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GSM Co-Channel and Adjacent Channel Interference Analysis and Optimization*

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Abstract: Most current Global System for Mobile Communications (GSM) frequency planning methods evaluate the interference and assign frequencies based on measurement reports. Assigning the same or adjacent frequencies to cells close to each other will introduce co-channel and adjacent channel interference which will reduce network performance. Traditionally, man power is used to check and allocate new frequencies which is time consuming and the accuracy is not satisfactory. This paper presents an intelligent analysis method for optimization of co-channel and adjacent channel interference by exploiting cell configuration information. The method defines an interference evaluation model by analyzing various factors such as the base station layer, the azimuth ward relationship, and the cell neighborhood relationships. The interference for each frequency is evaluated and the problem frequencies are optimized. This method is verified by a large number of actual datasets from an in-service GSM network. The results show this method has better intelligence, accuracy, timeliness, and visualization than traditional methods.

Key words: GSM frequency optimization; co-channel and adjacent channel interference; interference evaluation model; base station site layer; azimuth ward; neighborhood relationship; triangulation

Introduction

The current frequency allocation methods always use measured data to analyze interference and do not directly consider the disturbance intensity which is directly related to the distance, azimuth, relative position, and other factors. During the measuring period, many problems may occur such as not enough sampling points, barriers, base station failure or other problems caused by accidental factors. Such problems affect the data accuracy and the same or adjacent channel frequency allocation results. Same and adjacent channel interference then affects the network performance. Therefore, factors such as distance, azimuth, and relative position of the network should be considered for adjacent channel interference verification and optimization[1-5].

Co-channel and adjacent channel interference occurs among cells in neighboring areas. The distances between base stations differ in different regions. But determining the site of the neighboring area is a problem. The antenna azimuth ward launching rally signal is an important reason for the interference but it is difficult to check whether the azimuth is rally launching. The interference is reduced by assigning a group of new frequencies. The problem is to evaluate the interference to choose the best frequency.

This paper presents an intelligent analysis and optimization method for co-channel and adjacent channel interference based on the cell configuration. An interference evaluation model is used to analyze various key factors. The interference is evaluated for each

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frequency to change problem frequencies.

1 Interference Definition

1.1 Cell size

Co-channel and adjacent channel frequency interference is mainly caused by neighboring cells[2]. Thus cells in the coverage area of the serving cell should be checked.

There are large numbers of base stations in large mobile networks. The base station density varies much in different regions. In the countryside, the distances between base stations are much longer than in cities. Thus, the cell coverage radius in the countryside is much larger than in cities and the coverage radius can not be set to a constant value. The cell coverage is then usually indicated by the base station site layer and the azimuth award side.

Cells in site layer 1 are in the smallest circle around the serving cell. Cells in site layer 2 are in the next larger circle around the base station outside the smallest circle and so on. The cell coverage area is inside site layer 3.

The front part of the azimuth is the 120° wedge around the azimuth center line, while the rest is the back part. In general, the coverage area for a cell should be the front part of layers 1-3 and the back part of layer 1. The area inside the front part of levels 1 to 3 and the back part of level 1 is the correct coverage region. The area outside of front part of level 3 and outside the back part of level 1 should not be covered. The cell sets C, in the coverage area of the serving cell, should be checked for co-channel and adjacent channel frequency interference with the serving cell. The cells in the outermost layer whose azimuths point away from the serving cell azimuth are not in set C, but those whose azimuths point towards the serving cell are in set C.

1.2 Base station site layer stratification

A key problem is the divisions of the base station site layers. The Delaunay triangulation algorithm is usually used to partition the base station nodes. Delaunay triangulation requires that each circumcircle of each triangle does not contain any other points in the network. This ensures that each triangle is formed by the three closest nodes[6-8]. Figure 1 shows a cell stratification graph by the triangulation method.

