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Power Efficient Dynamic Resource Scheduling Algorithms for LTE

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Abstract: **This paper presents a link level analysis of the rate and energy efficiency performance of the LTE downlink considering the unitary codebook based precoding scheme. In a multi-user environment, appropriate radio resource management strategies can be applied to the system to improve the performance gain by exploiting multi-user diversity in the time, frequency and space domains and the gains can be translated to energy reduction at the base station. Several existing and novel resource scheduling and allocation algorithms are considered for the LTE system in this paper. A detailed analysis of the performance gain of different algorithms in terms of throughput, rate fairness, and power efficiency is presented.**

I. INTRODUCTION

The energy consumption of mobile phone networks is contributing to the global climate change as the worldwide telecommunications industry is currently responsible for 183 million tones or 0.7% of the total carbon dioxide emissions [1]. In addition, the growing energy costs are becoming significant OPEX (Operational Expense). The core 5 Green Radio programme of mobile VCE (MVCE) [2][3] aims to develop more power efficient wireless networks in order to reduce CO_2 emissions and operating expenditure without compromising the Quality of Service (QoS) of the end user.

Long Term Evolution (LTE) is the next major step in mobile radio communications, introduced as Release 8 in the 3rd Generation Partnership Project (3GPP) [4]. The new evolution aims to reduce packet delays, improve spectrum flexibility and further reduce the cost for operators and end users. Orthogonal Frequency Division Multiple Access (OFDMA) has been selected as the downlink access technology for the 3GPP LTE system. Recently, a number of closed-loop MIMO scheduling and precoding techniques have been proposed for the LTE of 3G systems [6], incorporating an improved interface between the Physical (PHY) and the Data Link Control (DLC) layers, in order to provide increased support for on demand QoS [7]. In [9], a linear precoding method for a MIMO-OFDMA scheme has been proposed in accordance to the LTE standard [6] due to its practicality and simplicity. Both the base station (BS) and the mobile terminal (MT) are aware of the predefined set of unitary precoding matrices, and MTs feed back only the index of a preferred pre-coding matrix and the corresponding effective signal-to-noise ratio (ESINR) of the preferred matrix. Previous work [5] has shown the capabilities of this precoding scheme in achieving spatial multi-user diversity gain and spatial multiplexing (SM) gain.

Further multi-user diversity gains in both the time and frequency domain can be exploited by adopting an appropriate joint time/frequency scheduling strategy. An initial user pre-selection stage is implemented in the time domain, imposing fairness constraints to all users. Dynamic scheduling and allocation in the frequency domain is then applied to the subset of eligible users to further improve the system performance. In this paper, seven resource allocation algorithms are investigated. Round robin (RR) does not rely on channel state information whilst the greedy algorithm (GA) maximises system throughput without considering fairness. The remaining proposed algorithms jointly consider throughput, power efficiency and fairness issues. The window size in two variants of the proportional fair algorithm (PFA) and the tuning parameter in the relative strength scheduling algorithm (RSSA) allow the system to tune fairness according to specific requirements. The equal gain dynamic allocation (EGDA) algorithm attempts to allocate PRBs that improves the perceived channel gain in a user without minimising the perceived channel gain in other users. The fair cluster algorithm (FCA) allocates a fair number of resource blocks to all selected users, and the current scheduling decision of the latter scheme, taking scheduling history into consideration. Whilst the conventional target of the scheduling and allocation algorithms is to improve system throughput, this can be translated to energy reduction to achieve a specific rate target. The performance of these various scheduling algorithms is examined and compared in terms of: throughput, throughput fairness, power efficiency and power fairness.

II. SYSTEM AND CHANNEL MODEL

Considering a multi-user scenario, the performance analysis is performed on the downlink of a 3GPP LTE-OFDMA system. The total system bandwidth is divided into sub-channels, denoted as physical resource blocks (PRBs), which can then be allocated to different users for multiple access purposes. The key parameters of the considered LTE OFDMA downlink system are given in Table 1. There are 100 PRBs in the 20MHz system, each consisting of 12 adjacent sub-carriers. For uplink feedback overhead saving purposes, a single CQI based on the average quality of the 12 grouped sub-carriers comprising the PRB is fed back for each PRB. Due to the increased computational complexity and the insignificant gain of power allocation in the frequency domain dynamic allocation, equal power allocation across PRBs is assumed throughout the simulations [8].

