Soft Computing in Wireless Mobile Networks

By R. K. Ghosh and P. Mitra

The role of soft computing in the domain of wireless networks can be classified into three broad categories, namely, *optimization*, *prediction* and *uncertainty management*. Evolutionary algorithms are mostly used for optimization. Neural networks and other learning systems are used for different types of prediction tasks. Uncertainties arising due to incomplete modeling and measurements are handled using fuzzy logic, either in stand-alone manner or in conjunction with the optimization and prediction algorithms. The synergistic integration of different soft computing tools is best demonstrated in solutions of problems related to communication and mobility in wireless networks. Three central problems are the focus of our discussion in this article, namely, base station placement, channel assignment and mobility management.

**Base Station Placement**

The first challenge in planning of a cellular network is to determine the number of base stations required to serve an area with a desired level of *Quality of Service* (QoS). Many soft computing approaches like genetic algorithms (GA), simulated annealing and tabu search have been used to solve the problem. The literature on use of other soft computing tools besides GAs (e.g., neural networks and fuzzy logic) are scarce at present, since only GAs are suitable for the multi-objective optimization involved in Base station Placement Problem (BPP). BPP should address a number of issues including traffic density, hot spots, quality of channels, interference scenarios, number of base stations, and other network parameters. Stated simply, the goal of base station placement is to select minimum number of base station locations which maximize the coverage area taking into account the characteristics of radio propagation in the said area.

BPP with multiple and conflicting objectives is known to be NP-hard [4]. A simple way to assess the complexity of BPP is that it can be viewed as an extension of capacitated facilities location problem with atomic demands. So regardless of optimization technique to be applied to solve BPP, the conflicts between competing multiple objectives need to be resolved. The concept of pareto optimality (a non-dominated solution) becomes important in this respect.

**Channel Allocation**

The constraints of channel allocation problem are derived from desirable physical characteristics of a communication between two entities. The impacts are felt in terms of quality of services as a connected mobile device moves from one cell to another. An efficient channel allocation scheme should

- minimize connection set up time,
- maximize the number of simultaneous communication sessions,
- be adaptable to change in load distribution,
- minimize computation and communication overheads for channel selection.

There are many channel assignment schemes. Broadly these schemes can be classified into three classes mentioned below:

- Fixed channel assignment (FCA)
- Dynamic Channel Assignment (DCA)
- Hybrid channel assignment (HCCA)

The channel assignment problem is also known to be NP-hard [3].
Fixed Channel Allocation

In a fixed channel assignment scheme, each cell is allocated a fixed number of channels. The demand for a new call in a cell can be served only if a free channel is available. An ongoing communication will be terminated if a connected mobile terminal moves from a cell to a cell which has no free channel. Not much variations are possible in FCA to adapt to changing traffic conditions and user distribution. Accurate knowledge of traffic and interference conditions is required for frequency planning in a microcellular environment employing FCA.

There are many genetic algorithm based approaches to solve FCA problem. An excellent survey of some of the important work in the area can be found in [6]. Broadly speaking there are two different ways to solve channel assignment problem. One approach treats interference as a soft constraint while the other approach treats it as a hard constraint. The former approach that treats traffic demand as a hard constraint always provides an acceptable solution with some interferences. Furthermore, it can be modified also to provide solutions with minimum bandwidth requirements. In the latter scheme where interference is treated as a hard constraint, the solution requires a large number of available channels per cell.

Neural Network Approach

Hopfield network approach uses an energy function containing the objective function and individual terms for all constraints of the problem. So, the major problem in using Hopfield network lies in ability to define an appropriate energy function. The terms of the energy function compete among themselves for minimization. So, the constraints and objectives trade against one another. Furthermore, the (strict descent) dynamics of the Hopfield network result in convergence to the local minima encountered first. Such an approach is, therefore, unlikely to be as competitive as the heuristics such as genetic algorithms which are able to escape from local minima easily.

The simulations using neural network consist of two alternated steps. The first step forces the interference to vanish by moving out of constraint hyper plane. It is like a steepest descent on the interference function. The second step applies a projection and cutting operations to force the solutions to stay in the constraint hyper plane.

Dynamic Channel Allocation

DCA algorithms can be divided into two categories, namely, (i) interference adaptive, and (ii) traffic adaptive. In interference adaptive algorithms, the decision to allocate channels is dependent on the measurement of carrier-to-interference (C/I) ratio. In traffic adaptive schemes, the allocation of channels is based on traffic conditions in neighbour-cells of the cell where a call has arrived. In the first category of algorithms propagation of C/I measurements are made from base station to mobile station and vice versa.

