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A Review on Energy Efficient Techniques and Power Optimization in Wireless Telecommunication Network

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Abstract- *With the increasing energy price, the increase in total power consumption of the networks goaded by the tortuous advanced transmission techniques put us into a challenge. In addition, the extreme spread of base station (BS) sites needed for increasing data, as well as high power consumption, is having a demolishing impact in terms of environmental pollution, mainly due to CO_2 emissions estimated at 125 million tons/yr. So, it becomes very much obvious that power consumption is a significant concern for next generations of wireless communication technology. The researchers from all over the world are studying on the problems pertaining to energy efficiency and remedies to overcome issues of increasing power consumption of networks. This review paper contains the methodology and outcomes of these researches which gives us solutions to face the challenge of energy efficient and optimized wireless telecommunication network. We categorize the solutions and techniques in four categories and give a clear concept of them with definitions and references.*

Keywords: Base stations, Power amplifier, Sleep mode, Cell zooming, Power Optimization

1. INTRODUCTION

Power consumption of wireless networks is a significant concern for all telecom operators throughout the world. To everyone's notice each year 120,000 new base stations are being deployed serving 400 million new mobile subscribers around the globe [1]. We are aware that Information and Communication Technology (ICT) infrastructure accounts for about 3%-4% of the worldwide energy [approximately 1.5 -2% by wireless].
So according to this prospect mentioned above, the reduction of power consumption, particularly within the BSs, is a complex and challenging issue to be solved for developing countries in order to allow a significant amount of saving resources for mobile network operators and also for achieving a "sustainable" development of wireless telecommunication technologies for the environment and society as a whole. Recent studies have indicated that the access network is responsible for about 50-60% of global power consumption of wireless mobile communications. From Fig. 1, taking Vodafone as an example and considering the contribution of the mobile user as negligible, we can conclude that in cellular networks most of the energy is consumed by BS. Power consumption in a BS can be subdivided into four main components that are due to power amplifiers (65%) during conversion by power amplifiers, air conditioning and cooling (17.5%), signal processing (10%) and power supply (7.5%) [3]. Research are focused only on minimizing power consumption of power amplifier. Other energy loses as a result of cabling, AC/DC current converting, and energy for cooling can also be reduced.

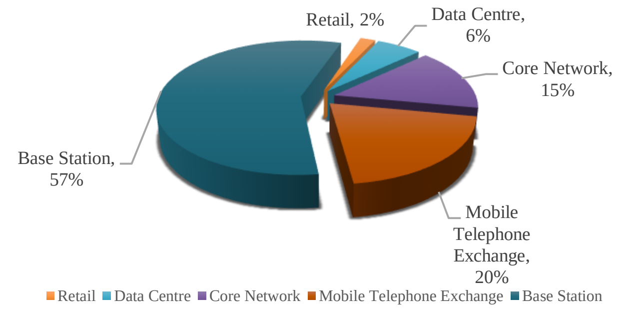

Fig. 1: Power consumption of a cellular network (Vodafone, [2])

Now in this paper, we will categorize the possible solutions to reduce power consumption and techniques to improve power optimization and energy efficiency in four categories:

1. Development of Architecture to save energy in BSs
   - Hardware improvements
     - Improvements in power amplifier, baseband signal processing unit
     - Sleep mode Techniques

- Power Saving protocols

- Energy-Aware cooperative BSs
  - Cell zooming
  - Self-organizing Network
- Using Renewable Energy Resources
  - Sustainable biofuels
  - Solar energy
  - Wind energy

2. Network planning using Heterogeneous network
   - Macro-cells, Micro-cells, Pico-cells
3. System design
   - Enabling allocation technologies
   - Energy- Efficient Resource management
4. Statistical project planning

In the next section researches on saving energy in the wireless communication sector will be reviewed category-wise. The Literature review examines 30 Papers with 35references where 21 references are under category 1, 6 references are under category 2, 2 references follow y papers are under category 3, 2 references are under category 4.