Unitary codebook based beamforming has shown capabilities in achieving spatial multiuser diversity gain and spatial multiplexing (SM) gain [5]. Depending on the spatial resource allocation process, unitary codebook based beamforming defines two modes of operation. In each PRB, the MIMO channels can be decomposed into several separate spatial layers which can be allocated to the same user for SU-MIMO or to different users for MU-MIMO. This paper focuses on SU-MIMO. Every user calculates the average ESINR across all the sub-carriers in each PRB. The serving BS receives CQI information from all users, each on their preferred matrix that optimises spectral efficiency

independently. The achievable data rate of a user on each PRB can be estimated from the ESINR feedback. The BS allocates each PRB to a user according to the adopted resource allocation algorithm.

This paper evaluates the performance of SU-MIMO employing various scheduling algorithms in a single cell scenario by software simulation. The simulation employs the 3GPP Spatial Channel Model Extension (SCME) as specified in [11]. Users are uniformly distributed in the cell and thus experience different SNR, based on their relative location from the serving Base Station (BS) and respective shadowing conditions. It is assumed that the channel quality of each user is fed back in an ideal fashion to the BS. Path loss, large scale shadowing fading and temporal fast fading are included in the simulation. SCME defines three environments (Suburban Macro, Urban Macro, and Urban Micro) where the default scenario used in the results presented below is Urban Macro. A low spatially correlated channel is assumed for all the users where 10λ spacing at the BS is employed. 5000 temporary correlated channel instances were established, updated after each subframe. The system level simulation parameters are summarised in Table 1. A representative sample of the modulation and coding schemes (MCS) adopted by LTE are used, indicated in Table 2. The PER vs SNR performance of the MCS are presented in Figure 1. A link adaptation (LA) target of 10% is assumed and thus a look up table can be derived from the figure. According to the Figure 2, the (per user) switching point between space frequency block coding (SFBC) and spatial multiplexing (SM) is assumed to be approximately 9dB for a multi-user scenario with more than 10 users. Nonetheless, it should be noted that a 2x2 MIMO architecture is considered in this paper but the analysis is readily extendible to higher MIMO orders.

Table 1: Simulation Parameters for LTE OFDMA Downlink

Transmission Bandwidth	20 MHz
Cell Configuration	Single Cell
Time Slot/Sub-frame duration	0.5ms/1ms
Sub-carrier spacing	15kHz
Sampling frequency	30.72MHz (8x3.84MHz)
FFT size	2048
Number of occupied sub-carriers	1201
BS Tx Power	43dBm (20W)
Propagation Model	SCM Urban Macro
Path Loss Model	Cost-Hata [11]
Shadowing Log-Normal Deviation	8dB
Cell Radius	750m
Noise Power	-104dBm
User Equipment Noise Figure	6dB
Packet Arrival	Full Buffer
Number of users	25
User Velocity	30km/h
CQI Measurement Error	Ideal
MCS Selection Rule	CQI Measurement
MCS Update Rule	Per frame (1ms)
Link Adaptation Target	10%

Table 2: Modulation and Coding Schemes

Mode	Modulation	Cod. Rate	Data bits per time slot (1x1), (2x2)	Bit Rate (Mbps)
1	QPSK	1/3	5333/10133	10.66/20.26
2	QPSK	1/2	8000/15200	16/30.4
3	QPSK	3/4	12000/22800	24/45.6
4	16 QAM	1/3	10666/20266	21.34/40.54
5	16 QAM	1/2	16000/30400	32/60.8
6	16 QAM	3/4	24000/45600	48/91.2
7	64 QAM	3/5	28800/54720	57.6/109.44
8	64 QAM	3/4	36000/68400	72/136.8
9	64 QAM	6/7	41142/78172	82.28/156.34

IV. RESOURCE SCHEDULING ALGORITHMS

In this paper, a joint time/frequency scheduling approach is considered. The first layer of scheduling is implemented in the time domain (TD) and the second layer in the frequency domain (FD) [14]. The TD scheduler attempts to identify users with relatively good channels whilst maintaining an overall fairness for all users. Seven FD schedulers with different targets in terms of throughput and rate fairness and energy consumption are considered.

