Modelling of Power Consumption in Two Base Stations, Using Ugbor Station and Benson Idahosa University Station in Benin City as a Case Study

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Abstract:- This research is on the analysis and modelling of power consumption in a base transceiver station. For the purpose of this research, two base transceiver stations in Benin (BEN) were visited and data were collected and analysed: Ugbor station referred to as BEN035 (site A) and Benson Idahosa University referred to as BEN198 (site B). Analysis was made on AC power consumption and its Matlab plot. The model of Base station instantaneous DC power consumption for high and low traffic global system of mobile communication (GSM) usage was carried out by Matlab software to show how power is been consumed in a Base transceiver Station (BTS) and for future forecast.

Keywords:- *Base transceiver station, modelling, power consumption, Forecast, Matlab software and telecommunication.*

I. INTRODUCTION

This covers the power consumption of the equipment that make up the base transceiver station, the modelling of the BTS from the data collected from the two base stations. It also shows the plot of the alternating current (AC) power consumption consisting of the three phases and direct current (DC) instantaneous power consumption in the sectors of the base station technology. Base stations equipment is likely to consume more power depending on its usage. Being able to forecast the power consumption at a stipulated period of time will provide a measure and techniques to reduce the power consumption at an early stage and hence save cost and optimize profit for the operators.

II. THEORETICAL POWER CONSUMPTION OF BASE TRANSCEIVER STATION (BTS)

Base Transceiver Station (BTS) - is a transceiver and acts as interface between the mobile stations (MS) to the network. A BTS will have between 1 and 16 Transceivers (TRX), depending on the geography and demand for service of an area. Each TRX represents one Absolute radio frequency channel number (ARFCN). However, depending on geography, service demand and operator's network strategy and architecture, a BTS may be host up to two, three or six sectors, or a cell may be serviced by several BTSs with redundant sector coverage. Each sector is covered by sector antenna, which is a directional antenna.

Fig 1:- Typical macro base station

In Figure 1, there are several power consuming equipment. Some equipment are used per sector such as the digital signal processing (DSP) which is responsible for system processing and coding, the power amplifier, the transceiver which is responsible for generating the signal and also receiving signals to the mobile station and the rectifier as shown in Figure 2.The power consumption of such equipment should be multiplied by the number of sectors when determining the power consumption of BTSs. Within these equipment the transceiver and the power amplifier are one per transmitting antenna. Other equipment such as the air conditioning and the microwave link, when no fiber link is available for backhaul, are common to all sectors.

Power consumption for each of the equipment is always the same except for the power amplifier and the air conditional system. For amplifier, the power consumption solely depends on the efficiency of the amplifier.
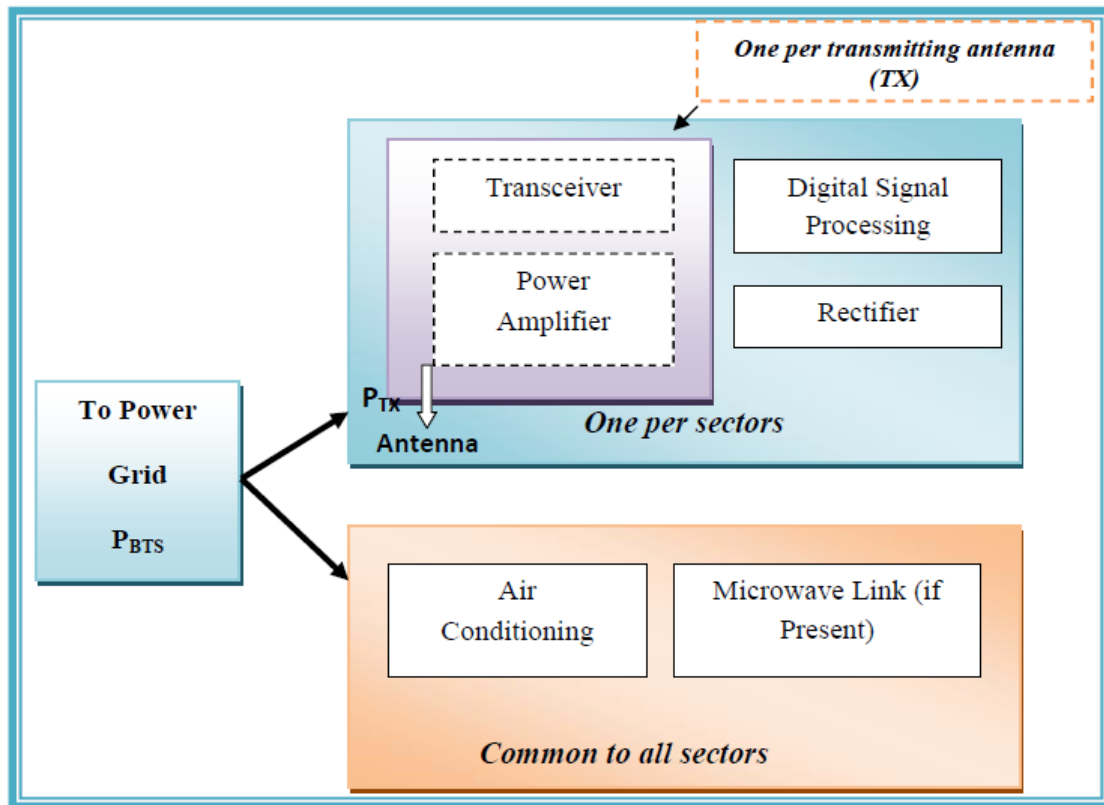

Fig 2:- Block Diagram of Base Station Equipment.

In the case of the air conditioning system (AC), the power consumption varies with the internal and ambient temperature of the BTS cabinet. Considering the ambient temperature to be 25^0C, this is not always the case in Nigeria. The internal and ambient temperature varies with locations.

Therefore, when estimating power consumption of air conditioning system, the worst case temperature scenario is considered.

In theoretical based power consumption, analytic model is developed to estimates the power consumption of a base station. Though in some cases, the estimation never gives the realistic power consumption but somehow approximations. This indicates that once the power consumption of individual equipment of the base station is known, the total power consumption could be evaluated

A. *Load Demand in a Base Transceiver Station*
In this work, two base station is been considered, which are BEN035 (Base station A) and BEN198 (Base station B) in Benin City, Edo State, Nigeria. Base station A has many links, services more geographical area (more subscribers) and in turn consumes more power than the base station B which serves less geographical area (less subscribers).

A Base transceiver station that is operating in Nigeria (BEN035) has the load demand in the table 1. It consists of 3G network access cabinet.

