An Energy Optimization Model (EOM) to reduce Mobile Service Providers Network Costs: a Multi-Objective Optimization Approach

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Abstract—— This paper presents an Energy Optimization Model (EOM) for Mobile Service Providers (MSP) that enables the optimization of power efficiency and the integration of optimum renewable and clean energy sources into the mobile network. The model approach drives both Operational Expenditure (OPEX) and Capital Expenditure (CAPEX) reduction via re-engineering power provisioning and site solutions. The features for the selection of Base Transceiver Station (BTS) type based on low power consumption are discussed within the context of establishing a direct impact on the site construction, power source type and dimensioning, and hence, the network cost structure. The K-mean clustering algorithm is used to cluster sites based on those features. HOMER® software was used to optimize the solution within each cluster of sites. This follows a multi-objective optimization function with power saving and CO2 emission as the dominant target factors and the cost, OPEX, Operation & Maintenance (O&M) as constraints. We focus on the lowest power optimization in this paper. Network energy optimization for between clusters (intra-cluster) is performed. Both Traffic and power profile data from Zain-Sudan MSP during the two month period from May-to-July 2013, is obtained and used as input to the EOM model. The optimum parameters for the set of solutions are then determined for deployment under budget & cost constraints. Renewable energy power generation profile for solar and wind from Laqawa site in the South-West of Sudan is used. Results indicate the effectiveness of the EOM model in finding optimum solutions per cluster of sites while facilitating for multi-objective optimization formulation across geographical regions and site types.

Keywords— BTS, Environmental Management System, Linear Programming, Optimization, Renewable Energy

I. INTRODUCTION

The Information and Communication Technology (ICT) Sector is responsible for about 2% CO2 emissions and about 1.5 of global CO2 emissions [1], the Radio Access Network (RAN) of Mobile Service Providers (MSPs) is a major contributor to this increase attributing to the growth in both the number of Base Transceiver Stations (BTSS) and tin number of subscriptions (reaching 3.7 billion unique subscribers worldwide). The EU commission was issue a call for ICT industry to reduce it CO2 footprint by 20% as early of 2015 [2]. In spite of this entire environment burden, mobile industry today is enabling significant reductions of CO2 emissions and energy costs across a range of sectors of the economy, and the opportunity exists for mobile communications to enable a great deal more savings. Total global electricity and diesel energy consumption by all mobile networks was approximately 120 tenwatt hours (TWh) in 2010, resulting in energy costs of $13 billion and responsible for 70 Mt CO2e. Almost 80 TWh of the energy consumption is from grid electricity, and over 40 TWh is from calorific value of the diesel used to power generators used in off-grid and unreliable grid locations. The 40 TWh from diesel corresponds to about 8 TWh of electricity generated, given a typical generator efficiency of 20%[4]. In addition to this inefficiency of Diesel Generators (DG), DG is the major source of pollution and releasing nitrogen oxides (NOx) a major cause of urban smog and a contributor of repository ailments and acid rain [3] highlighting the importance of power source selection, proper sizing and introducing Wind Turbine and Photo Voltaic (PV) as green energy sources.

GSMA’s Mobile Energy Efficiency MEE was established in order to benchmark Mobile Networks performance in energy efficiency and Green House Gas (GHG) emissions [4]. Zain Sudan (ZAIN SD) is a subscriber to this program since 2010. The 2011 benchmarking report showed that Zain SD is a high energy network on the three main KPIs: RAN energy per connection (11.8 KWh/connection), RAN energy per cell site(66.1MWh/cell), and RAN energy per unit traffic(28KWh/MB). It has actually the highest energy per cell site in the GSMA data set. The results indicates that in 2011 Zain had the potential to save about $12m per annum, which is 52% of its RAN energy costs, if it improved its performance to the top quartile. The $12m savings will require investment and not all of this will be cost-effective [5].

Based on this benchmarking results ZAIN SD is eager to develop an effective framework that aids in finding the most suitable solutions which bring the saving, optimize the CAPEX investment efficiency while at the same time reduce CO2 emissions. In 2010 a study was done to investigate the potential opportunities of saving through carefully studying the power demand, the structure, and efficiency of power usage in the RAN. The study recommended 3 key steps to reduce energy
consumption mainly through BTS Selection, power source optimization and site structure. The introduction of this generic energy policy enabled the introduction of alternative Power solutions, supported outdoor BTSs deployment and resizing generators, these three act as heuristic rules for the power source planning.

