Interference Avoidance with Dynamic Inter-Cell Coordination for Downlink LTE System

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***Abstract*—The investigation of co-channel interference mitigation techniques (such as, interference cancellation through receiver processing, interference randomization by frequency hopping, and interference avoidance through resource usage restrictions imposed by frequency and power planning) has become a key focus area in achieving dense spectrum reuse in next generation cellular systems such as 3GPP LTE, LTE-advanced, and WiMAX. In this paper, we propose an interference avoidance scheme for LTE downlink that uses dynamic inter-cell coordination facilitated through X2 interface among neighbouring evolved UTRAN nodeBs (eNBs, i.e., LTE base stations). Proposed scheme is evaluated by extensive simulations and compared with a number of reference schemes available in the literature. It has been observed that the proposed scheme attains superior performance in terms of cell-edge and sector throughput compared to those in the reference schemes.**

***Key Words*— Interference avoidance, inter-cell coordination, 3GPP LTE, Hungarian algorithm, OFDM, OFDMA.**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) has been widely accepted as a promising air-interface technology for future generation systems by various standardization bodies and forums, for example, the third generation partnership project long term evolution (3GPP LTE) [1], worldwide interoperability for microwave access (WiMAX) [2], and the wireless world initiative new radio (WINNER) [3]. Equipped with OFDM's inherent robustness against frequency selective fading, orthogonal frequency division multiple access (OFDMA) offers flexibility for radio resource allocation [4]. The finer resource granularity of the OFDMA allows each resource unit to be allocated and modulated adaptively to obtain frequency as well as multiuser diversity. In order to meet user demands in terms of data-rate ubiquitously, dense reuse of available spectrum is envisaged in future systems. The obvious pitfall of such a dense reuse is the strong inter-cell interference which limits network as well as cell-edge throughput. To obtain the full potential of OFDMA in a dense reuse environment, appropriate radio resource management (RRM) algorithms for interference mitigation are necessary.

Interference mitigation is one of the key issues currently under investigation in different standardization bodies and forums. Based on approaches used, mitigation technique is generally categorized into three major classes, i.e., i) interference cancellation, ii) interference averaging, and iii) interference avoidance techniques. The basic principle of interference cancellation technique is the receiver signal processing to estimate interference and subtract it from the desired signal component. Interference averaging technique such as frequency hoping (FH) ensures user equipments (UEs) to access a range of channels rather than a narrow set in a specific pattern so that interference effect is averaged out for all UEs. Finally, the interference avoidance technique focuses on finding an optimal effective reuse factor often achieved through restrictions on frequency and power allocations to achieve network performance goals. The benefits of each of these schemes are mutually exclusive; therefore, a combination of the above strategies is expected in future systems. The focus of this paper is on interference avoidance through dynamic inter-cell coordination.

UEs at the cell[1] border experience high interference from neighbouring transmitters in addition to high path-losses. Scheduling schemes with objective to achieving maximized network throughput find these UEs with poor channel conditions less attractive as they do not contribute much to the total throughput. A blunt approach to improve cell-edge UEs' rates by assigning more resources (i.e., prioritizing cell-edge UEs in a certain way) would jeopardize the rates for other UEs in the cell-centre, and hence, such an approach is highly undesirable. The objective of interference avoidance is to provide better services to cell-edge UEs without sacrificing cell-centre throughput. In this paper, an interference avoidance scheme that uses dynamic inter-cell coordination through X2 interface is investigated.

