A Grouping Harmony Search Algorithm for Assigning Resources to Users in WCDMA Mobile Networks

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Abstract. This paper explores the feasibility of a particular implementation of a Grouping Harmony Search (GHS) algorithm to assign resources (codes, aggregate capacity, power) to users in Wide-band Code Division Multiple Access (WCDMA) networks. We use a problem formulation that takes into account a *detailed* modeling of loads factors, including *all* the interference terms, which strongly depend on the assignment to be done. The GHS algorithm aims at minimizing a weighted cost function, which is composed of not only the detailed load factors but also resource utilization ratios (for aggregate capacity, codes, power), and the fraction of users without service. The proposed GHS is based on a particular encoding scheme (suitable for the problem formulation) and tailored Harmony Memory Considering Rate and Pitch Adjusting Rate processes. The experimental work shows that the proposed GHS algorithm exhibits a *superior* performance than that of the conventional approach, which minimizes only the load factors.

Keywords: Harmony Search, Grouping Harmony Search, Wide-band Code Division Multiple Access mobile networks

1 Introduction

Currently about 80% of mobile operators worldwide are investing to upgrade their Wide-band Code Division Multiple Access (WCDMA) networks [1], which have 1.83 billion users. High Speed Packet Access (HSPA), based on WCDMA technology, is the most widely used mobile *broadband* technology *deployed* at present. This is because HSPA allows operators to cost-efficiently *upgrade* their already deployed WCDMA networks to provide both speech and broadband data services (high speed Internet access, music-on-demand, or TV and video streaming, to name just a few). WCDMA/HSPA technology is expected to serve 90% of the world's population by 2020, with about 3.8 billion users [1].

The question that motivates this work is how to assign the limited WCDMA resources to users (mobile users or users equipments). As in other mobile access systems, frequency is one of these scarce resources. This is why in WCDMA networks a number of users are allowed to use simultaneously the same frequency. To separate these communications, the network assigns a "channelization code" to each communication. However, a given amount of *interference* appears between communication links using the same frequency. To quantify the influence of interference, a parameter called "load factor" η is used. It is defined as the ratio between the interference and the total perturbation (thermal noise + interference) [2]. The most used conventional approach (CA) for dimensioning WCDMA networks is based on keeping the interference and load factor lower than some suitable empirical thresholds [2]. Other limited resources in any base station (BS) are the maximum backhaul capacity, the number of channelization codes, and the the maximum power [3, 4].

Regarding this, the *purpose* of this work is to explore the feasibility of a Grouping Harmony Search (GHS) algorithm [5] to near-optimally assign WCDMA resources (codes, capacity, power) of $\mathcal{N}_B$ base stations to $\mathcal{N}_U$ users, by *minimizing* a cost function composed of the following *weighted* constituents [3]: 1) "Detailed" load factors [3] (which include *all* possible interference signals), the *utilization factor* of the available resources to be used (aggregated capacity, power, codes), and the fraction of users *without service*. The latter is critical because the smaller the number of users without service, the greater service availability. High service availability help operators increase market share.

There are two recent papers [3, 4] that also study this problem. The proposed work differs from [4] in the use of detailed load factors (instead of approximate ones), and also differs from [3] in the use of a GHS (instead of a Grouping Genetic Algorithm (GGA)).

The structure of the rest of this paper is as follows. While Section 2 states the problem along with a characterization of the resources to be assigned, Section 3 describes the GHS algorithm we propose. Section 4 shows the experimental work and, finally, Section 5 completes the paper by discussing the main findings.

