Self-Adaptive Inter-Cell Interference Coordination Scheme for LTE Systems*

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Abstract*- Self-adaptation is a key factor for the future evolution of mobile networks due to their increasing complexity and required management efforts. In this paper, we propose an autonomous self-adaptive scheme based on *Harmony Search (HS) Algorithm* for radio resource management and interference coordination. One of the main strong points of the proposed scheme is that the computations are independent on the number of users and cells in the network. This allows the proposed scheme to adapt to networks of any size and with an arbitrary number of users. The proposed scheme is based on the continuous "selfish" minimization of the violations to the user's rate requirements. Each cell operates individually leading to the decomposition of the complex multi-cell allocation problem into a set of distributed simpler single-cell optimization problems. No a-priori frequency planning and/or explicit inter-cell coordination is required. The scheme also achieves a level of altruism by restricting the use of channels satisfying certain rate criterion to allow other cells to utilize them without being affected by interference. Through extensive simulations, we demonstrate that the proposed scheme leads the network to self-adapt into efficient frequency reuse patterns that provides substantial performance improvements to edge users without penalizing other users. We also conducted sensitivity analysis that showed that the values of *HS* parameters have minimum effect on the scheme performance.

Keywords-OFDMA; LTE; ICIC; Harmony Search

I. INTRODUCTION

In 3GPP Long Term Evolution (LTE) systems, downlink transmission is based on Orthogonal Frequency Division Multiple Access (OFDMA). By orthogonal allocation of the OFDMA sub-carriers, intra-cell interference can be avoided. However, inter-cell interference (ICI) still presents a challenge that considerably limits the system performance and seriously affects the throughput of edge user-equipment terminals (UEs). Inter-cell interference coordination (ICIC) has been investigated as a key technology to alleviate the impact of ICI to improve system performance and increase edge-UEs' rates.

High-speed mobility of UEs in LTE systems (350km/h [1]) leads to large channel variations and continuous changing of traffic distribution. This poses a challenge when coupled with the requirements of supporting high transmission rates (300Mbps [1]). *Dynamic* ICIC schemes emerged as a more efficient and realistic solution as opposed to the conventional static schemes. However, resource block (RB) assignment problem in dynamic ICIC schemes is known to be NP-hard [2]. Accordingly, several heuristics have been proposed to solve the problem in a computational efficient manner, such as: game theory [3], integer programming [4-6], graph coloring/genetic algorithms [2], and water filling [7, 8].

In this paper, we extend our work [9] that required explicit coordination between eNBs (inter-eNB) and propose a self-adaptive autonomous decentralized ICIC scheme based on Harmony Search (HS) algorithm [6]. An important feature of the proposed approach, which makes it feasible and attractive for application, is that it does not require a centralized controller or coordination between eNBs. The key idea of the proposed approach is that each cell constantly performs a "selfish" optimization to minimize the violations to the user's rate. To support deployment in large networks, the proposed scheme computations are independent of the number of cells and users in the system. To the best of our knowledge, HS has not been adopted before in solving this problem. Results reported in the literature show that the HS provides fast and better quality solutions compared to other optimization algorithms [7][13].

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

II. RELATED WORK

This section presents a brief overview of some recent dynamic schemes. A comprehensive survey of various ICIC schemes can be found in [8].

In [10], Rahman *et al.* proposed a scheme that shares the computations between a central entity and eNBs. Each eNB creates a wish-list of RBs to be restricted in its neighboring cells. The central entity solves the restriction requests for all eNBs and returns a decision to eNBs to apply locally. The scheme is dependent on number of users, coordinated cells, and RBs requested to be restricted. This limits the usability of this scheme to only small networks.

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.

Centralized schemes as in [10] are too heavy for implementations as all interference information has to be gathered at the central entity [5]. In [10, 11], equal static power allocation to edge-RBs is used to reduce the

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computations. However, allocating different power levels can achieve higher spectral efficiency by allocating different power levels to the same RB in different cells. Lower ICI can be achieved by reducing power levels of dominating interferers and power waste can be reduced by exploiting the tradeoffs between over/under RB power allocations.