A. Time Domain Scheduler

In the time domain, a well known PF scheduler is adopted to assign approximately the same number of resources to all users (averaged over a period of time) and to try to allocate resource in any given scheduling interval to a user whose channel condition is near its peak. At any time slot, proportional fairness can be achieved by transmitting to user k^* having the highest priority based on:

$$k^* = \arg\max_k P_k(t) = \arg\max_k R_k(t)/T_k(t) \qquad (1)$$

where $R_k(t)$ represents the current requested transmission rate chosen from the set of available MCS. $T_k(t)$ represents the user's average throughput over a window in the past and it is calculated by:

$$T_{k,c}(t) = \begin{cases} \left(1-\dfrac{1}{t_c}\right)T_k(t-1)+\dfrac{1}{t_c}R_k(t) & k = k^* \\ \left(1-\dfrac{1}{t_c}\right)T_k(t-1) & k \neq k^* \end{cases} \qquad (2)$$

Figure 1: PER vs SNR for different MCSs
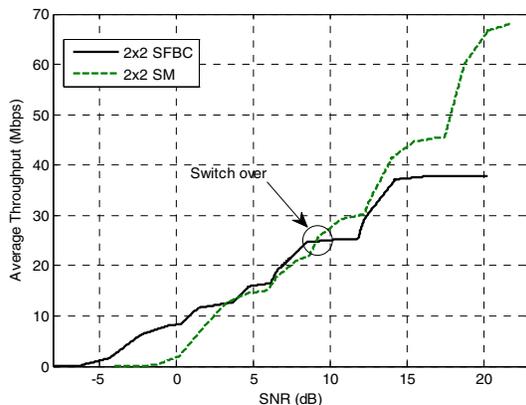
Figure 2: Switching point for SFBC and SM schemes

where t_c is the window size of the average throughput. For larger t_c, the scheduler maximises throughput but has a lower latency tolerance to some applications. In this paper t_c is set to 500 to compromise between throughput and delay constraints. The initial average throughput value for PF ranking will be defaulted to the first reported CQI and will be based on the MCS selected for the user via LA. In the context of OFDMA, the subset of users with the highest priorities, the number of which is termed 'multiplexing users' and denoted by k, is selected for subsequent FD scheduling.

B. Frequency Domain Scheduler

A number of scheduling algorithms are integrated to an OFDMA system, allocating resources in the frequency domain to the subset of the selected users.

1) Round Robin (RR)

The selected users are serviced in a round-robin fashion across different PRBs. All users must be allocated a PRB before re-allocating to the same user.

2) Greedy Algorithm (GA)

To maximise the overall system throughput, *GA* assigns a PRB c to the strongest user based on:

$$k^* = \arg\max_k \alpha_{k,c}(t) \quad \text{for PRB } c \tag{3}$$

3) Proportional Fair Algorithm (PFA) Scheme 1 and 2

For PRB c, the highest ranked user k^* is scheduled to transmit:

$$k^* = \arg\max_k R_{k,c}(t)/T_k(t) \tag{4}$$

Where $R_{k,c}(t)$ denotes the instantaneous achievable rate at PRB c and $T_k(t)$ is the user's average throughput.

The extension of PF scheduling to multicarrier, OFDM transmission has been examined in [12]. Two variations of the PF algorithm, returning different degrees of tradeoffs in terms of complexity and fairness are examined.
PF I: The average throughput metric $T_k(t)$ is updated for each new time interval (after all PRBs are allocated).
PF II: The average throughput metric $T_k(t)$ is updated after the allocation of each PRB This enhances fairness at the cost of greater complexity.

4) Equal Gain Dynamic Allocation(EG-DA))

This allocation algorithm proposed in [13] for a SISO OFDMA system exploits multiuser diversity by allocating PRBs to users so as to achieve substantial increases in perceived channel gain, approximately equal for all users. If users experience similar SNR levels, this is a fair approach and ensures different users achieve similar PER and BER performances. This algorithm is modified here to a SU-MIMO OFDMA system.