In order to utilize the annual CAPEX investment efficiently to achieve maximum savings and GHG reduction, there is a need for optimization function that searches for the optimum number of site per certain solution within a budget constraint. HOMER® (Hybrid Optimization of Multiple Energy Resources) software is a micro-power optimization model developed by NREL (National Renewable Energy Laboratory) USA and has wide acceptance of use in finding optimum alternative solutions and sensitivity analysis of the result [3]. HOMER is used in this paper to determine the suitable solution for each cluster then search for optimum number of sites according to budget constraint.

The rest of this paper is organized as follows. Section II presents the general heuristic rules for power source selection, section III presents the methodology of the EOM providing details on the site profile and clustering of the sites and the optimization function used. Section IV presents the results from the model.

II. HEURISTICS RULES FOR LOWERING THE POWER CONSUMPTION

Optimizing the power consumption of the RAN involves both the use of optimization tools and building on knowledge and experience and would usually be relevant only in a cross-vendor exercise. Three main rules are discussed within this context: i) proper BTS selection based on BTS power consumption, ii) power source optimization and ii) site structure. Those rules are looked at within the context of the multi-objective optimization framework roll-out and power source selection.

A. BTS Selection

Proper BTS selection for various capacities can minimize the site cost and when site density increase, operational and transmission costs tend to dominate rather than radio equipment and site costs. The BTS selection may vary if the BTS cost and power consumption are introduced to the set of selection criteria. For example an outdoor solution offering the same capacity result in savings of the shelter constructions cost and 2 Air Conditions (A/C) power consumption (~ 1.8-2.6 kW) from a typical A/C of 26000 Btu. It is reported that on average up to 25% reduction in power consumption [7]. There is a high potential to fundamentally optimize energy efficiency of BTSs through improved transmitter efficiency, system features, modular BTS and use of fresh air cooling [3], this will ensure low BTS load. EARTH research project (Energy Aware Radio and neTworking tecHnologies) which will complete this year was set to develop holistic approaches to new generation of energy efficient network product, deployment strategies, energy-aware Radio Resources Management (RRM), and advanced terminal capability to work with multi-RAT [1], with CO₂ consumption reduction target of 50%. Selecting BTS that is properly sized to fit those potential saving will be the first step in energy efficient network.

B. Power Source Sizing

The design and selection of power source wrt CAPEX, OPEX, and capacity follows the same method of selecting BTS in the network. Proper sizing of generator is needed as over-dimensioning occurs for various reasons (some are purely linked to procurement processes). The process of power source optimization with consideration of environmental impact is a challenge. To study the options for alternative power sources (wind,solar,hybrid) requires collecting site load profile data and power source model data (price, capacity model, replacement, emissions and O&M costs).

C. Site Structure

Tower Top site model where baseband processing is split from RF processing using Fiber to carry the RF signal has shown significant power savings up to 50% of RF power which make tremendous saving in AC power (1 W produce 20mW) [4]. Changing the sites structure will contribute further in CAPEX structure since feeder constitute 8% of site cost in addition to eliminating the need for shelter with the A/C which reduce the power consumption further down. Such features will accelerate site deployment, reduce Total Cost of Ownership (TCO) while facilitating the inclusion of solar within the BTS site

III. OPTIMZATION METHODOLOGY

In order to increase the population coverage in developing countries, rural areas with low traffic profile require BTSs with high transmission power. This is problematic due to the lack of electricity grid which count to increase the TCO and reduce the reliability of the services. If the traffic segmentation demands are matched with the optimum product, significant energy and TCO reduction can be gained [3]. The evolution of RAN has facilitated for different configurations, different BTS types, and different site housing solutions indoor/outdoor to meet differing loads and traffic profiles. The site features emerging from that difference map to different power consumption of BTSs. Based on this principal concept, the EOM methodology comprises of the following steps:

A. Site Features Selection

Sites features are numerous and could be selected based on several requirements. In addition to the system technology (WCDMA, HSPA, and LTE) and RAN range (range of KPIs interlinked to network status KPIs for ongoing RAN operation), below are few features that we feed as input in the EOM optimization model.

1) Geospatial data

The latitude and longitude used for solar insolation (altitude is important in wind energy modelling).

2) Site Solution

The Site solution is selected based on the specific network purpose and functionality needed. It helps to clusters sites according to load and traffic correlation. Typical solutions in a RAN include single-RAT, multi-RAT, co-siting, truck, switch, hybrid (radio & truck). The number of nodes from each type
and their power consumption characteristics results in different options for cost and power reduction.

