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Real Time Traffic Base Station Power Consumption Model for Telcos in Ghana

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***Abstract*— The mobile telecommunication market in Ghana has grown significantly within the past few years, recording voice subscription base of 35 million and data subscription base of 18 million. The total number of base transceiver stations and Node Bs stand at 7502 and 4996 respectively. The rapid growth of mobile subscribers and number of base stations necessitate the need to study the relationship between traffic load and power consumption at a base station. There is energy crisis in Ghana currently and it is exigent to study the growing energy consumption in base stations. In this article, we investigate the effect of traffic variations on base station (BS) power consumption in Ghana. Continuous power and traffic load measurements were carried out at fully operated base stations in Ghana. Our measurement results show a linear relationship between cellular traffic load and BS power consumption. We then propose a real time traffic base station power consumption model for Ghana. Our study confirmed the claim that remote radio unit architecture is more energy efficient compared to ground mounted radio unit architecture. Remote radio unit technique increases base station energy efficiency by 32%.**

***Index Terms*— Base Station, Cellular Traffic, Power Consumption and Linear Regression**

I. INTRODUCTION

PREVIOUS research studies have shown that about 3% of the world-energy is consumed by Information and Communication Technology (ICT) infrastructures [1]. The energy consumed by ICT infrastructures are mostly being generated from non-renewable energy sources [2]. As a result, ICTs have been identified to contribute significantly to the amount of CO_2 emissions worldwide. Today, its share of global greenhouse gas (GHG) is around 1.6% [3]. In order to lessen the impact of the ICT industry on the environment, effort to increase energy efficiency of these technologies is on the rise.

Cellular network, one branch of the ICT sector, is a major contributor to this energy consumption. Within the cellular network, the energy consumption of the Base Transceiver Station (BTS) represents more than 56% of the total cellular network energy consumption [4]. Fig. 1 shows the energy consumption levels of the various components of a cellular network. Aside the environmental impact associated with this high energy consumption, energy costs can account to 15% of the total network operating expenses (OPEX). This can rise to about 50% in areas where the number of off-grid sites is very high, or electricity supply from the national grid is highly unreliable [5].

There has been a tremendous growth in mobile subscribers worldwide over the last few years. Presently, there are about 7 billion mobile cellular subscribers worldwide. Ghana currently has six mobile operators. According to the data released by the National Communications Authority (NCA) for December 2015, the total mobile voice subscribers stand at 35,008,387 with a penetration rate of 127.63%. This shows a significant increase from the 30,629,604 subscribers recorded in January 2015. The total number of mobile data subscribers also increased from 15,805,646 as of January 2015 to 18,031,188 as of December 2015. Fig. 2 shows the general trend in cellular communication subscribers in Ghana for both voice and data for the year 2015 [6], [7]. With a population size of 27 million, the high level of mobile penetration in Ghana can be attributed to the multiple connections owned per person for reasons like optimizing pricing by different operators for different calls and data services. This rapid increase in data and voice traffic is expected to continue in the coming years.

