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ACHIEVING ENERGY EFFICIENCY FOR 5G AT BASE STATIONS LEVEL

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ABSTRACT

As the era of 5th Generation (5G) networks is dawning, several pertinent issues associated with the improvements that have to be achieved in future communications are attracting increasing research attention. This work, considered achieving energy efficiency for 5G at base stations level. Energy efficiency simply means using less energy to perform the same task thereby, eliminating energy waste. The objective of this paper is to examine the ways of deploying energy efficient hardware at the base stations in order to make the base stations more green energy based. Considering the current energy concerns, base stations in emerging wireless networks range from low-energy BSS to high-energy BSS with entirely different constraints in either case. In view of these extremes, this paper examines the major components behind energy-efficient wireless communication network design during the peak and off-peak traffic periods. It was discovered that the Power amplifier consumes up to 59% of the energy at the base stations. Improving a Power amplifier by bringing linearity could improve the efficiency of the BS and hence reduce the energy crunch at the BS level from 59% to 51%.

Keywords: Base station, Energy efficiency, Technologies, communication, traffic

INTRODUCTION

Energy efficiency is defined as the power consumption needed to cover a certain area (in W/m^2).Owing to the rapid development of new mobile Internet services and the popularity of IoT (Internet of Things) technologies, it has been found that existing wireless mobile communication technologies like 3G and 4G have become increasingly difficult to meet the growing demands in the rate of power efficiency. Sequel to the effects of low energy efficiency on the present mobile networks(2G.3G & 4G), the new generation of mobile communication system of 5G has become the hub of worldwide attention. In ITU's (International Telecommunication Union) requirement of 5G to achieve a leap forward increase in transmission speed in the 2020s, each 5G base station should provide at least 20 Gb/s downlink and 10 Gb/s uplink bandwidth transmission performance to certify the efficiency of next generation network.

5G Energy Efficiency

Energy consumption has become a primary concern in the design and operation of wireless communication systems. Indeed, while for more than a century communication networks have been mainly designed with the aim of optimizing performance metrics such as the data rate, throughput, latency, quality of service (QoS) etc., in the last decade energy efficiency has emerged as a very prominent figure of merit, due to economic, operational, and environmental concerns.

Energy efficiency simply means using less energy to perform the same task thereby, eliminating energy waste. Energy efficiency brings a variety of benefits: reducing greenhouse gas emissions, reducing demand for energy imports, and lowering our costs on a household and economy-wide level. The design of the next generation (5G) of wireless networks will thus necessarily have to consider energy efficiency as one of its key pillars. (Ericsson white paper 2011).

In order to avert the energy crunch, new approaches to wireless network design and operation are needed. The key point on which there is general consensus in the wireless academic and industry communities is that the 1000× capacity increase must be achieved at similar or lower power consumption as today's networks (NGMN alliance, 2015). This means that the efficiency with which each Joule of energy is used to transmit information must increase by a factor 1000 or more. Increasing the network energy efficiency has been the goal of the GreenTouch consortium. The increasing energy consumption is one of the important issues related to the problem of global warming, and reducing the energy consumption of mobile communication networks has gained significant attention since it takes a major part of the total energy consumption of information and communication technology (ICT). The base station (BS) is the major source of energy consumption of mobile communication networks, and the energy consumption of the BSS depends on the traffic load which varies depending on the geographical location. To reduce the energy consumption of mobile communication networks, significant work has been carried out regarding the energy saving of a BSS.

