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A hybrid swarm intelligence approach to the registration area planning problem

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ABSTRACT

Proper management of locations of the mobile devices is of great importance in this era of wireless communication networks, as the use of the mobile devices has grown exponentially. The registration area planning (RAP) problem aims to group the wireless network cells into contiguous areas called registration areas in order to minimize the cost of managing the location of mobile devices. Since the RAP problem is a grouping problem, therefore, a grouping-based artificial bee colony algorithm coupled with a local search is developed for this problem. An artificial bee colony algorithm is a recently developed swarm intelligence technique based on the intelligent foraging behavior of honey bee swarm. We have compared the proposed approach with the state-of-the-art approaches available in the literature. Computational results clearly show the superiority of the proposed approach in comparison to these approaches in terms of both the solution quality and the running time.

1. Introduction

Cellular-based wireless network is divided into cells. Each cell comprises a contiguous geographical region and has a base station which services all the mobile devices located within that cell's region. All the users whosoever are connected to this network must exist in only one of the cells. The mobility of wireless devices within the network at an affordable price, attracted a huge number of customers to use this facility. But, the huge number of subscribers put pressure on the available limited network bandwidth, thereby, emphasizing the need to utilize the available bandwidth in an efficient manner. The most common way to increase the network capacity is to reduce the size of the cells, thereby, increasing frequency reuse. Actually, adjacent cells cannot use the same frequency, but the cells that are sufficiently far apart can use the same frequency. However, as the cell size decreases, the number of cells increases, and as a result, the total number of control functions which a wireless network has to perform in order to continuously provide connectivity also increases. For example, higher number of cells in the same area means an increase in the number of devices moving from one cell to another which in turn increases the number of functions that a network has to perform for smoothly transferring an active call or data session from one cell to another. Such functions are collectively referred to as hand-off functions. Moreover, this also makes the task of locating a mobile device in the network more cumbersome.

When a mobile device is called, a location function is used to determine the exact cell in which the called mobile device is located. This location function is implemented in an efficient manner with the help of combined use of location update and

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paging [28]. To manage the locations of mobile devices efficiently, cells are grouped into various contiguous geographical regions called registration areas (RAs) or location areas. For each mobile device, a location database keeps track of its current RA. When a mobile device moves from one registration area (RA) to another, this database is updated through a location update function to reflect the new location of this mobile device. When a mobile device is called, this database is first consulted to determine the current RA of the called device. After that all the base stations within that RA try to establish the connection to the called device through a process called paging. The mobile device responds to the base station closest to it, thereby, precisely locating the cell in which it currently resides. Therefore, locating a mobile device generates lots of control traffic. The manner in which RAs are designed, i.e., the grouping of cells into RAs can have significant impact on the amount of control traffic generated which in turn impacts the cost or efficiency of the location function. The location cost is the sum of the costs incurred in location update (update cost) and paging (paging cost). The registration area planning problem (RAP) seeks to group cells into RAs so that the location cost is minimized. The RAP problem is $\mathcal{NP}$-Hard as the graph partitioning problem, which is $\mathcal{NP}$-Hard [16], reduces to the RAP problem in polynomial time [39]. The update cost is proportional to the amount of mobile devices migrating from one RA to the other. The paging cost of an RA is proportional to the number of incoming calls to the mobile devices located in that RA. When the size of RAs increases, the paging cost also increases, but the update cost decreases. On the other hand, if the size of RAs decreases, the paging cost decreases, but the update cost increases. If we have only one RA in the whole network, then update cost is zero, but paging cost will be highest. On the contrary, when each RA is composed of one cell only, then paging cost is zero, but the update cost is highest. Hence, these two costs are inversely related and any strategy for grouping cells into RAs involves a tradeoff between these two costs. However, as pointed out in [10,9], these two costs are incomparable and any attempt to assign relative weights to these two costs are also futile as these weights vary a lot from one part of the network to the other and from one network to the other. Therefore, standard practice is to put the paging cost in the constraints and minimize the update cost.