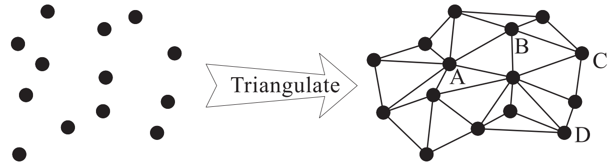

Fig. 1 Cell stratification by triangulation

In Fig. 1, the base stations in the mobile network are partitioned into a triangle network using the triangulation method. In the triangle network, a site layer can be defined as the length of the shortest path between two cells. For example, assume cell A is a serving cell. The shortest path from cell B to cell A is 1, so cell B is in site layer 1. The shortest path from cell C to cell A is 2, so cell C is in site layer 2 and cell D also is in site layer 2. This type of partitioning result has been verified in the real world experience.

The site layers in the base station triangulation network can also be calculated using the shortest path in graph theory. The base station triangulation network is an undirected connected graph $G=(V,E)$, where V denotes the set of nodes in G and E denotes the set of edges. The site layer between any two base station nodes u and v is the shortest path between the two nodes. The adjacency matrix and graph theory method to determine the connectivity can then be used to compute the site layers[9].

Define matrix $\boldsymbol{A}$ as the adjacency matrix of graph G. $\boldsymbol{A}=(a_{ij})_{m\times m}$, where $m=|V|$, m is the number of the nodes in G, and $a_{ij}=|e_k|$, $e_k=\langle v_i,v_j\rangle\in E$. If nodes v_i and v_j are connected by an edge, then $a_{ij}=1$; else $a_{ij}=0$, where $(a_{ij}^{(k)})=\sum_{h=1}^{m}a_{ih}^{(k-1)}\cdot a_{hj}$, $a_{ih}\cdot a_{hj}\neq 0$, if and only if $a_{ih}\neq 0$ and $a_{hj}\neq 0$. Thus there are connectivity paths from node v_i to v_h and from node v_h to v_j. $a_{ij}^{(2)}$ indicates the number of paths with 2 edges from v_i to v_j. $a_{ij}^{(k)}$ indicates the number of paths with k edges from v_i to v_j. $a_{ij}^{(k)}=0$ means there is no k edges path from v_i to v_j. Therefore, if $\sum_{h=1}^{k-1}a_{ij}^{(h)}=0$ and $a_{ij}^{(k)}\neq 0$, the shortest length path from v_i to v_j is k.

Applying this theory to compute the base station site layer gives $\boldsymbol{A}^k=(a_{ij}^k)_{m\times m}$, $k=1,2,\cdots$. The matrix for all the network site levels can be computed as: $\boldsymbol{L}=(l_{ij})$, where l_{ij} is the site layer from base station i to base station j. In general, only the site layers 1-4 are calculated.

Figure 2 shows the cell stratification by triangulation in a real Global System for Mobile Communications (GSM) network based on a GIS platform[10]. The four site layers of the serving cell (the red cell) are indicated by different colors. The site layers are correctly divided based on their locations in the network.

1.3 Azimuth rally determination

In an actual frequency optimization work, the azimuthal sector must be considered whether a rally occurs. Practical experience is used to judge the rally azimuth as shown in Fig. 3 where the serving cell is cell S and the target cell is cell T. P_{ST} is the connecting path between S and T. s is the angle between the antenna S and P_{ST}. t_1 is the angle between the antenna T and P_{ST} when S and T is on the same side. t_2 is the angle between T and P_{ST} when T is on the opposite side of S.

The angles s, t_1, t_2, and their sums $(s+t_1)$ and $(s+t_2)$ have set thresholds. If an angle is less than the threshold, cells S and T are determined to rally. The thresholds differ when antennas S and T are on the same side or on opposite sides. Based on practical engineering experience, if $s<45°$, $t_1<60°$, and $(s+t_1)<90°$, S and T will rally on the same side. If $s<30°$, $t_2<45°$, and $(s+t_2)<45°$, S and T will rally on opposite sides.

