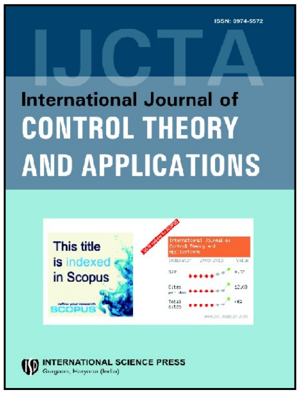

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Minimize the Cost of Two-Tier Cellular Network Using Genetic Algorithm

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Abstract**:** Multitier architecture in cellular network enhances the spatial reuse of radio spectrum in order to improve the QoS. Therefore, determining number of cells in each tier without compromising the quality can realize the network design as an optimization problem. In this paper, we have considered a two tier cellular network design as constraint optimization problem. Call blocking probability, call dropping probability, and number of microcell covered by a macrocell as odd integer are taken as constraints in order to minimize the implementation cost of the network. A two dimensional Markov chain model has also been developed to determined the steady state probabilities of number of calls served by macrocells and microcells. Further, we have proposed to solve the optimization problem using Genetic Algorithm. The results of the GA based algorithm are compared with the results of simulated annealing. It has been observed that GA based algorithm gives better results in terms of the cost of the network, and convergence rate.

Keywords: Cellular Network, Tier, Genetic Algorithm, Simulated Annealing, Markov Chain

I. INTRODUCTION

In current scenario of mobile communication, cellular network technology is considered as one of the fastest growing form. Cellular network are experiencing rapid growth in the traffic demand & internet connectivity due to increasing number of smart phones and tablets .The most important objectives in the deployment of wireless cellular networks are higher capacity, better service quality, lower power usage, and ubiquitous coverage.

It is expected that by 2020 there will be more than 50 billion connected devices, and the cellular infrastructure should be developed accordingly [1]. For satisfying various Quality of Service (QoS) requirements, several global standards have been developed for providing voice and data services anytime and anywhere regardless of user mobility. Since the frequency spectrum allocated for cellular communications is limited and makes QoS challenging. Therefore, Multi-tier networking becomes vital in providing QoS.

Multi-tier architecture improves the spatial reuse of radio spectrum in cellular networks. The coverage area is divided into cells, each of which is served by a base station (BS). Each BS (or cell) is assigned a group of radio channels according to the transmission power constraints and availability of spectrum. In two-tier cellular network the area is covered by macrocell as well as microcell. Area covered by one macrocell is also covered by number of microcells. During movement of mobile terminal from one cell to another cell as well as from microcell to macrocell and vice versa, an efficient resource management is required. Two important QoS measures used when designing two-tier cellular network are the probabilities of call blocking and call dropping. Call blocking occurs when a cellular network is unable to assign network resources to allow a call initiated in a cell, whereas call dropping occurs when a cellular network is unable to assign network resources to continue an ongoing call during the handoff. A higher priority is normally assigned to handoff calls over the new calls.

In this paper, we are presenting two-tier cellular networks problem as an optimization problem with call blocking, call dropping probability, and number of microcell covered by a macrocell as odd integer [5] as constraints and minimizing the implementation cost of the network. Further we are proposing to solve the optimization problem using Genetic Algorithm.

The remaining of the paper is as follows. Research work related to two-tier cellular network carried out in the literature is presented in section 2. The mathematical model developed in this work is explained in section 3. Genetic Algorithm used for solving the optimization problem in Cellular Network (GACN) is presented in section 4. Numerical results obtained are discussed in section 5. Finally the work presented in paper is concluded in the last section.

II. RELATED WORK

Handoff calls limit the call handling capacity of a cellular system due to higher delays and limited bandwidth source. Hierarchical Cellular Network (HCN) [2–3] may be considered as solution of managing in increase of traffic, while preserving the frequency reuse advantage of small-cell systems. In HCN, to provide high coverage and capacity over a given service area, tiered networks are designed. In a two-tier network, upper tier consists of macrocell with few km radius and second tier consists of microcell with few hundred meters of radius.

In HCN, upon entering the system, the mobile terminals can select the service layer based on their mobility or traffic patterns[4][5]. All new and handoff calls are first directed to the microcells. In case of non-availability of channel in the microcells, calls can be overflowed to the macrocell. On the other hand, in the speed-sensitive strategy, the high speed mobile terminals (fast-mobility subscribers) are normally serviced by the macrocell, whereas low-mobility subscribers are managed by the microcells [4]. In class based selection strategy which is based on speed, if there is no sufficient resources in the current tier using overflow calls are transferred to other tier [6].

