A Genetic Algorithm Based Hybrid Channel Allocation Scheme

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Abstract

This paper investigates the application of a Genetic Algorithm (GA) to the hybrid Channel Allocation (HCA) scheme in mobile cellular communication systems. The HCA scheme is a combination of the Fixed and Dynamic Channel assignment schemes. In HCA, the available set of channels is divided into fixed and dynamic sets. The ratio of fixed to dyanamic channels is a significant parameter which defines the performance of the system. This being an optimization problem. it presents an ideal opportunity to apply GAs. The problem of determining the ratio of fixed to dynamic channels by using a GA is approached in two ways. First, the total number of channels available is constrained and the best set is determined. Second, the minimal set of channels which provides optimal performance is determined. In both cases, the GA converged to the optimal solution. A comparison is made between this approach and the corresponding Fixed Channel Assignment scheme.

1.Introduction

The tremendous growth of the mobile user population, coupled with their bandwidth requirements, requires efficient reuse of the radio spectrum allocated to mobile communications. Efficient use of the radio spectrum is also important from a cost-of-service point of view. where the number of base stations required for a certain geographical area is an important factor. A reduction in the number of base stations, and hence in the cost of service, can be achieved by more efficient reuse of the radio spectrum. The basic prohibiting factor in radio spectrum reuse is interference caused by the environment or other modules. Interference can be reduced by making use of channel assignment techniques.

Channel assignment strategies can be classified as a) fixed b) dynamic and c) flexible [1].In all fixed channel assignment strategies, a set of channels is permanently assigned to each cell. The same set of channels is reused by another cell at some distance. The minimum distance at which radio frequencies can be reused with no interference is called the 'cochannel reuse distance'. Due to short term temporal and spatial variations of traffic in cellular systems, Fixed Channel Allocation (FCA) schemes are not able to attain high channel efficiency. To overcome this, Dynamic Channel Allocation (DCA) schemes have been proposed. In contrast to FCA, there is no fixed relationship between channels and cells in DCA. All channels are kept in a central pool and assigned dynamically to radio cells as new calls arrive. After a call is completed, its channel is returned to the central pool. In DCA, a channel is eligible for use in a particular cell if it satisfies the interference constraints. In general, more than one channel may be available for selection.

Hybrid Channel Assignment (HCA) schemes are a mixture of FCA and DCA techniques . In HCA, the total number of channels available for service is divided into fixed and dynamic sets. The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes and are preferred for use in their respective cells. When a call requires service from a cell and all its nominal channels are busy, a channel from the dynamic set is assigned to the call. The dynamic set, therefore, results in increased flexibility of the system. The channel assignment procedure from the dynamic set follows any of the DCA strategies. Call blocking probability is defined as the probability that a call finds both the

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fixed and dynamic sets busy. The possibility that a dynamic channel is free but cannot be assigned due to interference constraints is also taken into consideration here.

The ratio of fixed to dynamic channels is a significant parameter which defines the performance of the system. A measure of the performance of a mobile system is its blocking probability. In general, the ratio of fixed to dynamic channels is a function of the traffic load. When the load is high FCA schemes perform better since they are able to maintain the minimum reuse distance [2]. On the other hand when the load is low DCA schemes are better since they have greater flexibility. In HCA, which combines FCA and DCA, the manner in which the division into fixed and dynamic channels is made assumes importance. This division must be done in such a way the the system is able to adapt to varying traffic loads and give acceptable performance. This paper investigates how a Genetic Algorithm (GA) may be used to efficiently determine this ratio. The GA is applied to a HCA scheme employed in a Highway microcellular environment.

2.Genetic Algorithms

Genetic Algorithms (GAs),[3], are iterative search algorithms based on an analogy with the process of natural selection and evolutionary genetics. GAs ensure the proliferation of quality solutions while investigating new solutions via a systematic information exchange that utilizes probabilistic decisions. It is this combination which allows GAs to exploit the search space with expected improved performance.

The search aims to optimize some user-defined function called the fitness function. To perform this task, GA maintains a 'population' of candidate points over the entire search space. At each iteration, called a 'generation' a new population is created. This new generation generally consists of individuals which are more fit, than the previous ones, as represented by the fitness function. As the population iterates through successive generations, the individuals will in general tend towards the optimum of the fitness function. To generate a new population on the basis of a previous one, a GA performs three steps:

1. Evaluate the fitness score of each individual of the old population.
2. Selects individuals on the basis of their fitness score
3. Recombines selected individuals using 'genetic operators' such as mutation and crossover.