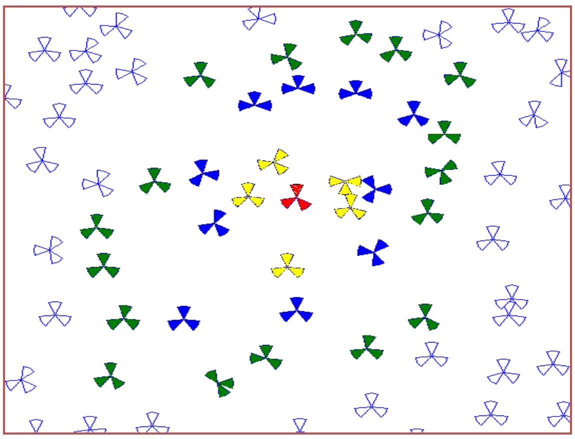

Fig. 2 Site layer stratification of a base station network

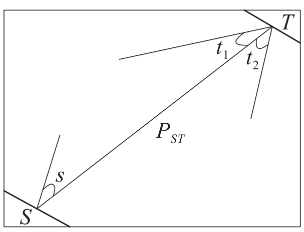

Fig. 3 An azimuth rally determination

1.4 Azimuthal regions

The region award neighbor cell T has inner and extra regions relative to the serving cell S based on the azimuth as defined in Fig. 4.

In Fig. 4, line P_{ST} is the connecting path between source cell S and neighbor cell T. Line P_T is the azimuthal direction of T. t is the angle between P_{ST} and P_T. If t is greater than 90°, the azimuthal region of T relative to S is outward; Otherwise, the azimuthal region of T is inward relative to S.

2 Frequency Optimization Algorithm

2.1 Interference level classification

Frequency optimization methods seek to avoid interference between co-channels or adjacent channels using frequency allocation that meets the following requirements[11]:

(1) Cells in the same station cannot be assigned co-channel or adjacent channel frequencies.

(2) Neighboring cells can not be assigned the same frequency and should avoid adjacent channels.

(3) An azimuthal sector can not rally with a co-channel or an adjacent channel.

(4) Other neighboring cells should avoid co-channels or adjacent channels.

According to these principles, the co-channel or adjacent channel interference can be analyzed by whether they are in the same station, neighboring stations or have azimuthal sparring. Interference levels are divided into 8 levels from low to high according to the type of interference and its impact, as shown in Table 1.

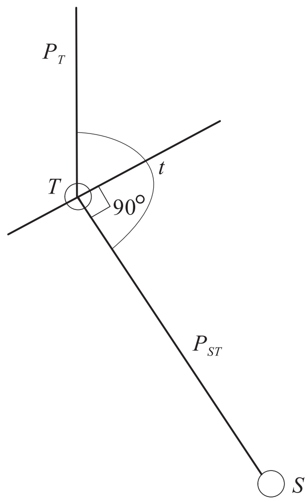

Fig. 4 Neighbor cell azimuthal region determination

Table 1 Interference level classification

Level	Same base station	Neighbor	Azimuthal rally	Co-channel or adjacent channel
0	NA	NA	NA	No
1	No	No	No	Adjacent channel
2	No	No	No	Co-channel
3	No	Yes	No	Adjacent channel
4	No	NA	Yes	Adjacent channel
5	No	No	Yes	Co-channel
6	No	Yes	NA	Co-channel
7	Yes	NA	NA	Co-channel or adjacent channel

The interference levels are classified from Level 0 to Level 7 in Table 1 with the interference intensity increasing from Level 0 to Level 7. Level 0 indicates no co-channels or adjacent channels. Level 1 indicates an existing adjacent channel. Level 2 indicates an existing co-channel. Level 3 indicates an existing adjacent channel in a neighboring cell. Level 4 indicates an existing adjacent channel in the rally azimuth. Level 5 indicates an existing co-channel in the rally azimuth. Level 6 indicates an existing co-channel in a neighboring cell. Level 7 indicates an existing co-channel or adjacent channel in cells in the same base station.

Typical cell co-channel and adjacent channel verification results on frequencies of ARFCN (Absolute Radio Frequency Channel Number) 34 and 90 are listed in Table 2.

Frequency of AFRCN 34 has 1 Level 6 interference, 2 Level 3, 1 Level 2, and 2 Level 1. Frequency of AFRCN 90 has 1 Level 5 interference and 1 Level 2. The frequency performance can then be evaluated based on the number of interferences using the sum of the number of interferences for each frequency in a cell. A channel with a high level of interference should have the frequency reassigned.

