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# ENERGY EFFICIENT TECHNIQUES FOR NEXT-GENERATION WIRELESS NETWORKS

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**ABSTRACT.**
A consistent issue of concern in the design of future mobile cellular systems is the energy consumption of the radio access network. The deployment strategy has a huge impact on the overall energy performance of the network. This paper considers a high data rate network using 4G Long Term Evolution technology to evaluate the energy performance of the network given variable base station densities in both urban and rural environments. The paper quantifies the amount of energy savings that can be obtained due to the deployment of different cell sizes in an area with a given user density. It also compares the increase in cost that arises due to the deployment of small cells with the gains that are realized by using small cells. Our results show that there are specific optimal cell radii in rural and urban environments at which the energy performance of the network is maximized. In addition, it is shown that small cells are more suited to urban environments where users can exploit them to enhance network capacity. However, due to their sparse population densities, rural areas require relatively larger cells to maximize energy gains.

**Keywords:** 4G, 5G, network optimization, energy efficiency

## 1.0 INTRODUCTION

The issue of energy consumption in cellular networks has attracted significant attention in both industry and academia. This is due to the explosive growth in traffic demand which is driving the need for innovative solutions for mobile broadband services. This drive has led to the evolution from 2G to 4G networks, and now to 5G that promises to deliver improved end-user experiences through gigabit speeds, and improved performance and reliability (ITU, 2018). The volume of transmitted data increases approximately by a factor of 10 every five years, which corresponds to an increase of the associated energy consumption by approximately 16 to 20%. This has led to increased capital expenditure and increased operational costs including the cost of energy. In cellular networks each base station can require up to 2.7kW of electrical power which can lead to an energy consumption of tens of MW per annum for wide area networks. Energy consumption analysis shows that between 50% and 80% of the total energy in a wireless network is consumed in the base stations (Mugume *et al*, 2013, Hasan *et al*, 2011, Badic et al, 2009).

Operators are looking for economical and sustainable solutions to reduce their operational expenditure most especially the cost of energy. Several techniques can be used to reduce network energy consumption such as improved radio base station equipment design, energy-efficient cooling systems or avoiding cooling by using remote radio units (Marsan *et al*, 2009, Chabarek *et al*, 2008, Hodes, 2007, Rinaldi *et al*, 2007).

One technique in particular has both an energy saving component as well as a key service delivery mode, particularly in the case of 5G networks. This is the use of innovative infrastructure sharing. Early 5G deployments are expected to be largely evolutionary to 4G/LTE primarily to support high-bandwidth mobile data in dense urban or suburban areas (GSMA, 2017). For 5G to be a success, policies and regulations that strengthen the viability of 5G networks include innovative spectrum and infrastructure sharing models, dynamic renting of infrastructure and backhaul, and enabling capacity sharing models. Open and universal access to broadband infrastructure as well as infrastructure sharing are also key principles of Uganda's National Broadband Policy (MoICT&NG, 2018).

Infrastructure sharing and, in particular, the notion of a neutral host provider gains even more prominence as a strategy for cost effective high-speed services. Neutral hosts could be in form of a wireless infrastructure provider that supplies passive mast and tower infrastructure only to neutral host providers that could deploy their own active equipment (DDCMS, 2018). With active equipment, a neutral host may transmit on behalf of mobile network operators (MNO) and mobile virtual network operators either in their own spectrum or the MNOs' spectrum. As such, neutral hosts can boost energy efficient coverage in various scenarios including (1) dense urban areas where shared networks could be desirable in order to reduce deployment costs including energy requirements, (2) remote rural areas where there could be insufficient demand to justify multiple networks, and (3) in offices and factories where local networks can be deployed to provide coverage and capacity within the building.

A neutral host approach also lends itself well to a key component of 5G networks which is the use of small cells. To deliver on the promise of high-speed connectivity anywhere any time calls for an ecosystem of heterogeneous, multi-access network infrastructure in which small cells play a critical role in three usage scenarios: indoors, outdoors in dense urban areas, and outdoors in economically challenging areas (GSMA, 2017). A proposed spectrum allocation includes a low capacity layer providing wide area 5G coverage using the 700 MHz band, high capacity small cells in areas of high demand using 3.4 – 3.6 GHz band, and in the longer term, even smaller hotspots of very high capacity using mmWave bands in the range of 30 – 300 GHz (DDCMS, 2018). This again raises to the fore a key issue of innovative regulation for spectrum management. It is therefore timely that the regulator is developing a Radio Spectrum Management Policy to guide the efficient and effective radio spectrum management towards the realization of national social economic development (UCC, 2018).

This paper compares energy savings that can be obtained by deployment of small cells in two areas, one urban and one rural. This paper is organized as follows. First the system model used in the simulation is analyzed, followed by the results obtained in the simulation and the observations and conclusions as per the results obtained.

