PERFORMANCE ANALYSIS AND EVALUATION OF ENERGY EFFICIENCY RESOURCES IN CELLULAR MOBILE NETWORKS

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ABSTRACT

The aim of this paper is to provide an in-depth analysis of network power characteristics, in order to be able to address the basic power estimation and behavior under extreme load conditions, these being the main resources in a cellular network. Currently, one of the biggest challenge is continuous growth of energy consumption by cellular infrastructure equipment, especially base station which take up to 80% in total of input energy into cellular networks. A set of good metric were proposed that significantly reflect the energy efficiency and allow for performance to be evaluated. These metrics include Energy Consumption Index (ECI) that measures efficiency of power utilization for a base station, its lower value indicate better energy efficiency and Performance Indicator (PI) measures power consumption per coverage area, its higher values indicates better energy efficiency. The effect of traffic, interference and path loss exponent on the energy efficiency of cellular network were investigated and the analysis results obtained by Monte-Carlo (MC) simulations were discussed based on the proposed energy efficient model. When considering heaviness index and minimum traffic rate, the numerical results show that there exist a maximum value for energy efficiency under each parameter configuration. The maximal energy values are 0.52, 0.43.0.24 and 0.22 bits/Hz/Joule corresponding to the intensity ratio of MSs to BSs of 105, 78, 120 and 82, respectively. The proposed energy efficient metrics provide effective means for design objective and evaluating the performance efficiency of components of cellular network.

Keywords: *Access point, Base Station (BS), Power consumption, Energy efficiency, Cellular Network*

INTRODUCTION

Power consumption in cellular networks is a significant aspect that requires the attention of researchers to improve on consumption pattern of all the elements of the network involved. The researchers, since the inception of the cellular networks have been working on spectral efficiency, maximum throughput, which does not lead to energy efficiency being maximized. This work will create a good impact on the network because of exorbitant power bills paid by Telecommunication service providers. Data traffic in cellular network is increasing because of proliferation of end user's equipment such as smart phones and tablets (Lin Xiang et. *al*., 2012) that motivates new high speed that consumes more energy. It is now realized by the service providers that large proportion of their operating cost expenses is related to energy consumption (Premalatha and Sahaya, 2019). The ever increasing growing of deployment of cellular networks as a result of increasing demands from numerous subscribers posed a serious challenge in terms of power consumption requirements (Radha,2015)(Albrecht *et al*,2010). In mobile telecommunication today, about 80% energy consumption is due to cellular access infrastructure equipment, especially the base stations (BSs) which is the major consumer of energy. (Lin Xiang et. *a*l, 2012). Radio network constitutes an important part of wireless cellular systems; it establishes connection with end user's equipment and its core network to implements a radio access technology (Yon, 2012). The base station power consumption during transmissions depends on how high is the traffic and other factors includes size of coverage area, and the higher the energy consumed (Eric et. *al*, 2018).There is accelerated expansion of network to pave way for more access points; for a diverse number of services such as digital broadcasting, messaging, high speed internet etc. The area with higher number of base stations will incur significant energy consumption by the main elements in the BS (Lorincz and Matijevic, 2014). A set of good metric were proposed that significantly reflect the energy efficiency and allow for performance to be evaluated. These metrics include Energy Consumption Index (ECI) that measures efficiency of power utilization for a base station, its lower value indicate better energy efficiency and Performance Indicator (PI) measures power consumption per coverage area, its higher values indicates better energy efficiency (Wu, 2016) The order in which each component consumes power must be examined so that the appropriate techniques that will bring about achievable improvement on power consumption will be identified. One of the most effective ways to bring about significant improvement on energy efficiency is to enhance the network design (Fred et. *al*, 2009).

RELATED WORK

In the recent years, power consumption analysis have become popular important research topic, as evidenced by a varieties of research being conducted in the area. The work of (Victor et al.,2020) explored optimization of energy consumption in cognitive radio networks based on renewable energies, energy–efficient cognitive radio techniques and optimization of wireless networks fed by non-conventional energy sources. A throughput of small cell networks designed in (Chang *et. al.,* 2013) to evaluate the network throughput. The work of (Congshan *et. al*, 2018) proposed caching in the cellular as a technology for reducing content delivery latency. A new scheme (Zhang *et. al*, 2018) which proposed a framework for performance in cell-free (MIMO) with classical hardware models, provided significant insight into the practical impact of hardware impairments on CF massive MIMO. Most of the previous work focus on metric such as, outage probability and radio coverage without much consideration for power consumption (Romeo et. *al.*, 2014).