5G Energy Efficiency Schemes

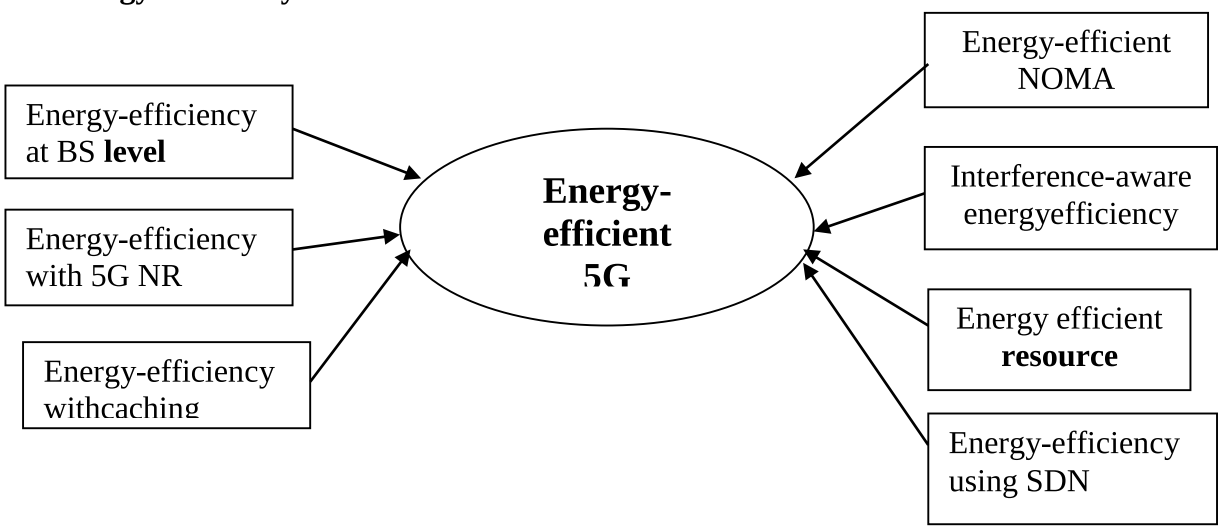

Figure 1: Outline of the energy-efficiency schemes (Ali et al., 2017).

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Base Station Power Consumption Breakdown

A base station (BS) site consists of multiple transceivers (TRXs). A TRX comprises an Antenna Interface (AI), a Power Amplifier (PA), a Radio Frequency (RF) small-signal transceiver section, a baseband (BB) interface including a receiver (uplink) and transmitter (downlink) section, a DC-DC power supply, an active cooling system, and an AC-DC unit (mains supply) for connection to the electrical power grid. In the following the various TRX parts are analyzed.

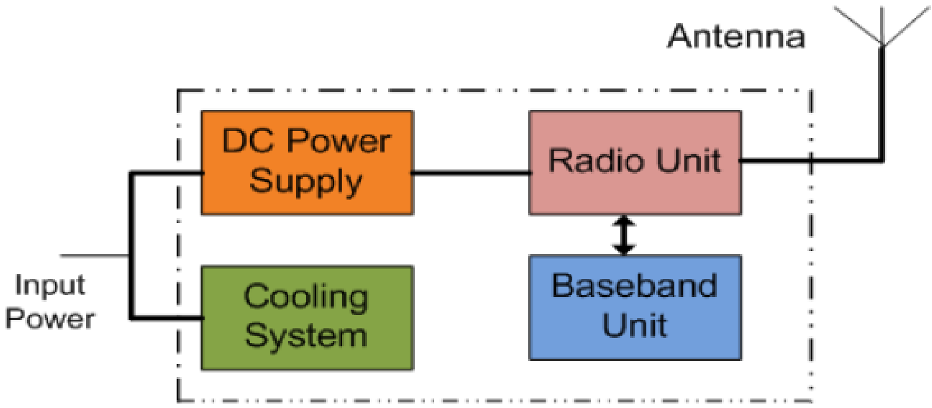

Figure 2: Base Station Block diagram (Akihiro et al., 2016)

(a) **Antenna Interface(AI):**

The influence of the antenna type on power efficiency is modeled by a certain amount of losses, including the feeder (where relevant), antenna bandpass filters, duplexers, and matching components. *Power Amplifier (PA):* Typically, the most efficient PA operating point is close to the maximum output power (near saturation). Unfortunately, non-linear effects and OFDM modulation with non-constant envelope signals force the power amplifier to operate in a more linear region, i.e., 6 to 12 dB below saturation (Cripps, 2006). This prevents Adjacent Channel Interference (ACI) due to non-linear distortions, and therefore avoids performance degradation at the receiver. However, this high operating backoff gives rise to poor power efficiency, which translates to a high-power consumption (Cripps, 2006).

