DEPARTMENT OF COMMUNICATIONS ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA - NIGERIA

Proceedings of the 1st National Communication Engineering Conference 2018

Data Rate-based Sleep Mode in LTE Hetnet

Abubakar Ahmed, Kabiru Abubilal, Suleiman Sani
Department of communications engineering
Ahmadu Bello University Zaria, Nigeria
habusadik@gmail.com, kb.ahmad74@gmail.com, smsani_2@yahoo.com

ABSTRACT—Base stations significantly contribute to power consumption in cellular networks. This is a factor which needs to be addressed when modelling cellular networks. This is due to the fact that high power consumption will result in high operational cost. Several energy saving algorithms have been proposed to save energy in heterogeneous networks. This paper therefore introduces a Data Rate-Based Sleep Mode Algorithm for energy savings for a pico evolved NodeB (eNodeB) cell in a Long-Term Evolution (LTE) heterogeneous network (HetNet). The algorithm switched the operating state of some pico eNodeB cells to sleep mode (inactive state) at low traffic and medium traffic during which the users are offloaded to other pico eNodeB and macro eNodeB cells to save overall energy consumption in the network. As traffic increased and the average user data rate of the overall network reduced (less than 2Mbps), the pico eNodeB cells return to active state to ensure service delivery was not obstructed. The work considers temporal fluctuations of traffic with a view to achieving higher energy savings.

KEYWORDS—base station, cellular networks, heterogeneous network (HetNet), sleep mode, evolved NodeB (eNodeB), Long Term Evolution (LTE), pico, macro, average user data rate

INTRODUCTION

The number of subscribers and the demand for cellular traffic has increased. Hence, mobile operators find meeting these new demands in wireless cellular networks inevitable, while they save to keep their costs minimum [1]. In a wireless network, base stations (BSs) consume about two-third of total network power consumption and are logically responsible for 70% of CO2 emission from the entire network. For this reason, management of energy consumption of wireless base station has become an essential topic of discussion in the research society [2].

Increase in the number of small cell base stations in HetNets as well as their power consumption has made energy savings an important topic for research. Sleep mode technique helps in the reduction of power consumption in HetNets. Most researches implemented sleep mode focusing on base station transmit power, constant data rate, number of users, signal-to-interference-and-noise ratio (SINR) and traffic load. These factors do not efficiently represent realistic traffic load conditions. This paper considers average user data rate as a metric for sleeping pico evolved NodeB (eNodeB) cells in a Long-Term Evolution (LTE) HetNet.

A traffic model, data rate model and a power consumption model were used to implement the sleep mode in the LTE HetNet. The traffic model was based on Round Robin resource allocation, the data rate model was based on SINR link adaption mapping, and the power consumption model was based on power consumption parameters of the pico eNodeB cells.

PROBLEM DEFINITION

It has been found out that little or no investigation has been made on the effect of average user data rate on sleeping pico eNodeB cells. However, setting a pico eNodeB cells into sleep mode could lead to poor service delivery. Therefore, there is a need to consider the realistic average user data rate of 2Mbps [3] when implementing sleep mode for LTE HetNets.

A. LTE Network Architecture

The Long-Term Evolution (LTE) encompasses the evolution of the Universal Mobile Telecommunications radio access through Evolved Universal Mobile Telecommunications System Terrestrial Radio Access Network (E-UTRAN). It is accompanied by an evolution of the non-radio aspects under the term System Architecture Evolution (SAE) which includes the Evolved Packet Core (EPC) network. Together LTE and SAE comprise the Evolved Packet System (EPS). The access network of LTE, E-UTRAN, simply consists of a network of eNodeBs as illustrated in Fig. 1. For normal user traffic (as opposed to broadcast), there is no centralized controller in E-UTRAN; hence the E-UTRAN architecture is said to be flat [4].

