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Optimizing the mobility management task in networks of four world capital cities

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In this paper, we study one of the most important management tasks in any Public Land Mobile Network: the mobile location management. In this management task, the network cells are grouped into logical areas (called the Registration Areas) in order to avoid the overload of the signaling network. The proper dimensioning of these Registration Areas is an important engineering issue that is modeled as a bi-objective optimization problem. In previous works by other authors, the Registration Areas planning problem was optimized by using the linear aggregation of the objective functions. This technique allows simplifying the optimization problem but has several drawbacks. That is why, we use our versions of two multiobjective optimization algorithms. Furthermore, a multiobjective approach provides a wide range of solutions among which the network operator could select the one that best meets its real requirements. With the aim of studying the mobile location management in realistic mobile environments, we have generated four novel mobile activity traces by importing four real networks topologies into a mobile networks simulation tool. Experimental results show that our proposals are very interesting because they achieve better solutions than the single-objective optimization algorithms proposed by other authors in a very less execution time.

1. Introduction

The Public Land Mobile Networks (PLMNs) are the networks that provide mobile services to a huge number of subscribers with limited radio-electric resources. For it, the geographical coverage area is divided into several smaller regions (known as cells) among which the radio-electric resources are distributed and reused (Agrawal and Zeng, 2010; Al-Surmi et al., 2012). Therefore, every mobile network requires of a system to automatically track the subscribers' movement across the network cells. This system must control two main tasks: the subscriber's Location Update (*LU*) and the Paging (*PA*) (Zhang et al., 2009). The location update is initiated by a mobile station (the subscriber's terminal) according to a predetermined method (Boukerche, 2005). On the other hand, the paging is used to know the exact cell in which the callees are located. This is accomplished by sending broadcast messages around the last known geographical area (for the mobile stations in question). These broadcast messages might be sequentially sent within a fixed time constraint (Kyamakya and Jobmann, 2005).

In the earliest mobile networks (with few Base Stations (BSs) and mobile subscribers), there was no location management because the resource consumption of the paging procedure was not important. Thus, the callee had to be searched in the whole mobile network. This strategy (known as Never Update) is unfeasible in current mobile networks due to the huge number of mobile subscribers and BSs. In current PLMNs, the network cells are grouped into several areas with the aim of delimiting the number of location updates and the number of paging messages (Lescuyer and Lucidarme, 2008). These areas can receive different names depending on the mobile network technology (e.g. Location Areas (LA), Routing Areas (RA), UTRAN Registration Areas (URA), and Tracking Areas (TA)), but overall are referred as Registration Areas. In an area-based location update strategy, a mobile station only updates its location when it moves to a new Registration Area, and the paging procedure is only performed within the cells of the last updated Registration Area. The proper dimensioning of these Registration Areas is an important engineering issue in which the main challenge is to find the configurations of Registration Areas that simultaneously minimize the number of location updates and the number of paging messages.

Recently, this planning problem has gained great importance due to the exponential increase in the number of mobile subscribers. For example, Nowoswiat and Milliken (2013) show that the signaling traffic associated with the mobility management in a

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large metropolitan LTE (Long Term Evolution) network is more than 33% of the total signaling load. That is the reason why we can find several works in which different optimization techniques have been applied to optimize the registration areas planning (in Section 2 we detail these works). In our previous works (Berrocal-Plaza et al. 2012a,b, 2013, 2014a,b), we analyzed the behavior of our algorithms in a set of test networks widely studied in the literature: the SUMATRA network (SUMATRA) (a test network developed by the Stanford University) and the test networks published in Taheri and Zomaya (2004, 2005a,b, 2007). After studying these networks, we noticed that both the SUMATRA network and the set of test networks presented in Taheri and Zomaya (2004, 2005a,b, 2007) have important weaknesses. On one hand, the mobile activity in the SUMATRA network (in which the subscribers have low mobility and high call rate) is far from the estimations of the CTIA report (Mobile Communications Association, 2011) (CTIA is the acronym for Cellular Telephony and Internet Association). This is because the SUMATRA network is based on a real network of 1995, an era when the Public Land Mobile Networks were in their infancy. On the other hand, the test networks developed in Taheri and Zomaya (2004, 2005a,b, 2007) present a few number of regular cells (up to 63), which is far from the topology of current mobile networks (with hundreds of heterogeneous network cells). In this work, we provide to the research community four novel test networks that avoid these drawbacks and combine the goodness of the SUMATRA network (SUMATRA) (high number of heterogeneous network cells) and the goodnesses of the test networks presented in Taheri and Zomaya (2004, 2005a,b, 2007) (user's call and mobility patterns close to those that we can find in current mobile networks, Kyamakya and Jobmann, 2005; Mobile Communications Association, 2011). The test networks proposed in this paper are based on real mobile networks, which were recorded by using a Symbian software application running on consumer mobile terminals (Cowling, 2004). Our test networks are hosted on http://arco.unex.es/vicberpla/MAT.html.