GAs differ from classical optimization methods like steepest descent, simplex, etc., in the following manner:

1. GA works in parallel on a number of parts and not on a unique solution
2. GA requires only a fitness function and no other information nor assumption such as derivatives.
3. Selection and combination are performed by using probabilistic rules rather than deterministic ones.

3.Mechanics of a GA

A simple GA is composed of three operators: 1) reproduction 2) crossover and 3) mutation. Each of these operators are implemented by performing the basic tasks of copying strings, exchanging portions of strings and generating random numbers. The GA begins by randomly generating a population of N strings, each of length m. Each string represents one possible solution to the problem. These strings are evaluated with some objective function and assigned some fitness value. Fitness values are then used to produce a new population of strings. The new strings are again decoded, evaluated and transformed until convergence is achieved or a suitable solution is found.

Reproduction is simply a process by which strings with large fitness values receive correspondingly large number of copies in the new population. Several reproduction schemes like the Roulette wheel ,Elitist strategies etc., may be used. The scheme used, however, is not critical to the performance of the GA.

Crossover provides a mechanism for strings to mix and match their desirable qualities through a random process. The crossover site is selected uniformly at random. When combined with reproduction it is an effective means of exchanging information and combining portions of high quality solutions.

The third operator, mutation, enhances the ability of the GA to find near optimal solutions. Mutation is the occasional alteration of a value at a particular string position. Mutation helps in those situations where neither reproduction nor crossover will ever produce the optimal solution. Any information that may have been lost in previous generations may be reinjected by this operator.

4.Highway Microcellular Structure

A basic cellular system consists of three parts: a mobile unit, a cell site and a mobile switching office (MTSO), with connections to link the three systems. A mobile telephone unit contains a control unit, a transiever and an antenna system. The cell site provides the interface between the MTSO and the mobile units. The MTSO is the heart of the cellular mobile system and provides central co-ordination and cellular administration.

Microcellular digital mobile radio systems have been proposed where the cell shapes are tailored to the physical environment [4]. These cells may vary from the size of a room to a few hundred meters for hand held portables. Microcells for vehicular mobiles, on the other hand, would typically be longer than half a mile. As highways have many mobiles restricted to narrow confines for long periods of time the potential for relatively high teletraffic rates encourages us to consider a relatively complex cellular structure .

Highways may be considered to be composed of segments having different radii of curvature ρ, where ρ is infinity for straight stretches and which may be quite small for mountainous hairpin bends. A cell may be conceptually viewed as a parallelopiped of length L along, and D across, the highway, respectively, where $L \gg D$. The length L, however, might change if the highway has a sudden decrease in curvature, meets an intersection, tunnel etc. In general, the cochannel interference will be greatest in straight highways, as a mobile will experience interference from a transreceiver radiating directly into the mobiles cell.

5.Application of a GA to HCA

As previously mentioned, in the HCA scheme, the ratio in which the available channals are split is of crucial importance. This problem of dividing a group of channels into two can, in general, be approached in two ways:

1. Constrained approach: Here, the number of channels available to the system is constrained and the optimal manner in which these may be divided is determined, i.e., if there are N channels available, the combination (D, S) such that $N = D + S$ where D is the number of dynamic channels and S is the number of static or fixed channels is determined.
2. Unconstrained approach: The number of channels available is assumed to be unlimited and the optimal set is determined. There are again two approaches to this unconstrained optimization problem.
   - To find a subset of channels that results in the lowest blocking probability
   - To determine that subset of channels for which the blocking probability is less than a given threshold.

   In the first case the blocking probability and the total number of channels feature in the fitness function. In the second case it is only the blocking probability that serves as a measure of fitness.

In this paper on the application of GAs to the HCA scheme, the constrained approach and the unconstrained one with the blocking probability below a certain threshold are considered. In most practical cases the emphasis is on a certain grade of service and not on the global minimum that can be achieved. The threshold constrained optimization problem is therefore a more practical scenario.

Population size	Probability of crossover	Probability of Mutation
6	1	.05

Table 1: GA Parameters

6.Constrained Channel Approach

Here, the total number of channels is fixed and the aim is to determine that set which which gives optimal performance. Since the blocking probability is a measure of the performance of a mobile system we are looking for a subset which results in the minimum blocking probability. Since the number of channels is constrained it is sufficient if either the static or dynamic channels is modelled. The other set can be obtained as the difference. This implies that the size of the search space is equal to the number of available channels. Further, since the number of channes is not variable it does not feature in the fitness function.

