Power Control in Opportunistic and Efficient Resource Block Allocation Algorithms for Green LTE Uplink Networks

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***Abstract*—The energy efficiency in wireless networks is currently a central concern of research. We propose in this paper a new energy efficiency scheme which allocates the mobile's transmission power in function of the allocated Resource Blocks (RB) and the channel conditions of the user on the allocated RBs. We focus on the energy efficiency of the Opportunistic and Efficient Resource Block Allocation (OEA) algorithm and its variant adapted to the Quality of Service (QoS) of the traffics: the QoS based OEA for LTE uplink networks. The OEA and the QoS based OEA allocate the RBs to UEs efficiently and with respect to the SC-FDMA constraints, such that, for one user, contiguous RB are allocated, and the same Modulation and Coding Scheme (MCS) is used over the whole allocated RBs. Once RBs are allocated to UEs, power control is then applied to the mobile's transmission power considering the MCS used and the channel conditions. This energy efficiency allows users to achieve the same throughput than before the power control and does not affect the MCS selection established at the RB allocation step. This new scheme allows the transmission of a high number of bits per Joule.**

Keywords: Energy Efficiency, Power control, Resource Block allocation, SC-FDMA, LTE.

I. Introduction

Nowadays, the telecommunications and information communities are facing a more and more serious challenge with the increasing traffic requirements in current and next generation mobile networks associated with the popularity and enhacend functionalities of smart terminals. Then the energy consumption of wireless communication networks and the relevant global CO_2 emission show continuous growth for several years. It has been pointed out that currently 3% of the world-wide energy is consumed by the information and communication technology infrastructure that causes about 2% of the world-wide CO_2 emissions [1]. Energy costs to the mobile's operators a half of the operating expenses [2]. Moreover, improving the energy efficiency as the resource efficiency is not only beneficial for the global environment, but also makes commercial sense for telecommunication operators supporting sustainable and profitable business.

Within the framework of green communications, a number of technical approaches are investigated in the literature. We focus on the energy efficient wireless transmission techniques on uplink 3rd Generation Partner Project (3GPP) Long Term Evolution (LTE) networks. The 3GPP standard adopted, for the LTE networks, the Orthogonal Frequency Division Multiple Access (OFDMA) and the Single Carrier Frequency Division Multiple Access (SC-FDMA) for both downlink and uplink respectively. The relevance of the SC-FDMA on the uplink is that in addition to the OFDMA advantages, the SC-FDMA generates a low Peak to Average Power Ration (PAPR), by considering the whole allocated Resource Blocks (RB) as a single carrier. The reduction of the PAPR can be more than 25% compared to the OFDMA technique [3]. This advantage not only leads to the decrease of the equalizer complexity and the cost of the mobile terminal by the same way, but also to the decrease of the mobile energy consumption. Using the SC-FDMA technique on the uplink is an encouraging start but it can not increase much the mobile battery life. Therefore, saving the battery life of the mobile's terminal becomes the central concern of the researchers. Works on this scope focus on: (i) maximizing the available energy and (ii) minimizing the energy consumption. The available energy can be increased by (a) the battery capacity improvement which is, unfortunately, not sufficient and is limited due to design aspect, and (b) using the surrounding energy sources, such as kinetic, thermal, and solar energy [4]. The mobile's energy consumption can be minimized by first, optimizing the hardware energy consumption, such as choosing power efficient components and applying power management like performing sleep modes for inactive hardware [5] or the Discontinuous Reception (DRX) in idle mode [6]. The second solution to minimize the mobile's energy consumption is the adjustment of the mobile's parameters, like the brightness display and the processor speed for some applications. In the radio access network, the power consumption reduction is performed by a power control of the mobile's transmission power. However, reduction on the mobile transmission power could lead to low user's Signal to Interference plus Noise Ratio (SINR) and a low individual throughput. Therefore, the power control should take into account the required SINR which allows the User Equipment (UE) to use the same Modulation and Coding Scheme (MCS) and reach the same throughput as before power control application. This study focuses on the energy efficiency of the terminals performed by a power control of the UE's transmission power considering the Resource Block (RB) allocation policy and the MCS used