The channel sub-rating strategy has found to be an effective technique to reduce the handoff force termination probability while preserving the new call blocking probability. Xiaolong et al. in their paper [7] proposed a call admission control scheme for HCN, which is based on the channel sub-rating using 1-D Markov process in microcell and 2-D Markov process in Macrocell. Martin Taranetz [8] evaluated the performance of typical indoor users in urban two-tier heterogeneous mobile networks with indoor-deployed small cell base stations (BSs) and outdoor BSs where indoor and outdoor environments are partitioned by walls with a certain penetration loss. An optimal allocation scheme for an integrated wireless cellular model with handoff priority and handoff guarantee services is designed by Madhu Jain & Ragini Mittal [9].The millimeter-wave (mmWave) frequency band is seen as a key enabler of multi gigabit wireless access in future cellular networks.MAC layer issues, such as synchronization, random access, handover, channelization, interference management, scheduling, and association for mmWave frequency band are discuss by Hossein Shokri-Ghadikola *et al.* [10].

Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems inspired by the process of natural selection, mutation and crossover. Since the frequency spectrum is limited, optimal assignment of channels becomes challenging task. It can greatly enhance the traffic capacity of a cellular system and decrease interference between calls. Optimal channel assignment in mobile communications using Genetic algorithms is proposed by Lipo Wang, S. Arunkumaar & Wen Gu[11].

III. MATHEMATICAL MODEL

3.1. Model assumptions

For constructing mathematical model, we have made the following assumptions:

1) There are two tier macrocell & microcell
2) Microcells are covered by macrocell
3) There are odd integer number of microcell in one macrocell
4) Radius of microcell is between 200m-600m and radius of macrocell is between 800m-1300m
5) There are two mobility classes slow and fast
6) Initially slow mobility calls are directed to microcell and fast mobility calls are directed to macrocell
7) Speed of mobile users are approximately same during the call and is exponentially distributed with mean velocity of fast user as v_f& slow user as v_s
8) If a new slow user arrives in a microcell and only guard channels are available there, it is then overflowed to macrocell
9) Handoff call in microcell with availability of guard channels only also gets overflow to macrocell
10) No call can arrive back from macrocell to microcell even if channels are available
11) Number of available channels are randomly distributed to both the macrocell as well as microcell
12) Half of channel are randomly distributed as guard channels of macrocell as well as microcell
13) Call arrival rate for both the users follow poisson distribution
14) The dwell time of a user is calculated as in [12]

3.2. Model formulation and parameter

3.2.1. Performance analysis of microcell

Microcell layer of two-tier cellular network can be modeled as a one-dimensional Markov chain[5]. The variables used in modeling are define as follows

λ_{1s} : slow mobility call arrival rate in microcell

λ_{1sh} : slow mobility asymptotic handoff rate in microcell

D_{1s} : dwell time of the slow mobility user in

Microcell

r : radius of microcell

R : radius of macrocell

v_s : mean speed of slow mobility user

$ch1$: number of channels in microcell

$G1$: Number of guard channels in microcell

SAm^2 : call arrival rate per second per m^2 for slow mobility user

P_{b1} : call blocking probabilities in microcell

P_{d1} : call dropping probabilities in microcell

Where

$$\frac{1}{D_{1s}}=\frac{r\pi}{2v_s},a=\lambda_{1s}+\lambda_{1sh},b=\lambda_{1sh},\qquad c=D_{1s},\qquad ch1=n,\qquad G1=n-m$$

A Markov chain for a microcell with n channels and (n-m) guard channels is presented in Fig. 1

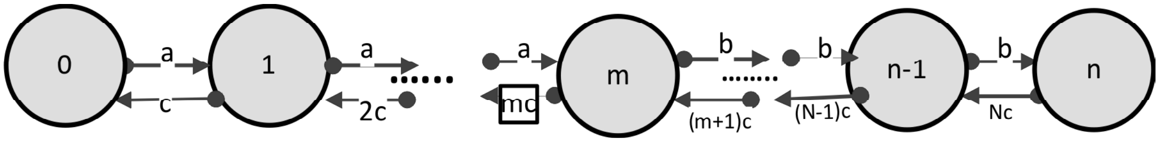

Figure 1: Transition diagram for microcell with n channels & (n-m) guard channels