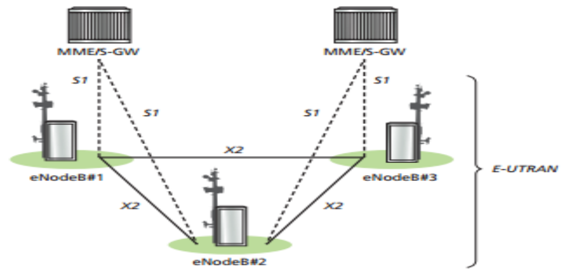


Fig. 1. Overall E-UTRAN Architecture. [4]

B. LTE Network Architecture

A macrocell base station consists of six power consuming components as discussed hereunder [5]:

1) *Rectifier:* Converts alternating current (AC) to direct current (DC), also known as a AC-DC converter.
2) *Digital Signal processing:* This is concerned with the conversion of the signal to a sequence of bits or symbols and the processing of these signals.
3) *Transceiver:* This is responsible for transmitting and receiving the signals.

4) *Power Amplifier:* This converts the DC input power into a significant radio-frequency (RF) signal.
5) *Air Conditioning:* Regulates the temperature in the base station cabin.
6) *Micowave Link:* This is responsible for the communication with the backhaul network.

The total power consumption of the base station is a sum of the power consumption of all the above-named components. The power consumption of these components should be multiplied by their number of occurrences to determine the base station power consumption. Some of the components depend on the number of sectors, n_{sector} and the number of transmitting antennas, n_{tx}. The n_{sector} determines the number of rectifiers, digital signal processing, transceivers and power amplifiers. Each sector requires one rectifier, one digital signal processing unit, one transceiver and one power amplifier. Therefore, the power consumption of these components should be multiplied by n_{sector}. The n_{tx} determines the number of transceivers and power amplifier. For each transmitting antenna, one transceiver and one power amplifier are needed. This means that the power consumption of the transceiver and the power amplifier should not only be multiplied by n_{sector} but also by the number of transmitting antennas n_{tx}. Taken this into account, the power consumption per macrocell base station for High Speed Packet Access (HSPA) and LTE (Advanced) is up to about 1672.6W [5].

The same components used for a macrocell base station are used for a microcell base station except for the backhauling. The backhauling of a microcell base station is typically established through the overlaying macrocell base station. A microcell base station supports only one sector covered by one antenna. This results in a power consumption of 376.6W per microcell base station. The size of a femtocell base station is much smaller than that of a macrocell and microcell base station and is comparable to that of a Wireless Fidelity (WiFi) access point. Therefore, the power consuming components are different from those of a macrocell and microcell base station. The femtocell base station consists of a microprocessor, a transceiver and a power amplifier. Femtocell base station power consumption is 12W per base station [5].

C. *Energy Savings in Base Stations*

Power consumption for each base station is about 1400 watts and energy cost per BS is about $3200 per annum with a carbon emission of 11 tons of CO2. The radio network itself adds up to 80% of the total network energy consumption. Therefore, BS equipment manufacturers have begun to offer a number of eco-friendly solutions to reduce power demands of base stations. A typical cellular network consists of three main elements; a core network that takes care of switching, base stations providing radio frequency interface, and mobile terminals for making voice or data connections [1].

There are different ways to reduce energy consumption in base stations, such as [6]:

Employing power saving protocols such as base station sleeping which enables an inactive operation mode for base stations under load conditions.

Improved power amplifier technology which makes the hardware design of a typical base station more energy efficient.

Cell size adjustment schemes such as cell-breathing and cell-zooming where different cells adapt their size depending on the received interference or traffic load conditions.

Deployment of relays (e.g. amplify-forward) improves the power reduction with reduced complexity at an increased cost for deployment of infrastructure.

D. *Heterogeneous Networks for LTE-Advanced*

LTE-Advanced (LTE-A) networks were developed to offer considerably high data rates than the existing 3rd Generation (3G) networks. In order to meet the requirements of LTE-A (e.g. peak data rates up to 1Gbps), more spectrum bands are needed. Besides the existing carriers for 3G networks, spectrum bands located at 450– 470 MHZ, 698–790 MHZ and 2.3–2.4 GHZ, and 3.4–3.6 GHZ can be used for the deployment of LTE and LTE-A networks. LTE-A has been designed to support scalable carrier bandwidth exceeding 20 MHZ, potentially up to 100 MHZ. The LTE-A consists of eNodeBs that are interconnected with each other by means of X2 interface. The eNodeBs are connected through the S1 interface to the core network [7].