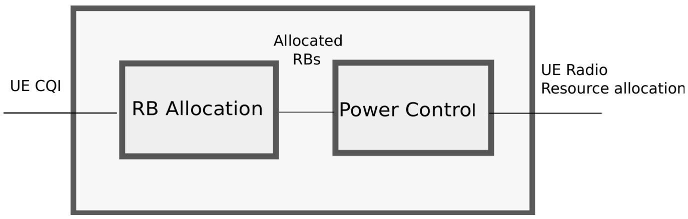

Fig. 1. Energy efficiency scheme

by each UE. We study the energy efficiency according to the Opportunistic and Efficient RB Allocation (OEA) algorithm and the Quality of Service (QoS) based OEA algorithm which is adapted to the QoS traffic, proposed in our previous work [7].
The paper is organized as follows. Section II presents the system model. In Section III, we define the proposed energy efficiency scheme including the RB and the power allocation methods. Simulation parameters are summarized in Section IV. Section V shows the numerical results and a comparison in terms of energy efficiency with other reference RB allocation algorithms. Finally, Section VI concludes the paper.

II. System Model

We consider an uplink LTE network composed of 19 hexagonal cells. Each cell is provided with a tri-sectored eNodeB (eNB). We allocate at each sector a different bandwidth B (i.e. we adopt a $1\times3\times1$ frequency reuse pattern), corresponding to N_{RB} available RBs. The proposed energy efficiency scheme is divided into two entities: (i) the RB allocation, and (ii) the power control, as shown in Figure 1. The RB allocation entity allocates the RBs to the UEs in function of their Channel Quality Identifier (CQI). One RB consists of 84 Resource Elements (REs) corresponding to $N_{sc}^{RB} = 12$ subcarriers of 15 kHz width each and $N_{symb}^{RB} = 7$ SC-FDMA symbols in the normal prefix cyclic case [8]. On the uplink, the CQI is evaluated by the dint of the Reference Signals (RS) which are sent at each time slot in the 4th SC-FDMA symbol [9]. The RS use 14% of the total number of REs. Then, the number of REs used for data transmission in one RB is equal to 72 and the real throughput (i.e. considering the MCS selection) that can be achieved by each user k can be computed as:

$$R_k = \sum_{c\in\mathcal{A}_k} \frac{72}{T_s} \mathrm{BRE}_k \mid \mathcal{A}_k \mid \qquad (1)$$

where, T_s is the time slot duration equivalent to 0.5 ms, BRE_k denote the number of bits per RE allowed for UE k by the used MCS and $\mathcal{A}_k$ is the set of RBs allocated to UE k by the RB allocation entity, with $\mid \mathcal{A}_k \mid$ its cardinal. The MCS selection is based on the channel conditions (i.e. the SINR level experienced by each user in each RB c). The specificity of the SC-FDMA technique is that each UE should use the same MCS over the whole allocated RBs. Thus, the MCS selection is based on the minimum signal to interference plus noise ratio experienced by the concerned UE on the whole allocated RBs (i.e. $\forall c \in \mathcal{A}_k$).

In case of frequency and time correlated fast fading and for a given RB, the SINR level of each UE is computed at each RE (i,j) (with $1 \leq i \leq N_{symb}^{RB}$ and $1 \leq j \leq N_{sc}^{RB}$), as:

$$\mathrm{SINR}_k^{(i,j)} = \frac{P_{k_{Tx}}^{(i,j)}\ G_t\ G_r(\theta_k)\Lambda}{N + I^{(i,j)}} \qquad (2)$$

where Λ is the total channel gain, expressed as:

$$\Lambda = G_c(r_k)\ \|A_f^{(i,j)}\|^2 A_s^{(i,j)} \qquad (3)$$

$G_c(r_k)$ is the path loss depending of r_k, the distance between the user k and the eNB. $A_s^{(i,j)}$ is the random shadowing over one RE which follows a log-normal distribution with parameter σ_s and $A_f^{(i,j)}$ is the time-frequency correlated coefficients fast fading.