Table 1: Key notations and symbols used

Symbol	Definition /Explanation
M	Number of transmit antenna/BS
ρ	BS-user identity ratio
γ	SINR threshold
λ_b	BS density
λ_u	User density
α	Pathloss exponent
η_{EE}	Network energy efficiency
P_s	Successful transmission probability
P_{out}	Outage probability
P_a	BS activity probability
R_a	Network throughput
R_u	Average throughput per user
R_0	Constant transmission rate.

(Chang et. *al*, 2013)

MATERIALS AND METHODS

Method of Data collection

There has been numerous research activities in wireless communication network in recent years, with emphasis on automation of radio networks, network evaluation and performance measurements have been carried out on electromagnetic field, energy harvesting, battery backup, antenna modelling has been implemented to improve energy efficiency without affecting the quality of signal. In this work, a comprehensive energy efficient framework that will be robust has been proposed. This approach incorporates all aspects of hardware components of base station from BS to end users. The strategy proposes integrating good performance alongside consuming less energy for each of its component. The proposed approach to reduce energy consumptions in a mobile network by improving energy efficiency of the hardware components with more energy efficient design required careful consideration in both operational and economical aspects. In general, the location of BS, dropping/blocking probability hand-over rates, coverage area, traffic load, signal-to-noise ratio, path loss and energy consumption level are the main elements that were taking into account for implementing and performance evaluation. The data obtained were extracted through review of relevant documents of standard organizations, these are private documents that the organization keeps hidden from the public, for proper maintenance of their infrastructure. Also, as network expected performance is important. Information theory approach was used to determine the expected performance, calculation were done for Monte-Carlo snapshots.(Lin et. *al)* This technique evaluates on a large number of snapshots drawn at random from a probability distribution describing the expected traffic intensity to aggregate different performance figures.

Allowable Power Levels for Mobile Phones

The range of 100 to 500 W is allowed to be used in base stations and the power levels used in any BTS depends on the frequency reuse pattern. A maximum of 500 W ERP (Effective Radiated Power) is allowed for carrier organization at the cell base stations. In an Ideal situation, it will take just the maximum energy required to provide coverage. A Macro-cell base station requires 20 to 100 W to cover an area from 12 to 48km. In order to avoid overloading equipment at the base station, base stations can and will throttle down the power of mobile phone. The BS may experience too much power from the mobile phone whenever it emit too much power and its location is very near the base station. The base station will release a signal through the control channel alerting the mobile phone to throttle down its power to a required level.

Table 2 depicts allowable power level for different types of mobile phones in cellular system in watts (W)

Power Level	Class 1	Class 2	Class 3
0	4.000	1.600	0.600
1	1.600	1.600	0.600
2	0.600	0.600	0.600
3	0.250	0.250	0.250
4	0.100	0.100	0.100
5	0.040	0.040	0.040
6	0.016	0.016	0.016
7	0.006	0.006	0.006

There are allowable power class assigned to mobile phones by the Federal Communication Commission (FCC). Each mobile phone has its value within a range from 0.006 to 4W. it is possible that mobile phone with higher values will emit high power.

Breakdown of Energy Consumption in Base Station

In this paper, energy efficiency has being the focus, the energy consumption is one of the most important aspects in wireless network, the three key component in mobile cellular network are taking into consideration: (1) the base station which provide access points for both signaling and commuting the mobile traffic, this subsystem consumes largest portion of energy in mobile network. (2) The network switching subsystem for data and calls and (3) end user that will access network. The total power consumption of a base station can be split into a fixed power consumption part and dynamic power consumption part.

The fixed power consumption is traffic independent and includes air condition system and power supply these account for one-quarter of total energy consumed, with this, energy is wasted and independent of the traffic load while the dynamic power depends on the distribution of the traffic load, however, accounts for transmission power consumed in the radio frequency (RF) transmission circuit's power dissipation such as heat, the switching subsystem consumes small amount of energy when compared with what BS consumes. The downlink is having direct relationship with the transmitted power by the BS which also depends on the volume of traffic i.e the number of live subscribers in the coverage area, the computation of number channels and other realistic parameters, which take into consideration the power of amplifiers of the base station are possible. The probability of the total BS power consumption can be obtained from the transmission power distributions.