3) Site structure
Unlike the “bottom down BTS” structure, which comes with half power dissipation in the coaxial feeder, the “tower-top design” offers reduced overall power consumption. Power and load profile data from Main-Remote site is used in this paper.

4) Radio Configurations
The 3-sector (A, B, C) radio TRU configuration technology and combination directly affects the power consumed. Multicarrier- Power Amplifier (MC-PA) technology improves the coverage/capacity while changing the power consumption characteristics [8].

5) Power Source and its associated system capacity
Whether it is a grid, diesel generators or batteries, the reliability and capacity of power source directly influences Total Cost of Ownership (TCO) and site cooling solutions and its efficiency.

6) Traffic profile – Instantaneous bps carried
7) Carried Traffic – In Erlang

B. Site Clustering
Given the set of site features space $F = \{f_1, f_2, \ldots, f_n\}$, $f_i$ being the feature, there is a matched cluster $c_i$ in the space $C = \{c_1, c_2, \ldots, c_m\}$, and this matching is performed using the K-means clustering in SPSS to maximize the similarity measure [6]. The cluster’s center is then taken as the representative site for passing to the next step. By applying K-Mean clustering, this clustering techniques split the sample of each solution types among different clusters.

C. Finding Optimum Solutions
Each cluster $c_i$ represent a group of sites with similar characteristic. The load range of the cluster (Minima and Maxima$[L-, L+]$) around the cluster centers is taken into account in the load sensitivity. The load values are shown in Table 2. Then, the optimum power source solution is calculated using HOMER® with fine sensitivity capability. The model cluster (cluster that has high number of sites. That is Cluster 4, 1 and 2 for BTSs 3900, 3900A and DBS3900 respectively from Table 1 for each site structure is used in the simulation.

We select a site in the South West of the Sudan to represent all sites especially in the case of renewable resources since it highly dependent on spatial coordinates. Laqawa site is selected and a corresponding solar and wind power profiles are generated as input to the simulation. The average solar radiation is 5.5 kWh/m²/d and wind speed of 3.6 m/s. The solar and wind profiles are taken from the wind power pilot study and business case in [9].

The input parameters to the simulations are referenced to a Base case scenario with two 30KVA generators as power source with 71.53 kWh/d average load and load factor of 0.5369 as shown in Table 2. The Fuel price is fixed at $0.4/L and the Interest rate at 9%, the inflation rate used is 12% (reported by Central Bank of Sudan as 36.9% which indicate the need for careful considerations). The economic and cost calculations are set for 25 years.

D. Report Optimized Solutions and KPIs
When each site associated with a nearby cluster has an optimum solution, the search across the number of sites will be deployed from each solution and conducted using a target function limited by the allocated budget $B$ and targets to maximize the benefit function $y = z(GHC, OPEX_saving)$. Searching for optimum solutions structure is performed using linear programming method in a further study.

The power source planning usually follows the same similarity measures to determine the best matched solution to a certain site cluster. This is then reported and systematically documented to facilitate for power savings and cost reductions methods.

The workings of the EOM is shown in Figure 1. The concept, in contrast to previous research, does not assume KPIs but rather develops the KPIs as outcomes of the optimization process across the BTS selection, power sizing and site structure dimensions [7].

IV. SIMULATION PARAMETERS AND RESULTS
Analysis of the power consumption data of two month (June-July) 2013 for 500, 59 and 166 BTSs of ZAIN-SD network corresponding to Huawei BTS3900(indoor) , BTS3900A (outdoor) and DBS3900 (Main-Remote site) BTSs respectively, is performed.

A summary of the K-means clustering is depicted in Table 1. Cluster 4, 1 and 3 are used as input to simulations for indoor, outdoor and Main-Remote sites respectively. Table 4 shows the site features used and the corresponding cluster centres.

Cluster load parameters for the HOMER® input files for the simulations are shown in Table 2. It shows the input parameters to the simulation. These are the scaled load constraints adapted from the cluster centres. The Huawei OSS iManager software [11] is used to collect energy measurements and to extract a 24hr power profile for input to the simulation.

An average power and Diesel Generator profile is then obtained from the period of one month (23/June-21 July). The cluster centre profile assume a linear scaled load profile which is used for each BTS site structure/type. We estimate the Fuel curve from the Fuel and Energy Consumptions of 14 sites during two weeks (1-18/August 2013) using least squares regression. The power profile for the generators is shown in Figure 2.

