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Enhancing the energy efficiency of 5G networks for optimal performance using co-operative techniques

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Abstract
This paper focuses on the enhancement of energy efficiency of 5G networks for optimal performance using cooperative techniques. With the fast increase in global human population as well as rapid development in mobile and internet technology, there is predictable growth 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 switching mode approach was deployed using separated control and data planes. Again, heterogeneous network was used with the macro cell base station (MBS) and microcell base station (μBS) to serves as the control plane and data plane. The energy efficient hardware approach involved deployment of enhanced energy efficient hardware to improve energy efficiency. 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 at the macro cell and micro cell base stations showed that the average daily input power in watt (W), output power in decibels and output power in watt (W) were 297495.45, 1641.945 and 166618.40, 16648.68, 1372.637 and 12576.98. However, the average power consumption at the macro cell and micro cell base stations with conventional, enhanced hardware and saved power during peak traffic period were 12675.37, 7742.553 and 4932.819, 700.375, 550.506 and 149.869. In conclusion, the proposed co-operative techniques of 5G networks have enhanced the energy efficiency that can handle high data traffic of various services.

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

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 (Shameek et al., 2016). 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 (Buzzi et al., 2016). Within the last ten years, energy efficiency has become an important distinction owing to operational, economic and environmental concerns. 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 (Shariatmadari et al., 2015). 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 (Guo et al., 2016).

The developing superiority in both user equipment and network has enhanced the energy efficiency and their functions have improved the energy transmission. 5G wireless networks constitute a major communication infrastructure for ever-present connectivity in the future, with the increasing expansion of mobile access to the Internet and its services (Ge et al., 2017). Increased energy consumption is one of the key challenges linked with global warming and decreasing the energy consumption of mobile communication networks has gotten a lot of attention since it accounts for a considerable amount of overall information and energy consumption. Mobile communication networks use a large portion of the overall energy consumed by information and communication technology, thereby reducing their energy usage has gotten a lot of attention (Hu and Qian, 2014). 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 and Zhang, 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 (Lorincz and Matijevic 2014). Furthermore, it is demonstrated in Tombaz, (2014) that energy efficiency issues and how to incorporate energy into the design of future wireless networks was investigated. Thus, a novel backhaul power consumption models and architectural options for urban and rural environments was proposed. The results indicate that macro cellular systems were the greatest energy efficient solution for moderate average traffic density. Hence, a framework for evaluating the variability of energy efficiency solutions was developed. The energy efficiency of 5G networks in wireless communication was evaluated. Different ways of deploying energy efficient hardware at the base stations was examined and power consumption at the macro and micro base stations were measured. The results obtained from three models such as Gex model, modified Gex model and Ismail model gave power consumption from macro and micro base stations. It was observed that the modified Gex model produced the best energy consumption that was close to the measured energy (Udo, et al., 2023). The statement of problem is that there is a rapid development in internet and mobile technology which led to foreseeable growth in wireless communication. The objective of the study is to enhance energy efficiency of 5G networks for optimal performance using cooperative techniques.

Mathematical models for three stage switching mode

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

$$E_{daily} = \sum\left(R_{BS}^{active} * W_{op}^{BS}\right) * hour \quad (1)$$

Where E is the daily energy consumption, R is number of active base stations and W is the power consumed by the base station. The total power consumed in the network per cluster is given in equation 2.

$$\mathrm{P_{total}} = \mathrm{P_E} + \mathrm{P_{sleep}} + \mathrm{P_{on}} + \mathrm{P_N} \quad (2)$$

Where P_{total} is the total power consumed in the network per cluster. P_E is the power consumed by the macro cell base station, P_{sleep} is the total power consumed by the micro cell base station when it is on sleep mode. P_{on} is the total power consumed by the base station when it is on ON mode and P_N is the total power consumed by the base station when transiting from one state to another. The power consumed between C_i and Hj is denoted as P_{ve}, where C_i corresponds to a macro base station and Hj corresponds to a micro base station.

$$\mathrm{P_{ve}}\left(\mathrm{C_i}, \mathrm{H_j}\right) = \begin{cases} 0, & if\ d \le 0.5 \\ 0.6 & if\ d(< 0.85) \\ 1, & otherwise \end{cases} \quad (3)$$

Y_j is related with whether the Hj is in ON state or not while Dj is related with whether the Hj is in Safe-mode state or not. E_j is related with whether the Hj is in SLEEP state or not is given in equation 4.

$$\mathrm{Yj} = \begin{cases} 1 & \text{if Hj is in on state} \\ 0 & otherwise \end{cases}, (0 \le j < g + 1) \quad (4)$$

$$\mathrm{Dj} = \begin{cases} 1 & \text{if Hj is in safemood state} \\ 0 & otherwise \end{cases}, (0 \le j < g + 0.6) \quad (5)$$

$$\mathrm{Ej} = \begin{cases} 1 & \text{if Hj is in sleep state} \\ 0 & otherwise \end{cases}, (0 \le j < g) \quad (6)$$

The state transitions of a micro base station are Y_j, D_j and E_j and their values are defined in equations 7, 8 and 9.

