Intrasite Scheduling for Interference Avoidance in LTE

Ashley Mills*, David Lister*
*Vodafone Group Services Limited, Research & Development, Faraday House,
The Connection, Newbury, Berkshire, RG14 2FN, ENGLAND.
Email: (Ashley.Mills@vodafone.com, David.Lister@vodafone.com)

***Abstract*—A novel method of intra-site interference avoidance is developed that seeks a balance between intra-site resource orthogonality and independent frequency selectivity. The method is compared against existing time and frequency selective scheduling approaches, as well as a static priority based interference avoidance scheme. The intra-site method promoted obtains better total and percentile throughputs compared to the schemes examined, and demonstrates the benefits that access to intra-site scheduling information can realise. Statistically robust results are obtained through system level simulations of LTE in the downlink direction only.**

I. Introduction

The next generation wireless technology, Long Term Evolution (LTE), has been designed to deliver higher spectral efficiency and increased cell-edge throughputs relative to HSPA [1]. It is expected that LTE will be deployed in a reuse one configuration, in which all frequency resources are available to use in each cell. Although LTE can operate at SINRs as low as -6.5dB [2], concern still persists over cell-edge performance.

This has led to the proposal of numerous inter-cell interference coordination mechanisms. A large group of these are static or semi static in nature [3], [4], [5], [6], [7]. However, upon examining results derived from these ideas [3], [8], [6], [9], [10], [11], [12], [13], [14] it is clear that while particular scenarios may benefit from one or another technique, for heterogeneous networks there is unlikely to be a net gain from static approaches [15].

Dynamic approaches which adapt to network conditions, and usually assume communication between basestations have thus been developed [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [8], [26]. These schemes have tended toward taking more and more cells into account, and it maybe that the future lies in convergence toward multi-cell processing with a centralised RAN architecture [27], [28].

Our work falls into the dynamic group. We present a novel means of interference avoidance for communicating groups of cells (illustrated for the intra-site case) which we believe could be applied now to real networks within the existing LTE standards framework. The method is compared with existing scheduling approaches which do not employ communication between cells.

The rest of this paper is organised as follows: Section II outlines the system simulation assumptions, describes the compared scheduling strategies in detail, and enumerates the parameter space over which they are compared. Section III presents the simulation results. The results are discussed in Section IV and the work concludes in Section V.

II. Methodology

A. LTE Model

The left of Figure 1 illustrates the essential components of a 10MHz LTE DL frame. In time, the frame consists of 10 subframes which each last 1ms. Half of a subframe is called a slot. In frequency, each subframe is split into 50 Virtual Resource Blocks (VRBs). Each VRB is comprised of a pair of physical resource blocks (PRBs). One VRB is the smallest unit of allocation in LTE [29]. Each PRB spans 12 subcarriers in frequency and 7 symbols in time (shorter cyclic prefix was used). Each element of a PRB is called a Resource Element (RE). An RE spans one subcarrier in frequency and one symbol in time. An RE has a frequency width of 15kHz and lasts approximately 70μs.

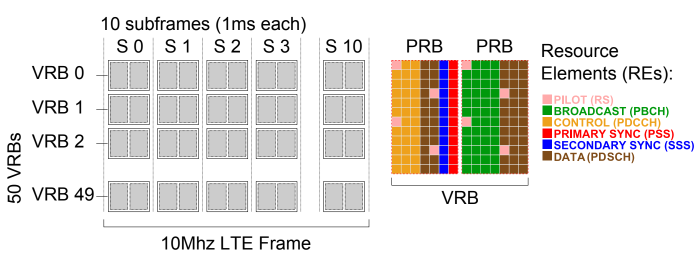

Fig. 1. The essential components of a DL LTE frame.

The right of the figure shows a VRB in detail, containing the RE types modelled here. Primary and secondary synchronisation, and broadcast channels, only occur on the three VRB either side of the central carrier. The former only occur in frames 0 and 5 and the latter only in frame 0. Their detailed action is not modelled: the channels only consume space that would otherwise be occupied by data REs. In the majority of the frame, only pilot, control, and data REs are present.

Pilot symbol positions and associated RSRP computation is modelled accurately according to [29]. Control channels are assumed to consume the first 3 symbols of every subframe, their action is not modelled, and they only consume space that would otherwise be occupied by data symbols. The average number of data REs per VRB was computed as 124.8720.