The paper is organized as follows. The related work is discussed in Section 2. Section 3 defines the problem formulation. The main features of a Multiobjective Optimization Problem are presented in Section 4. Our versions of two well-known multiobjective evolutionary algorithms (the Non-dominated Sorting Genetic Algorithm II (NSGAII) and the Strength Pareto Evolutionary Algorithm 2 (SPEA2)) are shown in Section 5. Our test networks, simulation results, comparisons with other algorithms, and an analysis of our solutions are discussed in Section 6. Finally, our conclusion and future work are summarized in Section 7.

2. Related work

There are several works in which different optimization techniques have been applied with the goal of finding the best possible configuration of Registration Areas. Gondim was one of the first authors to argue that the Registration Areas planning (concretely the location areas planning) is an NP-hard combinatorial optimization problem due to the huge size of the objective space. In his work, he proposed a Genetic Algorithm (GA) to solve this optimization problem (Gondim, 1996). Demestichas et al. investigated the dimensioning of location areas in different environments with three single-objective metaheuristics (Simulated Annealing (SA), Tabu Search (TS), and GA) (Demestichas et al., 2000). Ozugur (2005) proposed a Genetic Algorithm for finding the configuration of LA-RA that best balances the signaling load associated with the mobile location management. Subrata and Zomaya studied a dynamic location update based on the location areas strategy in the SUMATRA network (Subrata and Zomaya, 2003). Taheri and Zomaya proposed a set of test networks (Taheri and Zomaya, 2004, 2005a,b, 2007) in which the user's call and mobility patterns are close to those that we can find in real networks (Kyamakya and Jobmann, 2005; Mobile Communications Association, 2011). Furthermore, they implemented the following optimization algorithms: Hopfield Neural Network (HNN), Simulated Annealing (SA), Genetic Algorithm (GA), and combinations of GA with HNN. Subsequently, Almeida-Luz et al. proposed the use of Differential Evolution (DE) (Almeida-Luz et al., 2008, 2011) and Scatter Search (SS) (Almeida-Luz et al., 2009a,b) to optimize the location areas planning in the SUMATRA network and in the test networks presented in Taheri and Zomaya (2004, 2005a,b, 2007).

It should be noted that, in all these previous works, the two objective functions related to the location management problem were linearly combined with the aim of simplifying the optimization problem. However, the linear aggregation of the objective functions has several drawbacks (see Section 3). That is the reason why our research focuses on the design of multiobjective metaheuristics to find the best possible configurations of Registration Areas. Furthermore, a multiobjective approach provides us (in a single run) a wide set of solutions among which the network operator could select the one that best meets the real state of the signaling network (i.e. considering the signaling load of the remaining management tasks).

3. Registration areas planning problem

Mobility management is an important task in any Public Land Mobile Network. When the mobile terminals are in ‘active mode’, the network must know the subscriber location at a cell level to automatically switch the radio-electric resources of a call-in process whenever the caller/callee moves to a new cell. This is driven by the handover procedure, which is out of the scope of our work. For mobile terminals in ‘idle mode’, a cell level location management leads to an unnecessary overload of the signaling network. For that reason, the location management of ‘idle’ terminals is performed at a registration area level. In this way, a mobile station only updates its location when it moves to a new registration area (every network cell periodically broadcasts the identity of its registration area), and a paging message is sent in all the cells within the last updated registration area (for the callee's terminal in question) (Kyamakya and Jobmann, 2005). For definition, a registration area is a continuous and non-overlapped set of network cells (except in UMTS, where the registration areas might be overlapped) (Lescuyer and Lucidarme, 2008).

The proper dimensioning of the registration areas is an important engineering issue that involves two objective functions:

$$\boldsymbol{f}_1 = \min\left\{ \mathrm{LU} = \sum_{t=T_{ini}}^{T_{fin}} \sum_{i=1}^{N_{user}} \gamma_{t,i} \right\}, \tag{1}$$

$$\boldsymbol{f}_2 = \min\left\{ \mathrm{PA} = \sum_{t=T_{ini}}^{T_{fin}} \sum_{i=1}^{N_{user}} \rho_{t,i} \cdot \mathrm{NA}[\mathrm{RA}_t[i]] \right\}. \tag{2}$$

Eq. (1) formulates the first objective function: minimize the number of location updates (or location update cost, *LU*). The second objective function is expressed as Eq. (2): minimize the number of paging messages (or paging cost, *PA*). The nomenclature used in these two equations is explained in Table 1. Note that these two objective functions are conflicting:

- The number of location updates is reduced to its minimum when all the network cells belong to the same registration area ($\gamma_{t,i} = 0, \forall t \in [T_{ini}, T_{fin}]$, and $\forall i \in [1, N_{user}]$). However, this configuration of registration areas maximizes the number of paging messages because an incoming call will generate a paging