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Automatic Frequency Planning and Optimization Algorithm for Cellular Networks

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Abstract—**Frequency planning in ever growing cellular networks is an extremely arduous task. Any effort to lay down manual frequency plans promulgates inefficiency in the cellular radio systems. The extensive deployment and penetration of cellular networks necessitate the need to carry out automatic frequency planning. This paper presents a novel and ingenious algorithm for automatic generation and optimization of the frequency plan whereby curtailing the intra-system interference levels within the acceptable ranges of the key performance indicators (KPI's) defined for any real time cellular network. The automatic frequency planning and optimization has been done using the concept of Inter-Cell Dependency Matrix (ICDM) which contains cell correlations in terms of the affect one cell has on the other primarily with regards to the co-channel interference. The proposed algorithm was simulated in MATLAB. It has been set forth and tested using inputs from live network data. It has been found to satisfy the verifiable network performance metrics.**

Index Terms—**Automatic Frequency Planning, Inter Cell dependency matrix, Intra-system Interference, Co-channel Interference, Traffic based ICDM.**

I. Introduction

Cellular telephony has rapidly evolved as the prime form of wireless communication over the last decade. The widespread deployments of cellular networks derive motivation from the need to provide mobile telephony service, so as to enhance the capacity in terms of the number of users. However, radio spectrum is a scarce resource, which inhibits the indefinite growth of user-based capacity [1]. As a consequence, the radio frequencies have to be efficiently reused numerous times for several thousand transceivers by exploiting the inherent property associated with propagation of radio waves that the signal strength decreases with increase in distance [1]. The reuse takes place after a safe minimum distance at which cells having same frequencies (co-channels) do not interfere. Additionally, no two-neighbor cells/sites use adjacent frequencies to avoid in-band interference. In order to satisfy the cellular frequency reuse principle, frequency planning is required. In this regard, the concept of manual frequency planning has become obsolete due to its computational inefficiency and inability to fulfill the conditional interdependencies for a large number of transmitter sites. Automatic frequency planning is basically an NP-hard problem but the matter of fact is that cellular systems are 24/7 and hence cannot afford long wait durations to get the improved plans as the business is at stake [2]. The automation of frequency planning, therefore, is an inevitable compulsion. For the frequency plan to be benignant, the use of frequency channels should be in a way that the criteria for maximum coverage and capacity are met with minimal infliction of intra system interference. This calls for optimization of the frequency plan based on variety of dynamic parameters, which govern the cell coverage profiles and traffic capacity distributions. Frequency plan has to be adaptive so as to take into account the on-ground terrain and traffic profile changes and also the effect they have on received power levels of any arbitrary user in one cell with respect to interference from another cell. The interference correlation among cells is well depicted in terms of the Inter Cell Dependency Matrix (ICDM), which can serve as input to the frequency planning and optimization algorithm and is illustrative of the real time network conditions [3]. The paper presents a novel algorithm to which ICDMs based on area and traffic are provided as input and the result is an optimal frequency plan which incurs the minimum number of violations of the frequency assignment principle.

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II. Preparing Input Data for Algorithm

A. Development of Hypothetical Grid for Topographical Analysis

The very first step is to divide the geographical area under consideration into square regions of identical dimensions. These small regions are called bins. The concept of bin facilitates in analyzing the topography because the network parameters are changing with changing values of geographical coordinates, and by following the hypothetical grid approach it has been assumed that network parameters do not change within a bin, which is basically a small unit area. An important aspect to be highlighted here is that keeping the size of the bin smaller enhances accuracy. So, in this regard the dimensions of these bins have been set to be so minute that the bin can be approximated to have the same value of longitude and latitude. Also due to this minute area of bins, it is assumed that the signal strength does not change or deteriorate in a particular bin. The coverage area of each of the base station in the network is a calculation of the total number of bins for which that particular base station acts as the best server.

B. Inter Cell Dependency Matrix (ICDM)

Development of an efficient frequency planning algorithm requires in-depth knowledge of the cellular environment and live system measurements can also be of great help in this regard. As the ICDM is calculated by taking live network data and system measurements, it provides a better approach to address the frequency

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allocation problem. Area and traffic based inter cell dependency matrices are the two types of ICDMs that are given as input to the frequency planning algorithm.

The calculation of best server for each bin in the coverage area provides the foundation for calculating the area based ICDM. Area based ICDM contains the percentage of area in a cell that is affected by another cell if those two cells are given either co-channel or adjacent channel frequency as shown in fig. 1 which contains the percentage interfered area of a particular cell due to another cell.