Solar and wind Renewable resources for the power source selection are used in the simulation. The abundant solar energy in Sudan (average daily solar insolation is nearly 5-7 kWh/m²) is source to be yet fully tabbed into by MSP. Sudan is in the 9th position in the world for solar radiation (recorded in 2008) with a potential of generating 8,702,766,346 MWh/year [12].
The field of wind energy resources has promising also rewards in terms of electricity production. South East Sudan and the North West regions of Sudan are identified to have sufficient wind average speed for use in telecoms [13]. Careful study of the number and size of each power source component with regard to the available energy resources is also important further optimization to consider from the cluster solutions obtained in this paper [14].

The Fuel Prices has experience ramp rise since the session of South Sudan while at the same time there is regional fuel and transportation costs price differences. A range of 0.4$/L – 0.633$/L fuel price is used. It is noted that 10% of the network outage is due to the lack/shortage of fuel and due to fuel logistical issues in Sudan.

Table 1. K-Means clustering results

<table>
<thead>
<tr>
<th>Cluster</th>
<th># BTS3900 sites</th>
<th># BTS3900A sites</th>
<th># DBS3900 sites</th>
<th>Total sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38.000</td>
<td>40.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>34.000</td>
<td>7.000</td>
<td>135.000</td>
<td>136.000</td>
</tr>
<tr>
<td>3</td>
<td>150.000</td>
<td>12.000</td>
<td>30.000</td>
<td>182.000</td>
</tr>
<tr>
<td>4</td>
<td>277.000</td>
<td>-</td>
<td>-</td>
<td>166.000</td>
</tr>
<tr>
<td>Total sites</td>
<td>499.000</td>
<td>59.000</td>
<td>166.000</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Cluster Load Parameters Input for the Simulation

<table>
<thead>
<tr>
<th>Power Source</th>
<th>BTS3900 Cluster</th>
<th>BTS3900A Cluster</th>
<th>DBS3900 Cluster</th>
<th>Base Case Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaled Average Load (kWh)</td>
<td>65.162</td>
<td>22.224</td>
<td>18.460</td>
<td>71.532</td>
</tr>
<tr>
<td>Scaled Peak Load (kW)</td>
<td>5.0273</td>
<td>1.070</td>
<td>1.4972</td>
<td>5.5516</td>
</tr>
<tr>
<td>Load Factor</td>
<td>0.5401</td>
<td>0.5125</td>
<td>0.5137</td>
<td>0.5369</td>
</tr>
</tbody>
</table>

Table 3. Optimum Solutions Results per cluster from the Simulation

<table>
<thead>
<tr>
<th>Power Source</th>
<th>BTS3900 Cluster</th>
<th>BTS3900A Cluster</th>
<th>DBS3900 Cluster</th>
<th>Base Case Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total net present cost($)</td>
<td>451019</td>
<td>67607</td>
<td>89048</td>
<td>431604</td>
</tr>
<tr>
<td>Levelized cost of energy($/kWh)</td>
<td>0.341</td>
<td>0.349</td>
<td>0.364</td>
<td>0.326</td>
</tr>
<tr>
<td>Load Consumption (kWh/yr.)</td>
<td>36,498</td>
<td>5,336</td>
<td>6,737</td>
<td>36,498</td>
</tr>
<tr>
<td>Cost/COE($)</td>
<td>0.476939</td>
<td>0.3641062</td>
<td>0.364458</td>
<td>0.37258</td>
</tr>
<tr>
<td>Carbon Dioxide (kg/yr.)</td>
<td>32765</td>
<td>835</td>
<td>1615</td>
<td>32830</td>
</tr>
</tbody>
</table>

The figures 3-6 shows the base case sensitivity space and the optimal solution from the simulation for the indoor, main-remote and outdoor site clusters respectively. The Y axis is the fuel price is L/$ and x axis is the scaled load average in kwh/day. Figures 3-6 shows the base case sensitivity space and the optimal solution from the simulation for the indoor, main-remote and outdoor site clusters respectively. The Y axis is the fuel price is L/$ and x axis is the scaled load average in kwh/day. Figure 4 shows that for the Indoor cluster of 277 sites, for loads less than 74 kwh/day, a rule of thumb is to use solar PV panels. This is the solution with the minimum COE. Whereas Figure 5 shows that for the outdoor sites cluster of 40 sites, this rule of thumb threshold is 73.6 kwh/d (PV solar and wind combination for the power source selection). For the main-remote sites cluster of 136 sites, results indicate that for loads less than 74 kwh/d, the combination of wind and PV provide the optimum power source selection. In this paper we do not aim to compare sites or clusters as the loads constraints are different but rather to depict and show the usefulness of the EOM model for inter-cluster and intra-cluster site optimization. While we have looked at costs and costs of energy constraints, the optimization could be repeated to constraint for example the GHC emissions. So the optimization approach is modular and flexible.

