

SFBC MIMO Energy Efficiency Improvements of Common Packet Schedulers for the Long Term Evolution Downlink

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Abstract— It is desirable that energy performance improvement is not realized at the expense of other network performance parameters. This paper investigates the trade off between energy efficiency, spectral efficiency and user QoS performance for a multi-cell multi-user radio access network. Specifically, the energy consumption ratio (ECR) and the spectral efficiency of several common frequency domain packet schedulers in a cellular E-UTRAN downlink are compared for both the SISO transmission mode and the 2x2 Alamouti Space Frequency Block Code (SFBC) MIMO transmission mode. It is well known that the 2x2 SFBC MIMO transmission mode is more spectrally efficient compared to the SISO transmission mode, however, the relationship between energy efficiency and spectral efficiency is undecided. It is shown that, for the E-UTRAN downlink with fixed transmission power, spectral efficiency improvement results into energy efficiency improvement. The effect of SFBC MIMO versus SISO on the user QoS performance is also studied.

Keywords- ECR; SFBC; MIMO; Packet Scheduling; LTE;

I. INTRODUCTION

Limitations on the available spectrum, have traditionally, led to the development of spectrally efficient technologies for mobile cellular systems. However, due to the rapid growth of wireless technologies and usage, a new issue in the design of future mobile cellular systems has recently become apparent, namely, the energy consumption of the radio access networks. The volume of transmitted data increases approximately by a factor of 10 every five years, which corresponds to an increase of the associated energy consumption by approximately 16 to 20%. Currently, 3% of the world's energy is consumed by telecommunications infrastructure which accounts for 2% of the world's CO₂ emissions [1]. In a suburban area of 100 Km², LTE requires a total of 124 base stations and transmits a total power of 607.2KW [2]. Thus each base station can require up to 4.9KW of electrical power which can lead to an energy consumption of tens of mega watt hours (MWh) per annum. If this energy consumption is doubled every 5 years, serious energy supply and environmental problems will arise. Therefore, there is an essential need to create innovative methods for the reduction of the total energy needed to operate a radio access network. Owing to the energy and spectrum constraints, a complete solution requires both spectral and energy efficiency.

The specification of the Universal Mobile Telecommunications Systems (UMTS) terrestrial radio access network (UTRAN) long-term evolution (LTE) system or the Evolved UTRAN (E-UTRAN) for release 9 is currently being finalized by the Third Generation Partnership Project (3GPP) standardization body. The LTE performance targets are highlighted in [3]. The multiple access scheme for the LTE downlink is Orthogonal Frequency Division Multiple Access (OFDMA) while the uplink employs Single Carrier Frequency Division Multiple Access (SC-FDMA) [3]. LTE also supports both time-division duplex (TDD) and frequency-division duplex (FDD). Here we focus on the LTE downlink with FDD which translates to a time-frequency grid of available physical resource blocks (PRB). The number of physical resource blocks depends on the system bandwidth. Here we only consider a system bandwidth of 20 MHz with 100 resource blocks. A physical resource block spans 12 subcarriers each with a subcarrier bandwidth of 15 KHz over a 0.5ms time slot, each time slot consists of seven OFDM symbols. Resource allocation is performed at intervals of 1ms in the time domain called the transmission time interval (TTI). Thus one TTI is made up of 100 resource blocks in the frequency domain and 14 OFDM symbols in the time domain spanning 2 resource blocks. The first three OFDM symbols of every TTI are reserved for transmission of related downlink control channels e.g. the physical downlink control channel (PDCCH) and the physical control format indicator channel (PCFICH) while the remaining eleven OFDM symbols constitute the physical downlink shared channel (PDSCH) used for transmission of user data.

