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Energy Efficiency of 5G Cellullar Network Using Co-Operative Techniques

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Research Article

Abstract

With the fast increase in global human population as well as rapid development in mobile and internet technology, there is projected increase in wireless communication traffic. These have led to the development of energy efficient techniques in wireless communication systems. This paper adopts two methods that will reduce the energy consumption of 5G network using the switch mode and energy-efficient hardware approach. The base station consumed energy that ranges from low-rated energy to high-rated energy transceivers with entirely varying constraints and limitations. The results obtained showed that the average daily input power in watt (W), output power in decibels and output power in watt (W) at the macro cell base stations were 297495.45, 1641.945 and 166618.40. Again, the results of the average daily input power in watt (W), output power in decibel and output power in watts (W) at the microcell base stations were 16648.68, 1372.637 and 12576.98. However, the average power consumption during peak traffic period with conventional hardware and enhanced hardware at the macro base station were 12675.37, 7742.553 and 700.375. Again, the average power consumption during high traffic period with conventional hardware and enhanced hardware at the micro base station were 550.506, 4932.819 and 149.869. In conclusion, the researchers recommend that the energy efficient hardware technique should be adopted to improve energy efficiency in wireless communication networks.

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Keywords

Internet technology, 5G Network, Switch mode, Hardware Approach, Wireless Communication

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1. Introduction

With the negative impact of climate change, energy sources and consumption has become a key issue in the process of cellular wireless communication networks (Gabry*et al.,* 2015). In the past years, communication set ups and systems have been primarily planned to optimize the performance metrics such as throughput, latency, and information rate (Marson *et al.,* 2015).

Within the last ten years, energy efficiency has become an important distinction owing to operational, economic and environmental concerns (Ge *et al.,*2017). The benefits of energy efficiency are to minimize greenhouse gas emissions, energy imports and decrease on economic expenditures. The 5th generation (5G) systems will serve an extraordinary number of devices which provides connectivity as well as state-of-the-art services (Louhi *et al.,* 2016). It has been forecasted that there will be an increase of about fifty billion connected devices by the year 2030, ranging from human type communication to device type communications, as noted in Ali *et al.,*(2017).

The consumption of energy for any given area in fourth generation (4G) system normally consume more power per cluster and smaller cells are necessary in their placements because of their advantages of improved connectivity. The developing superiority in both user equipment and network has enhanced the energy efficiency and their functions have improved the energy transmission (Lorincz and Matijevic 2014).

The existing energy improvement methods comprise the use of green energy sources to power base stations which reduces the area of coverage with connectivity over the user equipment to the macro base stationZhang *et al.,*(2018).

Advances in wireless communication in the present technology has provided wireless network to be more robust and accessible. There will be an improvement of data rates within the millimeter range with the initiation of 5G network Wang *et al.,*(2014).

The power consumption at the base station will rise due to the availability of heterogeneous devices such as sensors, routers and tablets. A projected increase of about 50% in the power of various baseband systems has been forecasted to handle this traffic surge (Guo *et al.,* 2016).

1.1 Mathematical models for three-stage switching mode

The total energy consumed by base stations per day in a cluster can be obtained and energy efficiency for the system can be computed considering the peak and the off peak period as shown in equation 1.

$$E_{cons}^{day} = \sum\left(K_{BS}^{active} * U_{op}^{BS}\right) * hour \qquad (1)$$

Where E= energy consumed per day, K= number of active base stations, U= Power consumed by the base station when it is on and hour = number of hours in the day

$$P_{total} = P_{si} + P_{sleep} + P_{on} + P_{sw} \quad (2)$$

Where P_{total} is the total power consumed in the network per cluster. P_{si} is the power consumed by the macro cell base station, P_{sleep} is the total power consumed by the small cell base station when it is on sleep mode. P_{on} is the total power consumed by the base station when it is on mode and P_{sw} is the total power consumed by the base station when transiting from one state to another.

The power consumed between S_i and Mj is denoted as P_{con}, where S_i corresponds to an MBS and Mj corresponds to an SBS.

$$P_{con}(s_i, m_j) = \begin{cases} 0, & if\ d \leq 0.4 \\ 0.5 & if\ d(< 0.75) \\ 1, & otherwise \end{cases} \quad (3)$$

Z_i is related with whether the Mj is in ON state or not while Ej is related with whether the Mj is in Safe-mode state or not. F_i is related with whether the Mj is in SLEEP state or not is given in equation 4.