2 Problem Statement

Let $\mathcal{A}$ be the service area of a WCDMA network with $\mathcal{N}_B$ base stations (BSs) and $\mathcal{N}_U$ active users. Fig. 1 represents two of these $\mathcal{N}_B$ BSs for the sake of clarity. The dashed area represents the *cell* covered by a BS or "node B" (nB) in WCDMA terminology. Throughout this work, both words will be used interchangeably. $n_u^{B_k}$ is the number of users that the nB B_k is serving. In particular, a reference user u_l assigned (associated) to B_k is denoted "$u_l \in B_k$". $p_{\mathrm{R},B_k}(l)$ represents the power received at B_k emitted by user u_l ($p_e(l)$). To separate the "reference" communication link $u_l \leftrightarrow B_k$ from others using the *same* frequency f, the network assigns a different code to each communication. Although codes help ideally reduce interference, however, the remaining communications using the same frequency become interference signals. The total interference contains not only those interferences generated by the users in the "own-cell" (for instance, user u_j in Fig. 1) but also those arising from users located in *other* cells (user u_m). Note that, apart from the interferences appearing in the uplink (UL) –signals moving from the users to the BS–, there are also others in the downlink (DL). A representative example is the interference produced by the base station B_q $(q \neq k)$, which interferes on the reference link $u_l \leftrightarrow B_k$. Load factors model to what extent interferences affect the network performance [2]. As explained in [3], the *detailed* UL load factor of a cell B_k with $n_u^{B_k}$ users is

$$\eta_{\mathrm{UL}}^{\det}(B_k) = \sum_{j=1}^{n_u^{B_k}} (1 + \xi_{u_j \to B_k}^{\mathrm{UL}}) \cdot \frac{1}{1 + \frac{1}{(e_b/n_0)_S(j)} \cdot \frac{W}{R_{b,S}^{\mathrm{UL}}(j) \cdot \nu_S^{\mathrm{UL}}(j)}}, \tag{1}$$

where $\xi_{u_j \to B_k}^{\mathrm{UL}}$, the ratio of "other-cell" to "own-cell" interference *on* the uplink $u_j \to B_k$, is defined in Table 1 along with other parameters in Exp. (1). The *key point* is that $\eta_{\mathrm{UL}}^{\det}(B_k)$ has very different values depending on the particular user-cell association selected [3]. Similarly, the *detailed* DL load factor is [3]:

$$\eta_{\mathrm{DL}}^{\det}(B_k) = \sum_{j=1}^{n_u^{B_k}} \left[(1 - \overline{\alpha}) + \xi_{B_k \to u_j}^{\mathrm{UL}} \right] \frac{(e_b/n_0)_S(j)}{\frac{W}{R_{b,S}^{\mathrm{DL}}(j) \cdot \nu_S^{\mathrm{DL}}(j)}}, \tag{2}$$

$\overline{\alpha}$ being an average orthogonality factor over cell B_k [2].

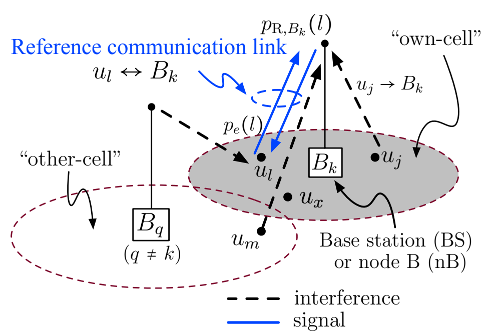

Fig. 1. Simplified representation of the communication signals (blue solid line) and interferences (black dashed lines) on the "reference" communication link $u_l \leftrightarrow B_k$.

In addition to frequency, any base station B_k has also a limited amount of each other resource, $\mathcal{R}$, which has to be shared among the $n_u^{S_k}$ users associated to B_k. For any resource, $\mathcal{R}$, we define the corresponding *utilization ratio* $\Delta_{\mathcal{R}} \doteq \mathcal{R}_{\mathrm{used}}/\mathcal{R}_{\max}$ as shown in Table 2. See [3] for further details.

Finally, a critical point for operators is the fraction of users *without* service, $\Delta_{n_u}^{\mathrm{WS}} \doteq n_u^{\mathrm{WS}}/\mathcal{N}_U$ (n_u^{WS} being the number of users without service), because the smaller $\Delta_{n_u}^{\mathrm{WS}}$, the higher the user satisfaction. This can help the mobile operator to increase its market share.