(b) **Baseband (BB) Interface***:*

The baseband engine (performing digital signal processing) carries out digital up/down conversion, including filtering, FFT/IFFT for OFDM, modulation/ demodulation, digital-pre-distortion (only in DL and for large BSs), signal detection (synchronization, channel estimation, equalization, compensation of RF non-idealities), and channel coding/decoding. For large BSs the digital baseband also includes the power consumed by the serial link to the backbone network.

Improving the efficiency and linearity of RF power amplifier:

Presently, Wireless Communication Operators/ Service Providers are interested in high efficient linear power amplifier to adjust the current wireless technology. 4G LTE, UMTS network and past communication network propose high data rate transmission and transmitting the power, which bears high peak to average ratio signal. The BTS power amplifier drives at low power level than the maximum and result in degrading the efficiency. The total energy consumption of fourth generation BTS is more than the third generation BTS whereas current BTS use higher frequency carriers and have more signals processing units. As a result, the RF power amplifier consumes a large portion of the power. So it has become more important to reduce the power consumption of the RF power amplifier for achieving the high capacity base station. In order to obtain best achievement in reduction of power consumption of amplifier, the energy efficiency and linearity of the power amplifier must be increased.

Various types of power amplifier for wireless communication system

An amplifier is the most important device to study for frequency data transmission networks, since it takes the responsibility for the largest power consumption at base station. RF power amplifier approximately consumes 57% power in typical UMTS and 4G base stations while the DC rectifier, cooling system and base band signal processing system of BTS, consumes rest of the power. More efficient and linearity Power amplifier can reduce more energy consumption and heat dissipation. The classifications of the power amplifier are as follows.

(a) Class A AMPLIFIER

Class A amplifier has a high linearity when compared with other classes. It has some drawbacks with low efficiency due to high-energy consumption because of operating point of PA in the middle of saturation region, which provides dc current during the whole operation (Brubaker, 2009).

(b) Class B AMPLIFIER

Class B operates at the cut off voltage of the transistor, which only provides half-sinusoidal waveform when a full sinusoidal waveform is applied to the input. It has maximum efficiency around 79% and lower bandwidth as compared with class A. (Brubaker, 2009)

(c) Class AB AMPLIFIER

The operating point of this amplifier is cooperating in between Class A and Class B operating point. Class AB amplifier has maximum efficiency of 50% and 79% in the lowest and highest linear operation. It has higher bandwidth as compared with class B and lower bandwidth as compare with class A.

(d) Class C AMPLIFIER

This power amplifier has relatively high efficiency and low power radiated. The bandwidth of class C is smaller than class B but it is the highly nonlinearity.

(e) Class E AMPLIFIER

This amplifier has higher efficiency; it is close to 100%.that means it has no power losses theoretically. Linearization techniques can be applied for eliminating the nonlinearity behavior. This amplifier has better performance if it can be used in base station because of high efficiency .It has lower bandwidth as compare with Class A,B,AB. (Brubaker, 2009)

(f) Class F AMPLIFIER

This class of amplifier is a high efficiency amplifier. It is similar to Class E amplifier. But the major difference is that it could be used in millimeter wave range frequencies.

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Class F amplifier is also suitable for base stations that operate within such range because of higher efficiency. (Oishi et al., 2002) (Brubaker, 2009).

MATERIALS AND METHODS

To understand the power consumption problems in cellular BSs, one must explore the architecture of base station systems and the power consumption of their parts.

