International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 7 Issue 3, March - 2023, Pages: 10-23

On-Site Energy Utilization Evaluation of Telecommuncation Base Station a Case Study of Western Uganda

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***Abstract**: In Uganda, the need for network coverage has expanded dramatically over the past few years in both urban and rural areas. As of March 2022, there were 30.6 million mobile phone subscribers and more than 4300 base station sites, thus this increase calls for the development of base stations for the end users to transmit and receive both calls and data. As network operators continue to add base stations to meet customer demand, this is increasing monthly. Energy use also rises as a result of this rise in coverage needs. Power consumption increases as traffic increases, although this scenario changes from geolocation to geolocation because traffic loads at sites in rural and urban areas vary. Thus, it is vital to examine these sites and provide a model that network operators can use in order to handle various power consumption issues. This study evaluated how traffic volume affected energy usage in both rural and urban areas of Ishaka and Mbarara City. Because the effects of traffic load on both rural and urban sites were not sufficiently taken into consideration by earlier models. To investigate these effects of traffic load on power usage, regression models are used. On the basis of data gathered over twenty-eight days, linear models have been provided at three urban and rural areas. Based on the site layouts, the results demonstrated that both rural and urban BTS were well-fitted by the recommended linear models.*

Keywords: ***Base stations; Traffic load; Energy; Power consumption; Models.***

1. INTRODUCTION

For many years, high base station energy consumption (BTS) has been a challenge for telecom firms worldwide, even in undeveloped countries like Uganda [1]. The considerable increase in energy use every day makes it challenging for network providers to maintain market dominance. Due to the rising network traffic in rural areas with inadequate grid coverage, where network operators are compelled to establish their own power sources and set up their own generators for the generation of the energy to the equipment at site, the development of this energy consumption is huge [8]. In total, there were about 4300 base station sites and 30.6 million mobile phone subscriptions in Uganda as of March 2022, according to the Uganda Communications Commission (UCC). Figure 1 depicts the way a cellular system uses energy. Comparing the base station (BS) to other cellular network components, it can use up to 58% more energy.

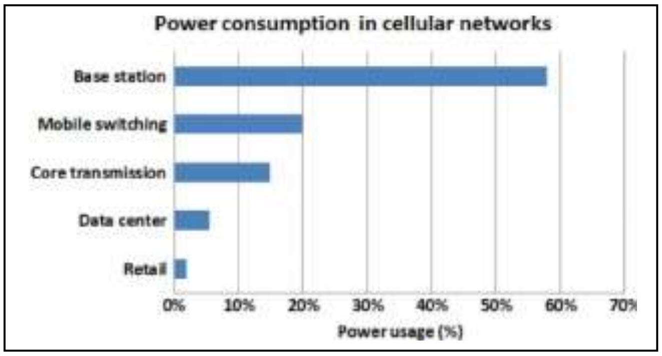

Figure 1. *Power Consumption in the cellular Network (Jing, 2017).*

In order to address this growing problem, emphasis must be paid to energy consumption in the communications base station due to this high demand at the BS level. As Roy stated in 2008, a telecom network is like an eco-system in that one cannot just install any energy-saving techniques without taking into account the consequences on the other system components [2]. One of the essential elements of telecommunications technology is the power system, which makes it possible to manage mobile communications networks more cheaply and to achieve "sustainable" development goals [13]. In other words, lowering energy consumption is a useful chance that can benefit network operators and subscribers in Uganda and everywhere else.

Because that 1% of the world's energy is produced by communications networks, combating global warming is very crucial [12]. This is equivalent to the combined energy use of 29 million autos and CO2 emissions from 15 million households. In addition to the negative effects on the environment caused by this high energy usage, energy prices can make up 15% of all network running costs (OPEX). This can increase to roughly 50% in locations with a significant percentage of off-grid sites or extremely unstable national grid electrical supplies [11]. More base stations are currently needed in Ishaka and Mbarara due to the rise in rural telecom industry subscribers, environmental impact, and financial issues associated with this issue, especially in the western region where there are more grid coverage zones. Power models were developed to solve the problem by generating adequate less consuming and more efficient energy consumption for these base stations. The various models were thoroughly surveyed and investigated in order to develop a stabilized model for on-site energy use. Considering that 4G is now only used for data in Uganda and 5G is yet being implemented, this study concentrated on traffic calls rather than data.

The correlation between power consumption and traffic volume at cell Uganda is still unknown. It is crucial to create a regression model for base station power consumption in light of the rise in mobile subscribers and BTS deployment in Uganda. Based on transceiver combinations and base station architecture, this article investigates the relationship between traffic volumes and base station power consumption. For the technologies of the Universal Mobile Telecommunication System (UMTS) and the Global System for Mobile Communication (GSM), a base station power consumption model was created.

2. RELATED WORKS

In this section, we explain the research gap that this paper covers, a review of the related work is seen in this section.

According to [2], the majority of academics have become quite concerned about cellular network power consumption during the past ten years. The purpose of this research was to "discover statistical relationships between the energetic consumptions and the BTS operating parameters." The authors did not support their claim with any field measurements. By doing on-site measurements at 3 distinct sites in the aforementioned research domains, this report aims to validate the success of that the strategies.

Our study is broad and concentrates on three different sites with different settings and of different technologies, making measurements in 12 hours a day. We then proposed models for all the sites visited in order to improve the efficiency of the power consumption at site. These studies carried out the actual measurements on site, but only focused on one site for their conclusion [4] et al, [12]. [20]. This work focuses on the investigation and modeling of power consumption in a base transceiver station. Data was obtained and analyzed from two base transceiver stations in Benin (BEN): Ugbor station, also known Benson Idahosa University, also known as BEN198, and BEN035 (site A) (site B). A MATLAB figure was created after an analysis of AC power use. MATLAB software was used to construct a model of Base station instantaneous to show how power is utilized in a Base Transceiver Station (BTS) and to provide a forecast for the future. DC power requirements for both heavy and light traffic GSM usage. Three sites were visited by our research team. Two sites in various locations with different BTS configurations were set up for 2G and 3G while the other One were set up for 2G, 3G, and 4G. Models for all three locations were created using MATLAB and EXCEL, differences in traffic do not correspond to changes in power use. Variations in traffic, it has been believed that traffic volume had little bearing on BTS power consumption. In this study, we further the research by investigating the impact of transceiver design on BTS power consumption and confirming the relationship between the electric power consumption of BTS and the pattern of traffic loads.

3. ON-SITE POWER CONSUMPTION MEASUREMENTS

This section presents the methods of this study. This includes, full descriptions of the sites visited, measuring set up of the sites visited during this research, and power model parameters.

3.1. Site Description

Three fully operational BS stations in Ishaka and Mbarara underwent extensive on-site tests to demonstrate the relationship between BS energy use and traffic volume. One cellular technology spread across two frequency bands is present in each of these locations at two different places. GSM 900 and GSM 1800MHz, respectively. Two stations use voice and data traffic technologies [4] at GSM 900 and 1800 MHz and UMTS 2100, respectively. The One urban BS sites are among the busiest considering the one city site has three different technologies (GSM 900 and 1800, UMTS, 4G, and LTE), it is possible to compare the voice and data traffic flows between the three sites (Long Term Evolution). These three sites were all outdoors, and Fig. 2 provides a good perspective of the components of each location.

