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Cell-to-switch level planning in mobile wireless networks for efficient management of radio resources☆

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Abstract

A major step in effectively managing radio resources in a cellular network is to design an appropriate scheme for assigning cells to a location area (LA), serviced by a switch, and allocate resources for individual switches. However, this assignment is already proven in the literature to be an NP-hard problem [Merchant A, Sengupta B. Assignment of cells to switches in PCS networks. IEEE/ACM Transactions on Networking 3(5) (1995) 521–6] that requires efficient heuristic search techniques for obtaining real-time solutions. This work presents a state-space search technique, which is a variant of best first search heuristic technique. The algorithm called the block depth first search (BDFS), allocates cells to switches during switch level resource planning. Under various simulated performance criteria, we compare the performance of the proposed technique with other similar procedures in the literature. Our results indicate that the BDFS outperforms the meta-heuristic procedures in terms of both efficiency and quality of solutions. Hence, we conclude that our proposed technique can be effectively used for switch level planning leading to an efficient management of scarce radio resource in cellular networks.

Keywords: Cell to switch assignment; Radio resource management; Depth first search

1. Introduction

In order to utilize better the scarce radio spectrum in mobile communication systems, all available radio resources (transmitter powers, channels and base stations) must be used in the most efficient way. A cellular network service area [1] is divided into a collection of inter-connected cells. A mobile client may operate within a given cell or move between different cells. Each cell contains a base station (BS) that provides communication channels to the mobile clients that reside in it. To ensure interference-free communication, cellular communications using time division multiple access (TDMA) (e.g., global systems for mobile (GSM)) allow reuse of communication channel subsets (radio frequencies). Efficient use of radio spectrum is important from a cost-of-service point of view, where the number of BSs required to service a given geographical area is an important factor. The designer of a mobile communication network may cluster several cells into a few location areas (LAs), where each LA is serviced by a mobile switching center (MSC) that

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maintains several databases including the home location register (HLR) and the visitor location register (VLR) databases. The HLR database maintains data on client profiles and real-time locations of the mobile terminals (MTs) that reside in its LA. The VLR maintains data for MTs that are visiting the LA [1,2].

When a call arrives for a particular MT, the MSC tries to find the MT by searching for it in the set of cells under its LA. This search is called *paging* and the cost associated with paging is called the paging cost. Whenever an MT crosses the cell boundary into another cell, and the new cell belongs to a different LA then the MT has to register its new location to update the HLR database. This process is called *registration* or *location update* and the cost associated with registration is called the registration cost. Location update involves complicated procedures and needs a large amount of network resources.

In an LA planning, if the total capacity of an MSC is ignored, the upper bound on the size of an LA is the entire service area. In this case, the registration cost for an MT will be zero, but the paging cost will be at its maximum because, at every call arrival, a larger number of cells will have to be paged. On the other hand, if each cell is an LA then an MT has to perform a registration operation whenever it crosses a cell boundary. In such a case, the registration cost will be very high but, since the number of cells to be paged on arrival of a call is one, the paging cost will be very small. The registration cost and paging cost have an inverse relationship, and therefore central challenge in LA management is to design algorithms that simultaneously minimize both the registration and the paging costs [3].

The cellular network planning under a budgeted cost requires decision-makers to group cells into LAs so that the operating cost (recurring registration cost along with amortized fixed cost) is minimized. The task of grouping cells into LAs during switch level planning of a cellular wireless network is known as the *cell-to-switch assignment* (CSA) problem in the literature [4]. The term switch refers to an MSC. The CSA problem can be formulated in two ways: single-homing and multi-homing. In the single-(multi-)homing CSA problem, each cell belongs to one (multiple) LA(s). Thus, in single-(multi-)homing, a cell is connected to one (multiple) switch(es). In a multi-homing CSA problem, the HLR and VLR databases are not centralized, and are operated in a distributed manner. However, in a single-homing situation, a switch maintains centralized HLR and VLR databases. In this paper, we have considered the single-homing CSA problem.

Among the recent studies on the CSA problem, Merchant and Sengupta [4] used a meta-heuristic technique (termed H-I hereafter) to solve the CSA problem. The H-I algorithm had two phases. In the first phase, the cells in a service area were ordered in a descending order of call volume, and feasible cell assignments were generated. In the second phase of the algorithm, the assignment of each cell was changed in a systematic manner to obtain a feasible assignment with improved cost. Saha et al. [5] used a meta-heuristic technique (termed as H-II hereafter) based on cluster analysis. In this method, it was assumed that a cluster around a switch could be generated incrementally. This implied that a cluster around a switch must begin with the cell that housed the switch. This cell was the seed cell. Initially, every seed cell was a cluster and the number of clusters was equal to the number of switches. A cluster grew as the neighboring cells were selected to join the seed cell in an optimal manner [5]. The addition of a cell to a cluster was allowed only if it led to a feasible assignment. The algorithm stopped when all cells were assigned to switches.

Pierre and Houeto [6] used a tabu search (TS) [7] approach for solving the CSA problem. Their technique started with a solution obtained by assigning each cell to the closest switch, ignoring any feasibility constraints. The algorithm did not guarantee the feasibility of the first solution, but performed a neighborhood search to improve the solution quality till a sub-optimal solution was found. Demirkol et al. [8] solved the CSA problem by using a simulated annealing (SA) technique. The SA algorithm started with an initial feasible solution, beginning with this point in search space, a random move was made in the neighborhood of the initial point. If the move introduced a better point (lower cost), it was accepted. If the move introduced a worse point (higher cost), it was accepted with a decreasing probability over time. The algorithm terminates when a fixed number of non-improving iterations were realized in a predefined number of temperature decreases.

An imminent limitation of all the afore-mentioned techniques was that they all need the number of switches and their locations as inputs. The techniques cannot help a designer, who is undecided on the number of switches and their locations, plan on using some potential sites as switch locations. Moreover, it appears that the existing literature would benefit from the following two distinct and important areas. First, none of the proposed CSA solution techniques has the ability to obtain an optimal solution given sufficient time for problem solving (here after called the *optimality criterion*) for reasonable size problems. Second, none of these tech-