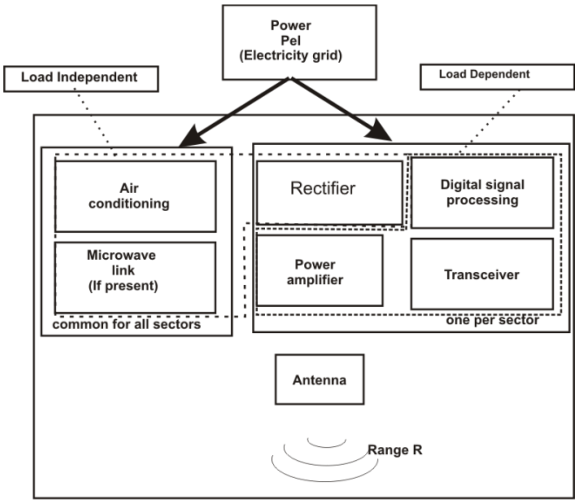

Figure 4: Block diagram of a macro cell Base station

An important parameter to investigate is the energy efficiency of a base station. The power consumption PCarea per covered area is then defined as:

1

With P_{el} as the power consumption of the base station and R the range of the base station. The lower the PCarea, the more energy-efficient the base station is. Here, it is assumed that the users are uniformly distributed and all requiring the same bit rate. In this case, the metric is equivalent to PCarea according to GeX et al., (2017). These assumptions are proposed to make a fair comparison between the energy efficiency of the individual macrocell and microcell base stations.

Considering the power consumption of each component, the components can also be divided in the following categories. First category consists of the components whose power consumption is not load dependent. The second category is the equipment that has load-dependent power consumption. The power consumption Pel/amp of the power amplifier also depends on the input power P_{Tx} of the antenna and is calculated as follows (in Watt):

2

With η the efficiency of the power amplifier, which is the ratio of the RF output power to the electrical input power.

According to Gex et al., (2017), once the power consumption of each component is known, the power consumption Pel/macro of the macrocell base station can be determined as follows (in Watt): Equations 3.3a, 3.3b and 3.3c show Gex model for macrocell base stations.

3a

With

3b

3c

These stations cover a cell that is divided into several sectors, with each sector being covered by sector antennas as shown in Figure 4. Cellular BSs are classified into macro-, micro-, pico-BSs and femto-, according to their area of coverage, and each cell has a unique size, output power, and data rate. Smaller BSs generally consume lesser power because of their small coverage range and low radiation power demand.

According to Auer et al., (2011) and Ismail et al., (2015), the macro-BS operating power can be mathematically expressed as follows: Equation 4 shows Ismail's model for macrocell base station.

4

Where: $\mathbf{P_{PA}}$: Power consumed by power amplifier (PA)

$\mathbf{P_{BB}}$: Power consumed by digital signal processing or baseband unit (BB)
$\mathbf{P_{RF}}$: Transceiver (RF) power.
$\mathbf{P_{mw}}$: Microwave backhaul link
$\mathbf{P_{au}}$: Auxiliary equipment
$\boldsymbol{\sigma_{MS}}$: Losses incurred by the rectifier
$\boldsymbol{\sigma_{DC}}$: Losses incurred by the regulator,
$\boldsymbol{\sigma_{cool}}$: Losses incurred by the active cooling
$\mathbf{N_{Sect}}$: Number of sectors
$\mathbf{N_{TX}}$: Number of transmitting antennas

The output of PA is a linear function of BS transmission power (P_{tx}) and is expressed as P_{tx}/η_{PA}, where η_{PA} denotes PA efficiency. These losses **($\boldsymbol{\sigma_{MS}}$, $\boldsymbol{\sigma_{DC}}$, $\boldsymbol{\sigma_{cool}}$:)** are scaled linearly with the power consumption of the other components. Given the multiple sectors and antennas in a BS, the power consumption of these components must be multiplied by the number of sectors (N_{Sect}), and the power consumption of the BS must be multiplied by the number of transmitting antennas (N_{TX}) for one sector. Air conditioning (σ_{cool}) is usually omitted in small BSs (micro- and pico-BSs, fiber links are used instead of microwave links (P_{mw}) to communicate with the backhaul network as shown in equation 2, and all sectors are equipped with a rectifier (σ_{MS}) and regulator (σ_{DC}). Table 2 shows the power consumption of the components of BSs per antenna and sector. According to Ismail et al., (2015) and Auer et al., (2015), the micro-BS operating power can be mathematically expressed as shown in fig 3.5a.