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B. System Assumptions

Four scheduling schemes were compared: one novel intra-site scheme (FD-PF-Intrasite) and three existing non-intrasite schemes (FD-PF, TD-PF-RD, TD-PF-SS). The schemes are defined in the subsections which follow. Each scheduling strategy was tested for 9 different parameter configurations: the Cartesian product of three cell load conditions U and three scheduling biases α.

U represents the traffic load in each cell. $U = x$ means that each sector is limited to assigning exactly the fraction x of all available VRB within one TTI. The motivation for this approach was that it was desired to abstract from a particular traffic class and capture the essence of intra-site interference. From the perspective of a serving cell at a given site only three scenarios are relevant:

1) Low interference/load: each sector uses less than 1/3rd bandwidth. Full resource orthogonality among sectors is in principle possible.
2) Partial interference/load: each cell uses over 1/3rd of the bandwidth, but less than the full bandwidth. Partial orthogonality among sectors is possible.
3) Full interference/load: no orthogonality is possible among sectors.

These three scenarios capture the possible types of intra-site interference that a sector can experience, independent of traffic class. The above scenarios are represented here by U values of 0.3, 0.65, and 1 respectively.

α is defined in Equation 1 and controls how much emphasis is put on the instant rate exponent in the proportional fair weighting of UEs. For $\alpha > 1$, the scheduler approaches a Maximum C/I scheduler and for $\alpha < 1$, the scheduler approaches a round robin scheduler, for $\alpha = 1$ a normal PF approach is followed. The values 0.1, 1, and 10 were examined here.

For each of the 9 parameter tuples, and for each scheduling strategy, a system simulation was executed to collect throughput statistics. Each simulation was performed on a two-tier network of 57 cells with wraparound and a lognormal shadowing standard deviation of $8dB$. The intrasite and site to site correlations assumed values of 1 and 0.5 respectively. Each simulation was repeated for 50 different shadowing seeds, and the collated results averaged.

Each simulation lasted for a duration of 1.25 seconds, the first 0.25 seconds of which were used for warmup during which round robin scheduling was used and no statistics were collected. Fast fading was modelled using the SCME sub-urban macro model [30] assuming a constant UE velocity of $1.5ms^{-1}$.

A 3dB offset Shannon mapping between SINR and bitrate was employed with a ceiling of 5.52 bits per symbol. MCS targets were assumed to exist at 1dB intervals, and packets received with 0.1dB or less than the target SINR were assumed to have been received in error. This approximation produces a curve very similar to realistic throughputs seen by trial equipment, but owing to the simplifications inherent in the model, is only suitable for relative comparisons as in this work.

C. FD-PF (Frequency Domain Proportional Fair)

Time domain proportional fair [31] has been extended to the frequency domain in various ways and gives better performance than the former (See for example [32], [33], [34], [35]). The approach used here to determine the score $S_{i,m}(t)$ for UE i on subband m at time t is as follows:

$$S_{i,m}(t) = R_{i,m}(t)^{\alpha} / MR_i(t)^{\beta} \tag{1}$$

Where $R_{i,m}(t)$ is the instantaneous rate of UE i on subband m (in bits per symbol) at time t, $MR_i(t)$ is the mean rate of UE i at time t. The mean rate is updated recursively as follows:

$$MR_i(t+1) = A_i(t) \cdot (1 - 1/t_c) + MR_i(t) \cdot 1/t_c \tag{2}$$

Where $A_i(t)$ is the payload allocated to UE i at time t. In this work, payload was expressed simply in bits. The parameter $t_c = 0.01$ controls the size of the averaging window. β is set to 1, because fairness can be controlled using only α.

Exactly 9 subbands were employed here containing 6 VRB each in accordance with the LTE specification [36] for $10Mhz$ (See Table 7.2.1-3). At TTI t, subband m is assigned to the UE i^* with highest score $S_{i^*,m}(t) = \underset{i}{\operatorname{argmax}}\, S_{i,m}(t)$.

D. TD-PF-RD (Time Domain Proportional Fair, Random Distributed)

Time domain proportional fair is a special case of frequency domain proportional fair where the number of subbands is set to 1. The random distributed aspect refers to the ordering of VRBs during assignment. Assignment begins at VRB index k, which is chosen randomly, and proceeds contiguously, wrapping back to index 0 if necessary. The effect is that interference is partially distributed among neighbours.

