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A stop-and-start adaptive cellular genetic algorithm for mobility management of GSM-LTE cellular network users

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ABSTRACT

The optimisation of the user tracking process is one of the most challenging tasks in today's advanced cellular networks. In this paper, we propose a new low-complexity adaptive cellular genetic algorithm to solve this problem. The proposed approach uses a torus-like structured population of candidate solutions and regulates interactions inside it by using a bi-dimensional neighbourhood. It also automatically adapts the algorithm's parameters and regenerates the algorithm's population using two algorithmically-light operators. In order to draw reliable conclusions and perform an encompassing assessment, extensive experiments have been conducted on 25 differently-sized realistic networks. The proposed approach has been compared against 26 state-of-the-art algorithms previously designed to solve the mobility management problem, and a thorough statistical analysis of results has been performed. The obtained results have shown that our proposal is more efficient and algorithmically less complex than most of the state-of-the-art solvers.

1. Introduction

The popularity and accessibility of the services provided by cellular networks made them leaders in the field of communication. According to the GSM[1] association, in 2017 almost half of the world is using mobile communication services (Berrocal-Plaza, Vega-Rodriguez, & Sanchez-Perez, 2015a). This has made the mobile industry a field with tremendous technological and economical competition, where service quality is a key component. Quality can be measured by how good, reliable and fast a service is delivered/requested to/from a user. This has made the Mobility Management System (MMS) a sensitive core since it handles necessary information for the user's mobility management. Studies have shown that messages generated by the MMS when trying to locate a mobile user induce more than 33% of the signalling traffic passing through the bandwidth (Berrocal-Plaza, Vega-Rodriguez, & Sanchez-Perez, 2014d; Dahi, 2017). Besides the fact that the bandwidth is the most economically-valuable resource, such overhead results in many issues such as network congestion, service failure and communication failure, that are unacceptable by both operators and costumers (Dahi, Mezioud, & Alba, 2016). This has made the optimisation of the users tracking one of the most challenging tasks in today's 2G, 3G, and 4G networks.

The high complexity of the Mobility Management Problem (MMP) (Bar-Noy & Kessler, 1993; Hać & Zhou, 1997) has made of metaheuristics a promising solution. Many approaches have been previously devised in the literature and are summarized in Table 1.

Cellular Genetic Algorithms (cGAs) are Evolutionary Algorithms (EAs) that organise the population as a grid in which each node represents an individual and where interactions between the latter are restricted to a neighbourhood. Like the cGAs, most of today's algorithms proposed to solve problems such as the MMP are problem or instance-dependent. Actually, their performance is greatly related to the quality of their parameter tuning. The latter is performed over many exhaustive and long processes in order to better suit a particular problem or instance. In addition, such tuning requires advanced knowledge of the algorithm used and the problem being addressed (Dahi et al., 2016). So, any change in the problem/instance properties will probably decrease the efficiency of the algorithm and a new loop of tuning will be necessary each time in order to recover the sought efficiency.

All these facts restrict the use of most of today's hand-tuned (static) metaheuristics to experts within pure abstract research instead of practitioners within real-life industrial environments. As a solution to this shortfall, many research efforts are being deployed in order to design algorithms containing mechanisms that can adapt automatically the value of the algorithm's parameters in

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[1] GSM: Global System for Mobile communications.

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Table 1
Literature review: state-of-the-art solvers of the mobility management problem.

	The approach	Proposed in
Mono	Genetic Algorithm (GA), Tabu Search (TS) and Ant Colony Optimisation algorithm (ACO)	(Subrata & Zomaya, 2002a; 2002b; 2003a; 2006)
	Geometric Particle Swarm Optimisation algorithm (GPSO) and Hopfield Neural Network with Ball Dropping (HNN-BD)	(Alba et al., 2008)
	A modified Hopfield Neural Network combined with Ball Dropping technique (HNN-BD)	(Taheri & Zomaya, 2008)
	Differential Evolution algorithm (DE)	(Almeida-Luz, Vega-Rodriguez, Gomez-Pulido, & Sanchez-Perez, 2008; Almeida-Luz et al., 2011; Patel & Bhatt, 2014; Wang et al., 2009)
	Simulated Annealing-based approach (SA)	(Mehta & Swadas, 2009a; 2009b)
	Combined Particle Swarm Optimisation algorithm with the Genetic Algorithm (GA-PSO)	(Wang & Si, 2010)
	Ant Colony Optimisation algorithm (ACO)	(Kim, Kim, Mani, Kim, & Agrawal, 2010)
	Scatter Search algorithm (SS)	(Almeida-Luz et al., 2010a; 2010b)
	Parallel cooperative strategy based on a team evolutionary algorithms	(González-Álvarez et al., 2012; Rubio-Largo et al., 2010)
	Genetic Algorithm (GA)	(Baburaj & Alagarsamy, 2011; Baburaj et al., 2010; Parija, Addanki, Sahu, & Singh, 2015; Patra & Udgata, 2011)
	Particle Swarm Optimisation algorithm (PSO)	(Kim et al., 2012)
	Group Search Optimizer (GSO)	(Wang et al., 2014)
	Hybrid approach combining both the GA and the SA	(Vekariya & Swadas, 2015)
	Evolving cellular automata-based-solution	(Subrata & Zomaya, 2003b)
	IBM ILOG CPLEX Optimizer and the Non-linear Optimization with the Mesh Adaptive Direct search (NOMAD)	(Berrocal-Plaza et al., 2014c; 2014d)
	Oscillatory-Increasing adaptive Genetic Algorithm (OI-GA)	(Dahi et al., 2016)
Multi	Strength Pareto Evolutionary Algorithm 2 (SPEA 2)	(Berrocal-Plaza et al., 2014b; 2014c; Berrocal-Plaza et al., 2015b)
	Non-dominated Sorting Genetic Algorithm II (NSGA II)	(Berrocal-Plaza et al., 2014a; Berrocal-Plaza et al., 2014d; 2015a; Berrocal-Plaza et al., 2015b)