Network coverage and high data rate requirements in hotspot and indoor environments have brought new challenges to LTE systems. In order to improve the system capacity and energy efficiency for hotspot and indoor environments, HetNets and their enhancements have been proposed. The architecture of a HetNet for an LTE-A system is shown in Fig. 2. Among the different technologies that have been proposed and studied in 3GPP HetNet, small cell (pico cell) enhancement is one of the major techniques.

The benefits of using pico cell enhancements include [7]

Flexible pico cell deployment according to users and traffic distributions.

Optimized pico cell mobility by reducing Radio Access Network (RAN) to core network signalling.
Increased data rates by using macro and pico cells together.

Energy saving by using dynamic pico cell sleeping.

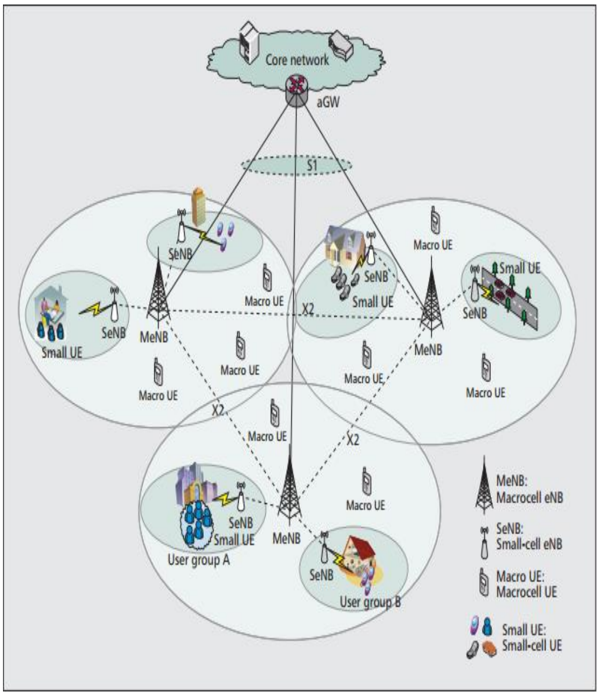


Fig. 2. Architecture of HetNet for LTE-Advanced Systems. [7]

E. 3GPP Heterogeneous Network Topologies

Two heterogeneous network topologies are supported in the LTE system level simulator toolbox developed by Wireless Systems Research Lab, Hitachi America Ltd. These topologies are in line with the standard 3GPP specifications that are widely used in industrial simulations. They are used for evaluating performance metrics such as coupling loss (link gain) and geometry (received SINR) distributions [8].

Reference [9] specified the heterogeneous network scenarios as follows

1) HetNet Configuration 1: 3GPP specified HetNet Configuration 1. Reference [8] implemented the configuration in the system level simulator Toolbox in MATLAB to illustrate the pictorial representation of the topology. In this configuration, small cells (Pico eNodeB cells) are overlaid in the macro area coverage with uniform density. The macro and small cells serve both indoor and outdoor users that are uniformly located in the macro coverage area as shown in Fig. 3.

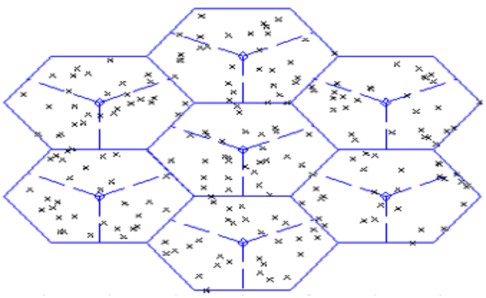


Fig. 3. Schematic Diagram of HetNet Configuration 1. [8]

2) HetNet Configuration 4b: 3GPP specified HetNet Configuration 4b. Reference [8] implemented the configuration in the system level simulator Toolbox in MATLAB. It comprises urban area with small cells overlaid in macro coverage area with uniform density. The macro and small cells serve both indoor and outdoor users, a fraction of whom are clustered around the Pico eNodeB cells modeling a hot-spot scenario as shown in Fig. 4.