Table 1. Definition of parameters [3] used in this work. Uppercase UL(DL) is used to label either the uplink or downlink parameters. Subscript S stands for service.

Symbol	Definition and/or value
W	Chip rate: $W = 3.84$ Mchip/s (standardized value)
$(e_b/n_0)_S(j)$	Ratio between the mean bit energy and the noise power density (thermal noise and interference) required to achieve a given quality for service S
$R_{b,S}^{\mathrm{UL(DL)}}(j)$	Bit rate of service S in the j-th UL(DL) within cell B_k.
$\nu_S^{\mathrm{UL(DL)}}(j)$	Utilization factor: $0 < \nu_S^{\mathrm{UL(DL)}}(j) < 1$ (for voice), $\nu_S^{\mathrm{UL(DL)}}(j) = 1$ (for data services) [2]
p_{e,u_m}	Power emitted by user u_m
ℓ_{u_m,B_k}	*Total* propagation loss in the link $u_m \to B_k$
$i_{u_j\to B_k}^{\mathrm{UL},B_k}$	$= \sum_{u_m\in B_k, u_m\neq u_l} \frac{p_{e,u_m}}{\ell_{u_m,B_k}}$, UL own-cell-interference (from users on the own cell, $u_m \in B_k$)
$i_{u_j\to B_k}^{\mathrm{UL},B_q}$	$= \sum_{u_m\in B_q, B_q\neq B_k} \frac{p_{e,u_m}}{\ell_{u_m,B_q}}$, UL other-cell-interference (from users on other cell, $u_m \in B_q$)
$\xi_{u_j\to B_k}^{\mathrm{UL}}$	$= \frac{i_{u_j\to B_k}^{\mathrm{UL},B_q}}{i_{u_j\to B_k}^{\mathrm{UL},B_k}}$, ratio of other-cell to own-cell interference *on* the UL $u_j \to B_k$

Table 2. Resources ($\mathcal{R}$ = power, codes, capacity) and utilization ratios $\Delta_{\mathcal{R}}$ in BS B_k (serving $n_u^{S_k}$ users) when aiming at allocating resources to user u_l. See Fig. 1.

$\mathcal{R}$ and corresponding $\Delta_{\mathcal{R}} \doteq \mathcal{R}_{\mathrm{used}}/\mathcal{R}_{\max}$	Definition
$p_{B_k\|\max}$	Maximum power that base station B_k can emitt
$p_{B_k\to u_j}^{\mathrm{DL}}$	Power emitted by B_k for serving user u_j
$\Delta_{P_{B_k}} \doteq \frac{1}{p_{B_k\|\max}} \sum_{j=1}^{n_u^{S_k}} p_{B_k\to u_j}^{\mathrm{DL}}$	Power utilization ratio of B_k
$N_{\mathrm{Cod}}^{S_h}$	Maximum no. of codes in B_k for service S_h
$n_{u,S_h}^{B_k}$	Number of users in B_k demanding service S_h
$\Delta_{\mathrm{Cod}} \doteq \sum_{h=1}^{N_S} \frac{n_{u,S_h}^{B_k}}{N_{\mathrm{Cod}}^{S_h}}$	Code utilization ratio in B_k
$C_{\mathrm{Ag}}^{\mathrm{UL(DL)}}$	Maximum aggregated capacity of B_k in UL(DL)
$R_{b,S}^{\mathrm{UL(DL)}}(j)$	Bit rate of user $u_j \in B_k$ in UL(DL)
$\Delta_{C_{\mathrm{Ag}}^{\mathrm{UL(DL)}}} \doteq \frac{1}{C_{\mathrm{Ag}}^{\mathrm{UL(DL)}}} \sum_{j=1}^{n_u^{S_k}} R_{b,S}^{\mathrm{UL(DL)}}(j)$	Capacity utilization ratio in B_k

