Expert Systems With Applications 55 (2016) 388–402

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

# A novel Grouping Coral Reefs Optimization algorithm for optimal mobile network deployment problems under electromagnetic pollution and capacity control criteria

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ARTICLE INFO

*Keywords:*
Coral Reefs Optimization
Mobile network deployment
Grouping-based heuristics
Electromagnetic pollution minimization
BTS capacity

ABSTRACT

This paper proposes a novel optimization algorithm for grouping problems, the Grouping Coral Reefs Optimization algorithm, and describes its application to a Mobile Network Deployment Problem (MNDP) under four optimization criteria. These criteria include economical cost and coverage, and also electromagnetic pollution control and capacity constraints imposed at the base stations controllers, which are novel in this study. The Coral Reefs Optimization algorithm (CRO) is a recently-proposed bio-inspired approach for optimization, based on the simulation of the processes that occur in coral reefs, including reproduction, fight for space or depredation. This paper presents a grouping version of the CRO, which has not previously evaluated before. Grouping meta-heuristics are characterized by variable-length encoding solutions, and have been successfully applied to a number of different optimization and assignment problems. The GCRO proposed is a novel contribution to the intelligent systems field, which is able to improve results obtained by two alternative grouping algorithms such as grouping genetic algorithms and grouping Harmony Search. The performance of the proposed GCRO and the algorithms for comparison has been tested with real data in a case study of a MNDP in Alcalá de Henares, Madrid, Spain.



## 1. Introduction

Since the pioneering work by Falkenauer (1992), bio-inspired grouping approaches have been a hot topic in Computational Intelligence. By grouping-based algorithms it is meant those techniques that take advantage of special encoding strategies and searching operators towards obtaining compact hierarchical arrangements in grouping-based problems with a high performance in terms of a hierarchy-dependent metric (Brown & Sumichrast, 2005). The mentioned grouping encoding leads to a variable-length optimization algorithm, in which a solution to the problem is structured in two parts: an *element* section and a *group* section. Specific searching operators are then defined over this encoding to exploit the hierarchical structure of the searching space.

The first bio-inspired algorithm leveraging grouping encoding and related operators was the so-called Grouping Genetic Algorithm (GGA), developed by Falkenauer et al. in a series of publications in the last 90s (De Lit, Falkenauer, & Delchambre, 2000; Falkenauer, 1992; 1998), which was applied thereafter to a number of specific applications such as manufacturing (Hung, Sumichrast, & Brown, 2003; James, Brown, & Keeling, 2007b; Kreng & Lee, 2004), mobile communication network design (Agustín-Blas, Salcedo-Sanz, Vidales, Urueta, & Portilla-Figueras, 2011; Brown & Vroblefski, 2004; James, Vroblefski, & Nottingham, 2007a), routing (Rekiek, Delchambre, & Saleh, 2006), finances (Höglund, 2013), assignment (Agustín-Blas, Salcedo-Sanz, Ortiz-García, Portilla-Figueras, & Pérez-Bellido, 2009; Agustín-Blas et al., 2010; Brown & Sumichrast, 2003; Cuadra, Salcedo-Sanz, Carnicer, Del Arco, & Portilla-Figueras, 2015; Quiroz-Castellanos et al., 2015), clustering (Agustín-Blas et al., 2012; Salcedo-Sanz, Del Ser, & Geem, 2014b) or Big Data (Houri Razavi, Omid Mahdi Ebadati, Asadi, & Kaur, 2015). Following the proven good performance of the GGA, alternative meta-heuristic optimization engines for grouping problems have been subsequently developed within the last few

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http://dx.doi.org/10.1016/j.eswa.2016.02.032
0957-4174/

years, mainly the Grouping Harmony Search (GHS) (Landa-Torres, Manjarrés, Salcedo-Sanz, Gil-López, & Del Ser, 2013; Landa-Torres, Salcedo-Sanz, Gil-López, Del Ser, & Portilla-Figueras, 2012), with specific applications in which this approach outperformed the GGA (Kashan, Akbari, & Ostadi, 2015; Manjarres et al., 2013), the Grouping Particle Swarm Optimization algorithm (GPS) (Kashan, Kashan, & Karimiyan, 2013a) and the Grouping Evolutionary Strategy approach (Kashan et al., 2015; Kashan, Razaee, & Karimiyan, 2013b).