Inter-cell interference can be reduced significantly with the traditional frequency reuse strategy as presented in the classical article [5] on cellular clustering. Fig. 1 shows reuse of 3 along with reuse of 1 and other static partition-based schemes. The higher the cluster size the greater the reduction in inter-cell interference. However, this improvement in interference can only be realized with the reduction in cell throughput. Although such a traditional reuse scheme might have been good enough to support traffic demands of the early networks, the rate requirements in the future systems warrant more aggressive reuse. In recent years, a large number of available studies in the literature consider reuse partitioning in which cell-edge UEs are assigned resources with higher reuse factors compared to the UEs at the cell-centre to obtain an effective reuse which is somewhat greater than 1 but not too high. In general these schemes are referred to as fractional

[1] The terms cell and sector are used interchangeably in this paper; inter-cell interference implies the interference power received from any sector antenna to a UE in a sector of interest.

frequency reuse (FFR) schemes. Evolved from the idea of classical reuse clustering, FFR was first introduced in [6] for Global System for Mobile (GSM) systems. Variants of FFR such as soft frequency reuse (SFR) and partial frequency reuse (PFR) have been adopted in the WiMAX and 3GPP LTE systems (see [7] and [8] for example). This idea is also explored extensively in the WINNER project [9]. While this approach improves interference to the cell edge UEs, there is a great potential to lose overall cell throughput due to resource loss resulted from partitioning.

An optimal partitioning depends on the distribution of the UEs, arrived traffic, and channel dynamism. Therefore, any static reuse partitioning scheme would be a highly sub-optimal solution. A dynamic partitioning based on UEs' traffic load as well as mutual interference situation may provide balanced improvements for both the cell-edge and cell-centre UEs' rates. Such a dynamic reuse adaptation requires dynamic inter-cell coordination. An interference avoidance scheme with dynamic inter-cell coordination is presented for the WINNER system in [10]. The scheme requires a central entity such as radio network controller (RNC). Centralized processing of RRM algorithms is not encouraged in LTE due to the absence of RNC. However, inter-cell coordination among neighbouring cells facilitated through X2 interface [11] is supported in LTE. We modify the scheme presented in [10] to suit to LTE downlink as well as further improve by separating handling of interference originated from the sectors of own eNB and that from the other eNBs. In particular, we present a novel approach to utilize Hungarian algorithm by devising utility matrix in a multi-cell fashion to handle inter-cell intra-eNB interferers.

The remainder of this paper is organized as follows. Section II gives overview of the available static schemes in the literature. The proposed scheme is described in Section III. Section IV provides LTE simulation environment and parameters. Simulation results are discussed in V followed by conclusions in VI.

II. Static Interference Avoidance Schemes

A. Soft frequency reuse

Soft frequency reuse scheme is a variation of FFR, where the reuse factor is 1 and equal or greater than 1 in the cell-centre and cell-edge areas, respectively. It was proposed in [12] and [13] under 3GPP LTE framework to provide a higher rate to disadvantaged UEs such as those near the cell boundary.

Fig. 1.c shows an example SFR scheme for cell sites with sectorization. For 3-sector cell sites, the cell edge band is usually 1/3 of the available spectrum and is orthogonal to neighbouring cells. The cell-edge subcarriers are called major subcarrier group while the cell-centre frequency band is termed as minor subcarrier group. The total transmit power is set fixed and each group is assigned transmission power depending on desired effective reuse factor, which is determined by the power ratio of cell-centre to cell-edge groups.

Transmissions use higher power on the major band as shown in the right side of Fig. 1.c. Let us consider that the power per physical resource block (PRB) is 1 in the case of reuse of 1 and power per PRB for the cell-edge (major) band is α for the SFR scheme. Then power per PRB in the minor band would be $(3-\alpha)/2$ giving a power ratio of $(3-\alpha)/2\alpha$. Minor band is available to cell-centre UEs only and major band can also be used for cell centre areas. Adjusting power ratio from 0 to 1 effectively moves the reuse factor from 3 to 1. Therefore for a tri-sector cell, SFR is a compromise between reuse 1 and 3. UEs are categorized into cell-edge and cell-centre based on user geometry.

B. Partial frequency reuse

The idea of the partial frequency reuse (PFR) was first presented in [14]. While somewhat similar to SFR in terms of frequency planning, the effective reuse factor of this scheme is always greater than 1. PFR and its variants are studied in the 3GPP and WINNER projects (see, for example, [9] and [15]). Fig. 1.d shows an example of PFR for sites with sectorization. Let us consider that the total bandwidth is β and it is divided to inner zone and outer zone with β_1 and β_2, respectively. For a reuse factor of 3 in the outer zone, the frequency band assigned to each sector's outer zone is $\beta_2/3$. Therefore, the effective frequency reuse is given by $\beta/(\beta_1+\beta_2/3)$. Like SFR, the power used for the outer zone PRBs can be amplified as shown in the figure.