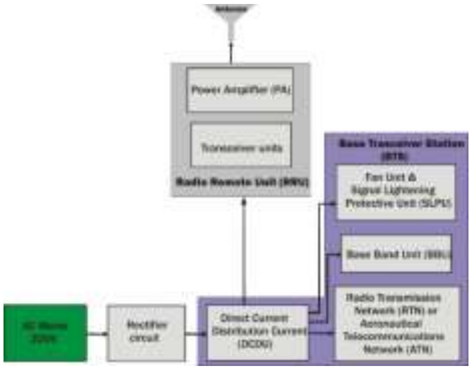

Figure 2. *Block diagram of Cellular BTS*

Two rural locations either use the on-site AC generator that is developed and supported by battery banks in the Rectifier Units Current (AC) for two of the sites, or the commercial electricity supplied by UMEME in Mbarara city. Direct Current Distribution Unit (DCDU) module is connected to the rectifier, it changes 48V DC from 220V AC. The Base Band Unit (BBU), Fan Unit, and DCDU all get DC power from the DCDU, RTN (Radio Transmission Network) or ATN, and Radio Remote Unit (RRU). Data is processed by the BBU. The RRU obtaining its output. Power amplifiers (PA) and transceivers make up the RU [21]. Using jumper wires, it transforms digital signal into radio frequency signal and transfers that to the antenna. The SLPU (Signal Lighting Protection Unit), a monitoring device, allows the Network and Operations Center (NOC) to keep track of all site alerts, such as those for a generator failure, a power outage, a high temperature, etc. Direct current (DC) power supply voltage measurements range from 48 V to 57 V. A site's most typical mode of operation is for an AC/DC converter to provide time-invariant DC voltage of 53.8 V, which is defined by continuous power supply from the electrical grid.

Some sites with technologies like Radio Frequency Remote Units (RFUs), Multi Radio Frequency Remote Units (MRFUs), and Global System for Mobile Communication Radio Frequency Remote Units (GRFUs) were not taken into consideration for this study because they are almost no longer in use in Uganda and only a few sites still have them. As a result, we did not see the need to use sites with these technologies [12]. As a result, we concentrated on the sites that, as seen in Figs. 3a and 3b, used RRUs as their transceivers. From the cabinet to the tower, Small Form-factor pluggable (SFPs), also known as transceivers, are used to interface the radio remote units to the BBU using Common Public Radio Interface (CPRI) cables or fiber cables. With the aid of jumper cables, the RRU are connected to the antennae.

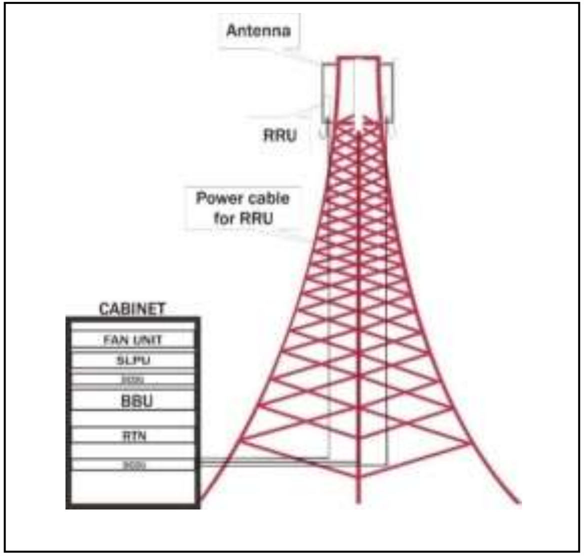

Figure 3a. *BTS and Tower Layout*

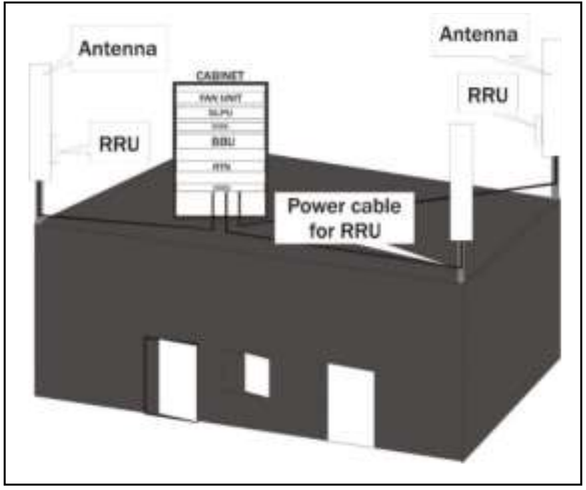

Figure 3.b. *Rooftop site layout.*

3.2. Measuring set up

A clamp the DC current passing through the connections linking the radio units was measured using a meter, which are interfaced to each sector on the sites, for these locations. As shown in Figs. 4a and 4b, hourly measurements were taken at each cell location over the duration of a month, or four (4) weeks.

Figure 4a. *Clamp meter*

Figure 3.b. *Multimeter*

With the help of these measures, this study was able to perform additional analysis on the on-site sample for the outdoor locations visited during data collection. Since this study solely examines DC circuitry, the power equation for DC is provided in (1) as seen below, this study was able to compute and obtain the power and energy numbers that it required in order to conduct its analysis and suggest a model for the sites.

$$\boldsymbol{P}_{(W)} = \boldsymbol{V}_{(V)} \text{ x } \boldsymbol{I}_{(A)} \qquad (1)$$

The Average Voltage from 6am to 6pm is given by;

$$\boldsymbol{V}_{(av)} = \frac{\sum_{t=0}^{12}(V)}{12} \qquad (2)$$

The Average Current from 6am to 6pm is given by;

$$\boldsymbol{I}_{(av)} = \frac{\sum_{t=0}^{12}(I)}{12} \qquad (3)$$

Therefore, the Average Power consumption from 6am to 6pm is given by;

$$\boldsymbol{P}_{(av)} = \boldsymbol{V}_{(av)} \text{ x } \boldsymbol{I}_{(av)} \qquad (4)$$

3.3. Power Consumption Model Parameters

The table below displays the elements of our BS along with the factors impacting how much electricity they utilize [21].

Table 1. Power Consumption parameters

Components	Power consumption parameter
Base Band Unit	P_{BBU}
Radio Remote Unit	P_{RRU}
Rectifier	P_{REC}
Fan unit	P_{FU}
Fluorescent Bulb	P_{FB}
Base Station Power	P_{BTS}

Using the measured current, (1) was used to determine the power consumed by each component (A).

$$\boldsymbol{P}_{(W)} = \boldsymbol{V}_{(V)} \text{ x} \boldsymbol{I}_{(A)} \qquad (5)$$

The power consumed by a BTS as a whole is determined by adding the power consumed by each of its component elements:

$$\boldsymbol{P}_{BTS} = \boldsymbol{P}_{BBU} + \boldsymbol{P}_{RRU} + \boldsymbol{P}_{REC} + \sum_{k=1}^{k} \boldsymbol{P}_{FB} + \sum_{m=1}^{m} \boldsymbol{P}_{FU} \qquad (6)$$