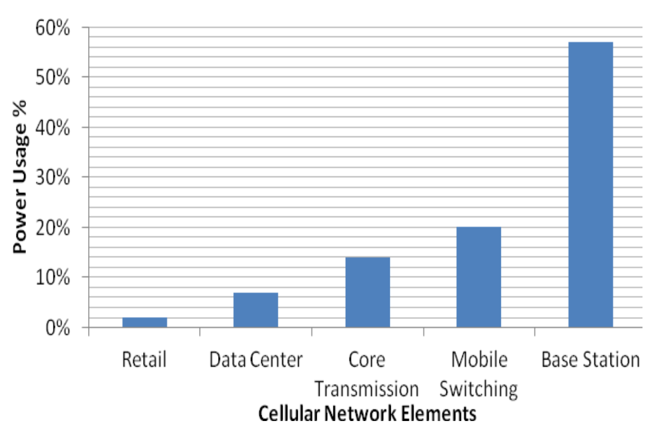


Fig. 1. Cellular networks elements and their power consumption

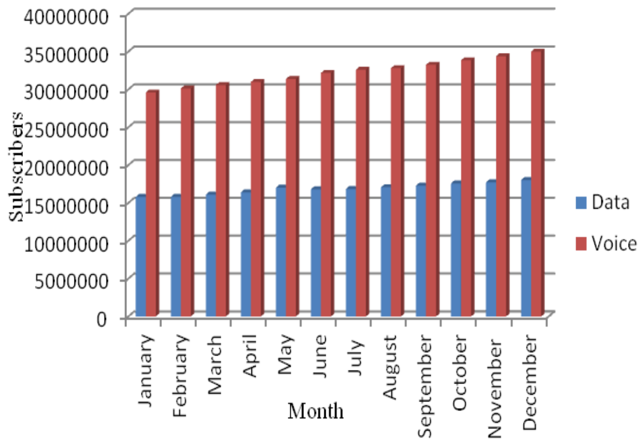


Fig. 2. Cellular mobile voice and data subscription trends in Ghana for 2015

Ghana has a network base of 7502 BTS and 4996 Node Bs as shown in Table I. With this network size, network coverage is still far from reaching 20% of the population living in remote rural communities. Most of the mobile operators report of the installation of new BTS and Node Bs sites to accommodate the ever increasing subscribers. It is estimated that five years from now the number of BTSs and Node Bs will increase to 12000 and 9000 respectively.

Table I. Number of BTSs and Node Bs per mobile operator in Ghana

Mobile Operator	Number of BTS	Number of Node Bs
MTN	2361	1201
Vodafone	1146	959
Glo	1600	800
Tigo	1050	900
Airtel	1354	1136

The Bank of Ghana reported in February 2015 that Ghana's GDP growth had slowed from 7.3% in 2013 to 4.2% in 2014 [8]. This is due to the energy crises Ghana has been battling with since 2006 [9]. During peak hours, demand for electricity stands between 1900 MW and 2200 MW but currently the country is able to supply about 1500MW. With an expanding economy and a growing population, Ghana faces major challenges in providing the required energy in a reliable and sustainable manner having in mind the environmental and economic impacts of energy production and use. There is a direct link between energy use, economic growth and standard of living [10]. The rising demand for communication services in Ghana will require a stable power supply in the future.

Presently there is no knowledge on the relationship between power consumption and traffic load at cell sites in Ghana. In light of Ghana's energy crisis and the general increase in mobile subscribers and BTS/Node Bs deployment, it is imperative to develop a mathematical model for real time traffic base station power consumption. This paper studies the relationship between base station power consumption and traffic loads based on transceiver configurations and base station architecture. We will develop base station power consumption model for Global System for Mobile Communication (GSM) and Universal Mobile Telecommunication System (UMTS) technologies.

The remainder of this paper is structured as: Section II reviews existing power consumption models and other related works. Section III describes the base station site and explains the measurement setup. It also introduces the parameters for finding the power consumption of a base station. In Section IV, we present all the results from our measurements and introduce our proposed power consumption models for GSM and UMTS cellular technologies in Section V. Section VI concludes this article.

II. RELATED WORKS

Lately, cellular network power consumption has become a major concern for most researchers [4], [11]-[14]. In [5], [15] the authors proposed power saving strategies. Two of the strategies were removal of feeder cables and finding alternative cooling system to the use of air conditioners. They authors did not use any field measurements to confirmed their claim. This paper seeks to validate the effectiveness of those two strategies using real time measurement results from fully operational BTS in Ghana.

Our study also tries to determine how much power savings can be achieved from those two strategies. In [16] the authors proposed a power model to calculate the total power consumption of a radio transceiver. In their model, the power consumption of the power amplifier was described to vary with transmission settings like the number of antennas, energy per bit, bit rate, channel gain, while the consumption of other circuit blocks was assumed to be constant. The focus of this work was to determine the power consumption of the power amplifiers. The authors in [17] proposed a power consumption model for both macro cell and microcell base station for Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) and High Speed Packet Access (HSPA) wireless technologies.

They argued that traffic variations are not followed by similar variations in power consumption. More often than not, traffic load variations have been assumed to have minimal influence on BTS power consumption [18], [19]. In this paper we extend the work in [20], by confirming the direct correlation between BTS electric current drawn and traffic load pattern while investigating the impact of transceiver configuration on BTS power consumption. In [21] the authors report that the expansion in power infrastructure and supply has fallen short of the tremendous expansion of telecom infrastructure across in West African countries.

