A Decentralized Inter-Cell Interference Coordination Scheme using Multi-Objective Optimization

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***Abstract*— In this paper, we propose a dynamic decentralized scheme, namely, the Multi-Objective Harmony Search (MO-HS). The proposed scheme improves on the conventional single-objective HS scheme by attempting to optimize two objective functions simultaneously. In particular, the MO-HS scheme attempts to minimize the use of the same channels by edge users in neighboring cells, and the average cell interference. Simulation results demonstrate that, with a slight degradation in fairness, the proposed scheme achieves 21% throughput improvements to edge users as compared to the conventional HS without penalizing other users.**

***Index Terms*—LTE-Adv; ICIC; Harmony Search; Multi-objective Harmony Search; Pareto Set.**

I. INTRODUCTION

Long Term Evolution (LTE) aims at providing higher data rate throughput not only for users near the base station, but also for cell edge users [1]. To do so, LTE adopts Orthogonal Frequency Division Multiple Access (OFDMA) to reduce the interference and efficiently meet high performance requirement [3]. Even though OFDMA can reduce the intra-cell interference; however, Inter-cell Interference (ICI) still pose a real challenge to achieve higher throughput, especially for cell edge users. ICI is the caused between a frequency channel in one cell and the same frequency channel used in another adjacent cell [2].

Various ICI Coordination (ICIC) techniques have been proposed in the literature in order to mitigate the Signal-to-Interference Ratio (SINR) degradation that result from the reuse of same frequency channels in neighboring cells. Generally speaking, ICIC techniques can be classified into *centralized* (e.g., [4][9]) and *decentralized* (e.g., [2]). In the former, a central entity is needed to collect data about user equipment (UE) from base station, optimize system parameters and allocate available Resource Blocks (RBs) to each base station in order to increase system performance. In the latter, on the other hand, RB allocation is performed on each base station without the need of a central entity to perform the coordination. This paper focuses on decentralized ICIC to avoid the known shortcomings encountered by the use of a central unit in the Centralized ICIC.

Existing decentralized ICIC schemes typically attempt to optimize one objective to either reduce overall power consumption or enhance system throughput. This is due to the fact that multiple objectives typically conflict with each other.

In this paper, we explore, for the first time to the best of our knowledge, the use of multi-objective optimization to enhance ICIC in LTE systems. In particular, we propose a decentralized Multi-Objective Harmony Search (MO-HS) scheme. Unlike the single best solution obtained by using the conventional single-objective HS scheme proposed in [6], the MO-HS provides a set of solutions (known as the Pareto set) that can be further analyzed as each solution satisfies the objectives at an acceptable level without being dominated by any other solution [7]. This leads to enhanced results in term of overall system throughput, edge user rates and power consumption. The proposed scheme does not require a centralized controller and only makes use of minimum amount of information exchange between eNBs. To support deployment in large networks, the proposed scheme computations are independent of the number of cells and users in the system. Simulation results show that the MO-HS provides fast and better quality solutions compared to existing optimization schemes including the conventional HS.

The rest of this paper is organized as follows. Section II reviews related work. Sections III and IV presents the system model and the proposed scheme. Section V presents the results of the performance evaluation of the proposed scheme. Conclusions are given in Section VI.

II. RELATED WORK

A comprehensive survey on various ICIC schemes including the decentralized schemes can be found in [2]. Since the work presented in [6] demonstrated that HS performs better than most existing schemes (e.g., Reuse-1, Reuse-3, PFR, SFR), we focus in this section on reviewing the schemes proposed in [6] and [11].

In [6], a dynamic decentralized ICIC scheme based on the concept of Harmony Search (HS) is proposed. The proposed HS scheme can be deployed in the LTE flat network architecture. A power control strategy is also proposed where more power is allocated to users that have not reached their required rate by starting the allocation with 1.25X of default power, and increases by a step of 0.25 until the required rate is achieved or a predefined threshold of 3X is reached. The HS scheme guarantees maximum system throughput by allowing each cell to restrict channels to its users by defining new parameters called Selfishness Index (SI).