Figure 7 shows the fuel price against the inflation rate. This figure is provided due to the recent economic changes in Sudan which directly influences the selection process for the optimum solution for cost constraints. For high inflation rates, which is the case for Sudan, the optimization recommends – as the fuel price decreases- investing in solar PV panels. Such conclusion could be of interest when comparing another level of the energy optimization for example intra-cluster variations within different regions of the country.

It is also noted that the indoor optimal solution and use of A/C lead to over dimensioning of the generator size. It is clear that most telecommunication sites can be served by 10KW generators for certain types of A/C without power shortage. In this paper, the maximum capacity of 30KW generator is used to scale the curve slope for the 10KW generator before inputting to the simulation in order to generate the power profile for the 10KW generator. Hence we note the effect on the economics and environmental burden of the solution.

Using the base case scenario as a reference, it is noted that the Indoor cluster results in the highest net present cost as well as high cost/COE($). The outdoor solution greatly reduces those costs. The main-remote structure have the lowest cost/COE($) but slightly higher net present cost and carbon emissions compared to the outdoor solution.
Table 4. Cluster Centers for various site features

<table>
<thead>
<tr>
<th>Site Feature</th>
<th>Clusters- BTS3900 sites</th>
<th>Clusters- BTS3900A sites</th>
<th>Clusters- DBS3900 sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A (# TRUs 900 Hz)</td>
<td>4.79</td>
<td>4.65</td>
<td>4.15</td>
</tr>
<tr>
<td>B(# TRUs 900 Hz)</td>
<td>4.76</td>
<td>4.85</td>
<td>4.31</td>
</tr>
<tr>
<td>C(# TRUs 900 Hz)</td>
<td>4.76</td>
<td>4.44</td>
<td>4.19</td>
</tr>
<tr>
<td>A1(# TRUs 1800 Hz)</td>
<td>2.42</td>
<td>4.21</td>
<td>2.07</td>
</tr>
<tr>
<td>B1(# TRUs 1800 Hz)</td>
<td>1.95</td>
<td>4.09</td>
<td>2.28</td>
</tr>
<tr>
<td>C1(# TRUs 1800 Hz)</td>
<td>1.50</td>
<td>3.56</td>
<td>2.08</td>
</tr>
<tr>
<td>Avg GSM900_TRUs</td>
<td>14.32</td>
<td>13.94</td>
<td>17.65</td>
</tr>
<tr>
<td>Avg GSM1800_TRUs</td>
<td>5.87</td>
<td>11.85</td>
<td>6.43</td>
</tr>
<tr>
<td>Avg Power_Consumption(KW)</td>
<td>25.45</td>
<td>32.33</td>
<td>25.42</td>
</tr>
<tr>
<td>Average Erlang</td>
<td>2171.58</td>
<td>1601.77</td>
<td>994.68</td>
</tr>
<tr>
<td>Average_Data (GBytes)</td>
<td>1227.89</td>
<td>4320.52</td>
<td>2384.46</td>
</tr>
</tbody>
</table>
From the inter-cluster optimization results, more accurate conclusions could be drawn about the best areas in the network for optimization intervention. As we hinted to above, intra-cluster optimization would be the next logical step to isolate variations within the same cluster and achieve more energy and cost savings.

II. CONCLUSION

An Energy Optimization Model (EOM) for Zain-Sudan MSP using a cost function constraint is presented in this paper. The optimization approach is built on three rules: BTS type selection, power source selection and site structure rules. The optimization methodology starts with site features, and then site clustering using utilizes the K-Means clustering algorithm, and continues to find the optimum solutions for each cluster. Simulations results are presented for three Huawei site types – Indoor, Outdoor and Main-Remote using load constraints for the cluster centres. Accurate generator fuel profiles are fed to the simulation. Results indicate the usefulness of the model in quickly finding model solutions for large number of sites belonging to clusters and scattered at different geographic locations in the MSP network. The innovative approach of EOM will fundamentally change the way MSP address energy & network cost issues and promises a long term cost savings, business process and growth strategy. Further work include inferring suitable KPIs from for each cluster/site type, investigating the impact of site feature selection and investigating intra-cluster optimization.

REFERENCES