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

$$\text{Dj} = \begin{cases} 1, & \text{if Mi switches between Safemood to on state or off state} \\ 0, & otherwise \end{cases} (0 \leq j < g+0.6) \quad (8)$$

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

The power consumption of an Hj, P(k) at minimum is obtained as shown in equation 10.

$$P_{(k)min} = Y_j \times (1 - E_j) \times (P_s^r + p_s \times P_S^{tx}(j)) + D_j \times (1 - w_j) \times P_S^e \quad (10)$$

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. The load dependent power consumption, P_k (j) for a small cell base station is given in equation 11.

$$P_{k(j)} = P_w^{tx,max} x \begin{cases} 0, \\ 0.6 \\ 1, \end{cases} \left(d_i x a_{j,i} x \frac{(r_i x C_h + (1 - r_i) x C_j}{b_S^{max}} \right) \quad (11)$$

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.

$$P_{total} = \frac{P_x}{P_0} + P_c \quad (12)$$

$$\eta_E = \frac{P_r}{\frac{P_x}{P_0} + P_c} \quad (13)$$

Where P_x is the transmitted power, P_r is the received power, η_E is the energy efficiency, P_c is the circuit power and P_0 is the input power of the base station.

2.0 Material and methods

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.

2.1 Modified mathematical models for energy-enhanced hardware approach

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

$$P_{macro} = P_{el/const} + P_{el/load}.F_l \quad (14)$$

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

$$P_{macro} = \left((n_{sect} P_{rec} + P_{link} + P_{airco}) + \left(n_{sect} \left(n_{tx} (P_{amp} + P_{trans}) + P_{proc} \right) F_l \right) \right) \quad (15)$$

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

$$P_{micro} = P_{el/const} + P_{el/load}.F_l \quad (16)$$

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

$$P_{micro} = \left((P_{rec} + P_{airco}) + \left((P_{amp} + P_{trans} + P_{proc}) F_l \right) \right) \quad (17)$$

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

$$P_{cluster} = P_{macro} + 7P_{micro} \quad (18)$$

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

$$P_{cluster} = \Big(\big(n_{sect}P_{rec} + P_{link} + P_{airco}\big) + \big(n_{sect}\big(n_{tx}\big(P_{amp} + P_{trans}\big) + P_{proc}\big)F_l\big)\Big) + 7\Big(\big(P_{rec} + P_{airco}\big) + \big(\big(P_{amp} + P_{trans} + P_{proc}\big)F_l\big)\Big) \quad (19)$$

Where P_{rec} is the power consumption of the rectifier unit, P_{amp} is the power consumption of the power amplifier, P_{link} is the power consumption of the microwave link, P_{trans} is the power consumption of the transceiver, P_{proc} is the power consumption of the digital signal processing, F_l is the load factor, P_{airco} is the power consumption of the air conditioning system. N_{trans} is the number transmitting antenna and n_{sect} is the number of sector (Udo, et al., 2023).