In [11], Kimura *et al.* proposed a distributed dynamic ICIC scheme where cell-center bands dynamically adapt (shrink/expand) depending on user behavior, cell load, and interference situation. In this scheme, no central controller is used and only communication between eNBs is required. However, the scheme suffers from the "fake" unavailability of edge-RBs, as each eNB can only selects a pre-determined number of RBs as edge-bands regardless the number of edge-UEs. This prevents the usability of the scheme in networks with irregular cell shapes and large number of edge users.

III. System Model

The LTE-Advanced OFDMA downlink transmission in a multi-cellular network with I cells is used in this paper. Each eNB (base station) is located at the centre of each cell and allocates downlink resources in the time and frequency domains to each of the Ui active users with $i \in \{1,2,\ldots I\}$. Users in each cell are divided into center and edge UEs using an adaptive Bandwidth Proportionality SINR threshold that guarantees that the number of users in each class is proportional to the percentage of RBs allocated to the user's class.

The total bandwidth B is divided into J channels (each of 12 orthogonal subcarriers occupying a total of 180 kHz). Time is divided into slots (0.5ms each). Each RB represents a single channel for the duration of one time slot. One or more RBs can be allocated to a UE at a time. Each RB is assigned exclusively to one UE at any point of time within a given cell; neighboring cells may use the same RB at the same time. Each cell utilizes all system channels and operates with total transmission power P_i^{total}.

To calculate throughput, the total rate that user u^{th} achieves using j^{th} RB in i^{th} cell is given by:

$$R_{u,i}^{j} = C(\gamma_{u,i}^{j})$$

Where C (.) is the adaptive modulation and coding (AMC) function that maps the SINR to rate. The modulation schemes range from the robust low rate QPSK scheme to high rate but more error prone 64-QAM scheme.

IV. The Proposed MO-HS scheme

A general multi-objective optimization problem can be formulated in the following manner. Given an n-dimensional solutions space of decision variables vector, it is required to find a vector that satisfies a given set of criteria depending on objective functions. The solution space is restricted by a series of constraints, such as for, and bounds on the decision variables [8]. In multi-objective optimization there is a set of solutions called the Pareto Set (PS) to contain all solutions that are not dominated by any other solutions [9].

The difference between the original Harmony Search and multi-objective Harmony Search is in adopting the concept of *Pareto dominance*. To do so, a new memory will be defined; namely, the Pareto Set (or non-dominated memory) in which all the non-dominated solutions during all iterations will be saved in it [10].

After generating the New Harmony memory the current Pareto set will be compared with it. Each solution (harmony) in the generated HM will be compared with all solutions in the Pareto set to check if this solution will dominate any solution in the Pareto set; if yes, the solution in the Pareto set will be replaced with this solution. This process will be repeated during all iterations and the solution of the problem will be the set of non-dominated solution that stored in the final Pareto set.

The key features in the proposed MO-HS scheme can be summarized as follows: (1) it supports scalability to adapt with changes in dynamic LTE environment by ensuring that the scheme computations are independent of number of users and cells, (2) it supports fast adaptation as the resource allocation is performed at the base station level with no central controller needed, (3) it supports efficient usage of the at various cells by assigning different power level to RBs, and (4) it further reduces user interference by applying the second objective function as a minimization problem. Algorithm 1 depicts the detailed steps of the proposed MO-HS algorithm.

A. Multi-Objective Harmony Search weight functions

As in [6], achieving fast adaptation to the varying channel conditions requires minimizing the data exchange between eNBs [6]. We adapt a modified version of the data exchange strategy presented in [11]. Similar to [11], each eNB sends only its calculated weights, instead of all of channel information of its users, to the neighboring cells on regular intervals.

1) First weight function

In proposed scheme, the first weight function represents the number of all users in the cell in which the power of the signal received from the serving cell is less than that received from the neighboring cell. The key advantage of this approach than what proposed in [11] is taking into consideration the center users allows the proposed scheme to prevent assigning very high power to edge users in one cell that can affect a center user in some neighboring cell.

The first objective function is the weight $w_{i,k}$ denotes cell *i* weight with respect to neighboring cell *k* as calculated at cell *i* using:

$$w_{i,k} = \sum_{u}^{U_i} H(P_{u,k} - P_{u,i})$$

where U_i is the set of UEs in the i^{th} cell. H(x) is unit step function, H(x) = 1 only if x > 0. Otherwise H(x) = 0. $P_{u,k}$ is the received power by the u^{th} user from the k^{th} neighbouring cell and $P_{u,i}$ is the received power by the u^{th} user from the i^{th} cell.