It further explains that Ghana's telecom infrastructure sector has experienced a decrease in the reliability of grid power supply owing to an unbalanced growing grid infrastructure and stagnating power generation capacities. This paper seeks to provide a thorough investigation on power consumption by telecom infrastructures in Ghana.

II. POWER CONSUMPTION MEASUREMENT AT A BASE STATION

In order to investigate the interdependence between BS power consumption and traffic load, extensive on-site power consumption measurements were carried out at fully operated BS sites in major cities of Ghana. The power consumption measurements were made under different transceiver configurations and BS architectures for three different cellular access technologies: GSM 900, GSM 1800 and UMTS 2100.

A. Base Station Site Description

In Ghana, the primary source of power supply to a cell site is from the Electricity Company of Ghana's (ECG) mains. Each site has a standby diesel generator which takes over when ECG mains goes off. The last source of power supply to the BS is the backup battery which can supply DC power mostly for 12 hours. Typical cell site components are as shown in Fig. 3.

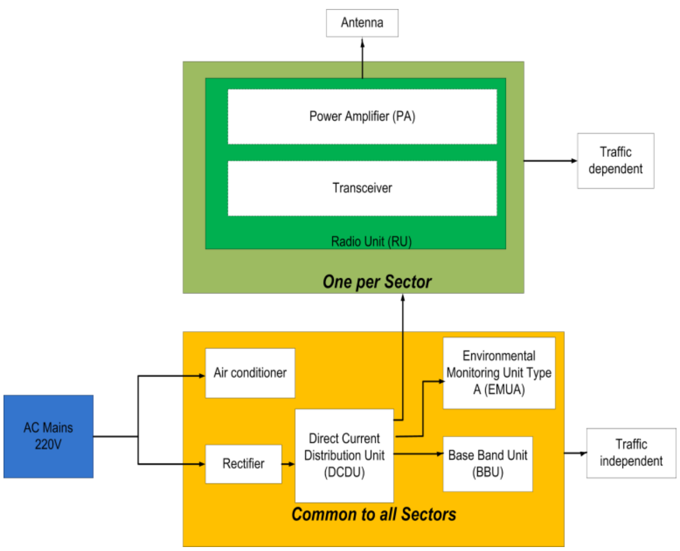
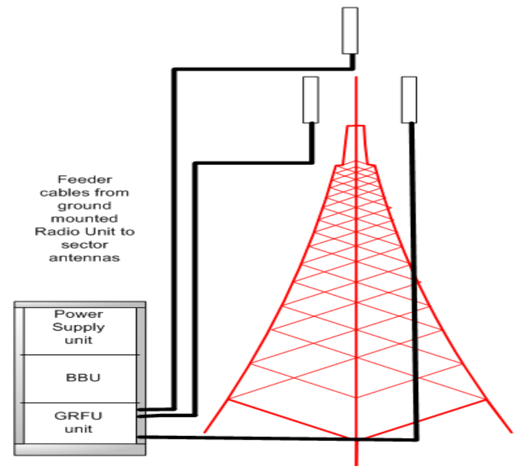


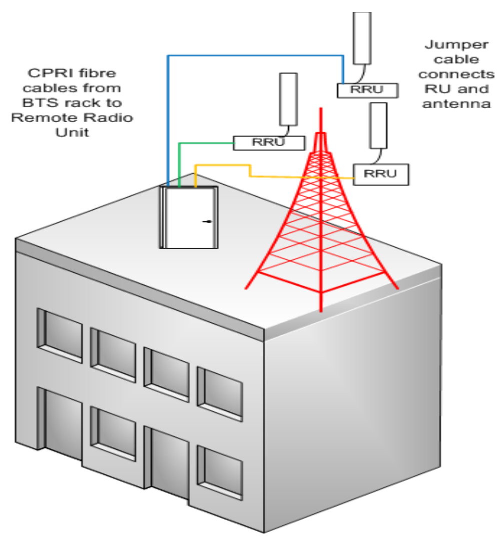
Fig. 3. Components of a BS

The rectifier, which interfaces the Direct Current Distribution Unit (DCDU) module, converts 220 V AC to 48V DC. The DCDU supplies DC power to the Base Band Unit (BBU), the Environmental Monitoring Unit Type-A (EMUA), and the radio unit (RU). The BBU processes digital data. Its output is fed into the RU. The RU consists of PAs and transceivers. It converts digital signal into radio frequency signal and feeds it to the antenna via feeder cables. The Environmental Monitoring Unit Type-A (EMUA) is a monitoring unit that enables Network and Operations Centre (NOC) to monitor all environmental alarms like gen set failure, mains failure, and high temperature etc.