The spectral efficiency and throughput performance of packet scheduling protocols in a UTRAN long term evolution (LTE) system have been studied e.g. in [4], [5], [6], [7] and [8]. However, the energy consumption performance has received considerably less consideration despite the inefficiency of base stations. In this paper we present, for the first time, a characterization of the energy performance together with the spectral efficiency performance, of well known packet schedulers in a multi-cell multi-user environment, in order to determine whether a spectrally efficient system is also energy efficient. In order to adequately compute the energy efficiency of the packet schedulers, energy metrics need to be specified. A framework for measuring the energy efficiency of a telecommunications network and equipment can be found in

[9] where the average power consumption to effective throughput ratio has been proposed as an energy consumption ratio (ECR) metric. In order to quantify the spectral and energy efficiency, the following radio resource management techniques are studied and compared. Firstly, the impact on energy efficiency and spectral efficiency is determined as the frequency domain scheduling scheme is altered for both the SISO transmission mode and the 2x2 Alamouti SFBC MIMO transmission mode. Secondly, the energy and spectral efficiency of the frequency domain scheduling schemes is determined for both Urban Micro and Urban Macro cell deployment scenarios. In addition to the energy and spectral efficiency performance, this paper also presents the user Quality of Service (QoS) performance of the packet schedulers measured as a percentage of scheduled users together with their associated realized user data rates.

The rest of the paper is organized as follows. Section II describes the packet scheduling model considered. Section III presents the system model and list of simulation assumptions. The simulation results comparing the performance of the schedulers are presented in Section IV. Finally, Section V concludes the paper.

II. PACKET SCHEDULING MODEL

The packet scheduler is decoupled into two stages with the Time Domain Packet Scheduler (TD-PS) as the first stage and the Frequency Domain Packet Scheduler (FD-PS) as the second stage. Fig. 1 illustrates the two-step packet scheduling implementation proposed in [8].

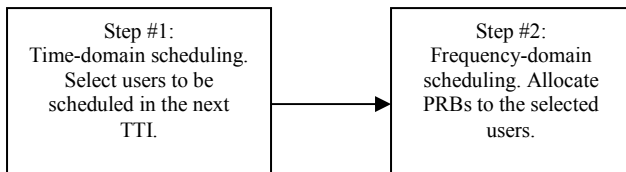


Figure 1. Decoupled TD-PS and FD-PS

A. Time Domain packet Scheduling

The Time Domain Packet Scheduler (TD-PS) selects users to be scheduled in the next TTI and passes the candidate selection list (CSL) to the Frequency Domain Packet Scheduler (FD-PS). The candidate selection list is obtained by sorting all the users according to the Time Domain Proportional Fair (TD-PF) metric. The time domain scheduling priority metric $M[n]$ for user n is

$$M[n] = \frac{D[n]}{R[n]} \quad (1)$$

where n is the user index, $D[n]$ is the wideband throughput estimated by link adaptation and $R[n]$ is the past average throughput of user n calculated with exponential average filtering as defined in [11]. This implies that the user with the highest TD-PF metric is given the highest priority while the user with the lowest TD-PF metric is given the lowest priority.

It is assumed that each of the users constituting the candidate selection list (CSL) has full buffer data traffic.

B. Frequency Domain Packet Scheduling

The Frequency Domain Packet Scheduler (FD-PS) allocates physical resource blocks (PRB) to users in the candidate selection list (CSL) provided by the Time Domain Packet Scheduler (TD-PS). The resource block allocation is carried out based on the concept of localized resource allocation whereby an entire resource block is assigned to a single user. The following common frequency domain packet scheduling schemes have been considered;

- Maximum SINR Scheduler: Following the priority assigned by the time domain packet scheduler, the maximum SINR scheduler assigns resource block i to user n that maximizes the metric

$$i' = \arg \max_{i \in N} M[i, n] = \text{SINR}[i, n] \quad (2)$$

where i is the resource block index, n is the user index and N is the total number of resource blocks. $M[i, n]$ and $\text{SINR}[i, n]$ denote the priority metric and average signal to interference noise ratio of user n on resource block i respectively. This metric has the property of maximizing the system throughput.