## 2.0 SYSTEM MODEL

### 2.1 Case Study

Two areas of 2 square kilometers were studied for a rural and an urban deployment. The areas considered were Kampala, Central Uganda, for the urban area and Kisoro, South Western Uganda, for the rural area. The mean number of users to be served in that area for a given cell radius was determined. Population estimates were based on Uganda Bureau of Statistics 2018 estimates which give a population density of 1,932 and 417 people per square kilometer respectively for Kampala and Kisoro which are of area 839 $km^2$ and 728 $km^2$ (UBOS, 2017, UBOS, 2019). For purposes of this work, Kampala District was selected as an urban area since it has a population density of over 1,000 persons/km$^2$, and Kisoro District was selected as a suburban/rural area since it has a population density of under 1,000 persons/km$^2$ (Blume *et al.*, 2013). To obtain the mean number of subscribers in the two regions, we assumed that mobile subscriber population is distributed in accordance with the population distribution per country. Using 2018 figures for mobile subscribers nationwide of about 24.5 million subscribers (UCC, 2018a), and assuming an operator with a 52% market share, we obtained the mean user density per square kilometer for the operator at 630 and 135 respectively for the urban and rural areas under consideration for this study.

The number of e-NodeB's that cover the area for the varying cell radius was calculated for the different inter e-NodeB distances, assuming a maximum distance of 2 km for a single e-NodeB. Hexagonal cellular cell deployment was considered in the selected areas. The radius of a cell-site denoted by *R* is fully adjustable with the inter-site distance = 1.5*R* for a hexagonal geometry. Base stations are configured with three sector antennas, with directions of 0, 120, and 240 degrees. The area, $A_{cell}$, that is defined for N cells each of radius *R*, and the mean cell transmission power $P_{cell}$ per sector are given by (Auer *et al*, 2011):

$$A_{cell} = \frac{R*R*3\sqrt{3}}{8} \qquad (1)$$

$$P_{RAN} = P_{cell} \times N \qquad (2)$$

The path loss model considered was the COST 231 Model for path loss in various areas for propagation up to 2 GHz band (Hassan *et al*, 2013):

$$L_p = 46.3 + 33.9\log f_c - 13.82\log h_b - a(h_m, f_c) + (44.9 - 6.55\log h_b)\log d + C \qquad (3)$$

where $f_c$ is the frequency of transmission in MHz (between 1500 and 2000 MHz); $h_b$ is effective base station antenna height in meters (between 30 and 200m); $h_m$ is mobile antenna height (between 1 and 10m); *a(.)* is a mobile station antenna height correction factor in meters for large and medium sized cities; *d* is in km; *C* is a correction factor with *C* = 0 dB in medium and suburban areas, 3dB in urban and metropolitan areas, and -17 dB in rural areas.

To determine the best deployment cell size, the energy efficiency performances of large cells and small cells is evaluated by measuring the energy efficiency performances (e.g. energy consumption ratio, energy consumption gain) achieved for various cell sizes and antenna heights while maintaining the quality of service (for a given cell coverage and mean cell capacity) under a cell transmission power constraint. After comparing the Energy Consumption Ratio (ECR) for each cell size, a suitable system deployment option can then be found in terms of the cell size. Similar calculations are performed for the Energy Consumption Gain (ECG) across the radio access network.

## 2.2 Power Model

A base station consists of multiple transceivers (TRXs), each of which serves one transmit antenna element. A TRX comprises a power amplifier (PA), a radio frequency (RF) small-signal TRX module, a baseband engine 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. The following power model was used while carrying out these simulations (Auer *et al*, 2011):

$$P_{in} = N_{TRX} \times P_O + \Delta \times P_{OUT}, \; 0 < P_{OUT} \leq P_{MAX} \qquad (4)$$

$P_{OUT}$ is output power, $N_{TRX}$ is the number of transmit chains, $P_0$ is the power consumption at the minimum non-zero output power, Δ is the slope of the load-dependent power consumption and $P_{MAX}$ is the output power at maximum load. It should be noted that for this project, sleep mode capability is not investigated. The power savings that are quantified are due to deployment of small size cells.