The amount of power used near an antenna base the two categories of PBTS were traffic dependent and traffic independent. Because some base station components' measured current values were not affected by the amount of traffic [12]. The observed current values for components including the fan unit, fluorescent lamps, and BBU were unaffected by traffic load. However traffic load had an impact on the RRU's measured current levels. The entire base station power can be shown in (6).

$$\boldsymbol{P}_{BTS} = \boldsymbol{P}_{Traffic\ independent} + \boldsymbol{P}_{Traffic\ dependent} \qquad (7)$$

Hence,

$$\boldsymbol{P}_{Traffic\ independent} = \boldsymbol{P}_{BBU} + \boldsymbol{P}_{REC} + \sum_{k=1}^{k} \boldsymbol{P}_{FB} + \sum_{m=1}^{m} \boldsymbol{P}_{FU} \qquad (8)$$

$$\boldsymbol{P}_{Traffic\ dependent} = \boldsymbol{P}_{RRU} \qquad (9)$$

For each Technology;

$$\boldsymbol{P}_{RRU} = \boldsymbol{P}_{RRU\ Sector\ 1} + \boldsymbol{P}_{RRU\ Sector\ 2} + \boldsymbol{P}_{RRU\ Sector\ 3} \qquad (10)$$

As mentioned earlier, this analysis focuses on the dependent traffic of the Base station's power consumption. That is, we shall only use the P_{RRU} for our analysis and discussion

4. DISCUSSION OF THE RESULTS FROM THE DC MEASUREMENT

In this section, we examined the data related to the measured power and the traffic load. The samples for GSM 900, GSM 1800, and UMTS 2100 below show a linear correlation between power consumption and traffic load. The table below includes some statistics regarding the measured average values for power consumption and traffic load because the measurement spanned a full month, or 4 weeks. Keep in mind that the NOC provided the average traffic load data (Network operating Center of Airtel Uganda).

Table 2. Average Power and Traffic load.

Days	Power consumption (kW) Site-1	Traffic load (Erl) Site-1	Power consumption (kW) Site-2	Traffic load (Erl) Site-2	Power consumption (kW) Site-2	Traffic load (Erl) Site-3

Day 1	0.836	21	0.654	4.4	0.435	4
Day 2	0.787	19.2	0.757	18.5	0.565	5
Day 3	0.853	21	0.475	7	0.345	3.1
Day 4	1.046	26.1	0.437	7.7	0.471	4.2
Day 5	1.045	26	0.593	2	0.715	18
Day 6	1.027	26.2	0.463	2	0.475	5
Day 7	0.983	22.5	0.474	2	0.397	2
Day 8	0.732	18.8	0.836	20.5	0.704	10
Day 9	0.651	5	0.857	22.5	0.622	5.5
Day 10	0.651	5.5	1.042	25	0.682	6.5
Day 11	0.741	18.5	1.042	25	0.683	7
Day 12	0.845	20	0.853	19.8	0.604	7
Day 13	0.662	5	1.028	24.5	0.683	7
Day 14	0.851	20	0.983	22.1	0.682	8
Day 15	0.736	18	0.826	21	0.582	5.5
Day 16	0.725	17	0.881	20	0.512	5
Day 17	0.75	18	1.045	26	0.381	2
Day 18	1.01	26	1.027	25	0.723	18
Day 19	1.041	26.5	0.983	19.8	0.785	19
Day 20	1.068	27	0.854	19.8	0.615	7
Day 21	0.843	19	0.475	2	0.425	4
Day 22	0.631	2	0.612	4	0.731	18
Day 23	0.685	6.2	0.604	5	0.76	18.7
Day 24	0.682	6.2	0.652	5.5	0.415	4
Day 25	0.934	18	0.512	2	0.562	5
Day 26	0.75	18	0.762	18.2	0.612	6.8
Day 27	0.845	21.5	0.615	4	0.452	5
Day 28	1.045	25	0.633	5.5	0.623	8

Graphs were created to understand the relationship between power usage and traffic load using the data from Table 2 above. The graphs below provide a clear image of how power and traffic relate at a particular base station; however, only three sites are shown, therefore not all data were displayed here.

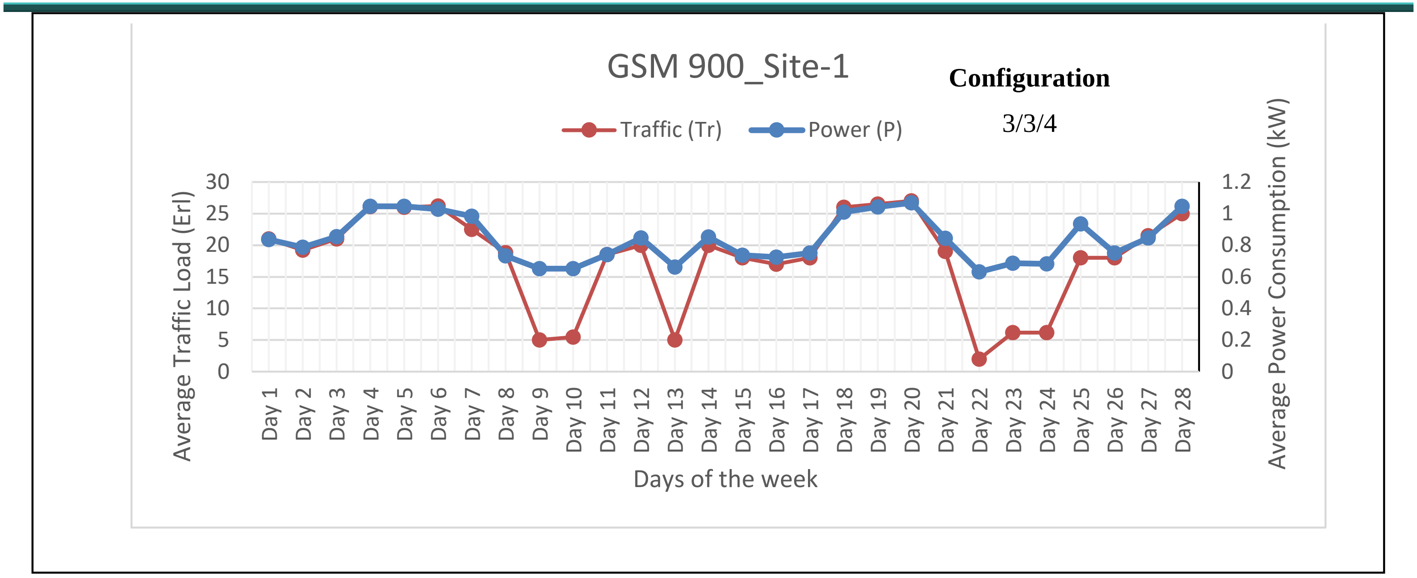

Figure 4. *GSM 900-site 1_Average power consumption vs Average traffic load.*

Figure 5 compares the energy usage and the equivalent traffic load of Site 1 for 900 MHz while taking into account the RF configuration (3/3/4). We can see that the average consumption is high, reaching 1.1 kW in this case, exceeding the expected rate of 900 MHz power consumption, indicating that the more RF transceivers present, the more energy is required. Yet, the shapes of average power consumption and average traffic load are the same. This indicates that the amount of traffic somehow regulates how much energy is used.

