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Power Control and Adaptive Scheduling for Uplink Interference Mitigation in a Mixed Mode LTE networks

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ABSTRACT: The ever-increasing demand on mobile wireless operators to provide efficient voice and high speed data services has led to search for powerful methods to share the available spectrum in most efficient way. In order to guarantee the user QoS requirements with high utilization of the radio resources in LTE cellular networks, both the channel rate and transmission power of each user should be dynamically adjusted. Against this back drop, this work has proposed a joint power control and adaptive SINR-based scheduling algorithm to mitigate interference on the uplink of a mixed mode LTE network. The proposed algorithm serve as the main switching technique for user equipment in the eNBs by distributing the available system resources to users in each scheduling time interval according to individual bandwidth and QoS requirement. The obtained results showed that our proposed scheme has a performance gain of about 4dB in terms of rate achievable for the cell as compared to the benchmark scheduler and comparable fairness index.

KEYWORDS: Adaptive, Channel rate, Fairness, Interference, Scheduler, SINR

1. INTRODUCTION

Long Term Evolution network is gradually being introduced into most of the world market with attendant increase in data throughput, interference is sometimes the cost associated with capacity increase to system designer and researchers. This is mainly as a result of limited spectrum of LTE which makes most of the operators to deploy single frequency in order to maximize system capacity. Even though single frequency is spectral efficient, it also has a high probability of interference to the network. Resource allocation in LTE systems has been widely investigated, with most contributions achieving significant improvement in system performance by increasing the spectral efficiency, with some observed issues with applicability, complexity, and performance gains. LTE technology presents a very challenging multiuser problem: Several User Equipment (UEs) in the same geographic area require high data rates in a finite bandwidth with low latency. Scheduling LTE's uplink requires particular attention hence, there is the need to develop an efficient and effective scheme that would guarantee a trade-off between network performance gain and the technological complexity associated with the solution implementation. Therefore, in this work a hybrid solution of power control technique and adaptive scheduling will be used to mitigate interference in the uplink of an LTE network. The hybrid solution would be a desirable radio resource management scheme that will efficiently reduce the ICI at the same time as will not drastically reduce the utilization of the scarce frequency spectrum.

II. RELATED WORKS

(Kulkarni and Pujar, 2017) developed a new scheduling algorithm, known as the NewQueue algorithm, which offered a means of not only scheduling packets, but also managing queues. Simulation results showed that the New Queue algorithm was more efficient than the existing Droptail algorithm with respect to delay, jitter and throughput. In (Motea

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et al, 2016), the authors introduced the resource allocation technique-based cuckoo search algorithm RACSA for cross-tier interference mitigation in orthogonal frequency division multiple access based long term evolution (OFDMA-LTE) systems. Simulation results showed that RACSA reduced cross-tear interference and improved system performance. In their work (Qian et al, 2012), proposed a combined subcarrier and power allocation scheme, where system throughput can be increased by jointly adjusting subcarrier and power allocation in a soft frequency reuse (SFR) system. Simulation results showed that the proposed algorithm outperforms existing reuse 1, FFR and static SFR schemes in both system throughput and cell edge user performance. Similarly, (Qian et al, in 2015), proposed an inter-cell resource allocation algorithm, referred to as the adaptive SFR algorithm (ASFR), for multicell wireless networks to improve system efficiencies. Simulation results showed that ASFR achieved a higher system throughput and better cell edge user performance than existing frequency reuse schemes. Power control for OFDMA networks was introduced in (Combes et al, 2011), where fractional power control (FPC) offered a modification of traditional power control to control the tradeoff between system capacity and cell-edge rate. Numerical simulations of large-scale long-term evolution (LTE) networks showed the potential benefits of self-optimizing schemes with significant performance gains brought about by dynamic fractional reuse scheme. The authors in (Alexiou et al, 2013) proposed a power control mechanism for efficient power allocation that used priority grouping in small scale networks in which each user was assigned to one of the available groups with different priorities in terms of power requirements and traffic load. Its advantages are centered on the distance (between the access points (AP) and the user's parameter) and the load as a parameter. (Chaves et al, 2013) proposed the use of LTE uplink (UL) power control to improve LTE/Wi-Fi coexistence. The performance of this simulation network was measured by average user throughput and resulted in improved Wi-Fi coexistence and slightly reduced LTE networks but it focuses only on indoor networks.

