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Comparison of Energy Efficiency Between Macro and Micro Base Stations Using Energy Saving Strategy

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Abstract:
To meet the subscribers ever increasing traffic demand, micro and macro base stations are being deployed excessively. As the traffic pattern varies according to the user's behavior, the deployment of micro and macro base stations plays a vital role in saving energy while maintaining the traffic demand of the subscribers. A macro base station consumes more than double the energy than a micro base station. Due to the space and time characteristics of the traffic, the BS cannot allocate resources effectively, which results in wasting energy consumption and low energy efficiency. Therefore, energy saving through deployment of base stations play a significant role to increase the energy efficiency. In this paper, the user traffic pattern is determined and the resources needed to fulfill the traffic are analyzed and finally the deployment strategies for the base stations are formulated.
Since the base stations are fully loaded only for few hours a day, energy saving on the stations during low traffic will be significant. The energy saving schemes saved up to 18.8 % of energy in macro and 26.9 % of energy in micro BS. So, it would be more efficient to implement a heterogeneous network with more micro cells with energy saving schemes than just macro base stations.

Keywords: Energy Efficiency; Energy Consumption, Base Stations, Measurement Energy Saving, Green Communication

1 Introduction

Several studies indicate that the wireless communication systems consume high power [1,2]. Information Communication Technology (ICT) industries are responsible for about 3 % of the world's total electrical energy [3]. It is expected that the amount of energy consumption will grow up to 1700 TWh by the end of 2030 [4]. Moreover, the global footprint of CO_2 emission will increase by a factor of three between 2007 to 2020 rising about 235 Mton of CO_2 [5]. Correspondingly, energy consumption in the ICT sector as well as CO_2 emission from the same is increasing alarmingly, which has drawn a greater attention. The carbon footprint from the wireless communication is also increasing exponentially, which indicates the important power issue. To avoid the enormous greenhouse gas emission from ICT industries, it is important to control the power consumption, and concurrently, to fulfill the users ever growing requirement and reduce the operation cost of the operators. It implies that the "Green cellular communication" deployment needs a primary focus on power energy consumption reduction in BSs [6].

The demand of wireless communication thorough out the world is increasing significantly from an increased volume of traffic. This trend in turn has triggered a wide deployment of wireless access networks. Therefore, cellular network operators are facing exponentially increasing data traffic demand. A forecast of the global mobile data traffic for the period 2015-2020 confirms that this trend will continue over the future [7,8]. The mobile data traffic grew by 74 % from 2014 to 2020, a 53 % compound annual growth rate. [9]. The tele-density in Nepal has surged to 130.52 % up to March 2018 [10]. The annual gross domestic product (GDP) per capita of Nepal was 830 $ in the year 2017, and every 10 % increase in broadband penetration yielded an additional 1.38 % in GDP growth [11]. The growing interest in new and reliable telecom services has resulted in increased number of installed base stations (BSs) in Nepal and worldwide.

Cellular operators provide service to the subscribers by dividing the area, namely cells which are served by the BSs. The network capacity is enhanced by increasing the number of BSs. A base station is defined as the equipment needed to communicate with mobile terminals and with the core network [12]. The area covered by a base station is called a cell which, is further divided into a number of sectors, macro BS, which is the basic layer of coverage of a cellular system. Its range is between 1 and 5 km and it is used usually for outdoor coverage. Micro BS, which has a range lower than 500 meters. Several micro cells can overlap to one macro cell in order to increase the capacity of a certain area, for example dense urban areas.

As the traffic increases, the investment to deploy the BSs also increases and finally the operating cost increases. BS consumes 60 % of the total network power as shown in Figure 1 [12,13]. When the number of BS increases, the energy consumption and the electricity cost also increase. The traffic load in the urban area is comparatively high in the commercial areas and low in residential areas [14]. The traffic depends on time and space. Since the network is planned for high traffic but in real scenario, the full load traffic is only for few hours a day [15].