A linear average BS power distribution model is simply built as follows, applying Palm's theorem (Lin Xiang *et. al*, 2012)

$$P_{BS} = \frac{P_{real}}{\eta_{EE}} + P_{Circuit} \tag{1}$$

$$= \frac{\int_0^{P_{max}\int} xfP_{real}(x)dx}{\eta_{EE}\cdot\int_0^{P_{max}\int} fP_{real}(x)dx + P_{Circuit}}$$

where η_{EE} is the average efficiency of the network and $P_{Circuit}$ fixed as a constant.

Network Performance Metrics on Energy Consumption

In this paper, the focus is majorly on relevant energy performance metrics, many schemes, algorithms, and even protocols are being developed to improve the consumption energy in cellular networks, the energy efficiency performance metric for networks is obtained here take into consideration all elements of the network at different levels. The most significant factor in determining power efficiency of cellular network are the number of users served by the base station, the coverage area, the bandwidth and the power consumed.

$$Power\ Efficiency = \frac{Powerconsumed}{Bitrate \times Numberofusers} \tag{2}$$

$$Number\ of\ users = Area \times Subscriber\ Density \tag{3}$$

The required power consumptions by BS is denoted as $P_{BS,}$ so that network energy efficiency can be evaluated. The energy consumption metric which will be good for standard organizations is also needed to enumerate other power consumption, at all level of the system, taking related parameter into consideration (Chang *et. al,* 2013) and is given by

$$P_{BS} = \frac{1}{\eta}P_t + MP_C + P_0 \tag{4}$$

where P_c is power in the circuit, η denotes power amplifier efficiency, M is the number of transmit antennas, P_0 is determined by the non-transmission energy consumption, such as processing, battery backup cooling etc. If equation (4) is taking into account, the average power consumption per unit area is the transmit power, and is given by

$$P_a = \lambda_b p_a \left(\frac{1}{\eta} P_t + MP_c\right) + \lambda_b P_0 \quad (5)$$

Bits-per-Joule is a metric used widely to compute efficiency of energy, it forms the basis for all other fundamental techniques. One the fundamental techniques and widely-used metric to compute the energy efficiency for communication networks is Bits-per-Joule (Albrecht *et. al*, 2010). Energy consumption per delivered information bit is the reciprocal of Bit-per-Joule measurement, and is referred to as Energy Consumed Ratio (ECR). In industrial environment, the effective means to compute the performance of energy efficiency is brought about by the proposed energy efficient metric and is not complicated or difficulty to understand and derive. Energy Consumption Index (ECI) (Wu, 2016), and is given by

$$ECI = \frac{P_{site}}{KPI} [\%] \quad (6)$$

where the Key Performance Indicator is designated as KPI and denotes either coverage area or throughput and P_{site} is input power of base station. The efficiency of energy utilization for a base station is measure by ECI. Better energy efficiency is indicated by lower values of ECI. The Energy Consumption Ratio (ECR) is an example of ECI. The energy efficiency at the system level is measure of average power consumption per subscriber unit area is Performance Indicator (PI) is an example, this metric was proposed by European Telecommunication Standards Institute (ETSI) (Maciej *et al.,* 1st edition) and expressed as

$$PI_{rural} = \frac{Total\ cov\ eragearea}{Powerconsumption} \left[{km^2}/{W}\right] \quad (7)$$

$$PI_r = \frac{Numberofuser\ sin\ p\ eakhour}{Powerconsumption} \left[{km^2}/{W}\right] \quad (8)$$

For the purpose of macro cells designs, it is useful to know the terrain data, be it urban or rural area, as related parameter must be taking into consideration in the process of determining the performance index of an area. In the less density areas, performance is measured in average power consumption per coverage area, rural area is less populated, number of subscribers are very low, but high-density area will experience power consumption that is thought to be a more accurate measurement because of high density of subscribers. Better energy efficiency will be indicated by higher values of PI. The close variants of PI can be found in telecommunication documents and in a number studies.