With these concepts in mind, the problem consists in finding the user-cell association that assigns resources (power, codes, capacity) by *minimizing* the cost function [3]

$$\mathcal{C} = \frac{1}{\mathcal{N}_B} \sum_{k=1}^{\mathcal{N}_B} [w_\eta \cdot (\eta_{\mathrm{UL}}^{\mathrm{det}} + \eta_{\mathrm{DL}}^{\mathrm{det}}) + w_{\Delta_{C_A}} \cdot (\Delta_{C_{\mathrm{Ag}}^{\mathrm{UL}}} + \Delta_{C_{\mathrm{Ag}}^{\mathrm{DL}}} +)$$
$$+ w_{\Delta_{P_{B_k}}} \cdot \Delta_{P_{B_k}} + w_{\Delta_{\mathrm{Cod}}} \cdot \Delta_{\mathrm{Cod}} + w_{\Delta_{n_u}^{\mathrm{WS}}} \cdot \Delta_{n_u}^{\mathrm{WS}}], \tag{3}$$

constrained to the conditions that all the aforementioned components $\phi = \eta_{\mathrm{UL}}^{\mathrm{det}}$, $\eta_{\mathrm{DL}}^{\mathrm{det}}$, $\Delta_{C_{\mathrm{Ag}}^{\mathrm{UL}}}$, $\Delta_{C_{\mathrm{Ag}}^{\mathrm{DL}}}$, $\Delta_{P_{B_k}}, \Delta_{\mathrm{Cod}}, \Delta_{n_u}^{\mathrm{WS}}$ are real numbers fullfiling $0 \leq \phi \leq 1$ [3].

w_ϕ represents a weight factor for any of the involved components. Unlike [3], which uses a GGA, we tackle this problem by the GHS proposal that follows.

3 Proposed GHS algorithm

A GHS [5] is a modification of the Harmony Search (HS) algorithm to deal with grouping problems. HS is a meta-heuristic, population-based algorithm, inspired by the improvisation process of an orchestra in their effort of composing the most harmonious melody. Put it simple, a candidate vector solution in HS is called "harmony" while any of its compounding elements is named "note", the set of harmonies being commonly denoted as "Harmony Memory" (HM). The initial HM is evolved by applying optimization processes −"Harmony Memory Considering Rate" (HMCR) and "Pitch Adjusting Rate (PAR) −, producing a new improvised harmony in any iteration. The way the HS algorithm works can be summarized in four basic steps: (1) Initialization of the HM; (2) Improvisation of a new harmony; (3) Inclusion of the newly generated harmony in the HM (its fitness improves the worst fitness value in the previous HM); (4) Returning to step (2) until a termination criteria (maximum number of iterations or fitness stalls) is fulfilled. A useful survey on applications of the HS algorithm is [6].

3.1 Problem encoding

The encoding is based on separating each harmony $\mathbf{h}$ into two parts: $\mathbf{h} = [\mathbf{e}|\mathbf{g}]$, the first one being the *element* section, while the second part, the *group* section. Since the number of base stations in our network is *constant* ($\mathcal{N}_B$), we have used the following variations of the classical grouping encoding:

1. The element part $\mathbf{e}$ is an $\mathcal{N}_U$-length vector whose elements ($u_j^{B_k}$) mean that user u_j has been assigned to base station B_k.
2. The group section $\mathbf{g}$ is an $(\mathcal{N}_B + 1)$ length vector, whose elements (labeled $n_u^{B_j}$) represent the number of users assigned to each j-th base station (B_j). Subscript j ranges from -1 to $\mathcal{N}_B$, $j = -1$ being used to represent those users that are *not* connected to any node, that is, those in an "imaginary" or virtual base station that we have labelled "base station -1". As will be shown, this group part is necessary since the PAR operator acts first on the group part.