II. LITERATURE REVIEW

First of all, we will discuss research which are related to the development of architecture to save energy in BSs. Our first option is to improve hardware like power amplifier. To simultaneously achieve high linearity and to increase energy efficiency various designs of Doherty Power Amplifier (DPA) with different topologies are proposed in [4] - [11]. A study [3] on gallium–nitride (GaN)-based unsymmetrical DPA has recently received significant attention in the academic community, which has defined an input offset line for amplifier path while peaking at a back-off level. In the cases where phase variation through the path of carrier is power dependent, this DPA design using a base-band digital pre-distortion technique (DPD) can enhance linearity and maximize the power-added efficiency (PAE) for multicarrier wideband code division multiple access (WCDMA) applications. The results found in this study are impressive in terms of efficiency, tradeoff performances, and linearity of a GaN-based DPA. Compared to the configurations described in [5] - [11] the designed DPA in this research achieved 49% of PAE.

They described the cause of this problem briefly. Another study [12] on a highly linear and efficient asymmetric Doherty power amplifier (ADPA) represented a wideband code division multiple access repeater system (2.14 GHz) with adaptively bias-controlled pre-distortion drivers (PDDs). They verified the proposed method using two 2-W GaN high electron mobility transistors (HEMTs) as driving cell and two 20-W GaN HEMTs as main cells. A total drain efficiency of 27.9% and a total gain of 28.7 dB with an adjacent channel leakage ratio (ACLR) of - 51.5 dBc was achieved using ADPA with PDDs. On the other hand, an ACLR of -38.2 dBc was achieved with the total drain efficiency of 37.2 % and a total gain of 26.5 dB for the asymmetrical Class-F DPA with PDDs. Adaptive control of the gate biases of PDDs for a one-carrier WCDMA signal was the key of their method. Therefore, the proposed method can be an effective solution having higher peak-to-average power ratio for WCDMA repeater systems. PAs with envelope tracking (ET) technique amplifies the input signal amplitude and phase with a controlled voltage using DC-DC converter. This technique of using output voltage envelope of DC-DC converter has been implemented widely for improving PAE of wireless transmitters [13]-[16]. The amplitude and phase of input signal can also be amplified with a separate extraction of the envelope with high linearity and then combined again to restore the envelope to phase-modulated carrier, referred to envelope elimination and restoration technique [17].

The paper [18] proposed a non-ideal PA based on block diagonalization for multi-user multiple-input multiple out-put (MU-MIMO) system. They designed a sparse beam-forming design algorithm using a method of successive convex approximation to improve per-antenna power constraints, and spectral efficiency. A GaAs heterojunction bipolar transistor based differential PA is proposed in [19] for long-term evolution (LTE) application to mitigate the parasitic effect of base-collector capacitance. They implemented a neutralization technique which achieved PAE of 40.4-44.5% and a gain as high as 26.6-28.1 dB with 30.5-31.1 dBm saturated power. A common source-common gate GaN based PA design on SiC technology was presented in [20] for IEEE 802.11p standard Wi-fi application that achieved 31% drain efficiency at a 28.8 dBm saturated power. [21] proposed an improved memory polynomial design for IEEE 802.11ac standard Wi-fi application of wideband PAs. [22] also proposed an energy efficient design of Lateral MOSFET transistor based balanced PA for IEEE 802.16 OFDM application, that has achieved PAE greater than 50% at 41 dBm saturated power.

Energy also can be saved by using Remote Radio Unit (RRU) as base band signal processing unit as it is small and can install anywhere on the tower without cooling system. In some countries normally, Double Radio Frequency Unit (DRFU), GSM Radio Filter Unit (GRFU), WCDMA Radio Frequency unit and Multi-Carrier Radio Frequency Unit (MRFU) are used, which need indoor cooling system as they are heat sensitive. In Africa, they are only using RRU to optimize the power consumption by the cooling system by conventional Radio Frequency (RF) unit.