In Fig. 1, number of calls served by a microcell corresponds to a state. Erlang–Bformula [13] is used to calculate the steady state probabilities P_i as follows:

$$P_i=P_0\left(\frac{a}{c}\right)^i\frac{1}{i!},\ \ i\le m \tag{1}$$

$$P_i=P_0\left(\frac{a^m}{c^i}\right)\frac{b^{i-m}}{i!},\ \ m<i\le n \tag{2}$$

$$\sum_{i=0}^{n}P_i=1 \tag{3}$$

The Asymptotic handoff rate λ_{1sh} used in a and b is calculated iteratively until difference between two iteration is less than 0.000005 using the following formula

$$\lambda_{1sh}(k)=\sum_{i=0}^{n}i.P_i.D_{1s} \tag{4}$$

After calculating λ_{1sh} from equation (4), we calculate steady state probabilities using equation (1), (2) and (3). We can also calculate call blocking (P_{b1}) and call dropping (P_{d1}) probabilities using the following formula

$$P_{b1}=\sum_{i=m}^{n}P_i \tag{5}$$

$$P_{d1}=P_i,where\ i=n \tag{6}$$

The overflow call rate (λ_{os}) (for new calls due to unavailability of channel and overflow handoff rate (λ_{osh}) due to unavailability of guard channel from microcell to macrocell (covering N_c microcell) can be calculated [2]as

$$\lambda_{os}=N_c.\lambda_{1s}.P_{b1} \tag{7}$$

$$\lambda_{osh}=N_c.\lambda_{1sh}.P_{d1} \tag{8}$$

Where $N_c=N_{c-4}+6(c-2),\ N_{1=1}\,\&N_{-1}=0$ (9)

3.2.2. Performance analysis of the macrocell

Macrocell layer of two-tier cellular network can be modeled as a two-dimensional Markov chain[5]. The variables in modeling defined as follows

λ_{2f} : Fast mobility call arrival rate in the macrocell

λ_{2fh} : Fast mobility asymptotic handoff rate in the Macrocell

λ_{2sh} : Slow mobility asymptotic handoff rate once they enter in macrocell

D_{2s} : Dwell time of the slow mobility user in the Macrocell

D_{2f} : Dwell time of the fast mobility user in the Macrocell

$1/D_t$: Mean call duration

v_f : Mean speed of fast mobility user

$ch2$: Number of channels in a macrocell

$G2$: Number of guard channels in a macrocell

FAm^2 : Call arrival rate per second per m^2 for fast mobility users

$\boldsymbol{P}_{b2}$: Call blocking probability in a macrocell

$\boldsymbol{P}_{d2}$: Call dropping probability in a macrocell

Where

$$\frac{1}{D_{2s}} = \frac{R\pi}{2v_s}, \qquad \frac{1}{D_{2f}} = \frac{R\pi}{2v_f}$$

$$X = \lambda_{2sh} + \lambda_{osh} + \lambda_{os}, Y = \lambda_{2f} + \lambda_{2fh}$$

$$D = D_t + D_{2s}, \qquad E = D_t + D_{2f}$$

$$a = \lambda_{2sh} + \lambda_{osh}, b = \lambda_{2fh}, \quad ch2 = n,$$

$$G2 = n - m$$

A Markov chain for a macrocell with *n* channels and (*n-m*) guard channels is presented in fig 2.

In this figure a state corresponds to the number of fast users *I* and slow users *j* served by a macrocell. Using state transition diagram given in figure 2, the equilibrium equations can be written as follows

$$(X + Y)P_{0,0} = DP_{0,1} + EP_{1,0} \tag{10}$$

$$(X + iE + Y)P_{i,0} = DP_{i,1} + YP_{i-1,0} + (i+1)EP_{i+1,0}, 0 < i < m \tag{11}$$

$$(a + iE + b)P_{i,0} = DP_{i,1} + YP_{i-1,0} + (i+1)EP_{i+1,0}, i = m \tag{12}$$

$$(a + iE + b)P_{i,0} = DP_{i,1} + bP_{i-1,0} + (i+1)EP_{i+1,0}, m < i < n \tag{13}$$

$$iEP_{i,0} = bP_{i-1,0}, \qquad i = m \tag{14}$$

$$(X + Y + jD)P_{0,j} = XP_{0,j-1} + EP_{1,j} + (j+1)DP_{0,j+1}, 0 < j < m \tag{15}$$

$$(a + b + jD)P_{0,j} = XP_{0,j-1} + EP_{1,j} + (j+1)DP_{0,j+1}, j = m \tag{16}$$

$$(a + b + jD)P_{0,j} = aP_{0,j-1} + EP_{1,j} + (j+1)DP_{0,j+1}, m < j < n \tag{17}$$

