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ORIGINAL RESEARCH ARTICLE

ANALYSIS AND EVALUATION OF ENERGY EFFICIENCY OF 5G NETWORKS IN WIRELESS COMMUNICATION

E. U. Udo, L. I. Oborkhale, C. C. Nwaogu*

Department of Electrical/Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria
**Corresponding author's email address: cxtopher20091@gmail.com*

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ABSTRACT

This paper focused on the analysis and evaluation of energy efficiency of 5G networks in wireless communication. The projected rise in wireless communication traffic has necessitated high operating costs of conventional wireless cellular networks and scarcity of energy resources in low power applications. This paper examined different ways of deploying energy efficient hardware at the base stations in order to make the base station non-polluting energy. The method employed involves the measurement of power consumption at the macro cell and micro cell base stations. The results of the power consumption obtained from the macro cell base stations were used in three models, namely the Gex model, the modified Gex model and Ismail model for the periods of 0am – 1am, 12pm – 1pm and 11pm – 0am were 11228.63W, 11561.15W, 11231.06W, 12821.65W, 12983.29W, 12981.64W, 13020.56W, 15342.30W, 11323.83W, 11634.23W, 11374.37W and 13196.66W. Again, the results of the power consumption obtained from the micro cell base stations for the periods of 0am – 1am, 12pm – 1pm and 11pm – 0am were 717.09W, 754.83W, 729.65W, 748W, 723.67W, 743.34W, 717.6W, 741W, 643.5W, 667.74W, 642.9W and 718W, respectively. Therefore, it is concluded that the modified model produced energy consumption that are in consonance with the measured energy. Therefore, it is concluded that the modified Gex model produced energy consumption values which are in closed range with the measured energy values.

1.0 Introduction

The fifth generation of mobile communication system (5G) has become the hub of worldwide attention because it meets growing demand of the users. Each 5G base station shall provide at least 20 Gb/s downlink and 10 Gb/s uplink bandwidth transmission capability, according to the International Telecommunication Union criteria for 5G to accomplish a leap-forward improvement in transmission speed (Cai et al., 2016). The need to support exponential growth in data traffic with the availability of a diverse range of mobile devices has resulted in an important escalation in the number and density of base station devices, as well as their complexity, resulting in increased power consumption and usage. 5G wireless networks represent a major communication infrastructure for connectivity of the future, with the rising increase of mobile access to the Internet and its services (Auer et al., 2011).

Energy Efficiency has provided the most significant supports in the design of the next generation (5G) of wireless networks. Again, 5G systems will serve an unprecedented number of devices, providing ever-present connectivity as well as innovative and rate-demanding services. Devices such as drones, medical devices, cars, sensors and wearable devices will make use of cellular networks to connect with one another thereby interacting with human end-users to provide a variety of innovative services such as smart cities, smart cars, tele-surgery, smart cars and advanced security systems. To accommodate such a high number of terminals, future networks capacity will need to be greatly increased (Zhang et al., 2013). However, contemporary networks are built to maximize capacity by increasing transmit power thereby giving rise to the rapid increase in the number of linked devices. Increasing communication capacity by using more and more energy will result in unacceptable high operating expenses. Again, by scaling up the transmit powers, current wireless communication systems are unable to offer the needed capacity increase (Ge et al., 2017).

Presently, wireless communication systems are primarily fueled by carbon-based energy sources. Information and communication technology (ICT) systems currently account for 5% of global CO_2 emission, although this percentage rises at the same rate as the number of linked devices. Recently, it is expected that 75% of the ICT industry will be wireless, indicating that wireless communications will become a significant area to address in terms of lowering ICT-related CO_2 emissions (Joshua et al., 2020). Increased energy consumption is a major challenge linked with global warming and decreased in energy consumption of mobile communication networks has accounts for a considerable amount of overall information and communication technology energy consumption. Since future 5G networks are predicted to have higher traffic loads, the impact of mobile communication network energy consumption will grow more rapidly (Shameek et al., 2016).