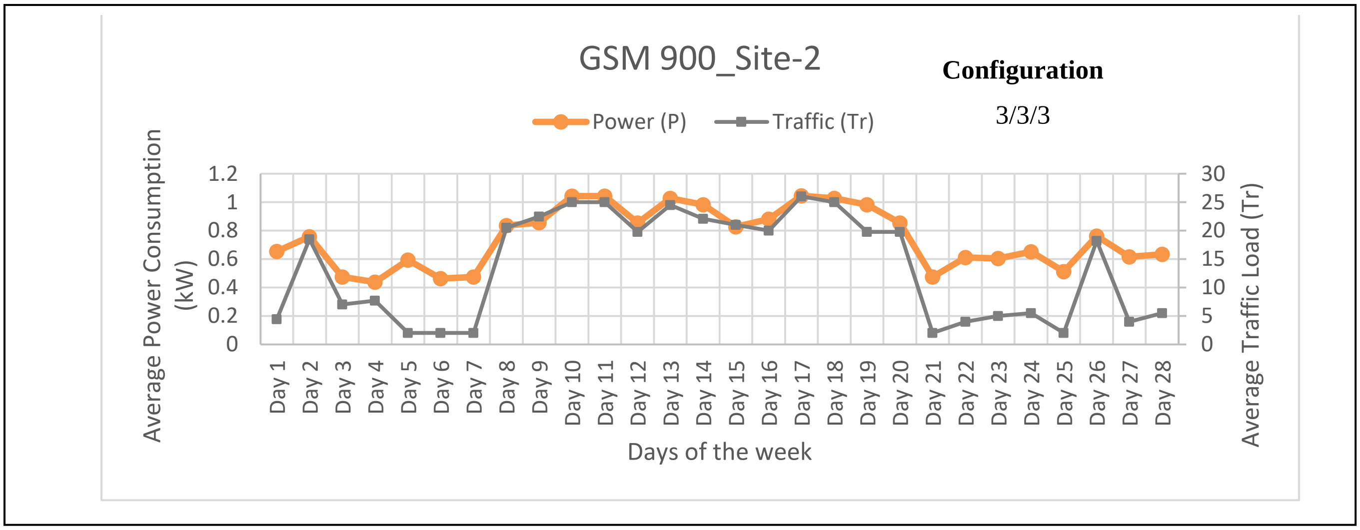

Figure 5. *GSM 900-site 2_Average power consumption vs Average traffic load*

According to Figure 6, which compares energy usage and the equivalent site 2 traffic load for 900 MHz using the RF configuration (3/3/3), we can see that the average power consumption is significantly higher than anticipated, reaching 1.13 kW in this case. This means that the more RF transceivers that are used, the more energy is required. Yet, the shapes of average power consumption and average traffic load are the same. This implies that the power usage is somehow regulated by traffic demand. Figures 5 and 6 depict essentially the same events, as can be seen; both sites have nearly identical consumption patterns and reach 1 kW within the measurement period.

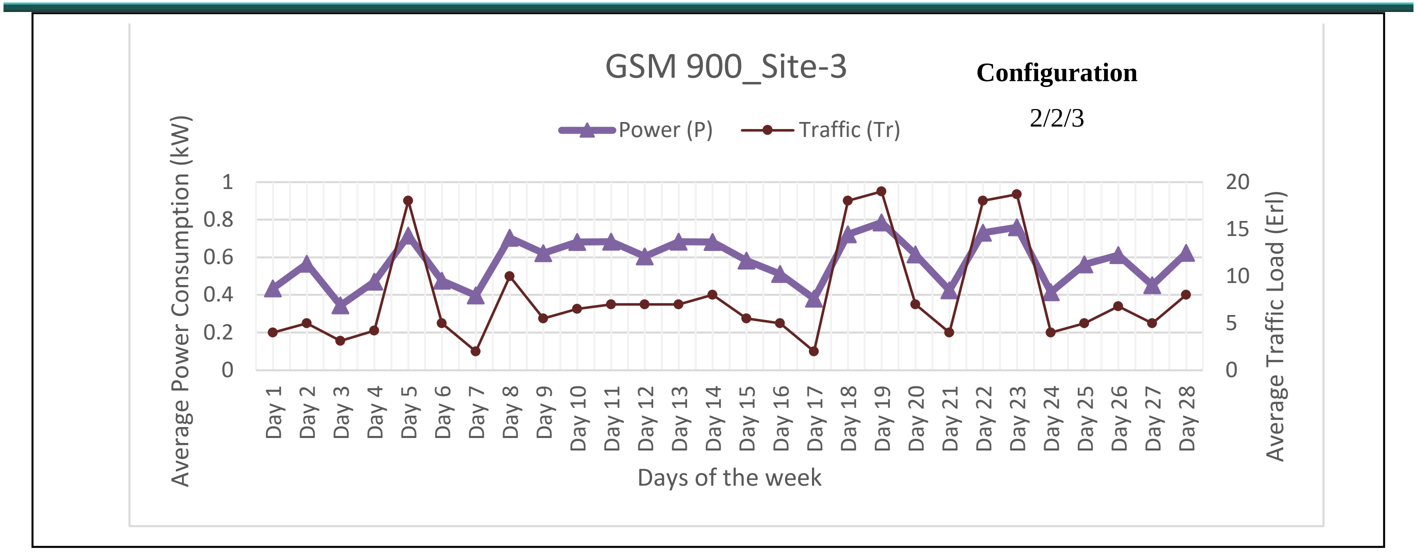

Figure 6. *GSM 900-site 3_ Average power consumption vs Average traffic load*

According to Figure 7, which depicts site 3's average power usage and equivalent average traffic load for 900 MHz using the RF configuration The average power usage is lower than it was for the previous sites (2/2/3). Maximum average consumption in this situation reaches 0.85 kW, which is nearly equal to the necessary power consumption for Huawei equipment operating at 900 MHz. As a result, there are less RF on the network, which lowers power consumption. However, power consumption on the network takes the form of the average traffic load; the more traffic, the greater the consumption, and vice versa.