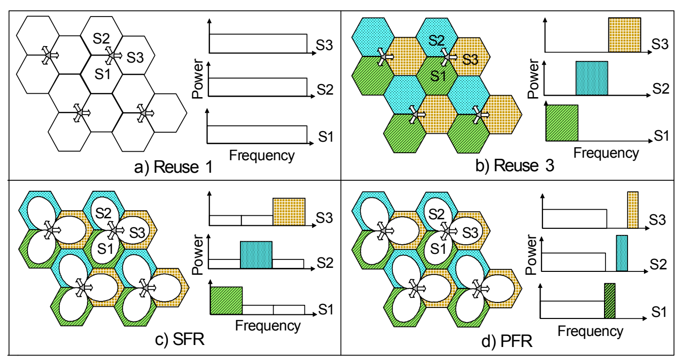

Fig. 1: Reuse 1 and other static partition based schemes

III. Description of the Proposed Scheme

Inter-cell interference is categorized into two groups, i.e., intra-eNB and inter-eNB interference as shown in Fig. 2. UEs receive dominant interference from the first-tier of interferers, 2 from own-eNB and 4 from cells of other neighbouring eNBs, as illustrated in the figure. Based on mutual interference situation and UE rate requirements resource restrictions are prepared using two algorithms, one for intra-eNB and the other for inter-eNB interferers. Interference originated from cells of own eNB should be handled separately as eNB can take appropriate measures itself without the need for inter-eNB communication through X2 interface. Both algorithms involve preparation of utility matrix and applying Hungarian algorithm [16] on the utility matrix in an iterative manner in order to find PRBs to be restricted in the neighbouring cells. Hungarian algorithm is optimal for one-to-one PRB to UE allocation; however, it becomes sub-optimal when it is used iteratively to assign more than one PRB to a UE.

The restrictions on the usage of PRBs are determined from time-to-time at a time-interval within the channel coherence time, i.e. depending on the speed of the mobile. This interval is denoted as resource restriction refresh interval. Once the PRB restriction list is available at a sector, the scheduler can perform PRB scheduling based on its own criteria. We studied two variations of the proposed scheme; restricted PRBs are not used at all in one and these PRBs are used, however, only with reduced power (for example, with 10 dB lower) in another variation.

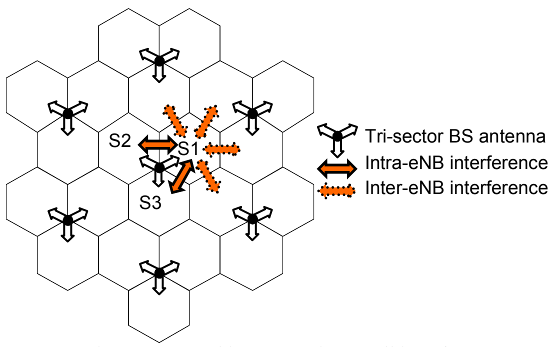

Fig. 2: Intra and inter-eNB inter-cell interference

A. Intra-eNB inter-cell interference avoidance

For a particular PRB, a sector can restrict only one dominant intra-eNB interferer. A utility matrix covering all three sectors of an eNB is constructed as follows.