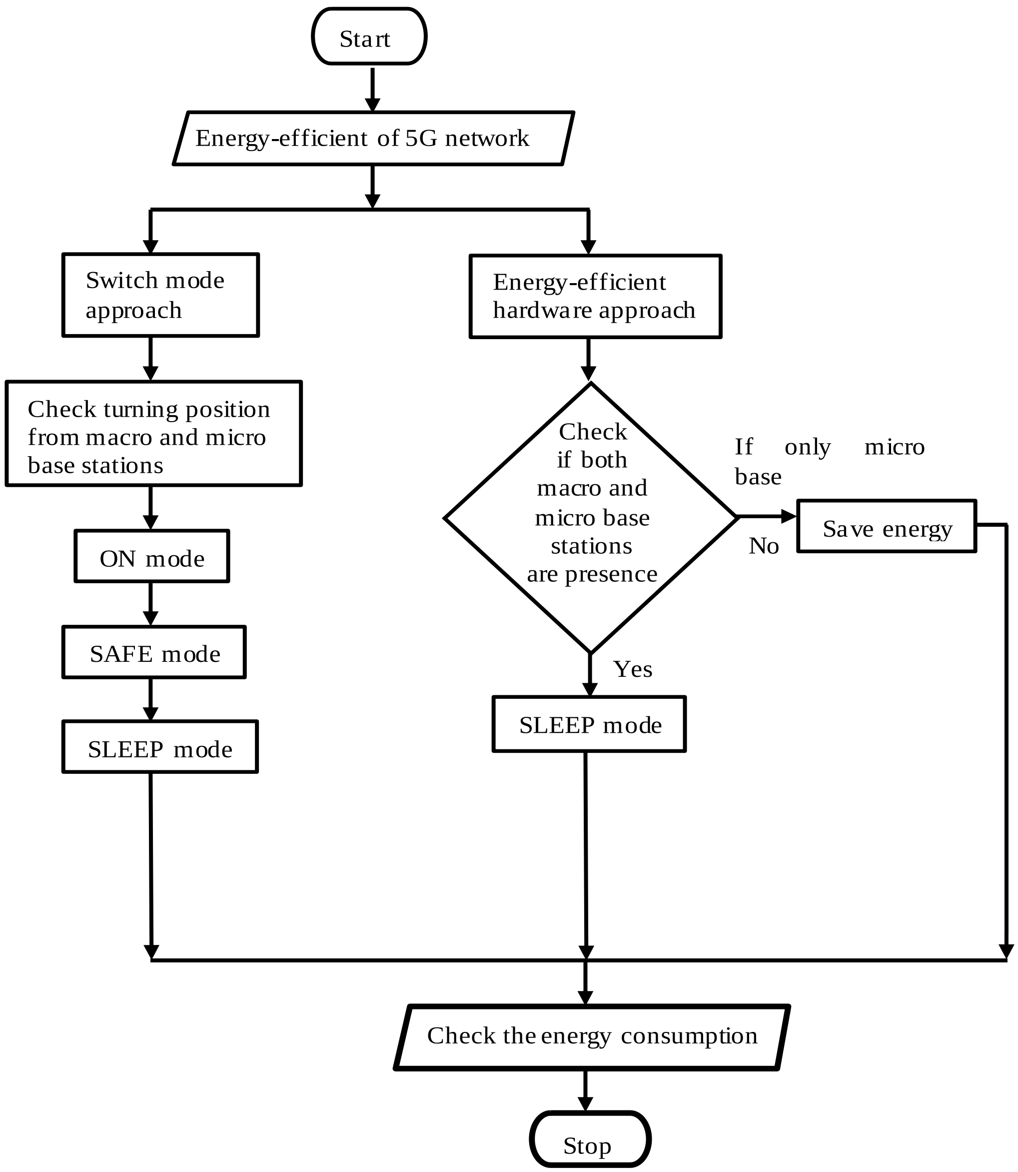

Figure 1: Flowchart for the two approaches used for the energy-enhanced hardware technique

3.0 Results and Discussions

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. Figure 2 shows the comparison of power consumption for the conventional hardware and the enhanced hardware for macro base station. Figure 3 indicates the comparison of power consumption for the conventional hardware with the enhanced hardware for micro base station. Figure 4 shows the comparison of the efficiency of the macro base station for conventional and enhanced hardware and Figure 5 indicates the comparison of the efficiency of the macro base station for conventional and enhanced hardware.

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

	Macro cell base station			Micro cell base station		
Hour	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 of power energy from 700W to 550W.