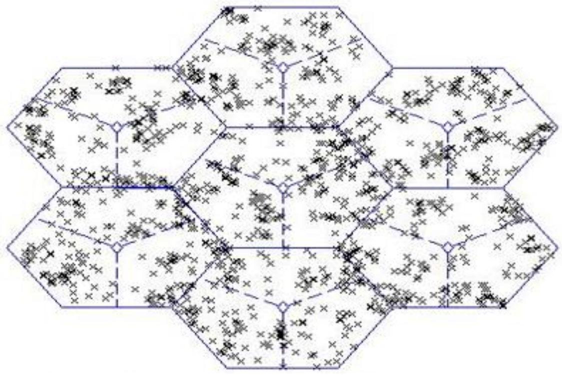


Fig. 4. Schematic Diagram of HetNet Configuration 4b. [8]

F. Base Station Sleep Mode Algorithms

Whenever a base station is working in sleep mode, the other energy consuming equipment such as air-conditioner have to be switched off. The energy consumption of cellular network can be largely reduced when the base station is sleeping. However, in such a case the cell with base station working in sleep mode will be zoomed in to zero and its neighbouring cell will zoom out to guarantee coverage [10].

The idea of sleep mode activation in pico base stations is the introduction of a low-power state in the hardware, referred to as the SLEEP state. Pico cells are in one of the following states at any given time [11]:

1) Ready State (RE): In this state, all hardware components in the pico base station are fully switched on. This can also be referred to as the ACTIVE state.

2) Sleep State (SL): In this state, some of the hardware components in the pico cells are either completely switched off or operated in low-power modes. The base station is correspondingly said to be in SLEEP mode. The exact components to be switched off are a function of the specific hardware architecture and the particular energy saving algorithm. During SLEEP mode, it is assumed that the power consumption is 0W.

METHODOLOGY

Three models were used to achieve the sleep mode in this research work; the traffic model, data rate model and power consumption model.

G. Traffic Model

Round robin resource allocation was used. The simulations were based on fair scheduling of resources. Thus, all the available resources are scheduled among all the users and the users are utilizing all the allocated resources. In order to efficiently allocate equal number of resource blocks to users, the Number of Resource Blocks (NRB) was divided by the number of UE in the eNodeB cell. Thus, the number of resource blocks allocated to a user at distance, d, from an eNodeB cell per transmission time interval according to [12] is expressed in (1), as in:

$$NRB(d) = (NRB / TTI) / NumUEperCell \quad (1)$$

Where: *NRB(d)* is the number of resource blocks per eNodeB cell, *NumUEperCell* is the number of UE per eNodeB cell, and *TTI* is the transmission time interval (1ms).

H. Data Rate Model

The Data rate model was based on Signal-to-Interference and Noise Ratio (SINR) mapping for link adaptation to accurately estimate individual user data rate. Equation (2) gives the expression for the SINR which was adopted in this research work. For a UE placed at distance, d, from the eNodeB (eNB), the average Signal-to-Interference and Noise Ratio (SINR) at the UE is given by [13] as in:

$$SINR(d) = P_{TX} + G_{TX} + G_{RX} - N - I - SF(d) - PL(d) - PLN \quad (2)$$

Where: P_{TX} is the eNB transmission power (per cell sector) in dB; G_{TX} and G_{RX} are the eNB and UE antenna gains respectively. *N* and *I* are the noise and the inter-cell-interference (ICI) power from all the interfering eNBs 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 [13].

Depending on the SINR(d) at the user equipment (UE) calculated using (2), and the intervals of CQI state, the data rate *R(i)* at the UE is expressed according to [13] by (3) as in:

$$R(i) = [TBS(i) \times NRB(i)] / TTI \times [1 - BLER(i)] \quad (3)$$

Where: *TBS(i)* is the physical transmission block information capacity in bits, and *BLER(i)* is the average Block Error Rate (BLER) for the CQI state i, *TTI* is the transmission time interval and *NRB(i)* is the number of resource blocks allocated to UE *i*.