Another process of hardware improvement is applying sleep mode algorithms in BSs to shut down them during low traffic. [23] proposed three algorithms based on energy efficient sleep mode for small cell deployments (e.g. macro, micro and Pico cell). Sleep mode allows the hardware infrastructure in the BS to go into absolutely switched off mode in idle conditions, along with modulated power consumption over the variations in traffic load conditions. Small cell driven, core network driven, and user equipment driven approaches that three different strategies were discussed for controlling algorithm. Small cell BSs can be operated in two prime operational modes: 'open access mode' to give access to all users of the operator's network; and 'closed access mode', to service only users who are registered to access the operator's network. Energy saving procedures employed in small cell BSs can vary significantly based on the access control mechanism. The introduction of a low-power state in the hardware is the basic idea of underpinning 'sleep' mode activation in small cell BSs. There are two states of sleep mode activation/deactivation i.e. 'Ready' state (RE) and sleep state (SL). When RE state is on, then the small cell BS hardware components are switched on fully. And in SL state, some of the specific hardware equipment's in the small cell BSs are either fully switched off or operated in low-power modes. When a user equipment (UE) unit is inside the coverage range of the small cell sniffer connects to the macro-cell, the sniffer detects a rise in the received power on the uplink frequency band.

If the received signal power exceeds a predetermined threshold level, the detected UE is considered close enough to be potentially covered by the small cell. At this instance, switching of small cell to the RE state is processed along with activation of pilot signal transmission. Another way was to place the sleep mode control at the UE side, which can broadcast wake-up signals to wake up small cell BSs within its coverage range. In the UE at idle mode, this solution can mainly be used whereas the small cell driven, and core network-controlled solutions require the UE to put a connection with the network.

In a wireless sensor network (WSN), there are deployment of small and independent nodes continuously sensing, monitoring, computing, and transmitting data; hence consumed a good amount of power. The power consumption in a WSN can be minimize by adopting routing protocols to find shortest path to transmit the data since transmission is the activity where most of the power consumption happened. Moreover, adjustment of transmission power can lead to a well trade-off between the quality of service (QoS) and lifespan of network [24]-[27]. There are protocols such as Medium Access Control (MAC) [28], [29], IEEE 802.15.4 [30], WirelessHART open standard [31]. To improve the lifetime of WSN [32] proposed a model which used two fuzz logic controllers simultaneously to achieve an adaptive control on transmission power and sleeping time. They achieved 30-40% improvement on the network lifetime by using this technique with an adaptation of MAC and WirelessHART protocol. There are also some clustering protocols such as LEACH [33], PEGASIS [34], LEFC [35], which basically are clustering mechanism to divide WSN into clusters. In this mechanism, sensor nodes send information to randomly selected cluster head, which aggregates all the information and transmit them to the BS. Many optimization algorithms are also proposed in several studies such as ant-colony optimization (ACO) [36], [37], particle-swarm optimization (PSO) [38]-[43] and resampling particle-swarm optimization (RPSO) [44] for using routing protocols more efficiently. Another study [45] proposed an RPSO-ACO based optimization method for clustering and optimization method, which achieved a 37.5% increase in coverage ratio compared to LEACH, a 2.7% increase in coverage ratio compared to PSO-ACO, and 28.8% increase in coverage ratio compared to PSO based clustering along with high accuracy in calculation and speed of convergence.

Now moving on the energy-aware cooperative BSs. In a research work [46] researchers reduce the number of active cells when low traffic and then characterized the amount of power saved. They showed the way of improving energy efficiency by turning of any fraction of cells can be turned off. Then the limitations producing from the cell layout is considered. In their research work they thought of four general telecom network configurations. Which are: i) Hexagonal cells along with omnidirectional antennas, ii) BS cells along with omnidirectional antennas, iii) Hexagonal cells along with tri-sectorial antennas and iv) Manhattan layout. They examine these four cases with two daily traffic scenarios: the symmetric trapezoidal traffic scenario and an asymmetric traffic scenario. Finally, 25-30% energy savings were achieved by researchers.

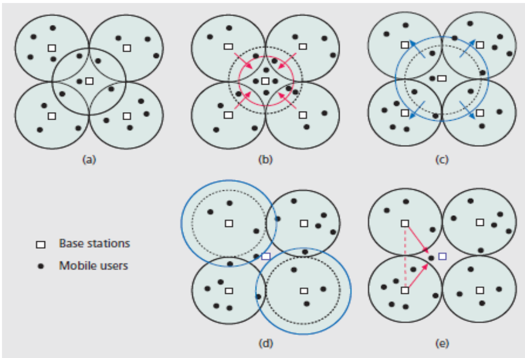

Fig. 2: Operating principle of cell zooming in cellular networks: a) when cells having actual size; b) when load increases; c) when load decreases; d) when central cell sleeps and neighboring cells zoom out; e) central cell sleeps and neighboring cells transmit cooperatively [16]

