LOCATION AREA PLANNING FOR PERSONAL COMMUNICATION SERVICES NETWORKS

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Abstract: This paper presents a practical approach for planning location areas (LAs) in a personal communication services network (PCSN) considering the hybrid cost and the recurring cost. Given the number of users, penetration factor, average speed of mobile users, number of mobile switching centers (MSCs), call handling capacity of each MSC and handoff cost between adjacent cells, an important consideration in a PCSN design is to identify the cells in every LA to be connected to a particular MSC in a cost effective manner. The complete planning of LA, in this work, has been done in two stages. In the first stage, the hybrid cost is optimized. This is done by integrating two techniques, namely estimation of LA boundary (subproblem I), and identification of the cells in an LA (subproblem II).

I. INTRODUCTION

The cost involved while planning an LA consists of a hybrid cost and a recurring cost. The hybrid cost comprises of handoff cost and cable cost. The recurring cost is made of paging cost and location update cost. While recurring cost factor is optimized in [5], [7]-[9], a couple of works, such as [1], optimized the hybrid cost without considering the other aspects of LA planning. We divide the complete problem of optimization of hybrid cost into two subproblems each of which can be solved in a less complex, heuristic way. In subproblem I, we find an estimate of an LA assuming it to be of square size. Then, we solve subproblem II by applying Greedy Heuristic Algorithm (GHA) to get the actual size of an LA. While optimizing the hybrid cost, we follow a two step refinement procedure, which captures most of the important aspects of LA design. In each step, we solve a subproblem (less complex than the complete problem) and try to improve the solution as much as possible. An estimation of the perimeter of an LA is obtained in subproblem I using the model [2]. Subproblem II determines the exact cell to switch assignment (CSA) pattern without taking into account the average speed of MTs, population density, and penetration factor. The two techniques used here to solve the subproblems I and II have been designed to be complementary to each other, and thereby the integrated technique is better than earlier simple LA planning techniques without CSA.

II. OPTIMIZATION OF HYBRID COST

NOTATIONS:

N = Total number of general users in an SA
Q = Number of MSCs available in an SA
S_j = Total number of cells in jth LA
M_j = Traffic handling capacity of the jth switch, $j \in [1,Q]$ (Erlangs)
λ_{av} = Average traffic originated from each MT (Erlangs)
D = Distance required between any two co-channel cells
K = Frequency reuse factor
R = Radius of the a cell, (km.)
p = Penetration factor ($1>p>0$)
v = Average speed of a mobile terminal (kmhr $^{-1}$)
L = Approximate perimeter of an LA (km)
L_j = Actual perimeter of an LA
ρ = Density of MTs (km^{-2})
α = Computational parameter
λ_i= Traffic of ith cell, $i \varepsilon [1,S]$ (Erlangs)
h_{ij} = Hand-off cost per unit time from ith cell to jth cell $\forall i \varepsilon [1,2,..S_i]$, $\forall j \varepsilon [1,2,..S_j]$, $i \neq j$
CIR = carrier interference ratio
μ = Average number of calls terminated to an MT
φ = call to mobility ratio, (CMR)
$C_p(S_j)$ = Paging cost per cell in jth LA
$C_r(S_j)$ = Registration cost in a boundary cell of jth LA
$C_{pc}(S_j)$ = Cost per call in jth LA
$C_t(S_j)$ = Recurring system cost
$C_{nt}(S_j)$ = Normalized recurring system cost = $C_t(S_j)/ S_j$
A_{cell} = Area of a cell
T_p = Time taken to transmit paging messages
B_p = Paging bandwidth
$S_B(S_j)$ = number of cells in the boundary region of jth LA containing S_j contiguous tightly packed cells
S_T =Total number of cells in the coverage area = ($\sum S_j$)
L_f = Fraction of a boundary cell's perimeter that lies on the boundary
T_u =Time taken to transmit location update (LU) messages
B_u =bandwidth required for LU

Let us assume that all cells are hexagonal in shape and identical in dimension. A base station (BS) is located at the center of a cell. Each BS is having an omni-directional antenna. As there are a finite number of channels in the trunking pool of a cell and the calls originate in a memoryless manner, Erlang-B formula gives the probability that a call is blocked. In other words, given the radius of a cell, density of MT, average traffic per user and the call blocking probability, the number of channels should be such that Erlang-B formula is satisfied. We also assume free space propagation with path loss exponent equal to four and fixed channel assignment strategy. An LA is assumed to be a

square with side equal to 0.25L. However, if an LA is considered to be circular, then the radius will be $L/2\pi$.
Using the notations listed earlier, we can write:
Total number of attached mobile users = Np;
Total traffic generated from all the cells $=\Sigma\lambda_i$
Average number of mobile users in a cell $=\pi\rho R_j^2$
Call to mobility ratio (CMR) is used to indicate the relative frequency of movement of an MT and call arrival rate to it. It is defined as $\varphi=(\mu\sqrt{A_{cell}})/v$. It is a unit-less quantity.