The base station is the principal energy consumer in mobile communication networks and its energy consumption is determined by traffic load, which varies depending on geographic location. There has been a lot of effort put into the energy savings of a base station in order to lower the energy consumption of mobile communication networks (Lee et al., 2013). Energy efficiency is maximized to obtain better average performance and 5G wireless networks constitute a major communication infrastructure for connectivity in the future, with the increase in expansion of mobile access to the Internet and its services. Also, Mobile communication networks use a large portion of the overall energy consumed by information and communication technology (Antonopoulos et al., 2015).

However, 5G network make use of the IEEE 802.11ac standard as its foundation and can also grow to hundreds of thousands of connections (Joshua et al., 2020). In 5G wireless internet networks, the following technologies like Ultra Wideband, Orthogonal Frequency Division Multiplex, Code Division Multiple Access, IPv6 and Multi-Carrier Code Division Multiple Access are very useful (Niu et al., 2012).

The deployment of 5G with small cells makes millimeter wave based carriers to improve overall coverage area in the range of 30 GHz to 300 GHz. When combined with beam forming, small cells can deliver fast coverage with low latency and testing of 5G range in millimeter wave has produced good results of approximately 500 meters from the tower (Hanson et al., 2015).

The statement of problem is that there are high operating costs in wireless network which leads to scarcity of energy resources. The objective of this study is to evaluate energy efficiency of 5G networks by deploying energy efficient hardware at the base stations.

2. Materials and Method

The materials used in this paper are spectrum analyzer to analyze the frequency components of the transmitted signals. The main supply unit produces power for the entire equipment of the base station transceivers. It also takes alternating current supply as an input and produces direct current voltage as the output. The antenna interface serves as an interface between radio waves propagating through space and electric currents moving in the metal conductors. The base band unit consists of base band transmitters and receivers. It produces data that were fed into the radio unit. The radio frequency chains are cascade of electronic components such as filters, mixers, amplifiers, attenuators and detectors. The cooling units are responsible for maintenance of the base station temperature and heat generated by the power amplifier. Data used were collected from the MTN office at Aba, Abia State, Nigeria for a period of one year and the authors have gained experienced at the base stations during the periods of the research.

MATLAB/SIMULINK was used for the simulation. The energy efficient hardware technique necessitates the deployment of enhanced energy efficient hardware like microwave link, digital signal processing unit, power amplifier, transceivers to improve energy efficiency in the network. The experimental results were obtained using several measurements at the base stations. The Gex model, modified Gex and Ismail models were used to determine the power consumption at the macro cell and micro cell base stations.

However, the modified Gex model was used to calculate the energy consumption. The use of the load factor provided a significant effect on power consumption at the base station which indicates the real power.

The measurements of power consumption was done based on specific time range at their respective base stations as shown in Tables 1 and 2. The step used for the measurement of power involves three models and the tools used were the wattmeter and multimeter. The intention was to verify the energy consumption that was in closed relationship with the measured energy using different models such as Gex model, modified Gex model and Ismail model.

2.1 Mathematical Modeling of Energy Enhanced Hardware Approach

Energy Efficiency is measured as the number of bits transmitted per joule of energy (b/j). The cell coverage (C) is the fraction of the area within a cell receiving signal power $P_{min.}$

$$Efficiency\ \eta = \frac{Total\ output}{Total\ Input} \tag{1}$$

Energy Efficient Hardware approach is computed using Equation (2).

Therefore, Energy Efficiency $\eta E = \frac{Total\ Energy\ radiated}{Total\ Energy\ input}$ (2)

In terms of percentage, energy efficiency is calculated as shown in Equation (3).

$$\eta E = \frac{E_{out}}{E_{in}}\ x\ \frac{100}{1} = \frac{P_{out}\ x\ t}{P_{in}\ x\ t}\ x\ \frac{100}{1} \tag{3}$$

Also, the energy efficiency can also be defined as the ratio of the radiated signal to the input power consumption as given in Equation (4).

$$EE = \frac{P_{tt}}{P_{tin}} \tag{4}$$

Where EE is the energy efficiency, P_{tttx} is the radiated signal power of the transmitter and $Ptin_{in}$ is the input power consumption.