$P_{k_{Tx}}^{(i,j)}$ is the transmission power of user k over one resource element. Since the power is equally divided over all the resource elements of one RB, $P_{k_{Tx}}^{(i,j)}$ can be expressed as:

$$P_{k_{Tx}}^{(i,j)} = \frac{P_{k_{Tx}}}{N_{symb}^{UL} N_{sc}^{RB} \mid \mathcal{A}_k \mid} \qquad (4)$$

with $P_{k_{Tx}}$ the mobile's transmission power, set at its maximum before the power control (i.e. $P_{k_{Tx}}$ equal to P_{max}). The mobile's transmission antenna gain and the eNB antenna reception gain are denoted respectively as G_t and G_r. The eNB antenna reception gain G_r depends on θ_k, angle between UE k and eNB antenna boresight. N is the thermal noise in the considered subcarrier and $I^{(i,j)}$ is the ICI level at each resource element (i,j) obtained by Monte Carlo simulations.

The signal to interference plus noise ratio over one RB c for user k is computed using the mean instantaneous capacity method defined in [10]. It is denoted the effective SINR ($\mathrm{SINR}_{\mathrm{eff}_k}$) and is computed as follows:

$$\mathrm{SINR}_{\mathrm{eff}_k}^c = 2^{C_k/N_{symb}^{UL}} - 1 \qquad (5)$$

with C_k the theoretical Shannon capacity over the whole RB, computed as:

$$C_k = \frac{1}{N_{sc}^{RB}} \sum_{i=1}^{N_{symb}^{UL}} \sum_{j=1}^{N_{sc}^{RB}} \log_2\left(1 + \mathrm{SINR}_k^{(i,j)}\right) \qquad (6)$$

The effective signal to interference plus noise ratio computed for each user k and over each RB c ($\mathrm{SINR}_{\mathrm{eff}_k}^c$) will be used as a metric for the RB allocation algorithm detailed in the next section.

III. Energy efficiency scheme

The LTE uplink radio resource management includes the RBs and the power allocation, which can be performed: (i) conjointly, or (ii) separately. The conjoint manner is proposed in [11], where the Binary Integer Programming (BIP) is used to optimally minimize the total power expenditure subject to the rate constraints. The authors consider the contiguity constraint directed by the SC-FDMA technique but compute the total mobile throughput using the theoretical upper bound (i.e. the Shannon capacity). The BIP is commonly proposed as an optimal solution for resource allocation in wireless network, but this method is NP hard. Since the radio resource management occurs at each transmission time interval (which is equal to 1 ms), using the optimal method becomes irrelevant and would cost a lot in terms of computational complexity in the context of freen communications, which motivated us to use a heuristic in allocating the RBs and the mobile's transmission power.

The proposed energy efficiency method allocates the mobile's transmission power after the RB allocation. The power control applied to the mobile's transmission power on the allocated RBs ensures the throughput maximization while minimizing the mobile's power consumption without disrupting the RB allocation, the QoS or the MCS selected. The two steps: (i) RB allocation and (ii) the power control, are described as follows:

A. RB allocation step

For RBs allocation, we use the Opportunistic and Efficient RB Allocation algorithm. We consider that there are N_{UE} users able to transmit their data. Thus, we define $\mathcal{K}$ the set of users able to be scheduled $\mathcal{K} = \{1, \cdots, k, \cdots, N_{UE}\}$ and $\mathcal{C}$ the set of free RBs $\mathcal{C} = \{1, \cdots, c, \cdots, N_{RB}\}$. The OEA algorithm aims to maximize the aggregate throughput of the network by allocating efficiently the resource blocks.

$$\max \sum_{k=1}^{N_{UE}} R_k \tag{7}$$

where R_k is the total individual throughput of user k over the whole allocated RBs, and is computed using Equation 1. The maximization problem is subject to:

1) the exclusivity of the allocated RBs:

$$\sum_{k=1}^{N_{UE}} x_k^c = 1 \quad \forall c \in \mathcal{C} \tag{8}$$

2) the contiguity constraints:

$$x_k^j = 0 \ \forall j > c+2 \text{ if } x_k^c = 1 \text{ and } x_k^{c+1} = 0 \tag{9}$$

3) the MCS robustness:

$$\text{BRE}_k = \min_{c \in A_k} \text{BRE}_k^c \tag{10}$$

where, x_k^c is equal to 1 if the RB c is allocated to UE k, and equal to 0 otherwise and BRE_k^c is the number of bit per RE allowed for UE k on each allocated RB c.