- Frequency Domain Proportional Fair Scheduler: Following the priority assigned by the time domain packet scheduler, the frequency domain proportional fair scheduler assigns resource block i to user n that maximizes the metric

$$i' = \arg \max_{i \in N} M[i, n] = \frac{d[i, n]}{R[n]} \quad (3)$$

where i is the resource block index, n is the user index and N is the total number of resource blocks. $M[i, n]$, $d[i, n]$ and $R[n]$ denote the priority metric, the achievable throughput of user n on resource block i , and $R[n]$ is the past average throughput of user n calculated with exponential average filtering as defined in [11]. The FD-PF scheduler involves the user time averaged throughput in its metric. Also the FD-PF scheduler tends towards the FD-Max SINR scheduler.

- Round Robin Scheduler: Following the priority assigned by the time domain packet scheduler, the round robin scheduler assigns resource blocks to the users in a closed loop circular manner without regard to the users' channel state information or signal to interference noise ratio (SINR). This scheduler has the property of allocating resource blocks fairly to all users.

It is assumed that any user from the candidate selection list that is not assigned a physical resource block is dropped.

III. SYSTEM MODEL

In this paper we have focused on the main Radio Resource Management (RRM) functions defined for LTE, namely; Channel Quality Indication (CQI), Link Adaptation (LA), Dynamic Scheduling, and Admission Control (AC) as presented in Fig.2.

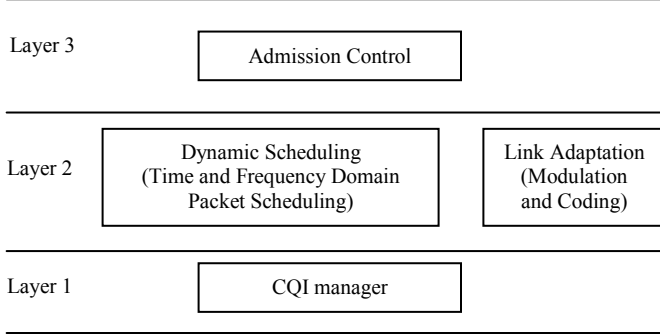


Figure 2. RRM Functions at different layers

An LTE simulator has been developed in MATLAB to evaluate the E-UTRAN downlink energy consumption ratio, spectral efficiency and user QoS for various packet schedulers in a multi-cell multi-user system model. Communication between the evolved Node B (eNB) and the user equipments (UEs) is based on two criteria, namely; the single input single output (SISO) transmission mode for a fixed transmit power and the 2x2 SFBC Alamouti multiple input multiple output (MIMO) transmission mode also for a fixed transmit power. The location coordinates of the user equipments (UEs) are randomly assigned following a uniform distribution while the location coordinates of the eNBs are fixed. In addition each user equipment (UE) experiences inter-cell interference from the first tier of six neighboring cells. The path loss and the multipath fading are computed from the WINNER II Urban Micro and Urban Macro channel models [10]. The packet scheduler interacts with the Admission Control (AC), Channel Quality Indication Manager (CQI), and Link Adaptation (LA). Channel Quality Indication (CQI) calculates the average signal to interference noise ratio (SINR) of each user on every resource block. Link Adaptation (LA) selects the modulation and coding scheme (MCS) based on the channel quality measurement. Admission Control (AC) selects the users to be passed to the packet scheduler. The main simulation parameters are detailed in Table I.