## 2.3 Energy Metrics

In the study of energy metrics, the total system wide energy includes embodied energy as well as operational energy for services delivery. The operational energy is a function of the radio access architecture which includes cell size, base station antenna height, antenna radiation pattern, distance of the transmitting and receiving antennas, interference, multipath fading, shadowing, radio resource management, user density, user mobility, and traffic scenarios. Embodied energy is the energy consumed by all processes associated with the production of a device (Humar *et. al*, 2011). It comprises of initial embodied energy that is used to acquire and process raw materials, transport, manufacture components, and assemble and install all products in the initial device construction. It is also comprised of maintenance embodied energy associated with maintaining, repairing, and replacing materials and components of the device throughout its lifetime. For this paper, embodied energy is taken as a fixed component in the energy performance evaluation and the focus is on the operational energy that is known to decrease when sleep-mode or power-down strategies are applied. The primary energy metric used in this paper is the Energy Consumption Gain (ECG). This is the ratio of the power of a RAN for large cell deployment to small cell deployment for a given period of time:

$$ECG = \frac{P\ (RAN\ LARGE) * t}{P\ (RAN\ SMALL) * t} \qquad (5)$$

ECG can also be obtained by dividing the Energy Consumption Ratio (ECR) of a large cell deployment to that of a small cell deployment. The ECR is an energy performance metric that expresses the energy consumed per delivered bit of information, i.e. ECR = $\frac{E}{M}$ , where *E* is the energy that is used to deliver *M* bits of information over time *T*.

## 3.0 RESULTS AND ANALYSIS

Results obtained for this are based on the VIENNA LTE level network simulator that was developed in MATLAB. System parameters and simulation assumptions are chosen to comply with known LTE standards. Some of the main parameters used in the simulation are shown in Table 1 and are based on a similar study undertaken for Kampala and Kisoro (Okello *et al*, 2015). The cost of the different cell sizes was computed based on a Nokia flexi e-NodeB that supports up to 250 active users/devices simultaneously.

**Table 1: Simulation Parameters**

| Name | Parameter |
|---|---|
| Frequency | 2 GHz |
| Bandwidth | 5 MHz |
| Propagation model | COST 231 HATA |
| Transmitter height | 20 m |
| Receiver height | 1.5 m |

The plot in Figure 1 is the total power consumed in the considered area against the different cell sizes for both rural and urban areas. This plot shows that the power consumed decreases as cell size reduces to a radius of about 350m for the urban area and 1,000m for the rural area. Below these two radii, power consumed increases for the respective areas. This is because deploying a small cell size in the same area would entail using very many of them for a given user density. Though these would be transmitting at lower power values, their total fixed power increases linearly. As the number of small base stations increases further, there is a point beyond which the overall power consumption begins to increase.

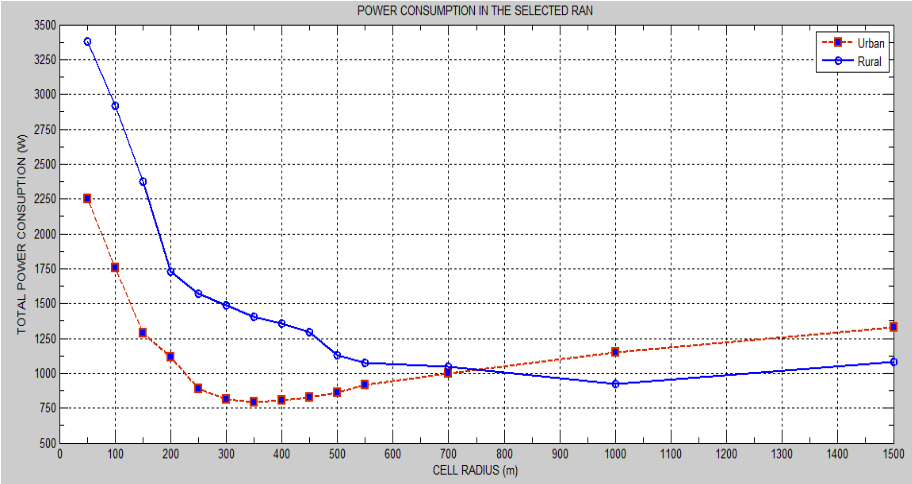


**Figure 1: Total power consumption vs Cell radius**

Figure 2 shows the percentage power savings and cost increase for both urban and rural areas. Power savings are achieved for urban areas as compared to the rural environment up to a cell radius of about 200m. The costs are based on the total number of base stations required to cater for users within a given radius. It is assumed that a base station can meet the traffic requirements for up to 250 active users simultaneously. It is observed that the percentage increase in cost for small cells is relatively narrow as compared to large cells.