Three modulation levels of Quadrature Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (16-QAM) and 64-QAM are supported according to the LTE specification in [14] with 26 Modulation and Coding Schemes (MCSs), this implies that there are 26 Channel Quality Indicator (CQI). The SINR to TBS mapping for these MCSs, assuming a Block Error Rate (BLER) target of 10% was established is expressed in (4):

$$SINReff(d) = max\{SINR(d), SINRthreshold\} \quad (4)$$

Where: *SINReff (d)* is the effective SINR of a UE for mapping to corresponding CQI and TBS. *SINR(d)* is the SINR as a result of the UE's instantaneous channel conditions. And *SINRthreshold* is the SINR value corresponding to the 26 MCSs level.

Using the SINR value allocated to the UE, the mapping of the SINR to TBS was obtained in the system level simulator in MATLAB. Substituting for *SINReff(d)* obtained from (4) is expressed in (5), as in:

$$TBS(d) = TBS\{ SINReff(d)\} \quad (5)$$

Where: *TBS(d)* is the *TBS* in bits allocated to UE based on *SINReff (d)*.

Therefore, to obtain the average user data rate (realistic data rate of a user) of a single UE, the overall data rate of the HetNet was divided by the total number of user equipment as in (6):

$$Average\ UE\ Data\ Rate = RtotalUE / NumUE \quad (6)$$

Where: *Average UE Data Rate* is the average user data rate, *RtotalUE* is the total data rate in a macro area coverage, and *NumUE* is the total number of UE.

I. Power Consumption Model

The power consumption equation for a base station of [15] was adopted and expressed as in (7):

$$P_{C(i)} = N_{SEC} \times N_{ANT} (A_i P_{TX} + B_i) \quad (7)$$

Where: N_{SEC} and N_{ANT} denote the number of sectors of the eNBs and the number of antennas per sector, respectively. $P_{C(i)}$ is the average total power per base station in Watts and P_{TX} is the power fed to the antenna. The coefficient A_i accounts for the part of the power consumption in Watts that is proportional to the transmitted power, which includes radio frequency amplifier power and feeder losses. While B_i denotes the power that is consumed in Watts independent of the average transmit power which includes signal processing and site cooling [16]. The values for A_i and B_i are given in Table 1.

TABLE I. POWER CONSUMPTION PARAMETERS [16]

Base Station	Power Coefficients	
	A_i *(W)*	B_i *(W)*
Macro	21.45	354.44
Pico	5.5	38.0

a.

RESULTS AND DISCUSSIONS

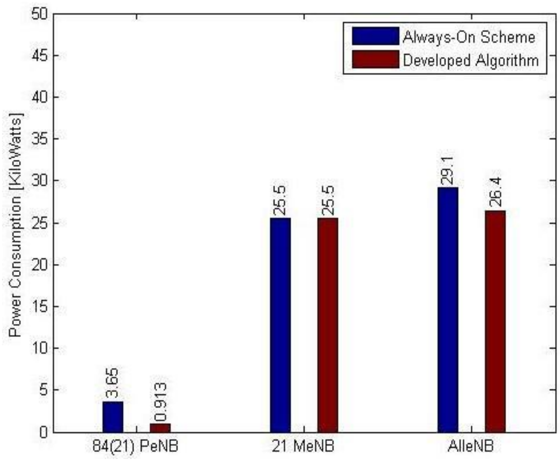
In order to validate the model developed in this research, it was compared with the standard 3rd Generation Partnership Project (3GPP) Always-On Scheme. The results for the power consumption of the various nodes [pico eNodeBs (PeNB), macro eNodeBs (MeNB) and all the eNodeBs in the HetNet (AlleNB)] is presented below.