III. ANALYTICAL MODELS

The model adopted in this work is an interference limited multiple cell OFDMA system with three cells, each cell equipped with a base station (eNB) with N antennas, serving K single-antenna users in the uplink as shown in Figure 3.1. The "weak" UE_k is served by eNB_1 and is allocated the n-th RB and the "interfering" set of users IP_k^1 transmitting over the n-th RB is located in eNB_2 and eNB_3 neighboring cells . The uplink interference I_k^1 which is the inter-cell interference caused by the set of users "interfering" with the weak UE_k, results in a reduction in the obtained signal-to-interference-plus noise ratio (SINR) at UE_k at its own serving base station. The signal received on eNB1 for UE_k before receive combining is given as:

$$y_{1,k} = P_{1,k}\boldsymbol{g}_{1,k}x_{1,k} + \underbrace{\sum\nolimits_{a\in IP_k^1} P_{1,a}\boldsymbol{g}_{1,a}x_{1,a}\partial_{1,k}}_{\text{Inter-cell interference}} + z_{1,k} \qquad (1)$$

where $p_{1,k}$ is the transmit power of UE_k, $\boldsymbol{g}_{1,k} \in \mathbb{C}^{N\times 1}$ is the channel (including fading and shadowing) between UE and eNB, $\boldsymbol{g}_{1,a}$ denotes the interfering channel between the desired UE and the interfering set, $x_{1,k}$ is the normalized transmit symbol for UE to unit 1 such that $\mathbb{E}\left[\left|x_{1,k}\right|^2\right] = 1$. $\partial_{1,k}$ is a binary variable indicating that users in neighboring cells share the same RB or not, $\partial_{1,k} = 1$ indicates that the user is scheduled with the same RB as our desired user and $\partial_{1,k} = 0$ otherwise. The noise is modeled as a spherically symmetric complex Gaussian distributed as $z_{1,k} \sim \mathcal{CN}(0, \sigma_{1,k}^2)$), where $\sigma_{1,k}^2$ is the noise power.

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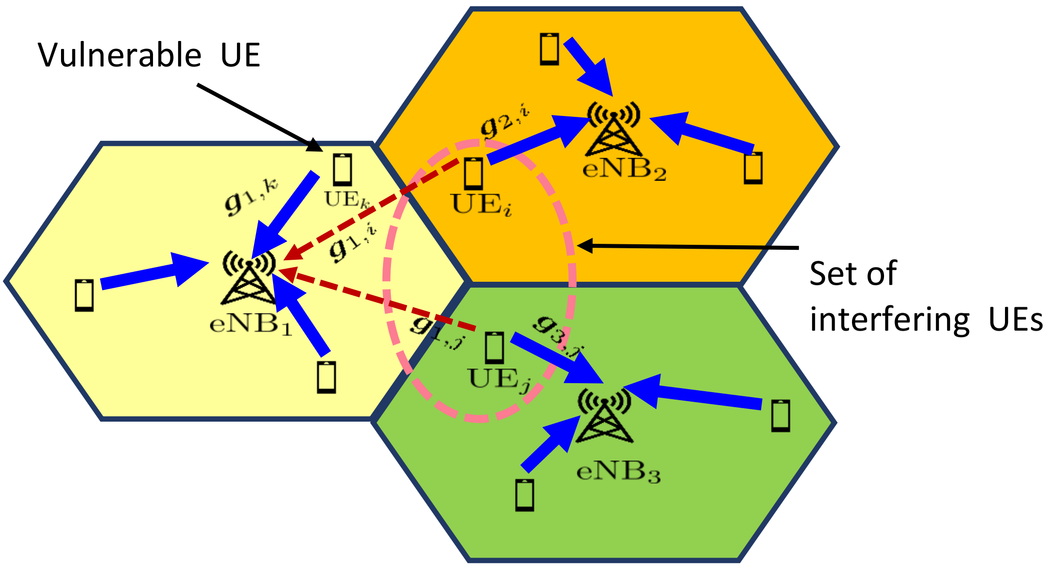

Figure 1: Interference Limited Multiple Cell LLTE System

The SINR of UE_k at its serving base station eNB1 is given by:

$$\Gamma_{1,k} = \frac{P_{1,k} g_{1,k}}{\sum_{a \in I_k^1} P_{1,a} g_{1,a} \partial_{1,k} + \sigma_{1,k}^2} \qquad (2)$$