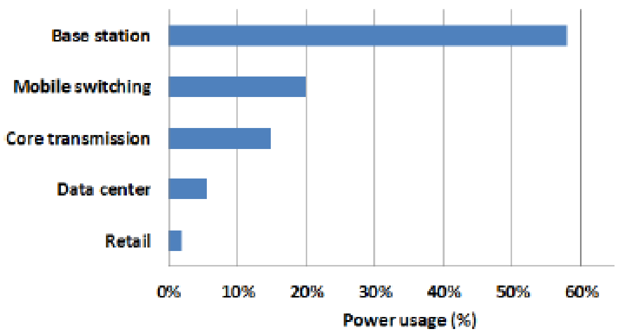

Figure 1: Power Consumption of a Typical Cellular Network

2 Related Work

When multiple types of BSs are compared, it is challenging to determine which one is the most energy efficient as one type of BS could consume higher power consumption but also higher coverage ranges; another one could have a smaller range but also a lower power consumption [16]. One of the most important parameters to investigate the BS is the energy efficiency.

Cellular operators are not paying due attention to energy efficiency but instead are focusing on variety, capacity and stability of communication services. One of the widely accepted parameters that determine the energy efficiency of a BS is area energy efficiency. In this research, heterogeneous BSs are compared in terms of energy efficiency. This parameter helps to compare the energy efficiency of different wireless technologies like 2G, 3G and 4G.

All the BSs at present are working on the ' always-active state', regardless of the traffic intensity. A BS consumes power as usual even when there is no traffic load in its coverage. Energy saving can be achieved by different ways as mentioned in various researches:

- Sleep Mode Techniques
- Cell zooming Techniques
- Dynamic Transmitter Shutdown Techniques
- Radio Resources Management

Many efforts on power saving have concentrated on switching off some underutilized transceivers. The feasibility of reducing the number of active transceivers can be done by considering the traffic intensity [17]. The dynamic power management for cellular networks developed and derived power saving ratio [18]. Recent advancement of BS sleep mode techniques in cellular network is surveyed [19]. The strategy for the reduction of unnecessary usage of energy consumption of base transceiver stations is analysed by using Monte Carlo simulation method for experimental data collected [20]. The two adaptive algorithms which are based on traffic forecast and real time measurements are compared with the goal optimal radio resource management [21]. An energy-efficient cell breathing and offloading mechanism in both macro cellular and heterogeneous networks has shown a combined approach in a single framework for macro/femto environment [22]. The use of relays and small cells are focused to improve the energy efficiency of the upcoming 5G networks [23].

3 Methodology

3.1 Energy Efficiency

An important parameter to determine the energy efficiency of a BS is the area energy efficiency. One of the widely accepted parameters that determine energy efficiency of a BS is area energy efficiency. In this research, heterogeneous BSs are compared so power consumption PC_{area} per covered area (W/m^2) is defined to measure the power consumption and efficiency for different technologies. The energy efficiency of BSs is commonly defined as the instantaneous BSs power consumption (P_{el}) needed to cover a certain area with radio signal (in W/m^2). The Power consumption PC_{area} per covered area is then defined as [12].

$$PC_{area} = \frac{P_{el}}{\pi r^2} \tag{1}$$

where, P_{el} is BS power consumption (Watt) and r is the range of BS coverage (meters). This parameter helps to compare the energy efficiency of different wireless technologies like 2G, 3G and 4G. For simplicity, it is assumed that each of the analysed BSs has circular coverage area. Lower the PC_{area}, more energy-efficient is the BS. The antenna gain of the analyzed BS is equal to 16 dBi. For the coverage computation, Okumura-Hate propagation model has been used for macro BSs and Walkfish-Ikagemi propagation model for micro BSs [24].

3.2 Energy Saving Techniques

The emergence of green cellular networks is not only due to the rising cost of energy, but also because of the reduction of their environmental impacts. The traffic pattern shows that most of the time the cellular network is underutilized in most of the BSs [25]. The different energy saving techniques in cellular networks are the efficient hardware design, hybrid energy sources, network planning & management and energy aware radio technology. Dynamic Transmitter Shutdown Technique (DTST) has been studied critically, which is a promising technique to save energy and is the main theme of this research. DTST is a noble method, which does not require the frequency management technique and can be implemented easily on the current network.