In our study, we considered two different cell site architectures namely ground mounted RU and remote RU as shown in Fig. 4a and 4b respectively. The ground mounted RU has its GSM Radio Filter Unit (GRFU) housed in a cabinet on the ground and connected to the antenna through feeder cables. With the remote RU, a Common Public Radio Interface (CPRI) cable connects the BBU on the ground and the RU at the top of the tower. The RU connects to the antenna using jumper cables. The remote RU architecture the Telcos claimed reduces energy consumption a claim we seek to verify in this work by quantifying the energy savings in this architecture.



(a) Ground mounted RU architecture



(b) Remote Architecture

Fig. 4. Ground and remote mounted RU architecture

B. Measuring Setup

As shown in Fig. 5, clamp-on meter was used to measure the DC current flowing through the cables connecting the following components the EMUA, BBU and the RU. At each cell site we took hourly current measurements for six (6) days i.e., four (4) week days and two (2) weekend days.

C. Power Consumption Model Parameters

The components of our BS and the parameters for their power consumption are summarized in Table II:

Fig. 5. DC current measurement setup

Table II. Parameters of the power consumption model

Components	Power consumption parameter
Base Band Unit	P_{BBU}
Radio Unit	P_{RU}
Rectifier	P_{Rec}
Air Conditioner	P_{AC}
Incandescent Bulb	P_{LB}
EMUA	P_{EMUA}
Base Station Power	P_{BS}

The power consumed by each component was figured out from the measured current using equation 1.

$$\boldsymbol{P(t) = V \times I(t)} \quad (1)$$

The power consumption of an entire BS is the sum of the power consumed by its components and it's given by:

$$P_{BS} = P_{BBU} + P_{RU} + P_{\text{Rec}} + \sum_{j=1}^{J} P_{AC} + \sum_{m=1}^{M} P_{LB} + P_{EMUA} \quad (2)$$

Since the measured current values for some components at the base station did not vary with traffic load the power consumed at a base station P_{BS} was divided into two categories: traffic dependent and traffic independent. Measured current values for components such as the EMUA, AC, and BBU were traffic load independent. However, the measured current values for the RU were traffic load dependent. The total base station power is as shown in equation 3.

$$P_{BS} = P_{traffic\,dependent} + P_{traffic\,independent} \quad (3)$$

Thus,

$$P_{traffic\ independent} = P_{BBU} + P_{EMUA} + \sum_{j=1}^{J} P_{AC_j} + \sum_{m=1}^{M} P_{LB_m} + P_{Rec} \quad (4)$$

$$P_{traffic\,dependent} = P_{RU} \quad (5)$$

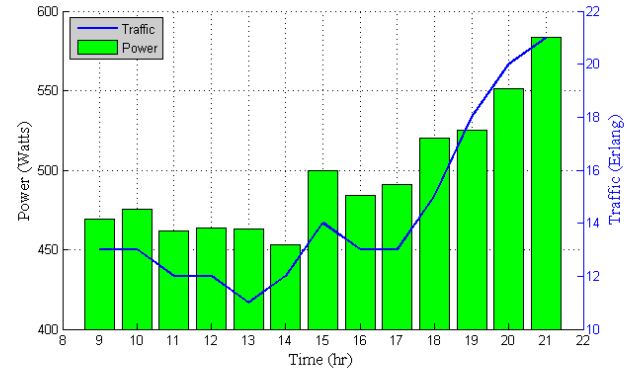
For a particular technology;

