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A Regression Analysis for Base Station Power Consumption under Real Traffic Loads – A Case of Nepal

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Abstract- With the advent and rapid development of mobile and wireless technology, the field of Information and Communication Technology (ICT) has become so lucrative and expanding at an alarming rate. Correspondingly energy consumption is also growing at a staggering rate. With this note, mobile operators are already among the top energy consumer. As the mass deployment of 3G systems in developing countries and later 4G systems rolling out worldwide, mobile communication consume significant amount of energy with large electricity bills. More than 50% of the total energy is consumed by the radio access part, whereas 50-80% is used for the power amplifier. This paper critically analyses the power consumption of Base Stations (BSs) as per the traffic generated at various urban-dense location of Kathmandu, Nepal. It deals with real time traffic data on full load in per hour basis of ten BSs for consecutive ten days. The results revealed a linear relationship between the power consumption and traffic loads. As of findings, this paper vow an urgency to pursue an optimal capacity while designing wireless networks and also suggests an imperative pathways for energy efficient wireless communication.

Keywords-Base Station Traffic;Power Consumption Modeling;Regression Analysis; Energy Efficient Wireless Communication

I. INTRODUCTION

Telecommunication is playing significant role in daily life of people in today's globalization context. The tele-density has surged to 100% this year in Nepal [1]. Nepal had an annual GDP per capita of USD 696.9 in the year 2014 and for every 10% increase in broadband penetration provides a 1.38% increase in GDP [2]. The growing interest in new and reliable services in mobile communications has resulted in increased number of installed Base Stations (BSs) worldwide. In addition, the traditional concept of BS deployment assumes continuous operation in order to guarantee the quality of service anywhere and anytime. Both of these reasons have synergetically contributed during the last decade to the significant growth of the total energy consumed by BSs of cellular network operators. In the case of Italy, the average yearly consumption of a BS is ca. 35,500kWh, considering that in Italy there are about 60,000 BSs, the total average yearly consumption of the Italian BTS sys-tem is ca. 2.1 TWh/year, which is the 0.6% of the whole national electrical consumption. In terms of economic and environmental impact, the data correspond to ca. 300 million euro yearly energy costs and ca. 1.2 Mton of CO2eq emitted in the atmosphere every year [3]. Sim-ilarly, about 3% or 600 TWh of the worldwide electrical energy is consumed by ICT sector. It is estimated that energy consumption for ICT sector will grow up to 1,700

TWh by 2030. The total global carbon footprint of ICT industries in the order of 860 million tons of CO2 which is about 2% of the global emissions [4]. Nepal is severely facing energy crisis with an aver-age 12 hours of load shedding per day. So the challenge is to provide reliable and cost effective power solution. For this, a power consumption model is developed as per traffic generated. BSs are the most energy consum-ing part of cellular mobile network with more than 50% share in total network consumption [5]. It is however important to determine the consumption of the whole wireless access network and thus to model the power consumption of each part of this network. Within these networks, 10% of the energy is consumed by the user terminals, while 90% is caused by the BSs. These num-bers indicated that the power consumption of wireless access networks is going to become an important issue in the coming years [6].

In the exploding world of wireless communications and networking, improving the power efficiency of radio networks is an important research topic [7]. To evaluate the energy efficiency of today's mobile communication systems and to identify improvements for next genera-tions system, a high level energy efficiency evaluation (E^3F) has been developed with Energy Aware Radio and neTworking tecHnologies (EARTH) project [8]. This framework covers the complete system, including net-work and radios.

A power consumption model is developed based on the power consumption and the traffic generated by BSs. Energy efficiency at various loads viz. low traffic and high traffic are compared. The power consumption of BSs consists of two parts. The first part describes the static power consumption - a power figure that consumed already in an empty BSs and dynamic power consump-tion which changes with traffic load. Depending on the load situation, a dynamic power consumption part adds to the static. In this study, only dynamic power consumption with respect to the traffic load has been considered. A power model is derived for typical BSs that are installed here in Kathmandu valley. In response to characterize a relationship, this study provides an ample of knowledge between the traffic load and corresponding BS power consumption. The most remarkable contribution to this study can be found where power consumption modelling of BSs is developed with real time traffic load of various heterogeneous BSs of Kathmandu valley. To the knowledge of the authors, such study comprising of power consumption as per generated traffic with real time data has not been carried out yet in Nepal.

II. RESEARCH ELABORATIONS

For the relationship between the BS energy consump-tion and traffic load, extensive measurements were taken from a fully operated BS site located at various urban-dense area. The selected BSs sites are divided into most loaded, average loaded and least loaded city sites in terms of voice and data traffic. BSs of the GSM 900, GSM 1800, GSM 2100 were considered for the data collection. GSM 2100 is used for 3G services. LTE is not considered because it is in testing phase. GSM 900, GSM 1800 is the indoor type of cabinet located inside a protected room dedicated solely for keeping site equipment but GSM 2100 is outdoor type BSs. Antenna lines connect each BS cabinet with corresponding antennas located on either pole tower and self supported tower.

