Analysis of power efficiency of schedulers in LTE

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***Abstract*—In this work we analyse the behaviour of six different LTE scheduling algorithms, namely the round robin, best CQI, proportional fair, Max-Min, resource fair and the iterative hungarian schedulers. A downlink LTE network is simulated and the properties of the schedulers are analysed for a varying number of served users. These schedulers are studied from a throughput and fairness perspective through system level simulations. Furthermore the impact of each scheduler on the energy consumption is also computed with the aid of a flexible base station power model. The simulations show that the best CQI scheduler proves to deliver the highest data rate but lowest fairness while the Max-Min achieves exactly the opposite. The round robin delivers the worst overall performances while the other ones behave similarly in between . This work argues for the introduction of an energy consumption figure of merit for a fair and insightful comparison between specific scheduling algorithms.**

I. Introduction

The dramatic increase in cellular technology usage has resulted in a number of portable devices which is most likely going to surpass the number of people on the planet [1]. Considering also that the whole ICT industry is currently responsible for 2-3% of the overall carbon dioxide emissions [2], the power efficiency of the various cellular technologies is currently under fervent investigation by the scientific community. Long Term Evolution (LTE) emerges among the other cellular network technologies as the "de facto" standard for 4th generation communication and has been chosen as the reference technology for this work. LTE is designed to improve spectral efficiency and flexibility, increase the Quality of Service (QoS) for the final users and reduce overall network costs for the operators [3]. The employment of downlink access technologies such as Orthogonal Frequency Division Multiple Access (OFDMA) permits a very flexible Resource Allocation (RA) at the cell level. Traditionally the RA is performed so that a utility function, usually the cell's capacity or the fairness, is maximized. The scope of this work is to compare different state of the art LTE RA algorithms using a more comprehensive figure of merit which includes energy or power consumption in a multi-cell, multi-user downlink LTE network. To model the network a system model simulator presented in [4] has been used and in order to quantify the power, the flexible LTE base station power model presented in [5] was utilised; this model takes into consideration the power consumption of different types of LTE base stations and how the components of such base stations affect the overall power consumption. Different works in literature discuss the energy efficiency of RA algorithms but to the best of our knowledge they make use of simplistic approximations of the power consumption of the base stations [6], [7].

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Section II introduces briefly the system and the power model; in section III we introduce the different RA algorithms and their design specifications. In section IV we explain the evaluation metrics. In section V we give the simulation results and, finally, in the section VI we present the conclusions.

II. System and Power Models

In this work we consider a LTE Downlink OFDMA scenario. The available bandwidth is divided into physical resource blocks (PRBs) which represent the smallest granularity the resource allocation manager can assign to each user. The system bandwidth is flexible and can vary between 1.4 MHz (6 PRBs) and 20 MHz (100 PRBs). For each time slot, each mobile station (MS) transmits via uplink a channel state indicator (CSI) packet. Each CSI contains a channel quality indicator (CQI) value for each PRB seen by the user. These CQIs are directly linked to the SINR experienced by the user [8]. The base station, then, using the adaptive modulation and coding (AMC) strategy decides which modulation and coding scheme (MCS) to use for the transmission. Different MCS lead directly to different transmission efficiency and to minor power consumption differences for the base stations, given by the different behaviours of the sub-components of the base station. There is then a link between RA and the network energy expenditure.

The power model used in this work [5] is capable to adapt to various LTE scenarios and accurately scale power figures to match different kind of base stations, e.g., macro, micro, pico and femto, and their conditions of operation eg: MIMO, bandwidth, MCS and so on. The model computes the total power consumed by the base stations by considering the power consumption of each of its main components: the analog RF transceiver, the base band, the power amplifier and the AC-DC-DC-DC conversion and cooling (overhead). The total power consumption is then the sum across the components. Figure 1 shows the typical effect on power consumption of a macro base stations by its components components.

The relation between CQI values and MCS is presented in table I; the same table also shows the relation between total power consumption and MCS adopted by a macro base station when the network operates in full load on a single sector.