GA Approach

A simple adaptive interference based GA for dynamic channel allocation has been proposed in[8]. The algorithm has two subsystems. One subsystem is responsible for scanning and selecting a channel. The other subsystem provides a prioritized list of channels per access point (AP). An AP scans a fixed number $N_f$ of channels and selects highest priority channel on the basis of a threshold level of interference. If no such channel can be found then channel with the lowest level of interference is chosen. The measured interference levels of $N_f$ channels are sent to a control server. The control server uses a GA to select $N_c$ channels out of total number of available channels and ranks these selected channels per AP. The set of sorted lists are sent to corresponding APs. However, the APs use existing ordered lists for allocation instead of waiting for the update from control server to reach them. Since a control server is connected to a fixed number of APs without overlap (see figure 1(a) on page 3), the degree of centralization is limited. The GA used by
control server encodes the concatenated string of priority lists of all APs (under the control server) in its chromosome. For example, with 3 APs under a control server, an individual in population can be coded by the string shown in figure 1 (b).

Neural Network Approach

The focus of neural-network-based DCA schemes has been predominantly on performance measures relating to the computational time of convergence or new-call blocking probability. Most of these give less or no importance to the impact of traffic mobility on performance. But mobility is the single most important cause for triggering intercell call handoffs. Handoffs have a considerable impact on the system performance. Generally, from users' prospective, blocking of new calls - known as Grade of Services (GoS) - is more preferable then blocking of ongoing calls (QoS).

The HNN-DCA modeling describes how channel allocation problem can be represented by an energy function. A HNN-based DCA algorithm should attempt to maintain an optimum balance between the probabilities for call blocking and call dropping. Essentially, it means that the energy function should include both QoS and GoS as joint performance estimator.

Fuzzy Logic Approach

Sung and Wong [5] consider the dynamic Channel assignment problem in a hierarchical cellular system, which consists of a macro layer and a micro layer. The macro cells accommodate fast mobile users. However, if one directs too many mobile users to the macro cells, the system capacity becomes low. On the other hand, the microcells are designed to increase capacity, but they cause a large number of handoffs. The aim is to maximize the system capacity while keeping the number of handoffs small. In [5], the DCA algorithm minimize the handoff rate by a fuzzy layer selection algorithm, which makes use of the past cell residence times of a user and the channel occupancy of the target cell. To maximize the capacity, they propose a distributed channel assignment algorithm to dynamically allocate the channels among the two layers. Exchange of information is allowed between neighboring macrocells. The state of channel assignment in a macro cell and its interfering cells are tabulated in a channel allocation table, which provides all information required in the integrated resource allocation scheme.

In [9], a novel call admission control (CAC) scheme using fuzzy logic is proposed for the reverse link transmission in wideband Code Division Multiple Access (CDMA) cellular communications. The fuzzy CAC scheme first estimates the effective bandwidths of the call request from a mobile station and its mobility information, then makes a decision to accept or reject the connection request based on the estimation and system resource availability. Numerical results demonstrate the effectiveness of the proposed fuzzy CAC
augmented with additional techniques like channel carrying, channel borrowing, channel reservation, etc to handle handoff. On the top of this, tackling handoff also requires the measurement of the received signal strengths (RSS) from neighbouring base station to be able to initiate handoff at opportune time. There is not much scope for optimization in the handoff process as it should guarantee that there is no perceptible interruption in ongoing communication. Different techniques have been proposed to improve the handoff methods. These include adaptive prediction based algorithm and fuzzy logic based algorithms. The former provided a significant improvement in terms of reducing the number of handoffs, while the latter was shown to provide a fast and stable handoff for both line-of-sight and non line-of-sight signal conditions. Fuzzy inferencing techniques and pattern recognition approaches are used in a number of handoff decision systems. These systems typically look up a fuzzy rule base and fire the appropriate handoff process.

Location Management

The efficacy of out-of-session mobility management depends mainly on how quickly a path can be setup to the current cell location of a mobile terminal. Location management involves two basic operations: (i) paging, and (ii) updating. Paging forces a mobile terminal in standby mode to come alive. Update is invoked to keep track of movement of a mobile terminal to new locations. Both paging and update contribute to network traffic and consume scarce bandwidth resources. But these are orthogonal cost. If exact information is maintained at each and every network site, the updates have to be made with every move and disseminated to all the sites. So, subsequent look ups become immediate. The other extreme case could be no information about location of any object is maintained anywhere. The search for a mobile in this situation becomes an exhaustive search at each network site. Between the two extremities several combinations of approaches regarding location update and look up can be possible.
GA Approach

Das et al. [2] proposed a genetic algorithm based approach for solving location management problem. Their solution focuses on minimizing per user cost for tracking an individual mobile user. In particular they devised an update strategy for each mobile that considers a subscriber mobility pattern and a call arrival pattern. In a conventional scheme the update is done when a mobile user crosses a location area (LA) boundary. The LAs are numbered sequentially from 1 to \( n \). Update per user is represented by a binary string \( \{u_1, \ldots, u_n\} \), where

\[
u_i = \begin{cases} 1, & \text{if update occurs in LA}_i \\ 0, & \text{otherwise} \end{cases}
\]

