Development of an Energy Estimation Algorithm for LTE Mobile Access Networks

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***Abstract* - This work proposes the development of an energy estimation algorithm for LTE mobile access networks. The LTE network environment and the eNodeBs power consumption models were developed with a view to implementing an energy estimation algorithm that will estimate the energy consumption of the LTE access network. The energy estimation algorithm for the LTE eNodeBs was developed and implemented in MATLAB environment. The daily energy consumption of the LTE access network was simulated and analysed in respect to 37 eNodeBs which was used as a case study. The daily energy consumption of the LTE access network was evaluated while varying the energy load proportionality constant (q) which ranges from $0 - 1$. The daily minimum and maximum energy consumption of the LTE access network were found to be $87\ kWh$ and $1121\ kWh$ for the energy load proportionality constant of $q = 0$ and $q = 1$ respectively. The result showed that the energy consumption of the simulated LTE access network increases linearly as the values of the energy load proportionality constant tends towards 1.**

Key words - LTE Network, Load Utilization Factor, Bandwidth Efficiency, Data rate and Signal-to-interference-noise-ratio

1. INTRODUCTION

The information and communication technology (ICT) systems consume up to 10% of the world's energy which is responsible for about 2% of global CO_2 emissions [1]. The telecommunication network is one of the main energy consumer of the information and communication technology sector [1]. About 37% of the total emissions from ICT devices and systems are due to the telecommunication infrastructure and devices, where about a tenth of the estimate is due to cellular mobile communication networks. This accounts for about 0.2% of the global CO_2 emissions and 1% of the world energy consumption [2]. The mobile cellular communications sector alone consumes approximately 60 billion kWh per year. Correspondingly, energy consumption as well as CO_2 footprint of mobile cellular networks are increasing at an alarming rate due to the exponential growth in mobile data traffic [3]. This has led to a high network operating costs and a considerable contribution to the worsening global warming phenomenon respectively [4]. On the other hand, cellular mobile network traffic exhibits a high-degree of temporal-spatial diversity, which means that traffic demand varies both in time and space [5]. This variation is directly related to the random call making behaviour and mobility pattern of the mobile users [6]. However, under the current network operation approach, all eNodeBs are kept powered on irrespective of traffic load [7]. Thus, it is imperative to analysis the energy consumption of this eNodeBs with respect to its utilization.

The authors in [8] developed an Always-On (AO) scheme to estimate the network energy consumption when all base stations are always powered on for a time period T. The algorithm adapted the current network capacity to the actual traffic, while guaranteeing an adequate quality of service to users. However, the scheme was based on the UMTS standard of cellular network. In view of this, there is also a need to develop a robust energy estimation algorithm for the LTE cellular access networks that will incorporate the inherent temporal-time traffic diversity of cellular access networks and the load-proportional power consumption model of eNodeBs.

2. SYSTEM ARCHITECTURE AND MODELS

2.1 Architecture and Power Consumption

An architecture of an LTE, 4G eNodeBs having three sectors and four transceiver chains per sector is as shown in Figure 1 [9].

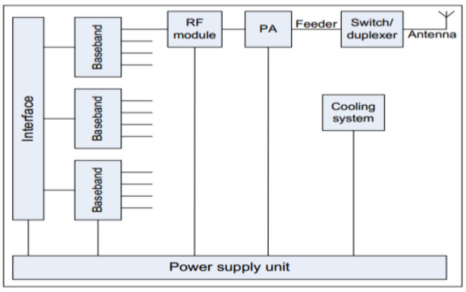

Figure 1: Architecture of a Three Sector LTE 4G eNodeB with Four Transmit Antennas

A transceiver chain consists of a radio frequency (RF) module which is an equipment for generating transmit signals to the mobile stations, a power amplifier (PA) that amplifies the transmit signals from the radio frequency module to a high power level suitable for transmission, an antenna feeder, a transmission antenna for radiating the signals, a switch/duplexer, a base-band module for both uplink and downlink, a power supply unit and a cooling system. A single power supply unit and a cooling system is normally shared by all the transceivers of an eNodeB [9].