Improving the energy efficiency of the hardware components

Antenna

This aims to improve hardware components such as amplifiers or antennas to have energy efficient design. The performance of the present-day network must be improved upon, substantial amount of energy can be achieved if more energy saving efficient components were adopted in the network. The properties of an antenna as a hardware component such as the types, configuration or arrangement of its elements, this formed part of BS that consuming the highest proportion of energy; about 80% of the total input power. This work aims to conserve substantial amount of energy by using energy saving components. The following proposition reveals the effect of number of BS antennas on energy efficiency. If $\eta_{EE}(G)$ as energy efficiency with G antennas per BS, energy efficiency is given as

$$\eta_{EE}(G) = \frac{\sum_{n-0}^{G-1} t_n}{\frac{1}{\eta} P_t + MP_c + \frac{P_0}{P_a}} R_0 \quad (9)$$

There exist optimal number of BS transmit antennas G^* that maximizes the energy efficiency. The energy efficiency will decrease when $G > G*$, while for $G < G^*$ will improve the energy efficiency when number of antennas are increased. G* is the greatest integer that is smaller than the solution of the equation

$$F(G) = \frac{p_a\left(\frac{1}{\eta}P_t\right)+P_0}{p_a p_C} \quad (10)$$

where $F(G) = \frac{p_S(G)}{t_{M-1}}$

Since $F(G) = \frac{1}{t_{G-1}}\sum_{n=0}^{G-2}(t_n - t_{G-1})$, it can be shown that F (G) is an increasing function of G. If BSs are deployed with smaller P_c, then the optimal number of transmit antennas will be larger. This will significantly improve the energy efficiency. A special case is G*=1 which implies that using single-antenna BSs can provide higher efficiency than using multi-antenna BSs. For this case, we can find the condition from

$$P_C \geq max(k_1 P_0)\frac{k_1\left(\frac{1}{\eta}P_t + P_0\right)}{1 + k_0 - k_1} = \gamma p_c \quad (11)$$

is satisfied, single-antenna BSs is more efficient than multi-antenna BSs. Therefore, multi-antenna BSs are preferable in terms of energy efficiency only when the circuit power consumption is smaller than the threshold γp_C (Chang *et. al*, 2013).

Power amplifiers

Power amplifiers are electronic device used to increase the signal level of wireless communication link for effective performance over the communication channel. The hardware-specific techniques are the energy-efficient hardware component design and renewable energy resource deployment. Hardware conditioning (sleep mode technique) and system operation (energy-efficient transmission technique) (Augustus *et. al, 2022*). Understanding these techniques will ensure the development of an integrated energy efficiency framework that will be robust enough to provide smooth services in the evolving and emerging communication architecture. A Doherty power amplifier is recommended; it satisfied the base stations certain conditions which include the efficiency and linearity Advancements are still ongoing to improve the efficiency of power amplifiers in using sequential power amplifiers, good RF switching techniques, and smart antennas, among others.

Renewable Energy Resources

Renewable energy is a type of energy from natural resources like the sun, wind, etc. Renewable energy is commonly in the areas that has low or difficulty in accessibility to national power grid sources (Augustus *et al,2022*). Network operators using renewable energy resource in wireless communication will incur a lower operational cost to produce the same amount of energy that would have been provided if other means. Higher operational cost will transmit equivalent information when renewable energy is not used, resulting in energy inefficiency. Renewable energy resources is environmental friendliness; renewable energy resources do not produce too many gas emissions compared to diesel generators (Augustus *et al, 2022*). Since less emissions are produced, most natural energy is transformed into useful electrical energy. Different techniques can be used on natural resources to realize renewable energy technology. Some of these are wind hydropower, biomass, hydrogen, geothermal, solar (photovoltaic and solar thermal). If large scale renewable technologies is deployed, it has an optimum operational cost that outweighs the operational or running cost for the normal and frequently used energy supply (diesel generators) (Augustus *et al,2022*). Factors affecting this are increased and unstable oil prices, air pollution, cost of transportation, epileptic energy supply, etc.