A. Energy Metrics

In this paper we only consider the Radio Frequency (RF) energy of the radio access network which is a function of the radio access architecture. The energy consumption ratio (ECR) is defined as the energy per delivered application bit. This energy metric provides the energy consumption in Joules consumed for transportation of one application bit and it is strongly dependent on the traffic pattern, and the location and mobility pattern of the network nodes. Equation (4), computes the ECR for one eNB with fixed power allocation per resource block, where E is the energy required to deliver M application bits. The E-UTRAN ECR is the average ECR over all eNBs in the E-UTRAN.

$$ECR = \frac{E}{M} = \frac{\beta \sum_{i=1}^Q k_i}{\sum_{i=1}^Q k_i f(SINR[n, i])} \quad (4)$$

$$\beta = \frac{P}{N} \times 1 \times 10^{-3} \quad (5)$$

P is the maximum transmit power and N is the total number of resource blocks. k_i is the fraction of utilized resource block i . Q is the number of used resource blocks which is a subset of the total number of resource blocks N . $f(SINR[n, i])$ is the LA function which determines the modulation and coding scheme and hence the number of bits that can be transmitted on resource block i by scheduled user n . From equation (4) we observe that in order to minimize the ECR we need to maximize the LA function. This implies that energy efficiency can be achieved by scheduling users with good SINR values.

The percentage energy reduction gain (ERG) is defined as;

$$ERG = \frac{ECR_1 - ECR_2}{ECR_1} \times 100 \quad (6)$$

where ECR_1 and ECR_2 are the energy consumption ratios for test case scenarios 1 and 2 respectively.

B. Cellular Model

The study in this paper is based on both Urban Micro and Urban Macro network scenarios. A hexagonal deployment is considered with 19 cell sites each employing Omni-directional antennas.

C. SINR Calculation

The signal to interference noise ratio is computed for each UE on every sub carrier from equations (7) and (8).

$$SINR_{SISO} = \frac{|h|^2 P_{r_{AVG}}}{\sum_{i=1}^6 P_{i_{AVG}} + Noise} \quad (7)$$

$$SINR_{MIMO} = \frac{\left(|h_{11}|^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2 \right) P_{r_{AVG}}}{2 \times \left(\sum_{i=1}^6 P_{i_{AVG}} + Noise \right)} \quad (8)$$

where, $P_{r_{AVG}}$ is the average received signal power, $P_{i_{AVG}}$ is the average received power from the i^{th} interferer. h is the multi-

path channel gain modeled as a circular symmetric Gaussian random variable of zero mean and a variance of 1.

TABLE I. SIMULATION PARAMETERS AND MODEL ASSUMPTIONS

Parameter	Setting
System bandwidth	20 MHz
Sub carriers per PRB	12
Cellular Layout	Hexagonal grid, 19 cell sites, Omni-directional
Cell-site radius	150m Micro cell and 1000m Macro cell
Total transmit power	SISO 20 Watts, MIMO 10 Watts per antenna
Number of users (UEs)	25 users per cell
Downlink Transmission Band	2.11-2.17 GHz
Number of Resource Blocks	100
Path Loss Model	WINNER II Channel model (Urban Micro and Urban Macro)
Multipath Fading Model	WINNER II Channel model (Urban Micro and Urban Macro)
eNB Height	10m (Urban Micro) and 25m (Urban Macro)
UE Height	1.5 m
UE antenna gain	0 dB
Number of interfering cells	6
Channel Estimation	Ideal
CQI delay	1 ms
Modulation and coding schemes	QPSK 1/3, 1/2, 3/4 & 16QAM 1/3, 1/2, 3/4 & 64QAM 3/5, 3/4, 6/7
EPS Bearer data amounts per TTI	1000 bits

IV. SIMULATION RESULTS

The performance of the frequency domain packet scheduling schemes is evaluated in terms of energy consumption ratio (ECR), energy reduction gains (ERG), spectral efficiency and user Quality of Service (QoS).

A. Energy Performance Results

Fig. 3 and Fig. 4 present the energy consumption ratio CDF plots of the various packet schedulers for the Urban Micro and Urban Macro network scenarios respectively.