The site is connected with a backbone network using optical lines over a manageable link. The AC power grid is connected to 430/220V site. The rectifier is the medium for AC power grid and battery. The Battery is connected from the rectifier and BSs takes power from the Battery. The rectifier converts ACvoltage to DC voltage and it charges the battery. There are two banks of battery each of 2V and 600 Ahr. When the AC power grid is available then it will charge the battery and will then supply the DC current to the BS. If there is no AC power grid then BS will take power from charged battery. The battery voltage ranges from 44V to 56V. The rectifier has fused up to 100 A. The electric current is drawn by each BS on hourly basis. Similarly, the traffic generated by each BS is also measured on hourly basis so that it would be easy to model the power consumption of BS as per traffic generated.

Here, in this research, 10 GSM BSs are taken for particular concern. Real time traffic load is monitored and collected for continuous 10 days on hour basis for the consistency. Networks are designed for maximum traffic and are optimized for operation at full load. But in real scenario, real network are not fully loaded. In fact, most networks are busy for some hours only in a day. Also traffic depends on spatial location and time. High traffic was measured during day at commercial area while high traffic were seen during morning and night time at residential area. In network level, an important approache for reducing energy consumption is a dynamic management of network resources, which allows shutting down of entire BSs during a low traffic load. In such a scenario, neighbouring BSs must provide coverage and take over the traffic load of those BSs that are turned off [9]. This can be combined with dynamic transmitter power selection, antenna tilting, multi-hop relaying or by coordinated multipoint transmission and reception [10].

III. METHOD

An important parameter to investigate is the energy efficiency of a BS. The energy efficiency is here defined as the power consumption (PC) needed to cover a certain area (in W/m2). PCarea per covered area is then defined in equation (1).

$$PC_{area} = P_{el}/\pi R^2 \text{ --- } (1)$$

Where, Pel is BS Power Consumption and R be the range of BS coverage [11]. Lower the PCarea, the more energy-efficient the BS is. BS is defined as the equip-ment needed to communicate with the mobile stations and with the back-haul network. The area covered by a BS is called 'CELL' which is further divided into a number of sectors. Each sector is covered by a sectored antenna, which is a directional antenna with a sector-shaped radiation pattern.

To determine the load, measurements are performed for an actual micro BS in the urban area of Kathmandu - Nepal. During 10 days (including weekend days), the power consumption of the BS is measured. The group of load-independent components i.e., the rectifier, the air conditioning and the microwave link are not included in this measurements. For the equipment considered, the voltage is constant (i.e. approximately 54V) and thus the current is measured. The power consumption P(t) (in Watt) at a certain time 't' is then determined as in equation (2).

$$P(t) = V.I(t) \text{ --- } (2)$$

Where, V is voltage (in Volt) and I be the current at any time t (in Ampere). The current is measured with an AC/DC current clamp. Every second, the value of the current was saved which results in 864000 samples for he measurement period of 10 days. For the week days, it is noticed that the power consumption during the night is lower than that of the day because during day-time more people are active. In weekend days, power consumption iffered by small compared to weekdays. The power consumption/hour for both weekdays and weekend are collected. It is found that the mea-sured equipment consumes between 1016 W and 1087W. Mostly, traffic is high during the weekdays (Sun-day to Thursday) and low during weekends (Friday and Saturday).

IV. DATA INTERPRETATION AND RESULTS

Figure:1 shows the power consumption and traffic load generation for a single day. The peak traffic of 230.137 Erlang with corresponding power 1.635 KWh was detected during 10:00 to 11:00 hours. When the traffic load is high, the correlation (R^2=0.83 to 0.94) between power consumption and respective traffic load is also high. Here, the power consumption pattern is a direct consequence of a daily traffic pattern variation. It was observed that the increase in the traffic results in an increase in the power consumption of BSs.

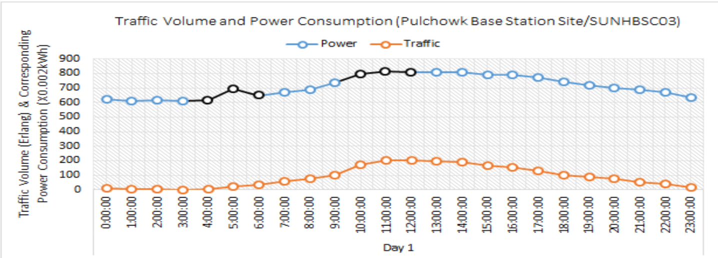

Figure 1: Traffic load and corresponding power consumption of Nepal Telecom – Pulchowk BS site in a day.