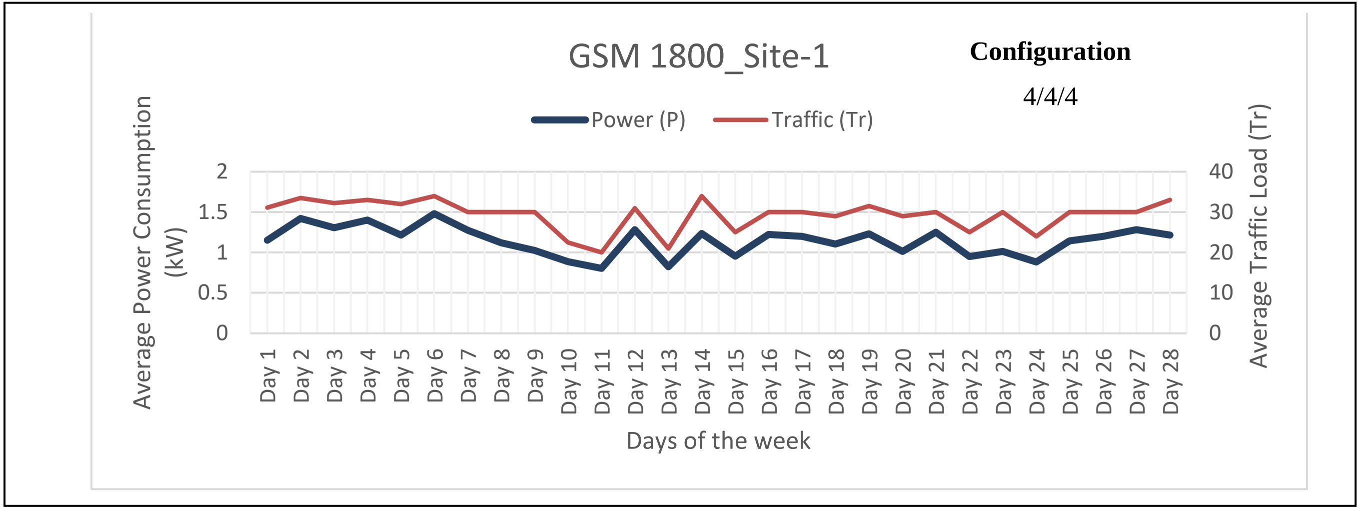

Figure 7. *GSM 1800-site 1_Average power consumption vs Average traffic load*

For site 1, see Figure 8 and 1800 MHz. One thing is consistent across all sites and frequency bands: the average traffic load varies with the average use of electricity. Power usage reduces as traffic volume does, and vice versa. The configuration shows us more transceivers than 900 MHz sites, which explains why there is more consumption as compared to the sites with fewer transceivers.

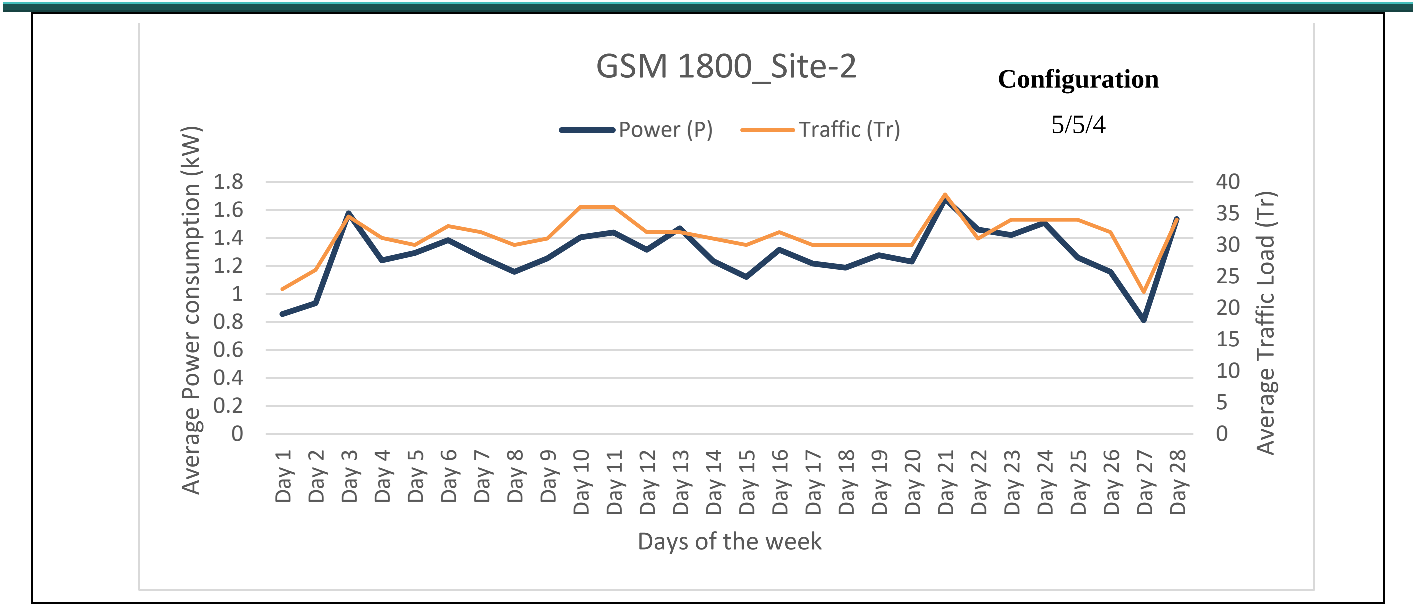

Figure 8. *GSM 1800-site 2_Average power consumption vs Average traffic load*

For site 2, see Figure 9 and 1800 MHz. The configuration is high (5/5/4) and provides an indication of how much energy will be used. This is proven when we look at the graph and see that day 1 has the lowest power usage of 0.853 kW and day 21 has the greatest power consumption of 1.678 kW. This demonstrates that this location consumes more power. We notice that this frequency band consumes a lot of energy, even more than the required energy as estimated by the consumption rate of Huawei equipment, despite the fact that the shape of the average traffic load and the one of the average power consumptions do not differ much.

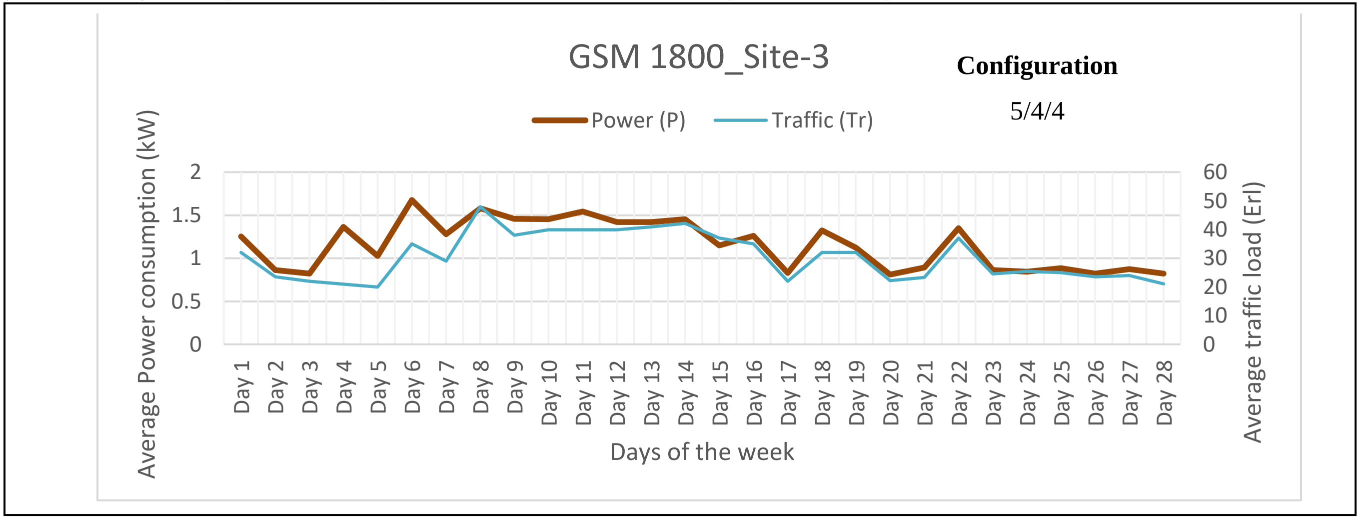

Figure 9. *GSM 1800-site 3_Average power consumption vs Average traffic load*

For site 3 on Figure 10, 1800 MHz. Power consumption increases to 1.678 kW on day 6 and 0.821 kW on days 3, 17, 20, 26, and 28 due to the configuration's high (5/4/4). While the lowest traffic load is 20 on day 5 and reaches a maximum of 48 Erl on day 8, respectively. According to the specifications at which these devices function and the frequency range in which they operate, this consumption is not excessive. Due to the near-far problem at each base station, especially for mobile users in rural places far from the cell tower, 1800 MHz, which serves as a frequency for the purpose of coverage, requires a lot of power as it works.