The traffic volume on weekends and holidays are higher than on weekdays. The behavior of traffic pattern is dependent on daily, weekly and accidental variations [26]. During day time, the traffic is high during busy hours and low during night time. The traffic is high in working days in commercial areas and high on weekends in residential areas and vice versa. Sometimes, abrupt traffic is generated due to some festivals, accidents. Since accidental variation of the traffic is random in nature, it cannot be forecasted by statistical tools due to lack of past data [27]. The Holt – Winter's method is a quantitative forecasting technique that performs prediction of future values of a time series based on properly weighted previous values including seasonal component (It), trend component (bt) and level component (St) [28].

$$S_t = \propto \left(\frac{Y_t}{I_t - L}\right) + (1-\propto)(S_{t-1} - b_{t-1}) \tag{2}$$

$$I_t = \beta\left(\frac{Y_t}{S_t}\right) \tag{3}$$

$$b_t = \gamma(S_t - S_{t-1}) + (1-\gamma)b_{t-1} \tag{4}$$

$$F_{t+m} = (S_t + mb_t)I_{t-L+m} \tag{5}$$

The initial conditions are:

$$S_t = \sum_{t=1}^{L} \frac{Y_t}{L} \tag{6}$$

$$b_t = 0 \tag{7}$$

$$I_t = \frac{Y_t}{S_t} \text{ for t } = 1 \ldots\ldots \text{ L} \tag{8}$$

L is the number of seasons in a year (L = 12 for monthly data & L =4 for quarterly data) and α, β, γ are respectively the overall smoothing parameter, seasonal smoothing parameter and the trend smoothing parameter. The parameter α, β, γ has a value between 0 to 1. The parameter values of α, β, γ are selected to minimize Root Mean Squared Error (RMSE). RMSE defines the error between forecast results and real historical data. An m step ahead prediction made at time t can be computed by equation 8. These parameters can be calculated starting from the measured values Yt and, as shown in equations (6-8), used to obtain the forecast F_{t+m}.

For DTST, the fraction of time that the TRX spends in shut down mode Tdtst over a period Ttotal which can be expressed as [18].

$$Saving\ from\ DTST\ \ (S_{DTST}) = \frac{T_{BS}}{T_{total}} \tag{9}$$

During DTST duration, certain TRX will shut down and the energy consumption for these TRX will be zero. In this study, the DTST duration is from 22:00 to 6:00 of the next day.

The available channels are assigned to all BSs. Since the traffic is high only for a certain time, the channels will not be used during low traffic. During this situation, all the TRXs will not be needed. The traffic was predicted hour by hour, by Holt – winter's method, which was used to calculate the required number of channels that finally helped to decide how many TRX can be switched to sleep mode. The required number of channels was obtained by Erlang B formula for a given block probability and a predicted value of traffic [29]:

$$P_B = \frac{A^n}{\sum_{k=0}^{n} \frac{A}{K!}} \tag{10}$$

Where PB is the blocking probability, A is the predicted traffic in Erlang, n is the number of channels. The Erlang B formula can be written in a recursive manner as follows

$$P_B(n, A) = \frac{AP_B(n-1, A)}{n + AP_B(n-1, A)} \tag{11}$$

and the number of channels can be found simply by means of recursion formula for given A until the right value of PB is reached. Energy efficiency is generally measured in area power consumption per unit area [12].

$$Area\ Power\ Consumption(E_E) = \frac{Power\ Consumption(P_C)}{Area(A_c)} \tag{12}$$

The idle TRXs will be shut down to reduce the power consumption when the estimated traffic load is light, and the disabled TRXs can be switched on so that they are available for use when the estimated traffic load is heavy by the above proposed algorithm.

4 Results and Discussions

4.1 Energy Efficiency

The antenna gains of analyzed GSM 900 BS is equal to 16 dBi, while for GSM 1800 BS and UMTS 2100 MHz, it is 18 dBi as shown in Table 1.