$$U_{\text{intra}} = \left[\overbrace{U^1_{2,3} \quad U^2_{1,3} \quad U^3_{1,2}}^{\text{Sector 1,2,3}} \overbrace{U^1_2 \quad U^2_1}^{\text{Sector 1,2}} \overbrace{U^2_3 \quad U^3_2}^{\text{Sector 2,3}} \overbrace{U^1_3 \quad U^3_1}^{\text{Sector 1,3}} \right], \quad (1)$$

where each element of the above composite matrix is itself a matrix of size $N \times M$; N and M are the number of PRBs and the number of UEs per sector, respectively. The first three elements are the utility matrices for sectors 1, 2, and 3 respectively, given remaining sectors (i.e., {2,3}, {1,3}, and {1,2}) use PRBs concurrently. Subsequent subsets of matrices show utility, when one of the intra-eNB sectors is restricted to use PRBs. These utility matrices conditioned on the possible concurrent intra-eNB inter-cell interferers are given by:

$$U^{i1}_{i2,i3} = \begin{pmatrix} u_{1,1} & u_{1,2} & \cdots & u_{1,M} \\ u_{2,1} & u_{2,2} & \cdots & u_{2,M} \\ u_{3,1} & u_{3,2} & \cdots & u_{3,M} \\ \vdots & \vdots & \vdots & \vdots \\ u_{N,1} & u_{N,2} & \cdots & u_{N,M} \end{pmatrix}. \quad (2)$$

The utility measure $u_{n,m}$ is the product of the achievable rate on PRB n if it is assigned to UE m ($r_{m,n}$) and the current demand factor of UE m (d_m), when both intra-eNB interferers are active. The demand factor of a UE is defined as the ratio of the received throughput to average sector throughput. When an intra-eNB sector is restricted, a penalty (in terms of rate) is introduced in the calculation of the utility as below.

$$u_{n,m} = \begin{cases} r_{n,m} \times d_m & ;\text{ all transmit} \\ \left(r_{n,m} - r_p\right) \times d_m & ;\text{one restricted} \end{cases} \quad (3)$$

where r_p is the rate penalty considered in the utility measure to account for resource loss due to restriction imposed to one of the intra-eNB sectors. In simulations, r_p = 1.5 bps/Hz is considered such that average number PRBs restricted by intra-eNB avoidance algorithm is around 10% of the system PRBs. It should be noted that in calculating $r_{m,n}$, all other inter-eNB interferers are considered active.

Entries in U_{intra} corresponding to UEs having demand factors less than 1 (i.e., rate satisfied in the past) are set to zero so that restrictions are made only for the rate deprived UEs. Then, the Hungarian algorithm is applied to U_{intra} . In each iteration, algorithm selects best PRBs for UEs in three different sectors so that the sum of utilities of the chosen PRBs is maximized. Note that an entry from a matrix with restriction is chosen only when the rate improvement due to interference suppression exceeds the penalty r_p. U_{intra} is updated after each iteration as follows.

- If a chosen entry is from the matrix where PRB restriction is not required, for example $U^1_{2,3}$, utility entries for the corresponding PRB for all UEs in U^1_2, U^2_1 , U^2_3 , U^3_2 , U^1_3 , and U^3_1 in addition to $U^1_{2,3}$ would have to be replaced by zeros. However, utility entries in $U^2_{1,3}$ and $U^3_{1,2}$ remain unchanged in order to allow future iteration to reselect this PRB.
- If a chosen entry is from the matrix where a PRB restriction is required, for example U^1_3 (sector 2 has restriction on the selected PRB), following actions are required.
  - Place the PRB index in restriction list for sector 2
  - Entries corresponding to this PRB for all UEs in all matrices except U^3_1 have to be replaced by zeros. In this case, future iterations will allow this PRB to be used only by a UE in sector 3.

The above steps are repeated until all entries in U_{intra} are zero. In this process, each sector prepares PRB restrictions for its intra-eNB neighbours. The number of required iterations varies depending on the number of rate deprived UEs as well the utility values of the matrix.

B. Inter-eNB inter-cell interference avoidance

Similar to [10], each sector prepares PRB restrictions for inter-eNB interferers, based on dominant received interference from four inter-eNB interferers. This algorithm involves preparation of utility matrix U_{inter} by using heuristics and applying Hungarian assignment algorithm to this matrix. Then, neighbouring eNBs are communicated about these resource restrictions over X2 interface. The details of this algorithm are discussed below.