RESULTS AND DISCUSSION

This result was prepared with the same trends as found in (Lin Xiang *et. al.,* 2014) but with different parameters, the sequential arrangement of figures in their results make it more fascinating to be adopted. The effect of traffic, hardware components and wireless channel parameters on the energy efficiency of cellular network was investigated and the analysis results obtained by Monte-Carlo (MC) simulations were discussed based on the proposed energy efficient model. The section presents both the numerical and Monte-Carlo simulation results with which analysis results were validated. Some specified simulation parameters are as follow, the moment of receiving power is configured as -75dBm, and the path loss exponent $\alpha = 4$, while the intensity ratio of interfering links to BSs is configured as $\lambda Inf/\lambda_B = 0.7$, the BS intensity is given by $\lambda_B = 1/(\pi\times800^2)$ m ,shadowing deviation $\sigma = 6$ and K = -31.53dB, the heaviness index $\theta = 1.8$ and SIR = 8.5 dB, the normalized minimum rate $\rho_{min} =$ 2bit/s/Hz, the transmit power is P_{max}= 46dBm, the average efficiency of BS is configured as $\eta_{RF} =$ 0.047 and the static power consumption is set as $P_{const} = 354.4$ W.

Figure 1 show the energy efficiency of cellular network with respect to hardware components, the heaviness index θ and minimum traffic rate ρ_{min} at MSs where “MC” stands for MC simulation results and “NUM” stands for numerical results, the value of minimum rate is fixed at 2 to 3bit/s/Hz and analyze the impact of the hardware components and the heaviness index on the energy efficiency of the networks. Both the numerical and the MC simulation results consistently demonstrate that cellular network consumes more power when the heaviness index θ is decreased from 1.8 to 1.2.

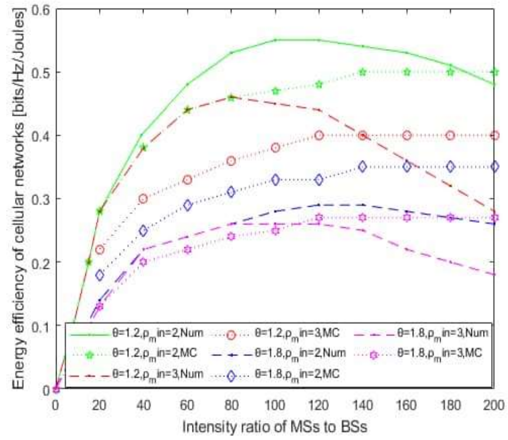

Figure 1 Energy efficient of cellular networks with respect to intensity ratio of MSs to BSs considering the heaviness index and minimum traffic rate (Lin Xiang *et. al.,*2012)

The impact of minimum traffic rate ρ_{min} on energy efficiency of cellular network was analyzed (when the value of heaviness index is fixed at 1.2 or 1.8.(Lin Xiang et. al.,2014)) The MC simulation results show that more power was consumed when minimum traffic rate ρ_{min} increases from 2 to 3 bit/s/Hz. However, the numerical results show that when heaviness index is fixed at 1.2 or 1.8 there exist turning points for intensity ratios of MSs to BSs. Below the turning point, more power is consumed and above the turning point, lesser power is consumed during the networking of the signal as the minimum traffic rate is increased from 2 to3 bit/s/Hz.

The numerical results in Figure 1 show that there exist a maximum value for energy efficiency under each parameter configuration. The maximal energy values are 0.52, 0.43.0.24 and 0.22 bits/Hz/Joule corresponding to the intensity ratio of MSs to BSs of 105, 78, 120 and 82, respectively. When the intensity ratio of MSs to BSs is low, indicating a few MSs in a typical cell, the increase of the intensity ratio of MSs to BSs leads to a moderate increase in total BS power consumption including mainly *fixed* BS power consumption and a small portion of *dynamic* BS power consumption. In this case, the energy efficiency of cellular networks is increased. However, when the intensity ratio of MSs to BSs in a typical cell exceeds a given threshold, a high aggregate traffic load resulted from a large number of MSs will significantly increase the total BS power consumption including mainly *dynamic* BS power consumption and a small portion of *fixed* BS power consumption. In this case, the energy efficiency of the cellular networks is decreased, where random medium access protocols are deployed. However, the MC simulation results in Figure1 demonstrate that the energy efficiency turns into saturation after having reached the maximal threshold.