As an example, following our notation, a candidate harmony $\mathbf{h}_i$, belonging to an HM with Γ harmonies $\{\mathbf{h}_1 \cdots \mathbf{h}_\Gamma\}$, could encode a solution –i.e., an assignment of $\mathcal{N}_U$ elements (users) to $\mathcal{N}_B$ base stations, forming thus groups of users– as

$$\mathbf{h}_i = [u_{1(i)}^{B_h} \dots u_{m(i)}^{B_j} \dots u_{\mathcal{N}_U(i)}^{B_w} \mid n_{u(i)}^{B_{-1}} n_{u(i)}^{B_1} \dots n_{u(i)}^{B_k} \dots n_{u(i)}^{B_{\mathcal{N}_B}}], \tag{4}$$

where $n_{u(i)}^{B_{-1}}$ is the number of users without service (n_u^{WS}), those that have not been able to be assigned to any nB and do not have service. We represents this by assigning then to a "virtual" nB labeled B_{-1}. Fig. 2 (a) shows a simple example of codification of an assignment in which $\mathcal{N}_U = 10$ users have been assigned to $\mathcal{N}_B = 4$ base stations (c1).

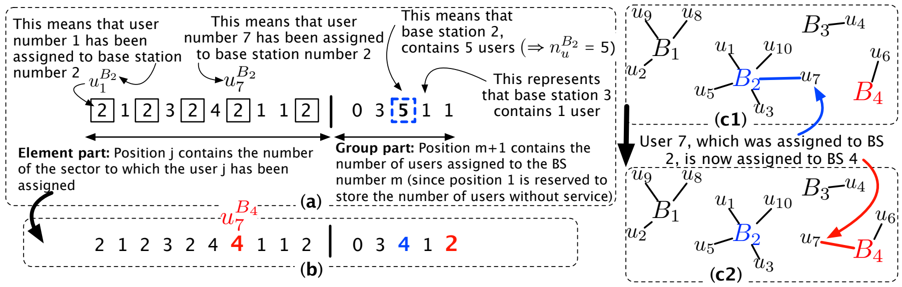

Fig. 2. (a) Harmony with 10 users and 4 base stations. The PAR process selects, in the group part, the BS B_2 (position 3 since the first one is reserved to quantify the number of users without service), which has assigned 5 users ($u_1, u_3, u_5, u_7, u_{10}$, as shown in (c1) and represented in the element part of (a)). (b) In a second step, the PAR process selects one of the elements (u_7, which was assigned to B_2 in (a)), and reassign it to B_4. (c) Representation of the reassignment process driven by PAR.

3.2 Algorithm implementation

a) The *initialization* of the notes' values of all harmonies included in the HM is only executed at the first iteration.
b) The *improvisation* process is sequentially applied to each note of the complete set of Γ harmonies. Two processes are used for improvising the new refined set of harmonies:
   b.1) The Harmony Memory Considering Rate (HMCR) establishes the probability that the new value for a note $u_{m(i)}^{B_j}$ (in the *element* part $\mathbf{e}_i$ of $\mathbf{h}_i$) is drawn from the values of the same note taken in all the other $\Gamma - 1$ harmonies existing in the HM, $(u_{m(\gamma)}^{B_p}, \gamma = 1 \cdots \Gamma, \gamma \neq i)$. Note that the smaller HMCR is, the less the use of partial knowledge acquired during the iterative process will be, and hence the more explorative the algorithm will behave. The new note will be chosen at random if it is not drawn from the HM.
   b.2) The Pitch Adjusting Rate (PAR) process works as a fine adjusting rate of the note vocabulary. In our implementation, it first selects at random a *group* in $\mathbf{g}_i$ (for instance, BS $B_k = B_2$ (blue dashed squared) in Fig. 2(a), which has assigned $n_u^{B_k} = 5$ users). In a second step, it selects one of the users assigned to B_k (for instance, element $u_{m(i)}^{B_k} = u_{7(i)}^{B_2}$ (user 7) in $\mathbf{e}_i$) and assigns it to another BS (B_4 in Fig. 2 (b), (c2)) with a given probability, $\mathcal{P}$. This probabilistic process defines the new value $u_m^{B_k^*}(i)$