Many heuristic and metaheuristic approaches have been proposed so far in the literature for the RAP and related problems. These include graph theory based approaches, greedy approaches and metaheuristic approaches based on simulated annealing, tabu search, genetic algorithms (GAs), etc. Gamst [13] developed a model based on the graph theory to represent registration area planning and presented a greedy approach to solve it. But this greedy approach usually provides solutions far from the optimal. Plehn [31] proposed a weighted greedy algorithm which outperformed the previously proposed algorithms. Bejerano and Cidon [2] introduced a hierarchical location management scheme for personal communication service network (PCSN). In this scheme, each level in the hierarchy represents a partition of geographical region. Partitioning is done with the intent of reducing congestion in the network. Whereas in [3], Bejerano and Cidon developed a method which uses the results from traffic flow theory to embody the location prediction idea in the location area approach. Bhattacharjee et al. [7] developed a practical approach to optimize the hybrid cost and recurring cost for registration area for PCSN. Hybrid cost is optimized with the combination of two techniques, first one is an estimation of registration area boundary (called subproblem I) and second one is identification of the cells in a registration area (called subproblem II). Whereas in [6], Bhattacharjee et al. proposed two paging strategies called sequential intelligence paging (SIP) and parallel-to-sequential intelligent paging (PSIP) to determine the cells to be paged. Unlike the conventional methods, in both the strategies only one cell is examined at a time rather than all cells at a time. These strategies performed well, but at the expense of additional processing power. In [4], Bejerano et al. focus their effort on decreasing the overhead on the bandwidth of the network. They presented a polynomial time approximation algorithm for minimizing the use of the bandwidth in location management in PCSN. Escalle et al. [11] combined three neighboring location areas into one big-location area (BLA) in their big-location area algorithm for location tracking in PCSN. A mobile device stores the identification of the BLA in which it is currently residing in its local memory. Every time a mobile device exits a BLA, a location update is performed to keep the location database up-to-date. A two-step selective paging strategy is adopted where a location area of the last interaction is paged first. If this fails to locate the mobile device, then the remaining location areas in the BLA are paged.

Simulated annealing method for the RAP has been used in Demirkol et al. [9], Saraydar and Rose [32], and Demestistichas et al. [8]. Early genetic algorithm based approaches have been reported in [17,39,8]. Demestistichas et al. [8] proposed genetic algorithm, simulated annealing and tabu search techniques to solve the registration area planning problem. Some literature focused on location management for the next generation, e.g., [5,1,40]. Sun and Lee [35] designed a paging scheme for forward control channel (FOCC) to minimize the paging cost and maximize the bandwidth utilization, which is based on multilayered model. To locate a mobile station as well as to minimize the bandwidth utilization for FOCC, they generated an optimal paging zone. For this they used a genetic algorithm and a probabilistic cost function. Hedible and Pierre [18] introduced a genetic algorithm for assigning cells to switches efficiently. They compare their algorithm with simulated annealing method for the same problem and found that their algorithm performs better.

Vroblefski and Brown [38] and James et al. [19] proposed grouping genetic algorithms to solve the RAP problem. Actually, the RAP is a grouping problem, i.e., a problem that seeks partitioning of objects (cells in case of the RAP) into various groups (RAs in case of the RAP) subject to some constraints so that the given cost function is optimized. Grouping genetic algorithm proposed by Falkenauer [12] is specially designed to handle grouping problems. These two grouping genetic algorithms have several common features including initial population generation, selection, crossover and repair. Hybrid grouping genetic algorithm of James et al. [19], which will be referred to as HGGA, employs an improvement operator, but uses no mutation. On the other hand, grouping genetic algorithm of Vroblefski and Brown [38], which will be referred to as GGARAP, uses a mutation operator, but no improvement operator. James et al. [19] presented another version of HGGA where no