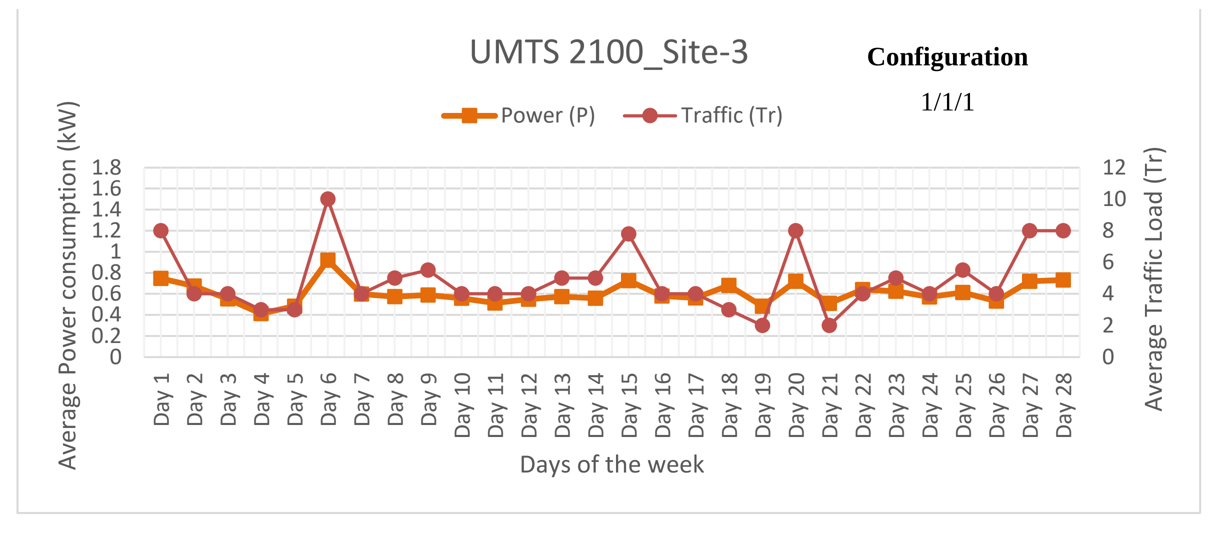

Figure 10. *GSM 900-site 3_Average power consumption vs Average traffic load*

For site 3 on Figure 11, use 2100 MHz. As there is one transceiver per sector and the configuration is high (1/1/1), we anticipate lower usage than at other sites with more transceivers. This being the case, the highest power consumption in this case is from day 6 with 0.921 kW, and the lowest is from day 4 with 0.412 kW. This is the lowest reading thus far in this study, and it confirms that 2100 MHz, which has new technology equipment compared to 900 and 1800 MHz, does not consume more power and is handling fewer sites than other frequency bands.

Figures 5 to 11 show that each base station's power consumption takes on a unique shape, which is a result of the various transceiver configurations. As mentioned earlier, GSM 900 is made in these sites as the primary call traffic, but do not cover a longer distance of radius within the cell. For site-1 GSM 900, power consumption increases from days 4 through 6 and increases to 1.046 kW. However, from days 7 through 20, power consumption increases again. This suggests that the first site consumes a lot of power. We also note that the form of traffic load is not much different from the shape of power consumption. This suggests that the quantity of cellular network calls made directly correlates with the rise in power usage. A characteristic throughout all of these technologies is that power consumption is inversely connected with traffic load; the lesser the traffic, the lower the energy consumption, and vice versa. Each technology has its own patterns for power consumption and traffic load.

Based on the various patterns of energy use and call volume depicted in Figures 5 to 11, we found that in rural cell regions, specifically sites 1 and 2 using the GSM 900 and GSM 1800 technologies, energy use is minimal and network calls are few. This explains why fewer users utilize the network in rural areas and why, depending on the site architecture, the energy consumption in each of these cell areas is determined by the volume of traffic.

Urban regions, or site-3, have quite varied TRX configurations and are heavily laden with TRXs. This is because there are so many subscribers in a single geographic cell. This is the reason why, at this specific location, the highest energy consumption of up to 1.1687 kW with a corresponding traffic load of 35 Erlang for the GSM 1800 technology was observed on day 6.

We may therefore say with certainty that a BTS's instantaneous power consumption rises as user activity does throughout the day. Confirmation of this can be found in Figures 5 through 11, which compare the measured traffic load and power consumption pull for the GSM 900, GSM 1800, and UMTS 2100 for all the sites visited during data collection. An operator's customized monitoring system was used to obtain data on the daily average traffic load.

4.1 COMPARISON BETWEEN GSM AND UMTS

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

Table 3. Comparison between Maximum and Minimun GSM and UMTS

Base stations	**Average Maximum Traffic (Erlang)**			**Average Minimum Traffic (Erlang)**			**Average Maximum Power Consumption (kW)**			**Average Minimum Power Consumption (kW)**		
Technologies	**900**	**1800**	**UMTS**	**900**	**1800**	**UMTS**	**900**	**1800**	**UMTS**	**900**	**1800**	**UMTS**
Site 1	27	20	N/A	2	34	N/A	1.068	1.545	N/A	0.631	0.757	N/A

Site 2	26	38	N/A	2	22.5	N/A	1.045	1.678	N/A	0.437	0.812	N/A
Site 3	19	48	10	2	20	2	0.785	1.678	0.412	0.345	0.814	0.921

We are thus able to compare the frequency bands that use more and less power based on the data of the three base stations visited during this research. The energy consumption of GSM 1800 is consistently higher than that of other frequency bands, as evidenced by all sites visited, regardless of their various BTS setups. We have observed that this technology uses more power than other technologies. In one month, or twenty-eight days, GSM 1800 utilized an average of 2.383 kW from all three locations, according to the daily average consumption, UMTS 2100's average power consumption for the twenty-eight days was 0.921 kW, lower than GSM 900's average power consumption of 1.413 kW. Because it provides a wider range of coverage than other frequencies, GSM 1800 frequency requires more energy to operate. 900 MHz, on the other hand, only comes to a stop at a specific distance, which accounts for their lower energy usage even if they use the same technology as 1800 MHz. On the other hand, when system load increases, capacity and interference both rise, and coverage decreases, the consumption decreases instead since the system's ability to handle large amounts of traffic has decreased.

4.2 Comparison between rural and urban sites

It was determined that the power usage of urban BTSs is around 20% greater than that of rural BSs. Due to their higher energy efficiency, rural (macro) BTSs are only suited for coverage needs, but urban (micro) BSs are ideal for a variety of clients that demand high data rates. As a result, urban places now use more energy. Urban sites manage a wide range of technologies, including GSM, UMTS, and LTE. Depending on the BTS configuration and traffic load, each of these technologies utilizes energy in a different way.