III. SYSTEM MODEL

The LTE OFDMA downlink transmission in a multi-cellular network with I cells is considered in this paper.

A. User Classification

An eNB is located at the center of each cell and allocates downlink resources in the time and frequency domains to each of the U_i active users with $i \in \{1,2,\dots,I\}$. Users in each cell are divided into center and edge UEs using the adaptive *Bandwidth Proportionality* SINR threshold. The threshold adapts itself according to the number of users in the cell to make the percentage of users in each class always match the percentage of RBs allocated to this class. For instance if 33% of the bandwidth is allocated to edge UEs, the threshold is set so that only 33% of the UEs are classified as edge UEs.

B. Throughput Calculation

The total bandwidth B is divided into J channels (each of 12 orthogonal subcarriers occupying a total of 180kHz). Time is divided into slots (0.5ms each) whereas scheduling is performed on the basis of transmission-time intervals TTI'e each of 1 ms duration. Each RB represents a single channel for the duration of one TTI. One or more RB can be allocated to a UE at a time. Each RB is assigned exclusively to one UE at any time within a given cell. Neighboring cells may concurrently use the same RB.

Each cell utilizes all system channels and operates with total transmission power P_i^{total}. The signal carrying the payload is transmitted by only one eNB. The signals coming from other eNB are considered as ICI. The signal to interference plus noise power ratio (SINR) of the u^{th} user allocated to the j^{th} channel in the i^{th} cell is given by:

$$\gamma_{u,i}^{j} = \frac{G_{u,i}^{j} P_{u,i}^{j}}{\sum_k^I G_{u,k}^{j} P_{u,k}^{j} + N_0}, k \neq i \qquad (1)$$

where $G_{u,i}^{j}$ is the channel gain between the i^{th} eNB and the u^{th} user 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. The achievable rate on the j^{th} RB for the u^{th} UE in the i^{th} cell is given by:

$$R_{u,i}^{j} = C(\gamma_{u,i}^{j}) \qquad (2)$$

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

IV. THE PROPOSED SCHEME

Based on the discussion in section II, the following features are considered in the design of the new scheme:

- *Autonomous and fast adaptable:* perform resource allocation only at the eNB level with no central coordinator for rapid adaptation to network dynamics.
- *Scalable:* computation is independent of the number of users and cells, in order to scale for crowded cells.
- *Manipulate RB Power:* assign different power levels to efficiently reuse the same frequency spectrum at spatially separated locations.

A. Problem Formulation

On frame bases (every 10 ms), each eNB solves the UE/Power-to-channel assignment problem individually using only the information collected from its UEs. The objective function carried out by the i^{th} eNB is minimizing the level of dissatisfaction of all of its users.

$$f(i) = Minimize \sum_{u\in U_i} Max(0,\ R_u^{req} - \sum_{j\in J_u} R_{j,u}) \qquad (3)$$

In all cells, the UE/Power-to-channel assignment employed at any given time 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 $|J_i|$:

$$\sum_{u\in U_i} |J_u| \leq |J_i| \quad \forall i \in \{1,2,..,I\} \qquad (4)$$

The total power used in all channels must be less than or equal the maximum available eNB transmission power P_i^{total}:

$$\sum_{u\in U_i} \sum_{j\in J_u} P_{u,i}^{j} \leq P_i^{total} \quad \forall i \in \{1,2,..,I\} \qquad (5)$$

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. $R_{j,u}$ is the achievable rate by allocating the j^{th} channel to the u^{th} user.

As a cell solves (3), it will have a tendency to put its edge-UEs into "good" channel(s) to make them close to satisfying their rate requirements, to minimize the total rate violations.