Interferers

Best Server	A1	A2	A3	B1	B2	B3
A1	0	0	0	0	61.7	0
A2	0	0	0	23.2	0	0
A3	0	4.89	0	0	39.3	0
B1	37.2	0	13.3	0	0	19.6
B2	71.1	0	0	0	0	0
B3	0	0	0	9.34	0	0

Fig. 1. An Example of Area based ICDM

The diagonal elements in the generated ICDM have to be zero because a base station can obviously not interfere in its own best server region. Percentage interfered area basically shows the percentage area of the cell in which the interferer cell has a signal strength within the range of 9dB and where the best server power is not 9dB stronger than the interferer power as shown in fig. 2.

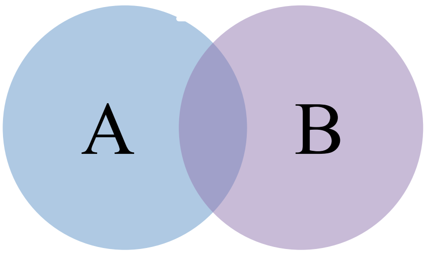

Fig. 2. Percentage Interfered Area (PIA)

In fig. 2, considering cell A as the best server, intersection area between cell A and B shows that area of cell A where its power is not 9dB stronger than that of cell B and has resultantly become interfered area and this percentage of interfered area between cell A and cell B is stored in the area based ICDM.

Although area based ICDM shows all the potential interferers in each base station coverage area, it cannot accurately describe the actual traffic profile. The area based ICDM assumes uniform traffic for each bin. For real time systems, this is rarely the case. Hence we need traffic based ICDM from live networks that show the actual traffic profile in the geographic area.

Traffic based ICDM provides the basis for the automatic frequency planning in the network because it is based on live data of the network and provides information that is authentic in nature in the form of PIT, the percentage interfered traffic. PIT is the percentage of traffic for a cell that is affected by another cell operating at same or adjacent frequency as shown in fig. 3, which contains the correlation between any two cells in the form of PIT.

Interferers

Best Server	A1	A2	A3	B1	B2	B3
A1	0	0	0	0	0	9.56
A2	19.4	0	0	0	12.8	0
A3	0	1.53	0	0	0	0
B1	0	0	9.34	0	0	0
B2	17.3	0	0	4.34	0	9.56
B3	0	0	0	0	3.45	0

Fig. 3. An Example of Traffic based ICDM

Apart from the diagonal elements there are other zeros in the traffic based ICDM which are basically due to two factors:

1). If base stations A and B are sharing same frequency F but they are located far apart as shown in fig. 4 then there will be no interfered traffic between them resulting in a zero entry in the ICDM.

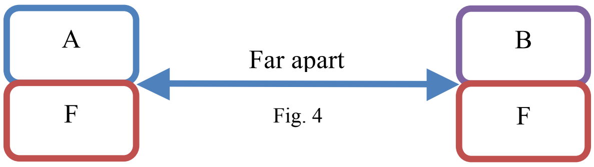

Fig. 4

2). If base stations A and B are operating at the same frequency F in each other's vicinity as shown in fig. 5 then there must be interfered traffic between them.

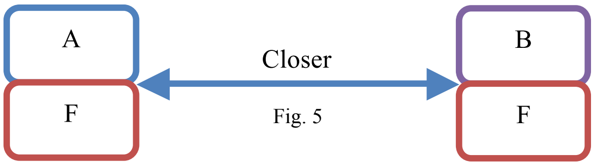

Fig. 5

But, in the calculation of traffic based ICDM the mobile station basically acts as a probe for the measurement of neighboring frequencies and thus does not account for the interferers operating on similar frequency. This is an inherent limitation in the traffic based ICDM.

To prevail over this limitation, the area based ICDM has been incorporated into the traffic based ICDM. The weightage given to percentage interfered area is less as compared to the percentage interfered traffic. Now the final matrix obtained after the incorporation of both traffic based ICDM (with 80% weightage) and area based ICDM (with 20% weightage) as shown in fig. 6 may also contain values which will be zero but these 'zero' values in the matrix correspond to the fact that base stations are located far apart.

Interferers

Best Server	A1	A2	A3	B1	B2	B3
A1	0	0	0	0	12.3	7.64
A2	15.5	0	0	4.64	10.2	0
A3	0	2.20	0	0	7.86	0
B1	7.45	0	10.1	0	0	3.93
B2	28.1	0	0	3.47	0	7.64
B3	0	0	0	1.86	2.76	0

Fig. 6. An Example of Combined ICDM

III. AUTOMATIC FREQUENCY PLANNING AND OPTIMIZATION ALGORITHM

A. Concept of Cost and Rule Breakage

The concept of cost is very important in the optimization process and its magnitude basically governs the assignment of frequencies thus acting as the basic judgment criteria for any optimal frequency plan. It is the penalty encountered whenever an unwanted frequency assignment takes place. Events, which are responsible for incurring cost, are called rule breakages. So, strictly following these rules will lead to an optimized plan with minimum cost.