Smaller weights indicate that the serving cell would be least affected by interference from the other cell [6]. Then we calculate the average weights of both the serving cell and neighboring cell to reflect the effect of the serving cell interference and neighboring cell interference on each other's UE. $\tilde{w_1}_{i,k}$ represents the average first weight between i^{th} and

k^{th} cells, and given is give by

$$w_{1\ i,k}^{\sim} = \frac{w_{i,k} + w_{k,i}}{2}$$

2) Second weight function

The second weight function is the average interference of the current cell, where we calculate the interference of each user in the current cell after assigning RB_x to them:

$$\gamma_{u,i}^{j} = \frac{G_{u,i}^{j}\ P_{u,i}^{j}}{\sum_{k}^{I} G_{u,k}^{j}\ P_{u,k}^{j} + N_0}\ , k \neq i$$

Where, $G_{u,i}^{j}$ is the channel gain between the u^{th}user and the i^{th} eNB using the j^{th}channel. $P_{u,i}^{j}$ is the transmission power allocated to the j^{th} channel by the i^{th} eNB to serve the u^{th}user. N_0 is the additive white noise power. $w_{2\ i}^{\sim}$ represents the average second weight for i^{th} cell, and given by

$$w_{2\ i}^{\sim} = \frac{\sum_{u}^{U_i} \gamma_{u,i}^{j}}{CN_i}$$

Where CN_i is the count of users in i^{th} cell. As in [6] weight update messages are transmitted every 10 ms with no retransmission policy on drop. Every update message is time-stamped, thus, eNBs use the update message with the latest time-stamp to calculate the average weights [6]. With every new update message (weight message every 10ms), each eNB solves the UE/Power-to-channel assignment problem individually using these information.

3) Objective functions

The first objective function in proposed scheme carried out by the i^{th} eNB is minimizing the use of the same channels by edge users in neighboring cells:

$$f1(i) = \min \sum_{j}^{J} \sum_{k}^{I} w_{1\ i,k}^{\sim}\, X_{i,j}\, X_{k,j} \quad , k \neq i$$

And the second objective function is minimizing the average cell interference with when assigning j^{th}channel to u^{th} user in i^{th} cell:

$$f2(i) = \min \frac{\sum_{u}^{U_i} \gamma_{u,i}^{j}}{CN_i}$$

In all cells, the UE/Power-to-channel assignment employed should always result in having the sum of the number of channels allocated to users less than or equal the total number of channels available $|J_i|$ at any given time:

$$\sum\nolimits_{u \in U_i} |J_u| \leq |J_i| \quad \forall\, i \in \{1,2, \dots I\}$$

Each eNB tries also to minimize the number of unsatisfied UEs given by the Soft Constraint:

$$\sum\nolimits_{j \in J_u} X_{i,j}\, R_{u,i}^{j} \geq R_u^{req} \quad \forall\, u \in \{1,2, \dots, U\}$$

where J_u is the set of channels allocated to the u^{th} user. R_u^{req} is the required rate of the u^{th} user. $X_{i,j} = \{0,1\}$ represents the usage of the j^{th} channel in the i^{th} cell. $X_{i,j} = 1$ only of the j^{th} channel is being used in the i^{th} cell.

B. Power Control Strategy

The proposed scheme used the same power control strategy that we proposed in [6] which is aimed to allocate more power to a UE that has not yet reached its required rate. it starts by attempting to allocate 1.25X of the default power $\frac{P_i^{total}}{|J_i|}$, and keep incrementing by a step of 0.25 until either the throughput of the UE increases or the power value of 3X is reached [6]. Also to minimize ICI, the scheme works to minimize the allocated power to UE that reached its targeted rate without affecting its rate. The scheme attempts to allocate 0.5X of the default power then keeps incrementing by a step of 0.1 until the UE becomes satisfied again [6].