S/N	Equipment	Model (Type)	Quantity	Power Rating (Watts)	No of Hours Used	Daily Hour Used (kwh)
1.	Transceiver(3G) (DC)	Huawei	4	3200	24	76.8
2.	Base band unit (DC)	Huawei	1	180	24	4.32
3.	Air conditioner (AC)	Chigo	2	1700	24	40.8
4.	Indoor light (AC)	Philips	2	64	12	0.768
5.	Security light (AC)	Tostar	1	32	12	0.384
6.	Rectifier (AC)	Delta	1	2400	24	57.6
7.	Microwave antenna (DC)	Ericsson	5	25	24	0.6
8.	GSM Antenna (DC)	Acatel	3	60	24	1.44
9.	Multiplexer (DC)	Acatel	1	240	24	5.76
10.	Intermediate frequency links (DC)	Ceragon	9	180	24	4.32
11.	Router (DC)	Ericsson	1	330	24	7.92
	Total energy consumption			8,411	240	200.712

Table 1:- Equipment of a base transceiver station and power rating per hours used in BEN035 (3G)

A   Base transceiver station that is operating in Nigeria (BEN198) has the load demand in the table 2. It consists of 3G network access cabinets.

S/N	Equipment	Model (Type)	Quantity	Power Rating (Watts)	No of Hours Used	Daily Hour Used (kwh)
1.	Transceiver(3G) (DC)	Huawei	2	2800	24	67.2
2.	Base band unit (DC)	Huawei	1	180	24	4.32
3.	Air conditioner (AC)	Chigo	1	900	24	21.6
4.	Indoor light (AC)	Philips	2	120	12	1.44
5.	Security light (AC)	Philips	1	60	12	0.72
6.	Rectifier (AC)	Delta	1	2100	24	50.4
7.	Microwave antenna(AC)	Ericsson	3	15	24	0.36
8.	GSM Antenna (DC)	Ericsson	3	60	24	1.44
9.	Intermediate frequency (IF) links	Ceragon	7	140	24	3.36
	Total energy consumption			6,375	192	150.84

Table 2:- Equipment of a base transceiver station and power rating per hours used in BEN198 (3G)

From the tables 1 and 2 above, Base station A will consume more power than base station B because base station A has so many links, covers more geographical area and consists of other equipment like the Add and drop multiplexer and router. The fact that base station A uses an indoor (shelter) system, its power consumption is higher since the air conditioning system will do more work compared to base station B which uses an outdoor system that operate on natural convection.

III.   MEASUREMENT OF POWER CONSUMPTION

Alternating current (AC) from the power grid which is connected to the base station site uses a three phase low voltage system (415/240V) with a proper TN-S grounding scheme. Residual current device characterized with a nominal current of 40A and a differential current of 500mA is based on a non-direct touch protecting system. For the base station cabinet to function properly, voltage values from direct current (DC) power supply range from 43V to 56V was used.

AC and DC power consumption obtained at the entire base station site was taken at two minutes intervals. This was carried out in the period from 17th February starting at 12:00pm until 21st February ending at 12:00pm.
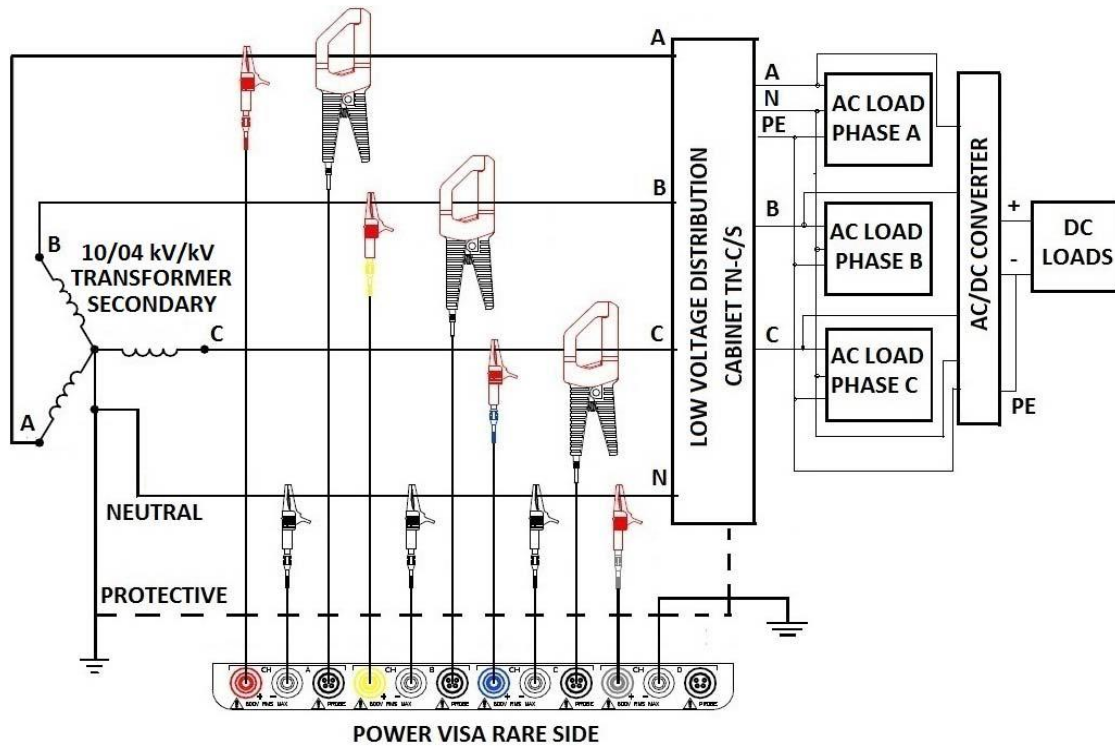
A. Alternating Current (AC) Power Consumption

Fig 3:- Contacting scheme for measuring AC consumption of complete BSs site.

Different equipment were used to measure the alternating current energy consumption of the entire site, as well as the air conditioner and the battery supply system. The equipment been used are as follows: laptop with specialized matlab software, flexible Rogowski current- clamps equipped with the embedded signal integrator for currents of up to 3Ka, current clamps for measuring currents up to 30A. UNI-T True Root Mean Square (TRMS) multimeter. The measured signals were concurrently stored to an embedded 2 GB SD memory card and transferred to the laptop via a corresponding adapter.

The measuring scheme according to which measurements of the power consumption on the AC side of the BS site were performed can be seen in Figure 3. As presented in Figure 3, the phase currents were measured using current clamps. The first five values of current from the 2880 values obtained in the period were shown in the tables below.