Actually, the algorithm respects by the SC-FDMA constraints. It allocates exclusively adjacent RBs to the same UE (by Formulas 8 and 9) and ensures the MCS robustness (by Formula 10). To maximize the aggregate throughput, the algorithm uses as a metric the effective SINR experienced by each user over each RB. It searches first the pair (UE-RB) which maximizes the metric, then extends the allocation to the adjacent RBs. The RBs expansion allocation is done if and only if the individual throughput of the UE increases. To adapt the OEA algorithm to the QoS required by users, we fix a maximum number of allocated RBs per UE which satisfies its QoS requirements. The RBs allocation expansion is performed as long as this maximum number of allocated RBs per UE is not reached. More important step, which is often neglected in the literature, is the update of the metric before each RBs allocation expansion. The update of the metric considering the update of the mobile's transmission power per RB (using Equation 4), allows us to recursively compute the correct value of individual throughput, the parameter which is based on the expansion decision of the RB allocation.

B. Power control step

Since each mobile user k has its set of allocated RBs $\mathcal{A}_k$, the second step determines the appropriate transmission power. It allows the UE to use the same MCS as before the power control and to reach the same throughput. To use a given MCS, the UE must experience in the whole allocated RBs a SINR level higher than the minimum SINR range of the used MCS ($\text{SINR}_{MCS,k}$) in dB. To ensure user k to use the same MCS as the one used before the power allocation, we define an SINR target (SINR_{Tg}) in dB as:

$$\text{SINR}_{Tg} = \text{SINR}_{MCS,k} + \Delta_{\text{SINR}} \tag{11}$$

where, Δ_{SINR} is an SINR margin in dB. The new mobile's transmission power per RB P_{e_k} allocated to UE k and which allows it to reach the target SINR and achieve the same throughput than the one achieved before the power control, is expressed as:

$$P_{e,k} = \frac{P_{k_{T_x}}}{\mid \mathcal{A}_k \mid} \frac{\text{SINR}_{Tg}}{\text{SINR}_{\text{eff}_k, min}} \tag{12}$$

where, $\text{SINR}_{\text{eff}_k,min}$ is the minimum effective SINR experienced by the UE k on the whole allocated RBs:

$$\text{SINR}_{\text{eff}_k,min} = \min_{c \in \mathcal{A}_k} \text{SINR}_{\text{eff}_k}^c \tag{13}$$

The MCS robustness is guaranteed by the $\text{SINR}_{\text{eff}_k,min}$ based power control.

IV. Simulation parameters

To evaluate the performance of the proposed resource allocation algorithm, we evaluate the mobile's energy consumption saving obtained thanks to power control. Our study focuses on the RB and power allocation to one sector of the central cell users. We compare the OEA algorithm performance with the literature reference's RB allocation algorithms, such as: the Heuristic Localized Gradient Algorithm (HLGA), the Frequency Domain Packet Scheduling - Largest Metric value First algorithm (FDPS-LMF) and the Recursive Maximum Expansion algorithm

(RME) proposed respectively in [12], [13] and [14].

The simulation parameters are taken from the LTE standards. The performance evaluation is studied in low and high loaded network. Then, the total number of pedestrian users per sector varies between 5 to 80 UEs per sector while a bandwidth B = 5 MHz is allocated to each sector. This correspond to $N_{RB} = 25$ available RBs per sector. We consider an infinite backlogged traffic, in which, for each user, there is always available data for transmission. The target Bit Error Rate (BER) is equal to 10^{-6} and the throughput is computed using the MCS lookup table from [15], restrictted to the MCS listed in Table I respecting the MCS robustness. The path loss is modeled by the Okumura Hata model [16] where the carrier frequency is set to 2.6 GHz, the eNB height is at 40 m and the UE height at 1.5 m. The remaining simulation parameters are summarized in Table I.