III. The Resource Allocation Algorithms

In this section the various RA algorithms and their key properties are briefly introduced. For a more in-depth

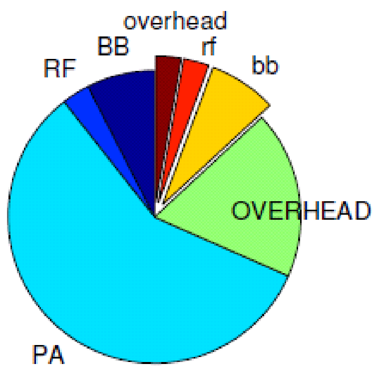

Fig. 1: Power impact of subcomponents: lowercase for uplink and uppercase for downlink

SINR	CQI	modulation	code rate (x 1024)	efficiency	Power(W)
-6.9360	1	QPSK	78	0.1523	292.13
-5.1470	2	QPSK	120	0.2344	292.55
-3.1800	3	QPSK	193	0.3770	293.03
-1.2530	4	QPSK	308	0.6016	293.62
0.7610	5	QPSK	449	0.8770	294.27
2.6990	6	QPSK	602	1.1758	294.95
4.6940	7	16QAM	378	1.4766	295.62
6.5250	8	16QAM	490	1.9141	296.46
8.5730	9	16QAM	616	2.4063	297.37
10.3660	10	64QAM	466	2.7305	298.08
12.2890	11	64QAM	567	3.3223	299.12
14.1730	12	64QAM	666	3.9023	300.13
15.8880	13	64QAM	772	4.5234	301.20
17.8140	14	64QAM	873	5.1152	302.23
19.8290	15	64QAM	948	5.5547	303.11

TABLE I: SINR and CQI mapping to modulation and coding rate with power consumption at full load

description we recommend the reader to refer to the appropriate references.

Round Robin (RR)
The round robin scheduler assigns the PRBs to the MS in a circular fashion. Once all MS have a RB assigned the RR scheduler starts again from the beginning. Each user is surely scheduled and no channel knowledge is required thus making the system fair but potentially weak in terms of achievable rate [9].

Best CQI (BC)
The Best CQI scheduler assigns each PRB to the user which presents the highest CQI for that PRB. This mechanism maximises the cell throughput but pays no consideration to the fairness of the system [9].

Proportional Fair (PF) This RA algorithm has the objective to increment each users rate. It takes into consideration the average data rate of each user in the previous transport blocks and assigns specific PRBs to each user so that the relation between the instantaneous rate of the MS for this trasport block over its past rate is maximised [10].

Max-Min (MM) The Max-Min scheduler has the objective to maximise the minimum rate that each user achieves. This is a convex optimization problem [11] and it's solved by assigning to each user the set of PRBs where the user presents best channel conditions.

Resource Fair (RF) This scheduler assigns to each user the same number of PRBs and then finds, through convex optimization, the set of PRBs that maximises that user's rate. [4].

Iterative Hungarian Scheduler (IHS) This scheduler makes use of the Hungarian assignment method [12] in its iterative form. At each iteration the IHS assigns the a single PRB to each user that maximizes the overall rate without reducing the rate of each other user. The process is repeated until all PRBs are assigned. The IHS is optimal, w.r.t. to user throughput maximization, when the number of users is equal to the number of PRBs, it becomes a good suboptimal solution when this identity is not valid and it achieves high data rates and fairness with the advantage of a reduced complexity when compared with the other throughput maximization algorithms [13].

IV. Evaluation Metrics

The behaviour of each scheduler is characterised by three different parameters: the throughput, the fairness coefficient and the energy cost.

Throughput The throughput is easily computed by the LTE downlink system level simulator; The average throughput is considered in order to gain insight in the performances of the schedulers. The throughput is expressed in Mbit/s.

Fairness The fairness of each scheduler is expressed using Jain's fairness index [14]:

$$F = \frac{(\sum_{m=1}^{M} R_m)^2}{M \cdot \sum_{m=1}^{M} R_m^2}$$

Where M is the total number of users and R_m is the rate of user m.