for a certain note $u_m^{B_k}(i)$ (after HMCR processing) as

$$u_{m(i)}^{B_k^*} = \begin{cases} u_{m(i)}^{B_q} & \text{, with } \mathcal{P} = \text{PAR}, \\ u_{m(i)}^{B_k} & \text{, with } \mathcal{P} = 1 - \text{PAR}, \end{cases} \quad (5)$$

where B_q $(q \neq k)$ is another BS (selected at random) at which user u_m will be assigned only if the distance between user u_m and BS B_q fulfills $d(u_m, B_q) < d_{\text{MAX}}$.

Analogously to the HMCR process, a high value of PAR jointly with a increased value of d_{MAX} sets a highly explorative behavior of the algorithm around the iteratively-identified potential candidates or harmonies, while narrower bandwidths (i.e. lower values of d_{MAX}) the PAR process leads to a restricted local search procedure (the user will be assigned to an adjacent cell instead of farther cells).

c) At each iteration the quality of the improvised harmonies is evaluated by means of the cost function $\mathcal{C}$ stated by Exp. (3). A harmony $\mathbf{h}_p$ "sound best" than another $\mathbf{h}_g$ if $\mathcal{C}(\mathbf{h}_p) < \mathcal{C}(\mathbf{h}_g)$. Then, based on these metric evaluations and their comparison with the cost of harmonies remaining from the previous iteration, the Γ best harmonies are kept and the HM is hence updated by excluding the worst harmonies.

d) The stopping criterion is selected based on a fixed number of iterations $\mathcal{T}$.

4 Experimental work

4.1 Experimental set up and comparative framework

We have considered the three different services listed in Table 3 along with their characteristic parameters. Other network parameters used are [2]: $\overline{\alpha} = 0.65$, $\overline{\xi} = 0.55$, $p_{B_k|\max} = 36$ W, and $C_{\text{Ag}}^{\text{UL}} = C_{\text{Ag}}^{\text{DL}} = 1536$ kbps. With these services, we have considered the following service profiles: 90% of users with service S_1, 9% with S_2, and 1% with S_3. We have carried out 20 runs of each GHS algorithm, with $\mathcal{T} = 300$ iterations each. This number has been found to be large enough for the algorithm to converge.

Table 3. Values of service parameters. ARM means Adaptive Multi-Rate.

S_h	$(E_b/N_0)_i$ (dB)	$R_{b,i}^{\text{UL}}$(dB)	$R_{b,i}^{\text{DL}}$(kbps)	$\nu_i^{\text{UL}} = \nu_i^{\text{DL}}$	$N_{\text{Cod}}^{S_h}$ (codes)
S_1 (ARM)	5	12.2	12.2	0.58	256
S_2 (data)	1.5	64	64	1	32
S_3 (data)	1	64	384	1	4

For comparative purposes to the conventional approach (CA) we have implemented a combination of two CAs: the "Best-Server Cell Selection" (BSCS) [2] and the "Radio Prioritized Cell Selection" (RPCS) [2] algorithms. For any user u_j (with $j = 1, 2, \cdots, \mathcal{N}_U$), we compute the SINR between u_j and all the base stations B_k (with $k = 1, 2, \cdots, \mathcal{N}_B$): $\Upsilon_{j,k}$. This leads to a $\mathcal{N}_U \times \mathcal{N}_B$ matrix of SINR ratios. For any user u_j, we compute an "assignment vector", $\mathbf{A}_j$, which contains a list of BSs, sorted from the one that provides the best SINR down to that giving the worst one. Initially, each user u_j is assigned to the nB with the corresponding best SINR ("best base station" (BBS) in the BSCS algorithm [2]), that is, to the first one of the assignment vector $\mathbf{A}_j$. In any cell, the algorithm checks whether or not the assignment leads to a load factor higher that the threshold (overload). In each overloaded cell (let say, for instance, B_g), the user with the worst SINR with respect to B_g (let say, for instance, u_f) is detached from B_g and assigned to the next non-overloaded BS of its assignment vector $\mathbf{A}_f$. The algorithm iterates until either the cells are no longer overloaded, which may cause some users fail to be assigned to any station.