Cellular layout	Hexagonal grid,19 tri-sector cells.
Max/ Min UE-BS distance	1000 m/30 m
Carrier frequency	2.6 GHz
System bandwidth	$B = 5$ MHz per sector $\Rightarrow N_{RB} = 25$
FFT size	512
Subcarrier spacing	15kHz
Time slot duration	$T_s = 0.5\ ms$
Target Throughput	300 kbps
SINR margin Δ_{SINR}	0.3
Radio channel gain	Okumura Hata for urban areas: $G_c(r_{jc}) = 10^{-a/10} * r_{jc}^{-b/10}$ $a = 136.7$ and $b = 34.4$
BS antenna pattern	$G_r(\theta_{jc}) = -min[12 * (\frac{\theta_{jc}}{\theta_{3dB}})^2, \beta]$ $\theta_{3dB} = 70°$, $\beta = 20$ dB
User power class	$P_{max} = 21$ dBm (125 mW)
User antenna gain	$G_t = 0$ dBi
Rayleigh fading	coef corr $= 0.5$, UE velocity $= 3$ km/h
Log-normal shadowing	$\sigma_s = 5$ dB
MCS setting	QPSK $1/2, 2/3, 3/4$ 16 QAM $1/2, 2/3, 3/4$ 64 QAM $1/2, 2/3, 3/4$

TABLE I
SIMULATION PARAMETERS

V. PERFORMANCE EVALUATION

The objective of the proposed energy efficiency method is to allocate both RBs and the mobile's transmission power efficiently, which allows users to benefit from a higher throughput without wasting RB while radiating at a lower power and increasing the mobile's battery life. Figure 2 shows the aggregate throughput of the central cell while varying the network's load (i.e. varying the number of UE from 5 to 80, which corresponds to a number of UE per number of RBs ratio of 20% to 320%). Since the number of UEs per sector and the number of served UEs increase, the aggregate throughput per sector increases whatever the used RB allocation algorithms. We notice that the OEA algorithm reaches its objective and maximizes the aggregate throughput. Its achieves more than 2 Mbps at low loaded network (when there are only 5 UEs per sector) and 6.5 Mbps at highly loaded network (80 UE per sector). The QoS based OEA algorithm achieves a lower aggregate throughput than OEA algorithm, due to the low target throughput fixed at 300 kbps. Then, the QoS based OEA algorithm allocates an adequate number of RBs to UEs which allows them to achieve the target throughput unlike the OEA algorithm, where an UE can be allocated all the RBs that maximize its individual throughput depending on its channel conditions even if it takes all the available RBs allocated to the sector N_{RB}. The HLGA and the FDPS-LMF algorithms achieve a lower aggregate throughput than QoS based OEA algorithm one. Since the RB allocation policy of the HLGA and the FDPS-LMF algorithms is similar, except for the allocation of the remaining RBs, we note a small difference between their total aggregate throughput. The aggregate throughput gap between HLGA and FDPS-LMF is notable at low load because there are more remaining RBs and the HLGA, by allocating the remaining RBs to users which satisfy the contiguity constraints whatever their SINR level, decreases the aggregate throughput. The lower aggregate throughput is given by the RME since it allocates a lot of RBs more RBs per UE without any SINR update before the end of the RB allocation. The resulting SINR value computed at the end of the process, id often even too low to unsure the minimum MCS. The HLGA, FDPS and RME also achieve a lower aggregate throughput than the OEA and the QoS based OEA algorithms due to their negligence of the metric update at each RB allocation expansion and the MCS robustness constraints.

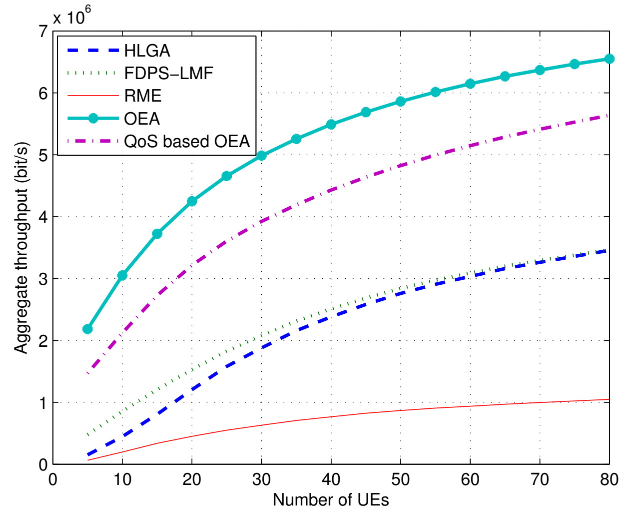

Fig. 2. Aggregate throughput

Figure 3 and 4 represent respectively, the energy efficiency of the transmitted data before and after the power control. The energy efficiency of the transmitted data in bits per Joule is defined by the ratio between the number of data transmitted in one second and the necessary consumed energy for transmission in one second. Before the power control, all