Table 1: Coverage range, transmit power and antenna parameters

BSs Type	Frequency (MHz)	Urban (km)	Antenna Height (m)	Transmit Power (dBm/W)
GSM micro	900	0.26	8	41.14/13
GSM macro	1800	0.19	20	47.8/60
UMTS macro	2100	0.38	20	47.8/60
GSM micro	1800	0.16	8	49/80

In Table 4, minimum and maximum estimated area power consumption per analysed BS and per single sector of analysed BSs are presented. It can be seen that macro BSs have higher total area power consumption as compared to micro BSs. This is primarily due to the lower transmit power footprint and consequently lower power consumption of micro BSs in comparison to macro BSs. This conforms that the concept of heterogeneous networks (HetNets) based on introducing micro BSs for boosting capacity in combination with already installed macro BSs, is acceptable from the energy-efficiency point of view.

Table 2: Power Consumption per covered area for analysed BSs

BS Type	Area	Coverage range(m)	P_{el} (W)	PC_{area} (mW/m^2)
GSM micro	Urban	160	795	9.890
	Suburban	390		1.665
	Rural	1560		0.104
GSM Macro	Urban	190	1530	13.498
	Suburban	490		2.029
	Rural	1660		0.177

The energy efficiency of macro BSs and micro BSs is analysed by the electrical power to the coverage area of particular BSs. Based on our calculations, Table 2 shows that the comparison of micro BS and macro BS in terms of power consumption per covered area. For this, the coverage range and power consumption of micro BS and macro BS is as shown in Table 3 which is calculated from the link budget [30, 31].

The power consumption per covered area of the micro BS is about 1.2 to 1.7 times higher than the macro BS. The coverage range of a macro BS is 1.25 times higher than for a micro BS due to its higher transmit power, antenna gain and antenna height (Table 1). As mentioned earlier, energy efficiency is inversely proportional to power consumption per covered area. So, a macro BS is more energy efficient than a micro BS in spite of its higher power consumption, which is similar to the result [12]. Therefore, it is concluded that macro BS is to ensure coverage only and is not suitable for quality service like high data rates and clear voice so they are appropriate for rural areas only. Micro BS is suitable for dense urban areas, where there is high concentration of users and high data rates are required.

4.2 Energy Saving

This study conducted the pilot test on energy saving techniques on both micro and macro BSs. The Holt-Winter's forecasting method (HWFM) was used for forecasting the traffic. The initial data required for the Holt-Winters's method has been taken from the real measurements of traffic. The real time traffic was taken from the Base Station controller (BSC). When the number of channels that the cell requires is smaller than that of the remaining channels after a transceiver is shut down then the TRX will shut down. The DTST algorithm predicts the number of channels that the cell requires. If the traffic channels carried by the TRX are occupied, then that channel should be handed over to the other TRX. This dynamic transmitter shut down mode can be implemented in certain time frame also. The TRX current is measured by the clamp meter and multi meter to measure TRX voltage [27].

Figure 2 and Figure 3 shows the number of active carriers for each hour during a day. The x-axis is the time on an hourly basis, whereas the y-axis is the TRX off duration in seconds. There are eight transceivers among which two use control channels, therefore, only 6 transceivers can be off/on for macro BSs.

On the other hand, the micro BS has only two transceivers as in Figure 3. The resources are off during low traffic only, in both micro and macro BSs. The number of resources shut down at different time depends on the traffic generation. When the traffic is low, the resources not carrying traffic will be off. In other words, the resources whose dynamic energy consumption is zero will be shutdown.

Figure 4 shows the cell availability during the resource's shutdown. The abscissa indicates the time; the ordinate represents cell availability in percentage. The cell availability is 100 % which clearly justifies the grade of service. Therefore, there is no impact on the network quality on using energy saving techniques for both micro and macro BSs.