A. Uplink Capacity

The uplink capacity of a mixed mode LTE network is given by the well-known Shannon capacity equation. The capacity gain is increasing logarithmically according to Shannon and the capacity is given by:

$$C = BLog_2(1 + SINR) \qquad (3)$$

where B is the bandwidth and SINR is the signal to interference plus noise ratio.
To specify a range of acceptable performance, let the system specify the values of the maximum and minimum SINRs as $\Gamma_{\max}^k$and $\Gamma_{\min}^k$, respectively. At any time t, a serving eNB may use a sub-channel for transmission and to ensure correct decoding of $x_{1,k}$the condition $\Gamma_{1,k} \geq \Gamma_{\min}$ must be satisfied. From (2), the maximum interference attainable at $\Gamma_{\max}$ is given as

$$I_{k,\max}^1 = \frac{P_{1,k} g_{1,k}}{\Gamma_{\max}^k} - \sigma_{1,k}^2 \qquad (4)$$

Similarly, the minimum interference attainable at $\Gamma_{\min}$ is given as

$$I_{k,\min}^1 = \frac{P_{1,k} g_{1,k}}{\Gamma_{\min}^k} - \sigma_{1,k}^2 \qquad (5)$$

Therefore, the link rates attainable for the scenarios can be determined using Shannon's potential equation and it is given as

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$$C_{1,k}\begin{cases} 0, & \Gamma_{1,k} < \Gamma_{\min}^{k} \\ Log_2(1+\Gamma_{1,k}), & \Gamma_{\min}^{k} \le \Gamma_{1,k} \le \Gamma_{\max}^{k} \\ Log_2(1+\Gamma_{1,k}^{\max}), & \Gamma_{1,k} > \Gamma_{\max}^{k} \end{cases} \tag{6}$$

In order to meet the minimum SINR requirement for the desired user ($\Gamma_{1,k} \ge \Gamma_{\min}^{k}$) the serving BS controls the transmit power of the UE by scaling it up using an interference margin factor f, ($\forall f \in \{\mathbb{R}^{+}; f > 1\}$). This scaling factor is used to compensate for the expected interference when neighboring UEs are sharing the same RB to avoid excessive power loss. From (2), the transmit power control solution to achieve the minimum SINR target becomes

$$\bar{P}_{1,k} \ge f\Gamma_{\min}^{k}\left(\frac{\sum_{\in I_k^1} P_{1,a}g_{1,a}\partial_{1,k}+\sigma_{1,k}^2}{g_{1,k}}\right) \tag{7}$$

$$P_{1,k}^{\min} \le \bar{P}_{1,k} \le P_{1,k}^{\max} \tag{8}$$

Where $P_{1,k}^{\min}/P_{1,k}^{\max}$ are the transmit power limits of the respective minimum and maximum UEs as per 3GPP standard requirements and $\bar{P}_{1,k}$ is the average transmitting power of the UE for the RB.

B. Developed Adaptive SINR Based Scheduling (ASBS)

The ASBS algorithm is described in the following steps;

1. The maximum and minimum SINR target for the UE are declared as $\Gamma_{\max}^{k}$ and $\Gamma_{\min}^{k}$ and are used to classify the UE link as strong or weak. The scheduler would group the UEs as high priority (UE with weakest SINR), low priority (UE with strongest SINR) and mid-priority.

2. The eNB calculates $\Gamma_{1,k}$ and correlates it with the SINR target, if $\Gamma_{1,k} \ge \Gamma_{\max}^{k}$ the UE is classified as a strongest link and assigned low priority index use a higher order modulation scheme, like 64 QAM. The maximum allowable transmit power (MATP) for the UE is adapted using

$$P_{1,k} = \frac{\Gamma_{\max}^{k}}{\Gamma_{1,k}}\bar{P}_{1,k} \tag{9}$$

This will cause a decrease in the transmit power because the UE requires less power due to its enhanced desired channel gain, and hence could cause less interference.

3. If $\Gamma_{\min}^{k} \le \Gamma_{1,k} < \Gamma_{\max}^{k}$ UE classified as a strong link and assigned mid-priority index and use a high order modulation scheme such as 16QAM. Equally, the maximum allowable transmit power (MATP) for the UE is adapted using (9) this will cause a decrease (no?

4. If $\Gamma_{1,k} < \Gamma_{\min}^{k}$ UE is classified as a weak link and assigned the highest priority index and use a lower order modulation scheme such as QPSK. The maximum allowable transmit power (MATP) for the UE is adapted using

$$P_{1,k} = \frac{\Gamma_{\min}^{k}}{\Gamma_{1,k}}\bar{P}_{1,k} \tag{10}$$

and subsequently its MATP is increased since it would require more power to achieve its Quality of Service (QoS) requirement.