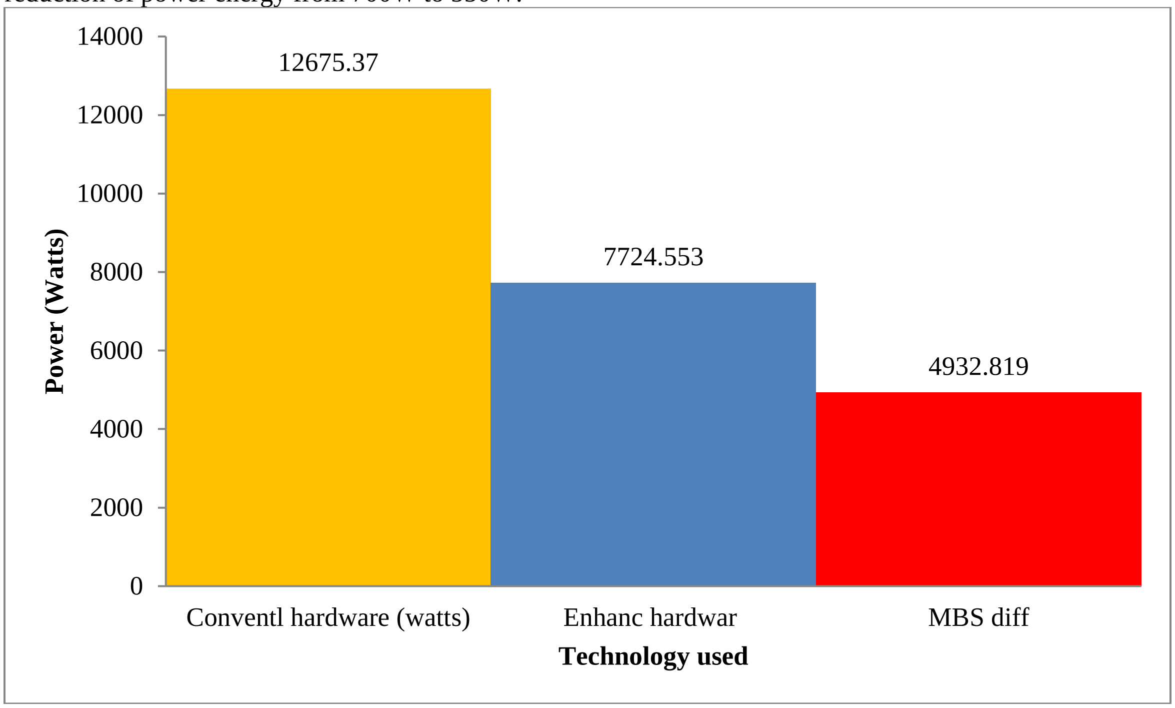

Figure 2: Comparison of power consumption for the conventional hardware and enhanced hardware for macro base station

Figure 2 shows the plot of power against enhanced hardware, conventional hardware and the difference in the power saved at the macro base station. 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 this make the system more enhanced by reducing waste energy.