B. Harmony Search Mapping

Harmony Search (HS) is utilized to rapidly optimize the UE/Power allocation updates by solving (3). We extend the traditional HS [6] to optimize two decision variables: *UE* and *power* to be allocated to each RB. In the proposed scheme, each *instrument* corresponds to a *RB*. The *cords* of an instrument correspond to the *UEs* in the cell. The range of *pitches* of a cord corresponds to the *power levels* (see section IV.C). A *Harmony* between all instruments corresponds to *the UE/Power to RB assignment matrix*. Finally, *audience's aesthetics* correspond to the *matrix cost* based on (3).

The HS algorithm is initialized by creating a *Harmony Memory (HM)* of size *HM Size (HMS)*. The initial *HM* consists of a number of random Harmonies. The algorithm iterates until it reaches the *Maximum Improvisation (MI)* limit. At each iteration, the algorithm introduces a single new Harmony that replaces the worst Harmony in the *HM*. For each RB in the new Harmony, the new UE and power level can be selected from the *HM* with a probability of *HM Consideration Rate (HMCR)*. Otherwise; they are generated randomly from the range of valid UEs and power with a probability of (*1- HMCR)*. If the new UE and power were selected from the *HM*, then there is a probability of *Pitch Adjustment Rate (PAR)* to adjust the power. At the final iteration, the best Harmony (assignment matrix) is chosen.

C. Power Control Strategy

The proposed power control strategy is carried out by attempting to allocate more power to a UE that has not yet reached its required rate. The increments start by attempting to allocate 1.25X of the default power ($\frac{P_i^{total}}{|J_i|}$) and keep incrementing by a step of 0.25X until either the throughput if the UE increases or the power value of 3X is reached. To reduce ICI, the scheme also attempts to minimize the allocated power to an UE that has satisfied its required rate without causing it to become unsatisfied. The scheme attempts to allocate 0.5X of the default power then keeps incrementing by a step of 0.1X till the UE becomes satisfied again.

D. Channel Restriction Stragtegy

To maximize the system throughput, each cell altruistically restricts channels based on the newly proposed *Selfishness Index (SI)* parameter, where $1 \leq SI \leq 20$. The higher the value of the index, the more the scheme becomes selfish and prefers allocating channels to its users rather than restricting them to enhance the quality of the channel in the neighboring cells. The strategy states that a channel is restricted if $\frac{RB\ achievable\ rate}{UE\ required\ rate} > SI$ or $\frac{RB\ achievable\ rate}{UE\ required\ rate} < \frac{1}{SI}$. The upper bound guarantees that the high achieving channels are allocated to UEs with high rate requirements to prevent the waste of "good" channels. The lower bound, on the other hand, guarantees that UEs are allocated their highest achieving channels to minimize the number of channels per UE in order to allow allocating those channels to other UEs that can achieve better rates, prevent their usage to minimize ICI.

E. Algorithm Computational Complexity

Algorithm I. Proposed HS RB/Power Allocation Algorithm

Initialization
Randomly assign UEs and Powers for all Channels in all *HM* Harmonies.
Run the Channel Restriction Strategy.
If Channel is not restricted, **Run the Power Control Strategy**.
While iteration number < *MI* **do**
Improvisation
Create a single new Harmony.
For Each Channel in the new Harmony **do**
If random1 < *HMCR* **then**
Randomly assign a UE from the *HM* to the Channel.
Run the Channel Restriction Strategy.
If Channel is not restricted & random2 < *PAR* **then**
Run the Power Control Strategy.
End If
Else
Randomly assign an unsatisfied UE to the Channel.
Run the Channel Restriction Strategy.
If Channel is not restricted, **Run the Power Control Strategy**.
End Else
End For Each
Update
Calculate the fitness value of the new Harmony using eq. (3).
Update *HM* by replacing the poorest Harmony with the new Harmony, if better.
Increment iteration number by 1.
End While
Termination
Select the best Harmony as the new assignment matrix.

The complexity of the proposed algorithm is a function of the *constant MI,* with *MI* iterations performed on the *HM* used to generate new Harmonies. Each new Harmony requires iterating on all *J* Channels, assigning UEs randomly, and setting the power using the power control strategy. The cost of each iteration is *O(J).* Thus, the overall complexity is *O(MI × J)*, which is independent of the number of users, cells, and power levels.