Low Traffic Power Consumption

It is observed from Fig. 5 that the Developed sleep mode algorithm performed better than the Always-on scheme, because 63 pico cells are in sleep mode, with only 21 active PeNB cells while 84 PeNB are active for always-on. This implies, there is only 1 active pico cell per macro cell coverage, and 3 sleeping pico cells per macro cell coverage. The Developed sleep mode algorithm was able to determine the required number of active pico cells by considering the average user data rate. With this low traffic, the power consumption of the MeNB remained the same for both algorithms because the sleep mode was only implemented for the PeNB cells. There was a decrease in power consumption for the overall HetNet (AlleNB) as a result of the PeNB power consumption improvement during low traffic.

Fig. 5. Low Traffic Power Consumption in Configuration 1.

J. Medium Traffic Power Consumption



From Fig. 6, as the number of user equipment increased, it is observed that the power consumption for the developed sleep mode algorithm is lower than the always-on scheme because 42 PeNB (two pico cells per macro cell coverage) are active while the other 42 PeNB cells are in sleep mode to save energy. The MeNB power consumption is still constant with an improvement in the overall HetNet (AlleNB) power consumption.

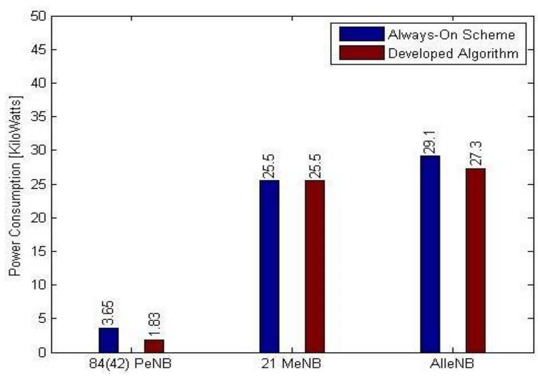


Fig. 6. Medium Traffic Power Consumption in Configuration 1.

K. Configuration 1 HetNet Power Consumption

In HetNet Configuration 1, the Developed algorithm achieved a reduction in power consumption for low (5UE per cell) and medium traffic (12 UE per cell) in the pico eNodeB cells of about 75% and 50% respectively. On the other hand, 9.28% and 6.19% reduction were achieved for the overall HetNet for low and medium traffic respectively.

In terms of power consumption reduction, the Developed sleep mode algorithm performed better up to about 20UE per cell than the Always-on scheme as shown in Fig. 7. The power consumption increases with increase in the number of users and becomes maximum at high traffic.

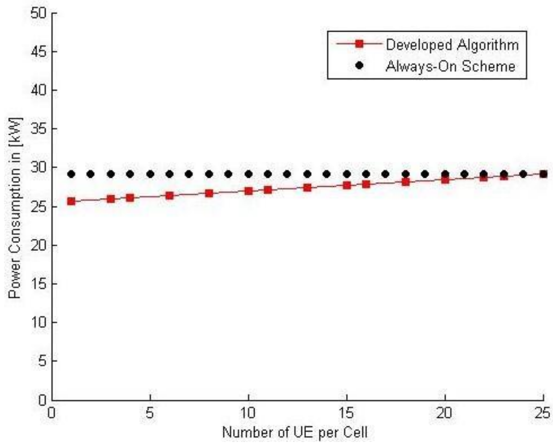
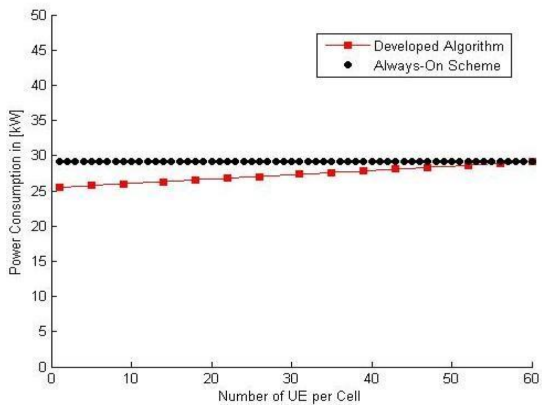


Fig. 7. Power Consumption in HetNet Configuration 1.

