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Time efficient heuristics for cell-to-switch assignment in quasi-static/dynamic location area planning of mobile cellular networks

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Abstract

This paper presents a set of time efficient, sub-optimal heuristics to solve the problem of assigning cells to mobile switching centers (or, switches in short) for an effective location area (LA) planning in a mobile cellular network (MCN). A common objective of this NP-hard optimization problem, termed as cell-to-switch assignment (CSA) in the literature, is to minimize the hybrid cost, comprising handoff cost between adjacent cells, and the cable cost between cells and switches, subject to the constraint that the call volume to be handled by a switch should not exceed its traffic handling capacity. To solve CSA for a quasi-static/dynamic LA design, we need fast algorithms capable of producing acceptable solutions within a reasonable time. In this work, we first propose four variants (termed as heuristics III through VI) of our earlier heuristic (termed as heuristic II) and compare all of them with other published heuristics in respect of execution time and solution cost. Results indicate that though no single heuristic performs equally well with respect to both optimality and speed, heuristic IV is the best of the lot. Secondly, we modify the original CSA problem to include the factor of load balancing amongst switches (thereby minimizing unfairness), and propose a new *C*SA *a*lgorithm with *l*oad *b*alancing (CALB), which emphasizes more on load balancing than on cost optimization. It is found that CALB is fast as heuristic VI, and performs extremely well in balancing the traffic amongst the switches, thereby increasing the overall scalability of MCNs against the increase in either mobile user density or per user traffic.

Keywords: Mobile communication; Cellular networks; Handoff; Location area partitioning; Hybrid cost; CSA; Load balancing; Optimization; Clustering and heuristics

1. Introduction

In a multi-tier *mobile cellular network* (MCN) [1,2], *total service area* (TSA) is divided into *cells* (usually represented by hexagonal shapes in the literature), whose radii vary from a few hundreds meters to several kilometers. For each cell in the lower tier, there is a *radio sub system* made of a *base station* (BS) [1] to provide communication links to *mobile terminals* (MTs) over some pre-assigned bands of radio frequency. Cells are grouped into clusters known as *location areas* (LAs) [3]. For each cluster (i.e., LA), normally a switch (known as *Mobile Switching Center* (MSC) [2]) is allocated to manage the interconnection of cells and to ensure interconnection with other networks. Thus, MSCs (logically representing the upper tier), located at some strategically chosen cells, form a part of the *network subsystem*. BSs within an LA talk to each other through the MSC for

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Nomenclature

List of notations used in this paper:

n	number of cells
m	number of switches
c_i	cell i, $i \in [1,n]$
A_k	final cluster of cells around switch k (i.e., location area under switch k), $k \in [1,m]$
x_{ik}	an assignment variable, $i \in [1,n]$, $k \in [1,m]$ $= 1$ if $c_i \in A_k$ (i.e., cell i belongs to switch k), $= 0$ otherwise
y_{ij}	another assignment variable, $i,j \in [1,n]$ $= 1$ if $c_i \in A_k$ and $c_j \in A_k$, $i \neq j$, $k \in [1,m]$ (i.e., cell i and cell j both belong to switch k), $= 0$ otherwise
h_{ij}	hand-off cost occurring between cell i and cell j, $i,j \in [1,n]$, $i \neq j$
h^i_{av}	average hand-off cost occurring between cell i and its neighbors $= (\sum_j h_{ij})$/(number of neighbors of cell i)
$C_{handoff}$	total handoff cost $= \sum_i \sum_j h_{ij}(1 - y_{ij})$, $i,j \in [1,n]$, $i \neq j$
C_{ik}	amortized cable cost for connecting cell i to switch k, $i \in [1,n]$, $k \in [1,m]$
C_{cable}	total cable cost $= \sum_i \sum_k x_{ik} C_{ik}$, $i \in [1,n]$, $k \in [1,m]$
C_{hybrid}	total hybrid cost $= [C_{handoff} + C_{cable}]$
set^l_k	set of cells in the cluster around switch k after lth iteration, $k \in [1,m]$ = A_k, when all iterations are finished
nset^l_k	neighboring cells of set^l_k, $k \in [1,m]$
λ_i	traffic from cell i (in Erlangs), $i \in [1,n]$
λ_{av}	average traffic from a cell (in Erlangs) $= (1/n) \sum_i \lambda_i$, $i \in [1,n]$
M_k	traffic handling capacity of switch k (in Erlangs), $k \in [1,m]$
η^u	desired switch utilization factor of a switch $= \sum_i \lambda_i / \sum_k M_k$, $k \in [1,m]$, ($\eta^u \leqslant 1$)
M^*_k	modified traffic handling capacity of switch $k = (M_k \eta^u)$, $k \in [1,m]$
β_k	increment factor for switch k, $k \in [1,m]$
η_k	actual utilization factor of switch k after load balancing, ($\eta_k \leqslant 1$), $k \in [1,m]$

that LA. This is referred to as *intra-cluster communication*. On the other hand, *inter-cluster communication* involves two different clusters connected to two different MSCs at the upper tier. We will use "LA" and "cluster", and "MSC" and "switch" interchangeably throughout the rest of the paper.

1.1. LA partitioning

To avoid interference [1], two contiguous cells should not use identical radio channels. The transmission must thus change channel every time an MT passes from one cell to another. This process of automatic transfer from one BS to another is called *handoff* (or *handover*). As described above, there can be two types of handoff [1,2], namely *intra-cluster* and *inter-cluster*. An intra-cluster handoff involves only one switch, whereas an inter-cluster handoff causes a change of switch. In the latter case, update operations in location registers (databases) are to be performed [1]. An inter-cluster handoff is understandably more complex than a simple intra-cluster handoff because it involves more network resources [1,2]. Thus, it would be desirable to estimate handoff frequencies among different cells in TSA, in order to assemble those cells with frequent mutual handoff into LAs, so that the total handoff cost in an MCN is reduced as much as possible. Consequently, while clustering cells (during the partitioning of TSA into LAs), an important design criterion should be minimizing the frequency of inter-cluster handoffs. Accordingly, the cells, among which the handoff frequency is high, should come under the same cluster, provided the MSC meant for the cluster can handle all the calls from these cells [2]. So, the constraint comes from the call handling capacity of an MSC, which is expressed in terms of the maximum number of call attempts that can be processed by the MSC in a fixed interval of time, while meeting all other service criteria. The afore-mentioned sort of clustering in MCNs is generally termed as *LA partitioning* [2].

In MCN literature, location management [4] that deals with the problem of tracking down an MT mostly deals with the location update (or, registration) [1] and the paging schemes [1] employed. Static schemes (in which LA boundaries are fixed, and the cells that participate in registration are defined) can be either zone-based or profile-based [4]. Dynamic schemes (in which LA boundaries are not defined, and the registration decision is made according to some criteria) can be time-based, or movement-based, or distance-based, or state-based [3,4,15]. Paging schemes may be blanket (or, parallel), sequential, parallelo-sequential, profile-based, probabilistic, etc. [2,3]. In this paper, we consider zone-based location update and blanket paging schemes because LAs are assumed to have fixed sizes. Although many studies have been reported in the literature in the area of location management [4] in terms of radio propagation, channel assignment, location update and paging, relatively few studies have been aimed to LA partitioning for a cost effective system design [15]. However, for the economic feasibility of any MCN, a good design method should be able to minimize both capital expenditure (capex) and operational expenditure (opex), while considering tradeoffs among factors such as network performance, traffic and technology upgrade.