\+ 5a

P_{RRU} =

5b

5c

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RESULTS

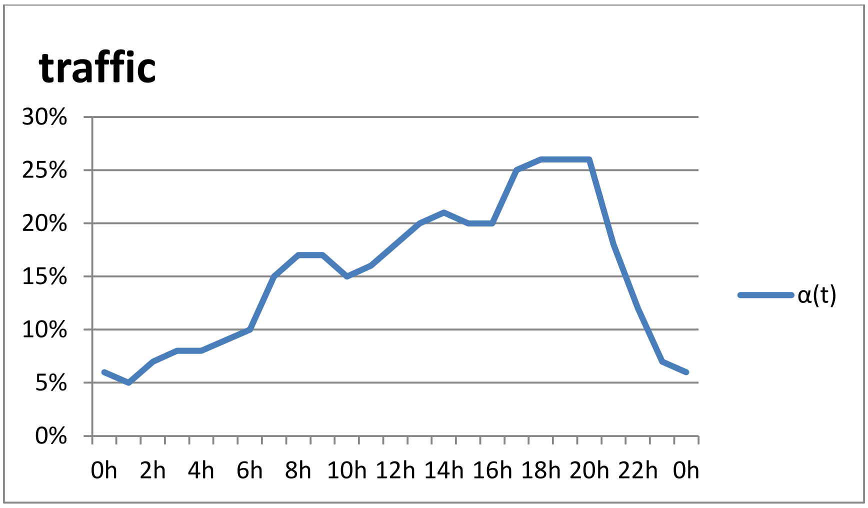

Figure 5: Data traffic profile in Nigeria.

Table 1. Average power consumption per hour during weekdays and weekends for a macrocell and a microcell base station (using load dependent equipment).

	Macro cell Base Station			Micro cell Station		
Hour	Weekday (Watts)	Weekend (Watts)	Factor (Fi)	Weekday (Watts)	Weekend (Watts)	Factor (Fi)
0am -1am	10905.40	11217.65	$F_0 = 0.94$	578.40	578.40	F_0=0.96
1am – 2am	10993.36	11004.89	$F_1 = 0.94$	558.48	559.41	F_1=0.93
2am – 3am	11019.74	11133.54	$F_2 = 0.94$	584.80	584.80	F_2=0.97
3am – 4am	11072.27	11073.27	$F_3 = 0.93$	574.56	575.52	F_3=0.96
4am – 5am	11116.91	11113.12	$F_4 = 0.93$	592.56	592.56	F_4=0.97
5am – 6am	11849.18	11811.52	$F_5 = 0.94$	610.10	610.10	F_5=0.95
6am – 7am	11954.34	11961.34	$F_6 = 0.94$	643.14	643.14	F_6=0.98
7am – 8am	12101.80	12101.80	$F_7 = 0.94$	622.63	624.57	F_7=0.97
8am – 9am	12451.76	12451.76	$F_8 = 0.96$	646.08	646.08	F_8=0.98
9am – 10am	12693.38	12693.38	$F_9 = 0.97$	629.32	635.08	F_9=0.96
10am – 11am	12786.59	12786.59	$F_{10} = 0.97$	664.66	665.64	F_{10}=0.98
11am – 12pm	12954.34	12830.68	$F_{11} = 0.99$	647.82	647.82	F_{11}=0.97
12pm – 1pm	12837.15	12837.15	$F_{12} = 0.97$	650.44	650.44	F_{12}=0.96
1pm – 2pm	12949.28	12951.28	$F_{13} = 0.98$	664.89	664.89	F_{13}=0.99
2pm – 3pm	12931.64	12933.64	$F_{14} = 0.98$	634.16	662.96	F_{14}=0.96
3pm – 4pm	13054.24	13090.05	$F_{15} = 0.98$	653.73	653.73	F_{15}=0.97
4pm – 5pm	13086.05	13079.17	$F_{16} = 0.99$	655.64	655.64	F_{16}=0.97
5pm – 6pm	13200.00	12928.70	$F_{17} = 1.00$	647.60	647.60	F_{17}=0.96
6pm – 7pm	12924.70	12418.40	$F_{18} = 0.99$	637.96	639.88	F_{18}=0.96
7pm – 8pm	12414.40	12380.50	$F_{19} = 0.95$	653.00	655.00	F_{19}=1.00
8pm – 9pm	12372.50	12429.84	$F_{20} = 0.95$	633.16	633.16	F_{20}=0.96
9pm-10pm	12184.76	11362.96	$F_{21} = 0.94$	622.64	622.64	F_{21}=0.96
10pm-11pm	11362.96	11226.42	$F_{22} = 0.94$	660.85	660.85	F_{22}=0.93
11pm-0am	11112.62	11217.65	$F_{23} = 0.94$	578.40	577.44	F_{23}=0.96