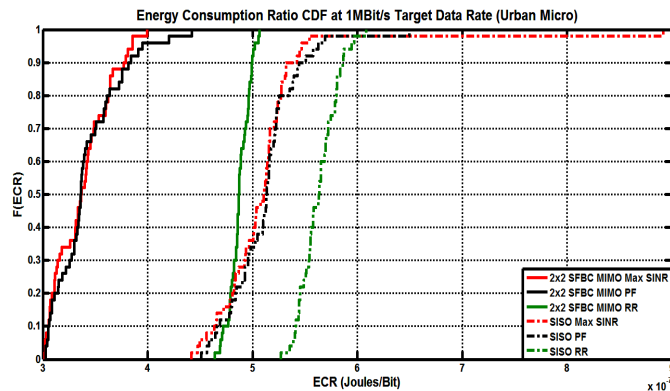


Figure 3. Energy Consumption Ratio CDF (Urban Micro)

Urban Micro: SFBC MIMO produces 75% quartile energy reduction gains (ERG) of 31%, 32% and 14% for the Max SINR, Proportional Fair and Round Robin schedulers respectively over SISO.

Urban Macro: SFBC MIMO produces 75% quartile energy reduction gains (ERG) of 40%, 39% and 49% for the Max SINR, Proportional Fair and Round Robin schedulers respectively over SISO.

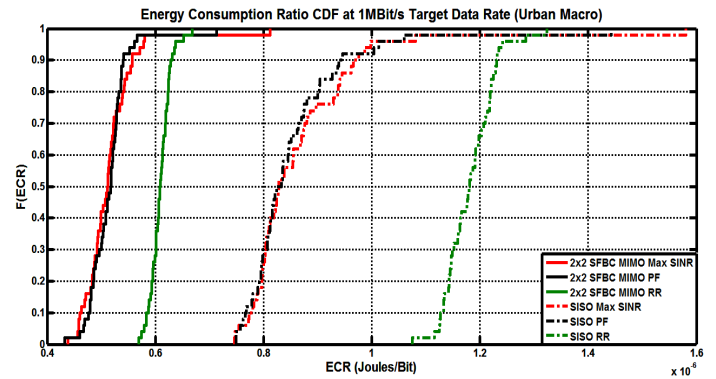


Figure 4. Energy Consumption Ratio CDF (Urban Macro)

B. User QoS Results

Fig. 5 and Fig. 6 present the user QoS performance of the packet schedulers for the Urban Micro and Urban Macro network scenarios, respectively.

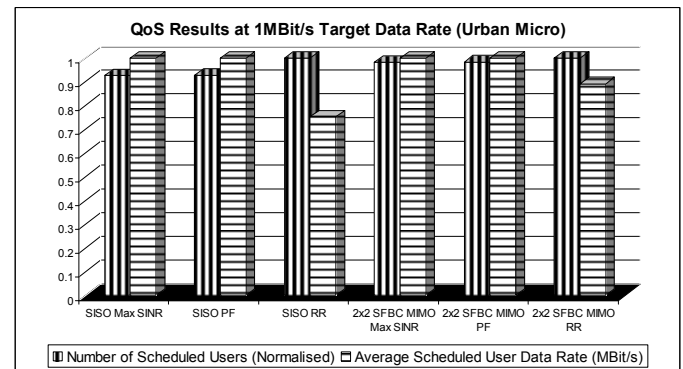


Figure 5. User Quality of Service (Urban Micro)

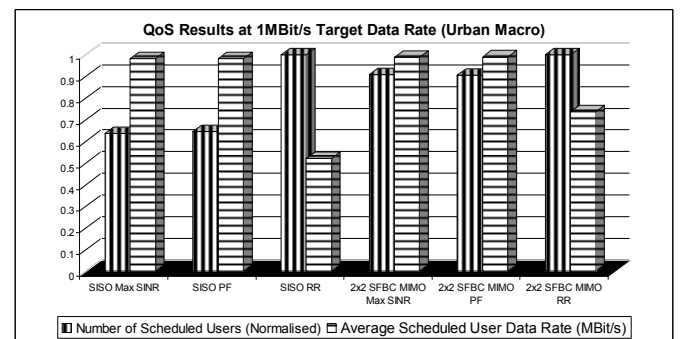


Figure 6. User Quality of Service (Urban Macro)

Urban Micro: For SFBC MIMO, the Max SINR, Proportional Fair and Round Robin schedulers scheduled 98%, 98% and 99% of the users at data rates of 1, 1 and 0.89MBit/s respectively. For SISO, the Max SINR, Proportional Fair and Round Robin schedulers scheduled 92%, 91% and 99% of the users at data rates of 1, 1 and 0.75MBit/s respectively.