$$P_{RU} = P_{RU\,sector1} + P_{RU\,sector2} + P_{RU\,sector3} \quad (6)$$

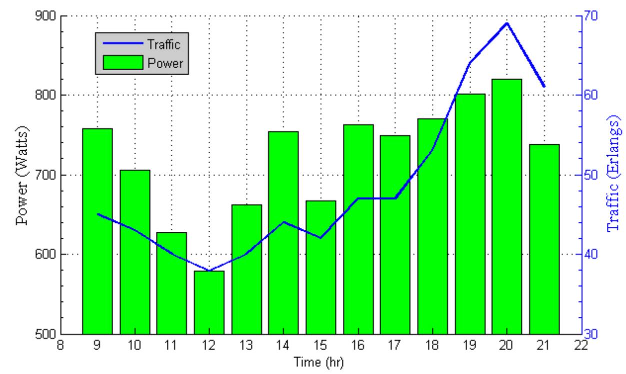
Our analysis is focused on the traffic dependent power consumption.

III. DISCUSSION OF MEASUREMENT RESULTS

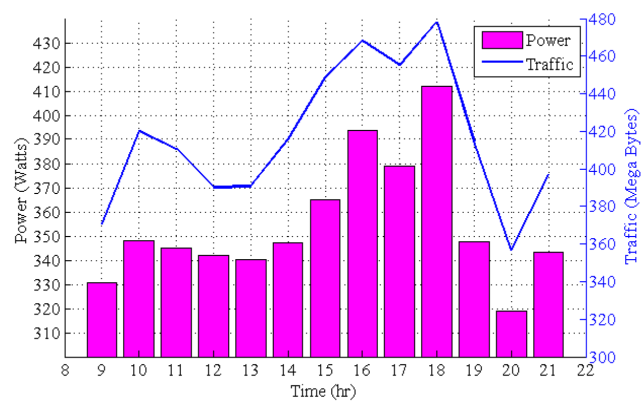
In this section we analyze the measured power and the corresponding traffic load values. The general observation for GSM 900, GSM 1800 and UMTS 2100 is that there is a linear relationship between the power consumption and traffic load as seen in Fig. 6.



(a) GSM 900 MHz cellular technology



(b) GSM 1800 MHz cellular technology



(c) UMTS cellular technology

Fig. 6. RU power consumption vs. traffic load for different cellular technologies

The average hourly power consumption values for remote and ground mounted GSM 1800 RUs are as shown in Fig. 7. It is seen that for a given time and traffic load the power consumed by the ground mounted RU is higher than that of the remote RU.

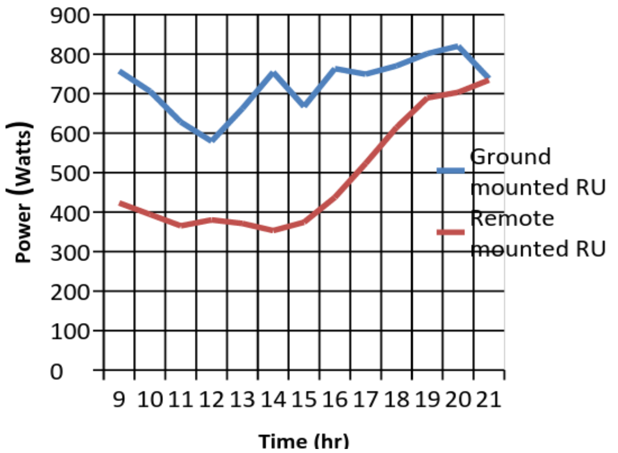
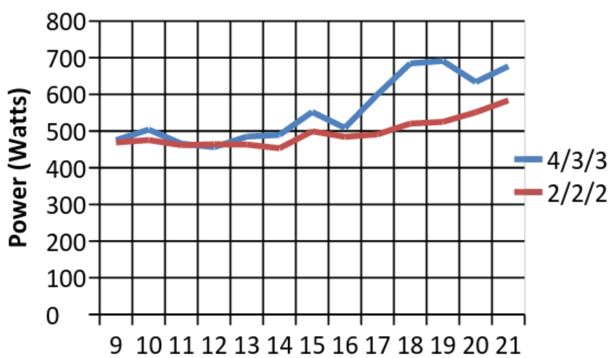
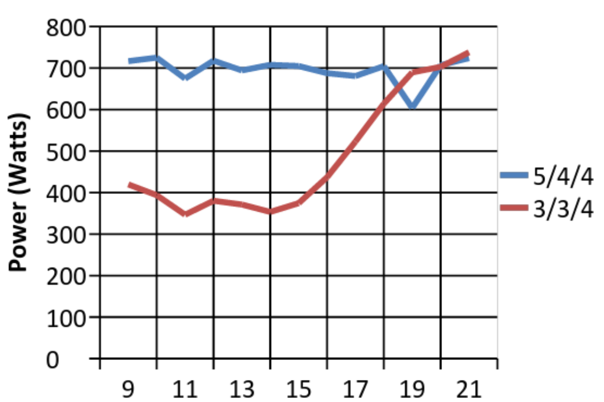