1) Preparation of utility matrix

Let us consider $r^{(i)}_{m,n_{(\min)}}$ and $r^{(i)}_{m,n_{(\max)}}$ to be the achievable rates for UE m and PRB n at sector i when none and all 1st-tier inter-eNB interferers are restricted, respectively. However, moving from $r^{(i)}_{m,n_{(\min)}}$ to $r^{(i)}_{m,n_{(\max)}}$ implies increasing penalty to the interfering sectors, as more and more interferers are to be restricted.

A threshold-based strategy is used to determine which interferers are to be restricted. Based on its demand factor and channel conditions, a UE can restrict two most dominant interferers at most. This limits the number of resulting PRB restrictions in the neighbouring sectors. In order to construct inter-eNB utility matrix, the following steps are repeated for each UE and PRB.

- Four inter-eNB dominant interferers are sorted in descending order into a dominant interferer set.
- $r^{(i)}_{m,n_{(\min)}}$ is calculated considering the presence of all inter-cell inter-eNB dominant interferers and taking intra-eNB restrictions into account.
    - If $r^{(i)}_{m,n_{(\min)}} \geq r_1^{TH}$, no interferers are to be restricted if PRB n is assigned to UE m irrespective of its demand factor. In this case, UE m is then either having a strong desired link from serving BS or is experiencing weak interference from all dominant interferers on PRB n. In simulations, we have used $r_1^{TH} = 3.5$ bps/Hz.
    - Else, calculate the new rate $r^{(i)}_{m,n_{(new)}}$ with the most dominant interferer being restricted.
        - If $r^{(i)}_{m,n_{(new)}} - r^{(i)}_{m,n_{(\min)}} \geq r_2^{TH}$, UE m will request this dominant interferer to be restricted irrespective of its demand. $r_2^{TH} = 2$ bps/Hz has been used in simulations.
        - Else if $d_m^{(i)} > 1$ (UE m has been rate derived in the past), $r^{(i)}_{m,n_{(\min)}} = 0$, and $r^{(i)}_{m,n_{(new)}} > 0$, the most dominant interferer is to be restricted. In some cases, both $r^{(i)}_{m,n_{(\min)}}$ and $r^{(i)}_{m,n_{(new)}}$ can be zero. If restricting two most dominant interferers provides achievable rate, these will be marked for restriction.

Note that the above threshold values are chosen such that the number of PRBs restricted by inter-eNB algorithm is on average around 15-20% of the available system bandwidth. After finding the inter-eNB dominant interferer(s) to be restricted on each PRB and each UE, achievable rates $r^{(i)}_{m,n}$ are calculated. Now, the utility of PRB n for UE m can be expressed as:

$$u^{(i)}_{m,n} = r^{(i)}_{m,n} \times d^{(i)}_m . \quad (4)$$

The utility matrix is given by $U^{(i)}_{\text{inter}} = \left[u^{(i)}_{m,n} \right]$. Each entry of $U^{(i)}_{\text{inter}}$ is associated with corresponding interferer(s) to be restricted in addition to the achievable rate and demand when PRB n is used by UE m.

2) *Applying Hungarian algorithm to utility matrix*

Hungarian algorithm is applied to $U^{(i)}_{\text{inter}}$ in an iterative manner similar to Section III(A). In each sector, steps given below are followed to prepare inter-eNB PRBs restrictions.

- Apply Hungarian algorithm to $U^{(i)}_{\text{inter}}$. If any selected utility entry has a corresponding interferer restriction, the restriction list will be updated with the marked interferer for the PRB.
- Update the columns of the utility matrix corresponding to assigned PRBs with zeros. Now, apply the Hungarian algorithm to the updated utility matrix.
- Repeat above steps until all entries of the utility matrix are zero. The number of required iterations is bounded by $\lceil N/M \rceil$.