2.2 Modeling the Power Consumption

The eNodeB power consumption model is used for evaluating the energy consumption of an LTE cellular network. The eNodeBs are modelled to consume power that is partly constant and partly varies with the load factor at any given instant of time. The mathematical representation of the instantaneous power consumed by the jth eNodeB is given as [10]:

$$P_j(t) = (1-q)\rho_j(t)P_j^a + qP_j^a \quad (1)$$

Where: $P_j(t)$ is the operational power of the jth eNodeB at time t; P_j^a is the maximum operational power of the jth eNodeB; $\rho_j(t)$ is the load utilization factor of the jth eNodeB at time t and $q \in [0,1]$ is called the energy-load proportionality constant of the eNodeBs which determines the level of dependency of the operational power of an eNodeB on it load utilization factor.

The operational power, P_j^a of the jth eNodeB is given as [11]:

$$P_J^a = aP_{TX,j} + b \quad (2)$$

Where: $P_{TX,j}$ is the transmit power of the jth eNodeB; The parameters 'a' and 'b' are termed as the power profile parameters [11].

The load utilization factor at the jth eNodeB, $\rho_j(t)$ at time t is given as [12]:

$$\rho_j(t) = \frac{N_{used.rb.j}(t)}{N_{rb.j}} \quad (3)$$

Where: $N_{used.rb.j}(t)$ is the number of used physical resource block at the jth eNodeB at time t; $N_{rb.j}(t)$ is the number of available resource block at the jth eNodeB.

Also, the number of used physical resource block at the jth eNodeB at time t is given as [12]:

$$N_{used.rb.j}(t) = \sum_{i=1}^{N_u} z_{i,j}(t)w_{i,t}(t) \quad (4)$$

Where: $z_{i,j}(t)$ is an assignment indicator variable which is equal to 1 when ith mobile station is served by jth eNodeB at time t and zero otherwise; $w_{i,t}(t)$ is the approximate number of physical resource block allocated by the jth eNodeB to the ith mobile station at time t.

The approximate number of physical resource block allocated by the jth eNodeB to the ith mobile station at time t is given as [13]:

$$w_{i,t}(t) = \frac{R_{i,j}(t)}{W_{RB}e_{i,j}(t)} \quad (5)$$

Where: W_{RB} is the bandwidth per physical resource block and it is 180 kHz; $R_{i,j}(t)$ is the bit rate requirement of the ith mobile station from the jth eNodeB at time t; $e_{i,j}(t)$ is the average bandwidth efficiency of the ith mobile station from the jth eNodeB at time t.

The average bandwidth efficiency of the ith mobile station from the jth eNodeB at time t is usually expressed using equation (6) when considering adaptive modulation and coding [13]:

$$e_{i,j} = \begin{cases} 0 & if\ \gamma_{i,j} < \gamma_{min} \\ \xi \log_2(1+\gamma_{i,j}) & if\ \gamma_{min} \le \gamma_{i,j} < \gamma_{max} \\ e_{max} & if\ \gamma_{i,j} \ge \gamma_{max} \end{cases} \quad (6)$$

Where: $0 \le \xi \le 1$ is the attenuation factor accounting the implementation loss; γ_{min} is the minimum signal-to-interference-noise-ratio; γ_{max} is the maximum signal-to-interference-noise-ratio; e_{max} is the maximum bandwidth efficiency and $\gamma_{i,j}(t)$ is the instantaneous received signal-to-interference-and-Noise ratio of the ith mobile station from the jth eNodeB.

The simulated traffic arrival pattern of an eNodeB follows a poisson distribution model given as [14]:

$$A(t) = \frac{p(t,\mu)}{\max[p(t,\mu)]} \quad (7)$$

$$p(t,\mu) = \frac{\mu^t}{t!}e^{-\mu} \quad (8)$$

Where: $A(t)$ is normalized traffic at time t, p is the poisson distribution function, t is the specific time in a day and μ is mean value where peak number of traffic occurred.