$$jDP_{0,j} = aP_{0,j-1}, \qquad j = n \tag{18}$$

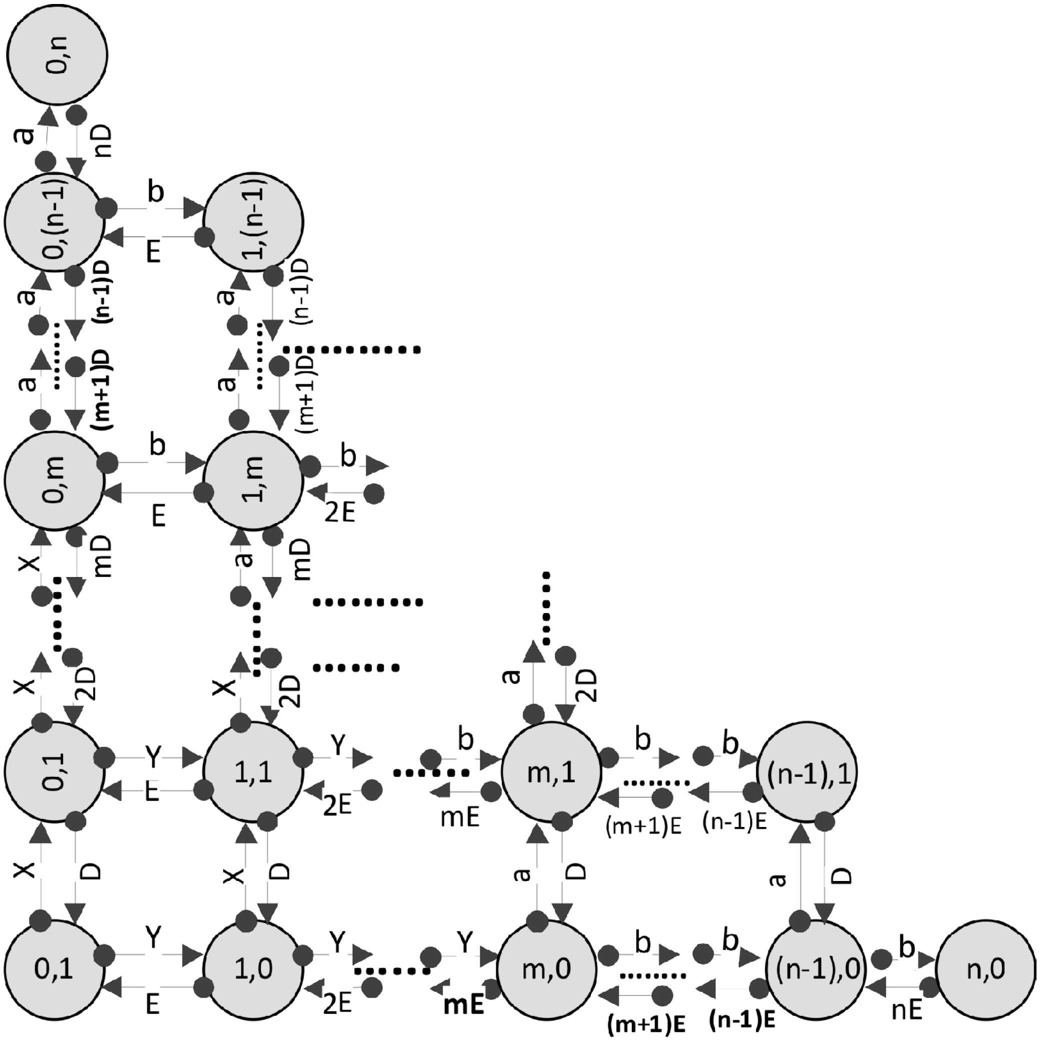

Figure 2: Transition diagram for macrocell with n channels & (n-m) guard channels

$$(X + jD + iE + Y)P_{i,j} = YP_{i-1,j} + XP_{i,j-1} + (j+1)DP_{i,j+1} + (i+1)EP_{i+1,j}, 0 < i + j < m \tag{19}$$

$$(a + jD + iE + b)P_{i,j} = YP_{i-1,j} + XP_{i,j-1} + (j+1)DP_{i,j+1} + (i+1)EP_{i+1,j}, \quad i + j = m \tag{20}$$

$$(a + jD + iE + b)P_{i,j} = bP_{i-1,j} + aP_{i,j-1} + (j+1)DP_{i,j+1} + (i+1)EP_{i+1,j}, \quad m < i + j < n \tag{21}$$

$$(jD + iE)P_{i,j} = bP_{i-1,j} + aP_{i,j-1}, \quad i + j = n \tag{22}$$

$$\sum_{i=0}^{n}\sum_{j=0}^{n-i} P_{i,j} = 1 \tag{23}$$

The Asymptotic handoff rate λ_{2sh} and λ_{2fh} used in X,Y, a and b is calculated iteratively until difference between two iteration is less than 0.000005 using formula