3) *Inter-eNB communication using X2 interface*

For a particular PRB, Fig. 3 shows an example scenario of inter-eNB inter-cell restrictions. In this figure, the green (solid line) and red (dashed line) arrows indicate that inter-eNB inter-cell interference received at the arrow-originating-sector from the arrowhead-sector is acceptable and unacceptable (to be restricted), respectively. For example, for a PRB of interest, sector B can tolerate interference from sector A, but the opposite is not true as there is a red (dashed) arrow from sector A toward B. In this case, either sector A or B has to be restricted for this PRB. In this case, eNB corresponding to sector A communicates with the eNB corresponding to sector B using X2 interface about restricting the PRB.

It is expected that a pair of sectors will have restrictions for the same PRB in some cases (i.e., red arrows to each other). In such cases, the sector that achieves higher utility survives. The negotiation of resolution of this type of conflicting restrictions is also carried over X2 interface.

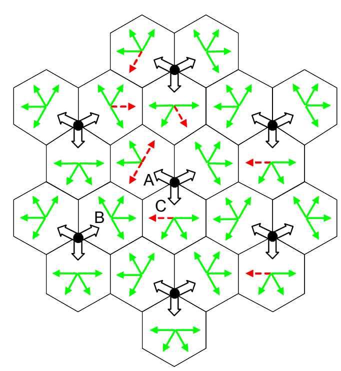

Fig. 3: Graphical representation of inter-eNB PRB restriction

IV. SIMULATION SYSTEM AND PARAMETERS

Considered simulation and system parameters are taken mostly from [1] and [17] as summarized in Table I.

Time-frequency correlated 6-taps extended spatial channel model (SCME) with power delay profile as defined in [18] is considered. Independent lognormal shadow fading with a standard deviation of 8 dB has been assumed.

20 MHz system bandwidth constitutes 100 PRBs. A PRB consists of 12 subcarriers (each of 15 kHz) in frequency and 7 OFDM symbols in the time dimension. We assume that 4 and 3 OFDM symbols per PRB are used for downlink reference and control signals, respectively, giving 77 OFDM symbols per PRB for data traffic. Therefore, a PRB can carry 77 information bits with QPSK rate 1/2 modulation and coding scheme (MCS).

TABLE I
SIMULATION PARAMETERS

Parameter	Assumption
Cellular layout	Hexagonal grid, 19 cell sites, 3 sectors per site
Inter-site distance	500 m
Carrier frequency / Bandwidth	2.0 GHz / 20 MHz (100 PRBs)
Distance-dependent path loss	$L = 128.1 + 37.6\log_{10}(R)$
Lognormal shadowing	Independent among links
Shadowing standard deviation	8 dB
UE speeds of interest	30 km/hr
Penetration loss	10 dB
Antenna pattern (horizontal)	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ θ_{3dB} = 70 degrees, $A_m = 20$ dB
Antenna configuration	Single-Input-Single-Output
BS antenna gain	14 dBi
UE antenna gain	0 dBi
UE noise figure	7 dB
AMC modes	QPSK, 16-QAM, and 64-QAM with varying rates
Channel model	6-Tap SCME
Total sector TX power	46 dBm
Downlink inter-cell interference modelling	Explicit modelling (all links are simulated)
Minimum distance between UE and BS	35 m
Traffic model	Full buffer
Scheduler	Hungarian algorithm based on utility matrix

Adaptive modulation and coding (AMC) is used with various MCS modes with quadrature phase shift keying (QPSK), 16-, and 64-quadrature amplitude modulation (QAM), and coding rates ranging from 1/8 to 4/5. Link adaptation is performed using attenuated and truncated form of Shannon bound, matched to link level performance curves with above mentioned modulation level and coding rates, as follows [19].

$$\eta = \begin{cases} 0 & ;\ \gamma < \gamma_{\min}, \\ \alpha S(\gamma) & ;\ \gamma_{\min} < \gamma < \gamma_{\max}, \\ \eta_{\max} & ;\ \gamma > \gamma_{\max}, \end{cases} \quad (5)$$

where η is the spectral efficiency in bps/Hz, γ is the signal-to-interference-plus-noise ratio (SINR) seen on PRB and α (0.75 used in simulation) is the attenuation factor applied to the Shannon bound given by $S(\gamma) = \log_2(1+\gamma)$ which achieves η_{max} (4.8 bps/Hz) at γ_{max} (19.2 dB) or beyond and 0 at γ_{min} (-6.5 dB) or lower. Automatic repeat request (ARQ) has not been considered in simulations.