E. TD-PF-SS (Time Domain Proportional Fair, Semi Static)

The TD-PF-SS approach differs from the TD-PF-TD approach described above, only in the order in which VRB are allocated within each cell. Instead of starting at a random VRB index, the start indices are coordinated in a tessellating pattern with adjacent cells in a manner analogous with reuse three. For three sectors at a given site with $10Mhz$ bandwidth: sector 0 starts scheduling at VRB index 0, sector 1 starts at VRB index 16, and sector 2 starts at VRB index 32. This pattern tessellates in hexagons, such that if all sectors are using less than 1/3rd of the bandwidth, then their VRB allocations will be orthogonal. Note that the TD-PF-SS approach described is essentially identical to that proposed in [37].

F. FD-PF-Intrasite (Frequency Domain Proportional Fair, Intrasite Variant)

This approach is novel, and is inspired by the TD-PF-SS approach, and the observation that the latter, although being able to obtain resource orthogonality for low loads, suffers reduced frequency selectivity due to the consequent restrictions on VRB use. The motivation behind our approach is to capitalise on the benefits of both resource orthogonality *and* frequency selectivity. The resource assignment algorithm, executed *for each site*, is shown in Procedure 1 below:

Construct a three dimensional scheduling "matrix" having:

- 150 rows: one row for each VRB at the site such that each consecutive 50 entries corresponds to a different sector.
- For each row, make as many columns as there are scheduled UEs at the corresponding sector.

Populate and order the scheduling matrix:

1) Obtain the scheduling score for each row (site-level VRB index) and column (UE) using the FD-PF scoring metric.
2) Sort each row by column according to UE scores.
3) Sort the rows by the UE score at the head of each row.

Schedule the UEs:

- Iterate three times through the matrix by row:
  1) Determine the sector-level VRB index for the row.
  2) Determine the parent sector for the current row.
  3) IF a VRB with this sector-level index has not been allocated this iteration AND the VRB has not already been allocated to the parent sector THEN:
     – Allocate the VRB to the UE at the head of the current row.

Procedure 1: Procedure for intra-site scheduling.

The algorithm begins by visiting each sector at the site independently, to obtain per sector, per VRB scores for each UE (according to the FD-PF algorithm). It then creates a site-level meta-score for each VRB using the highest scoring UE for that sector and on that VRB. Finally the site-level scores are sorted so that for a given VRB index the best scoring UE among all sectors at the site gets priority. A three round iterative process ensures that within a given round, a VRB with a given index can only be assigned to one sector. This ensures orthogonal assignment of VRB among sectors during each round, such that if the utilisation in each sector is less than 1/3rd, then VRBs assigned to each sector are completely orthogonal. It also ensures however, that when all neighbours are fully utilised, the algorithm will behave the same as the frequency selective scheduler.

In essence the aim of the algorithm is to find good orthogonal sets of VRBs for low utilisation scenarios, without sacrificing performance at high neighbour utilisations.

III. Results

Table-I compares the results of the four scheduling strategies for each proportional fair instant rate exponent α, and for each utilisation value U.

Within a given row, the four scheduling columns are comparable. The results are grouped into three sets according to the utilisation factor U.

Consider the performance of the FD-PF-Intrasite scheduler relative to the TD-PF-SS scheduler. According to a right tailed ttest with a significance threshold of 0.05, with Satterthwaites approximation to address the Behrens-Fisher problem [38], the intrasite scheduler, FD-PF-Intrasite, significantly outperforms the semi static TD-PF-SS scheduler in all but two cases. The two cases are for a PF instantaneous rate exponent of 10, where U is 0.3 and 0.65 respectively. This is because in these cases the scheduling is heavily biased toward the highest SINR UEs and the resources under the TD-PF-SS scheduler between interfering neighbours are orthogonal or near-orthogonal respectively.

α	U	**TD-PF-SS**	**TD-PF-RD**	**FD-PF**	**FD-PF-Intrasite**
0.1	0.3	1.96	0.54	2.71	**2.74**
1	0.3	4.55	1.13	4.51	**4.74**
10	0.3	**9.02**	3.38	8.51	8.76
0.1	0.65	2.98	1.85	4.05	**4.20**
1	0.65	6.71	3.83	7.62	**8.02**
10	0.65	**16.23**	10.73	15.44	15.73
0.1	1.0	3.86	3.86	**5.37**	**5.37**
1	1.0	8.57	8.57	**11.34**	**11.34**
10	1.0	21.17	21.17	**21.50**	**21.50**

TABLE I
System level results. α represents the exponent of the instantaneous rate of the proportional fair priority metric, and U represents the cell utilisation factor. As explained previously. For each row, the highest score is highlighted in bold font.