Fig. 7. Hourly power consumption levels for remote and ground mounted RU



(a) GSM 900 MHz cellular technology



(b) GSM 1800 MHz cellular technology

Fig. 8. Effect of transceiver configuration on BS power consumption

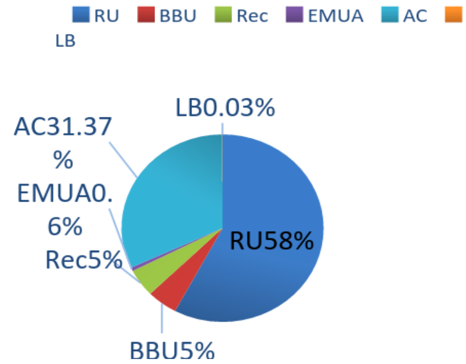


Fig. 9. Energy consumption by components for an indoor BS in Ghana

The average input power for the remote RU and ground mounted RU are 489 W and 723 W respectively. Both units have an output power of 240 W (80W/transceiver). Calculating the efficiency for the remote and ground mounted RU, the remote RU has a higher efficiency of 49% whiles the ground mounted RU has an efficiency of 33%.

The transceiver configuration also has effect on the power consumption as shown in Fig. 8. The greater the number of radio transceivers, the higher the radio unit's power consumption. The daily energy consumption of an outdoor BS for GSM (1800 & 900) and UMTS is 43.43612 kWh. An indoor BS of a similar kind has a daily consumption of 75.26736 kWh. The Outdoor BTS has a daily RBS efficiency of 39.78% whiles the Indoor BTS has an efficiency of 22.96%. The breakdown of the energy consumption for an indoor BS is shown in Fig. 9.

IV. POWER CONSUMPTION MODEL

In section IV, we observed a linear relationship between the power consumption and traffic load at a base station. We therefore use linear regression technique to develop a linear BS power consumption model based on our measurement results. Our model expresses power consumption as a function of the traffic load.

A. Linear Regression

For a set of paired observations $(t_1, p_1),\ (t_2, p_2)\ \ldots\ (t_n, p_n)$ with a random error Ɛ, a simple linear regression model of the form $p_i = \alpha_0 + \alpha_1 t_i + \varepsilon_i,\ \ i = 1 \ldots n$ can be formed. For these observations, *t* represents our independent variable (traffic load) and *p* our dependent variable (RU power). α_0 and α_1 are the intercept on the y-axis and the slope respectively. This can be written in a regression matrix as:

$$\begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_n \end{bmatrix} = \begin{bmatrix} 1 & t_1 \\ 1 & t_2 \\ \vdots & \vdots \\ 1 & t_n \end{bmatrix} \begin{bmatrix} \alpha_0 \\ \alpha_1 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix} \tag{6}$$

The equation above can be simplified as:

$$p = t\alpha + \varepsilon \quad (7)$$

The expected value for each of the $\varepsilon_{i's}$ is zero in a normal regression model.

$$\begin{bmatrix} E(\varepsilon_1) \\ E(\varepsilon_2) \\ \vdots \\ E(\varepsilon_n) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (8)$$

Equation 8 becomes, $p = t\alpha$, and we solved for α_0 and α_1.

B. Proposed Real Time BS Power Consumption Model

In our work, we used the curve fitting toolbox in MATLAB version R2014a and determined a line of best fit for our measured values and determined the coefficients α_0 and α_1.