$$Zj = \begin{cases} 1 & \text{if Mj is in on state} \\ 0 & otherwise \end{cases}, (0 \leq j < g + 1) \quad (4)$$

$$Ej = \begin{cases} 1 & \text{if Mj is in sfmd state} \\ 0 & otherwise \end{cases}, (0 \leq j < g + 0.5) \quad (5)$$

$$Fj = \begin{cases} 1 & \text{if Mj is in sleep state} \\ 0 & otherwise \end{cases}, (0 \leq j < g) \quad (6)$$

The state transitions of an SBS are Z_j, E_j and F_i and their values are defined as in equations 7, 8 and 9.

$$Zj = \begin{cases} 1, & \text{if Mi switches between on state and off state} \\ 0, & otherwise \end{cases}, (0 \leq j < g + 1) \quad (7)$$

$$Ej = \begin{cases} 1, & \text{if Mi switches between Sfmd to on state or off state} \\ 0, & otherwise \end{cases} (0 \leq j < g + 0.5) \quad (8)$$

$$Fj = \begin{cases} 1, & \text{if Bi switches between on state and sleep state} \\ 0, & otherwise \end{cases}, (0 \leq j < g) \quad (9)$$

The power consumption of an Mj, P(m) small is obtained as shown in equation 10. $P_{(m)small} = Zj * (1 - F_j) * (P_S^r + p_s * P_S^{tx}(j)) + E_j x(1 - w_j) x P_S^e$ (10)

When a small cell base station is in ON state, the power consumption is calculated as fixed sum of the consumed power and load dependent power consumption. Regarding load dependent power consumption, Pm (j) is given in equation 11.

$$P_{m(j)} = P_S^{tx,max} x \begin{cases} 0, \\ 0.5 \\ 1, \end{cases} \left(d_i x a_{j,i} x \frac{(r_i x C_h + (1 - r_i) x C_j)}{C_S^{max}}\right) \quad (11)$$

At small cell station (Mj) is in either ON, SAFE or SLEEP modes, the sum of L_j for ON mode and V_j for SLEEP state is smaller than or equal to 1.

The total power (P_{total}) used at the macro cell base station and the efficiency of the transmitted power can also be calculated as shown in equations 12 and 13.

$$P_{total} = \frac{P_t}{p} + P_c \quad (12)$$

$$\eta_E = \frac{P_t}{\frac{P_t}{P} + P_c} \quad (13)$$

Where P_t is the transmit power, P_c, P_r is the received power, η_E is the energy efficiency and P is the input power.

2. Materials and Methods

Data used in this paper was collected from the operators' stored data at IHS towers, Nigeria for a one-year period. Data analysis and simulations were carried out using MATLAB/Simulink.

Two approaches were adopted to enhance the energy efficiency of 5G network, namely the energy efficient enhanced hardware approach and the switching mode approach. The enhanced energy efficient hardware approach utilizes efficient hardware such as Power amplifiers, Base band units, transceivers, microwave links and digital signal processing units to enhance the energy efficiency in the network. In this approach, the architecture of heterogeneous network with overlapped macro and micro cell base stations remained in sleep mode with the presence of both stations but when micro cell base station was absent it turn to sleep mode operation to save energy. Again, the power consumed at the macro cell base station was calculated and the introduction of the load factor was a significance effect on the output. Again, the power consumed at the microcell base station was calculated with the load factor. The second approach is the switching mode approach which use separated control and data planes to enhance energy efficiency. In this approach distinct cell zooming structure permits the transmitted power of only discrete values and the transmitted power was increased with a small quantity from each discrete level to another. Switching modes from micro cell base station were controlled by macro cell base station using high traffic load network. The total power consumed at the macro cell base and the micro base stations were calculated to receive control signals to switch from the ON through SAFE to SLEEP MODE and vice versa when there are changes in traffic.

These approaches were combined to observe the impact of reducing the energy consumption of base stations for the 5G network. Figure 1 shows the flowchart of the two approaches used for the enhanced hardware technique.