Table 2 Verification results of cell co-channels or adjacent channels

AFRCN	Interference number						
	Level 7	Level 6	Level 5	Level 4	Level 3	Level 2	Level 1
34	0	1	0	0	2	1	2
90	0	0	1	0	0	1	0
Total	0	1	1	0	2	2	2

2.2 Frequency interference vector

The frequency interference vector for the interference level and the cell site layers is defined as $\boldsymbol{B}=(b_1, b_2, b_3, b_4, b_5, b_6)$. In this vector, element b_1 is the main level, the largest interference level; element b_2 is the smallest (i.e., nearest) site layer of the main interference source; element b_3 is the number of main interference sources; element b_4 is the smallest site layer of the interference source; element b_5 is the number of interference sources in the smallest site layer, b_4; and element b_6 is the total number of interference sources.

The performance for each frequency is indicated by vector $\boldsymbol{B}$. For example, consider 3 frequencies in a cell. The performance vectors for each frequency are $\boldsymbol{B}_1$, $\boldsymbol{B}_2$, and $\boldsymbol{B}_3$:

$$\boldsymbol{B}_1 = (4, 2, 1, 2, 1, 4);$$
$$\boldsymbol{B}_2 = (4, 2, 2, 2, 1, 5);$$
$$\boldsymbol{B}_3 = (4, 3, 1, 2, 2, 5).$$

The signal performance of each frequency is determined from $\boldsymbol{B}_1$, $\boldsymbol{B}_2$, and $\boldsymbol{B}_3$ based on b_1 to b_6. The b_1 for all three are the same as 4. Then compare b_2. Since b_2 in $\boldsymbol{B}_3$ (3) is bigger than b_2 in $\boldsymbol{B}_1$ or $\boldsymbol{B}_2$ (2), the site layer with the main interference source in $\boldsymbol{B}_3$ is farther away than $\boldsymbol{B}_1$ and $\boldsymbol{B}_2$, so the signal for $\boldsymbol{B}_3$ is better than for $\boldsymbol{B}_1$ or $\boldsymbol{B}_2$. Comparing b_3 for $\boldsymbol{B}_1$ and $\boldsymbol{B}_2$, $\boldsymbol{B}_2$ has 2 main interference sources while $\boldsymbol{B}_1$ only has 1, so the signal for $\boldsymbol{B}_1$ is better than for $\boldsymbol{B}_2$. The interference levels are then $\boldsymbol{B}_2 > \boldsymbol{B}_1 > \boldsymbol{B}_3$ and the best frequency is $\boldsymbol{B}_3$ which should then be assigned to the channel.

Thus the interference vector can be used to compare the frequency performance to identify serious interference. A group of the best frequencies can then be selected from the optional frequencies to replace frequencies with serious interference to achieve frequency optimization.

2.3 Frequency optimization process

The frequency optimization process is shown in Fig. 5.

The process consists of the following steps:

(1) Compute the base station site layers in the network and matrix $\boldsymbol{L}$.

(2) Compute the interference vector for each frequency i in each cell in the network, $\boldsymbol{B}_i$.