Energy cost In order to guarantee fair comparison between the various schedulers the average energy per bit and instantaneous power are considered.

V. Simulation Results

The main simulation parameters are listed in Table II. An LTE downlink scenario is simulated for a varying number of cell users. The network operates in full load and each user requests data from the base stations at all times. Different schedulers are implemented for each simulation run and the users behaviour are recorded. Firstly the behaviour of the schedulers is compared from a Throughput and a Fairness point of view for a varying number of served users. Figures 2 and 3 show the respective results for a varying number of users per sector.

Parameters	Values
Number of Macrocells	7
Sectors per Macrocell	3
Macro users per sector	5 to 25
Macro Transmit Power	46 dBm
System Bandwidth	20 MHz
Access technology	OFDMA
Number of antennae	1(Tx and Rx)

TABLE II: System Parameters

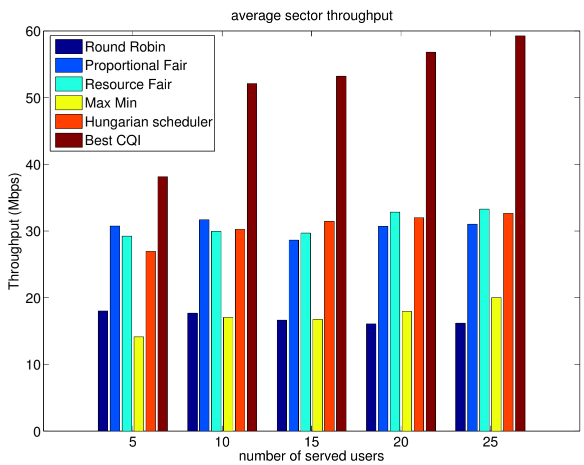

Fig. 2: Average Sector Throughput

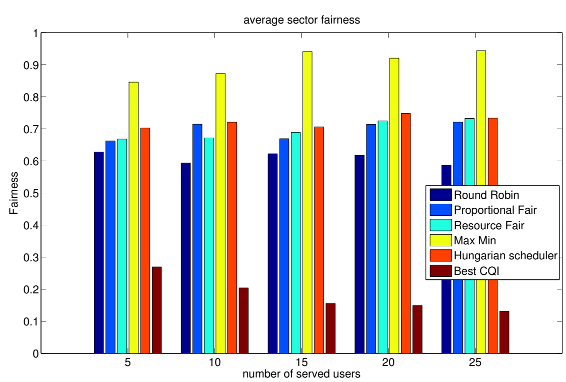

Fig. 3: Average Sector Fairness

We can see that, in accordance with [6], the number of served users does not modify heavily the average cell throughput in a full load scenario. The fluctuations are most likely due to the different channels experienced by the users. The two exceptions are the Best CQI and, to a lesser extent, the Hungarian schedulers which better exploit user diversity and thus perform better as the number of users increases. On the other hand the fairness coefficient presented in figure 3 depicts the dual scenario. The Best CQI scheduler presents the worst fairness while the Max-Min scheduler achieves reduced data-rates but very high fairness. Figure 4 presents the behaviour of the schedulers on a Throughput-Fairness graph. It is possible to see while the Best CQI and the Max-Min schedulers represent the extreme cases, with the exception for the Round Robin, the other schedulers are clustered together delivering similar performances.

