Energy Efficiency Analysis for LTE Macro-Femto HetNets

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Abstract—This paper presents a simulation based energy consumption analysis of a heterogeneous network (HetNet) consisting of Long Term Evolution (LTE) macro-cells and LTE femto-cells. Two potential areas of energy savings are evaluated, namely, sleep modes and spectrum assignment. Sleep modes are demonstrated with practical component level power models, resulting in considerable energy savings. Three spectrum allocation scenarios are considered: A) macro and femto nodes with frequency reuse 1 (no coordination), B) macro and femto nodes with frequency reuse 2, and dedicated femto channel with frequency reuse 1, C) reduced bandwidth macro and femto nodes with frequency reuse 2, and dedicated femto channel with reuse 1. The three mentioned scenarios are also compared against an ideal case, i.e. when nodes experience no interference. Our analysis indicate that static partitioning of spectrum is highly energy inefficient and calls for a need to develop dynamic frequency domain intercell interference coordination techniques for HetNets.

Index Terms—Femto Access Points, Energy Efficiency, Evolved Packet Core.

I. INTRODUCTION

The ever increasing demand for higher data rates and better quality of service over the last mile access networks has motivated the network operators to consider deployment of heterogeneous networks (HetNets) that comprise of macro cells and densely deployed small cells. This is considered as a promising solution for future networks [1].

According to a recent survey [2], by the end of 2012 a total of more than 36 million femto access points (FAPs) are expected to be in operation worldwide. It is estimated that a single femto access point FAP requires 12W power (105.12 kWh/annum); thus, the total energy consumption of all FAPs will amount to 3.784E9 kWh/annum. This would produce up to 2.05 million tonnes of CO₂ per year [2].

Majority of the existing work on HetNets have focused on improving spectral efficiency (SE), neglecting the high energy consumption effects of dense HetNet deployments to the environment. Though a detailed simulation based long term evolution (LTE) scenario is presented in [3], validating the fact that addition of smaller cells improves the SE as well as the energy efficiency (EE) of the network. This work is based on addition of few FAPs in the network, whereas based on expected heavy deployment of FAPs and considering the practical limitation that a limited number of user equipments (UEs) can be served by a FAP; we focus on high densities of FAPs. Some valid SE and EE investigations are also presented in [4] for mass deployment of FAPs but we emphasise on the fact that it is important to define for our simulations, an individual modular based energy model for different states of FAPs to clearly conclude our investigations.

A transmission node can be in a number of states, along with load condition. Load on the node mainly effects the total transmission energy consumption, where as the states of the node determine its circuit energy consumption. Other than the fully operation state, a macro/femto node can be put to ideal or sleep mode where most of the modules are turned off. Statistics show that indoor home and enterprise FAPs are not utilised about half of the hours of a day, hence the operational energy being wasted. Switching the node to sleep mode significantly reduces the energy consumption.

The simplest sleep mode technique is where the sites are put to idle mode, shutting down almost all the modules based on a fixed timer. This timer is manually configured for a statistical traffic cycle, usually during few hours of night when user traffic is very low [5]. A drawback of such a scheme is very obvious that since the sleep mode cycle is static and only based on traffic statistics, in event of unusual activity the system performance might degrade or needs to be manually reconfigured. In case of small home base stations such conditions shall arise on frequent basis and is not feasible to reconfigure. Adaptive sleep modes based on dynamic traffic monitoring are discussed in [6], [7].

The sleep/wakeup function of the node can be categorised into three types; node controlled, UE controlled and core network controlled [8]. In the core network controlled mode, the core network sends sleep/wakeup message to the FAP over the backhaul link which can be a logical X2-Interface [8], [9]. We in our simulations make use of this core network controlled sleep mode assuming there is a control interface between the FAPs and Evolved Packet Core (EPC).

The rest of this paper is organised as follows. Section II presents the system model consisting of the power model and system architecture considered. Performance analysis for sleep mode enabled FAPs and different spectrum allocation scenarios is given in Section III. And, Section IV concludes our investigations with future directions.