$$\lambda_{2sh}(k) = \sum_{i=0}^{n}\sum_{j=0}^{n-i}(iP_{i,j}D) \tag{24}$$

$$\lambda_{2fh}(k) = \sum_{i=0}^{n}\sum_{j=0}^{n-i}(jP_{i,j}E) \tag{25}$$

After calculating λ_{2sh} and λ_{2fh} from equation (24)and (25), we calculate steady state probabilities $P_{i,j}$ using equations (10) to (23). We can also calculate call blocking (P_{b2}) and call dropping (P_{d2}) probabilities in macrocell using the following formula

$$P_{b2} = \sum_{i}\sum_{j} P_{i,j}\& \quad i + j \geq (n - m) \tag{26}$$

$$P_{d2} = \sum_{i}\sum_{j} P_{i,j}\& \quad i + j = n \tag{27}$$

The total call blocking (P_b) and call dropping (P_d) probabilities are calculated using the following equations

$$P_b = \frac{N_c\lambda_{1s}P_{b1}P_{b2} \ +\lambda_{2f}P_{b2}}{N_c\lambda_{1s}+\lambda_{2f}} \tag{28}$$

$$P_d = \frac{N_c\lambda_{1s}P_{d1}P_{d2} \ +\lambda_{2f}P_{d2}}{N_c\lambda_{1s}+\lambda_{2f}} \tag{29}$$

3.2.3. Problem formulation

We have considered two-tier cellular network as a cost minimization problem[5]. Let C_1 and C_2 the cost of designing one unit of microcell and macrocell respectively. If N_1 and N_2 are number of microcells and microcells respectively. The radius of microcell and macrocell are represented by r and R respectively. P_{bmax} and P_{dmax} are maximum acceptable value of call blocking and call dropping probabilities respectively. C is the total cost of designing a system. The minimum cost problem can be formulated as follows:

$$Min\ C = C_1N_1 \ + \ C_2N_2 \tag{30}$$

$$P_b \leq P_{bmax} \tag{31}$$

$$P_d \leq P_{dmax} \tag{32}$$

$$\pi r^2 N_1 \ \leq Area \tag{33}$$

$$\pi R^2 N_2 \ \leq Area \tag{34}$$

$$\frac{R}{r} = Odd\ integer \tag{35}$$

Inequality constraints in equation (31) and (32) represent the call blocking and call dropping probabilities should less than the given limit. Inequality constraints in equation (33) and (34) represent total coverage area. Inequality constraints in equation (35) represents that there should be integer number of covering microcell in a macrocell. We solve the above optimization problem by proposing a Genetic Algorithm.

IV. PROPOSED GACN ALGORITHM

The Genetic Algorithm to solve Cellular Network (GACN) optimization problem proposed in this work is given as follows:

Step-1: Initialized population

First we considered genes of 6 cell with field

Ch1	*Ch2*	*G1*	*G2*	*r*	*R*

Where

- *Ch1 is number of channels in a microcell*
- *Ch2 number of channels in a macrocell*
- *G1 number of guard channels in a microcell*
- *G2 number of guard channels in a macrocell*
- *r radius of a microcell*
- *R radius of a macrocell*

The population is initialized by generating randomly Ch1, Ch2 between 11-20, G1 and G2 between 0-10, r between 200-600 and R between 800-1400.For example a gene C1 can be as follows

12	*17*	*5*	*8*	*428*	*1284*

Using the fitness function accept the population if R/r is an odd integer; otherwise again generate population .We have considered an initial population of 50 chromosomes.

Step-2: Mutation

```
Select a gene randomly and then select a random position p between 1-6 in the gene
    If(p<=4) then
        Generate that particular cell accordingly
  elseif (5<= p <=6 ) then
  Generate both cell 5 and 6 such that R/r is odd integer
```

For example if random gene is C1 and p=2 then new gene C2 is as

12	*19*	*5*	*8*	*428*	*1284*

If p=5 or 6 then r and R both are generated again such that ratio should odd integer

Step-3: Crossover

Select two random population e.g. C1 and C2 as follows.

12	*17*	*5*	*8*	*299*	*897*

17	*19*	*1*	*3*	*428*	*1284*

Select random position p between 1-6 e.g. p=4 then new genes are

12	*17*	*5*	*8*	*428*	*1284*

17	*19*	*1*	*3*	*299*	*897*

```
Step-4 : Apply the fitness function
Step-5:  Evaluate the population
Step-6 : Check the stopping criteria
If(stopping criteria not satisfied) then
    Go to step no 2
else end
```

V. EXPERIMENTATION AND RESULTS

The proposed GACN algorithm is used to solve the optimization problem described in 3.2.3 as follows. First an initial population of 50 is generated. Ch1 and Ch2 are randomly generated between (11, 20). G1 and G2 are randomly generated between (0,10). Let the radius of microcell(r) is between 200-600 meters and the radius of macrocell (R) is between 800-1400meters. Radius r and R are randomly generated between 200-600 and between 800-1400 respectively such that equation (4) is satisfied. If equation (4) is not satisfied, population is rejected and generated again. Using mutation and crossover operations new population is generated and evaluated. If the new population is better than already existing population satisfying the fitness function, it is accepted; otherwise rejected. First we apply GACN algorithm for the base problem using the parameters given in Table 1.