Initialization: Set $\alpha_k(t)=0$ for all users, C available PRBs
First time:
  Loop through the selected users, k, in random order
    User k selects a best PRB c, $\alpha_k(t)=\alpha_{k,c}(t)$
      Remove selected PRB c from available PRBs
    End user loop

While available PRB, C are not equal to 0
  Loop through the users from the one with the lowest $\alpha_k(t)$
    User k selects a best PRB c from the available PRBs

Update $\alpha_k(t)=\alpha_k(t)+\alpha_{k,c}(t)$
      Remove selected PRB from available PRBs
    End user loop
  End while loop

5) Fair Cluster Algorithm (FCA)

This algorithm aims to allocate the same number of PRBs to every selected user and achieve both short term and long term fairness [15]. $P_k(t)$ is the ratio of the scheduled data rate $a_k(t)$ (based on the *FCA*) over the best data rate $b_k(t)$ that user k can possibly achieve at time t under the constraint that every user is allocated the same number of PRBs. $C_k(t)$ is the number of PRBs allocated to MS k.
Initialisation: Set $P_k(0)=0$, $C_k(0)=0$, $a_k(0)=0$ for all users
Step 1(Start): For every user, all the PRBs are ranked in a descending order with $\alpha_{k,c(t)}$, $\{\tilde{\alpha}_{k,1}(t) > \cdots \tilde{\alpha}_{k,i}(t) > \cdots \tilde{\alpha}_{k,C}(t)\}$, where $\tilde{\alpha}_{k,i}(t)$ is the ESINR following the new index i after ranking. $b_k(t)$ is the sum of the data rate $\tilde{R}_{k,i}(t)$ (calculated based on $\tilde{\alpha}_{k,i}(t)$) of the best N_c PRBs $b_k(t)=\sum_{i=1}^{N_c} \tilde{R}_{k,i}(t)$.

Step 2: For $i=1$ to C
  For MS $k=1,\cdots,K$
  {
  If $C_{k^*}(t) < N_c$ (MS k^* has not been given N_c PRBs)
  Find the corresponding PRB c for k^* at this iteration i ($\alpha_{k^*,c}(t)=\tilde{\alpha}_{k^*,i}(t)$)
    - If c is unoccupied, allocate it to k^*
    - If c is occupied, (i.e. more than one user select c as its i th best PRB), priority is given to the user
      - With the lowest $P_k(t)$
      - For users with the same $P_k(t)$, allocate c to the user with the highest $\alpha_{k,c}(t)$

  Update C_{k^*} and $a_{k^*}(t)=a_{k^*}(t)+R_{k^*,c}(t)$ (calculated on $\alpha_{k^*,c}(t)$)
  }

The BS transmits signals to users based on the scheduling result. $P_k(t^*+1)$ of user k at time t^*+1 is computed as:

$$P_k(t^*+1) = \frac{\sum_{t=1}^{t^*} a_k(t)}{\sum_{t=1}^{t^*} b_k(t)} \tag{5}$$

The metric shows the ratio of the average rate that is actually transmitted over the average ideal rate for the best N_c PRBs during the time interval t^* for MS k.

6) Relative Strength Scheduling Algorithm (RSSA)

The relative strength scheduling algorithm (*RSSA*) proposed in [16], gives enhanced scheduling priority of weak users on their strong PRBs, resulting in a more equally distributed resource allocation process across an OFDM symbol. This approach achieves short term resource allocation fairness, without taking into consideration the throughput associated with the assignment of these resources. Therefore the RSSA algorithm is more appropriate for real time traffic, for which delay constraints and low throughput requirements exist. It is therefore expected that the

conventional notion of measuring fairness in terms of throughput assignment will fail to accurately represent the optimization target of RSSA. The relative strength metric compares the instantaneous PRB strength of each user with the average OFDM symbol strength. PRBs of a user k found to be above the average symbol strength experienced by this user are given increased priority and PRBs weaker than the average are reduced in priority. The RSSA algorithm selects a user according to:

$$k^* = \arg \max_{1 \leq k \leq K} \left(\frac{\alpha_{k,c}(t)}{\overline{\alpha}_k(t)} \right)^{\gamma} \alpha_{k,c}(t) \qquad (6)$$

The first part of the selection metric involves the PRB strength, $\alpha_{k,c}(t)$, relative to the average symbol strength $\overline{\alpha}_k(t)$.