II. SYSTEM MODEL

A. Energy Consumption Model and Performance Metrics

The EARTH project has done extensive work for the energy models of different base station types by hardware
measurements. Our power models are based on the framework defined in the EARTH project [10]. Since we are aware that for larger sites, macro and micro, more than half of the energy consumption is from the power amplifier (PA) due to high transmit power. Where as in case of FAPs this PA energy consumption equals to less than one third [11].

It is worth mentioning that the numerical values in Table I show that the energy consumption for FAPs is negligible as compared to macro nodes. But since the deployment of FAPs is expected to be very high, the constant power consumption of these small nodes would supersede the macro node’s energy consumption. To control this constant energy utilization specifically from the circuit part of the FAPs, it is important to enable sleep modes discussed in the previous section. From Table I, the total energy of the node is calculated as the sum of the following terms in (1).

\[
P_{\text{Active}} = P_{\text{DL}} + RF + BB_{\text{DL}} + DC + PS + CL \quad (1)
\]

\[
P_{\text{Idle}} = RF + BB_{\text{DL}} + DC + PS + CL \quad (2)
\]

\[
P_{\text{Sleep}} = RF + DC + PS \quad (3)
\]

\[
P'_{\text{Sleep}} = \alpha P_{\text{Sleep}} \quad (4)
\]

Where, \(P_{\text{DL}}\), \(RF\), \(BB_{\text{DL}}\), \(DC\), \(PS\), \(CL\) are the individual power consumed by power amplifier, small signal RF transceiver, base band, DC-DC power supply, main power supply and active cooling respectively. These modules can be seen in Fig. 1. When the FAPs are not serving any users they are considered to be in idle mode, consuming the circuit power as expressed in (2), this circuit power consumption is also known as power loss. Equation (3) expresses the sleep mode energy consumed by the FAP. Further considering future hardware improvements we use (4), where \(\alpha\) ranges between 0 and 1. We in this paper, assume \(\alpha\) to be 0.5. Equation (5) is used in our simulations to calculate the total energy consumed for the whole operational time in each case, expressed as \(T\).

\[
E_{\text{Total}} = \sum_{t=0}^{T} P_t \Delta t \quad (\text{Joules}) \quad (5)
\]

Where, \(P_t\) is the instantaneous power corresponding to the state of the nodes at a specific unit of time \(\Delta t\), with \(\Delta t\) considered to be equal to one transmission time interval (TTI) i.e. 1ms.

\[
E_b = \frac{E_{\text{Total}}}{Data_{\text{Total}}} \quad (\text{Joules/bit}) \quad (6)
\]

The most commonly used energy consumption metrics in literature are total energy consumed in Joules and Energy/Bit i.e. the total energy consumed to transfer one bit of information. We use these two metrics to present our findings.

B. Network Architecture

Our network topology consists of a single LTE eNodeB (eNB) placed in the centre of the area of interest, a number of uniformly random distributed LTE FAPs and UEs. In order to analyse the energy consumption of the network we will be transferring a fixed file for each user from a remote host to the user end. The energy consumption would be analysed for a fixed file downlink traffic between eNBs/FAPs and UEs. The simulation would run until every user’s file gets completely transferred. Since the file transfer would be simultaneous for all the users with all arrivals at the beginning of the simulation, proportional fair (PF) scheduler would be used for equal resource allocation to each user. We present our results with at least ten random repetitions to average out the results. We also ignore delays, building losses, shadowing and fading to keep our investigations simple and clear. To make our assumptions realistic, we put up a limit of maximum four users attached to each FAP at any instance, the remaining users are served by the macro node. This attachment is based on the maximum received signal to noise ratio (SNR) at the user from nearby nodes. Network Simulator 3 (NS3) is used for our simulations.