Table 1
Parameters of base problem

Parameter	*Value of base problem*
v_s	1 m/s
v_f	8m/s
SAm^2	8×10^{-8} calls per sec per m^2
FAm^2	2×10^{-8} calls per sec per m^2
$1/D_t$	100 sec
C_1	10 cost unit
C_2	30 cost unit
A	5000 Km^2
CS	7
$P_{b,max}$	0.01
$P_{d,max}$	0.001
Ch_{total}	150

Using GACN algorithm base problem is solved and the results obtained are presented in table 2

Table 2
Values of decision parameters for the base problem

Parameter	*Result of GACN algorithm*
C	114240
Ch_1	19
Ch_2	20
G_1	4
G_2	5
R	431m
R	1293m
R/r	3
P_b	$7.6392\text{x }\mathbf{10}^{-10}$
P_d	$7.6392\text{x }\mathbf{10}^{-10}$

Using GACN algorithm total system cost we obtained is 114240 while using same parameter SA algorithm [5] gives 152060. This shows that obtained result is better than the results of SA algorithm.

Now we study effect of some parameters. First we study change of slow mobility call arrival rate from 5×10^{-8} to 15×10^{-8} calls per sec per m^2 with a step size of 1×10^{-8} calls per sec per m^2. The result obtained are then compared with SA algorithm [5] and are presented in Figure 3.

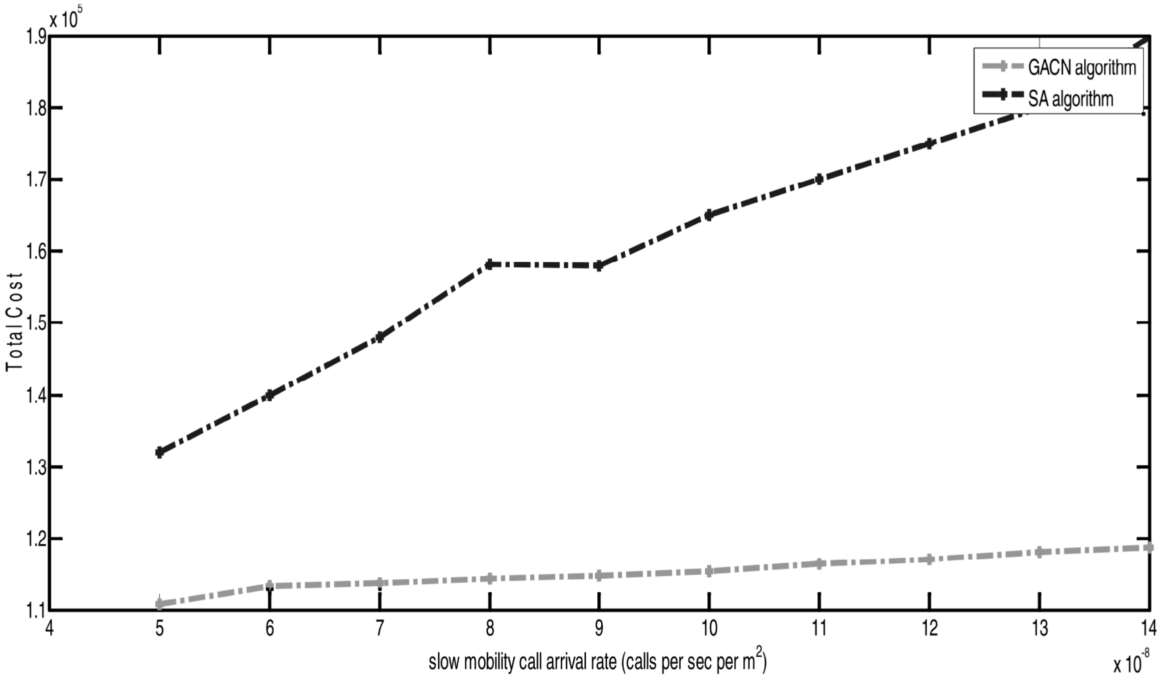

Figure 3: Slow mobility arrival rate versus total cost

To examine the effect of fast mobility user arrival rate on the total cost we considered the fast mobility user arrival rate from 1×10^{-8} to 4×10^{-8} calls per sec per m^2 with a step size of 1×10^{-8} calls per sec per m^2. The results are shown in Figure 4.