The power consumption PC_{area} per covered area is shown in Equation (5) (Deruyck et al., 2014).

$$PC_{area} = \frac{P_{el}}{\pi R^2} \tag{5}$$

Where P_{el} is the power consumption of the base station and R is the transmission radius of the base station. However, the lower the PC_{area}, the more energy efficient is the base station.

Again, to determine the power consumption for a specific hour at weekdays, the power consumption Pel/amp of the power amplifier depends on the input power P_{el} of the antenna as shown in Equation (6).

$$P_{\frac{el}{amp}} = \frac{P_{tx}}{\eta} \tag{6}$$

Where η is the efficiency of the power amplifier, which is the ratio of the RF output power to the electrical input power.

The power consumption Pel/macro of the macrocell base station can be determined as shown in Equations (7) (Cooper, 2018), and (8).

$$\mathrm{Pel/macro} = \mathrm{Pel/const} + \mathrm{Pel/load}. \tag{7}$$

With

$$P_{el/const} = n_{sector} P_{el/rec} + P_{el/link} + P_{el/airco} \tag{8}$$

Again, the power consumption in Gex et al., model for macro cell base stations is given in Equation (9), (Han et al., 2016).

$$P_{el/load} = n_{sector}\left(n_{tx} P_{elamp} + P_{eltrans} + P_{elproc}\right) \tag{9}$$

Where n-sector is the number of sectors supported by the macrocell base station, N_{Tx} is the number of transmitting antennas and $P_{el/rect}$, $P_{el/link}$, $P_{el/airco}$, $P_{el/amp}$, $P_{el/trans}$ and $P_{el/proc}$ are the power consumption of the rectifier, the microwave link, the air conditioning, the power amplifier, the transceiver and the digital signal processing (in Watt).

The power consumption Pel/micro of a microcell base station is given in Equations (10) and (11).

$$P_{el/micro} = P_{el/const} + P_{el/load} \tag{10}$$

With

$$p_{el/const} = P_{el/rec} + P_{el/airco} \tag{11}$$

The power consumption in Gex model for microcell base station is as shown in Equation (12). (Wang et al., 2018).

$$P_{el/load} = P_{el/amp} + P_{el/trans} + P_{el/proc} \tag{12}$$

The operating power for the Ismail model for macro base station and micro base station can be shown in Equations (13), (Faruk et al., 2012) and (14), respectively.

$$P_{macro} = (N_{sect} x\, N_{TX}) \frac{P_{PA} + P_{BB} + P_{RF}}{(1-\varphi_{MS})(1-\varphi_{DC})(1-\varphi_{cool})} + P_{mw} + P_{au} \tag{13}$$

$$P_{micro} = (N_{sect} x\, N_{TX}) P_{PA} + P_{BB} + P_{RF} + P_{mw} + P_{au} \tag{14}$$

where P_{au} is auxiliary equipment, P_{RF} is transceiver power, P_{mw} is microwave backhaul, PPA is power consumed by power amplifier, DC is the losses incurred by the rectifier, MS is the losses incurred by the mains supply, cool is the losses incurred by the active cooling and P_{BB} is the power consumed by the baseband unit.

3. Results and Discussion

The experimental results for the power consumption at the macro cell and micro cell base stations were obtained through measurements. The measured results were tested in Gex model, modified Gex and Ismail models for macro base stations shown in Equations (9), (13) and micro base stations shown in Equations (12), (14), respectively. Table 1 shows the results of the measured values, Gex model, modified Gex model and Ismail model values. When the experimental results shown in Table 1 were compared with the Gex model, modified Gex model and Ismail model values, it was discovered that the measured results were close to the modified model results. This indicated that the modified model results are in consonance with the Information Handling Service (HIS) measured data.