Table 3 Some of the values obtained from the AC measurement (Phase A) in BEN035 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	23.79	240	5710	5.710
2.	23.3	240	5592	5.592
3.	23.87	240	5729	5.729
4.	23.92	240	5741	5.741
5.	24.0	240	5760	5.760

Table 3

Table 4 Some of the values obtained from the AC measurement (Phase B) in BEN035 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	18.17	240	4361	4.361
2.	18.94	240	4546	4.546
3.	19.41	240	4658	4.658
4.	19.10	240	4584	4.584
5.	18.40	240	4416	4.416

Table 4

Table 5 Some of the values obtained from the AC measurement (Phase C) in BEN035 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	18.05	240	4332	4.332
2.	18.92	240	4541	4.541
3.	19.38	240	4651	4.651
4.	19.09	240	4582	4.582
5.	18.38	240	4411	4.411

Table 5

Table 6 Some of the values obtained from the AC measurement (Phase A) in BEN198 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	23.79	240	5710	5.710
2.	24.11	240	5786	5.786
3.	24.05	240	5772	5.772
4.	22.93	240	5503	5.503
5.	24.32	240	5837	5.837

Table 6

Table 7 Some of the values obtained from the AC measurement (Phase B) in BEN198 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	18.32	240	4397	4.397
2.	19.11	240	4586	4.586
3.	19.43	240	4663	4.663
4.	18.89	240	4534	4.534
5.	18.83	240	4519	4.519

Table 7

Table 8 Some of the values obtained from the AC measurement (Phase C) in BEN198 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	18.3	240	4392	4.392
2.	18.77	240	4505	4.505
3.	20.17	240	4841	4.841
4.	18.05	240	4332	4.332
5.	18.42	240	4421	4.421

Table 8

These values in table 3-8, other subsequent values that did not appear in tables were used to obtain 3G plots for AC power consumption in BEN035 and BEN198 respectively.

The changes in the alternating current (AC) power consumption of the entire base station site for phase A, B and C of the three phase electric supply are shown in figures 4- 9, respectively.
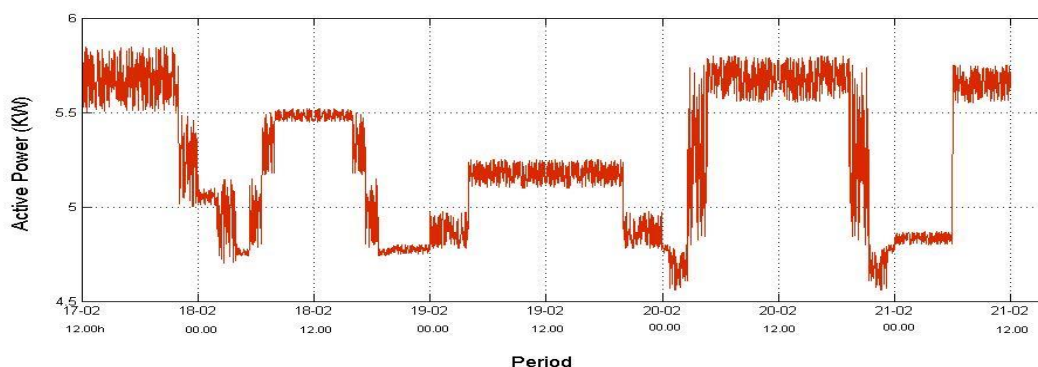

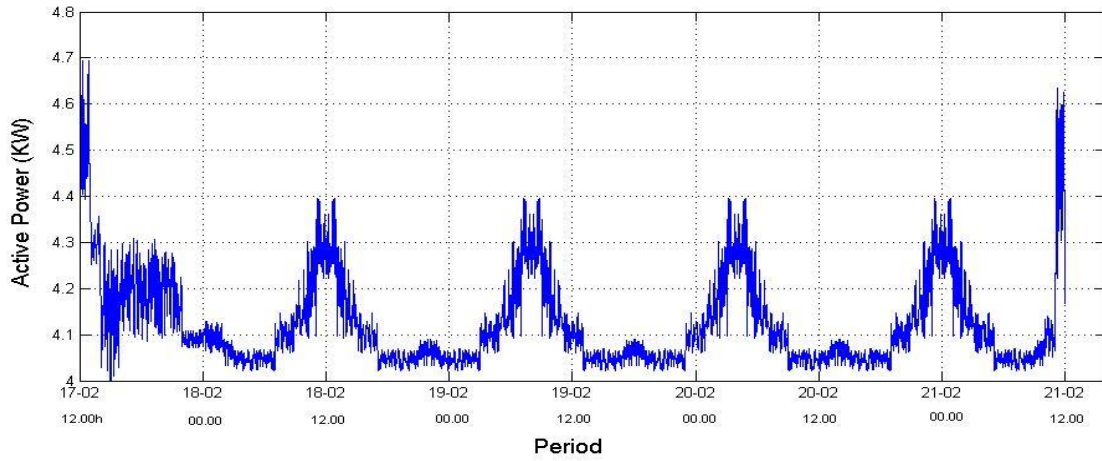Fig 4:- Active power of phase A for 17–21 February (BEN035).

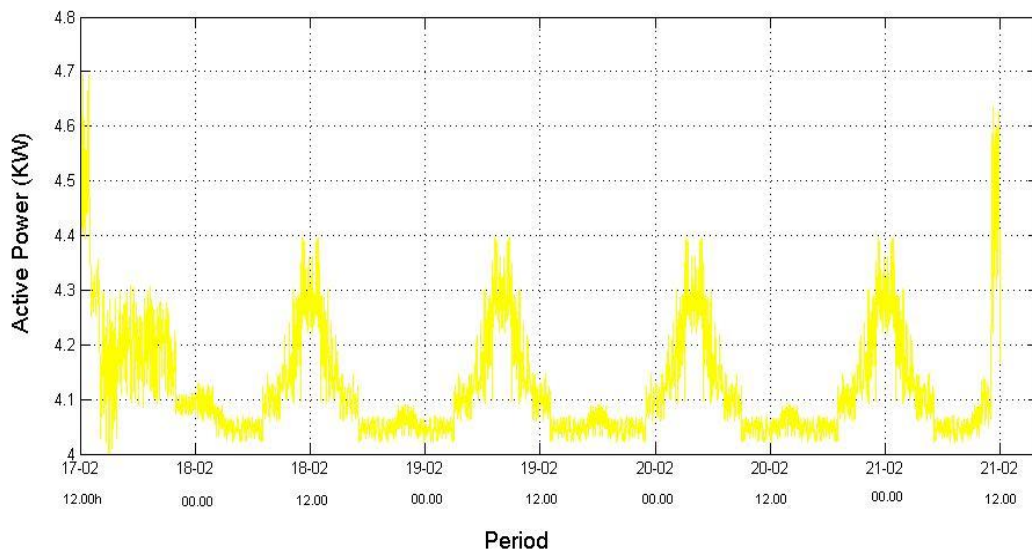Fig 5:- Active power of phase B for 17–21 February (BEN035).