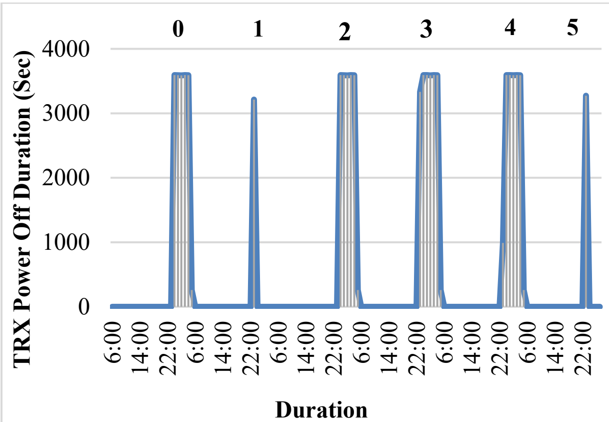

Figure 2: TRX Power off duration for macro BS

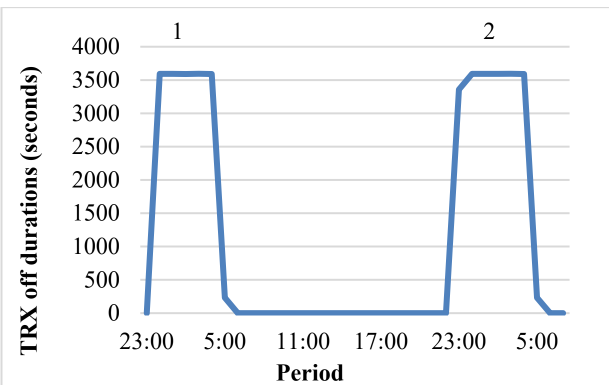

Figure 3: TRX Power off duration for micro BS

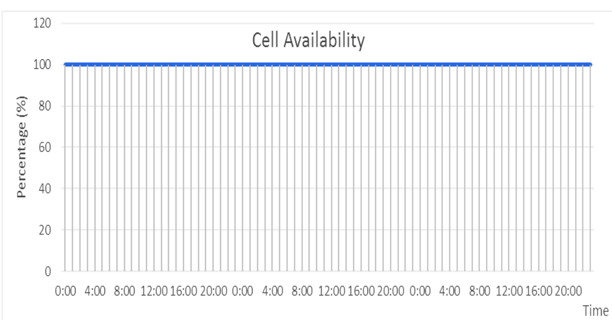

Figure 4: Cell Availability for both micro and macro BSs

Figure 5 shows the traffic channel availability and traffic volume on the BS. The traffic channel availability is 100 % during resource shutdown and during active period. Therefore, there is no adverse effect on the service quality.

Figure 6 and Figure 7 shows the analysis of energy consumption with traffic load before and after the application of energy saving techniques of macro and micro BSs respectively. As the traffic decreases, the resources used and the amount of energy consumption also decreases. The data analysis shows that the difference in energy consumption of minimum and maximum traffic is 1.092kWh and 1.635 kWh respectively for the macro BS whereas 0.65 kWh and 0.35 kWh for the micro BSs.

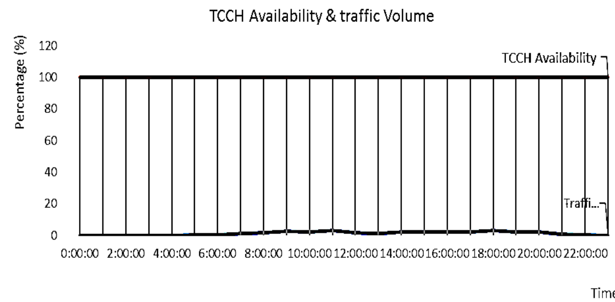

Figure 5: Traffic Channel Availability for macro & macro BS

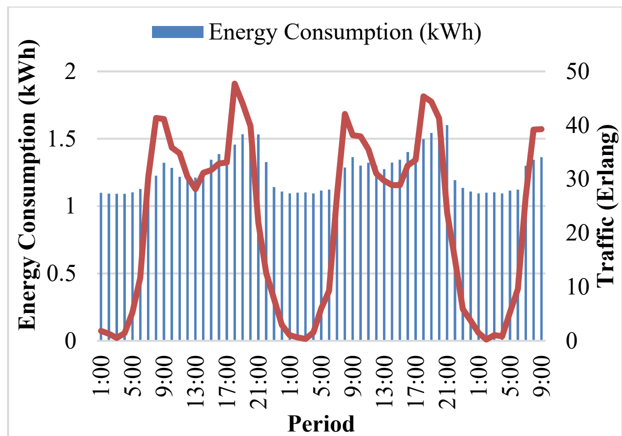

Figure 6: Comparison of energy consumption of macro BS before and after energy after energy saving techniques