Table 1: Measured and model values at macro base station

Hour	Power Consumption (P_{macro}) at the Macro cell Base Station			
Hour	Measured Value (Watts)	Gex Model (Watts)	Modified Gex model (Watts)	Ismail Model (Watts)
0am -1am	11228.63	11561.15	231.06	12821.65
1am – 2am	11193.54	11518.03	187.68	12935.53
2am – 3am	11218.82	11542.62	11220.73	12952.63
3am – 4am	11219.73	11521.17	11231.61	12773.19
4am – 5am	11309.04	11593.26	11319.29	12908.18
5am – 6am	12118.33	12374.29	12134.74	14068.76
6am – 7am	12257.43	12496.65	12238.48	14134.37
7am – 8am	12422.80	12673.52	12429.42	14461.23
8am – 9am	12639.78	12743.91	12658.31	14769.64
9am – 10am	12868.43	12804.11	12876.78	15278.80
10am – 11am	12989.59	12945.73	13017.51	15281.76
11am – 12pm	12999.42	12856.62	13134.86	15515.83
12pm – 1pm	12983.29	12981.64	13020.56	15342.30
1pm – 2pm	13052.34	12945.79	13153.32	15578.77
2pm – 3pm	13119.59	12971.42	13132.42	15369.30

3pm – 4pm	13169.34	13039.09	13274.21	15839.77
4pm – 5pm	13296.19	12959.74	13289.23	15770.78
5pm – 6pm	13289.09	12937.86	13288.42	15929.43
6pm – 7pm	13127.84	12846.89	13120.76	15484.74
7pm – 8pm	12611.39	12778.44	12720.89	15039.81
8pm – 9pm	12372.62	12758.64	12579.87	14794.31
9pm-10pm	12388.87	12628.40	12419.55	14783.19
10pm-11pm	11473.32	11854.20	11569.09	13537.28
11pm-0am	11323.83	11634.23	11374.37	13196.66

Again, when the measured results in Table 2 was compared with the Gex model, modified Gex model and Ismail model values, it was also realized that the modified model is in agreement with the Information Handling Service measured data.

Table 2: Measured and model values at micro base station

Hour	Measured Value (Watts)	Gex Model (Watts)	Modified Gex Model (Watts)	Ismail Model (Watts)
0am – 1am	717.09	754.83	729.65	748
1am – 2am	619.53	659.76	620.49	665
2am – 3am	620.20	669.95	649.18	664
3am – 4am	634.19	657.67	639.56	659
4am – 5am	648.34	668.71	656.9	667
5am – 6am	681.44	712.20	668.79	677
6am – 7am	719.63	723.88	719.41	721
7am – 8am	690.18	713.21	678.90	711
8am – 9am	719.31	720.16	715.46	723
9am – 10am	689.44	721.45	689.88	723
10am– 11am	739.54	745.67	734.32	754
11am– 12pm	719.14	731.89	712.90	734
12pm – 1pm	723.67	743.34	717.6	741
1pm – 2pm	722.17	743.81	731	742
2pm – 3pm	730.88	754.51	730.77	753
3pm – 4pm	740.78	743.78	742.63	741
4pm – 5pm	722.17	751.56	723.51	742
5pm – 6pm	723	741.99	720.34	739
6pm – 7pm	711.79	731.65	711.95	731
7pm – 8pm	689.56	720.74	688.23	722
8pm – 9pm	687.4	721.89	684.94	723
9pm – 10pm	716.17	718.56	711.24	717
10pm– 11pm	741.67	771.88	742.77	773
11pm – 0am	643.5	667.74	642.9	718

Figure 1 shows the plot of comparison between the measured values, the Gex model, modified Gex and Ismail models at the macro cell base station while Figure 2 shows the plot of comparison between the measured values, the Gex model, modified Gex model and Ismail models at the micro cell base station.