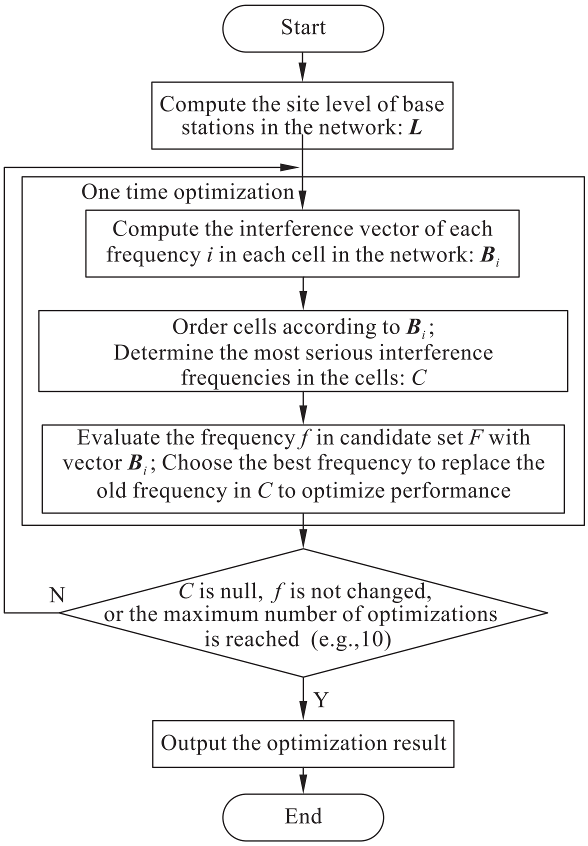

Fig. 5 Frequency optimization process

(3) Order the frequencies in the cells according to $\boldsymbol{B}_i$ and find the cells with the most serious interference which are put into cell set C, the cells to be optimized.

(4) Evaluate the frequency f in the candidate frequency set F with vector $\boldsymbol{B}_i$, and choose the best frequency to replace the interfered frequency to achieve frequency optimization.

(5) At the end of each optimization, end if C is null, the frequency is not changed, or the number of optimizations reaches the maximum (e.g., 10). Otherwise, return to Step 2.

(6) If the optimization end condition is satisfied, output the result.

In Steps 2, 3, and 4, complete one frequency optimization step. At the beginning of each optimization, the interference vector is computed again with the modified frequency from the previous step and a new interference cell set C is found. The optimization is executed several times to resolve all interfered frequencies. This method avoids duplication of operations and improves the operational efficiency.

3 Optimization Result Analysis

This method has been used for frequency optimization of co-channels and adjacent channels in a GSM network with about 400 cells. The serious interference level was set to 4, so that if the interference level is larger than 4, the frequency is changed. The maximum number of optimization loops was 10. The optimization results are shown in Table 3.

The optimization removed all Levels 4 to 7 channel interferences. All co-channel and adjacent channel frequency interference was cleared up. Higher interference levels will give more obvious results. For interference levels below the optimization limit (e.g., Levels 1 to 3), the interference has less impact on system performance, so they are not eliminated, but the worst interference has been removed.

4 Conclusions

This paper presents a co-channel and adjacent channel frequency interference analysis and optimization method for GSM networks. The approach consists of (1) analyzing the basic cell data consisting of base station site layer, azimuthal region, and neighboring cell relationships, (2) classifying the interference level based on the basic data, and evaluating the frequency performance with an interference vector model, and (3) optimizing the frequency usage in the network.

Unlike previous approaches based on a drive test, this approach is based on the basic configuration data collected from OMC, thus, the raw data is comprehensive, real-time, and really free.

The approach was evaluated using large amounts of data from a real GSM network. Over 90% of the co-channel and adjacent channel frequency interference problems were discovered and fixed. This frequency optimization method is very efficient.

Currently, this interference analysis method does not consider measurement factors so it can not be used directly for frequency planning. In actual network optimization, this method can supplement frequency planning to reduce the co-channel and adjacent channel interference to improve network performance.

Table 3 Statistics of frequency optimization results

	Interference number in old approach			Interference number in new approach			Decrease in number of interfered channels			Interference rate decrease (%)		
	Of BCCH	Of TCH	Total	Of BCCH	Of TCH	Total	With BCCH	With TCH	Total	With BCCH	With TCH	Total
Level 7	1	3	4	0	0	0	1	3	4	100.00	100.00	100.00
Level 6	2	70	72	0	0	0	2	70	72	100.00	100.00	100.00
Level 5	18	26	44	0	0	0	18	26	44	100.00	100.00	100.00
Level 4	56	102	158	0	0	0	56	102	158	100.00	100.00	100.00
Level 3	124	449	573	110	381	491	14	68	82	11.29	15.14	14.31
Level 2	259	512	771	225	485	710	34	27	61	13.13	5.27	7.91
Level 1	628	987	1615	555	966	1521	73	21	94	11.62	2.13	5.82

Note: BCCH, broadcast control channel; TCH, traffic channel.

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