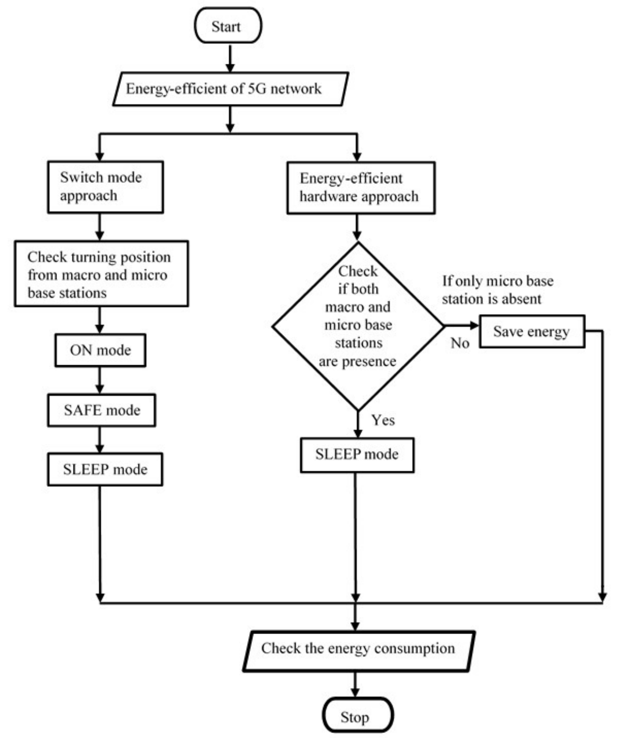

Figure 1: Flowchart that reflects the adoption of the two approaches used for the energy-enhanced hardware technique

2.1 Modified mathematical models for energy-enhanced hardware approach

The power consumed at the macro cell base station is given in Equation 14.

$$P_{macro} = P_{el/const} + P_{el/load}.F_i \tag{14}$$

The power consumed at the macro cell base station with the load factor is given in Equation 15.

$$P_{macro} = \Big((n_{sect}P_{rec} + P_{link} + P_{airco}) + \big(n_{sect}\big(n_{tx}(P_{amp} + P_{trans}) + P_{pro}\big)F_i\big)\Big) \tag{15}$$

The power consumed at the micro cell base station is given in equation 16.

$$P_{micro} = P_{el/const} + P_{el/load}.F_i \tag{16}$$

The power consumed at the micro cell base station with the load factor is given in equation 17.

$$P_{micro} = \Big((P_{rec} + P_{airco}) + \big((P_{amp} + P_{trans} + P_{proc})F_i\big)\Big) \tag{17}$$

With Fi (i=0-23, 0 ≤ Fi ≤ 1) the load factor Fi is determined based on machine indications.

The power consumed by a cluster is given in equation 18.

$$P_{cluster} = P_{macro} + 8P_{micro} \tag{18}$$

Again, the power consumed by the eight cluster is given in equation 19.

$$P_{cluster} = \Big((n_{sect}P_{rec} + P_{link} + P_{airco}) + \big(n_{sect}\big(n_{tx}(P_{amp} + P_{trans}) + P_{pro}\big)F_i\big)\Big) + 8\Big((P_{rec} + P_{airco}) + \big((P_{amp} + P_{trans} + P_{proc})F_i\big)\Big) \tag{19}$$

Where Prec is the power consumption of the rectifier unit, Pamp is the power consumption of the power amplifier, Plink is the power consumption of the microwave link, Ptrans is the power consumption of the transceiver, Proc is the power consumption of the digital signal processing, Fi is the load factor, Pairco is the power consumption of the air conditioning system. Ntrans is the number transmitting antenna and nsect is the number of sector.

3.0 Results And Dıscussıon

The results of the average input power which was obtained daily from the macro cell and micro cell base stations were computed. The results of the output power obtained from the measurement in decibel and wattage for both macro cell and micro cell base stations were also analysed. Table 1 shows the average power consumption per hour during weekdays and weekends at the macro cell and micro cell base stations. Table 2 indicates the power consumption during the peak traffic period with energy efficient enhanced hardware at the macro cell and micro cell base stations.

Table 1: The average power consumption per hour during weekdays and weekends for a macro cell and microcell base stations

Hour	Macro cell base station			Micro cell base station		
	Average daily input power (Watts)	Output power (dBm)	Output power (Watts)	Average daily input power (Watts)	Output power (dBm)	Output power (Watts)
0am -1am	11223.08	68.303	6765.34	718.53	57.276	534.03
1am – 2am	11195.79	68.295	6752.32	617.56	57.011	502.41
2am – 3am	11214.65	68.303	6766.12	637.06	57.070	509.33
3am – 4am	11224.59	68.302	6764.34	627.43	57.060	508.12
4am – 5am	11303.24	68.308	6773.23	640.8	57.086	511.16
5am – 6am	12121.62	68.345	6831.15	675.83	57.169	521.13
6am – 7am	12229.36	68.363	6859.07	707.23	57.218	527.04
7am – 8am	12428.30	68.416	6943.05	688.83	57.177	522.03
8am – 9am	12649.22	68.437	6978.09	707.35	57.219	527.08