The FD-PF-Intrasite scheduler significantly outperforms the FD-PF scheduler for every 0.3 and 0.65 load point, except when $\alpha = 0.1$ and $U = 0.3$. In the latter case the p value is 0.07 however, so is close to being significant at a threshold of 0.05.

For $U = 1.0$, the FD-PF-Intrasite and FD-PF schedulers have the same performance, because the algorithms behave exactly the same at full load. Similarly the TD-PF-SS and TD-PF-RD algorithms have the same performance for $U = 1.0$.

The FD-PF-Intrasite scheduler significantly outperforms the TD-PF-RD scheduler for every point.

The improvement of the FD-PF-Intrasite scheduler over the FD-PF scheduler is maximum at $\approx 5\%$ (as a percentage of the FD-PF value), and has a mean of $\approx 2.2\%$ with a standard deviation of $\approx 2.1\%$.

The improvement of the FD-PF-Intrasite scheduler over the the TD-PF-SS scheduler is maximum at $\approx 40\%$ (as a percentage of the TD-PF-SS value), and has a mean of $\approx 19\%$ with a standard deviation of $\approx 19\%$.

Finally, it is worth noting the difference between frequency *and* time selectivity compared to *only* time selectivity. The improvement of FD-PF over TD-PF-RD is maximal at 500% (as a percentage of the TD-PF-RD value), and has a mean of $\approx 232\%$ with a standard deviation of $\approx 36\%$.

A. Throughput Distribution

The CDF of throughput is interesting to examine in the context of the total throughput results, since it indicates to whom that throughput is distributed. Upon examining the CDFs for each of the input configurations examined Table-I it is however apparent that the general behaviour is very similar across these configurations. Therefore, in the interests of brevity, only three CDFs will be examined here. Figure-2 shows the throughput CDF for $U = 0.65$ and $\alpha = 0.1$.

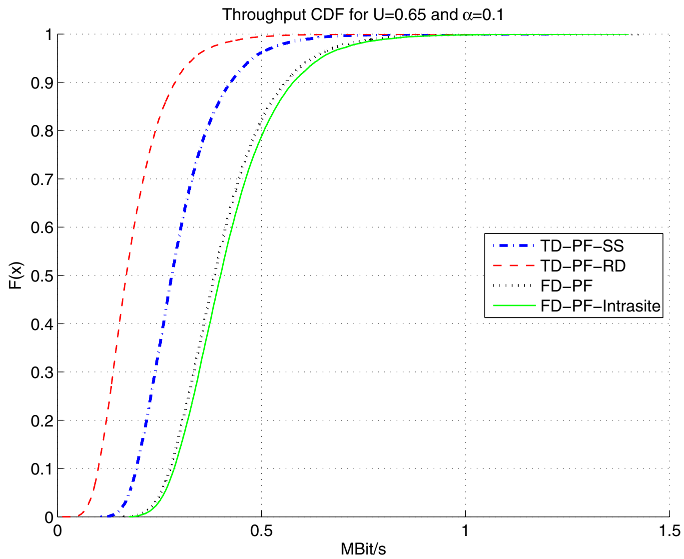

Fig. 2. Throughput CDF for $U = 0.65$ and $\alpha = 0.1$

As can be seen, the improvements of the FD-PF and FD-PF-Intrasite schemes over the TD-PF schemes are uniform over the distribution, with a slight increase in improvement toward higher throughputs. The improvement of FD-PF-Intrasite over FD-PF also appears very uniform. Figure-3 shows the throughput CDF for $U = 1.0$ and $\alpha = 1$.