V. Simulation Results and Analysis

A. Simulation Setup

The WINNER - Phase II (WIM2) shadowing and fading models [12] are 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. We consider a layout of three hexagonal cell of 500 m radius where each cell is equipped with an eNB with an omni-directional antenna located at the cell center. 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 −114dBm/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 1000 frames. For HS, the values of the *HMS*, *MI*, *HMCR* and *PAR* were set to 200, 200, 0.5 and 0.5, respectively. The proposed scheme is compared to four reference schemes: *Reuse-1* [8], *Reuse-3* [8], partial-frequency reuse (*PFR)* [8] and soft-frequency reuse (*SFR)* [8]*,* along with the *Kimura* scheme [11]. Proportional Fairness (PF) scheduling is used by all schemes while HS is used in the proposed scheme.

B. Performance Analysis

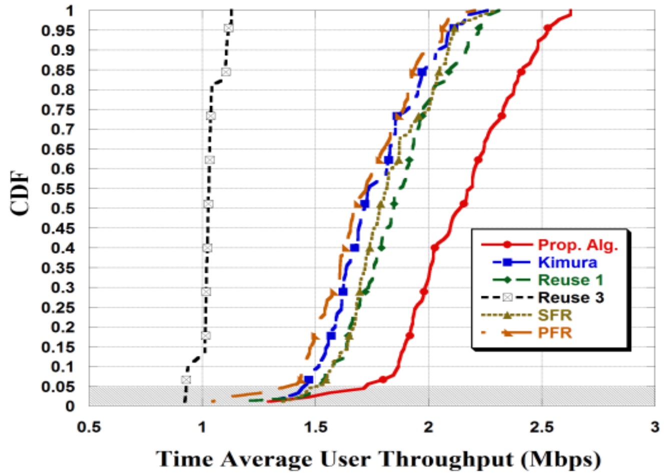

Figure 1. CDF of TATP for 30 users/cell at 3 Mbps/user. The 5% throughput (highlighted) presents edge TATP.

Fig. 1 depicts the Cumulative Distribution Function (CDF) of the Time-Average UE Throughput (TATP) under high mobility. In case of Reuse-3, with no ICI and PF Scheduling, all UEs have similar TATP (steep slope in Fig. 1). However, Reuse-3 achieves the worst TATP since all UEs share a small portion of the bandwidth. Both Kimura and SFR schemes achieve higher edge TATP than PFR scheme due to the availability of more RBs to edge UEs. Kimura achieves edge TATP less than SFR due to allocating a number of RBs with high power to more than one neighboring cells. Both Reuse-1 and SFR schemes achieve the same edge TATP. SFR has a limited number of edge RBs, but uses higher power, while Reuse-1 has more RBs for edge UEs but uses less power.

Similar to Reuse-1, 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, unlike Reuse-1 and similar to Kimura, both the information fed back from the cell UEs and the weights exchanged between eNBs are used to minimize ICI. This in turn leads to a higher edge TATP for the proposed scheme compared to all other schemes. Similar to Reuse-3 and PFR, the new scheme restricts channels in some cells to further minimize the ICI. However, it does the restrictions *dynamically* based on the *SI*, which prevents stalling due to the unavailability of channels. Similar to SFR and PFR, the proposed scheme uses different power levels. However, power levels are determined *dynamically* for each RB-UE allocation with the objective of increasing the SINR for unsatisfied users and decreasing the power consumption for satisfied users. The proposed scheme achieves a slightly lower fairness (less steep slope of the curve in Fig.1). This is expected as, unlike the PF scheduling used by other schemes, the proposed algorithm attempts to satisfy the largest number of users.