Urban Macro: For SFBC MIMO, the Max SINR, Proportional Fair and Round Robin schedulers scheduled 90%, 91% and 99% of the users at data rates of 0.98, 0.98 and 0.74MBit/s respectively. For SISO, the Max SINR, Proportional Fair and Round Robin schedulers scheduled 63%, 65% and 99% of the users at data rates of 0.98, 0.98 and 0.52MBit/s respectively.

C. Spectral Efficiency Results

Fig. 8 and Fig. 9 present the spectral efficiency performance of the packet schedulers for the Urban Micro and Urban Macro network scenarios respectively.

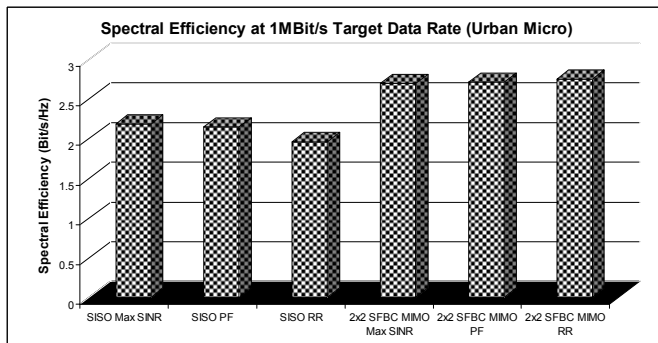


Figure 7. Spectral Efficiency (Urban Micro)

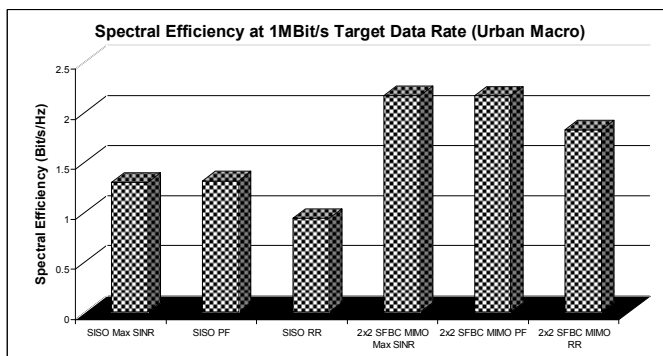


Figure 8. Spectral Efficiency (Urban Macro)

It is observed that SFBC MIMO is both more spectrally and energy efficient than SISO for all the packet schedulers considered in both the Urban Micro and Urban Macro scenarios.

The 2x2 SFBC Alamouti MIMO transmission mode improves the energy efficiency of the frequency domain packet schedulers by over 14% without compromising the spectral efficiency and the user QoS. The energy performance improvement is due to the fact that the 2x2 SFBC Alamouti MIMO transmission mode improves the user SINR thus maximizing the link adaptation (LA) function hence minimizing the ECR.

V. CONCLUSION

In this paper we have used the 2x2 SFBC MIMO versus SISO packet scheduler performance as a case study to analyze the impact of spectral efficiency on energy efficiency. It is observed that for the E-UTRAN, with fixed power allocation, spectrally efficient techniques are also energy efficient. Furthermore, spectrally efficient techniques improve the user QoS performance, in that, more users are scheduled and their associated achieved data rate is increased. The improved user QoS is due to the effective utilization of the available resource blocks as spectrally efficient methods can load more bits on to the resource blocks.

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