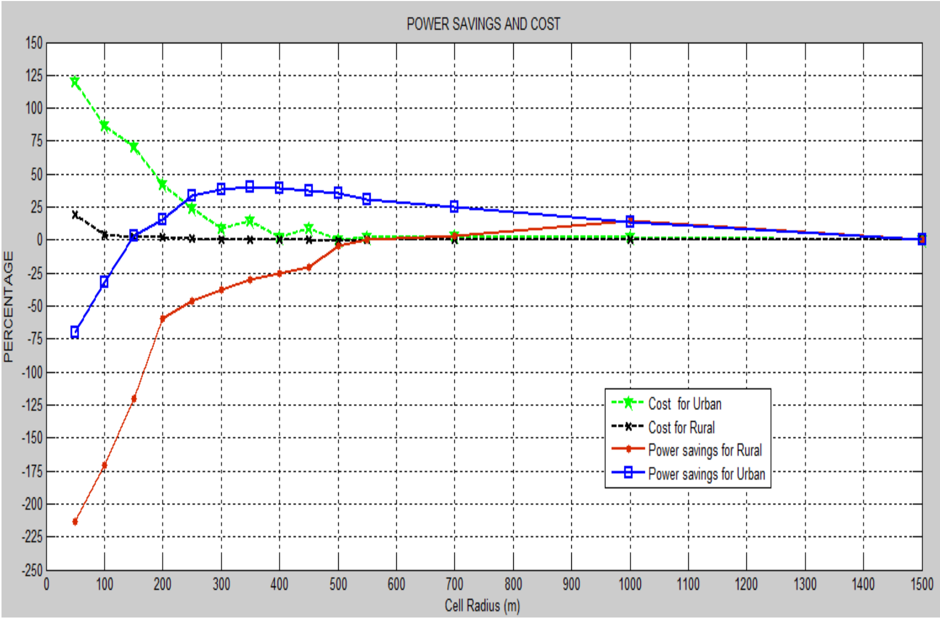


**Figure 2: Percentage power savings and cost vs Cell radius**

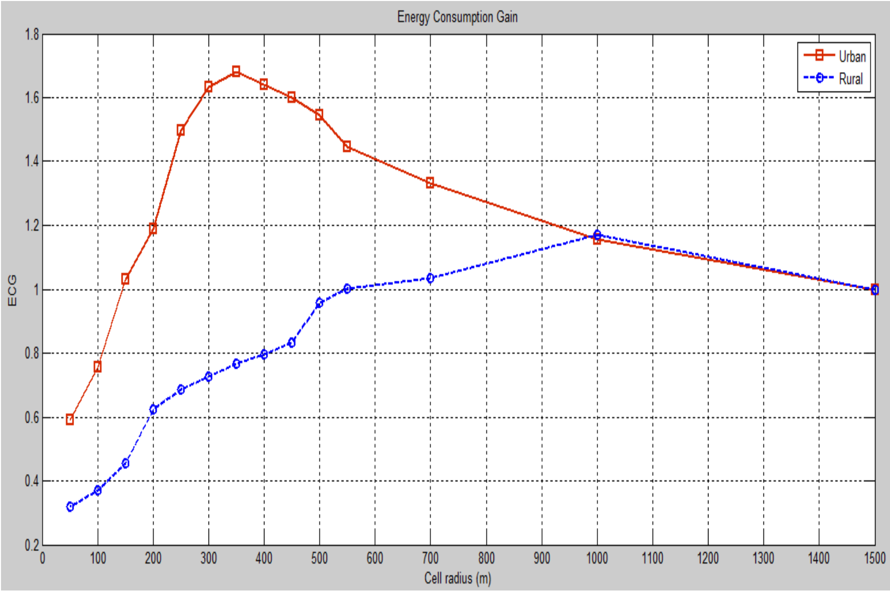


**Figure 3: Energy Consumption Gain vs Cell radius**

Figure 3 shows that with smaller cell sizes, an ECG greater than 1 is obtained for the urban environment over a wider cell radius variation. Note that ECG for the rural area is below 1 for small cell sizes. Therefore, from an energy efficiency perspective, small cells are more efficient to deploy in the urban areas as compared to rural areas.

## 4.0 CONCLUSION

In this paper, the effect of reducing the cell size was investigated in a 4G/LTE mobile network as an evolutionary path for 5G networks. Networks in Uganda are using both the 700 MHz range and the 2 GHz range for provision of LTE services, and hence the results are a good indicator for energy efficiency for 4G networks and beyond. The study has shown how percentage power savings reduced with decreasing cell sizes in the two regions considered, but up to a point. For instance, energy consumption gain reduces significantly below a cell radius of about 300m for an urban deployment. Even then, it is observed using energy consumption gain that deployment of smaller cells in the urban areas is more efficient than in the rural areas. Hence in addition to a critical examination of the business case for high-speed 5G networks in rural areas, there is need to promote broadband access strategies for rural areas that are both energy efficient and an appropriate technology mix of perhaps 3G/4G networks. In this way, national ICT development can progress without a widening digital divide.

Small cells are the preferred delivery mechanism for 5G given their ability to deliver on dense coverage, low latency and high bandwidth requirements (ITU, 2018). Furthermore, small cells can deliver on the anticipated high-speed capacity without the need for additional spectrum due to their enhanced frequency reuse capability. However, as shown, energy consumption gain for small cells drops for radii below 300m and 1,000m in the two regions under consideration. This means that careful balancing of the high-speed access versus energy requirements will be necessary as small cells, more so in 5G networks that are expected to go even much lower than the optimal 300m radius obtained in this work.

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