The aim of this approach is to determine a channel set which performs well for different traffic loads. The fitness function chosen, therefore, is the sum of the blocking probabilities obtained by simulating various call inter-arrival times, i.e.,

$$f(a) = \sum_{r_j} P_b \qquad \forall r_j \in r \tag{1}$$

where $a = (b_1 b_2 b_3 \cdots b_n)$ is a bit string representing a possible solution and $r = (r_1, r_2, r_3, \cdots, r_n)$ is the set of call arrival times.

Considering the FCA scheme, the blocking probability is generally found to be a monotonically decreasing function with increasing inter-arrival times. This implies that when the time interval between call arrivals increases the blocking probability decreases. Large inter-arrival rates translates to low load. For such kind of monotonic functions, DeJong [5] suggests that the elitist strategy produces the best results. In the elitist strategy it is made sure that atleast the most fit string is carried over to the next generation. Since in this investigation the blocking probabilities themselves serve as an estimate of the fitness function, the elitist strategy is followed.

7.Simulation

The system was modelled and the simulations were performed using the Simscript language. The following assumptions were made in this simulation:

1. Call arrivals are Poisson distributed which means that their inter-arrival times are exponentially distributed.
2. Each call requires only one channel.
3. The call holding time is exponentially distributed with a mean of $120sec$.
4. Blocked calls are dropped.
5. The highway is assumed to be circular, i.e., mobiles leaving the last cell circle back to the first. This assumption was made to eliminate end effects seen in models which consider a segment of a highway.

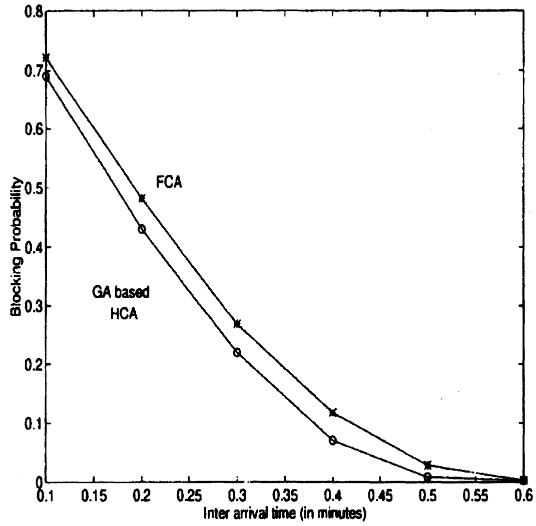

Figure 1: Blocking Probabilities for the constrained channel system with 10 cells and 31 channels.

The GA parameters are given in Table 1. Since the solution space is not very large a modest population size was chosen. Furthur the number of channels available was assumed to be a power of two to simplify the coding scheme.

A 10-cell highway environment was simulated for cases with 31 and 15 channels. Inter- arrival times ranging from 0.1 minutes to 0.6 minutes in steps of 0.1 minutes was considered. The strings representing possible solutions were binary coded into 5 and 4 bits respectively. In the first case the GA converged to 27 fixed and 4 dynamic channels while in the second case it converged to 12 fixed and 3 dynamic channels. In both cases the average number of generations before convergence was achieved was 12. Both configurations were compared with the corresponding FCA implementation. If the ratio of dynamic to static channels is denoted by $D : S$ and $D + S = NC$ where NC is the total number of channels, then while the FCA scheme would employ NC channels per cell the HCA scheme would allocate S channels per cell and D channels would be given to the entire system.

In the highway environment simulated a reuse distance of 2 is considered. Reuse distance refers to the minimum distance at which channel sets of the same frequency are reused. Therefore, in the case considered a minimum of two channel sets are required. When the total number of channels is divided into D and S, a total of $2 * S$ channels are made available to the entire system and each cell is alloted S channels. For example, if the division is 27 fixed and 4 dynamic channels, 8 channels are available to the entire system and 27 channels are alloted to each cell as nominal channels.

The results of the simulation are shown plotted in Figures 1 and 2. The graphs are a plot of the blocking probability against the inter-arrival times in minutes. It can be seen that in both cases the configuration chosen by the GA performs better than the corresponding FCA implementation. While the 31 channel case shows better performance over all the inter-arrival times considered, the 15 channel configuration shows improved performance for high and low loads. For moderate loads it is nearly equivalent to the FCA scheme.