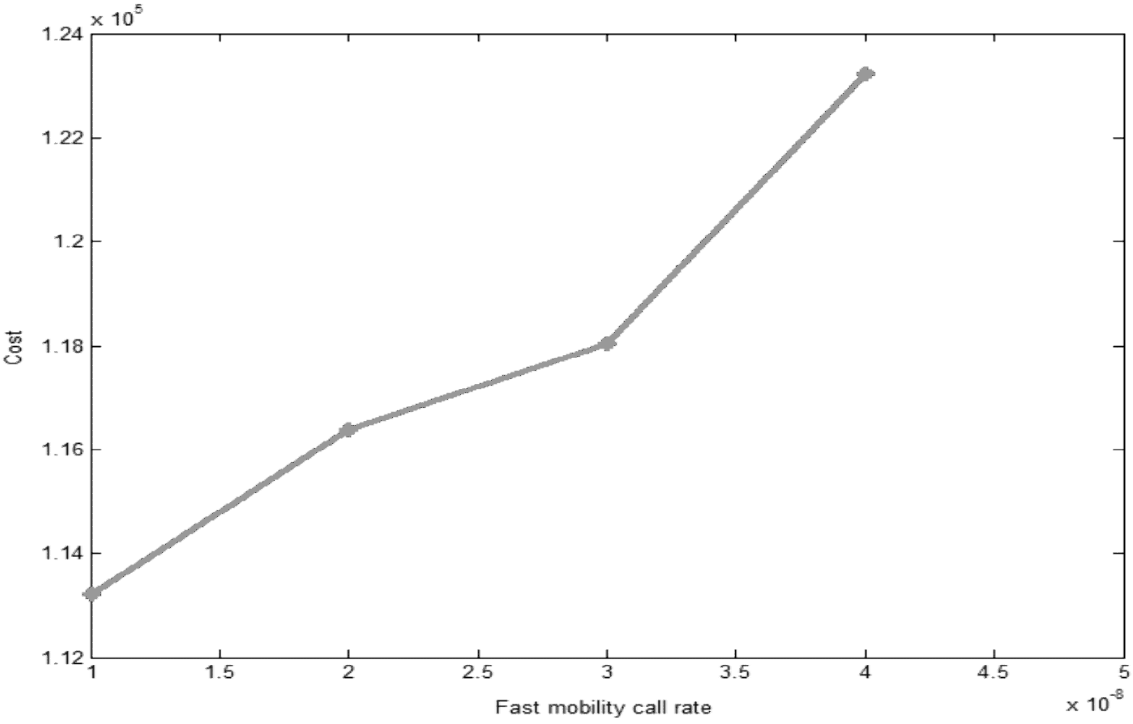

Figure 4: Fast mobility call arrival rate versus Cost

To observe the convergence of GACN algorithm total cost is evaluated for a large number of iterations which is shown in figure 5. Results in Figure-5 shows that as the number of iteration increases, GACN algorithm converges. In the starting total cost decreases, but after 400 iterations, the cost observed remains the almost same. In other word, there is no significant change in cost as number of iterations increases beyond 400.