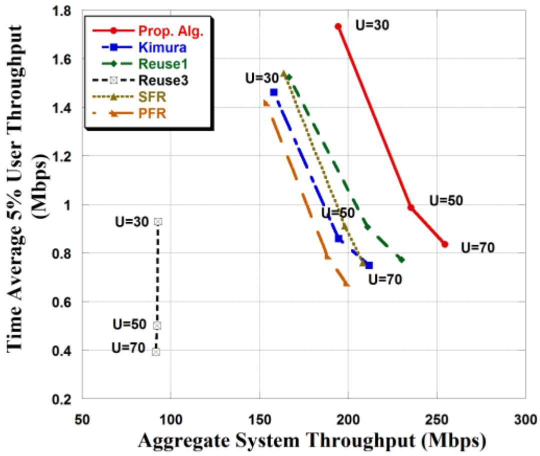

Figure 2. Edge TATP Vs ATP for (30,50,70) users/cell with 3Mbps/user.

Fig. 2 presents a closer look at the performance of the schemes under different number of UEs. As expected, the general trend is that as the 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 always achieves higher edge TATP and system ATP. It is worth noting that at a smaller number of users (e.g., 10 users per cell), Reuse-3 achieves the highest edge TATP as expected followed by the proposed scheme, while Reuse-1 has the worst value due to the excessive ICI. These results; however, are omitted from Fig.2 for clarity. It can be deduced from comparing the performance at small and large number of UEs that, ICI effect on the edge TATP is only significant when there are enough resources to serve all UEs; otherwise allocable resources size has higher significance.

Fig. 3 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. In Reuse-3, the system ATP and power efficiency remain constant with the different number of UEs. After saturation, no matter the number of UEs, Reuse-3 consumes the same amount of power and achieves the same rate, since there are no ICI. Reuse-3 achieves low power efficiency because of the limited allocable bandwidth, which limits the maximum achievable rate. As can be expected, Reuse-1 and SFR achieve higher power efficiency than that of Kimura scheme, as they can achieve higher system ATP. Interestingly, PFR also achieves higher power efficiency than Kimura scheme while it has always achieved lower system ATP. Our analysis of the Kimura scheme shows that, on average, 25% of the edge RBs are used by more than one cell with equal high power resulting in high ICI, and hence, the Kimura algorithm allocates more RBs to UEs to satisfy their required rate leading to power consumption larger than that of PFR with isolated edge RBs.

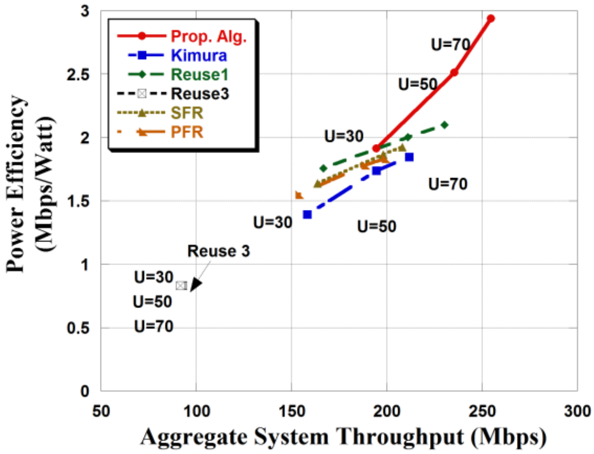

Figure 3. Power efficiency Vs ATP for (30,50,70) users/cell with 3Mbps/user.

As shown in Fig. 3, for the same number of UEs, the proposed scheme has significant higher power efficiency and system ATP than all other schemes because of the power control and channel restriction strategies. 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,* unlike Kimura scheme, thus achieving an acceptable SINR for the UEs and lower power consumption. 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 curve depicting the proposed scheme performance in Fig. 3 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.