8.Unconstrained Channel Approach

In this approach the constraint that the sum of the dynamic and fixed channels be equal to a constant is removed. This implies that each can take any value bound by an upper limit. In this application the upper limit is assumed to be 31. Since each parameter can take a maximum value of 31 the ssize of the solution space is 961. This problem is similar to the feature selection problem in pattern classification,

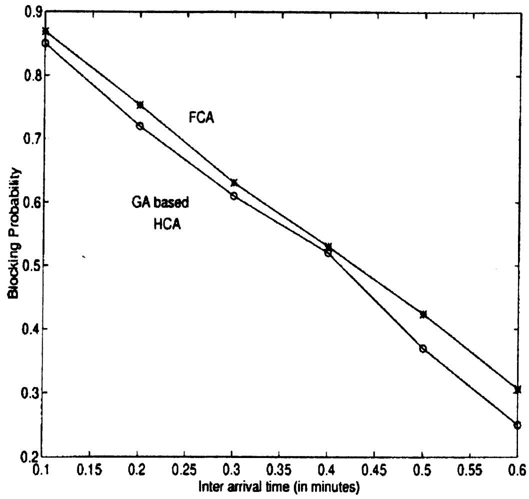

Figure 2: Blocking Probabilities for the constrained channel system with 10 cells and 15 channels.

in which the minimal set of features providing maximum classification accuracy is to be found [6]. Since the subset of channels for which the blocking probability is below a certain threshold is to be determined the fitness function involves both the blocking probability as well as the number of channels. First the set of channels which satisfy the threshold condition is determined and then the total number of channels is used to determine the optimal subset. The threshold is nothing but the blocking probability that is desired for a given traffic load. Once the threshold is satisfied the fitness assigned is given by

$$f(a) = exp^{(sum/62)^2} - 1 \tag{2}$$

where *sum* is the total number of channels. If the threshold condition is not satisfied then the blocking probability is itself assigned as the fitness. A function of the type given above is chosen so that among those channels sets satisfying the threshold condition the ones with lesser number of channels is rewarded with a lower fitness. Since this is a function minimization problem these are selected with a greater probability.

9.Simulation

The assumptions made in this case are the same as those in the previous approach . Initially a base load of 5 Erlangs or 150 calls/hour was chosen. A 20 cell highway system was simulated with the threshold fixed at 20%. The GA parameters were the same as those used in the previous approach and are given in Table 1. On simulating the system the GA was found to converge to a configuration of 10 fixed and 3 dynamic channels. Convergence in this case was achieved in an average of 10 generations. With this configuration other interarrival rates were also simulated. The performance of this system was compared to the corresponding FCA implementation with 13 channels. This comparison is shown in Figure 3. It can be seen that the GA based implementation performs significantly better than the FCA scheme over all the inter-arrival times considered. Furthur, the improvement in blocking probability is much greater in the unconstrained optimization case when compared to the constrained cases. This may be due to the freedom that the GA has to select the channel set which provides optimal performance.

10.Conclusion

This paper investigates the application of a GA to the problem of dividing a given set of channels into fixed and dynamic sets for use in a HCA scheme. Two approaches were considered and results obtained

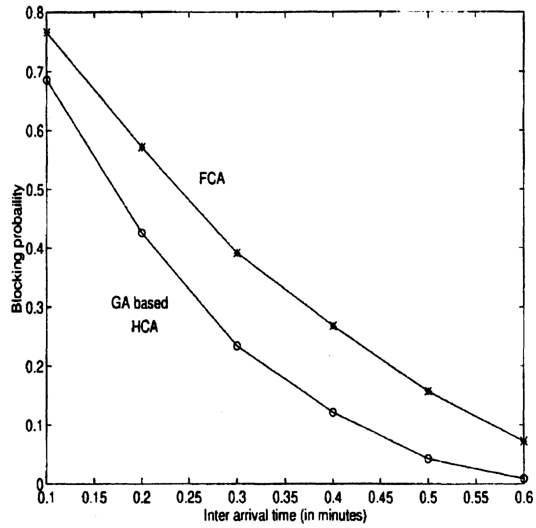

Figure 3: Blocking Probabilities for the unconstrained channel system with 20 cells.

show that the configurations obtained using the GA show better performance when compared to the corresponding FCA implementation. Since the performance is better over a range of inter-arrival times, the process need not be repeated when the traffic load changes.There is, however, the question of scaling. For the small channel configurations considered here the GA performs more optimally than an exhaustive search over all the possible channel combinations. Whether the GA can perform optimally when the size of the problem is increased is to be investigated. Further, the channel constraints have been chosen to be powers of two for simplicity. If this is not the case a suitable coding scheme has to be considered to take care of the illegal strings which may arise during the GA processing. Further study is also being done on how the fitness function may be tuned for the unconstrained optimization problem. A weighted sum of the blocking probability and the number of channels is currently being studied. The optimal weights themselves may be obtained in the same run.

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