B-HIVE: A CELL PLANNING TOOL FOR URBAN WIRELESS NETWORKS

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ABSTRACT

The paper presents a demand-based engineering method for designing urban wireless networks. We present an integrated approach to include the effects of both tele-traffic and radio signal coverage for cellular network planning. The novelty of our scheme is an application of clustering technique to determine the cell and base-station locations. We model the cell planning problem as a clustering problem and apply standard clustering techniques, with modifications to suit our needs, for designing the wireless network. We present the planning tool prototype *B-Hive*, which is based on these ideas and demonstrate initial results for cellular network planning of Mumbai.

1. INTRODUCTION

The tremendous growth in the demand for mobile communication services, with more and more carriers joining the market, has triggered the need of tools for system design optimisation and radio network planning. Modern mobile network design involves several inter-dependent factors such as cell coverage, traffic, topography, propagation characteristics and system capacity. The selection of the number of cells, cell locations, power at base station and other design parameters have to be determined in the context of one another. The cell locations can be determined based on the number of cells, the coverage performance, traffic distribution, and propagation environments. Design parameters at base station and mobile units cannot be specified until the cell allocation is completed. For example, the channel assignment, which can improve system performances in terms of traffic services and interference avoidance can only be determined after the architecture of the mobile cellular network has been specified. Finally, cell planning is not a one time task as the design has to be continually updated based on the mobile network scenario and hence such provision should be included in the design tool.

Many studies have been carried out in the areas of mobile cellular network planning in terms of coverage analysis, channel assignment, routing and propagation, but relatively few studies ([1], [2]) have been performed in the area of network planning for cost effective system design. In conventional cellular planning, the focus is mainly on the radio planning aspects which includes the optimal selection of cell sites, frequency channel allocation and antenna design. For example in [3], the authors have concentrated on channel allocation strategies and discussed how sectoring can be used to achieve better system performance. In [1], the authors have discretized the tele-traffic distribution in an area using the demand node concept and have formulated the radio network design as a set covering problem. As mentioned earlier cell planning tools need to be adaptive and the tools should have a provision for constant estimation of scenario and correction of the design. With set covering problem approach this becomes too cumbersome and leads to an inefficient implementation.

In this paper we focus on the problem of determining the best suitable base station placement. We follow an integrated approach to include the effect of both tele-traffic and radio signal coverage. The primary contribution of our scheme is an application of clustering technique to determine the cell locations and base-station locations. We model the cell planning problem as a clustering problem and use standard clustering techniques, with modifications to suit our needs, for designing the mobile network.

The rest of the paper is organised as follows. The next section gives a qualitative description of the cell planning problem. In Section 3 we present the clustering approach for determining the cell location and base-station placement. Section 4 presents the preliminary results of cell planning for Mumbai using the proposed approach and Section 5 concludes the paper.

2. CELL PLANNING

A cell is the area covered by a base station transmitter, which is the basic geographical unit of a cellular system. The cells can be classified according to their sizes as macro-cells, micro-cells and pico-cells, with size of macro-cells ranging from 1 to 30km and that of pico-cells ranging from 10 to 200m. Cell planning addresses the problem of placing the base stations and specifying the parameters for each base station so that the optimal system performance is achieved and the system cost is minimized. The system performance and cost are characterised by:

1. Coverage: The radio signal coverage must be guaranteed and holes in the coverage area should be avoided.

2. Capacity: In each cell, a sufficient number of channels must be available in order to meet its traffic demand for new calls and handoffs.

3. Transmission quality: The ratio of carrier to interference power (C/I) of radio channels must satisfy the requirements of transmission quality.

4. Cost: The deployment cost *ie,* the cost of putting the required number of base-stations, cost of transmitting power.

For cell planning, the area to be planned is discretized, the resolution depending on the type of cells (macro or micro or pico cells) being planned. Though the methods we have developed can be extended to all type of cells (with some modifications), in this paper we restrict to the planning of macrocells for 2.5 generation systems (like GSM) only. The topography and traffic distribution of the area are specified through digital maps.

3. DESIGN

We follow the commonly used three phase modular approach for cell planning. The design flowchart is shown in Figure 1. The design consists of initial planning (dimensioning), detailed radio network planning and finally network operation and optimisation. Each phase itself consists of several interacting modules. In the initial dimensioning phase we estimate the approximate number of base stations required, the base station configurations and the number of network elements. Many methods exists for this phase and can be referred from [4]. In the cell planning phase we estimate the approximate cell locations and base station parameters. Finally, the optimisation phase attempts to optimise the cell locations and base station parameters so that the system performance is further enhanced. The actual field measurements of signal strengths, tele-traffic *etc.* are taken into account and the plan is updated. In this paper we will concentrate on the cell planning phase only. We now discuss some of the important modules/functionality of the cell planning phase.