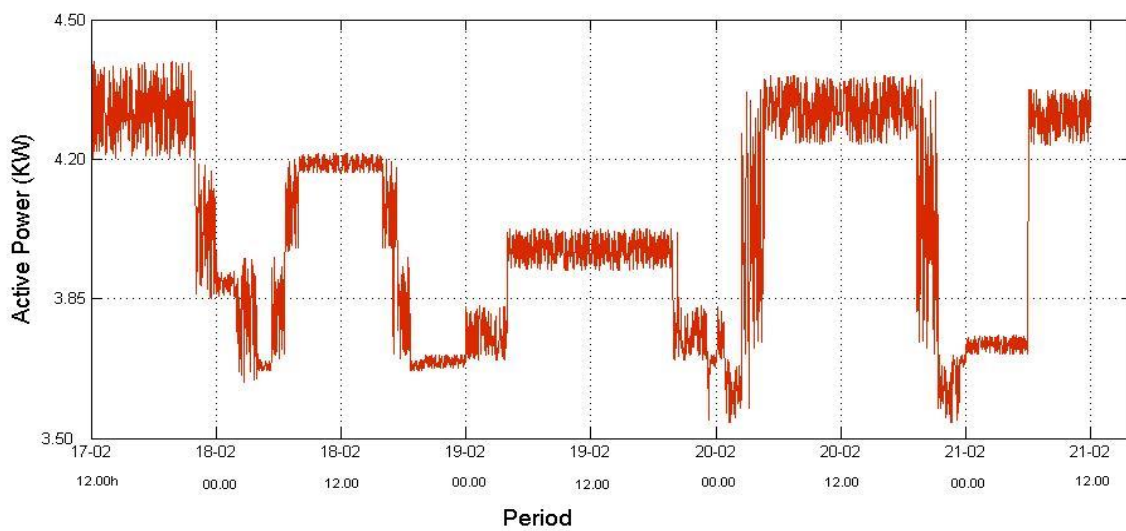Fig 6:- Active power of phase C for 17–21 February (BEN035).

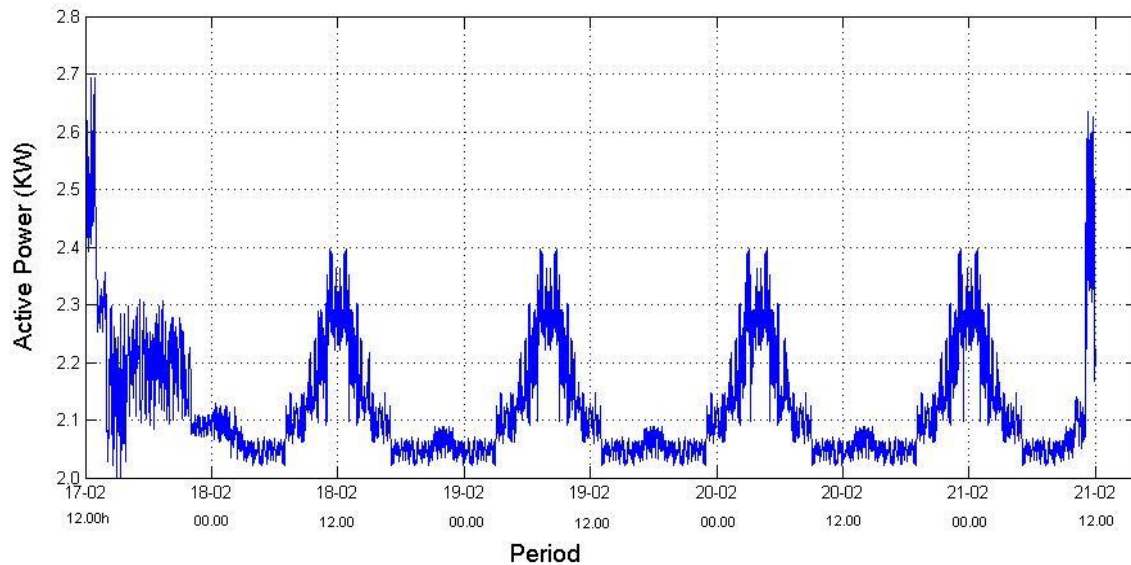Fig 7:- Active power of phase A for 17–21 February (BEN198).

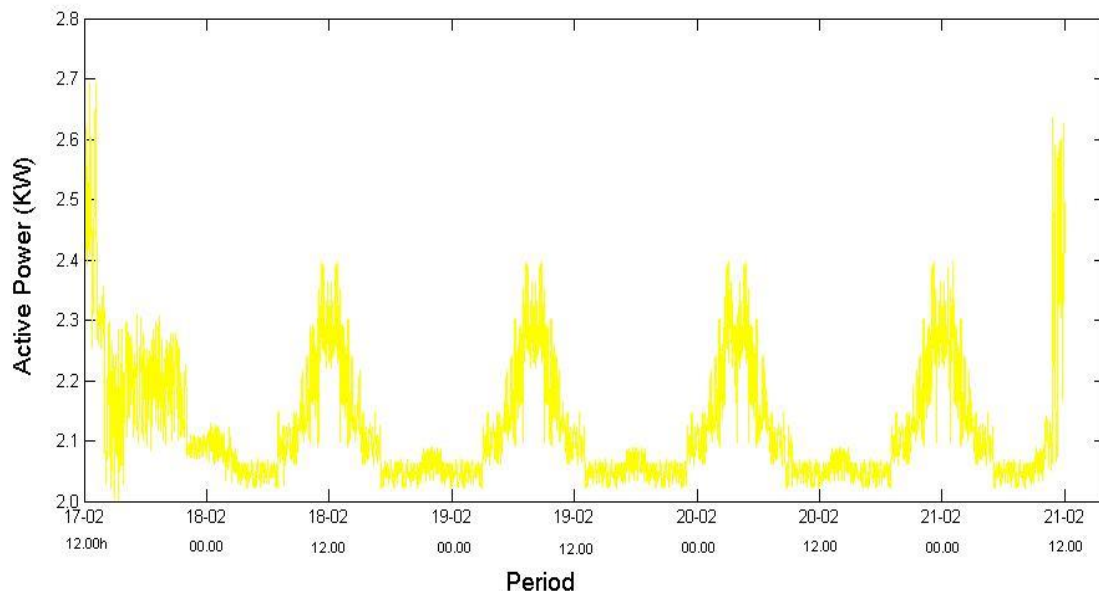Fig 8:- Active power of phase B for 17–21 February (BEN198).