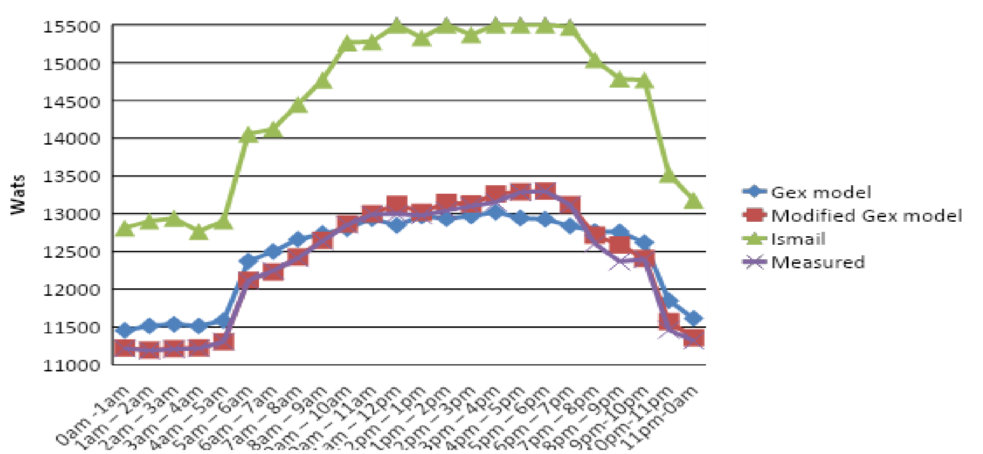

Figure 1: Comparison of the measured values with Gex model, modified Gex model and Ismail model for macro cell base station

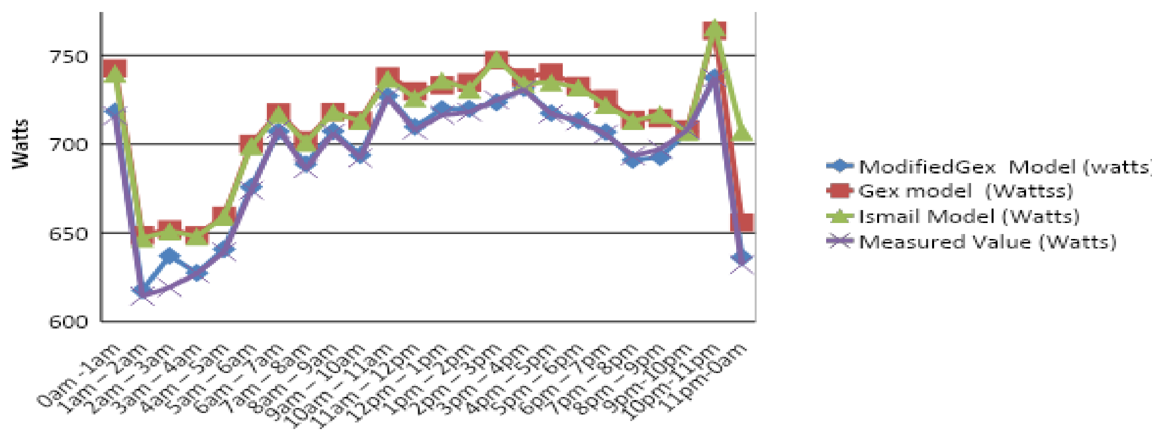

Figure 2: Comparison of the measured values with Gex model modified Gex model and Ismail model for micro cell base station

Figure 1 shows the plot of energy consumption against time. It was observed from the graph that the plot of the measured values is closer to the plot of the modified model. However, the plot of the Ismail model increases above the plots of the measured value, Gex model and the modified Gex model. Figure 2 also indicated the plot of energy consumption against time. It was realized that the plot of the measured values is very close to the modified model. However, the plot of the Ismail and Gex models are very close to each other.

When this was compared to the previous studies (Alsharif et al., 2016), it was observed that the modified Gex model values was in consonance with the measured energy.

4. Conclusion

It is important for 5G to provide a high data rates with better coverage and good signal quality by deploying small cells with energy efficient hardware at micro cell base stations. These cells normally decrease energy consumption when it is equipped with energy efficient hardware and intelligent power saving. The Gex model portends to be a better model for computing the energy consumption of 5G base station. However, heterogeneous network can handle higher data traffic while consuming less base station energy. When the density of data traffic density was high or when the base station transmission power was low, the placement of small energy base station determines the performance of heterogeneous network. Most modern wireless communication systems, operate in half-duplex mode resulting in resource utilization degradation. The potential of full duplex operation boosts the potential spectral efficiency of wireless communication systems by broadcasting and receiving across the entire bandwidth.

It is recommended that with the implementation of energy efficient hardware at the base stations, the energy consumption of 5G network improves its efficiency in wireless communications.

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