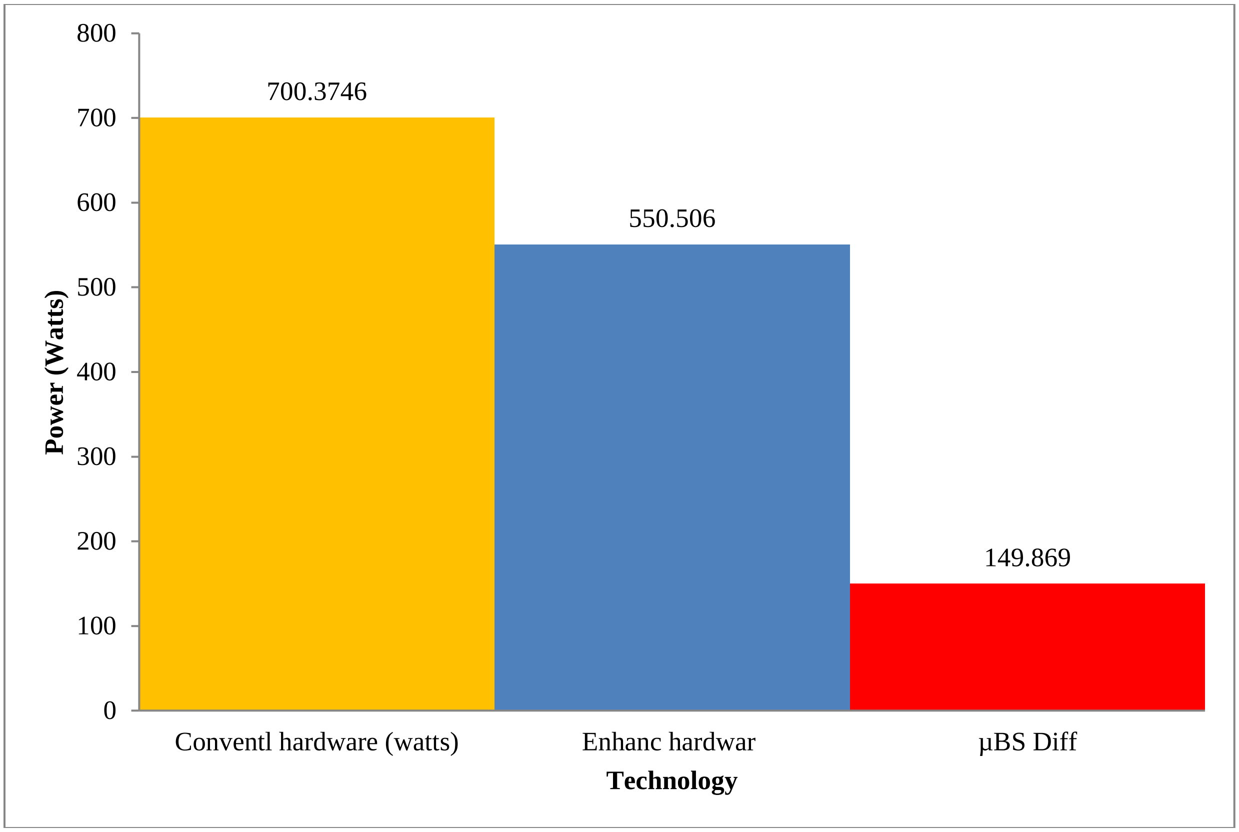

Figure 3: Comparison of power consumption for the conventional hardware with the enhanced hardware for micro base station

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 550.506watts against 700.375watts of the conventional equipment which provides power saving of 149.869watts 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. This results shows that 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	7742.553W	700.375W	550.506W
Output	6983.81W	6983.81W	522.11W	522.11W
Efficiency	55.1%	90.2%	74.6%	94.8%