This paper joins this recent interest on grouping meta-heuristic schemes by proposing a novel Grouping Coral Reefs Optimization (GCRO). The proposed algorithm encodes solutions in a similar way than algorithm proposed by Falkenauer (1992); 1998) for optimally solving complex grouping paradigms, but the searching mechanism is based on a different paradigm: the Coral Reefs Optimization algorithm (CRO). The CRO has been recently proposed in Salcedo-Sanz, Del Ser, Landa-Torres, Gil-López, and Portilla-Figueras (2014c), and thereafter applied to a number of discrete optimization problems in different fields (Li, Miao, & Leung, 2015; Medeiros, Xavier-Júnior, & Canuto, 2015; Salcedo-Sanz, Casanova-Mateo, Pastor-Sánchez, & Sánchez-Girón, 2014a; Salcedo-Sanz et al., 2014d; Salcedo-Sanz, García-Díaz, Portilla-Figueras, Del Ser, & Gil-López, 2014e; Salcedo-Sanz, Pastor-Sánchez, Blanco-Aguilera, Prieto, & García-Herrera, 2014f; Salcedo-Sanz, Sánchez-García, Jiménez-Fernández, Portilla-Figueras, & Ahmadzadeh, 2014g; Yang, Zhang, & Zhang, 2016). It is a bio-inspired approach based on the simulation of different processes that occur in a coral reef, such as coral reefs formation, corals' reproduction, fight for reef's space or depredation processes in the reef.

A second contribution of this paper is the application of the GCRO to problem of mobile network deployment problem (MNDP) with different optimization criteria: cost, coverage and electromagnetic pollution minimization. Different version of this problem were tackled before by applying alternative meta-heuristic approaches (García-Díaz, Salcedo-Sanz, Portilla-Figueras, & Jiménez-Fernández, 2013; Salcedo-Sanz et al., 2014e). However, in this paper we consider an additional criterion: a capacity constraint is imposed to base station controllers, which makes the problem closer to real-world applications. The MNDP version tackled in this paper is appropriate to be addressed with grouping-based heuristics so the main contributions of this works are the following: (1) we describe the fundamentals of the proposed GCRO algorithm, discussing the main modifications made in the basic CRO to be adapted to the grouping scheme; (2) we discuss the performance of the GCRO when applied to a real case study of the MNDP, in the city of Alcalá de Henares (Madrid, Spain); (3) finally, we compare the obtained results with those rendered by two versions of the previously published grouping approaches: the GGA and GHS, also specifically adapted to the MNDP under consideration.

The rest of the paper is structured as follows: the next section presents the problem tackled in this work, along with its different objectives and peculiarities. Section 3 introduces the proposed GCRO algorithm and provides details on the modifications made to the original CRO algorithm for tackling grouping problems and the specific MNDP at hand. Section 4 analyzes the performance of the GCRO algorithm when applied to the deployment of a mobile communication network over the city of Alcalá de Henares (Madrid, Spain), taking into account electromagnetic pollution and the capacity of BTSs. A comparison with two state-of-the-art grouping algorithms (GGA and GHS) is further provided so as to assess the superior performance of the proposed GCRO approach. Finally, Section 5 concludes the paper by giving some final remarks.