Site 3 consumes the highest power out of all of these sites, with an average power usage for GSM 1800 of 1.678 kW, according to data in Table 3. According to data in Table 6, site 2 has the lowest average power consumptions, with a GSM 900 usage of 0.437 kW. Site 3 GSM 1800 has the highest traffic average, with an average of 48 Erlangs, while site 2 has the lowest traffic load. Sites 1 and 2 are rural sites, but site 3 is an urban site, as was stated at the beginning of this section. We have concluded from the comparison above that urban sites use more energy than rural areas.

5. LINEAR REGRESSION MODELLING

The equations In this section, we discuss the line equations for each site according to their technologies, linear regression models for all sites visited and their various technologies, models were made for all the sites in their different technologies and data were validated using these models.

$$\boldsymbol{Y = a + x\beta} \qquad (\mathbf{11})$$

Where Y is the typical energy use (dependent variable)
(a) is Regression coefficient = (constant term),
β = the corresponding weight (coefficients)
X is an unrelated variable (traffic load)

The linear regression model for each site, obtained using MATLAB, is shown in Figures 12 through 18. This model tends to fit the data value with a 96% confidence interval. In Table 2, which shows the linear dependence of power consumption on traffic load, offers the intercept values, linear model coefficients, and average power consumption equations, separate linear regression models have been built for each analyzed BTS.

As seen in Figures 12 to 18, the average power consumption of each BTS increases linearly with an increase in traffic load. The proposed linear models demonstrate constant power consumption during periods of low traffic. The suggested models' intercept amounts also guarantee some static (residual) power use even when there isn't any traffic. This means that all of the sites constantly require a specified quantity of power at some point during no traffic time.

Table 4. Y GSM 900 Regression models that were analyzed, along with R-Squared and adjusted R-Squared values.

Base stations	**R-Squared**	**Adjusted R-square**	**Power consumption Y (kW)**
Site 1	0.7714	0.7626	Y = 0.0168*x + 0.5347
Site 2	0.8703	0.8653	Y = 0.0207*x + 0.4663
Site 3	0.6526	0.6392	Y = 0.0195*x + 0.4278

The values of the R-squared and modified R-squared for each of the three sites visited during this investigation for the frequency range of 900 MHz are shown in the aforementioned Table 4; this was done in Microsoft Excel. According to the tables, all of these locations underwent study and provided us with values of at least 50% (table 4), proving that the linear regression model is the most effective method for addressing the issue of on-site power usage. However this table just shows the values for the 900 MHz frequency band; in the following tables, we'll learn the values for the other frequency bands.

Table 5. R-squared and adjusted R-squared values for the analyzed Y GSM 1800 Regression models.

Base Stations	**R-Squared**	**Adjusted R-square**	**Power consumption Y (kW)**

Site 1	0.7979	0.7901	Y = 0.0422*x - 0.0936
Site 2	0.8121	0.8048	Y = 0.0527*x - 0.3694
Site 3	0.7049	0.6935	Y = 0.0295*x + 0.2565

The values of the R-squared and modified R-squared for each of the three sites visited during this investigation are shown in table 5 above. This analysis was carried out in Microsoft Excel for the frequency band of 1800 MHz. According to Table 5, all of these sites produced values after analysis that was greater than 50%, indicating that the linear regression model is the most effective method for addressing the issue of on-site power usage. The values for the remaining frequency bands are represented in the following table, which only shows the values for the 1800 MHz frequency band.

Table 6. R-squared and adjusted R-squared values for the Y UMTS 2100 regression models that were analyzed

Base Stations	R-Squared	Adjusted R-square	Power consumption Y (kW)
Site 3	0.7275	0.7170	Y = 0.0442*x + 0.3893

For the frequency range of 2100 MHz, the values of R-squared and modified R-squared for each of the three sites visited during this investigation are shown in table 6 above. This analysis was done in Microsoft Excel. Upon examination, each of these sites provided us with values greater than 50%, as shown in table 6. This suggests that the optimum method for addressing the issue of on-site power consumption is the linear regression model.

R-squared data is used to assess the created In order to correlate the variables and ensure accuracy, use linear regression models. The R-square range indicates how well a statistical model or regression line fits the actual values of the dispersed real data. Tables 4, Table 5, and Table 6 show the obtained R-squared values for all the sites and all the technologies, respectively. The R-squared for GSM 900, GSM 1800, and UMTS, respectively, ranges from 0.6526 to 0.8703, 0.7049 to 0.8121, and 0.7265, according to the statistics. The model clearly captures variance in reaction facts around its mean across all three sites and all technologies, as seen by here. The adjusted squared parameter is another statistic utilized in the analysis. The adjusted R-squared is an R-squared that has been altered to account for the variety of predictors in the model. The adjusted R-squared is always less than the R-squared parameter and may even be negative. The updated R-square values for GSM 900, GSM 1800, and UMTS, respectively, vary from 0.6392 to 0.8653, 0.6935 to 0.8048, and 0.7170, according to Tables 7, 8, and 9. The acquired results are nearly equivalent to those of R-squared values due to the relationship between adjusted R-squared values and R-squared values, indicating a precision sample of a similar size. Consequently, utilizing the built-in regression models, it should be quite helpful to predict the required power level to fulfill the continuously increasing traffic demand.

Tables 7, 8, and 9 show the line equations that we were able to get from the model's equations for each of the three locations we visited.

The model equation for all GSM 900 base stations is as follows:

$$\boldsymbol{Y = 0.0207 * x + 0.4663} \qquad \mathbf{(12)}$$

Where Y is the dependent variable, 0.0207 is the gradient, Tr is the average traffic, and 0.4663 is the intercept.

For all GSM 1800 base stations, the model equation is:

$$\boldsymbol{Y = 0.0527 * x - 0.3694} \qquad \mathbf{(13)}$$

The intercept is 0.3694, the dependent variable is Y, the gradient is 0.0527, and the average traffic is Tr (Regression coefficient).

The universal UMTS 2100 base station model equation is:

$$\boldsymbol{Y = 0.0442 * x + 0.3893} \qquad \mathbf{(14)}$$

Tr is the average traffic, Y is the dependent variable, and there is a gradient of 0.442 and an intercept of 0.3893. (Regression coefficient).

The graphical representations of the linear regression model, which was performed in MATLAB R2021a as our proposed model and solutions to the problem mentioned in this research study, are shown below in Figures 12 through 18.

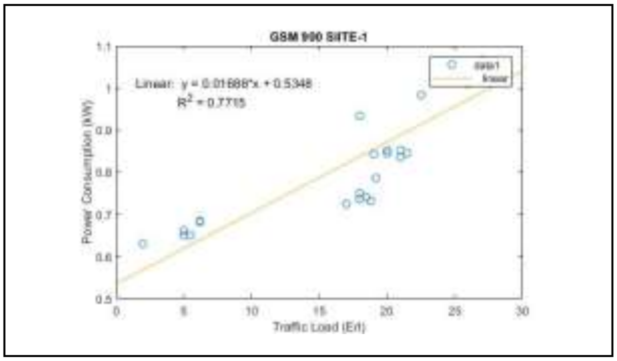

Figure 11. *Regression Model of site 1 GSM 900.*

The site-1 900 MHz linear regression model is shown in Figure 12. This regression is reliable and has good R-squared values of 0.7715 and Y = 0.0168*Tr + 0.5348 as its line equation.