Figure 2 shows the approximate traffic arrival pattern of a real traffic arrival pattern in a cell with a mean value of 15 [14]. Thus, the peak traffic rate during a day occurs at 3:00pm

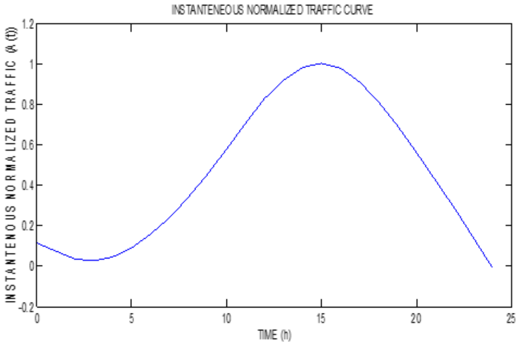

Figure 2: Instantaneous Traffic Normalization Factor

The load factor of each eNodeB in the LTE access network is normalized using the instantaneous traffic normalization factor $A(t)$. This is to make the traffic behaviour at each eNodeB of the propose model exhibits the temporal-spatial diversity of a typical mobile cellular network. The load factor of jth eNodeB after normalization is given as:

$$\rho_{j,new}(t) = A(t)\rho_j(t) \quad (9)$$

Where: $\rho_{j,new}(t)$ is the normalized instantaneous load factor of the jth eNodeB at time t; $A(t)$ is the instantaneous traffic normalization factor and $\rho_j(t)$ is the calculated load factor of the jth eNodeB at time t.

Thus, the instantaneous power consumed by the LTE access network of N eNodeBs at time t is given as:

$$P_N(t) = \sum_{j=1}^{N}[(1-q)\rho_{j,new}(t)P_j^a + qP_j^a] \qquad (10)$$

The total energy consumed by the N eNodeBs over a period of 24 hours can be computed using equation (11) and is termed as the original/base-case energy E_N^{orig}.

$$E_N^{orig} = \sum_{t=0}^{24} P_N(t) \qquad (11)$$

2.3 *Modeling Mobile Station Distribution*

In the proposed model, active mobile stations are selected randomly from a set of uniformly distributed mobile stations. Each mobile station is defined by its X and Y coordinates. Mobility is simulated by randomly selecting a set $(u_{x,i}, u_{y,i})$ of positions within a particular cell. The distance of a mobile station i from an eNodeB j is given as [15]:

$$d_{i,j} = \sqrt{((x_i - x_j)^2 + (y_i - y_j)^2)} \qquad (12)$$

Mobile stations are initially generated uniformly across the entire network. A set of active mobile stations is selected from the group of N_u uniformly distributed mobile stations belonging to each cell. Let D be the distribution factor of the mobile stations in each cell, such that the $X - axis$ is divided into $2(D+1)$ sub-divisions and the $Y - axis$ is divided into $4(D+1)$ subdivisions. If each point of intersection of the lines sub-dividing the $X - axis$ and $Y - axis$ mark the position of mobile stations, the number of mobile stations that are located within every cell for a given value of D can be expressed using:

$$N_u = 6D^2 + 8D + 3 \qquad (13)$$

2.4 *The energy estimation algorithm*

This algorithm comprises the step by step approach required to estimate the energy consumed by eNodeBs in the LTE access network while considering the random nature of mobile stations traffic classes and the daily traffic variation of the eNodeBs. The following steps of instructions are executed logically in order to effectively estimate the energy consumed by the eNodeBs at any time of the day. However the proposed model considers hourly traffic variation. The sequence of instructions are as follows:

i. Initialize timer.
ii. Generate the eNodeBs coordinate matrices.
iii. Generate the uniformly distributed mobile stations coordinate matrices.
iv. Randomly select active mobile stations and generate their coordinate matrices from the set of uniformly distributed mobile stations obtained in (iii).
v. For each of the active mobile station in (iv), randomly select a traffic type from the traffic category matrix (data rate and signal-to-noise-ratio).
vi. Compute the average bandwidth efficiency of each active mobile station based on its data rate and signal-to-noise-ratio.
vii. Determine the amount of resource block occupied by each active mobile station.
viii. Determine the total number of resource blocks occupied by the entire active mobile station of an eNodeB.
ix. Compute the load factor of each eNodeB in the LTE access network.
x. Compute the instantaneous traffic normalization factor $A(t)$.
xi. Normalize the load factor of each of the eNodeB.
xii. Compute the power consumed at each eNodeB at that instant and store the result
xiii. Increment timer.
xiv. Repeat (i) to (xiii) as long as the simulation time is greater than timer readings
xv. Output the total energy consumed by the eNodeB for the simulation time.