3.1. Mobile subscriber module

This module characterizes and calculates the traffic demand of an area. The concept of demand node [1] is used. A demand node represents the center of an area that contains a quantum of demand from tele-traffic viewpoint, accounted in a fixed number of call requests per time unit. We use the partition clustering [5] algorithm to determine the demand node positions in the area. To illustrate, for the map of Mumbai whose traffic distribution is shown in Figure 2a, the demand node distribution is shown in Figure 2b. Though the proposed approach uses the demand node concept, the scheme is not the same as [1]. The proposed scheme uses the demand node concept for

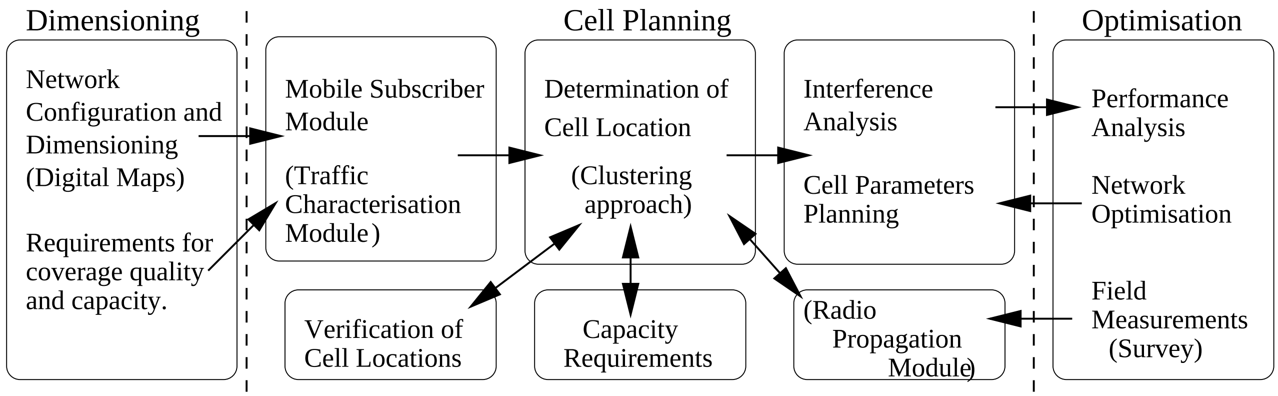


Figure 1: Design flowchart

traffic characterisation only. As can be seen from the next few subsections, our approach is not a mere modification of the approach used in [1].

3.2. Clustering module

Clustering is used to categorize or group similar data items together. The problem of cell planning can be modeled as a clustering problem where the aim is to cluster the demand nodes such that they accord to a certain set of properties. The set of properties being: a minimum signal strength should be guaranteeed over the whole area and the cell capacity should not exceed the maximum capacity of a base station. This modeling enables the application of the standard techniques developed for clustering.

Clustering methods can be divided into two basic types: hierarchical and partitional clustering. Hierarchical clustering proceeds successively by either merging smaller clusters into larger ones, or by splitting larger clusters. The clustering methods differ in the rule by which it is decided which two small clusters are merged or which large cluster is split. Partitional clustering, on the other hand, attempts to directly decompose the data set into a set of disjoint clusters. The criterion function that the clustering algorithm minimizes may emphasize the local structure of the data, as by assigning clusters to peaks in the probability density function, or the global structure.

The cell planning problem can be modeled in a better way using partitional clustering as we are not only interested in the local structure of cluster (involving traffic capacity and signal strength aspects) but global structure (involving the transmission quality C/I) of clusters also[1]. We take the demand node graph of the area and using radio propagation module and interference analysis module we determine the appropriate cell locations by applying clustering techniques. We then place the base station so that the signal strength received at each point in the cell is more than the minimum required.

We use the the KMeans [6] algorithm (of type partitional clustering) to cluster the demand nodes and form clusters, *ie.* cells. This algorithm assumes that the number of clusters to be formed is known in advance. K-means algorithm is a simple, iterative procedure whose criterion function, which needs to be minimized, is given by:

$$E_K = \sum_k (x_k - m_{c(x_k)})^2 \qquad (1)$$

where x_k is set of data points, $c(x_k)$ is the index of the centroid closest to x_k and m_i is the centroid of the i^{th} cluster. Centroid is an artificial point in the graph which represents an average location of a particular cluster. The coordinates of this point are averages of the values of all points that belong to the cluster.

An important parameter that can be provided to the KMeans algorithm is the initialization vectors which specifies the approximate location of

[1]The objectives of cell planning are used to control how clusters or cells are formed.

base station. The system performance of the outcome is directly related to how close the initialization vectors are from the optimal solution. We estimate the initialization vectors by using the repeated partition clustering.