Algorithm I. Proposed Multi-objective Harmony Search

Begin
Define objective function $f(h)$.
Set the *Selfishness Degree*, *HMCR*, *PAR*, *HMS* and *MI* values.
Set the number of instruments to the number of system channels *J*.
Set the valid chords/keys of all instrument to U_i
Set the valid pitches/tones of all instrument to P^{total}/J
Initialization
Randomly set the chords/keys and pitches/tones for the various instruments in all *HM* harmonies.
Restrict the instruments (channels) if the allocated chord/key (user) has rate requirements less than achievable rate by the *Selfishness Degree* percentage.
If instrument is not restricted, **Attempt** to increase the allocated power to edge-users to increase their throughput or decrease the allocated power to center-users without decreasing their throughput to minimize ICI and save power to edge-users.
Initialize Pareto set.
While iteration number < *MI* **do**
Improvisation
For Each instrument in the new harmony do
If random1 < *HMCR* **then**
Randomly choose a chord/key from the HM to the instrument.
Restrict the instruments (channels) if the allocated chord/key (user) has rate requirements less than achievable rate by the selfishness degree percent.
If instrument not restricted & random2 < *PAR* **then**
Perform **pitch adjustment** on the chord/key selected from the HM.
Pitch Adjustment: Attempt to increase the allocated power to unsatisfied users to increase their throughput or decrease the allocated power to satisfied users without turning them to be unsatisfied to minimize ICI and save power.
End If
Else
Randomly set the chord/key for instrument.
Restrict the instruments (channels) if the allocated chord/key (user) has rate requirements less than achievable rate by the selfishness degree percentage.
If instrument is not restricted, **Attempt** to increase the allocated power to edge-users to increase their throughput or decrease the allocated power to center-users without decreasing their throughput to minimize ICI and save power to edge-users.
End Else
End For Each
Update
Calculate the fitness value of the new harmony using $f(h^{new})$.
Update *HM* by replacing the poorest harmony with the new harmony, if better.
Update Pareto set.
Increment iteration number by 1.
End While
Termination
Select the best harmony as the new assignment matrix.
End

C. Computational Complexity

The complexity of the proposed algorithm is a function of the constant MI iterations on the HM used to generate new Harmonies. Each New Harmony requires iterating on all J Channels, assigning UEs randomly, and sets the Power using the power control strategy. Also each new harmony compare its weights values with other harmonies exists in the "pareto set" and if their vales (both of them) less than any other harmony in PS it replace a random one with the new generated harmony. The cost of each iteration is PS × O(J). Thus, the overall complexity is O(PS×MI × J), which is independent of the number of users, cells, and power levels.

V. Simulation Result and Analysis

A. Simulation Setup

The WINNER - Phase II (WIM2) shadowing and fading models [12] is used to generate a radio channel realization for a metropolitan suburban environment. Initially, UEs are randomly dropped and configured to dynamically move with random speeds between 0 m/s and 100 m/s in random directions. Three hexagonal cell layout of 500 m radius each was considered, wherein each cell is equipped with an eNB with an omni-directional antenna located at the cell centre. The bandwidth B is 20 MHz and the number of channels $|J_i|$ is 100. Total transmission power in each cell P_i^{total} is 40W, and N_0 is −114 dBm/Hz. Full buffer traffic model was considered for all users as it represents the worst case from the ICIC performance assessment perspective. Handover was executed at 3dB. Statistics are collected in the 3 cells over the time duration of 400 frames. For MHS, the values of the PS, HMS, MI, HMCR and PAR were set to 10, 200, 200, 0.5 and 0.5, respectively. Proposed scheme is compared to HS scheme.

B. Performance Analysis

Fig.1 presents the performance of the schemes under different number of UEs. Fig.1 draws the best solution from 10 solutions obtained by the MO-HS with different number of users, the HS solution, and other algorithm discussed before in [6] (Kimura, PFR, Reuse-1, Reuse-3 and SFR). As expected, the general trend is that as number of UEs U increases so does the aggregated system throughput (ATP). On the other hand, the edge TATP decreases because more UEs share the same resources. For the same number of UEs, the proposed scheme achieves better system ATP for all the generated solutions in Pareto Set (PS) and also achieves higher edge TATP. It is clear that the solution of MO-HS achieves both higher edge TATP and also System ATP with noticeable increase. In particular, it can be seen that the increase in edge TATP for U = 170 is about 21%. Moreover, the system ATP achieves higher throughput as compared to that obtained by the HS.