Fig 9:- Active power of phase C for 17–21 February (BEN198).

As a direct consequence, we noticed that there is more visible variations in phase A, which is as a result of the air conditioning connected to that phase. Therefore, reduction in the energy consumption of the individual base station sites a huge contribution to the energy contribution reduction of the complete macro base station site on the alternating current (AC) side. Also, reduced energy consumption of base stations will result in weakened heat dissipation, which consequently results in in lower energy consumed for site cooling. The appropriate design of macro base station sites, especially in the case of outdoor base station sites with natural air-cooling base station racks, can be used in order to completely eliminate the need for electrically supplied air-conditioning.

IV. INSTANTANEOUS DC POWER CONSUMPTION

In this research, consideration was taken for two universal mobile telecommunication system (UMTS) 3G BS cabinets dedicated for transferring traffic.

Changes in the instantaneous power consumption of the 3G BS is presented in Figure 10 for BEN035 and 3G BS is presented in Figure 11 for BEN198. These power consumptions of the individual Base stations were obtained by multiplying the measured values of the instantaneous Base station electric current consumption with constant DC voltage (53.6 V). According to Figures 10 and 11, it was observed that the power consumption of each Base station is not constant at every given time.

The first five values of current from the 2880 values obtained in the period were shown in the tables below.

Table 9 Some of the values obtained from the DC power consumption in BEN035 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	11.3	53.6	603	0.603
2.	12.6	53.6	675	0.675
3.	11.9	53.6	638	0.638
4.	11.8	53.6	634	0.634
5.	12.8	53.6	688	0.688

Table 9

Table 10 Some of the values obtained from the DC power consumption in BEN198 is as follows

S/N	Current (I)	Voltage (V)	Power (W)	Power (KW)
1.	10.0	53.6	537	0.537
2.	10.6	53.6	567	0.567
3.	8.5	53.6	454	0.454
4.	9	53.6	480	0.481
5.	12.8	53.6	509	0.509

Table 10

These values in table 9 and 10, other subsequent values that did not appear in tables were used to obtain 3G plots for DC power consumption in BEN035 and BEN198 respectively.

Actually, the instantaneous power consumption of the BSs varies during a day and these variations are inherent for the analyzed mobile technology (3G BTS).
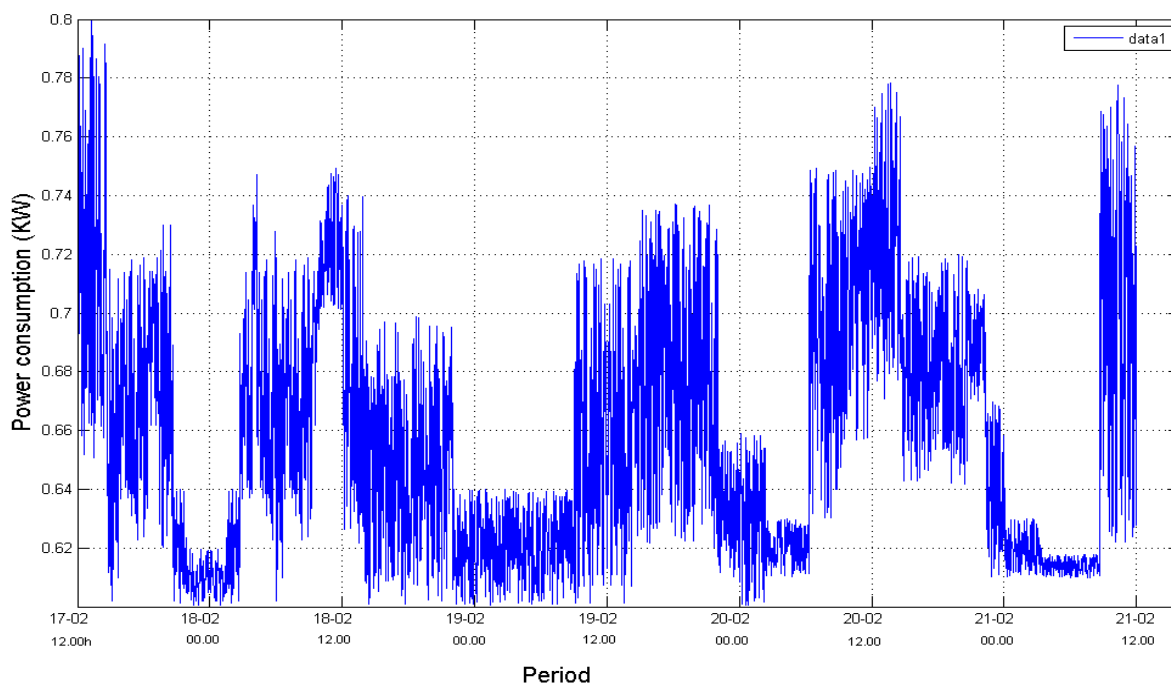

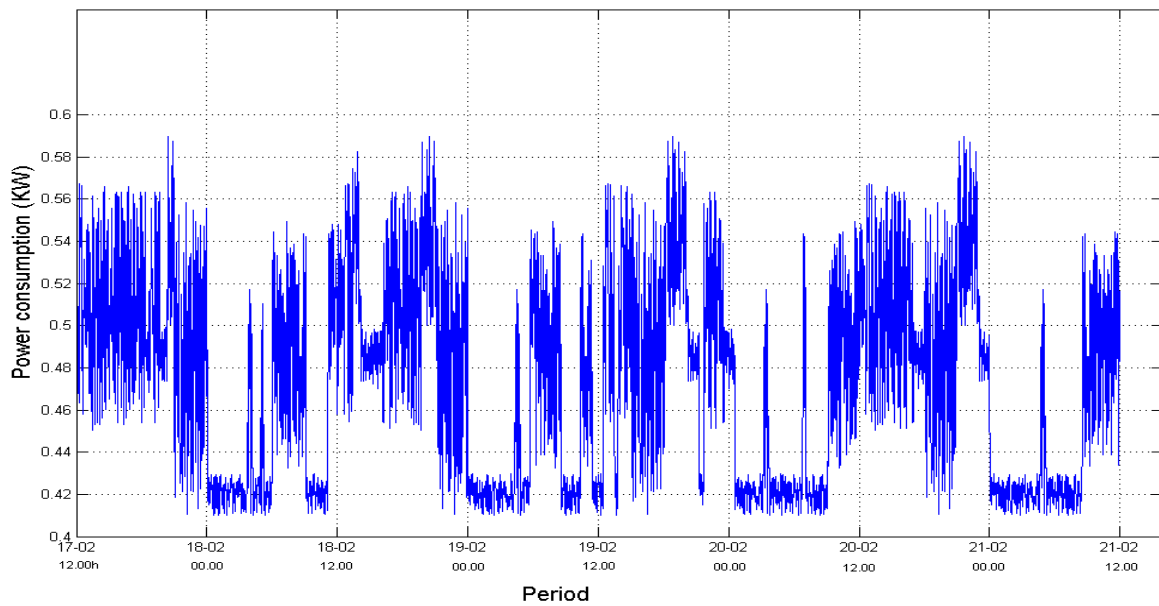Fig 10:- Power consumption of 3G (Sector 1) BS cabinet (BEN035).