3. SIMULATION AND RESULT

3.1 *Simulation Setup*

The performance of the proposed energy estimation algorithm was evaluated by simulation. The simulated LTE access network consist of 37 macro cells with a distribution factor of 3 and 50 active mobile stations per eNodeB as a case study. The standard parameters used for the simulation are shown in Table 1 which are consisted with the simulation scenario recommended by 3GPP [16]

TABLE 1: STANDARD SIMULATION PARAMETERS

Parameter	Value
Transmit power of eNodeBs	46 dBm
System bandwidth	20 MHz
Carrier frequency	2 GHz
Bandwidth per Resource	180 kHz
Resource block per eNodeB	100

The radius of the macro cell is chosen as 0.5 km. Adaptive modulation and coding (AMC) set parameters are given as $\xi = 0.75$, $\gamma_{min} = -6.5\, dB$, $\gamma_{max} = 19\, dB$ and $e_{max} = 4.8\, bps/Hz$ following [13]. Five classes of real time constant data rate having data rates equal to 64 kbps, 128 kbps, 256 kbps, 384 kbps and 512 kbps are randomly selected by mobile stations. It is assumed that only one resource block can be allocated to a mobile station from any class. Thus, the required signal-to-noise-ratio of the five classes, calculated using equation (5) – (6), are found equal to $-4.1\, dB$, $-0.3\, dB$, $4.3\, dB$, $7.9\, dB$, and $11.1\, dB$ respectively. The eNodeBs power profile parameters are: $a = 21.45$ and $b = 354.44$ for macro cells. These parameters provide the maximum operating power of the eNodeBs. The energy load proportionality constant q ranges from 0 to 1. A snap shot of the simulated network is as shown in Figure 2.

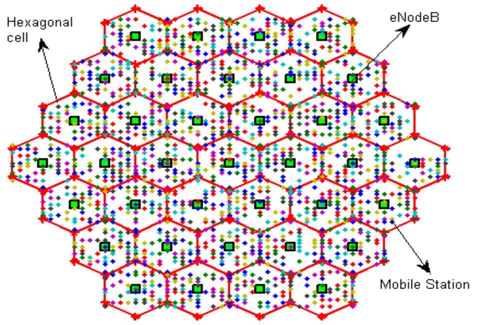

Figure 2: Simulated Network of 37 eNodeBs

3.2 Result and Analysis

The instantaneous power consumption of the 37 eNodeBs in the LTE access network was simulated for 24 hours for the energy load proportionality constants which ranges from $q = 0$ to $q = 1$ at the interval of 0.1 using equation (10). Figure 3 shows the plot of the results obtained.

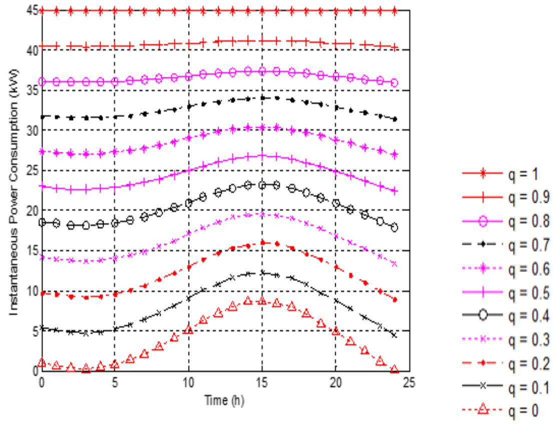

Figure 3: Instantaneous Power Consumption of the LTE Access Network

Figure 3 demonstrates the dependency of the instantaneous power consumption of the LTE access network as a function of the energy load proportionality constant. For $q = 1$, the instantaneous power consumption by the LTE access network is highest and constant because the power consumption does not vary with the normalized instantaneous traffic at the eNodeBs. However, as the value of q decreases the instantaneous power consumption of the LTE access network decreases, but varies more with the instantaneous normalised traffic at the eNodeBs. The instantaneous power consumption of the LTE access network is minimum at $q = 0$ and varies completely with the normalized traffic at the eNodeBs. Also the maximum instantaneous power consumption of the LTE access network was found to be at 15 hours which correspond to the peak hour traffic for the various value of q.