Then we can move on to well-popular approach, which is Cell Zooming. It can give numerous benefits in cellular networks. Firstly, cell zooming can be implemented for load balancing by moving traffic from high load to cells of light load. Secondly, cell zooming can be used for power saving by zooming in to zero when the traffic load is low enough. Sometimes BSs of an area can go into sleep mode, and potential coverage can be still achievable if the neighbor cells zoom out accordingly. Therefore, cell zooming can not only scatter but also focus the load for energy saving. In the above two cases, the resources are allocated to balance the traffic distribution, however, the direction of the load transfer is different i.e. opposite. The challenging problem is to determine which direction the load needs to be transferred. Figure 2 illustrated an example of cell zooming technique with a telecom network consists of five cells (fig. 2a) (four cells co-centric to one cell). BSs (represented by squares) are located at the respective center of the cells, and mobile users (represented as dots) are distributed across the cells. The central cell zooms in when there is congestion in central cell (fig. 2b) while central cell zooms out when there is congestion in neighboring cells (fig. 2c). But in case of high capacity neighboring cell, central can do both zoom in or out based on the coverage demand (fig. 2d) or serve the mobile user of a certain direction by cooperative transmission (fig. 2e). In [47], novel policies for spectrum allocation using cell zooming, user migration, and sleep mode technique. Another study [48] proposed cell zooming algorithm based on the method of load balancing (LB) and load concentration (LC) to improve EE of heterogeneous mobile network. In LB method, the transmission power was reduced in case of high traffic and in LC method, high traffic load was reduced by dispersing the traffic to the less loaded neighboring BSs. With respect to traffic scenario, an advanced idea of cell zooming proposed to regulates the cell size adaptively [49]. They also proposed a distributed cell zooming algorithm, in which selection of BS can be done by each mobile user itself depending on the measurement of channel conditions and BSs' traffic load.

This scheme offered a reduction in the information exchange and signaling overhead. In this distributed algorithm, BSs keep some extra bandwidth reserve for new mobile users coming from outside. In another research [50] about cell zooming, a fuzzy system corroborated with a control technique was proposed to design energy efficient BSs using cell zooming. The system consisted of five sub models, where two new fuzzy sub-models had been interfaced with the three Fuzzy sub model system as described in [51]. By employing this control method for power consumption around 39.5% power savings were achieved for a cycle of 24-hour.

High QoS can be achieved while minimizing operational expenses by using three different types of topologies such as self-optimization, self-configuration, and self-healing. These topologies are the key feature of self-organizing networks (SON). SON has advanced adaptive tools and automation mechanism that can help mobile network to achieve flexibility in deployment planning and efficient optimization, low capital and operational expenses [52]- [54]. A handful of research has been done to achieve self-configuration and self-optimization in [55]-[57]. A diagnosis system based on machine learning was proposed in [58].

The most important solution to attain an energy efficient telecommunication network is using renewable energy sources as an alternative backup. There is a challenge of providing feasible cellular mobile service at an extremely remote location because dependable power supply is not available there. The main causes of service interruption are failure of transmission backhaul links and power supplies. Moreover, when there is a power outage due to battery or backup power failure, the time taken to recover the situation is very long due to distance from the main service center. That's why remote BSs renewable energy sources can be used as primary sources of BSs. According to [59], one 15 KW photo-voltaic installation can be the replacement of 12 diesel generator installations along with saving 203,000 liters of diesel in 20 years.

To use in cellular BSs, PV power systems can be designed in four ways [60] - [62], which are:

- Systems having no battery backup capability connected with grid,
- Systems having battery as backup and interacting with the utility power grid,
- Stand-alone systems,
- Hybrid stand-alone systems.

[63] described a process to determine the cost-effective photovoltaic design for BSs or other applications using PVSYST 6.4.0 software. In a journal [64], a solution was presented using a hybrid of solar and wind power systems with a portable generator. It will provide reliable power for a mobile base station located behind the Himalayas of south Asia. The methodology described in this journal is a standard one to follow. Finally, tower selection (Green Power Tower) and installation of the PV systems with determined specifications by the process mentioned above have to be done. In a paper [65], different configuration of green tower had been described. For optimum solution, they recommended to include loads of solar in the initial design to avoid additional retrofitting costs. Other forms of renewable energy like wind power and sustainable biofuels are also can be used to supply power to the BSs to reduce dependency on the grid power.