Fig 11:- Power consumption of 3G (Sector 1) BS cabinet (BEN198).

From figure 10 and 11 it is observed that the highest power consumer is the 3G BS cabinet of BEN035, Compared with the base station consumption of the 3G BS cabinet of BEN198. This 3G BS of BEN035 has higher instantaneous power consumption at any moment. This is because the 3G BS of BEN035 cabinet serves all four sectors concurrently through configuration with 4 transceivers (TRXs) per sector (1/1/1/1). Since each transceiver has a separate power amplifier, and the power amplifier has the major share in the BS power consumption, the number of transceivers has an important influence on the total Base station power consumption. With this, the influence on the power consumption will be somewhat determined by the fact that the 3G Base station of BEN035 has been selected for maximum capacity utilization.

When power consumption was reduced by reducing the power consumed by some of the equipment that make up the BTS by using a lower power rated transceiver, multiplexer and base band unit, the plot remained exactly the same but spanned from 6kw to 4kw in 3G BS for BEN035, and from 4kw to 2kw in 3G BS for BEN198. This was carried out in the period from 24th February starting at 12:00pm until 28th February ending at 12:00pm. It is presented from Figure 12 and 13.
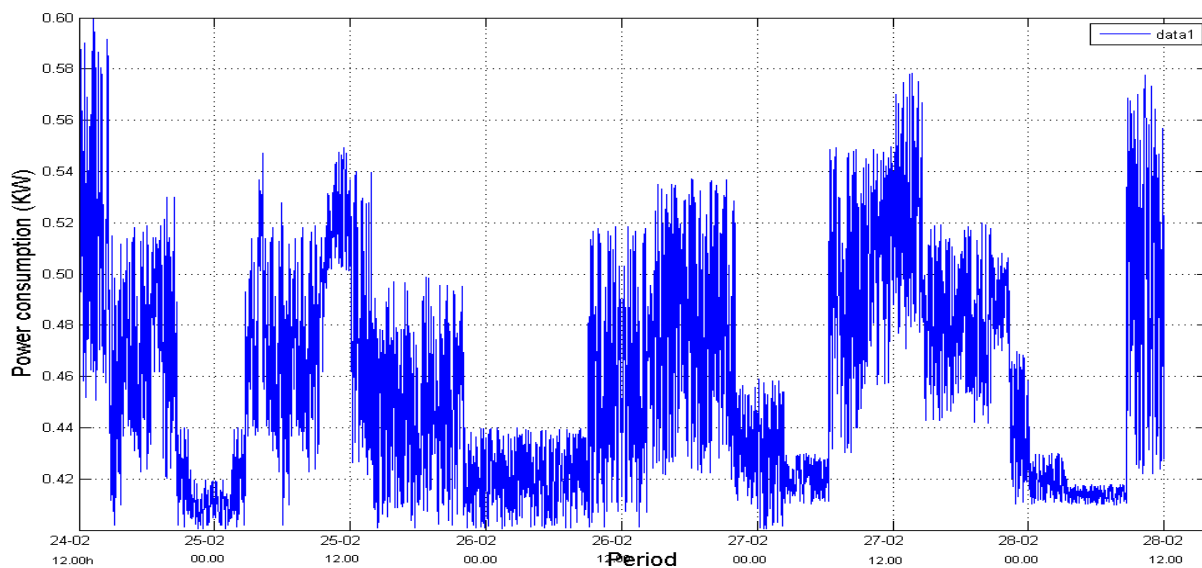

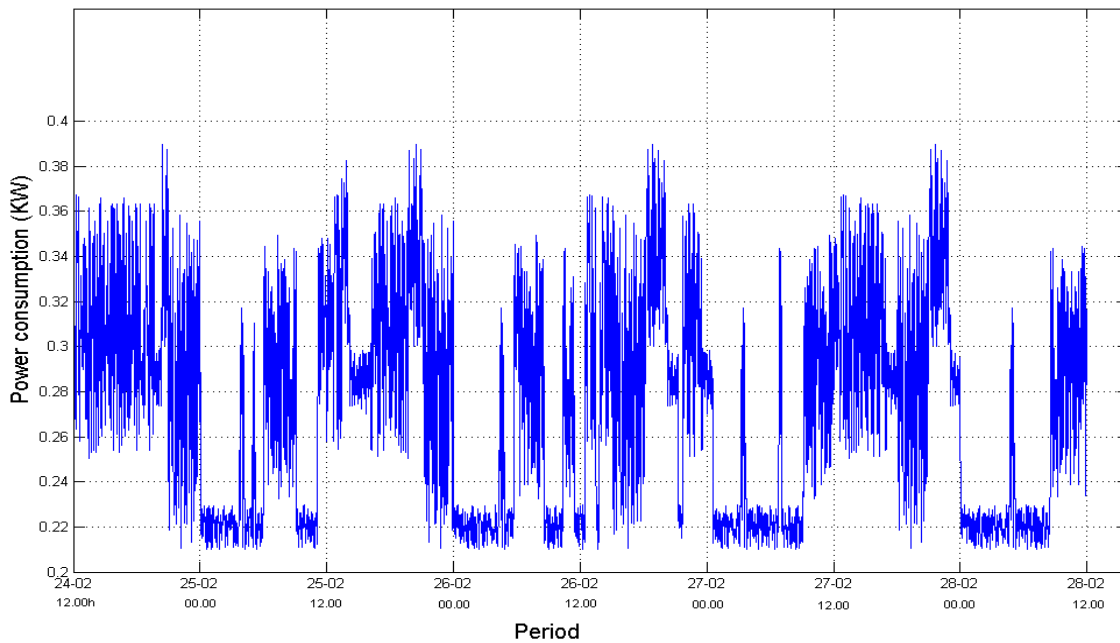Fig 12:- Power consumption (Low) of 3G (Sector 1) BS cabinet (BEN035).