The LTE architecture can be seen in Fig. 2. The remote host is connected to the EPC with a point to point link. The
TABLE II: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Macro eNodeB</th>
<th>Femto HeNB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>1</td>
<td>Upto 200</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2.1 GHz</td>
<td>2.1 GHz</td>
</tr>
<tr>
<td>Carrier bandwidth</td>
<td>15-20 MHz</td>
<td>5-20 MHz</td>
</tr>
<tr>
<td>Path loss model</td>
<td>$128.1 + 37.6 \log_{10}(d)$</td>
<td>17 dBm</td>
</tr>
<tr>
<td>Number of UEs</td>
<td>Upto 200</td>
<td></td>
</tr>
<tr>
<td>Noise Figure</td>
<td>9dB</td>
<td></td>
</tr>
<tr>
<td>Thermal noise density</td>
<td>-174 dBm/Hz</td>
<td></td>
</tr>
<tr>
<td>Node Placement</td>
<td>Random Uniform Distribution</td>
<td></td>
</tr>
<tr>
<td>Cell Association</td>
<td>SNR based</td>
<td></td>
</tr>
<tr>
<td>Traffic model</td>
<td>FTP</td>
<td></td>
</tr>
<tr>
<td>File size</td>
<td>1 MB per user</td>
<td></td>
</tr>
<tr>
<td>Scheduler</td>
<td>Proportional Fair</td>
<td></td>
</tr>
</tbody>
</table>

packets from the remote host are forwarded with the specific UE’s Internet Protocol (IP) address, these packets go through the EPC (SGW/PGW) which is the gateway IP address of the UE subnet. The standard LTE protocols are carried out, the signalling gateway (SGW) determines the eNB to which the UE is attached by tracing the destination IP address. Packets are classified using traffic flow templates (TFTs) to identify the belonging evolved packet system (EPS) bearer. EPS bearers have one to one mapping to S1-U hence the packets are forwarded with the added GTP-U header over the user datagram protocol (UDP) socket to S1-U P2P link address, tunnel end point identifier (TEID) of eNB. The eNB strips the IP/UDP/GTP header of S1 protocol and uses the radio bearer ID (RBID) determining the PDCP/RLC instances to forward the packet to the intended UE over the LTE radio interface. The LTE radio interface is expressed in the form of physical resource blocks (PRBs), each user gets a specific share of the radio interface or a number of PRBs based on the scheduler. Since in our case PF scheduler is being used with non fading environment, every user gets equal amount of resources over a period of time.

The adaptive modulation and coding takes place at the eNB medium access control (MAC) layer, where the logical channels from radio link control (RLC) layer are converted to physical channels. On the basis of this received signal strength at the UE the SE is calculated as in (8). This SE value is converted to a channel quality information (CQI) value ranging from 0-15 according to [3GPP R1-081483] which is reported back to the eNB. The eNB converts this CQI to modulation and coding (MCS) value and selects the appropriate transport block (TB) size. A maximum MCS value would ideally return the maximum throughput. The signal to noise and interference ratio (SINR) is calculated at the UE according to (7).

$$SINR = \frac{S_i}{I_i + N}$$  \hspace{1cm} (7)

$$\eta = \log_2(1 + \frac{SINR}{\Gamma})$$  \hspace{1cm} (8)

$$\Gamma = -\ln(5BER) / 1.5$$  \hspace{1cm} (9)

Where, $S_i$ is the desired signal and $I_i$ is the co-channel interference at a specific PRB. $N$ is the thermal noise. $\Gamma$ is known as the SNR gap, i.e. the target BER based gap between the information theoretic bound and the performance of the practical modulation and coding schemes [13] [14]. BER target is considered as $5 \times 10^{-5}$ [13]. For the purpose of calibration, Fig. 3 shows a plot of received SNR at the UE against the calculated MCS index, this further determines the TB size for the UE at a specific PRB.