For fair comparison, total transmit power per sector is kept constant in all schemes, which is $\approx P_t$. Accordingly, power allocated to PRBs for different schemes are shown in Table II. In the table, P_t (46 dBm), N (100), N_{res}, and N_{elig} are the total power per sector, system bandwidth in terms of number of PRBs, and the number of restricted (from intra and inter-eNB), and unrestricted PRBs, respectively. As shown in the table, restricted PRBs are unused in proposed scheme 1 and used with 10 dB lower power in proposed scheme 2.

TABLE II
POWER ALLOCATION FOR DIFFERENT SCHEMES

Scheme	Allocated power on PRBs
Reuse 1	$P_{rb}^{R1} = P_t/N$
Reuse 3	$P_{rb}^{R3} = 3P_t/N$
PFR eff reuse 1.3	$P_{rb,out}^{PFR1.3} = 2.25\,P_t/N$, $P_{rb,in}^{PFR1.3} = 1.13\,P_t/N$
SFR eff reuse 1.5	$P_{rb,out}^{SFR1.5} = 1.5P_t/N$, $P_{rb,in}^{SFR1.5} = 0.75P_t/N$
SFR eff reuse 2.0	$P_{rb,out}^{SFR2.0} = 2.0P_t/N$, $P_{rb,in}^{SFR2.0} = 0.5P_t/N$
SFR eff reuse 2.5	$P_{rb,out}^{SFR2.5} = 2.5P_t/N$, $P_{rb,in}^{SFR2.5} = 0.25P_t/N$
SFR eff reuse 2.75	$P_{rb,out}^{SFR2.75} = 2.75P_t/N$, $P_{rb,in}^{SFR2.75} = 0.13P_t/N$
Proposed scheme 1	$P_{rb,elig}^{PROP1} = P_t/(N - N_{res})$, $P_{rb,res}^{PROP1} = 0$
Proposed scheme 2	$P_{rb,elig}^{PROP2} = 10P_t/(10N_{elig} + N_{res})$, $P_{rb,res}^{PROP2} = P_t/(10N_{elig} + N_{res})$

V. SIMULATION RESULTS AND DISCUSSIONS

The performance of the proposed interference avoidance scheme is compared to that of the reference schemes in terms of cell-edge and average sector throughput. Cell-edge throughput is defined as the 5th percentile point of CDF of UE throughput. The reference schemes simulated are reuse 1, reuse 3, SFR (with effective reuse of 1.5, 2.0, 2.5, and 2.75), and PFR (effective reuse of 1.3).

Statistics are collected from a total of 300 drops. In each drop, UEs are uniformly distributed according to a density of 12 UEs/sector. Simulation time span is 25 ms (50 OFDM symbols) in each drop. Resource restriction refreshment interval considered is 6 OFDM symbols (within the channel coherence time for the UE speed of 30 km/hr).

UEs are placed in the central 21 sectors among the total 57 sectors of 19 sites. For the proposed scheme, allocation algorithms are run in these 21 sectors. Statistics are collected from the central eNB (3 sectors) only. Interference is calculated using central cell approach.

Fig. 4 shows CDF of UE throughput for the proposed as well as reference schemes. The lower tail of CDF is zoomed in Fig. 5 in order to view the cell-edge throughput clearly. Fig. 6 compares cell-edge and average sector throughput among all simulated schemes with reference to reuse 1 scheme. It is observed that while reuse 3 scheme achieves 168.4% improvement in cell-edge throughput compared to reuse 1 scheme, it suffers from sector throughput degradation by 49.2%. The PFR scheme improves cell-edge throughput by 149.7%, however, with 26% reduction in sector throughput.