The cost of location management is defined by the sum

\[
\sum_{i=1}^{n} \text{prob}(\text{LA}(i)) \cdot \text{cost}_{\text{avg}}(i)
\]

where, \text{prob}(\text{LA}(i)) \text{ is the probability of the user being located in LA}_i \text{ and cost}_{\text{avg}}(i) \text{ is the average location management cost in LA}_i \text{ which is computed assuming call arrival to follow Poison distribution. The fitness of string is evaluated by using reciprocal of above sum. Therefore, the above formulation of GA is found to minimize the overall location management cost in situation with low residence probability for a user in LAs, low call arrival rate, and high update cost by skipping updates in several LAs. Qualitatively, low call arrival rate with low residence probability in LAs together, would mean that skipping of updates in many LAs may affect the average paging cost only marginally.}

Another GA based approach for optimal planning of location areas to reduce update cost has been proposed by Wang et al [7]. It is based on static cell planning and requires that location update and paging traffic per cell are known in advance. Each LA consists of disjoint set of cells and paging bound is fixed for each LA. The LA planning is encoded as a binary string using border adjacency relation as shown in figure 2(a). A possible cell planning for above representation may be according to LA boundary shown in figure 2(b). With this Cell planning, the cell borders \( b_1, b_2, b_3 \) are adjacent between LA_1 and LA_2. Similarly, the borders \( b_4, b_5, b_6 \) are common to LA_1 and LA_3, while \( b_7 \) is common to LA_1 and LA_2. Therefore the binary string encoding this planning is 110011101010.

The chromosome fitness is evaluated using the function

\[
\alpha_1 \sum_{j=1}^{n} w_j + \alpha_2 \sum_{j=1}^{n} \max \{0, (P_j - B)\}
\]

Where the first term represent location update cost and the second term represents cost due to violation of paging bound. In the equation \( n \text{ is the total number of borders, } w_j \text{ is the crossing intensity of border } j, v_j \text{ is the } j \text{th bit of the chromosome being evaluated, } m \text{ is the number of LAs, } P_j \text{ is the paging traffic in LA}_j \text{, } B \text{ is the paging bound (considered fixed for each LA),} \) and \( \alpha_1 \text{ and } \alpha_2 \) are weighted constants for relative importance of update cost and paging bound violation respectively.

Neural Networks Approach

Multilayered perceptions and other feed-forward architectures can be trained on historical data of movement patterns of individual mobile user. Then such a trained system can be used for the prediction of current location of a mobile user. Besides
multilayer perceptions, Hopfield Neural Network (HNN) is also used to find the optimal configuration of location areas in a mobile network. Towards this end, the location area configuration of the network is modeled so that the mobility management cost of the system is related to the energy value of this artificial neural network. Since a pure HNN is not efficient enough to be used in solving this problem, some modifications are applied to deal with randomness of selection in manipulating the cells during the solving process.

Fuzzy Logic Approach

Locations of users are inherently uncertain and imprecise. Fuzzy logic based location management systems treat location as a fuzzy quantity and uses inferencing to predict the location in future. A fuzzy logic-based location management method to reduce paging cost has been proposed in [1]. The idea is to update location on the basis of an area-based method that uses direction-based method together with movement-based method. A partial candidate paging area is selected by fuzzy control rules, and then the fuzzy logic-based selective paging method pages only cells within the partial candidate paging area.

Adaptive fuzzy inferencing schemes has been used for mobility prediction and call admission control decisions. Current mobility information is obtained to real time measurements using pilot signals in the forward channel of a DS/CDMA. A fuzzy inferencing scheme combined with linear least square estimator is used to obtain decisions about call admission control. The system was found to provide superior performance compared to existing admission control mechanisms.

Concluding Remarks

Uncertainties and imprecisions are endemic to wireless communication due to user’s mobility, various forms of interferences and characteristics of radio propagation. The area is, thus, full of complex multi-objective optimization problems. It naturally offers huge opportunities for application of soft computing techniques. We came across many references to applications of simulated annealing, tabu search, other randomized methods in solving certain optimization problems in wireless and mobile computing systems. We did not include them for lack of space. One thing that came out clear is that the area still offers a variety of low hanging fruits for research and related developments.

References


About the author: Dr. R. K. Ghosh is a professor in Computer Science and Engineering Department. He received his PhD degree from the Indian Institute of Technology Kharagpur in 1985. His publication include a book, three edited books, and over fifty papers in refereed journals and conferences. He has served as reviewers for many International journals including those published by IEEE, Elsevier and Khnizer. Dr. Ghosh also has been associated with many International conferences in various capacities as program chair, steering chair and as programme committe members. He is a senior member of IEEE computer society. His area of interest are: mobile computing, wireless ad hoc networks distributed and parallel computing.

About the author: Dr. Pabitra Mitra is an assistant professor in Computer Science and Engineering Department (currently at Department of CSE IIT Kharagpur on leave of absence). Dr. Mitra’s areas of interest are: Data Mining, Machine Learning, Pattern Recognition and Soft Computing. He received his PhD from ISI Kolkata in 2003. He publication recordincludes over 25 papers in refereed journals and conferences.