The relationship between the BS power consumption as per the traffic load is obtained. The power consumed by 10 different BSs and their respective traffic loads per hour for 10 days gave rise to 2400 records of a real event for this study. It was found that the traffic load is high during 08:00-11:00 and 18:00-20:00 hours. The high and low traffic load was recorded to be 143.6 and 3.3 Erlang respectively. It was found that the BS power consumption varies from 1.25 KWh to 1.63 KWh. The range did not vary so much as the traffic load varied largely. The peak power consumption was recorded between 08:0 to11:00 hours for each day whereas the least power consumption during 00:00 to 6:00 hours (Figure: 2).To test the statistical model and to correlate the variables, we have used R^2-statistics. R^2 value is a number that indicates how well a statistical model/regression line fit the real scattered data values. It is also known as the coefficient of determination. 0% indicates that the model explains none of the variability of the response around its mean.

In this study, R^2 value varied from 0.765 to 0.949 for different urban-dense location, which indicates that the model explains good variability of the response data around its mean. Adjusted R^2 lets the percentage of variation explained only by the independent variables that actually affect the dependent variable. Here Adjusted R^2 varied from 0.7648 to 0.9489 (Table: 1).

Table 1: R^2 and Adjusted R^2 Values of Different BSs

BSs	R^2	Adjusted R^2
Dhapasi	0.7658	0.7648
Kalikasthan	0.7870	.7861
Maharajgunj	0.8042	0.8034
New Baneshwor	.8142	0.8134
Panipokhari	0.7931	.7922
Sinamangal	0.8167	0.8159
Sundhara	0.8890	0.8885
Babarmahal	0.8000	0.7999
Jawalakhel	0.8945	0.8940
Pulchowk	0.9491	0.9489

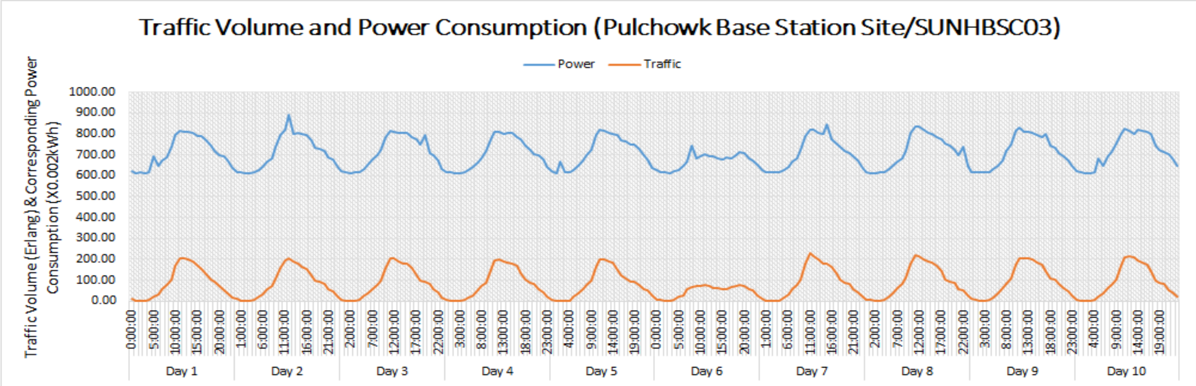

Figure 2: Observation Records for 10 Days of Power Consumption under Real Traffic Loads

Based upon the measured traffic load and corresponding BS power consumption, now the goal is to develop a power consumption model as per traffic generated. The developed model must express power consumption of each BS as a function of real time traffic load given by equation (3) [8].

$$y = \beta_1 f_1(x) + \ldots + \beta_p f_p(x) + \mathcal{E} \quad \text{----- (3)}$$

According to equation: 3, response y - Power Consumption is modelled as a linear combination of function of independent variable x - traffic load and a random error Ɛ. In this expression $f_j(x)$(j=1 to p) are the terms for the model, while β_j (j=1 to p) represents the weight correspond to $f_j(x)$. It is assumed that the model has up to p-different terms and corresponding coefficients. Uncontrolled factors and experimental erros are modelled in above equation by Ɛ and assumed to be uncorrelated and distributed with zero mean and constant variance.