- Strict rule says that co or adjacent frequency must not be assigned to co-sited cells and no violation of this rule should take place. Cost incurred on the breakage of this rule is very large in magnitude.
- Moderate rule says that co or adjacent frequencies must not be assigned to any of the remaining interferers. Violation of this rule should also be avoided but its breakage incurs lesser cost as compared to strict rule breakage.

For a cellular network comprising of 'N' cells based on the strict and moderate rules with optimum frequency allocation, the optimum cost function defined in equation (1) is the combined ICDM percentage interference of interferer cell 'i' with interfered cell 'j' according to their co-frequency and adjacent frequency relation [4].

$$\min_{f\ Optimum}\left[\sum_{\substack{1\le i\le N\\ f(i)=f(j)\\ i\ne j}} PI(i,j) + \sum_{\substack{1\le i\le N\\ |f(i)-f(j)|=1\\ i\ne j}} PI(i,j)\right] \quad (1)$$

B. Optimization Algorithm

The optimization algorithm works by comparing the total cost incurred in the current plan with the cost of the new plan obtained in the successive iteration. As the first step of the algorithm is to prioritizing cells based on the percentages of the interference, cells having higher percentages of the interference are dealt on priority. The network cost of the frequency plan is computed on the basis of ICDM that was the combination of traffic and area based ICDMs.

The algorithm keeps on executing unless the decaying cost graph becomes flat and attains a zero slope as shown in the fig. 7.

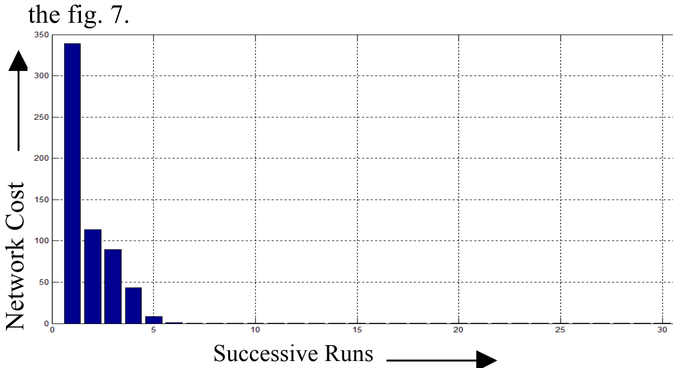

Fig. 7. Network Cost Analysis

It is to be noticed that network cost is deteriorating continuously but after a certain point it becomes flat. The continuously deteriorating network cost also reflects the optimum allocation of frequency to the cells and result as a significant proof of equation (1).

The algorithm that optimizes the frequency allocation has been elaborated in fig. 8.

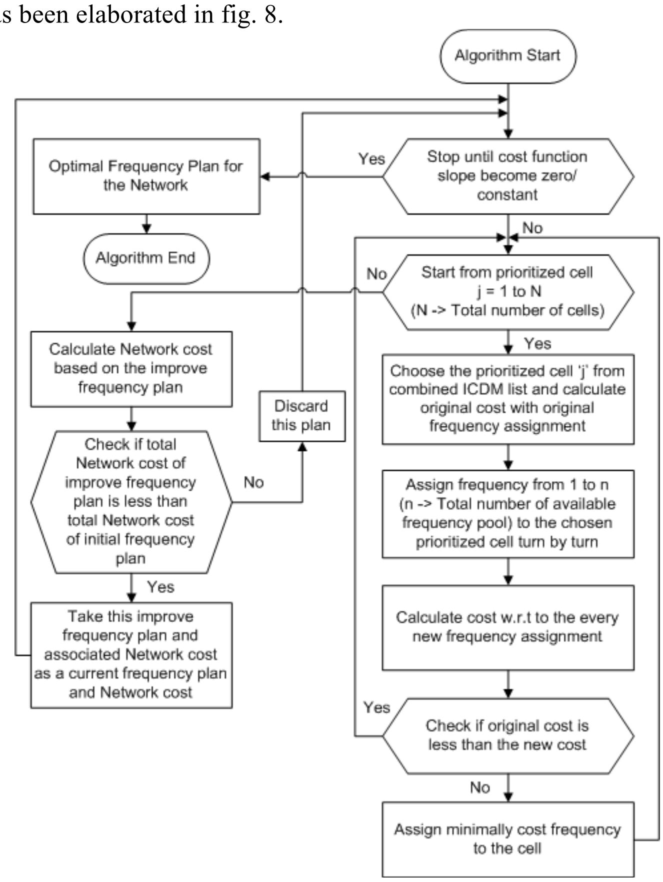

Fig. 8. The Automatic Frequency Planning and Optimization Algorithm

Pseudo code of AFP Algorithm

1. Algorithm starts
2. N = Total network cells, F = Total available frequencies pool
3. Select a prioritized cell 'j' from 1 → N
   Calculate cost at original frequency

$$Actual\ Cost(j, operating\ freq) = \sum_{\substack{1\le i\le N\\ f(i)=f(j)\\ |f(i)-f(j)|=1\\ i\ne j}} PI(i,j)$$