9am – 10am	12865.67	68.443	6987.08	693.79	57.184	522.91
10am – 11am	13001.44	68.462	7018.56	727.21	57.294	536.33
11am – 12pm	13123.70	68.463	7019.78	709.81	57.227	528.11
12pm – 1pm	13019.47	68.499	7078.59	719.8	57.235	529.01
1pm – 2pm	13148.25	68.510	7096.03	720	57.244	530.11
2pm – 3pm	13129.31	68.512	7099.17	723.65	57.251	531.04
3pm – 4pm	13262.13	68.516	7106.09	731.54	57.300	537.05
4pm – 5pm	13290.13	68.516	7106.07	717.49	57.227	528.11
5pm – 6pm	13299.30	68.518	7108.09	713.29	57.218	526.23
6pm – 7pm	13118.69	68.512	7098.86	706.85	57.217	526.91
7pm – 8pm	12714.96	68.441	6983.81	691.12	57.178	522.11
8pm – 9pm	12588.91	68.430	6965.56	692.71	57.184	522.83
9pm-10pm	12409.43	68.430	6965.67	707.16	57.211	526.12
10pm-11pm	11573.96	68.375	6878.24	737.54	57.313	538.67
11pm-0am	11360.25	68.244	6674.12	636.1	57.068	509.11
TOTAL	**297495.45**	**1641.945**	**166618.40**	**16648.68**	**1372.637**	**12576.98**

Table 2: Power consumption during peak traffic period with energy efficient enhanced hardware

Component	**Macro cell base station (13500Watts)**		**Microcell base station (700watts)**		**Saved power**	
	Conventional hardware (watts)	**Enhanced hardware (watts)**	**Conventional hardware (watts)**	**Enhanced hardware (watts)**	**MBS (watts)**	**SBS (watts)**
Power Amplifier	848.000	500.013	443.417	265.000	347.987	178.417
Base Band	143.000	105.000	62.917	50.600	38.000	12.417
RF	156.000	120.000	87.000	50.500	36.000	36.500
Cooling	227.000	170.000	Nil	Nil	57.000	Nil
Rectifier unit rating	180.333	80.000	61.167	45.000	100.333	16.167
Microwave link	100.333	100.000	60.167	48.600	0.333	11.567
Total	12675.37	7742.553	700.375	550.506	4932.819	149.869

From Table 2, it was observed that the adoption of energy efficient enhanced hardware has provided great improvement in energy reduction in various devices such as power amplifier, RF unit, cooling system, dc-dc rectifier unit, base band unit and microwave link at the macro cell and micro cell base stations. In the macro cell, there was a reduction of power energy from 12675W to 7742W whereas in micro cell base station there was a reduction in power energy from 700W to 550W.

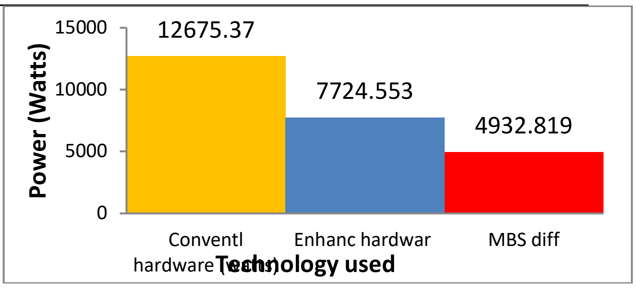

Figure 2: Comparison of power consumption for the conventional hardware and enhanced hardware for macro base station

Figure 2 shows the plot of power against enhanced hardware, conventional hardware and the difference in the power saved at the macro base station.

In Figure 2, it was observed that the conventional hardware consumed about 12675.37W per hour whereas the conventional hardware consumed about 7724.37W. Also, the amount of energy saved for the conventional and enhanced hardware was about 4932.819W which indicates significant development in energy reduction at the macro base station. Again, the power consumed using energy enhanced hardware at the macro cell base station was reduced by 4932.79 watts which represents 38.28% of the original power consumed with the conventional equipment. The advantages of the enhanced technology have provided saving of energy and make the system more cost effective by reducing waste energy.

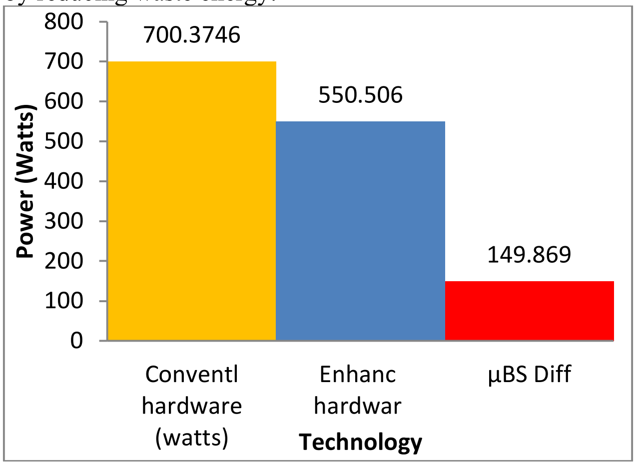

Figure 3: Comparison of power consumption of the conventional hardware with the enhanced hardware for micro base station

Figure 3 shows the plot of power against the conventional hardware, enhanced hardware and the difference in power saved at micro cell base station. At this station, it was observed that the conventional hardware consumed about 700W while the enhanced energy hardware consumed 550W. Again, the difference in power of 150W was realized as the energy saved when an enhanced energy efficient hardware was deployed.