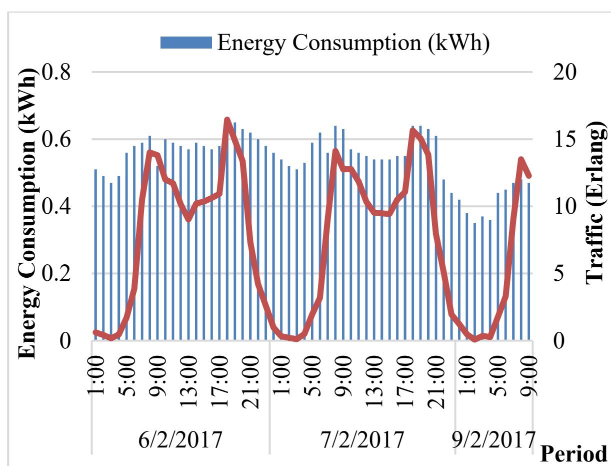

Figure 7: Comparison of energy consumption of micro BS before and after energy after energy saving techniques

The energy consumption is reduced after the energy saving techniques during low traffic.

Energy consumption observed

The BSs energy consumption has been compared before and after the dynamic transmitter shutdown mode is enabled.

Table 3: Energy consumption & Traffic of Macro BS

Date	Energy Consumption (kWh) (22:00 to 6:00)	Traffic (Erlang)	Throughput (Kilobytes)
Feb 5-6	10.724	104	911531
Feb 6-7	8.704	101	834090

Energy consumption saving = 10.724 - 8.704 = 2.02 kWh

% of energy consumption saving = 2.02/10.724 = 18.8 %

Table 4: Energy consumption & Traffic of Micro BS

Date	Energy Consumption (kWh) (22:00 to 6:00)	Traffic (Erlang)	Throughput (Kilobytes)
Feb 5-6	5.05	42	300643
Feb 6-7	3.69	39	299987

Energy Consumption saving = 5.05- 3.69 = 1.36 kWh

% of energy consumption saving = 1.36/5.05 = 26.9 %

The energy consumption saving for macro BS measured in real time environment was found to be 18.8% confirming the previous simulated result using Monte Carlo analysis, which shows 20 % energy saving can be obtained [20]. Similarly, the energy consumption saving for micro BS is found to be 26.9 %. Table 3 and 4 show the energy consumption and traffic measurements during 22:00 to 6:00. The voice and traffic are almost equal on both days. The energy consumption variation is 10.724 kWh for macro BS and 5.05 kWh for micro BS during normal scenario and 8.704 kWh in macro BS and 3.69 kWh for micro BS after the energy saving technique is used. The saved energy is 2.02 kWh for macro BS whereas 1.36 kWh for micro BS using energy saving techniques.

5 Conclusion

This study has developed energy saving techniques to reduce the energy consumption and compared the macro and macro BS in terms of energy efficiency, which was further validated by temporal measurements. The evolution of the energy consumption during the day is investigated by means of these measurements. The energy efficiency of the micro and macro BS is analyzed through energy consumption areas and energy saving techniques. The energy saving technique is compared with the absence of energy saving technique and found to be more energy efficient in energy saving without any coverage holes and continuous traffic operations. Using energy saving techniques, a micro BS is more energy efficient as the energy saving was found to be 26.9 % where as 18.8 % for macro BS. This suggests that micro BS is more energy efficient than macro BS. It is shown that presence of energy saving technique and absence of energy saving techniques, and the result shows that only energy saving technique contribute to energy consumption reduction and hence green communication cab be achieved. The main saving of energy consumption is from the underutilized resources. When the traffic is low, the needed resources will be minimum and the energy consumption will be higher on shutting down the resources. The energy consumption reduced is measured and compared with the normal condition. The potential of energy saving is higher where the traffic load is low. The cell availability and traffic channel availability show that there is no adverse effect on the network.

On the other hand, a macro BS is more energy efficient than micro a BS as the macro BSs consume about two times more power than the micro BSs. Therefore, macro BSs are suitable for the purpose of coverage whereas micro BSs are useful for a wide range of users, where there is high data demand.

Owing to the significant amount of energy saving achieve through the studied technique, it can be suggested that there is an imperative necessity to develop cell zooming techniques in the cellular network. It will perhaps be a popular research area in the future.

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