The hourly energy consumption of the LTE access network was simulated for 24 hours for energy load proportionality constants which ranges from $q = 0$ to $q = 1$ at the interval of 0.1. The simulation of the hourly energy consumption of the LTE access network was done using equation (11). Figure 4 shows the plot of the hourly energy consumption of the LTE access network eNodeBs.

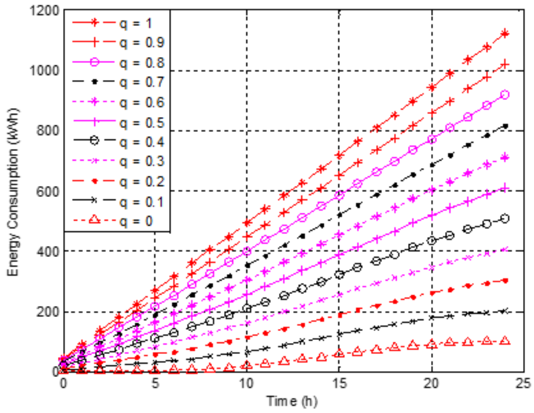

Figure 4: Hour Energy Consumption of the LTE Access Network

Figure 4 demonstrates the hourly energy consumption of the eNodeBs in a day while varying the energy load proportionality constant q from 0 to 1. The plot shows that the energy consumption increases as the time of the day increases. The energy consumption of the eNodeBs at a particular time of the day increases for higher value of energy load proportionality constant.

The daily energy consumption of the LTE access network while varying the energy load proportionality constant from 0 to 1 for 24 hours is tabulated as follows:

TABLE 2: VARIATION OF THE DAILY ENERGY CONSUMPTION WITH ENERGY LOAD PROPORTIONALITY CONSTANT

q	Daily Energy Consumption (kWh)
0.0	87
0.1	184
0.2	289
0.3	392
0.4	497
0.5	601
0.6	704
0.7	809
0.8	913
0.9	1017
1.0	1121

The plot of the variation of the daily energy consumption of the LTE access network with energy load proportionality constant is given in Figure 5.

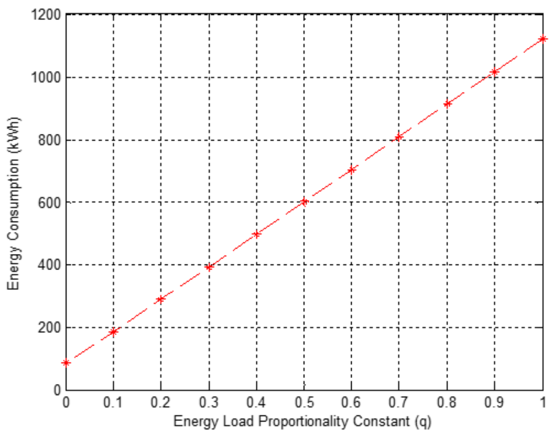

Figure 5: Energy consumption with change in Energy Load Proportionality Constant

Figure 5 demonstrates the variation of the energy consumption of the network with energy load proportionality constant. The daily maximum and minimum energy consumption of the simulated 37 LTE network eNodeBs are 1121 kWh and 87 kWh for an energy load proportionality constant of $q = 1$ and $q = 0$ respectively. Since $q = 1$ corresponds to constant energy consumption of eNodeBs requiring constant power consumption irrespective of traffic level, it resulted to the highest amount of energy consumption. Similarly $q = 0$ corresponds to the energy consumption of the eNodeBs that completely varies with the traffic level of the eNodeBs leading to the lowest energy consumption in the network.

4. CONCLUSION

The LTE network environment and the eNodeBs power consumption model have being developed. An energy estimation algorithm for the LTE eNodeBs has being developed and implemented in MATLAB version 2013b environment. The energy consumption in the eNodeBs has been simulated and analysed. The daily minimum and maximum energy consumption of the LTE network eNodeBs were found to be 87 kWh and 1121 kWh for the energy load proportionality constant of $q = 0$ and $q = 1$ respectively. The result showed that the energy consumption in the LTE eNodeBs increases linearly as the value of the energy load proportionality constant increases. Also, it was found that the dependency of the instantaneous power consumption of the eNodeBs increases as the values of energy load proportionality constant (q) tends to zero. Future work will consider integration a load/traffic sharing algorithm into the energy estimation algorithm to form an energy saving algorithm using sleep mode and self-organizing network.

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