Fig. 2 presents the power efficiency, which is calculated by dividing the system throughput by the power consumed. The general trend for all schemes is that, as number of users U increases, so does the power efficiency. This is due to the increase in the system ATP. However, all RBs in Reuse-3 use the same amount of power and also achieve the same rate, since there is no ICI, system ATP and power efficiency remain constant with the different number of UEs [6]. It is clear that for the same number of UEs, MO-HS solution has significant higher power efficiency and system ATP than HS scheme for all U. This is because of the power control and channel restriction strategies used. With power control, the proposed scheme allows some RBs to be allocated to edge UEs in two or more neighboring cells, but with different power levels. The channel restriction strategy prevents power wasting by not allocating RBs that suffer from high ICI. This approach conserves power in the restricting cell while increases the RB throughput in neighboring cells. The proposed scheme curve in Fig. 2 has a steeper slope as compared to other schemes indicating that as the number of UEs increases, only small extra power is consumed. The proposed scheme only allocates extra RBs if this would lead to a significant throughput increase. Thus, with less RBs used, less power consumed.

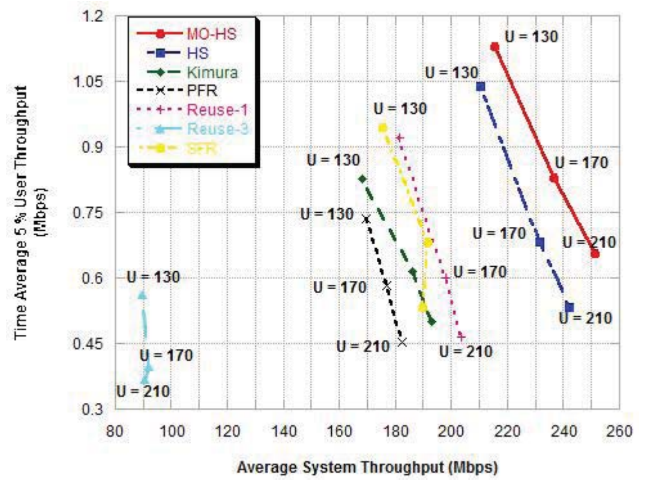

Figure 1. Edge TATP and ATP

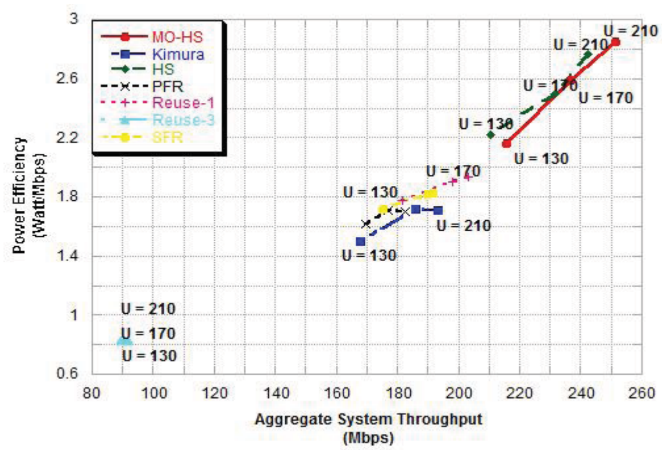

Figure 2. Power efficiency and ATP

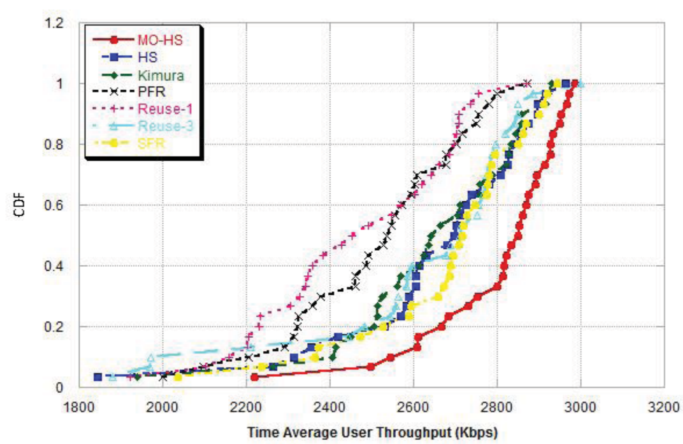

Figure 3. CDF of TATP for 30 users/cell

Fig. 3 depicts the Cumulative Distribution Function (CDF) of the Time-Average UE Throughput (TATP) under high mobility. Kimura and SFR achieves higher edge TATP rate than PFR because they have more available RB for edge users than PFR [6]. HS also achieve higher edge TATP rate from Reues-1 because it use the weight functions that exchange between eNBs to minimize the ICI [6].