Fig 13:- Power consumption (Low) of 3G (Sector 1) BS cabinet (BEN198).

V. POWER CONSUMPTION MODELLING

Depending on the measured average traffic load and the instantaneous power consumption obtained for each base station rack on the direct current (DC) side, the essence is to produce a linear base station power consumption model. The developed model must express instantaneous power consumption of each BS rack as a function of the current traffic load. In order to model the interdependence between the power consumption of each BS rack and corresponding traffic load, we use the following equation:

$$y = \beta_1 f_1(x) + \dots \beta_p f_p(x) + \varepsilon \qquad (1)$$

According to Equation (1), response y is modelled as a linear combination of functions of independent variable x and a random error ε. In expression (1), $f_j(x)$ $(j = 1, ..., p)$ are the *terms* of the model, while β_j $(j = 1, ..., p)$ represents the *coefficients*. It is assumed that the model has up to p different terms and corresponding coefficients. Uncontrolled factors and experimental errors are modelled in Equation (1) by ε, and assumed to be uncorrelated and distributed with zero mean and constant variance.

In our linear model, terms are $f1(x) = 1$ and $f2(x) = x$. For n independent observations $(x1, y1)$, …, (xn, yn), the linear regression model becomes an $n \times 2$ system of equations:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} f_1 x & f_2 x \\ f_1 x & f_2 x \\ \vdots & \vdots \\ f_1 x & f_2 x \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \qquad (2)$$

or, in the matrix notation:

$$y = X\beta + \varepsilon \qquad (3)$$

The **X** in Equation (3) is the design matrix of the system (Jacobiana). To fit the model with the data, the system must be solved for the coefficient $\beta1$ and $\beta2$.

Ignoring the unknown errors ε, the matrix equation expressed in Equation (3) can be written and solved as follows:

$$y = X\beta \qquad (4)$$
$$X^T y = X^T X\beta \qquad (5)$$
$$\beta = (X^T X^{-1}) X^T y \qquad (6)$$

For calculation of a confidence region, we need a variance s of coefficients $\beta1$ and $\beta2$. The approximate variance-covariance matrix of the regression coefficients is estimated by:

$$s^2(\beta) = \frac{xx^T}{n-2} (X^T X)^{-1} \qquad (7)$$

A. Telecommunication Traffic

Mobile telephone traffic data can be used to characterize resource usage and subscriber behaviors in mobile networks. Telecommunication traffic is measured in erlang.

B. ERLANG

An erlang is a unit of telecommunication traffic measurement. It represents the continuous use of one voice

path. In practice, it is used to describe the total traffic volume of one hour.

For example, if a group of user made 30 calls in one hour, and each call had average call duration of 5 minutes, then the number of erlang this represents is worked out as follows:

Minutes of traffic in the hour = number of calls x duration
Minutes of traffic in the hour = 30 x 5
Minutes of traffic in the hour = 150
Hours of traffic in the hour = 150/60
Hours of traffic in the hour = 2.5
Traffic figure = 2.5 Erlangs

Erlang traffic measurements are made in order to help telecommunication network designers understand traffic patterns within their voice networks. Traffic performance parameters are used to estimate the capacity and system utilization rate. This is essential if they are to successfully design their network topology and establish the necessary trunk group sizes.

The data/call traffic, which is a key performance indicator was collated by the radio network controller (RNC) for 3G and extracted through the operations and maintenance centre (OMC).

For a given period, from February 17th at 12:00pm to February 21st at 12:00pm, let the telecommunication traffic Tr (Erl) be represented as independent variable x, while the measured power (P) be represented as response y. Then the coefficient of regression line are: $\beta 1$ [W], which represents the intercept, and $\beta 2$ [W/Erl] which represents the slope of the line. Calculations were done by the use of function regression that is incorporated in a matlab software package. For the purpose of this work, power consumption measurements were taken at 60 values interval to obtain a better range of values for the model. The obtained results are shown in table 11 and the model in Figures 14 and 15.

Table 11 Average Power and Traffic for BEN035 and BEN198

(S/N)	Average Power P (W) for BEN035	Average Traffic Tr (Erl) for BEN035	Average Power P (W) for BEN198	Average Traffic Tr (Erl) for BEN198
1.	640	2	420	2
2.	635	2	423	2.1
3.	640	3	425	3.2
4.	650	4	435	4
5.	645	5.2	440	5
6.	650	4.3	445	4
7.	660	5	450	5
8.	653	5	455	5.2
9.	644	6	457	6
10.	660	6.2	462	6
11.	670	6	465	6
12.	680	6.5	460	6.3
13.	690	5.5	462	5.4
14.	680	8	470	8.5
15.	700	8	470	8
16.	680	8	473	8
17.	680	8	480	8.2
18.	715	8	477	8
19.	725	8	485	8
20.	720	9	489	9
21.	724	10	490	10.1
22.	730	11	500	11
23.	735	11	520	11.1
24.	740	12	510	12
25.	710	12	515	12
26.	748	12	520	12.3
27.	750	13	523	13
28.	752	13	530	13
29.	749	13	535	13
30.	755	14	540	14.2
31.	760	14	537	14
32.	758	15	545	15
33.	742	16	550	16
34.	759	16	552	16.5