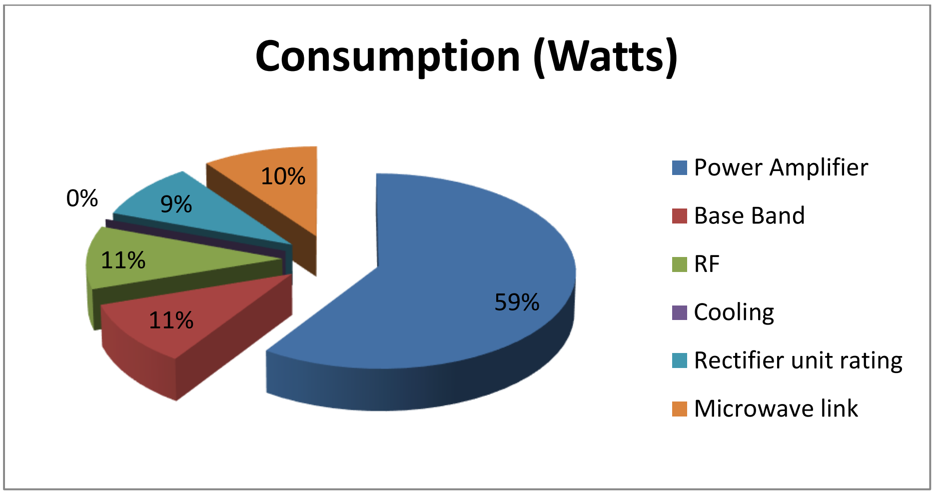

Figure 6: MBS Power component consumption using conventional hardwares during peak period

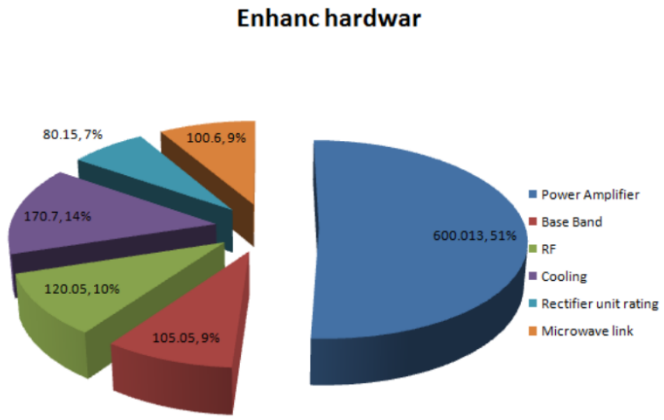

Figure 7: MBS Power component consumption using energy enhanced hardwares during peak period