Similar to HS, the proposed scheme does not dedicate any portion of the allocable bandwidth to any user class, thus edge RBs are dynamically redefined every frame. However, both the information fed back from the cell UEs and the weights exchanged between eNBs are used to minimize ICI. Also the second weight function which try to minimize the average cell interference by assigning RBs that lead to minimum interference on user level. This in turn leads to a slightly higher edge TATP for all solution (10 solutions) of the proposed scheme compared to HS scheme and all other schemes (Kimura, PFR, Reuse-1, Reuse-3 and SFR). The proposed scheme achieves a slightly lower fairness (less steep slope of the curve in Fig.3). This is expected as, the proposed algorithm attempts to satisfy the largest amount of users.

Fig.4 shows that the *Channel Quality Indicator (CQI)* for MO-HS algorithm is slightly better than the HS algorithm. It is expected that CQI will not have significant enhancement as the objectives in our problem conflicts with each other. Accordingly, we do not have a perfect multi-objective solution that simultaneously optimizes both functions.

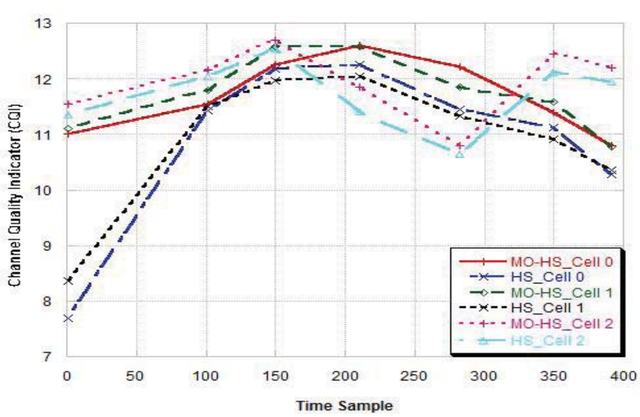

Figure 4. CQI and time sample for (MO-HS and HS) for 170 users/cell.

C. Multi-objective Harmony Search Quality

To measure the non-uniformity of the distribution of a Pareto front, the quantity $D(A)$ given by the distribution of the Euclidian distance (d_i) between two consecutive points (solutions), along with the Pareto front, is introduced:

$$D(A) = \sqrt{\frac{\sum_i \left(d_i/\bar{d} - 1\right)^2}{|A| - 1}}$$

This quantity is a standard deviation of the distances normalized by the average distance $\bar{d}$. The Euclidian distance depends on the scaling given to each of the objective. When $D(A) = 0$, the spacing in the Pareto front is uniform. The higher the value of $D(A)$, the more non-uniform the spacing in the Pareto front. Thus, a lower value of $D(A)$ is desired [5].

MO-HS algorithm was applied to three different scenarios (30, 90, and 170 users). Ten independent runs were performed with MO-HS. The quality of the Pareto-optimal solutions obtained is measured by Non-uniformity of Pareto front. We found that the values of *D(MO-HS)* were 0.049, 0.059, and 0.047 for the 30, 90, and 170 users scenarios, respectively. These values indicate that the solutions obtained by the proposed MO-HS are indeed uniform.

VI. Conclusion

In this paper, we propose a decentralized dynamic ICIC scheme based on Multi-Objective Harmony Search (MO-HS) algorithm in multi-cell LTE-Advanced systems. The proposed outperforms the conventional single-objective HS algorithm in term of edge throughput and power consumption where higher data rate are assigned to edge users with efficient usage in term of power. Moreover, the overall system throughput is improved as compared to the HS scheme. Similar to the HS, computations in the MO-HS are independent of number of users and cells in the system, which make our algorithm more practical for deployment for different type of area and different number of users.

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