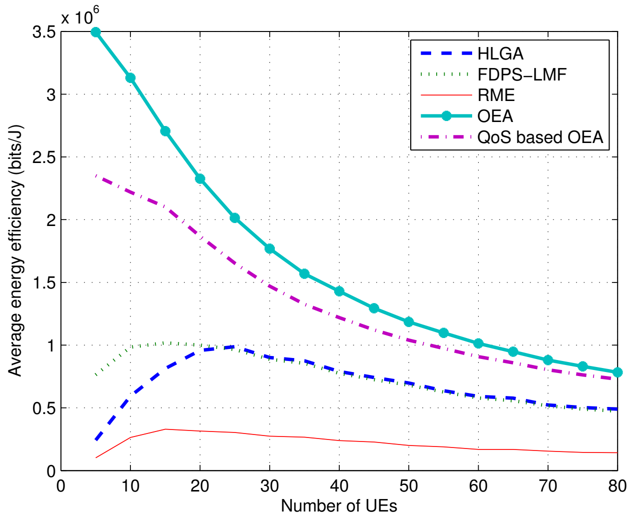

Fig. 3. Average energy efficiency before power control

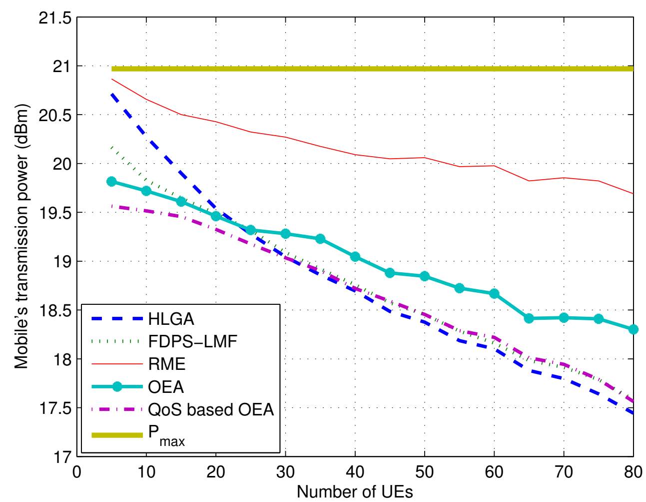

Fig. 5. Average mobile's transmission power per UE

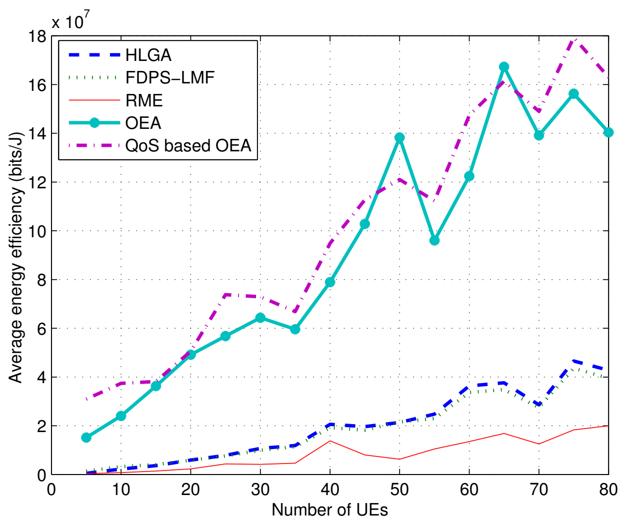

Fig. 4. Average energy efficiency after power control

the mobiles transmit at their maximum power P_{max}. Since the OEA and the QoS based OEA algorithms achieve a higher throughput, then they achieve a higher energy efficiency. They reach respectively $3.5\ 10^6$ and $2.4\ 10^6$ bits/J at low load, while the RME, FDPS-LMF and the HLGA do not exceed $8\ 10^5$ bits/J. In highly loaded networks, the energy efficiency decreases for the five algorithms to reach $7.5\ 10^5$ bits/J for the OEA algorithm and $7\ 10^5$ bits/J for the QoS based OEA algorithm, $5\ 10^5$ bits/J for both HLGA and FDPS-LMF algorithms and $2\ 10^5$ bits/J for the RME algorithm.