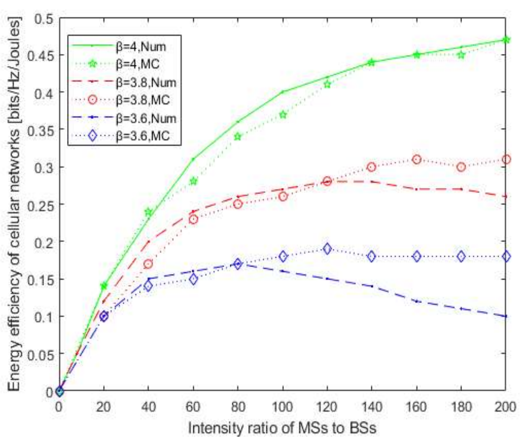

Figure 2: Energy efficient of cellular networks with respect to intensity ratio of MSs to BSs considering the interfering link. (Lin Xiang *et. al.,* 2012).

Figure 2 displays the effect of higher interference on cellular networks on the energy efficiency When the BS intensity λB is fixed, both numerical and MC simulation results show that the energy efficiency of cellular networks is decreased when the interfering link intensity λInf increases from 3.0×10^{-7} m^{-2} to 5.0×10^{-7} m^{-2}. Moreover, the maximum values of the energy efficiency in three different cases are 0.45, 0.28, and 0.20 bits/Hz/Joule, with corresponding intensity ratios of MSs to BSs as 180, 120, and 100, respectively. A good match of the MC simulation curves with the numerical curves was observed before the energy efficiency reaches the maximum, with deviations after the maximum value similar to the results shown in Figure 1 These results imply that interference has obvious impact on the energy efficiency of cellular networks. Finally, the impact of path loss exponent α on the energy efficiency of cellular networks is evaluated in Fig. 3.

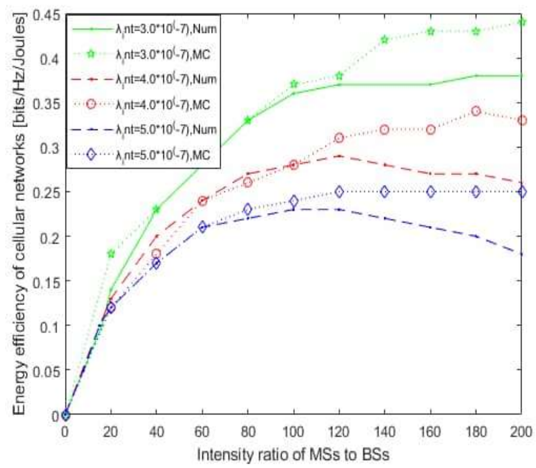

Figure 3: Energy efficient of cellular networks with respect to intensity ratio of MSs to BSs considering the path loss exponent (Lin Xiang *et. al.,* 2012).

Both numerical and MC simulation results illustrate that the energy efficiency of cellular networks is increased when the path loss exponent is increased and fixed at 4. Moreover, the maximal values of the energy efficiency in three different cases are 0.43, 0.28 and 0.19 bits/Hz/Joule, which correspond to the intensity ratios of MSs to BSs as 180, 120and 80 respectively.

CONCLUSION

In this paper, a new set of metrics were developed to improve the utilization of energy by cellular network and based on these metrics, energy efficiency at various nodes were investigated, these various efficiency metrics discussed show that the energy efficiency is a relative subjective concept, it depends on the environment and the other information available to compute the relevant metrics. The proposed metrics, when more components of BS are taking into account, give a comprehensive evaluation of energy efficiency of cellular networks. The metric proposed are energy consumption index (ECI), absolute energy temperature and energy consumption ratio (ECR), The parameters such as number base stations, population of end users, coverage area are better measurement and should reflected in the metrics. The effect of traffic, hardware components and wireless channel parameters on the energy efficiency of cellular network was investigated and the analysis results obtained by Monte-Carlo (MC) simulations were discussed based on the proposed energy efficient model when considering heaviness index and minimum traffic rate. The numerical results show that there exist a maximum value for energy efficiency under each parameter configuration. The maximal energy values are 0.52, 0.43.0.24 and 0.22 corresponding to the intensity ratio of MSs to BSs of 105, 78, 120 and 82, respectively. Also, when considering impact of interfering link; the maximum values of the energy efficiency in three different cases are 0.45, 0.28, and 0.20 bits/Hz/Joule, with corresponding intensity ratios of MSs to BSs as 180, 120, and 100, respectively. When impact of path loss exponent on energy efficiency is put into consideration the maximal values of the energy efficiency in three different cases are 0.45, 0.19 and 0.28 bits/Hz/Joule, which correspond to the intensity ratios of MSs to BSs as 180, 80 and 120 respectively. Therefore, performance indicator (PI), Area Power Consumption are also better metrics and particularly useful to evaluate energy efficiency.

