Frequency Planning optimisation in real mobile networks.[1]

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ABSTRACT[1]

Due to the annual increase of cellular subscribers, there is a growing interest by the network operators, in how to deploy the network infrastructure to achieve maximum capacity. A key point is the channel or frequency assignment, which implies efficiently assigning frequencies from a limited set, to each cell, while satisfying the electromagnetic compatibility constraints

1. INTRODUCTION

The sum over all co and adjacent-channel interference is the quality parameter of an assignment, and it is called the cost function. Some frequency allocation algorithms focus in reducing the number of required frequencies, but since network operators already have a fixed available band, it seems more interesting if a frequency allocation program (FAP) is given which minimises interference. So in this paper we compare several allocation algorithms on a real cellular network by the use of the cost function. This cost function can be calculated separately for traffic channels (TCH) and for broadcast control channels (BCCH). This is important because great care should be taken to protect BCCH from interference as it carries relevant information. Total cost function can be easily calculated as the sum of both TCH and BCCH cost functions. The other relevant parameter is the computational time, because network operators require methods spending short time to solve FAP.

Three types of algorithms have been tested: the first one is an heuristic technique based in successive iteration to solve denials in assignation, by randomly increasing the estimated difficulty of a denied assignation, and reordering the nets in a descending order of difficulty for the next iteration [1]. The second is also an heuristic technique which defines two ways to order the cells and the calls (by Node-color or Node-degree), and later uses either a requirement exhaustive strategy or a frequency exhaustive strategy. Combining all the options we have eight different FAP [2]. Finally the third technique is a simulated annealing algorithm, used to reduce the cost function from initial assignment [3,4].

The algorithms under study in this paper, also allow for both, dedicated frequency bands for BCCH and TCH, and an extension of this strategy which is known as Multiple Reuse Patterns (MRP). The main idea is the following: once we know the total assigned band, we choose a first set of frequencies, and running one of the algorithms assign one frequency to each cell taking into account the CM. This first assignment will represent the BCCH frequencies. In a second step, we introduce the frequencies already assigned as restrictions to the system. If no MRP is considered, the rest of frequencies are assigned, taking into account both RV and CM. If MRP is considered, we divide the rest of frequency band in two (or more) sets, being one set larger than the other. The larger set is used to assign the second TRX to all the cells in the system, while the smaller one is used to assign the third TRX. Implicitly the larger set has a lower reuse pattern, while the smaller set has a more aggressive reuse pattern. With this technique the MRP method allows for a gradual tightening of the reuse, as more TRXs are installed in the system (the reuse on the last transceiver can be tight since it will probably not be used in every cell).

As has been mentioned before, the calculation of separate cost functions for BCCH and TCH traffic allows to compare the behaviour of both type of channels, and also helps in determining the optimum number of frequencies deserved to BCCH. As TCH channels can benefit from power control (PC), discontinuous transmission (DTX) and frequency hopping techniques (FH), it seems

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reasonable if the largest set of frequencies is deserved to the BCCH as the only way to protect it against interference.
Finally, the use of MRP technique can also be applied to Frequency Hopping (FH) systems. For example, if a cell needs two TRXs for traffic and a Synthesised FH system with a FH fractional load of 0.5 is used, we have to assign two more frequencies to this cell. As FH reduces interference, it allows a tighter reuse, and we can assign separately this two frequencies from a small frequency set, allowing more interference in the system. In this case the cost function is modified to take into account interference reduction by FH gain (by introducing a weight factor lower than one).

2.PARAMETERS REQUIRED BY DE FAP

This paper considers the following conditions as assignment constraints, following recommendations from the Frequency Planning Subgroup from COST259 European project [5].

Default parameters:

- Available spectrum & globally blocked channels.
- Co-channel and adjacent-channel separation for TRXs installed at different sites (its is usual to consider that a separation of two rules out both interference, while a separation of one rules out only co-channel interference),
- Co-site separation for TRXs at the same site
- Co-cell separation for TRXs at the same cell
- Handover separation, between cells where a handover is possible, for BCCH/TCH channels from the passing on and the receiving cells.
- Minimum and maximum tolerable interference level between two cells: if the interference between them is lower than the minimum level, frequency reuse is possible. If the interference is higher than the maximum interference level, separation between frequencies should be applied. Between both interference levels, frequency reuse may be used, but with a careful evaluation of the system degradation. Of course the frequency planner can choose the same value for both interference levels, reducing the decision criterion to "reuse allowable or not allowable".