## 2. Problem definition

In this section we present the mathematical definition of the mobile network deployment problem (MNDP) with electromagnetic pollution control and capacity constraint tackled in this paper. We consider a metropolitan area $A$ with the following parameters:

- A set $\mathcal{O} = (\mathbf{o}_i), i \in \{1, \dots, O\}$ of points in area $A$ with a measured electromagnetic field (volts per meter, $V/m$) assumed to be known a priori. Each point is defined by its coordinates $(x_i^o, y_i^o) \in A$.
- A set $\mathcal{P} = (\mathbf{p}_i), i \in \{1, \dots, P\}$ of possible points where to locate new Base Transceiver Stations or BTSs. Intuitively, $\mathbf{p}_i \in A\ \forall i \in \{1, \dots, P\}$. If we denote the number of BTSs to be deployed as $N$, it is assumed that $P \geq N$, i.e. each point in $\mathcal{P}$ can host only one BTS.
- A set $\mathcal{P}' = (\mathbf{p}'_i), i \in \{1, \dots, M\}$ of points in $A$ that must be covered by the new mobile stations (namely, mobile telephony service at these points must be provided by the new stations). Such points are described by coordinates $(x'_i, y'_i) \in A$.
- A set $\mathcal{T} = (t_i), i \in \{1, \dots, T\}$ of different types of BTSs. Every BTS is characterized by its frequency (KHz), the transmission power (dBW) and total capacity (Erlangs) to serve over points in $\mathcal{P}'$.
- Individual cost function of a BTS $C : \mathcal{P} \times \mathcal{T} \to \mathbb{R}$. The cost of a BTS installation on $\mathcal{P}$ depends on the net price of the BTS and the location to install. Some locations are more expensive than others due to different reasons such as property taxes, acquisition fees, installation costs, etc.

With the above parameters in mind it is important to emphasize that two hard constraints are imposed in the problem: BTSs are assumed to feature (1) a limited coverage area and (2) a finite capacity to attend the demands of $\mathcal{P}'$ (namely, the coordinates to be served by the set of BTSs). The aggregate demand requested by all points within the set $\mathcal{P}'$ is considered to be fully served when all their locations fall within the coverage area of some BTS with enough capacity to allocate their respective demands, i.e. there is enough capacity to cover the total demand. In order to fulfill both requirements, it is necessary to establish a mapping $\lambda : \mathcal{P}' \mapsto \{1, \dots, N\}$ between the points in $\mathcal{P}'$ and the $N$ BTSs to be deployed.

These preliminaries being stated, the objective of the problem to be addressed is to obtain a deployment of new base stations, denoted as $D = \{(p_i, t_i)_{i=1}^N, \lambda\}$, that fulfills the following optimization criteria:

1. The no-ionizing radiation of the deployment $D$ over $\mathcal{O}$, which will be computed in terms of the increment on the electromagnetic radiation $\Delta E_T$ over the set of locations in $\mathcal{O}$, should be minimized.
2. The total cost of the deployment $\mathcal{C}_T(D)$, i.e., the cost of the installation of $N$ base stations on locations in $\mathcal{P}$, should be minimized.
3. The total number of non-satisfied demands in area $A$ should be minimized. As mentioned previously, a service demand at point $\mathbf{p}' \in \mathcal{P}'$ is not satisfied because the point $\mathbf{p}'$ at hand falls out of the coverage area of all BTSs in the network, or because all BTSs covering $\mathbf{p}'$ do not have enough capacity to allocate its demand.

In order to reflect the above criteria as a single objective function $F(\cdot)$ for this problem, we will consider the sum of three terms:

$$F \triangleq \kappa_1 \cdot \Delta E_T + \kappa_2 \cdot \mathcal{C}_T + \kappa_3 \cdot P_{no\ service}, \tag{1}$$

where coefficients $\kappa_1$, $\kappa_2$ and $\kappa_3$ weight contributions of different magnitudes. Therefore, units of $\kappa_1$ and $\kappa_2$ are $(mV/m)^{-1}$ and $(K€)^{-1}$, respectively. In the above expression, $P_{no\,service}$ refers to the percentage of points in $\mathcal{P}'$ with a non-satisfied service demand. In regards to the first term in $F(\cdot)$, the total electromagnetic field increment $\Delta E_T$ over the area $A$ is given by the sum of the electromagnetic field increases $\Delta E_i$ taken over the set of points $\mathcal{O}$,