order to better suit the problem or the instance being addressed without the intervention of an external agent. However, such an adaptation is generally resulting in more complex algorithms than static ones with extra hidden-tunable parameters and computationally heavier calculations. Many approaches of adaptation have already been proposed in the literature, but all can be classified as (1) *deterministic* (uses off-line deterministic rule), (2) *adaptive* (uses the algorithm's feedback) or (3) *self-adaptive* (parameters are evolved along with the problem solution) (Alba & Dorronsoro, 2005). The first category, deterministic, is the one studied in our work.

In this paper, we propose an efficient and low-complexity adaptive cellular genetic algorithm for solving the MMP. The scalability, efficiency and robustness of the proposed approach have been assessed by solving twenty-five realistic instances with different sizes. In addition, twenty-six of the top-ranked algorithms designed to solve the MMP are taken as a comparison basis and several statistical analysis tests have been performed.

The remainder of this work is structured as follows. In Section 2, we introduce basic concepts of mobility management, cGAs and adaptation within EAs. In Section 3, we present the proposed approach. Section 4 is dedicated to the experimental study. Finally, we conclude the paper in Section 5.

2. Preliminaries

In this section, we present basic notions of the mobility management in cellular networks, the cellular genetic algorithm and adaptation within EAs.

2.1. The mobility management of users

The mobility management consists of tracking mobile users to whom a given service (e.g. messages, calls, etc.) is destinated. Roughly speaking, it is widely believed that no matter the network's generation or technology being used, this task is performed by a given component in the system architecture. For each mobile user, this component keeps trace and manages two mobility pieces of information: the cell where the user is situated and the area to which this cell belongs. The latter is a set of cells that share the same and unique identifier. Thus, a user's mobile can freely move within cells of the same area without updating its area identifier. Each time a mobile user enters a new area, he has to update his identifier by notifying the mobility management core using a *location-update* message.

When a given service (e.g. video-call) is destinated to a user, the network has to know first in which cell the concerned mobile user is situated. Having the identifier of the user's area, the mobility management system performs a polling cycle. In each polling cycle, *paging* messages are sent to all the cells within the user's area in order to locate the mobile user.

A mobility management scheme defines how the location update and paging are performed. For the location-update task, two approaches exist: dynamic and static (see Fig. 1(a)). In the first approach, updates are based on the change of the user calls and mobility patterns, which usually requires the on-line collection and processing of data and consumes significant computing power, while updates in the static approach are independent of the user's characteristics. In fact, they are based on the network's topology change, which allows efficient implementation and low computational requirements. Thus, the static approach is the one studied in our work. In this last approach, we can cite the always-update, never-update, reporting cell and location area schemes. Both always and never-update schemes are almost never used in real networks since they imply either extreme costs of paging or location update, while the remaining schemes are considered as the standard location-update schemes and are practically implemented in real-life networks (Razavi, 2011). Considering these facts, the reporting-cell scheme is the one studied in our work. Within this scheme, cells of the network are labelled either as *reporting* or *non-reporting* cells. The user's mobile performs a location update only if it enters a reporting cell, while it can freely move within non-reporting cells without acknowledging its new location. Previous works (Razavi, 2011), showed that even with some helpful data got about the network, finding the optimum arrangements of the reporting cells is an NP-hard problem.

Let us consider now the paging task, two main schemes exist: *standard* and *selective* (see Fig. 1(b)). In the static paging schemes,