A. Formulation of subproblem I and its solution:

The formulation of the optimization problem and its solution using LRM and SHA is discussed below. The problem can be formulated as a *nonlinear minimization problem*

Minimize: $(\rho Lv/\pi)^\alpha$ (1)
Subject to:
$1>p>0$ (2)
$R<R_{max}$ (3)
$Q(L^2/16)\rho \geq Np$ (4)
$\lambda_{av}(L^2/16)\rho \leq M_j$ (5)
$K=(D/R)^2$ (6)

The basic relationships for minimum carrier to interference ratio, CIR for an omni-site are given by [14]:

$CIR= 0.667(D/R)^2$ (7)
$CIR=1.5K*K$ (8)

B. Problem formulation of subproblem II and its solution:

The subproblem II considered in this work, can be stated as: *given a group of cells ΣS_j, a group of switches, Q (whose locations are known) and an estimate of LA for each MSC, the problem is to assign cells to switches in an optimum manner such that it attempts to minimize the cost comprising handoff and cost of cabling. It is to be noted that if cells i and j are assigned to different MSCs, then a cost is incurred every time a hand-off occurs between cells i & j ($i=1,.. S_i$; $j=1,2, .. S_j$, $i\neq j$). The optimization is carried out in such a way that : i) call handling* capacity *of each switch is not violated, ii) total traffic generated from the attached MTs in an SA is less than the total traffic handling capacities of all the MSCs, and iii) the traffic generated by the attached MTs in an LA is less than equal to the traffic handling capacity of the respective MSC.*

It has already been calculated in [10]-[11] that the time complexity of GHA is ~ $O(S_T^{0.5})$. This is significantly less than the time complexity of the algorithm proposed by Merchant and Sengupta which is $\sim O(QS_T^4)$ [4]. Therefore, GHA is much faster than the algorithm of Merchant and Sengupta.

III. OPTIMIZATION OF RECURRING COST

We take the call arrival rate for three types of MT user namely working people constituting 66%, housekeepers constituting 15% and the rest 25% high mobility users [6]. When an MT crosses the boundary between two LAs, it sends a registration signal. So location update takes place for those MTs, which are crossing the boundaries. Using the mobility model [2] and [3], the rate of location update is $L_f(S_j)v\rho/\pi$. Registration cost in a boundary cell is $C_r(S_j)=T_uB_u L_f(S_j)v\rho/\pi$.

Each cell in an LA must carry the paging traffic associated with all MTs in all cells within that LA. Thus the cost of paging, C_p in any given cell of an LA is the product of number of cells in the LA, the incoming traffic per MT, density of MTs, area of a cell and time bandwidth product for paging i.e. $C_p(S_j)=S_jA_{cell}T_pB_p\mu\rho$. So the total recurring cost throughout an LA comprising S_j cells becomes

$$C_t(S_j)=S_j\, C_p(S_j) + S_B(S_j)\, C_r(S_j)$$

In the coverage area, there are S_T/S_j number of LAs because each LA comprises S_j cells. The overall recurring system cost in the entire coverage area is $C_t(S_j)(S_T/S_j)$. S_T being a constant for a certain coverage area, we minimize $C_t(S_j)/S_j$. This is equivalent to minimizing the overall recurring system cost. We define $C_t(S_j)/S_j$ as normalized recurring system cost, $C_{nt}(S_j)$.
So,

$$C_{nt}(S_j)= S_jA_{cell}T_pB_p\mu\rho + [S_B(S_j)/S_j]\, T_uB_u L_f(S_j)v\rho/\pi$$

For different call arrival rates at different times and different categories of MT users, we formulate a way to minimize the recurring system cost and thereby determine the optimum number of cells per LA. S_j^{opt} can be found by solving the following polynomial equation using any standard method of numerical analysis.

$$S_j^{1.925035} - 0.1837763\ (T_uB_u/T_pB_p)\ (Lv/\mu A_{cell})\ S_j^{0.425}\ 0.3151671(Lv/\mu A_{cell})\ (T_uB_u/T_pB_p) = 0$$

For different CMRs, we also compute $C_t^{opt}(S_j^{opt})/\mu$ i.e. optimum total recurring cost per call arrival at different times of a day using the data of [6].

When handoff cost from one cell to another is known, instead of finding out the number of cells on the boundary empirically, we solve CSA applying GHA. So, the average handoff cost in any direction is determined by dividing the total handoff cost by the number of cells on the boundary. Hence cost of registration in each boundary cell is $C_r(s)=[L_jv\rho/\pi] * (\Sigma_{i=1}^{Si}\ \Sigma_{j=1}^{Sj}\ h_{ij})/S_B$. Consequently, recurring cost per call arrival $C_{pc}(S_j)$ becomes $C_{pc}(S_j)= \rho\ S_jA_{cell}\ T_p\ B_p + v\sqrt{A_{cell}}\ C_r(S_j)/\phi$.