REFERENCES

Albrecht J. Fehske. Patrick Marsch and Gerhard P. Fettweis (2010.) "Bit per Joule efficiency of cooperating Base Station in cellular Networks" IEEE Conference on Gloecom workshop 6-10 December 2010

Augustus Ehiremen Ibhaze, Agbotiname Lucky Imozie, and Obinna Okeyeigbo (2022) "A Brief Overview of Energy Resources in Emerging Wireless Communication Systems". Telecom 2022 vol 3 pp 281-300

Chang Li, Jun Zhang, and Khaled B. Letaief (2013) "Throughput and Energy Efficiency Analysis of Small Cell Networks with Multi- antenna Base Stations. IEEE Transaction on wireless communications vol.13 Number 5.

Congshan Fan, Tiankui Zhang ,Zhimin Zeng and Yue Chen (2018) " Energy Efficiency Analysis of Cache Enable Cellular Networks with Limited Bahaul". Wireless communication and mobile computing. http://doi.org/10.1153/20186910876

Eric Sackey and Rajeev Paulus (2018) "Performance Analysis of Power Consumption in LTE-A Enb and its effect on the Overall System Efficiency". Indonesian Journal of Electrical Engineering and Computer Science. Vol.11 Number 3 pp 878-890.

Fred Richter, Albrecht J. Fehske and Gerhard P. Fettweis (2009). "Energy Efficiency Aspect of Base Station Deployment Strategies for cellular Networks" IEEE Conference on Vehicular Technology 20-23 September 2009

Jiayi Zhang, Yinghua wei, Emil Bjornson, Yu Han, and Shi Jin. (2018) "Performance Analysis and Control of Cell-Free massive MIMO Systems With Hardware Impairments" IEEE Access vol 6. DOI:101109/ACCESS 2918 2872715

Josip Lorincz and Toncica Matijevic (2014) "Energy Efficiency analysis of heterogeneous macro and micro base station sites" Computer and Electrical Engineering Journal vol. 40 number 2 pp330-349.

Lin Xiang, Xiaohu Ge, Cheng-Xiang Wang, Frank Y. Li and Frank Reichert (2012) "Energy evaluation of cellular Networks Based on Spatial Distribution of Traffic Load and Power Consumption" IEEE trans. on Wireless communications vol. 8 number 4 pp49-58

Maciej M, Nawrocki Dohler, and Hamid A. Aghvami "Understanding UMTS radio network: modelling, planning and automated optimization". John Wiley & Sons Ltd 1st Edition.

Premalatha J. Sahaya Anselin Nisha (2019) Energy Competence of Base Station in cellular Network. International Journal of recent Technology and Engineering. Vol.8 Number 2 pp1-4

Romeo Giuliano, Franco Mazzenga,and Marco Petracca (2014) Power Consumption Analysis and Dimensioning of UMTS-LTE with Relays Procedia Computer Science. Vol 40 pp 74-80

Radha Krishna Ganti "Energy Efficiency in Cellular Networks" India institute of Technology Madras rganti@ ee.iitm.ac.in. Source Cisco

Romeo Giuliano, Franco Mazzenga, and Marco Petacca "Power Consumption Analysis and Dimensioning of UMTS with Relays" Fourth International Conference on Selected Topics in mobile & Wireless Networking. 2014

Victor Gomez, Camila Salgado, and Cesar Hernandez (2020) "Optimization of Energy Consumption in cognitive Radio Networks based on Renewable Energies". International Journal of Engineering Research and Technology vol. 13, Number 8 pp1999-2006

Wu Jingjin Timothy (2016)" Performance Analysis and Energy Conservation of Cellular Mobile Networks". Ph.D. Thesis Department of Electronic Engineering, City University of Hong Kong.

Yun Won Chung (2012) "Performance Analysis of Energy Consumption of Smartphone Running Mobile Hotspot Application". International of Smart Grid and Clean Energy.vol.1 Number 1 pp 103-108