The results obtained for the various technologies GSM 900, 1800 and UMTS 2100 are as shown Fig. 10 to Fig. 12. In our proposed linear power consumption model we used confidence interval of 95%. Transceiver configuration tells the number of transceivers per each sector antenna. A transceiver configuration of 1/1/1 means 1 transceiver per sector antenna. In Ghana, a BTS with a transceiver configuration of 4/4/4 or higher serves densely populated areas and therefore categorized as high traffic. BTS with a transceiver configuration of 3/3/3 or lower serves less dense area and categorized as low traffic. For GSM 900 MHz, we developed models for two traffic categories: high traffic and low traffic. Equations 9 and 10 give the power consumption models for high traffic and low traffic respectively. Thus for a given traffic load the power consumption can be determined.

$$P_{RU} = 11.75(Tr) + 326.5 \quad (9)$$

$$P_{RU} = 58.23(Tr) + 40.44 \quad (10)$$

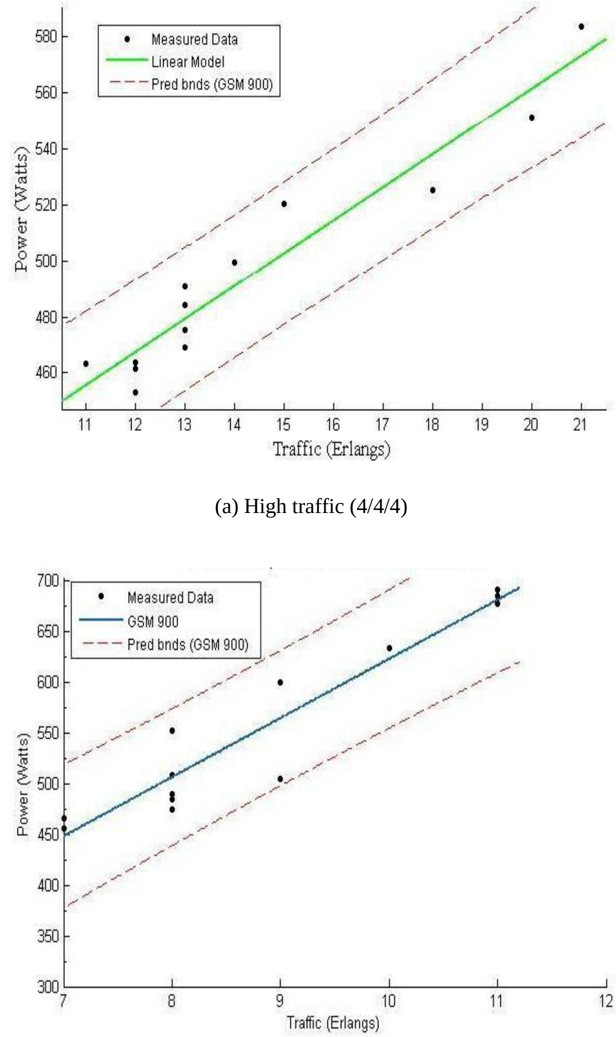
For 1800 MHz, using a transceiver configuration of 5/4/4, we create a model for the ground mounted and remote RUs. Equations 11 and 12 give the power consumption models for a ground mounted and remote GSM 1800 RUs.

$$P_{RU} = 5.45(Tr) + 457.2 \quad (11)$$

$$P_{RU} = 14.40(Tr) + 14.34 \quad (12)$$

In UMTS, RUs all use 1 transceiver per sector Equation 13 is the power consumption model for a UMTS RU.

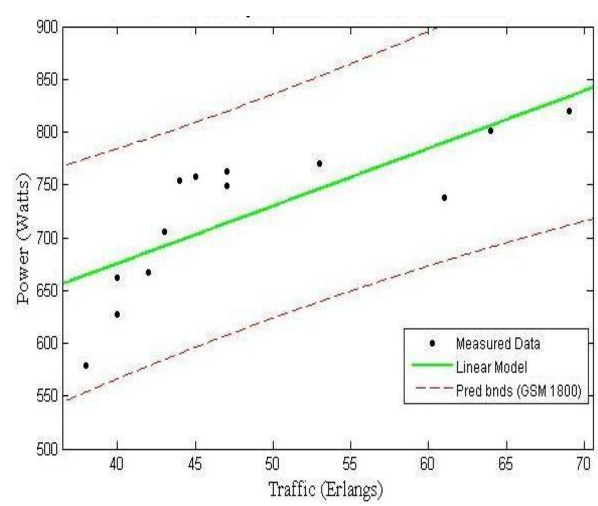
$$P_{RU} = 0.67(Tr) + 75.63 \quad (13)$$