L. Configuration 4b HetNet Power Consumption

Similarly, in HetNet Configuration 4b, the Developed algorithm achieved a power consumption improvement for low (5 UE per cell) and medium traffic (20 UE per cell) of about 75% and 50% respectively in the pico eNodeB cells as shown in Fig. 8. About 9.28% and 6.19% was achieved with the developed algorithm for the overall HetNet al low and medium traffic respectively. The Developed sleep mode algorithm performed better than the Always-on Scheme up to about 50UE per cell.

Fig. 8. Power Consumption in HetNet Configuration 4b.



CONCLUSION

A data rate-based sleep mode algorithm for energy savings for a pico eNodeB in LTE-Advanced HetNet has been proposed and implemented. The algorithm is a function of traffic situations, data rate and power consumption in the system. Simulations were carried out to evaluate the system level performance of the developed data rate-based sleep mode algorithm. The algorithm performed better in terms of energy savings when compared with the 3GPP Always-on scheme. However, the Developed algorithm did not consider the effect of interference. Interference management could further improve the service delivery and energy savings.

REFERENCES

[1] Z. Hassan, H. Boostanimehr, and V. K. Bhargava, "Green cellular network: A survey, some research issues and challenges," IEEE Communications Surveys & Tutorials, vol. 13, pp. 1–16, 2011.

[2] K. C. Tun, and K. Kunavut, "An overview of cell zooming algorithms and power saving capabilities in wireless networks," KMUTNB: International Journal of Applied Science and Technology. Vol. 7, No.3, pp. 1–13, 2014.

[3] Motrolla White Paper, Realistic LTE performance: from peak rate to subscriber experience, White Paper. www.motorola.com, 2009.

[4] LTE Alcatel White Paper. The LTE network architecture, Strategic White Paper, www.alcatel-lucent.com, 2009.

[5] M. Deruyck et al., "Reducing the power consumption in wireless access networks: overview and recommendations," Progress in Electromagnetics Research, pp. 2230–2235, 2012.

[6] A. R. Ekti, M. Z. Shakir, E. Serpedin, and K. A. Qaraqe, "Downlink power consumption of hetnets based on the probabilistic traffic model of mobile users," IEEE 24th Annual International Symposium on Personal Indoor and Mobile Radion Communications (PIMRC), pp. 2812–2817, 2013.

[7] X. Zhang, Y. Zhang, R. Yu, W. Wang, and M. Guizani, "Enhancing spectral efficiency for LTE-Advanced heterogeneous networks: a users' social pattern perspective," IEEE Wireless Communications, vol. 48, pp. 10–17, 2014.

[8] J. Acharya, L. Gao, and S. Gaur, Heterogeneous Network in LTE-Advanced, 2014.

[9] Technical Report 36.814 v9.0.0, Technical Specification Group Radio Access Network, Further Advancements for E-UTRA Physical Layer Aspects, 3GPP Release 9, March 2010.

[10] P. S. Gundawar, P. D. Dorge, and C. S. Gode, "Optimization of base station power using cell zooming technique, " International Journal of Advent Research in Computer and Electronics (IJARCE), vol. 2, no. 1, pp. 16–21, 2015.

[11] I. Ashraff, F. Boccardi, and L., Ho, "Sleep mode techniques for small cell deployments, " IEEE Commun. Mag., vol. 49, no.8, pp. 72–79, 2011.

[12] A. Ambrosy et al., "Definition and parameterization of reference systems and scenarios," EARTH Project Report, Deliverable D2.2 pp. 1-87, 2012.

[13] C. Khirallah, D. Rastovac, D. Vukobratovic, and J. Thompson, "Energy Efficient Multimedia Delivery Services over LTE/LTE-A," IEICE Transactions on Communications, 97(8): pp. 1504–1513, 2014.

[14] Technical Report 36.931, 3GPP Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) requirements for LTE Pico NodeB, 2011.

[15] F. Richter, A. Fehske, and G. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," In Proc. of IEEE Vehic. Technol. Conf. (VTC Fall), Anchorage, USA. pp. 1–5, 2009.

A. Abdulkafi et al., "Modeling of energy efficiency in heterogeneous network," Research Journal of Applied Sciences, Engineering and Technology 6(17), pp. 3193–3201, 2013