4.2 Comparison and discussion

Figures 3 (a) and (b), which represent respectively the different assignments that the GHS and CA algorithms have found, will help us compare both approaches.

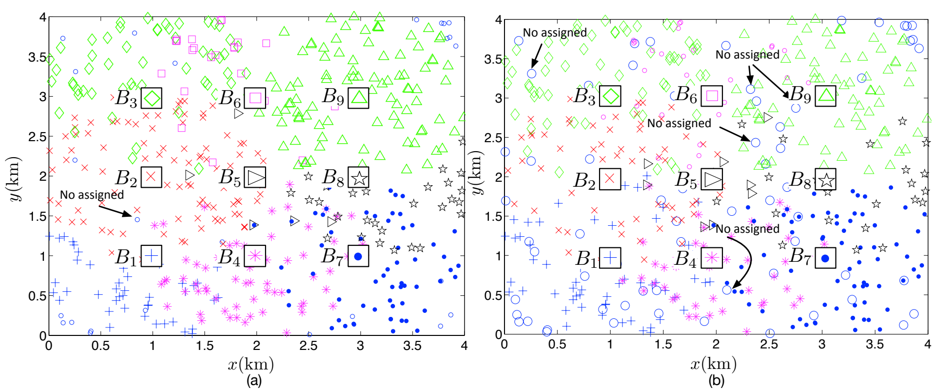

Fig. 3. Assignments of $\mathcal{N}_U = 500$ uniformly distributed users to $\mathcal{N}_B = 9$ BSs found, respectively, by the GHS algorithm (a) and by the CA (b).

Each BS in Fig. 3 has been represented by a square box containing a different symbol ($+, \times, \Diamond, \triangleright, \cdots$) so that any user attached, for instance, to base station B_3 ($\Diamond$-symbol inside the box), will be represented with that symbol ($\Diamond$). They correspond to $\mathcal{N}_U = 500$ users, which leads to a user density $D_{\mathrm{U}} \approx 31.25$ users/km^2. Note that both figures have *identical* user locations, but *differ in the way they are assigned to different stations*. This can be easily seen by taking a look at those users located in-between base stations B_6 and B_9 in both figures. While in Fig. 3 (a) the users are mostly labeled with green $\triangle$-symbols (what means that they have been assigned to B_9 ($\triangle$ symbol)), however, in Fig. 3 (b), many of these users located between stations B_6 and B_9 (which in Fig 3 (a) were mostly assigned to B_9) are now however *without service* (represented with blue ◯ symbols) since they have not been assigned to any nB. The CA assignment (Fig. 3 (b)) works worse in the sense that it leaves more customers unserved.

To proceed further in this regard, it is convenient to focus on Fig. 4 (a). It compares, respectively, the fraction of the different constituents ($\phi = \eta_{\mathrm{UL}}, \eta_{\mathrm{DL}}$, $\Delta_{C^{\mathrm{UL}}_{\mathrm{Ag}}}$, $\Delta_{C^{\mathrm{DL}}_{\mathrm{Ag}}}$, $\Delta_{P_{B_k}}, \Delta_{\mathrm{Cod}}, \Delta^{\mathrm{WS}}_{n_u}$) of the *minimized* cost function, computed by the CA (grey bars), the GGA approach [3] (blue bars), and the proposed GHS method (red bars). The most relevant aspect is that the proposed GHS method assigns resources to *many more users* than the CA: the fraction of users *without service* in the GHS assignment is only $\Delta^{\mathrm{WS}}_{n_u}|_{\mathrm{GHS}} = 3\%$ (mean value over 20 runs). This represents only 15 users in absolute terms, which is much smaller than that achieved by the conventional assignment, which is $\Delta^{\mathrm{WS}}_{n_u}|_{\mathrm{CA}} = 18\%$ (i.e., 90 users). Note that $\Delta^{\mathrm{WS}}_{n_u}|_{\mathrm{GHS}}$ is 6 times smaller than $\Delta^{\mathrm{WS}}_{n_u}|_{\mathrm{CA}}$. In this respect, the GHS strategy is more practical for the operator's economical strategy since it helps increase the number of active users without having to draw upon new, expensive deployments. Note also that the GHS method works slightly better than the GGA approach [3].