Network planning using heterogeneous network e.g. small cell distribution is also energy efficient. There is a saying that "big things come in small packages." However, small cell distribution in a large-scale way can rise in power consumption of the network with significant ecological and monetary implications if left unchecked. Small powered and low-cost radio BS known as small cell and the primary design objective of these types of cell is to give strong cellular coverage support to different areas. Small cells that are used to broaden cell size are: femtocells, picocells, and microcells. Heterogeneous network described in [66] and [67] kept monitoring the traffic (which was modeled) with a certain number of microsites at the macro cells' edges and varied the inter site distance to scale the deployment density. In another study [68], researchers extended that model of macro cell by placing a random number of microsites within it which leads them to take a specific distribution density in consideration at a constant inter-site distance. In [68], authors carried on a detailed analysis on the impact of macro site transmit power on energy EE and SE. 100 micro site placement realizations were averaged to obtain reproducible results. Finally, they got 20% of efficiency gain. [69] also carried an analysis of hierarchical telecom network configuration has been stated that large macro overlay cells because significant amount of interference due to their big scale transmit power. In another paper [70], authors provided a framework which helped them to evaluate and optimize cellular network distributions with respect to the average number of micro sites per macro cell as well as the macro cell size. They found that deduction in the power consumption can be achieved by distributing at least on micro site even if the power offset for micrositess per antenna was more than (3 times) that of macro sites.

But for modern green mobile communication, [71] presented an energy efficient Radio Resource Management (RRM) strategies without many drawbacks in terms of blockage or admission control and distribution guidelines which can be obtained in a multi-layer heterogeneous cellular network with the aim of the optimization of power consumption. 5 different algorithms have been considered in order to manage the cluster resources according to different optimization strategies and the traffic conditions. Their 1st algorithm was used as a solution for macro-cell BS that were able to allocate carrier dynamically. Their 2nd algorithm used Reduced Range (RR) Macro-cell BSs together with Macro BS. 3rd algorithm mostly resorts to the channels of the RR Macro BSs which are activated either for low or high traffic load. Algorithms 4 and 5 were combinedly based on a generalization of the 3rd algorithm, which used 7 or 19 micro-cell BSs with support of macro-cell BSs. These algorithms provide efficiencies of 20%, 30%, 55%, 60% consecutively. This heterogeneous network distribution has been shown to be highly efficient when supported by the green radio strategies.

Our 3rd category will contain reviews of three papers which are related to the system control to save energy in wireless telecommunication network. First paper is a research [72] on an LTE technology. Authors proposed an algorithm called green antenna switching (GAS). Awareness of the intensity and traffic topology controlled by each base station are its aim in to find the appropriate working conditions to switch on-off one of the MIMO antennas and the corresponding power amplifiers (PA). And they made it without any excessive performance degradation. They investigated the system performance and evaluated the amount energy saved while changing the traffic load during three different scenarios of the day: 1) Mid-night scenario, 2) Day time voice-oriented scenario and 3) Evening data-oriented scenario. Finally, they obtained results throughout the insertion of the GAS algorithm by using an LTE system level simulator. They successfully saved 14% and 16% energy (depending on different day times) compared to the classical approach followed in MIMO antenna system.