Unlike the maximum transmission power case, the energy efficiency curves increase when the network load increases after applying power control. In case of highly loaded networks the number of allocated RBs to each UE is low, due to the high number of UEs, which makes the power control more efficient. The number of bits transmitted per one Joule achieves 180 Mbits and 170 Mbits for the QoS based OEA and the OEA respectively. The curves are not smoothed as before the power control curves, because the power allocation depends on the minimum SINR range of the used MCS which is not linear.

Figure 5 shows the average mobile's transmission power in dBm. The thick line corresponds to the mobile's maximum transmission power set to 21dBm (i.e. 125 mW). The minimum observed mobile's transmission power is about 17 dBm, which is higher than the lower bound of the transmission power equal to -48 dBm allowed by the 3GPP standard [8]. We notice that the RME does not decrease a lot the mobile's transmission power still due to the high number of allocated RBs. The algorithms which allow a lowest mobile's transmission power are the HLGA, the FDPS-LMF and the QoS based OEA. This large power reduction is explained by the number of RBs allocated to each UE. Actually if $\mid \mathcal{A}_k \mid$ is low, $P_{k_{Tx}}$ is high and the power control according to the $SINR_{Tg}$ is more efficient. In Figure 6, we represent the ratio of saved energy after the power control. The RME algorithm saves only from 2% to 25% of the mobile's transmission power depending to the network load, where the QoS based OEA algorithm saves from 28% to 65% of the mobile's transmission power, which allows it to increase even more the mobile's battery life.

VI. Conclusion

In this paper, we investigate the energy consumption problem of the wireless network and more specifically the energy efficiency on the LTE uplink network, which leads to an increase of the LTE mobile's battery's life. We propose a new energy efficiency scheme which depends on the resource block allocation algorithms. The proposed radio resource allocation algorithm allocates first the resource blocks to the UEs, using the Opportunistic and Efficient RB Allocation algorithm and

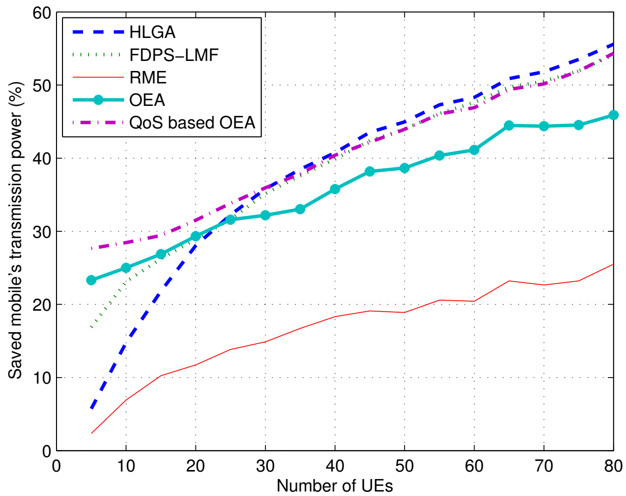

Fig. 6. Saved power (W)

the QoS based Opportunistic and Efficient RB Allocation algorithm, to allocate the RB to the active users. The RBs are first allocated to UEs according to their channel conditions and respecting the SC-FDMA constraints; then we apply a power control to the mobile's transmission power which reduces the mobile's radiated power without affecting the MCS selection and the individually reached throughput. To evaluate the performances of the proposed energy efficiency scheme obtained by the OEA and the QoS based OEA, we compare the saved energy after power control when the RME, FDPS-LMF and the HLGA algorithms are used for the RB allocation. The numerical results show that the OEA algorithms achieve the higher number of bits per Joule and in case of QoS traffic, the QoS based OEA allows to save more than half of the mobile's energy. In future work, we will compare the proposed energy efficiency scheme with the optimal one, using the binary integer programming method.

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