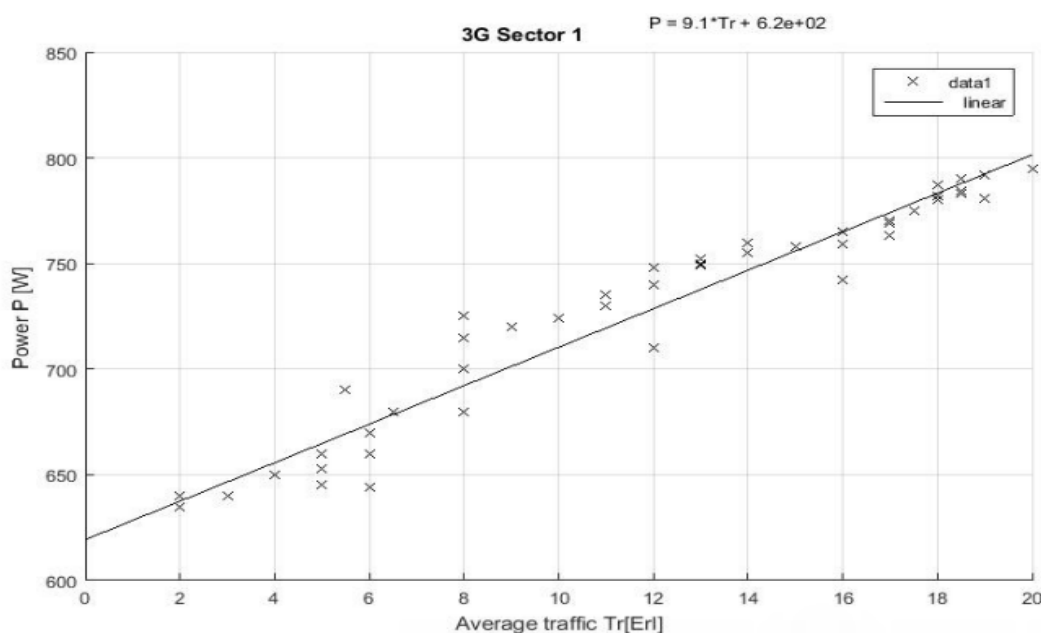| 35.	765	16	554	16
36.	770	17.3	560	17
37.	763	17.1	563	17
38.	769	17	567	17
39.	775	17.5	566	17.5
40.	780	18	570	18
41.	782	18	575	18
42.	784	18.5	571	18.5
43.	783	18.5	578	18.5
44.	790	18.5	580	18.1
45.	787	18	584	18
46.	781	18.8	590	19
47.	792	19.2	595	19
48.	795	20	597	20

Table 11

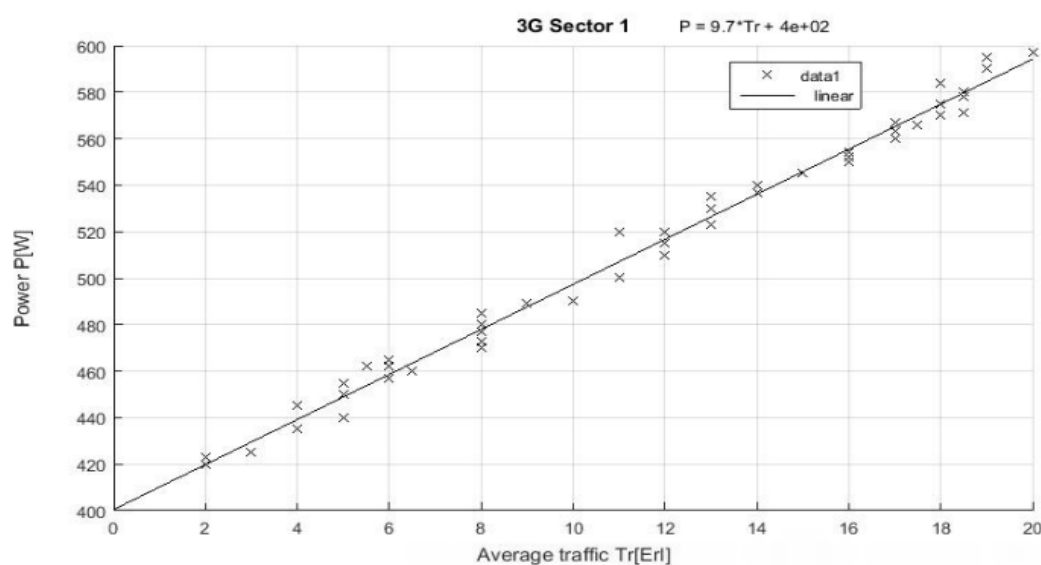Fig 14:- Power consumption model of 3G sector 1 BS rack (total measuring period) for BEN035.

Fig 15:- Power consumption model of 3G sector 1 BS rack (total measuring period) for BEN198.

C. Model Analysis and Results

From the equations of the model as shown in fig 14 and 15, this is the same as the equation of a straight line,

$$Y = mx + c$$

Y is the dependent variable, m is the gradient, x is the independent variable, predictor or regressor and c is the intercept.
For base station A (BEN035), we have the model equation to be:

$$P = 9.1*Tr + 6.2e + 02$$

Where P is the dependent variable, 9.1 is the gradient, Tr is the average traffic and 6.2e + 02 is the intercept (euler constant).
For base station B (BEN198), we have the model equation to be:

$$P = 9.7*Tr + 4e + 02$$

Where P is the dependent variable, 9.7 is the gradient, Tr is the average traffic and 4e + 02 is the intercept (euler constant).

The model equations $P = 9.1*Tr + 6.2e + 02$ for BEN035 and $P = 9.7*Tr + 4e + 02$ for BEN198 are used to determine the unit change of independent variable (Average traffic) on the dependent variable (Power) for the system.

From the model equations of the two base stations under consideration, comparism can be made on the base transceiver station that consumes more power and lesser power. It is evident that base station A (BEN035) consumes more power than base station B (BEN198). This shows that there are more network subscribers on base station A compared to base station B.

In Figures 14 and 15, in figures 14 and 15, 95% confidence interval was obtained from the developed linear models which have been plotted together with the measured results and the linear regression lines. According to these figures, it was possible to model the linear dependence of the instantaneous power consumption on the traffic load. An increase in the traffic load results in a linear increase of the instantaneous base station power consumption and also, the linear increase of the instantaneous base station power consumption results in an increase in the traffic load. In most cases, even when the traffic load is very low, the proposed model will still ensure some fixed amount of power consumption. The proposed linear model is made up of two components, which is fixed (not dependent on traffic load) and variable (directly proportional to traffic load). Each of the linear model obtained corresponds to the particular base station technology of the different sites and base stations of different manufacturers, year of production might have different linear models. Since the significant percentage of confidence is in line with the results gotten from the site measurements, the linear power consumption model can be seen as a model for evaluating the interdependence between traffic load and instantaneous base station power consumption. This perception gives as much possible confidence to the usage of a linear model in future studies which is focused on enhancing the energy efficiency of mobile radio access equipment already installed.

This model will help telecommunication network designers and operators understand traffic patterns and the power consumption in a base station. Decisions can then be taken to increase the number of base transceiver stations or increase the capacity of the equipment to service such areas when there are large number of network subscribers.

VI. CONCLUSION

In this research, overview of the latest activities focused on enhancing the power consumption efficiency of base stations and low cost of operation. Additionally, an investigation regarding the impact of the power consumed by equipment that makes up the Base stations was performed. Analyses have been performed on the BS equipment containing rectifier, transceiver, air condition, baseband unit, amplifier, microwave link and antenna. Power consumption model for each analysed base station sites was produced. From the site measurements, a significant percentage of confidence follows the result from the proposed model. Therefore, the linear power consumption model can be seen as a model for evaluating the interdependence between traffic load and instantaneous base station power consumption.

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