C. Proposed Scheme Sensitivity Analysis

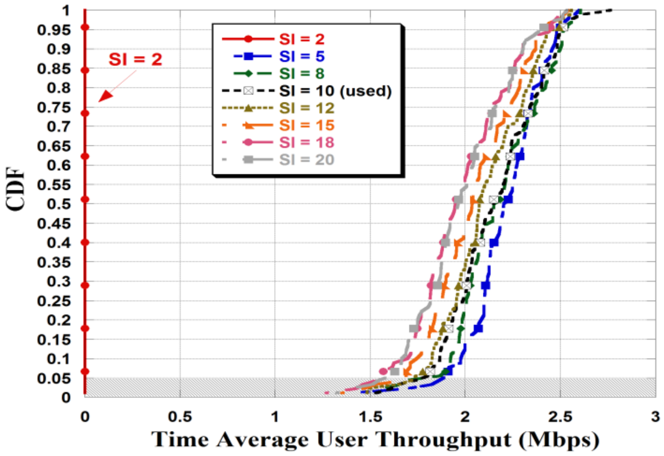

Figure 4. Effect of the *SI* on TATP for 30 users/cell at 3Mbps/user.

In Fig. 4, the effect of the *SI* is evaluated. At low SI (e.g., *SI=2*), a channel must be able to achieve 0.5 of the UE required rate to be allocated by the proposed algorithm. Thus, at *SI=2*, all eNBs restrict all channels as they see that all channels will not achieve a significant rate if allocated to any UE leading to a zero throughput. The best TATP is achieved with *SI* values between 5 and 10 as there is a large number of RBs allocated by the eNB but not large enough to cause significant ICI. With *SI* values above 10, each eNB becomes very selfish and prefers to allocate RBs to its UE rather than leaving them to neighboring eNBs, which results in an increase in ICI, and thus, a decrease in the TATP.

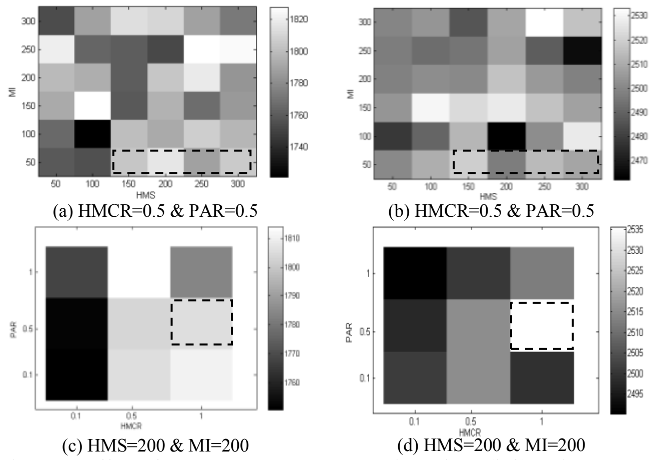

Figure 5. Effect of *HS* parameters on 5% UE throughput (left) and 95% UE throughput (right) for 30 users/cell at 3 Mbps/user.

As shown in Fig. 5, the performance of the proposed scheme is slightly affected by the various HS algorithm parameters (*HMS, MI, HMCR,* and *PAR*). However, as the computation complexity of the proposed scheme is dependent on the *MI*, small *MI* values are recommended, such as: *MI=50* and *HMS≥200* (dotted rectangle in Fig.5-a and 5-b). The analysis of the *HMCR* and *PAR* results shows that their best values are, respectively, *1.0* and *0.5* (dotted square in Fig.5-c and 5-d). It can be concluded from this analysis that having an initial large *HM* allows fast convergence to a good solution.

VI. Conclusion

In this paper, we proposed a self-adaptive autonomous decentralized ICIC scheme based on Harmony Search (HS) algorithm for multi-cell LTE systems. The proposed scheme does not require any frequency planning or inter-cell message exchange and is only slightly affected by the values of the *HS* parameters. Unlike other published dynamic ICIC schemes, the computational complexity of the proposed scheme is independent of the number of users and cells in the system making it more practical for deployment in large networks with rapidly moving users. The proposed scheme does not require any central coordination which further reduces the deployment cost and allows its deployment in the LTE-Advanced flat network architecture. The proposed power control and channel restriction strategies reduce the power consumption and lead to a better edge throughput without impacting the cell throughput.

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