In the end, they concluded by wishing that, the LTE will replace all the other cellular technologies such as GSM, EDGE, UMTS soon. They also added that the average power consumption in 24 hr could be reduced by about 15% which turns into an average annual savings of 5250 kwh equivalent to about 846.19 $ saved for each BS; this means that the entire telecom industry would have a significant cost saving around 50.77 M$ per year along with less environmental effect. Distributed Antenna System (DAS) is another example of system control. In [73], researchers considered a coordinated multi-cell DAS. They investigated two energy-efficient RRM schemes where, either ports can be switched on and off or their transmission power can be control in order to improve power optimization and energy efficiency. Their proposed technique offers ample increase in data rate with less total transmission power. Another solution fit this category is Energy-efficient Resource Management. In [74], researchers from the University of Bristol investigated seven Resource Allocation Algorithms (RRA).Among them, there are one time domain scheduler algorithm and six frequency domain scheduler algorithms. 1st one was Round Robin (RR), a frequency domain scheduler algorithm which does not depend on channel state information. 2nd one was Greedy Algorithm (GA), that did not take fairness into consideration and maximizes system throughput. The window size in Proportional Fair Algorithm (PFA) and the tuning parameter in the Relative Strength Scheduling Algorithm (RSSA) allowed their system to tune fairness according to specific requirements. The Equal Gain Dynamic Allocation (EGDA) algorithm helped them to allocate physical resource blocks that increased the channel gain in a user without minimizing the channel gain in other users. The Fair Cluster Algorithm (FCA) took scheduling history into consideration helped them to allocate all selected users with sufficient amount of resource block and the current scheduling decision of the latter scheme. The conventional target of RRA was to improve system throughput. The output of these several scheduling algorithms was tested. Finally, their proposed algorithms offer excellent tradeoff between achieving fairness standard and they achieved high throughput and energy efficiency. They concluded that traditional algorithms, such as the GA, RR and PFA failed to confirm power fairness and efficiency.

In our final category, we include the project-based planning like “EARTH” [75] and “TREND” [76]. “Earth” is a project which is integrating a way to observe the energy efficiency of wireless telecommunication systems. It is extravagantly ambitious and committed to the improvement of energy efficient devices for next generation, components, distribution strategies and energy-aware network management solutions etc. Fig. 4 shows the main perspective of the technical approach: EARTH serves the objective of analyzing the energy efficiency of present solutions and the improvements attained by distributing their imagined solutions in real core networks. They studied the fundamental limits and tradeoffs of the network management. Ultimately, they target for betterments beyond current development trends. Those betterments will be achieved by energy efficient distribution strategies including heterogeneous networks, relays and cooperative BSs. They will also use energy-aware network resource management, configurations and transceivers or BS equipment with high adjusting ability to the traffic condition. They will realize more improvements by employing advanced and optimized wireless transmission techniques for energy efficiency and power optimization instead of only for spectral efficiency improvements.

Another project like earth is “TREND (Toward Real Energy-efficient Network Design)” which was funded by the European Commission 7th Framework Program. They are the only project in the field of research about energy-efficient or green networking. Most of the TREND activities focused mostly on the top layer of data networks. But there are other researches which indicate the problem on achieving EE at the physical layer also. In their project, they concluded that devices in the network core consume power due to the huge amount of data transportation is not negligible. Similarly, Sleep modes can also be activated depending on the traffic conditions in the cellular networks. Moreover, switching activities on whole routers consume a lot of time. However, if certain parts in particular line cards can be activated and deactivated, it has been proved to have high energy efficiency.

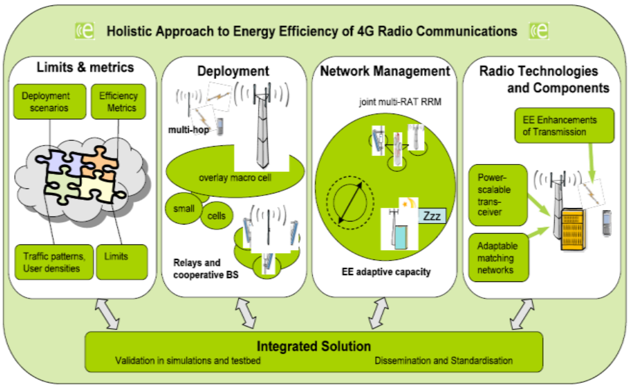

Fig. 3: Technical approaches of EARTH [35]

The more the number of collaborating institutions of the project is increasing, the more interests on the project growing around the research groups from all over the world.

III.CONCLUSION

The aim of this literature review is to summarize the worldwide emerging technologies and existing solutions to the problems pertaining to energy consumption in base stations and energy saving. Without the solutions reviewed above there also ongoing researches on different power allocation schemes, two tier femto-macro technology, relaying and multi-hop cellular technology and different MIMO resource allocation schemes. These technologies are the best reported emerging technologies till now. In Bangladesh, the telecom operators are also adopting these technologies with the help of vendors like Huawei or Ericsson.

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