5. Priority grouping is used by the scheduler as a metric for scheduling. The principle of allocation is to assign RBs from high-priority classes to low-priority classes in chronological order.

It is clear to see that distant UEs (from the serving eNB) will be assigned higher-priority RB, and adjacent UEs, which are shielded from neighboring cell interference, are assigned lower-priority RB. The middle-priority RBs will be assigned to the remaining UEs. The pseudocode for the ASBS algorithm is shown in Figure 2

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Algorithm:		**Adaptative SINR based Scheduling (ASBS)**
Input	:	Buffer Status Report, CSI
Output	:	Scheduled UEs
Step 1	:	Access the Buffer Status Report
Step 2	:	Calculate I_k^1 and $\Gamma_{1,k}$ For new UE use SNR
Step 3	:	If $\Gamma_{1,k} \geq \Gamma_{max}^k$, classify UE as Strongest, assign lowest priority index, adapt MATP by (3.9) and use 64 QAM If $\Gamma_{min}^k \leq \Gamma_{1,k} < \Gamma_{max}^k$, classify UE as strong, assign mid-priority index, adapt MATP by (9) and use 16 QAM If $\Gamma_{1,k} < \Gamma_{min}^k$, classify UE as weakest, assign highest priority index, adapt MATP by (10) and use QPSK.
Step 4	:	Supply priority grouping metric to the scheduler
Step 5	:	Schedule UE from highest-mid-lowest priority

Figure 2: Pseudo code for the ASBS algorithm

IV. DISCUSSIONS

Figure 3 shows the achieved rate performance comparison between our developed algorithm and other throughput-based schedulers. In this work, MT and BET are selected for performance comparison. From the output, it is seen that the developed ASBS which is a hybrid solution outperforms the considered scheduler with power control, it is observed that there is about 4 dB performance difference between ASBS and MT, whereas BET has shown higher in the high SNR region due to the fact that like the ASBS the BET also tries to consider user with poor channel condition instead of totally dropping them like the MT.

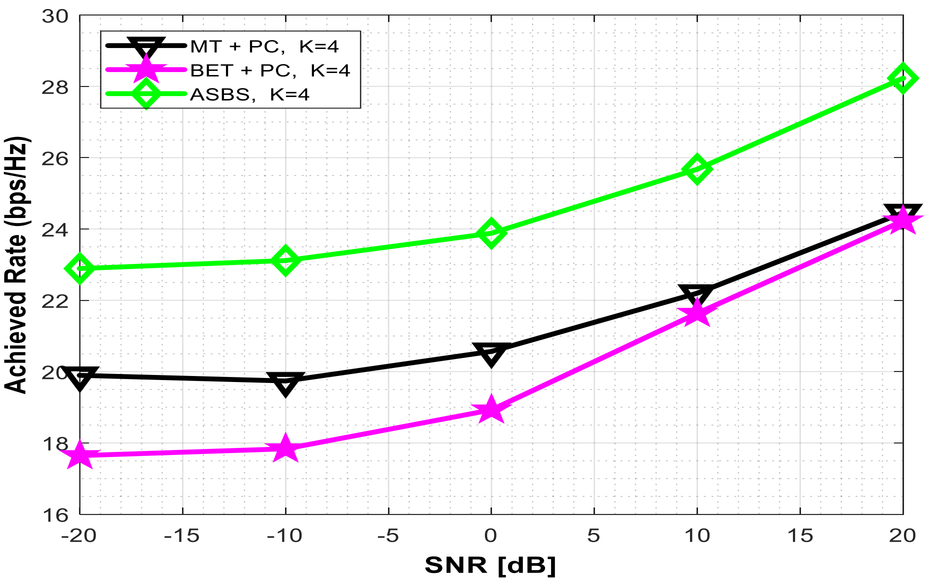

Figure 3: Comparison of performance with other schedules with power control, K=4

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In Figure 4, we also show the performance comparison between our developed ASBS algorithm and the considered schedulers, but in this experiment the considered schedulers are implemented without power controls.