The second part of the metric is the multiuser diversity factor. The γ parameter tunes the dependency of the metric to the relative strength parameter. Note that for $\gamma=0$, the algorithm reduces to GA scheduling. In this paper, γ is set to 50, providing is a good trade-off between throughput and fairness for a scenario where users experience distinctly different SNR levels.

V. SIMULATION RESULTS

In the first section, the results concentrate only on a FD scheduling process. The average achievable throughput for the different scheduling algorithms is presented in Figure 3 the corresponding Jain's rate fairness indices for these algorithms are shown in Figure 4. A direct tradeoff between throughout and rate fairness can be identified. Figure 3 indicates that the *GA* algorithm achieves the highest throughput performance, due to the fact that this algorithm relies only the instantaneous channel strength for resource allocation. The fairness index for the *GA* algorithm however suffers, rendering the GA algorithm inappropriate for many QoS requirements. Both the *PF* I and *PF* II algorithms achieve a relatively good performance in terms of throughput. The throughput performance is slightly lower compared to the *GA* algorithm but the fairness index is much higher. The *PF* I algorithm has higher throughput performance than *PF* II but on the other hand it has a worse fairness index. The *RSSA* algorithm has a good throughput, but under-performs slightly in terms of fairness. Both the *FCA* and *EG-DA* algorithms have approximately the same performance in terms of throughput and fairness. The RR algorithm has the worst throughput performance. Additionally, the fairness index of the *RR* algorithm is even lower than the *PF* II, *FCA* and *EG-DA* algorithms.

Subsequent results consider a joint TD/FD scheduling strategy. In this scenario only the 60% of the strongest users based on their average conditions over time are selected for resource allocation eligibility in the frequency domain. The throughput and rate fairness performance of the joint TD/FD implementation is presented in Figure 5 and Figure 6 respectively. Figure 5 shows that the throughput performance for most of the algorithms has improved except for the *PF* I algorithm. The throughput performance for *GA* and *RSSA* remain the same but the fairness index has increased, especially for the *GA* algorithms. In the case of *PF* II, *FCA* and *EG-DA* algorithms, the throughput has increased by an average of 8%, at the expense of a slight decrease in the fairness index. A metric that describes the dissipation of power as a function of the transmitted throughput: the power fairness index is considered, indicating the power fairness among all the users according to:

$$PFI = \frac{\left(\sum_{k=1}^{K} P_k / R_k \right)^2}{K \sum_{k=1}^{K} \left(P_k / R_k \right)^2} \qquad (7)$$

The power fairness index shows a similar trend to the rate fairness index. The GA algorithm once again shows an inferior performance in terms of power allocation fairness among all users despite achieving the highest total throughput in the system. On the other hand, algorithms such as FCA, *PF* II, EG-DA and RSSA achieve a better tradeoff between power fairness and throughput performance.

The power efficiency of each scheme can be represented by the Energy Consumption Rate (ECR) given by [18]:

$$ECR = \sum_{k=1}^{K} \frac{P_k}{R_k} (J/bits) \qquad (8)$$

Figure 8, shows the corresponding ECR values for the considered schemes. The lower the ECR, the higher the power efficiency is. A tradeoff between power efficiency and fairness is observed.
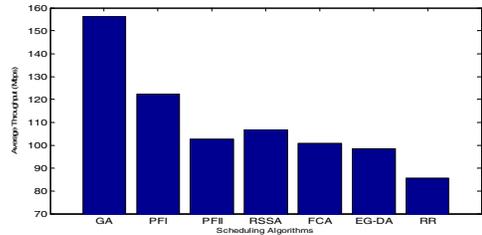

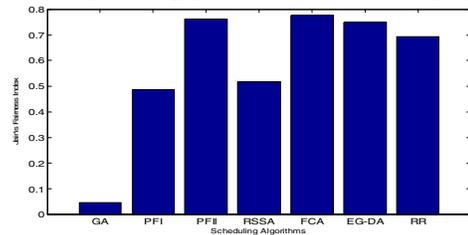Figure 3: Average Throughput for different scheduling algorithms

Figure 4: Jain's Rate Fairness Index for different scheduling algorithms
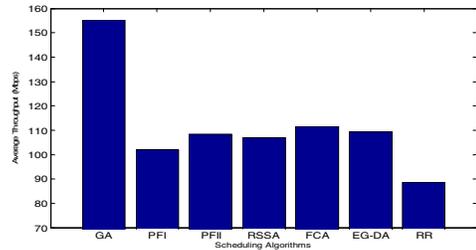