Local parameters:

- A cell may have locally blocked channels and also some already assigned channels. This allows to deal with a real case, where a frequency assignment is already in use, and the network operator wishes to perform an update (for ex. to increase capacity or to reduce interference by FH), adding frequencies to specific cells in the network.
- We also know how many channels should be allocated to each cell (non homogenous traffic is considered) and, consequently the channel requirements vector (RV).

Cell relations

- Interference analysis (cochannel and adjacent channel values). In the cases under study, the interference have been calculated as an area based interference, and have been normalised to a maximum value of one.
- neighbourhood list (handover),
- specific frequency separation between two cells can be given. This value should be applied instead of the corresponding from the default parameters.

All this parameters have been used to determine the compatibility matrix (CM).

3.FREQUENCY ASSIGNMENT ALGORITHMS

Two types of algorithms have been tested. An important feature of both types of algorithms is that they are applicable to any cellular system, not necessarily consisting of regular hexagonal cells. In this section, a short explanation of both techniques is given:

Heuristic iterative [1]: It is an heuristic technique based in successive iteration to solve denials in assignation, by randomly increasing the estimated difficulty of a denied assignation, and reordering /the nets in a descending order of difficulty for the next iteration. Initial net order is not important, and then the first step tries to assign a channel to each net in turn, alternately using the highest and the lowest available channels. Of course each new channel assignment must be compatible with all the assignments already made. If it is not possible to assign a channel to a given net it is market as a "channel denial". After one iteration, the estimated difficulty of the "channel denials" is increased by a random number between 0 and 1, and the nets are reordered by a decreasing order of estimated difficulty. The process is repeated until no denials appear or the number of denials becomes constant (no solution).

Heuristic non iterative [2]: It is also an heuristic technique defining two ways to order the cells and the channels (by Node-color or Node-degree), and using either a requirement exhaustive strategy or a frequency exhaustive strategy. Combining all the options we have eight different FAP. The main advantage of this algorithm is that it is fast compared to iterative algorithms.

Frequency Exhaustive strategy consists in starting at the top of the list, assign to each channel the least possible frequency consistent with previous assignments. The Requirement Exhaustive strategy takes frequency 1 and assigns it to the first channel and to all possible channels that can reuse this frequency without violating the separation constraints. Then the same procedure is used for frequency 2, etc. until there all the channels have been assigned frequencies.

In the Node-degree ordering, the cells are ordered in decreasing order of their degrees. In the Node-color ordering, the cell with the least degree is placed in the last place and removed from the system. The process is repeated with the remaining cells, until the ordering is completed.

The degree of a cell is a measure of the difficulty to assign a frequency to this cell and it is defined as:

$$d_i = \sum_{i=1}^{N} m_j c_{ij} - c_{ii} \qquad 1 \le i \le N \qquad (1)$$

where N is the number of cells, c_{ij} is the separation between a channel in cell i and cell j and m_j is the number of channels required in cell j.

The channels are ordered in a $N x m_{max}$ matrix (m_{max} is the maximum number of channels in any cell) so the channels associated to different cells are in different rows, starting where the previous row ends, and cyclically filling the row. The channels can be ordered reading by rows (Row-wise ordering) or by columns (Column-wise ordering).

4. QUALITY PARAMETER

The cost function is defined as the sum over all co and adjacent-channel interference and it is used as the quality parameter of an assignment. It has been calculated following [3] by this general expression:

$$\text{Cost} = \sum_{i} \sum_{a} \text{Cost\_level}(i,a) \qquad (2)$$

This is the sum over all the frequencies used in the planning (i) and over all the cells (a) of the cost of using the frequency i in the cell a. Obviously if frequency i is not used in cell a the Cost_level (i,a) is equal to zero. Otherwise it is calculated as the contribution of cochannel interference and adjacent channel interference by:

$$C\_I(i,a) = \sum_{k} \left(J_{k,a} + J_{a,k}\right) + adj\_factor \cdot \sum_{m} \left(J_{m,a} + J_{a,m}\right) \qquad (3)$$

where k and m are the sum over all the cells which are cochannel or adjacent channel with a respectively. The adjacent interference is reduced by filter selectivity around 18 dB and this means that the adj_factor is 0.015. $J_{k,a}$ is the interference in cell a due to cell k. To cope with the reduction of interference caused by the use of FH the previous interference should be multiplied by loadgain and hopgain factors lower than one (different values have to be taken into account according to the type of FH used: synthesised or with fractional loading, or base band with random or sequential hopping).