SFR schemes with effective reuse of 2.0, 2.5, and 2.75 show cell-edge throughput improvement by 21.4%, 69.4%, and 114.7% with degradation of sector throughput by 4.3%, 8.6%, and 26.1%, respectively. SFR scheme with effective reuse of 1.5 neither improves cell-edge nor sector throughput compared to reuse 1 scheme. Comparing with reuse 1 scheme, proposed scheme 1 improves cell-edge throughput by 266.1% with an improvement in sector throughput by 3.9%. Proposed scheme 2 shows inferior cell-edge and superior sector throughput compared to those in proposed scheme 1 as restricted PRBs are used with reduced power, which favors cell-centre UEs while harms those at the cell-edge. However, compared to reuse 1 scheme, proposed scheme 2 obtains 171.3% improvement in cell-edge throughput while improving the sector throughput by 7.2%.

The performance gain in the proposed scheme is achieved with the cost of increased overhead required for UE-BS feedback as well as eNB-eNB communication over X2 interface.

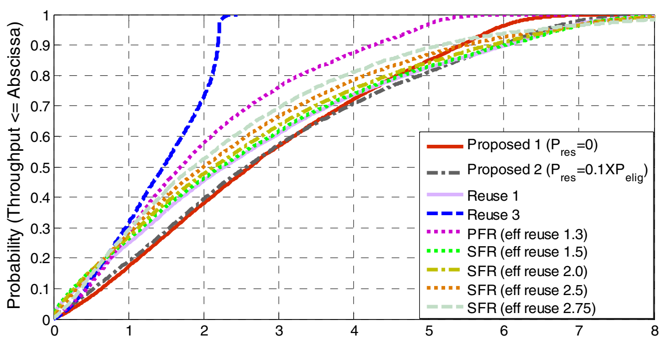

Fig. 4: CDF of UE throughput

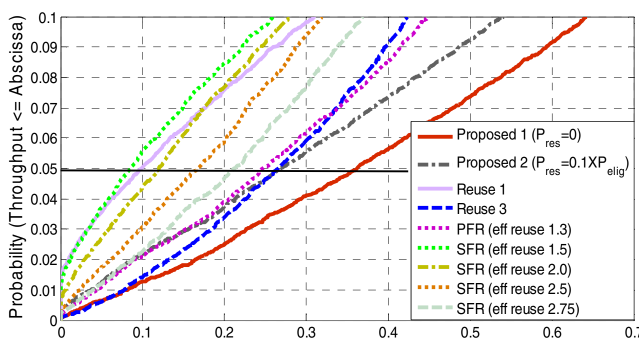

Fig. 5: CDF of UE throughput (zoomed to show cell-edge throughput)

VI. Conclusions

We have presented and evaluated an interference avoidance scheme for downlink LTE system that uses dynamic inter-cell coordination supported by X2 interface. Two variations of the proposed scheme have been compared with the reference reuse 1 scheme as well as the static partition based interference avoidance schemes in the literature. It has been observed that although static schemes achieve improved cell-edge throughput, they suffer seriously in terms of sector throughput. On the other hand, the proposed schemes not only achieve higher cell-edge throughput but also show improvement in average sector throughput compared to those in any static scheme.

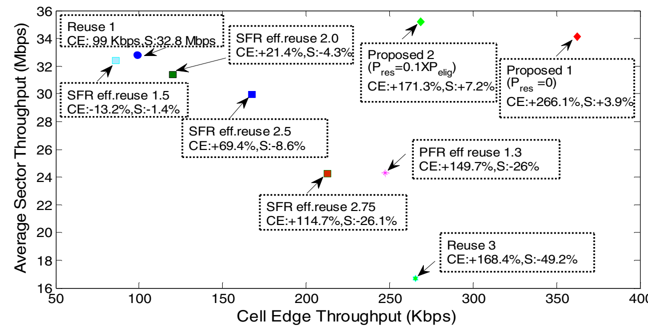

Fig. 6: Cell-edge vs. average sector throughput

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