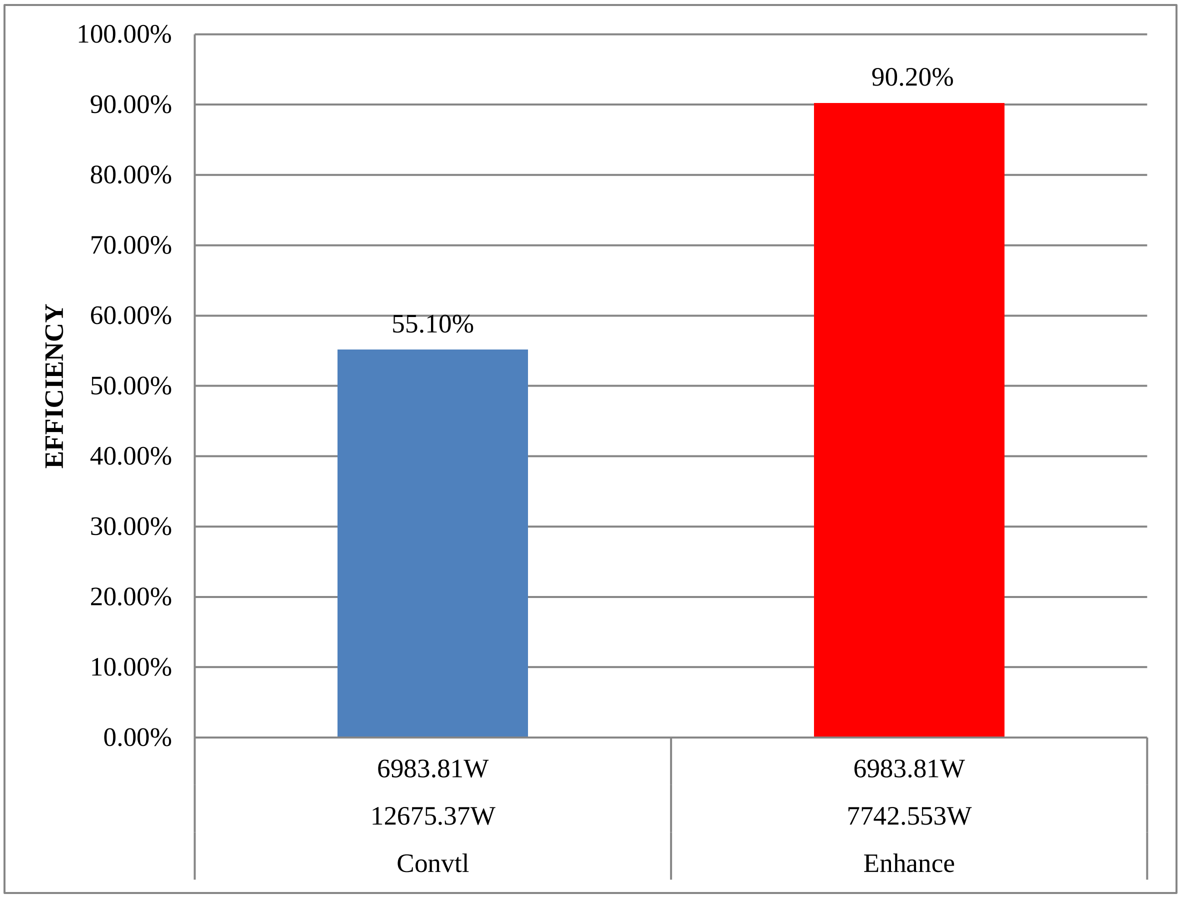

Figure 4: Comparison of the efficiency of the macro base station for conventional and enhanced hardware

Figure 4 shows the plot of efficiency against conventional and enhanced energy at the macro base station. 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.

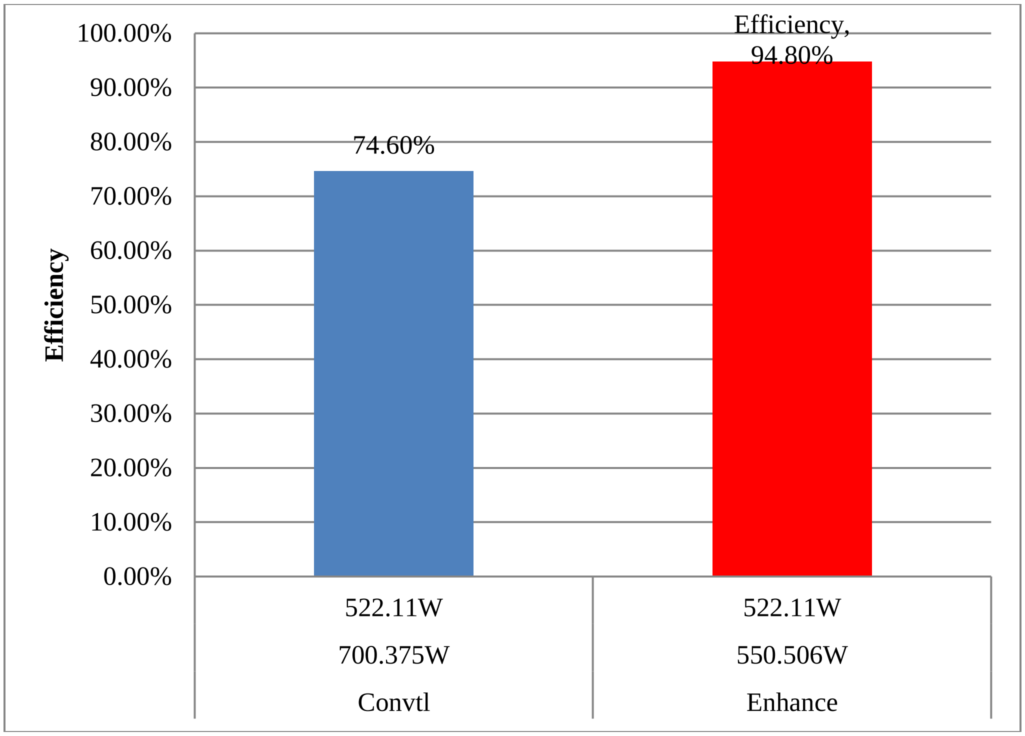

Figure 5: Comparison of the efficiency of the macro base station for conventional and enhanced hardware

Figure 5 shows the plot of efficiency against conventional and enhanced energy at the micro base station. 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, the utilization of energy efficient hardware is a better method in improving energy efficiency and the more the improvement on the technology the better the system. The switching mode has low energy consumption during low traffic and the base station with the number of connectivity above the threshold remains awake while most of the small base stations with the connectivity below the threshold are turned to sleep mode. At sleep mode, the power consumed at the base station was very low. Services provided by the network operators are required to ensure the consumers' satisfaction. The provision of high data rates with better coverage and good signal quality make small cells to be deployed with energy efficient hardware at micro base stations. These cells can decrease energy consumption if properly equipped with energy efficient hardware and intelligent power saving or distribution mechanisms. Again, heterogeneous cellular networks have emerged as the primary solution for explosive data traffic. However, an increase in the number of user equipment, energy enhanced small cell base stations inevitably leads to a decrease in energy consumption and energy efficiency has become a focal point in heterogeneous networks.

5.0 Recommendation

It is recommended that researchers should adopt other relevant methods to improve the performance of 5G networks in wireless communication.

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