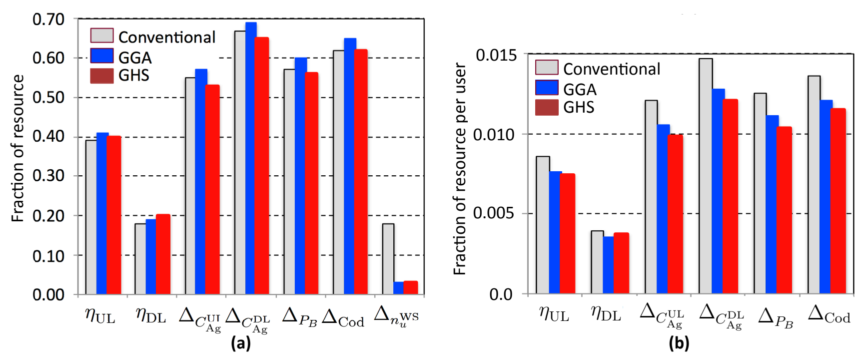

Fig. 4. (a) Fraction of used resources corresponding to the assignment computed by the CA (grey bars), the GGA method (blue bars) and the proposed GHS (red bars). (b) Fraction of resources *per* user (same color convention as (a)).

The true potential of the proposed GHS algorithm can be seen much more clearly in Fig. 4 (b), which represents the fraction of resources assigned *per user*. The fraction of resources used per user in GHS is lower than that of CA. On average, this is $\approx 85\%$ of those of the CA. In this sense, the use of resources is *more efficient* because the proposed method leads to an assignment in which there are *more users* with the required service ($500 - 15 = 485 = \mathcal{N}^{\mathrm{GHS}}_{\mathrm{U}} > 500 - 90 = 410 = \mathcal{N}^{\mathrm{CA}}_{\mathrm{U}}$) along with a *lower consumption-per-user* than that achieved by the CA and that by the GGA [3].

5 Summary and conclusions

In this work we have proposed a novel implementation of a Grouping Harmony Search (GHS) algorithm to assign resources (codes, capacity, power) to users in Wide-band Code Division Multiple Access (WCDMA) networks. The GHS algorithm aims at *minimizing* a cost function composed of not only the *detailed* load factors (including *all* interferences) but also *resource utilization ratios* and the fraction of users without service. We have proposed an encoding scheme, which is novel in GHS, and based on this, also tailored Harmony Memory Considering Rate (HMCR) and Pitch Adjusting Rate (PAR) processes. In particular, the proposed PAR process acts on the group part (by selecting a base station) and assigns one of its users to another base station with a given probability. The explored GHS exhibits a *superior* performance than that of the conventional approach (CA) –which minimizes only the load factors–, and is slightly better than that of the Grouping Genetic Algorithm (GGA) approach. The GHS not only assigns resources to more users (97% of users –in a scenario with 31.25 users/km^2, uniformly distributed–, higher than 82% of users assigned by the CA) but also it does it *more efficiently*, since the mean value of the *resources used per user* in the GHS assignment is 85% of that of the CA one.

6 Acknowledgments

This work has been partially supported by projects TIN2014-54583-C2-2-R (Spanish Ministerial Commission of Science and Technology) and S2013ICE-2933_02 (Comunidad Autónoma de Madrid).

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