3.3. Modification to KMeans

The standard KMeans algorithm forms clusters such that the objective function, which is based strictly on the euclidean distance between points in the map, is minimized. The algorithm in its present form hence may not achieve the minimum system performance required. For example, the clustering may result in a cell whose total traffic demand is so large that it cannot be serviced by a single base station. It may also happen that the resulting cell is so huge (spread over area) that it may not be possible for a single base station to service the whole area, *ie,* provide the minimum signal strength. To circumvent the above problems we modify the KMeans algorithm so that it takes into account the traffic demand and cell size too. We achieve this by modifying the objective function to include the effects of cluster size and the number of points in a cluster. The modified objective function is given by:

$$E = k_1 E_K + k_2 C_K + k_3 I_K \tag{2}$$

$$C_K = \sum_{i=1}^{k=K} (y_i - a)^2 \tag{3}$$

where a is the expected number of points in a cluster (*ie.* the ratio of total number of points to number of clusters), y_i is the number of points in the i^{th} cluster. E_K is given by equation 1, C_K is the cost of populating a cluster with more number of points than expected, I_K is the cross-channel interference cost supplied by the interference module and k_1, k_2, k_3 are the normalising factors.

3.4. Cell parameters planning

In this module we determine the parameters of the cell, *ie,* the appropriate base station position, power transmitted by each base station *etc.* We allocate a base station for each cell and place it so that the loss incurred at the entire boundary is approximately the same. The loss is estimated using the radio propagation module. Once the base station is placed, the power can be determined by considering the maximum loss and the minimum signal strength required.

3.5. Other important modules

3.5.1. The Interference analysis module

It determines the channel allocation strategy and calculates the inter-channel interference cost at each point on the area. In this module we check whether the required signal quality (C/I) in the area is maintained or not. Several standard techniques for channel allocation have been proposed. We use the sequential packing [7] algorithm for channel allocation.

3.5.2. Radio propagation module

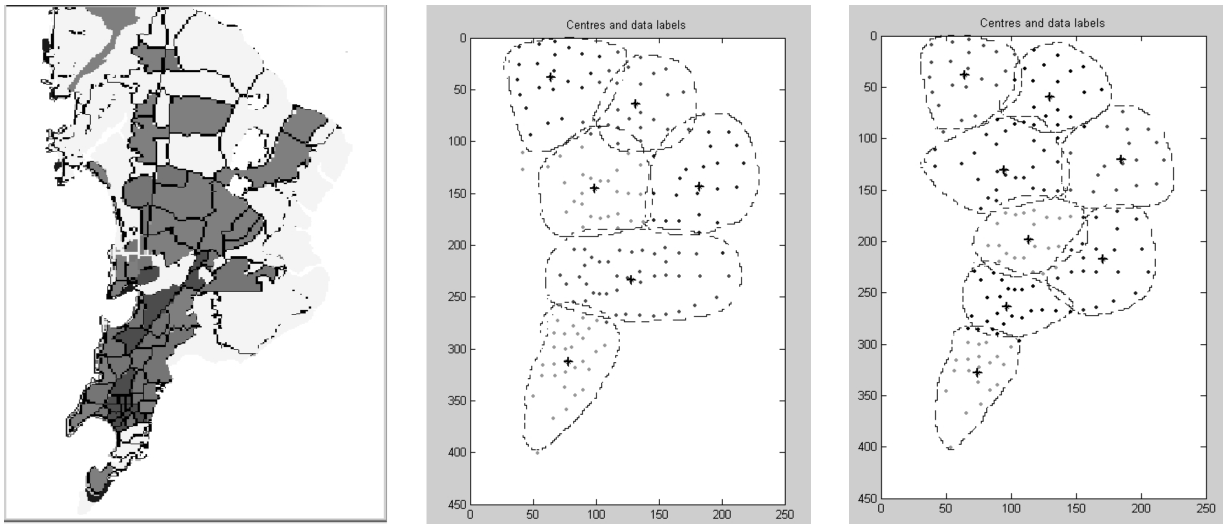
This module calculates the radio signal coverage. Several models have been proposed for the calculation of the signal strength in an area. We use the Okumura-Hata model [8] for determining the radio signal coverage. Okumura Hata model is an empirical model for calculating the signal loss.

4. RESULTS

To test the capability of our approach for cellular mobile network design, a planning tool prototype, *B-Hive*, has been implemented in Matlab 6.0 [9]. The prototype was tested for the design of cellular mobile communication system for Mumbai. We use the raster map of Mumbai for topography and population density map for calculating the traffic demand (Figure 2a). We have tested the tool for various number of cells/base stations. The task is to determine the best suitable placement of base station and determination of cell locations. The results are shown in Figure 2b, 2c.

5. CONCLUSIONS

In this paper we have studied the problem of automatic cell planning for urban wireless networks



(a) Traffic Demand (b) No. of Clusters=6 (c) No. of Clusters=8

Figure 2: Cell planning for Mumbai

and presented an innovative approach to solve the problem. We have modeled the cell planning problem as a clustering problem and then by applying the clustering techniques we have determined appropriate cell locations. Using the planning tool prototype *B-Hive*, which is based on the above ideas we demonstrated the results for cell planning for Mumbai.

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