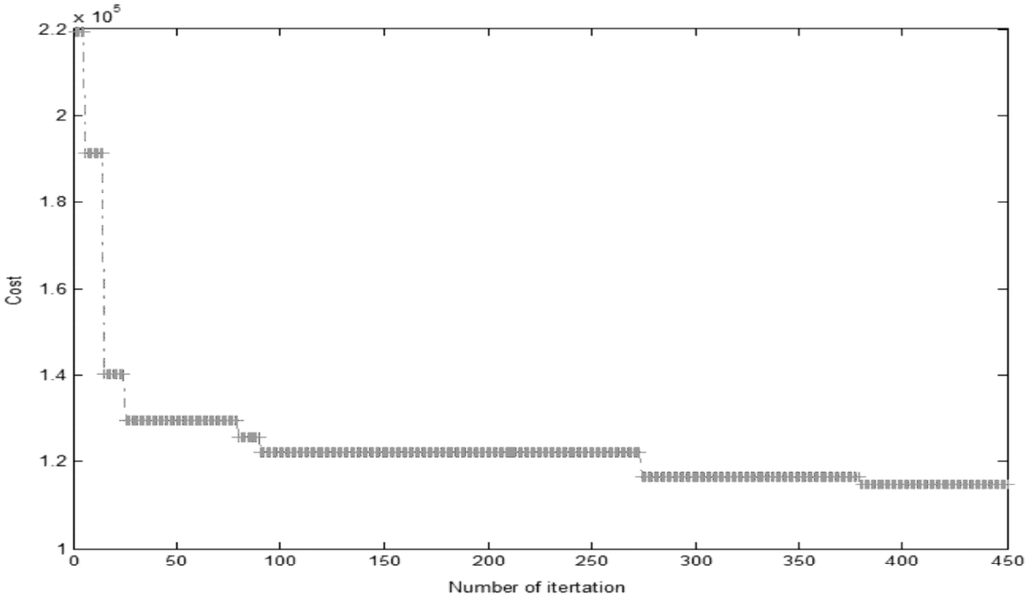

Figure 5: GACN algorithm iteration versus cost

Now, we study change in total cost as we change the average speed of slow mobility user from 0.25m/s to 2.25 m/s taking step size 0.25 m/s. We compared the results with of SA algorithm [5] as shown in Figure 6.

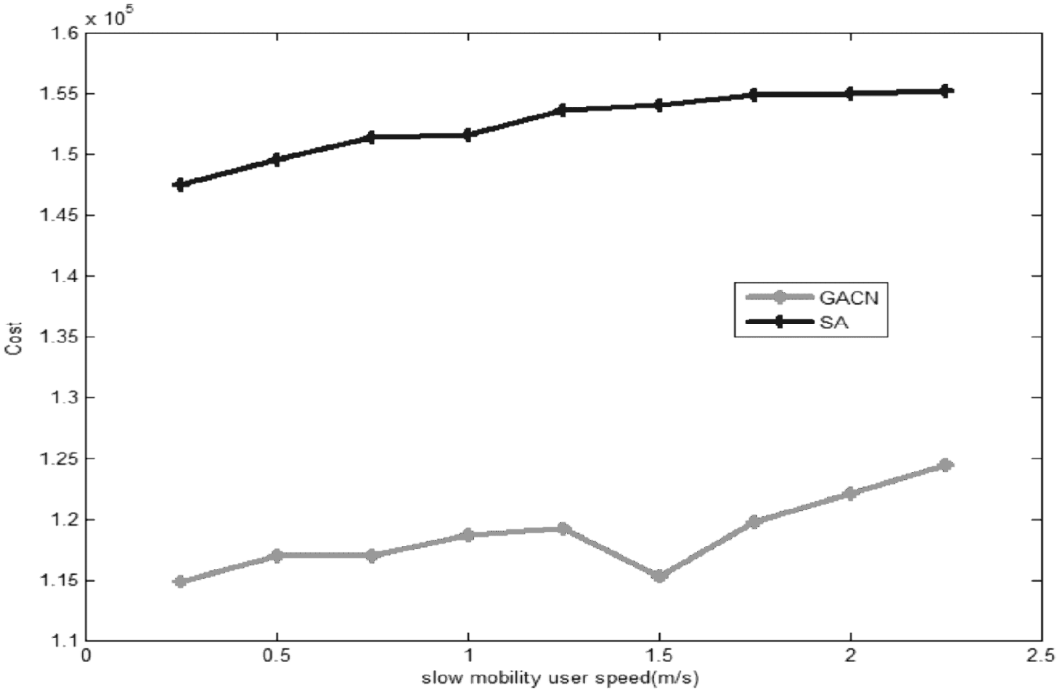

Figure 6: Slow mobility user speed versus cost

Comparison of GACN algorithm with Simulated annealing (SA) and Grady search (GS) algorithm on base problem with some change are given in Table-3.The total cost obtained using GACN algorithm is 114240; using SA algorithm it was 152060 while by using GS it was 155390. By conducting separate experiments, we have evaluated total cost by changing the total area, slow mobility user speed as 0.25 m/s and 3 m/s, and slow & fast mobility arrival rate. The results of these experiments are presented in table 3.

Table 3
Result obtained with GACN, SA & GS algorithm

Prb.N.	*description*	*GACN*	*SA*	*GS*
1	Base problem	114240	152060	155390
2	Area=1000 km^2	22980	30990	30380
3	Area=50 km^2	1160	1550	1660
4	Slow mobility, speed =0.25 m/s	113210	147000	154050
5	Slow mobility, speed = 3 m/s	116390	157200	161260
6	fast mobility, speed = 5 m/s	115870	149900	154540
7	fast mobility, speed = 20 m/s	113210	162440	165560
8	Slow mobility, arrival rate= $2x10^{-8}$	102960	112590	118280
9	Slow mobility, arrival rate= $15x10^{-8}$	116390	1955400	195860
10	fast mobility, arrival rate= $5x10^{-9}$	113730	76990	77380

VI. CONCLUSION

In this work, total minimum cost of two-tier cellular network calculated using GACN algorithm. We also compared GACN algorithm with SA algorithm. Our results show that GACN algorithm gives better results in most of situation with respect to SA.

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