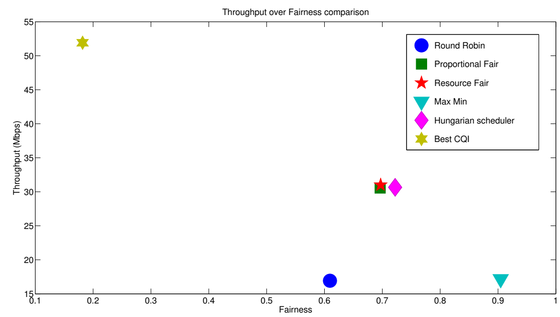

Fig. 4: Throughput over Fairness

The average power drawn by a cell is presented in figure 5. The power drawn is not dependent on the number of served

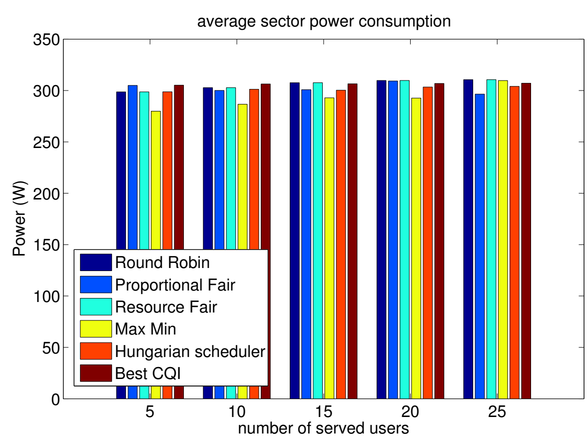

Fig. 5: Average Sector Power Consumption

users, since the simulations are in full load. Lower MCS lead to lower power consumptions and lower rates, thus making the Round Robin scheduler the least power hungry.
Different RA algorithms transmit, in a full load scenario, different rates of data, making a power comparison less meaningful than the energy per bit presented in figure 6.

The Best CQI scheduler transmits the highest amount of data consuming roughly the same power as the other schedulers achieving thus the lowest energy per bit. It is followed

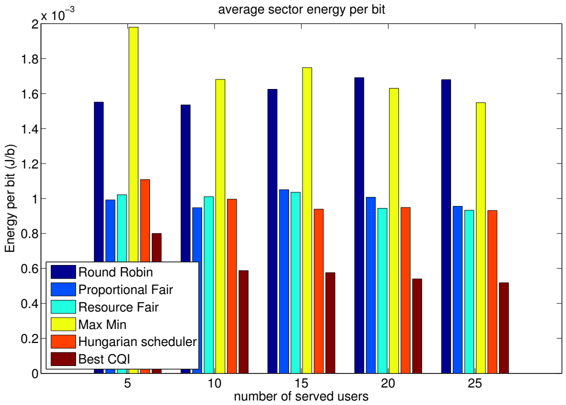

Fig. 6: Average Sector Energy per bit

by the Hungarian scheduler, Proportional Fair and Resource Fair schedulers which also deliver relatively high throughput but are also very fair. The Max-Min RA is highly energy inefficient but is designed to maximize the users' lowest rate and achieves very poor results together with the Round Robin scheduler. Figure 7 represents energetic cost of each scheduler over the fairness each scheduler can achieve.

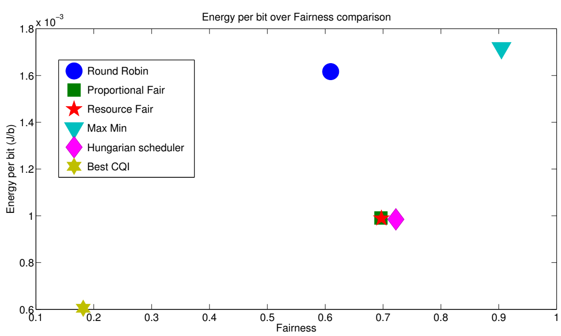

Fig. 7: Energy per bit over Fairness

VI. Conclusions

In this work we have presented an analysis of some of the most used schedulers for LTE networks from the perspectives of throughput, fairness and energetic cost. The study shows that the Best CQI scheduler achieves highest cell throughput but sacrifices fairness on the other hand the Max-Min scheduler behaves just the opposite by granting to all users a minimal rate. The Round Robin scheduler does not take into account either user requirements or channel conditions thus delivering very poor performances on all fronts.The other schedulers obtain results in between the extremes described above and assure reasonable data rates together with high fairness.There is then the necessity to expand this work, in the future, in order to account for variations in the network's load to obtain a clear picture of the base station's behaviour.

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