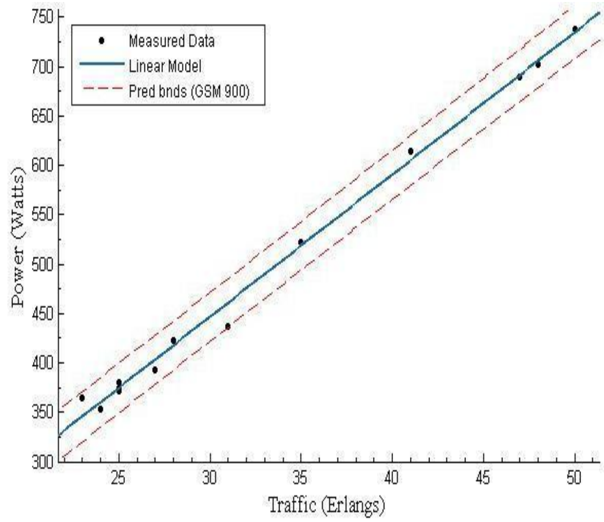
(a) High traffic (4/4/4)

(b) Low traffic (3/3/3)

Fig. 10. Proposed power consumption model for GSM 900 MHz



(a) Ground mounted RU



(b) Remote mounted RU

Fig. 11. Proposed power consumption model for GSM 1800 RU

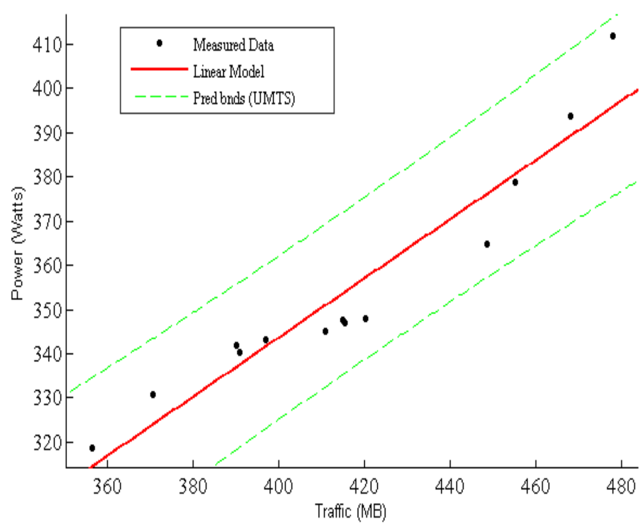


Fig. 12. Proposed power consumption model for a UMTS RU

V. CONCLUSION

In this paper, we studied the relationship between base station power consumption and its traffic load for GSM 900, 1800 and UMTS 2100 cellular technologies. We conclude from our analysis of the measured current and traffic load that there is a linear relationship between cellular traffic load and power consumption at a base station. Based on this relationship, we developed a linear BS power consumption model where given the traffic load the power consumption at GSM 900, 1800 MHz and UMTS 2100 MHz base stations can be figured out. The proposed real time BS power consumption model is the first step towards addressing power conservation problem base stations in Ghana. We provided field measurement- based proof that remote GSM1800 RUs are more energy efficient than ground mounted GSM1800 RUs. That ground mounted RUs consumes more power than remote mounted RUs. Remote mounted RUs have energy efficiency of 49% as compared to 33% for ground mounted RUs. The effect of transceiver configuration on RUs power consumption cannot be neglected. Analysis of our measured data proves that the higher the number of transceivers in the RU, the greater its power consumption needs and as result our developed power consumption takes into consideration transceiver configurations. Our study also indicates that the air conditioner is the second highest energy consuming device at a base station. Thus replacing air conditioners with natural ventilation system and eliminating feeder cables can increase base station energy efficiency by 32%. With our model any Telco in Ghana knowing its current traffic load or expected traffic at a BS can figure out the power consumption at that base station.

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