As has been mentioned in the introduction the cost can be calculated separately for TCH and for BCCH channels, and factors of interference reduction due to Power Control and DTX can be applied to TCH channels.

To obtain more information for the cases where a complete frequency assignment is not possible, the software also calculates how many times a frequency is used (to estimate the traffic carried by this frequency) and the cost associated to this frequency.

5. SCENARIOS UNDER TEST AND RESULTS

After running some short examples to validate the software, we have used some "hard" real Frequency Scenarios given by mobile network operators (hard in the sense that all of them has a great number of cells which means a high number of TRXs). In this paper we will consider the following examples:

Scenario 1: 506 cells, 930 chan., 43 available freqs.
Scenario 2: 254 cells, 977 chan., 75 available freqs.

Co-site and co-cell separations are 2 and 3 respectively, and handover separation is 2. Minimum and maximum significant interference are 0.08 and 1 respectively.

Scen.	Weight	N.F.BCCH	Cost	Cost BCCH
1	-	-	136.9	72.5
1	1	19	89.9	50.4
1	4	22	59.9	25.6
1	8	25	55.7	19.2
2	-	-	122.7	39.3
2	1	19	102.3	29.5
2	4	20	88.4	14.6
2	8	21	77.6	11.4

Table 1: *Cost of different assignations (iterative)*

In Table 1 cost values between assignations with and without BCCH/TCH frequency partition are given. Different weight factors have been applied to BCCH interference to penalise them. As can be appreciated in the table this helps in finding an assignation with a lower cost. If we apply DTX and Power Control reduction factors (3 dB) on the assignations of the table we obtain cost values of 28.3 and 27.9 for scenarios 1 and 2 respectively.
In Figure 1 the evolution of cost function for different band partition values between BCCH and TCH is given for scenario 1 and the heuristic iterative technique, while in Figure 2 the evolution of cost for different BCCH weight factors is given also for scenario 1 but for the 8 non iterative algorithms.

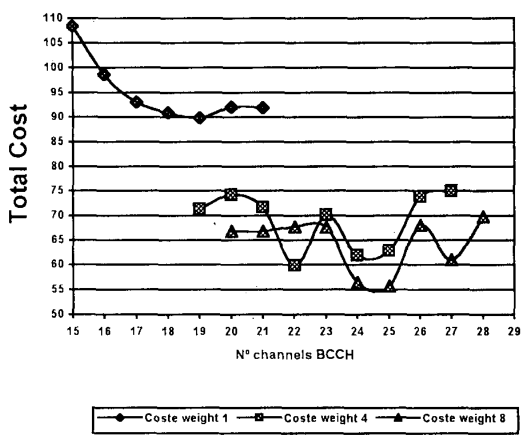

Figure 1: evolution of cost for scenario 1

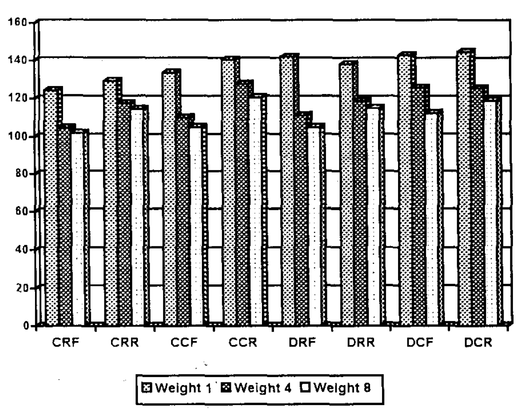

Figure 2: Cost for SC1 (non-iterative)

In general the heuristic iterative method gives lower cost values when it is able to find a solution, when compared with the 8 non iterative methods. In turn these methods sometimes find solutions that require less frequencies (around two channels less).