During the peak period, it was observed that the enhanced hardware was 550.506 watts against 700.375watts of the conventional equipment which provides power saving of 149.869 watts which amount to 21.48% of the original power. At both stations, the energy enhanced hardware components consume less power when compared with the conventional hardware components. The enhanced technology has shown increased in efficiency with lower cost.

Table 3: Comparison of power consumption and efficiency of the MBS and µBS

	Macro cell base station		**Micro cell base station**	
	Conventional hardware	**Enhanced Hardware**	**Conventional hardware**	**Enhanced Hardware**
Power consumed	12675.37W	7742.553 W	700.375W	550.506 W
Output	6983.81W	6983.81W	522.11W	522.11W
Efficiency	55.1%	90.2%	74.6%	94.8%

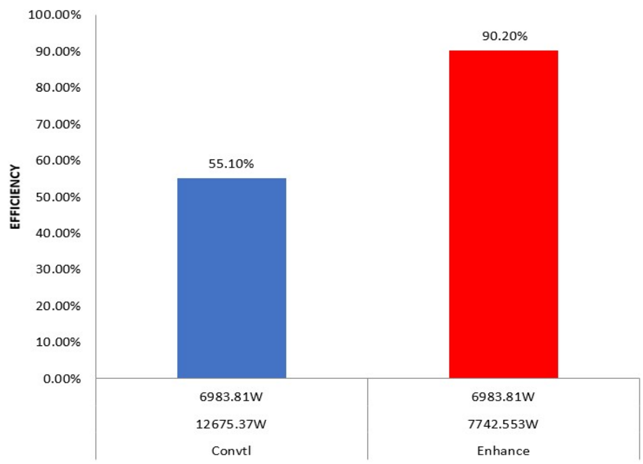

Figure 4: Comparison of the Efficiency of macro base station for conventional and enhanced hardware

Figure 4 indicates the energy efficiency at the macro base station during peak period. It was observed that the energy efficiency at the station is 55% whereas when the energy enhanced hardware was deployed the efficiency improved to become 90%. This shows a 40% improvement in energy efficiency. Again, the advantages of enhanced technology have helped in increasing reliability and efficiency.

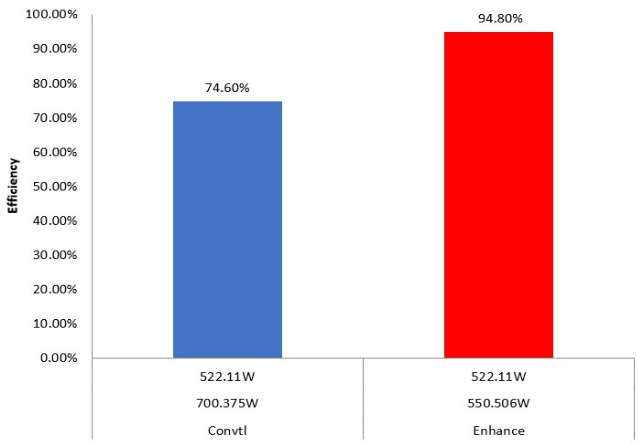

Figure 5: Comparison of the efficiency of macro base station for conventional and enhanced hardware

Figure 5 shows the energy efficiency at the micro cell base station during peak period. It was observed that the energy efficiency at this station when conventional hardware was deployed is 74.6% whereas when the energy enhanced hardware was deployed the efficiency improved to 94.8% which indicates a rise of 20% in efficiency. Again, the enhanced technology reduces waste energy, increases reliability and efficiency.

4.0 Conclusion

In conclusion, theutilization of energy efficient hardware is a better method in improving energy efficiency. The more the improvement on the technology the better the system. However, co-operative techniques of 5G have improved energy efficiency of a network that can handle high data traffic of various services.

The switching mode has low energy consumption since during low traffic, the base station with number of connectivity above the threshold remains awake while most of the small base stations with connectivity below the threshold are turned to sleep mode. At sleep mode the power consumed at the base station was very low. The cooperative technique involves combination of energy efficient hardware with the switching mode to recover the energy efficiency.

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