### III. Performance Analysis

A scenario for explaining the interference amongst nodes operating within the same EARFCN can be seen in Fig. 4. The overall network energy consumption is shown in Fig. 6 for an ideal case when none of the transmit nodes interfere with each other. The solid curves show a decreasing trend as the number of FAPs are increased, similarly we can observe that for less number of users in the network this energy saving is very nominal or in certain low demand cases even exceeds the energy consumption without any FAPs. The major reason for this trend is due to the circuit energy consumed by the FAPs even when they are not serving any users. To address this we simulate a network with sleep mode enabled FAPs. As soon as the attached users are completely served by each
FAP, the node goes into a sleep mode where only specific modules are operational according to (4). The dotted curve in Fig. 6 shows a noticeable improvement in energy consumption for high as well as lower data requirements. Our simulations are based on the completion of the data files to each user, these improvements in energy consumption would be more noticeable if the simulations are considered over longer fixed time period.

Sleep mode enabled FAPs do resolve the issue of reducing the energy consumption of underutilised nodes, but the operational energy also plays a major role. To evaluate the operational energy we simulate different spectrum configurations of LTE macro-femto HetNets. We consider a case where the macro and FAPs operate under same absolute radio frequency channel number (EARFCN), hence there is interference amongst the FAPs as well as with the macro node; we call it Case A. We also simulate a case where the FAPs operate within the same EARFCN value where as the macro node operates at a different band, hence there is only interference amongst the FAPs; We call it Case B. An explanation of the considered cases for different EARFCN configurations is presented in Fig. 5. A comparison of the above mentioned EARFCN configurations (Case A and B) with the ideal case where there is no interference amongst the nodes, is presented in Fig. 7. The dashed curve shows Case A. We can deduce that the interference amongst the nodes deteriorates the system performance or delivered throughput, hence increasing the energy consumption of the network as compared to the ideal case. We can also observe that in the higher user density regions the energy consumption goes up when there are fewer FAPs deployed, as the fewer FAPs serve lesser number of users where as cause interference to the macro users. As the density of FAPs increase the energy consumption relatively comes down. The dotted curve in Fig. 7 narrates the energy consumption for Case B. We can deduce that increment in number of FAPs is energy efficient as in the ideal case, but as the density of FAPs increases so increases the interference for the femto users. Hence the righter side of the curve moves up as compared to the ideal case.

The expected spectrum crunch limits the operators to a limited operational bandwidth. To address this concern we compare Case A with Case C. In Case C, the limited 20MHz Bandwidth is divided in a 15MHz and 5MHz portion for macro node and FAPs respectively. This static spectrum separation avoids the interference from the FAPs to the macro users but in return reduces the bandwidth for the macro node as well as for the FAPs.

The dashed curve in Fig. 8 depicts the energy consumption for Case C. We can clearly see that such a static configuration is not at all energy efficient. The curve shows a slight decrease in energy consumption for low density of FAPs indicating that there is less interference amongst the FAPs as well as the macro node is also offloaded but as the number of FAPs increases the macro node gets offloaded but the smaller FAP
bandwidth and the interference amongst them makes such a configuration highly energy inefficient. We also present a comparison of Case A, B and C with the ideal case in Fig. 9. It is visible that static partitioning of the spectrum is not at all effective, in fact has the worst performance.

With this discussion we come to a conclusion that sleep mode enabled FAPs save a noticeable amount of energy in any spectrum allocation configuration, where as the spectrum allocation for each FAP is another important aspect to consider in terms of not only the system throughput performance which is been widely studies in literature, as well as from green communications point of view.

IV. CONCLUSIONS

In this paper, a LTE Macro-Femto HetNet scenario is analysed from EE point of view. Realistic power models are used in our simulations to calculated the overall energy consumption for different spectrum configuration scenarios. We simulated HetNets with sleep mode capable femtocells to analyse the amount of energy savings for idle nodes. Our future work would be focusing on developing sleep and wakeup algorithms considering important factors like dynamic traffic states and wakeup delays. It is also indicated with our investigations that there is a potential for energy savings by developing EE spectrum management techniques, mitigating interference and dynamic bandwidth allocation for heterogeneous networks.

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REFERENCES