6. OPTIMISATION BY SIMULATED ANNEALING

In order to optimise the cost a simulated annealing algorithm has been also implemented [3,4]. As input of the algorithm we introduce a valid assignation calculated by the heuristic iterative method, and after adjusting the initial temperature to have enough valid solutions in the first loop (around 90%), we let the program running until the percentage of solutions is lower than 5%. A new solution is calculated changing the worst frequency used in a cell (by choosing the cell randomly) by the least interfered frequency (the one with lower cost) following of course the assignment constraints. If the cost of the new assignment is lower than the cost of the old one, it is automatically accepted. If the cost is higher we calculate its probability and decide by Bernoulli if its going to be chosen or not (in order to avoid or move from local minimum).
By using simulated annealing a great reduction in cost values has been obtained from the values previously given in table 1. The main inconvenient is that this algorithm is extremely dependent on the initial temperature and on the way to actualise the temperature. Of course this depends a lot of the scenarios under test, but up to now we have not found general rules to obtain always an assignment. Another problem is that depending of the scenario it takes a long time to find the optimum solution.

In Table 2 the results applied to scenarios 1 and 2 are given, starting with an initial temperature of 0.1. The reduction in cost is of 80.1% and 59.5 % for scenarios 1 and 2 respectively

Scenario	C.Initial	T final	C.Final
1	60,8	0,00922	12,1
2	101,6	0,00760	41,2

Table 2: Cost values applying simulated annealing

Of course if DTX and Power Control are considered the cost is reduced again to 4 and 18 approximately.
Another way to see if the algorithm is efficient in assigning frequencies is representing the costs due to the set of frequencies. As we can appreciate in figures 3 and 4, not only a reduction in interference is obtained by simulated annealing, but a more uniform frequency distribution.

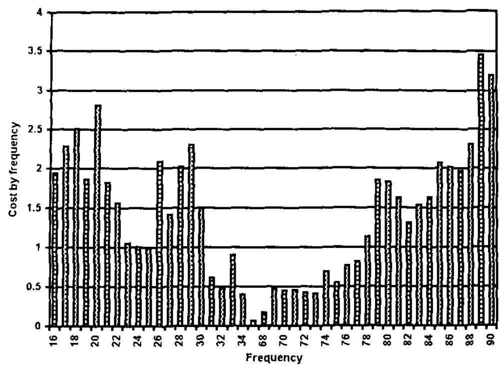

Figure 3: Cost associated to the frequencies in the band for scenario 1 before applying simulated annealing.

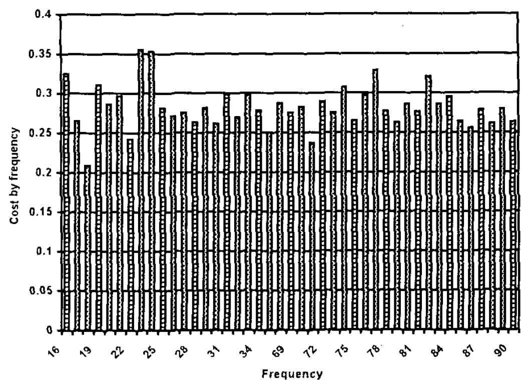

Figure 4: Cost associated to the frequencies in the band for scenario 1 after simulated annealing

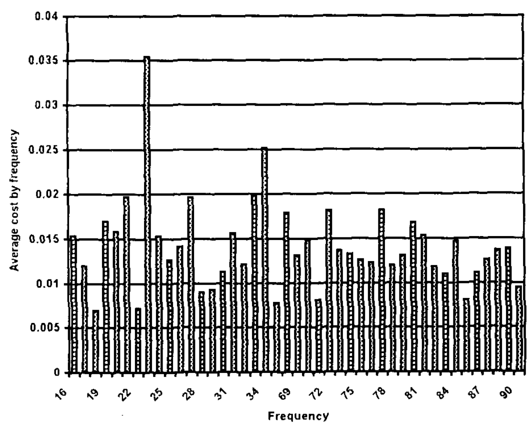

***Figure 5**: Average cost for frequency after simulated annealing (scenario 1)*

Finally in Figures 5 and 6 the average cost values for frequency are given before or after applying simulated annealing. The average is defined as the relation between the cost of a frequency and the number of times this frequency is used in the plan.

7. CONCLUSIONS

A lot of work has been done in order to implement many FAP algorithms and defining also parameters to be able to compare them. Simulated annealing has been shown to be a powerful technique to reduce cost starting from a previous assignment but depending on the scenario it shows a large computing time. More work has to be done in order to reduce computing time. For example, instead of choosing randomly a cell, trying to change the frequencies with a high average cost by another with lower cost. This has to be done maintaining a certain probability of choosing a worst solution, in order to avoid convergence to a local minimum.

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