IV. RESULTS

For a fixed number of cells per LA, Table I shows the asymptotic decrease in cost per call with increase in CMR. For low CMR, cost per call is high. It reaches an almost steady value for CMR≥16. The result furnished in Table I implies that for a network designed for CMR=16, cost per call remain almost unaltered for high CMR also.

Table II shows the nature of variation of normalized recurring cost with number of cells per LA. It is observed from Table II that paging cost increases with number of cells per LA whereas location update cost gradually decreases. As number of cells per LA increases, there will be less boundary crossings by MTs. Consequently location update cost decreases. With the increase in number of cells per LA, the paging cost increases proportionately as more cells are to be paged now before an MT is located. Using the data of [13], we compute the normalized recurring cost and plot it in Fig. 1. From Fig. 1 it is evident that the recurring cost is optimized for S_j=95 which is in close conformity with [13].

Fig 2 shows the exponential decrease in optimum recurring cost per call with the increase in CMR. The Fig. 16 has a similar nature as that of [9]. From Table II we observe that recurring cost is a small percentage (0.1%-1.%) of the hybrid cost. But recurring cost becomes substantial over a period of time. Hence our endeavor is to find an LA size for which both the costs i.e., recurring cost and hybrid cost are minimized.

V. CONCLUSION

In this paper, we have introduced a technique for LA planning for a PCSN which takes into account optimization of hybrid cost and recurring cost. While optimizing hybrid cost we combine a mobility model and cell to switch assignment (CSA). The complex problem of planning optimal cell-to-LA assignment in a PCSN is divided into two subproblems each of which is solved in a less complex way. Our investigation leads to an interesting finding that the size of location area is independent of the average speed of MTs. We observe that recurring system cost increases almost exponentially with the number of cells per LA when the number of arrival of calls is high. Given the number of users, penetration factor, average speed of mobile users, number of MSCs, call handling capacity of each MSC approximate perimeter of an LA can be determined. Thereafter applying CSA the cells to be included in LA are identified. Using the curve of optimum number of cells per LA versus CMR we can find the range of CMR upto which both the costs are optimized. The method of LA planning delineated here is good when average speed is low and rate of incoming calls is less. For higher speed the registration cost becomes high whereas the paging cost increases when rate of incoming calls is more. Intelligent location management strategy is to be deployed in such circumstances.

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Table I: Change in cost per call with CMR
R=1km, S_j=10, ρ=50km^{-2}

Call-to-mobility ratio	Cost per call arrival
0.003	2.502
0.01	0.5818
0.02	0.3376
0.04	0.1753
0.06	0.1212
0.12	0.0671
0.25	0.0400
0.50	0.0265
0.99	0.0197
1.98	0.0160
3.97	0.0147
7.94	0.0138
15.87	0.0135
31.75	0.0132
63.5	0.0131

Table II: Variation of hybrid cost and total recurring cost with average speed of MTs and incoming calls

No. of cells	No. of calls/hour	As speed of MTs	Hybrid Cost	Total recurring cost
11	0.6	5.7	114.23	0.14216
		5.0		0.51409
	4	5.7		0.67655
		5.0		1.0485
20	0.6	5.7	387.45	0.366092
		5.0		1.0514
	4	5.7		2.16232
		5.0		2.81768
23	0.6	5.7	484.73	0.52143
		5.0		1.3696
	4	5.7		2.8578
		5.0		3.6973
49	0.6	5.7	1391.95	2.2415
		5.0		5.118
	4	5.7		12.846
		5.0		15.7226

Figure 1: Variation of total recurring cost with no. of cells/LA

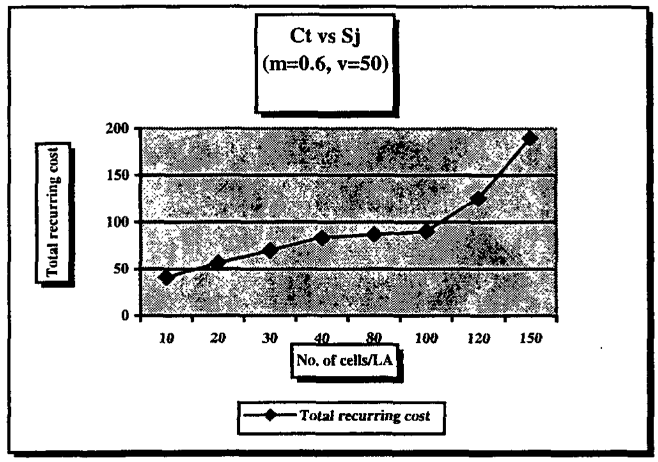

Figure 2: Variation of C_{nt} vs S_j