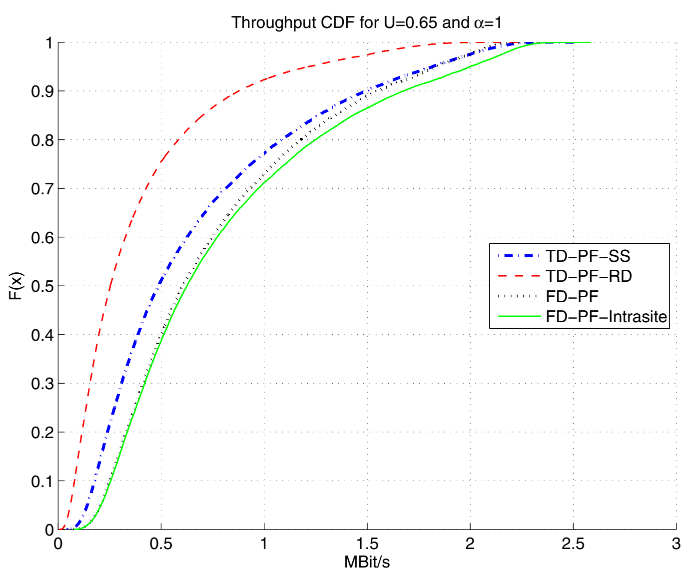

Fig. 3. Throughput CDF for $U = 0.65$ and $\alpha = 1$

The impact of the α value can be seen by comparing both plots. For example, the percentage of UEs getting more than 0.5Mbit/s in Figure 2 under the FD-PF-Intrasite scheme is $\approx 80\%$ whereas in Figure 3, this percentage is reduced to $\approx 40\%$. This should make it clear how much influence the scheduling strategy has on the tradeoff between percentile and total cell throughputs.

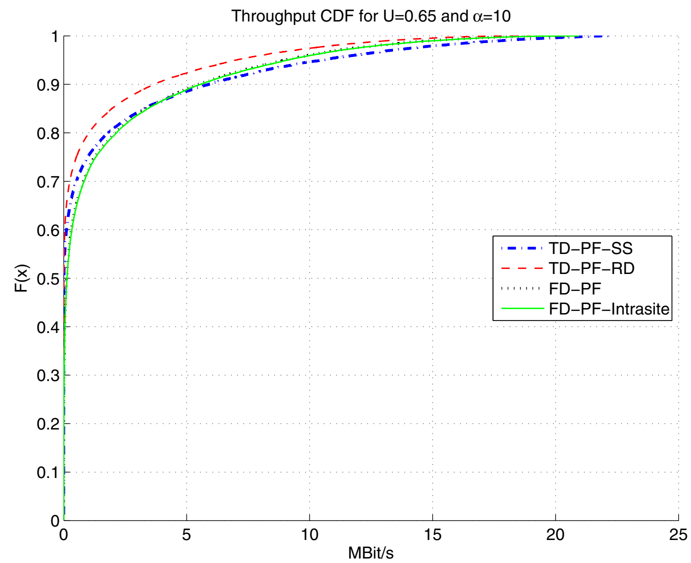

Fig. 4. Throughput CDF for $U = 0.65$ and $\alpha = 10$

In Figure 3 the gain of the FD-PF-Intrasite scheme over the FD-PF scheme is greater for higher throughputs (that is, higher SINR UEs). The gain of the FD-PF-Intrasite and FD-PF schemes over the TD-PF-SS scheme diminishes toward the higher SINR UEs. Figure 4 shows the CDF for $U = 0.65$ and $\alpha = 10$ and illustrates why the TD-PF-SS scheme does better than the FD-PF-Intrasite and FD-PF schemes for this point: it lies to the right of these schemes at the high end of the throughput distribution, and although it lies to the left at the lower end of the throughput distribution, in trade-off the result is that the TD-PF-SS scheme gets a higher throughput at the expense of the lower percentiles.

Notice however that with $\alpha = 10$ the scheduling strategy is so aggressive that it is approaching a Maximum C/I type scheduler. Closer inspection of the input data reveals that a large percentage of the UEs are never selected for scheduling under $\alpha = 10$. If the simulation were run for an infinite amount of time, the CDFs may lie marginally to the right, but the relative performance of schemes is unlikely to change. A more pertinent observation is simply that $\alpha = 10$ is an unrealistic scheduling strategy, albeit a useful illustration in this case.

IV. Discussion

When looked at over the full range of scenarios examined, it should be clear that FD-PF-Intrasite scheduling strategy gives the best total and percentile cell throughputs. Although the mean improvement in total throughput of FD-PF-Intrasite over FD-PF is only 2.2% it should be observed that this gain comes about at very little cost: the modification the eNB probably being a matter of a software change and interconnect install. Furthermore, the gain is statistically robust to changes in shadowing distribution, and therefore the actual gain is likely to vary from site to site. The recommendation therefore is strongly that these schemes should be pursued for deployment in LTE.

FD-PF-Intrasite here obtained no benefit over FD-PF for $U = 1$, since in this case the schemes perform identically. It has always been the intention to extend the scheme so to obtain differentiation in the case of $U = 1$, and this will be the subject of future work.

In brief, the investigation will proceed by examining pairs of UEs, or in principle triplets of UEs as candidates for enforced orthogonality at the VRB level. This is likely to produce a net gain for low SINR UEs, as evidenced by our previous work [15].

V. Conclusion

Intrasite scheduling offers small albeit robust gains over neighbour-naive frequency selective scheduling and should be pursued for deployment into LTE. Further gains can be expected by extension of the proposed scheme.

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