Figure 5: Average Throughput for different scheduling algorithms with joint time-frequency scheduling

In order evaluate the impact of the reduction of fairness index in the joint time/frequency scheduler, a normalised user throughput metric is considered. The normalized throughput bound is selected as a fairness criterion as suggested in [19]. The interpretation is that at least 90% of the users should have at least 10% of the average user throughput, indicated by the red dotted line in Figure 9. The cumulative distribution functions (cdf) of the normalized user throughput for the different schedulers (normalised to their corresponding means) are also shown in Figure 9.

As can be seen from the figure the *GA* algorithm fails to meet the throughput bound, whilst the *PF* I algorithm barely satisfies the fairness criteria. The proposed schedulers, *EG-DA*, *RR*, *FCA*, *RSSA* and *PF* II can easily fulfil the fairness criteria. It can be concluded that the proposed algorithms

offer good tradeoff between meeting fairness criteria, achieving high throughput and power efficiency. Conventional algorithms, such as the *GA*, *RR* and *PF* I fail to ensure power fairness and efficiency.
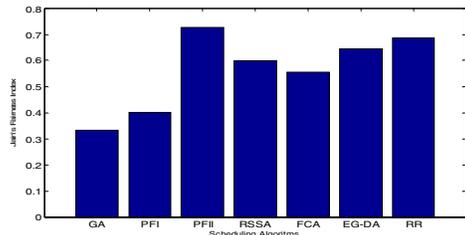

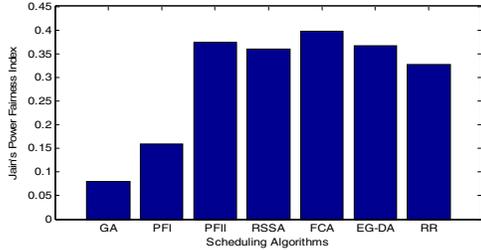Figure 6: Jain's Rate Fairness Index for different scheduling algorithms with joint time-frequency scheduling

Figure 7: Jain's Power Fairness Index for different scheduling algorithms with joint time-frequency scheduling
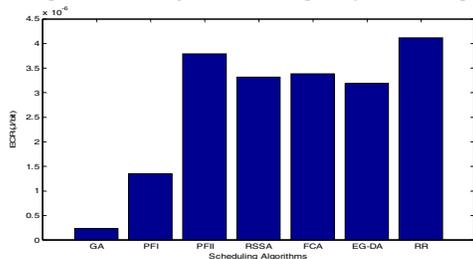

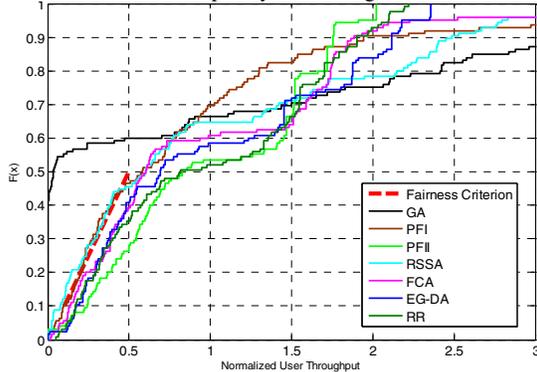Figure 8: ECR for different scheduling algorithms with joint time-frequency scheduling

Figure 9: Cumulative Distribution Function (CDF) of Normalized User Throughput

V. CONCLUSIONS

This paper investigated the rate and power consumption performance on the downlink of a 3GPP LTE-OFDMA system employing SU-MIMO in combination with a number of proposed dynamic resource scheduling and allocation algorithms. Opportunistic scheduling algorithms can achieve significant improvements over a fixed scheduling strategy such as RR. Algorithms such as *PF* (both), *FCA*, *RSSA* and *EG-DA* were shown to provide a good compromise between throughput and rate fairness, whilst meeting the specified green radio targets. Further enhancements can be achieved via joint time and frequency scheduling. Although the throughput

gain power reduction comes with a slight fairness trade-off, the fairness index still fulfils the commonly adopted fairness criteria, with the exception of the case of the *GA* algorithm.

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