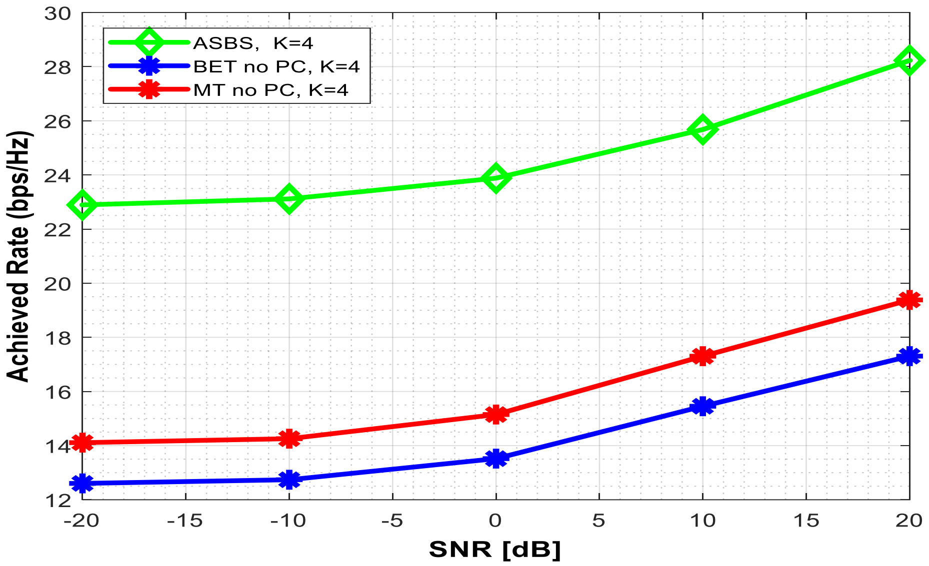

Figure 4: Performance comparison with other schedulers without power control, K=4

As compared to the previous result it is observed that the scheduler without power control performs very poorly with respect to power control and our developed ASBS algorithm.
Figure 5 shows the result of comparing the fairness index between the schedulers considered in this task with different users in the cell. It is not surprising that MT gives the worst value for fairness, because MT serves the users with the largest instantaneous supportable data rate which is advantageous in the achievable rate of the cell but at the expense of fairness. The ASBS and BET schedulers have comparable fairness values, which also improve with increase in the number of users in the cell. This is largely due to the fact, that from the operating view point of these schedulers' users with poor radio conditions such as the cell edge users are allocated with large amount of radio resources as opposed to MT scheduler.

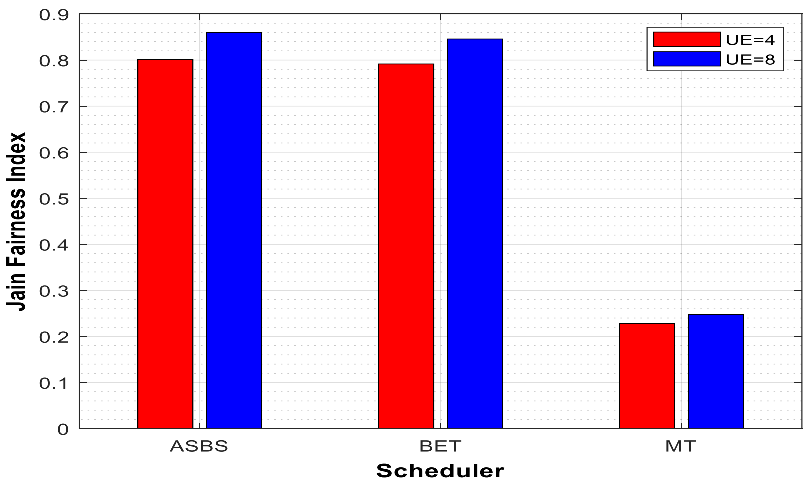

Figure 5: Fairness for 4 and 8 UEs

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V. CONCLUSION

This work implemented a hybrid power control and adaptive scheduling scheme to mitigate the uplink interference of LTE networks. The implemented scheduling scheme is adaptive with respect to the users' SINR. By giving high priority to cell edge users and high transmit power, our implementation ensures that fairness is given to all users within the cell. The proposed scheme was implemented in a system level simulator designed for LTE network simulation and the well-known maximum throughput (MT) and blind equal throughput (BET) schedulers are used as benchmarks to compare the performance of our proposed scheme. The obtained results demonstrated the importance of power control in scheduling as plans without power controls performed poorly compared to schemes with power controls. In terms of Fairness Index, which is another performance metric evaluated, the results showed that our proposed scheme has a fairness index of around 0.89 which is comparable with BET as both the schemes consider cell Edge user against MT which has the lowest fairness index.

VI. THANKS

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