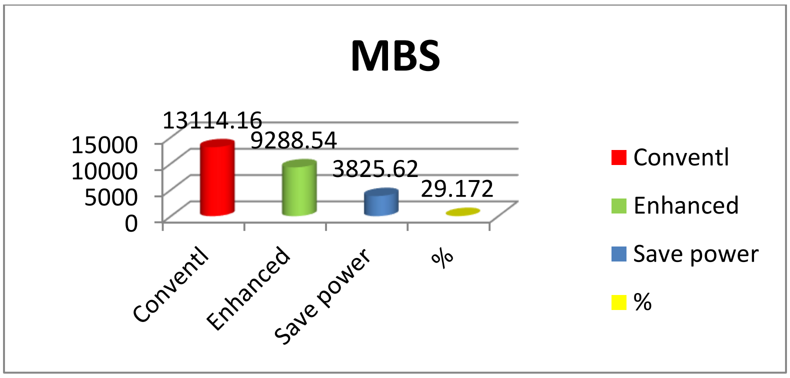

Figure 8: MBS power consumption during peak period

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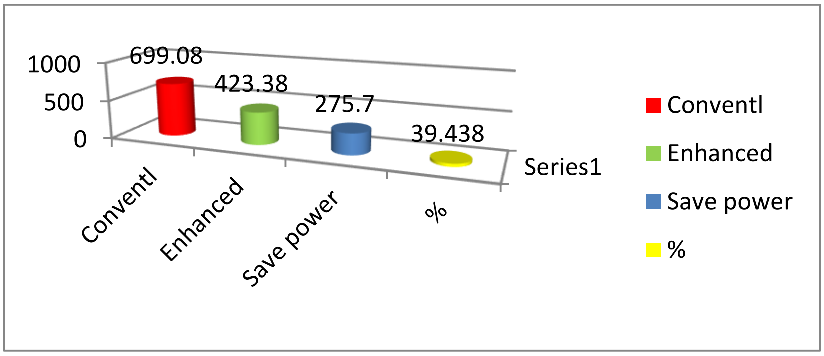

Figure 9: SBS SAVED POWER DURING THE PEAK PERIOD

Power amplifier consumes the bulk of the power in the base station. The conventional amplifier deployed for the 4g Base station was the Class D amplifier, which has a maximum of 35% efficiency. Bulk of the energy consumed by the class D power amplifier is wasted as heat.

The 5g network tends to deploy Class F amplifiers which has an efficiency of up to 75% and supports higher (micro wave) frequencies as required by 5g. The reason for adopting class F, 2018 model is to improve the energy efficiency of the base station. This model has an efficiency of up to 75%. It is also adaptive in its energy utilization according to Brubaker, (2009). It was observed from fig 4 that the traffic is lowest between 23hr and 2hrs (11pm to 2am), the traffic is at its peak between 17hr and 20hr (i.e 5pm to 8pm). Comparing it with table 1, the operator traffic does not reflect on the energy consumption at the base stations because the major energy consuming equipment is not proportional to the load (traffic).

5G radio access network (RAN) technology is far more energy efficient than earlier technologies because the hardware and software are designed specifically to be more energy efficient. There are several energy saving features at the radio base station and network levels, such as 5G power saving features, small cell deployments and new 5G architecture and protocols, which can be combined to significantly improve the energy efficiency of wireless networks. The tests used on-site base station energy consumption readings based on traffic load scenarios from 0 to 100%. The tests also monitored actual power consumption through the network management systems. 5G is a natively greener technology with more data bits per kilowatt of energy than any previous wireless technology generation. However, 5G networks require further action to further enhance energy efficiency and minimize CO2 emissions that will come with exponentially increased data traffic. The cells within 5g sectors should be redesigned to be smaller so that smaller base stations can cover it efficiently with lesser power. Each cell site should be connected to a network backbone, through a wired fiber connection. Within the sectors, packets of data are sent between sites using either low-, mid-, or high-band frequencies. Low-band frequencies typically operate below 2 GHz, mid-band sits between 2-10 GHz, and high-band enters the 20-100 GHz channels. Known as the “millimeter-wave” band, these previously unused frequencies are like data superhighways for latencysensitive and bandwidth-intensive innovations. 5G will require smaller cell sites in form of antennas to be installed to ensure connectivity.

CONCLUSION

Wireless communications are undergoing a rapid evolution, wherein the quest for new services and applications pushes for the fast introduction of new technologies into the market place. Operators are now realizing that to make better profits from their deployed networks; efficiency must be a key factor. Moreover, the wireless communications industry has begun to design for energy efficiency. As shown in this work, energy efficiency has gained much interest in the recent past. Energy efficiency serves as a performance measure in design. The constraint has to do with the communication networks environment, other challenges such as technical, regulatory, policy, and business challenges still remain to be addressed before the ambitious 1000-times energy efficiency improvement goal can be reached.

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