This paper analyse BS power consumption under the real traffic loads as a major contributing factor, hence the above model reduces to $f_1(x)=1$ and $f_2(x)=x$. and for 'n' independent observations (x_1, y_1) to (x_n, y_n), equation (4) represents a linear regression equation for our concern. On its counterpart, cell geography (coverage), hours ofoperation (time) and population movement plus day-night shift (load variance factor) do also matter for BSpower consumption. But these factors again boost up thetraffic intensity, hence they are under the considerationof traffic loads rather to dealt separately.

$$y = X\beta + \mathcal{E} \quad \text{------- (4)}$$

Where, 'x' represents telecommunication traffic in Erlang, while 'y' acts as corresponding measured power, in Watt. Whereas, the coefficients of the regression line, Ɛ = b_1 [Watt] represents the intercept and b_2 [W/Erl] represents the slope of line. Calculations were performed in Ms-Excel with regression analysis under data function (Table:2). This give rise to the linear relationship between traffic load (x) and corresponding power consumption (y) as given by equation (5).

$$y = 1.274 + 1.713x \quad \text{----------- (5)}$$

The developed linear model have been plotted as a linear regression line which tends to fit the data values with 95% of confidence interval (Figure 3).

Table 2: Regression Parameters Analysis

Base stations	Intercept (Ɛ)	x - Co-eff. (β)
Dhapasi	636.1630	0.8547
Kalikasthan	631.1256	0.7466
Maharajgunj	629.1695	1.9822
New Baneshwor	584.6320	1.0840
Panipokhari	685.4675	0.8905
Sinamangal	656.9946	5.10743
Sundhara	697.3975	2.7711
Babarmahal	602.7391	1.3878
Jawalakhel	626.3360	1.2840
Pulchowk	621.7678	1.0227
Weighted Average	637.1793	1.7131
PWA*	1.2743	1.7131

*PWA – Pure Weighted Average/Down Scaled Value

The linear dependence of the power consumption on the traffic load is observed from figure: 3. It is noted that the power level required goes hand in hand with increased traffic load, which is justified by the linerar regression line. When the traffic load is very low, the proposed linear models ensure some fixed amount of poewr consumption .

$$y = 1.22677 + 0.00057x \text{ --------- } (6)$$

Such that for a similar another event, the power consumption during very low traffic is out to be described by equation : (6). If we considere a null effect of low traffic demand (since, the weight of dependent variable is too small), the intercept value still ensures some residual power cosnumption. It means during no traffic, certain amount of power cosumption is always taken by BSs.

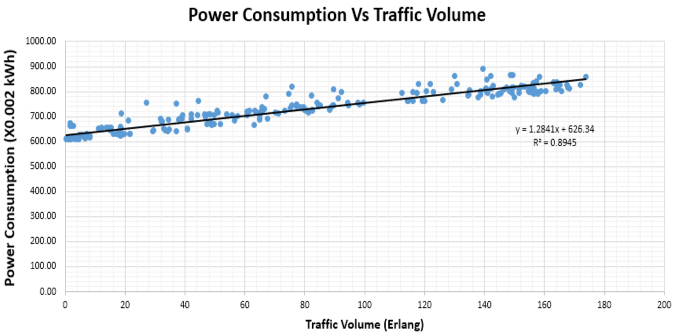

Figure 3: Fitting Data Values with Regression Line

A linear model developed for this particular study corresponds to the specific BS technology. Any other BS of different technologies, manufacturers and production years of configurations might have different linear models [6].

V. CONCLUSIONS

The main purpose of this research is to develop a model for the power consumption of BSs as per traffic generated. Hence, the impact of traffic on the BS power consumption is monitored. The traffic and power consumption data of 10 BSs were collected for 10 days for 24 hours on hourly basis with 2400 sample records in total. For each BS, the linear model has been developed where, R^2 value ranges from 0.765 to 0.949 with minimum error (standard error $\leq$ 25 per 240 observations for each analysis). Similarly, the regression line is about to fit the real data values and is justified with 95% confidence interval limit.

BS power consumption is found to be varied proportionally with the traffic loads showing a high correlation (R^2 value up to 0.94) between the variables, which means traffic loads could be a prominent source that the consumption of power heavily lies upon regardless of all other random constraints. Hence, the proposed model (a=95%) presents a significant results and can be accepted as a model for precise expression for BS power consumption under real traffic loads. During high traffic load, the developed linear model fits well but during low traffic, the model possess some indifference to fit the real data values (R^2 =0.0033 to 0.3123) and this limits the study. Later on, the developed model could be very useful forecast the required power level in order to justify high traffic demand. During no traffic (the least) also, BSs still let some energy (residual power) to maintain a tower in a standby mode for a continuous operation.

It is also noted that energy bill accounts for approximately 18 to 32% of the operation expenditure (OPEX) in the mature metropolitan cities like Kathmandu [12]. From the operators' perspective, energy efficient (EE) wireless communication is not only has great benefits and represents social responsibility in fighting climate change, but also has significant economic benefits [13]. Based on this research findings, further research on cell zooming as per the traffic, spectral efficiency, soft-handover strategies and quality of services are highly recommended. On the other hands, the rapid growth of ICT sector in Nepal also demands for larger energy requirement. So, it is urgent to shift towards energy efficient wireless communication with all possible measures in order to serve traffic on demand more dynamically.

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