. Operators and equipment vendors promoting greener telecommunication system are rewarded and those doing otherwise are scored low. The reward could come by way of tax incentives. The government too should lower tariff of renewable energy equipment such as batteries, PV cell, low energy transmitter and so on. This will further serve to motivate operators to roll-out more green BS.

Further research should be done on how to optimally extract energy from solar energy. This could be in the way of development of highly efficient PV cells. For instance, dual-axis maximum power point tracking mechanism could be incorporated to improve the amount of energy obtained from PV cells. Another thing that could be done is to train personnel to become skilled in the management and maintenance of accessories of greener energy sources.

In the future we hope to do a state of the art survey of highly energy-efficient radio frequency amplifiers will be done. This will reveal research trends in the development and deployment of environmentally sustainable amplifier for radio frequency communication. Opportunities for enhanced designs will also be revealed in so doing.

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