Where PI(i,j) = Combined ICDM percentage function, i = interfering cell , j = interfered cell

➔ Temporarily select the frequency 'f' from the frequency pool and assign to selected prioritized cell

$$New\ Cost(j,f) = \sum_{\substack{1\le i\le N\\ f(i)=f(j)\\ |f(i)-f(j)|=1\\ i\ne j}} PI(i,j)$$

Where PI(i,j) = Combined ICDM percentage function, i = interfering cell , j = interfered cell

If Actual cost > New cost
original frequency = temporary frequency

4. Calculate the network cost of frequency plan
   ➔ Calculate the network cost of the modified frequency plan
5. If $Network\_Cost_{\_modified} < Network\_Cost_{\_original}$
   Keep the plan
   else Discard the plan
6. Continue the steps until cost function slope become zero/constant

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IV. VERIFICATION OF PROPOSED ALGORITHM ON LIVE DATA

The proposed algorithm has been implemented and checked for real time systems and it has been found out that the algorithm optimizes the frequency assignment to its best. As per the ETSI recommendations, for the 2^{nd} generation GSM system the ratio between the serving cell signal powers to the interference power at the same frequency should be more than 9 dB. In other words, if the serving cell has frequency 'f1', then its power should be 8 times more than the power of all interferers at same frequency 'f1'. This ratio is called carrier to interference ratio (C/I).

The algorithm has been verified by noting the significant difference between the C/I plots generated from the initial plan and the final optimized plan. These plots have been generated by TCPU (TEMS Cell Planner Universal), which shows a very clear and notable difference between the initial, and optimum frequency plans.

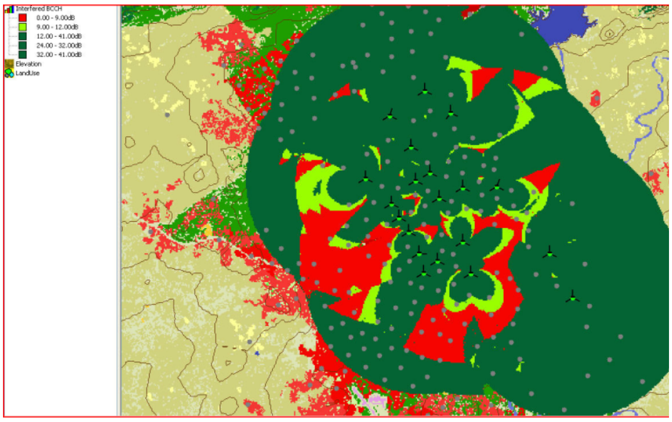

Fig. 9. TCPU plot before Optimization

After running the optimization algorithm the new C/I plots obtained is shown in the fig. 10, which clearly advocates the verification of the proposed algorithm.

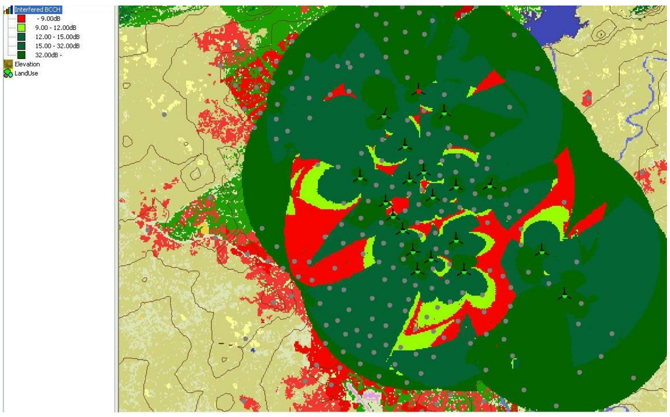

Fig. 10. TCPU plot after Optimization

In any real time mobile communication system, due to limited number of frequencies available, it is impossible to have all the points in the network with C/I > 9dB. But our algorithm optimizes the frequency plan in such a way that poor quality areas are minimized. Thus the performance of the network is improved.

V. CONCLUSION

While designing the cellular systems one of the most important tasks is the assignment of frequencies to all the base stations in the network. The accuracy and efficiency of the algorithm, its time consumption and cost effectiveness, and all factors contribute to enhance the system performance and enable it to become more user friendly and service oriented. The proposed algorithm is efficient and consumes less time because it never assigns co and adjacent frequencies to co-sited cells while on the other hand the co-channel breakage is also negligibly small. It has been tested and verified and it has been found to satisfy the key performance needs.

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