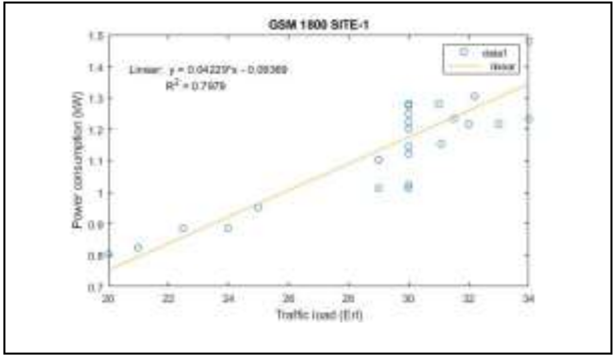

Figure 12. *Regression Model of site 1 GSM 1800.*

The site-1 1800 MHz linear regression model is shown in Figure 13. This regression is reliable and has good R-squared values of 0.7979 and Y=0.04229*Tr + 0.09369 as its line equation.

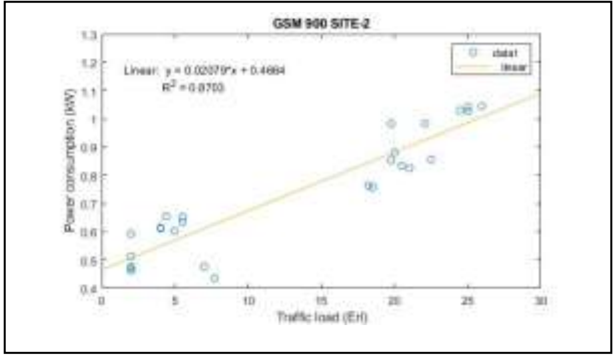

Figure 13. *Regression Model of site 2 GSM 900.*

The site-2 900 MHz linear regression model is graphically depicted in Figure 14. Given that it has a higher R-Squared value of 0.8703 and the line equation Y=0.02079*Tr + 0.4664, this regression is valid.

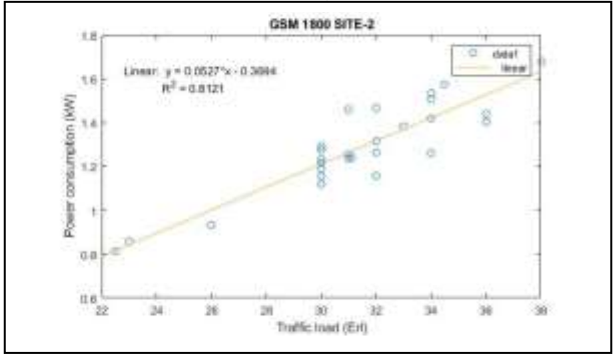

Figure 14. *Regression Model of site 2 GSM 1800.*

The graphical representation of the site-2 1800 MHz linear regression model is shown in Figure 15. Given that it has a higher R-Squared value of 0.8121 and the line equation Y=0.0527*Tr + 0.3694, this regression is valid.

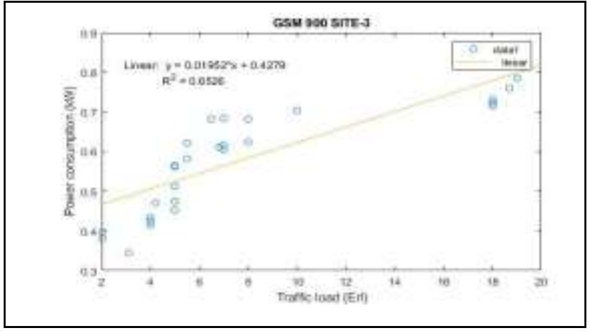

Figure 15. *Regression Model of site 3 GSM 900.*

The graph of the 900 MHz of site-3 linear regression model is shown in Figure 16. Given that it has a good R-Squared value of 0.6526 and the line equation Y=0.01952*Tr + 0.4279, this regression is valid.

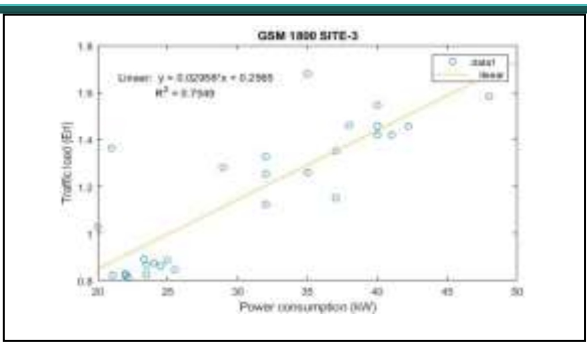

Figure 16. *Regression Model of site 3 GSM 1800.*

The graphical depiction of the site-3 1800 MHz linear regression model is shown in Figure 17. Given that it has a decent R-Squared value of 0.7049 and the line equation Y=0.02956*Tr + 0.2565, this regression is valid.

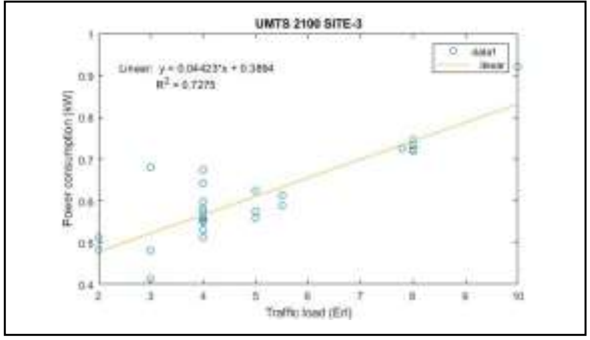

Figure 17. *Regression Model of site 3 UMTS 2100.*

The graph of the site-3 2100 MHz linear regression model is shown in Figure 18. Given that it has a good R-Squared value of 0.7275 and the line equation Y=0.04423*Tr + 0.3894, this regression is valid.

6. CONCLUSION

In this section, a broad conclusion has been provided, the section provides a clear conclusion on how this work was made and how the outcomes we discussed.

This document provides an overview of ongoing studies targeted at enhancing the energy use efficiency of mobile networks. In addition, we study the impact of traffic depth on BS power consumption. Information on UMTS, GSM 900, and GSM 1800 access technologies have been collected from locations with BTSs, and real-time traffic and power consumption have been examined. After twenty-eight days of non-stop observations, we acquired results confirming that the average traffic load affects how much electricity BTSs use on a given day. But, when there is less traffic, energy use is almost the same. Regression models developed additionally demonstrated that average power consumptions for rural and urban BTSs are considerably impacted by variations in traffic, depending on various areas (rural and urban). The power usage of the urban BTSs was discovered to be nearly twice that of the rural BSs. Due to their higher energy efficiency, rural (macro) BTSs are only suited for coverage purposes, whereas urban (micro) BSs are acceptable for a variety of consumers and require high data rates.

7. ACKNOWLEDGMENT

The author wishes to express his sincere gratitude to the Almighty God for this journal, great thanks to all the supervisors and the staff of the school of engineering and applied science of Kampala international university, Western campus, thanks to friends and family who contributed financially and spiritually for the success of this study.

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